FOURTH 4 EDITION

SUSTAINABLE CONSTRUCTION

GREEN BUILDING DESIGN AND DELIVERY



CHARLES J. KIBERT

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For Charles, Nicole, and Alina,
and in memory of two friends and sustainability stalwarts,
Ray Anderson and Gisela Bosch

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Preface

The significant additions and changes for this fourth edition of *Sustainable Construction: Green Building Design and Delivery* include revisions to the chapters on LEED and Green Globes, both of which have changed significantly over the past few years. LEED version 4 is now the main building assessment product being offered by the US Green Building Council for projects, and this recent addition is covered in detail. Because the US Green Building Council also allows projects to opt for LEED version 3 and familiarity with both systems is needed to allow flexibility for owners and project teams, LEED v3 is also addressed in an appendix. Green Globes has also changed; version 2 of this important rating system is covered in detail. Information about the other major assessment systems, such as Green Star, Comprehensive Assessment System for Building Environmental Efficiency, Building Research Establishment Environmental Assessment Method, and Deutsche Gesellschaft für Nachhaltiges Bauen, has been updated.

In addition to the changes to bring the information about the major building assessment systems up to date, a new chapter on carbon accounting addresses the increasing interest in reducing the carbon footprint of the built environment, from a green building perspective and also to provide clarity about the contribution of buildings to climate change.

A major emerging issue is transparency, and demands for transparency are appearing regarding several performance issues. These include the provision of information about building product ingredients and the risks of these ingredients to human health and ecosystems. Risk-based assessment, Health Product Declarations, and other approaches are emerging to address this demand, and manufacturers are buying into the concept of being more open about the content of their products. In addition, many major cities are requiring transparency regarding the energy performance of buildings. In New York City, for example, building owners are required to provide information about the performance of their buildings on an annual basis. This requirement dovetails with the shift in building assessment system strategies that explicitly provide credit for reporting of both energy and water data. Transparency is described and discussed in several locations in this fourth edition.

One of the new additions is coverage of the rapid growth in the numbers and quality of green skyscrapers around the world. Ken Yeang, the renowned Malaysian architect, first elaborated this concept in his 1996 book, *The Green Skyscraper: The Basis for Designing Sustainable Intensive Buildings*, and in his two other volumes on the subject, *Eco-Skyscrapers* (2007), and *Eco-Skyscrapers, Volume 2* (2011). In this volume, we address skyscrapers two chapters. In Chapter 1, one of the world's premier green skyscrapers, the Pertamina Energy Tower, located in Jakarta, Indonesia, is described in great detail because it represents perhaps the cutting edge of very large building design. This project is especially noteworthy because it is the first net-zero-energy skyscraper and represents the cutting edge of skyscraper performance. Later in the volume, in Chapter 16, two sets of skyscrapers—one group in New York City and the other group selected from green skyscraper projects around the world—are described and compared. I would like to express my gratitude to the group of architects and engineers at Skidmore, Owings & Merrill (SOM), who designed the Pertamina Energy Tower. These include the Gabriele Pascolini, Sergio Sabada, Luke Leung, Scott Duncan, David Kosterno, Stephen Ray, Elyssa Cohen,

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and Jonathan Stein. Although extremely busy with their day jobs designing significant skyscraper projects around the world, they gave generously of their time and resources to assist me. I would also like thank the team at HOK that designed the Lake Nona Research Building for the University of Florida, specifically Van Phrasavath and Mandy Weitknecht. Frank Javaheri, project manager for the University of Florida, was also very helpful in assisting in gaining access to information and documentation.

This fourth edition has significantly more graphics than the third edition of *Sustainable Construction*, and a large number of organizations and companies were kind enough to permit the publication of their content in this edition. Thanks to all the contributors of these invaluable materials.

Thanks to Paul Drougas and Margaret Cummings at John Wiley & Sons for once again guiding me through the initial stages of the publication process and to Mike New at John Wiley & Sons for keeping me on track. This edition would not have been possible without the enormous contributions of Tori Reszetar and Alina Kibert, who were extremely dedicated to helping produce a comprehensive, quality outcome. I owe an enormous debt to both of them for their very hard work and dedication.

Charles J. Kibert
Gainesville, Florida

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Chapter 1

Introduction and Overview

In the short quarter century after the first significant efforts to apply the *sustainability* paradigm to the built environment in the early 1990s, the resulting *sustainable construction* movement has gained significant strength and momentum. In some countries—for example, the United States—there is growing evidence that this responsible and ethical approach is dominating the market for commercial and institutional buildings, including major renovations. Over 69,000 commercial building projects have been registered for third-party green building certification with the US Green Building Council (USGBC), the major American proponent of built environment sustainability, in effect declaring the project team's intention to achieve the status of an officially recognized or certified green building. The tool the USGBC uses for this process is commonly referred to by its acronym, LEED (Leadership in Energy and Environmental Design). Thus far, 27,000 commercial projects have navigated the LEED certification process successfully. Nowhere has the remarkable shift toward sustainable buildings been more evident than in American higher education. Harvard University boasts 93 buildings certified in accordance with the requirements of the USGBC, including several projects with the highest, or platinum, rating and including more than 1.9 million square feet (198,000 square meters [m^2]) of labs, dormitories, libraries, classrooms, and offices. An additional 27 projects are registered and pursuing official recognition as green building projects. The sustainable construction movement is now international in scope, with almost 70 national green building councils establishing ambitious performance goals for the built environment in their countries. In addition to promoting green building, these councils develop and supervise building assessment systems that provide ratings for buildings based on a holistic evaluation of their performance against a wide array of environmental, economic, and social requirements. The outcome of applying sustainable construction approaches to creating a responsible built environment is most commonly referred to as *high-performance green buildings*, or simply, *green buildings.*

The Shifting Landscape for Green Buildings

There are many signs that the green building movement is permanently embedded as standard practice for owners, designers, and other stakeholders. Among these are four key indicators that illustrate this shift into the mainstream. First, a survey of design and construction activity by McGraw-Hill Construction (2013) found that, for the first time, the majority of firms engaged in design and construction expected that over 60 percent of their work would be in green building by 2015. South Africa, Singapore, Brazil, European countries, and the United States all report this same result: that green building not only dominates the construction marketplace but also continues to increase in market share. This same report suggests that around the world, the pace of green building is accelerating and becoming a long-term business opportunity for both designers and builders. The green building market is growing worldwide and is

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not isolated to one region or culture. According to McGraw-Hill Construction, architects and engineers around the world are bullish on green building. Between 2012 and 2015, the number of designers and building consultants expecting more than 60 percent of their business to be green more than tripled in South Africa; more than doubled in Germany, Norway, and Brazil; and increased between 33 percent and 68 percent in the United States, Singapore, the United Kingdom, and Australia. The reasons for the rapid growth in high-performance green building activity has changed dramatically over time. In 2008, when a similar survey was conducted, most of the respondents felt that the main reason for their involvement was that they were doing the right thing, that they were simply trying to have a positive impact. Fast-forward just six years to 2014, and the reasons had changed significantly. The most cited triggers for green building around the world are client demand, market demand, lower operating costs, and branding/public relations. Green building has become simply a matter of doing good business, and has entered the mainstream in both the public and the private sectors. Although those interviewed indicated that they were still interested in doing the right thing, this reason moved from the top of the list in 2008 to number five in the six-year period between the two surveys.

A second illustration of the green building movement's staying power occurred at the Arab world's first Forum for Sustainable Communities and Green Building held in late 2014. Mustafa Madbouly, Egypt's minister of housing and urban development, told the audience: "Climate change forces upon us all a serious discussion about green building and the promotion of sustainability" (Zayed 2014). According to the United Nations Human Settlement Program (UNHSP), cities in the Arab world need to introduce stronger standards for green building and promote sustainable communities if they are to have this chance of tackling climate change. The UNHSP estimates that 56 percent of the Arab world's population already lives in cities and urban centers. This number quadrupled between 1990 and 2010 and is expected to increase another 75 percent by 2050. In short, applying sustainability principles to the built environment is essential not only for the well-being of the region's population but also for their very survival. According to the World Bank, the unprecedented heat extremes caused by climate change could affect 70 percent to 80 percent of the land area in the Middle East and North Africa.[1] Green building and climate change are now inextricably linked, and the main strategy for addressing climate change must be to change the design and operation of the built environment and infrastructure to reduce carbon emissions dramatically.

Third, in the United States, activity in sustainable construction continues to increase, some of it marking the continued evolution of thinking about how best to achieve high standards of efficiency in the built environment while at the same time promoting human health and protecting ecological systems. The state of Maryland and its largest city, Baltimore, provide a contemporary example of how strategies are being fine-tuned to embed sustainability in the built environment for the long term. In 2007, both Maryland and Baltimore, the 26th most populous city in the United States, adopted the USGBC's LEED rating system, requiring that most new construction be LEED certified. At the time, this move was considered groundbreaking, and it paralleled efforts by many states and municipalities around the country to foster the creation of a much-improved building stock. Baltimore, along with 176 other American jurisdictions, mandated green buildings and supported their implementation with a variety of incentives, including more rapid approval times, decreased permitting fees, and, in some cases, grants and lower taxes. In 2014, in a move that is likely to become more common, both Maryland and Baltimore repealed the laws and ordinances requiring LEED rating certification and instead adopted the International Green Construction Code (IgCC) as a template for their building codes. A construction or building code such as IgCC, in contrast to a voluntary rating system such as LEED, *mandates* green strategies for buildings. This turn of events marks a significant change in both strategy and philosophy because it indicates a shift

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from third-party certification systems to mainstreaming green building through the use of standards and building codes enforced by local authorities.

The fourth sign of the shifting landscape for high-performance green building is the fact the major tech giants Apple and Google and a range of other tech companies have announced major projects that indicate their industry is embracing high-performance green building. Apple Campus 2 (see Figure 1.1), scheduled for a late 2016 completion, will house 14,200 employees. In first announcing the new project in 2006, the late Steve Jobs referred to it as "the best office building in the world." The architects for this cutting-edge facility are Foster + Partners, the renowned British architecture firm whose founder and chairman, Sir Norman Foster, was inspired by a London square surrounded by houses to guide the design concept. As the building evolved, it morphed into a circle surrounded by green space, the inverse of the London square. Located on about 100 acres (40.5 hectares) in Cupertino, California, the 2.8 million–square–foot (260,000 square meters) building is sited in the midst of 7,000 plum, apple, cherry, and apricot trees, a signature feature of the area's commercial orchards. Only 20 percent of the site was disturbed by construction, resulting in



Figure 1.1 Apple Campus 2 is an NZE building designed to generate all the energy it requires from photovoltaic (PV) panels located on its circular roof. Its many passive design features allow it to take advantage of the favorable local climate such that cooling will be required just 25 percent of the year. (*Source:* City of Cupertino, September 2013)

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abundant green space. Apple's Transportation Demand Management program emphasizes the use of bicycles, shuttles, and buses to move its employees to and from two San Francisco Bay regional public transit networks. The transportation program alternatives for Apple Campus 2 include buffered bike lanes and streets near the campus that are segregated from automobile traffic and also wide enough to permit bicycles to pass each other. Hybrid and electric automobile charging stations serve 300 electric vehicles, and the system can be expanded as needed. The energy strategy for Apple's new office building was shaped around the *net zero energy* (NZE) concept, with extensive focus on passive design to maximize daylighting and natural cooling and ventilation. The result is a building that generates more energy from renewable sources than it consumes. Energy efficiency is important for the net zero strategy, and the lighting and all other energy-consuming systems were selected for minimal energy consumption. The central plant contains fuel cells, chillers, generators, and hot and condenser water storage. A low carbon solar central plant with 8 megawatts (MW) of solar panels is installed on the roof, ensuring the campus runs entirely on renewable energy.

Another tech giant with ambitious high-performance green building plans is Google. Early in 2015, as part of a planned massive expansion, Google announced a radical plan for expansion of its Mountain View, California, headquarters into the so-called Googleplex. The radical design included large tentlike structures with canopies of translucent glass floating above modular buildings that would be reconfigured as the company's projects and priorities change. The area beneath the glass canopy included walking and bicycle paths along meadows and streams that connect to nearby San Francisco Bay. The emerging direction of design by the superstar collaboration between the Danish architect Bjarke Ingels and the London design firm, Heatherwick Studio was an eco-friendly project that would feature radical passive design and integration with nature and local transportation networks. However, in mid-2015, the Mountain View City Council voted to allow Google just one-fourth of its planned expansion, with the remaining site being made available to another tech firm, LinkedIn. In spite of this setback, Google, like many other technology-oriented companies, is committed to greening its buildings and infrastructure. One of its commitments is to investing in renewable energy, and the firm committed $145 million to finance a SunEdison plant north of Los Angeles. This was one of many renewable projects in which Google has invested a total of over $1.5 billion as of 2015.

Other tech firms are also leading the way with investments in architecturally significant, high-performance green buildings. Hewlett-Packard hired the renowned architect Frank Gehry to design an expansion of its Menlo Park, California, campus. It is clear that the behavior of these tech firms is part of an emerging pattern among start-up firms, which often begin their lives in college dorm rooms, storage units, garages, and living rooms. They move out of such locations as they mature, renting offices in industrial parks. Then, when they have become supersuccessful and flush with cash, they tend to build iconic monuments. However, in spite of the desire to make a splash by investing in signature headquarters buildings designed by well-known architects, the tech industries have managed to remain eco-conscious and serve as change agents by pushing society toward more sustainable behavior, particularly with respect to the built environment.

These trends, which mark the current state of high-performance green building around the world, indicate a maturing of the movement. The first of these buildings emerged around 1990, and the movement is now being mainstreamed, as evidenced by the incorporation of high performance building rating systems, such as LEED, into standards and codes. Since the inception of its pilot version in 1998, LEED has dealt with building energy performance by specifying improvements beyond the requirements of these standards to earn points toward certification. The main energy standard in the United States is the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) Standard 90.1, *Energy Standard for*

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Buildings Except Low-Rise Residential Buildings. In the years since 1998, the energy consumption standards for new U.S. buildings has been sliced by more than 50 percent, and each issue of ASHRAE 90.1 makes additional cuts. The outcome is that it is becoming more difficult to use green building rating systems to influence additional energy reductions because following ASHRAE 90.1 already results in highly efficient building. Nevertheless, many issues still need attention, such as the restoration of natural systems, urban planning, infrastructure, renewable energy systems, comprehensive indoor environmental quality, and stormwater management. To its credit, the green building movement has succeeded in creating a dramatic shift in thinking in a short time. Its continued presence is now needed to both push the cutting edge of building performance and to ensure that the success of its efforts are maintained for the long term.

The Roots of Sustainable Construction

The contemporary high-performance green building movement was sparked by finding answers to two important questions: What is a high-performance green building? How do we determine if a building meets the requirements of this definition? The first question is clearly important—having a common understanding of what comprises a green building is essential for coalescing effort around this idea. The answer to the second question is to implement a *building assessment* or *building rating* system that provides detailed criteria and a grading system for these advanced buildings. The breakthrough in thinking and approach first occurred in 1989 in the United Kingdom with the advent of a building assessment system known as *BREEAM* (Building Research Establishment Environmental Assessment Method). BREEAM was an immediate success because it proposed both a standard definition for green building and a means of evaluating its performance against the requirements of the building assessment system. BREEAM represented the first successful effort at evaluating buildings on a wide range of factors that included not only energy performance but also water consumption, indoor environmental quality, location, materials use, environmental impacts, and contribution to ecological system health, to name but a few of the general categories that can be included in an assessment. To say that BREEAM is a success is a huge understatement because over 1 million buildings have been registered for certification and about 200,000 have successfully navigated the certification process. Canada and Hong Kong subsequently adopted BREEAM as the platform for their national building assessment systems, thus providing their building industries with an accepted approach to green construction. In the United States, the USGBC developed an American building rating system with the acronym LEED. When launched as a fully tested rating system in 2000, LEED rapidly dominated the market for third-party green building certification. Similar systems were developed in other major countries: for example, *CASBEE* (Comprehensive Assessment System for Building Environmental Efficiency) in Japan (2004) and *Green Star* in Australia (2006). In Germany, which has always had a strong tradition of high-performance buildings, the German Green Building Council and the German government collaborated in 2009 to develop a building assessment system known as *DGNB* (Deutsche Gesellschaft für Nachhaltiges Bauen), which is perhaps the most advanced evolution of building assessment systems. BREEAM, LEED, CASBEE, Green Star, and DGNB represent the cutting edge of today's high-performance green building assessment systems, both defining the concept of high performance and providing a scoring system to indicate the success of the project in meeting its sustainability objectives.

In the United States, the green building movement is often considered to be the most successful of all the American environmental movements. It serves as a template for engaging and mobilizing a wide variety of stakeholders to accomplish an

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important sustainability goal, in this case dramatically improving the efficiency, health, and performance of the built environment. The green building movement provides a model for other sectors of economic endeavor about how to create a consensus-based, market-driven approach that has rapid uptake, not to mention broad impact. This movement has become a force of its own and, as a result, is compelling professionals engaged in all phases of building design, construction, operation, financing, insurance, and public policy to fundamentally rethink the nature of the built environment.

In the second decade of the twenty-first century, circumstances have changed significantly since the onset of the sustainable construction movement. In 1990, the global population was 5.2 billion, climate change was just entering the public consciousness, the United States had just become the world's sole superpower, and Americans were paying just $1.12 for a gallon of gasoline. Fast-forwarding almost a quarter century, the world's population is approaching 7.4 billion, the effects of climate change are becoming evident at a pace far more rapid than predicted, the global economic system is still floundering from debt crises in Europe, and Japan is still recovering from the impacts of a tsunami and nuclear disaster. Prices for gasoline have fluctuated widely due to a recent abundance of oil produced by fracking but are about two times higher than in 1990. The convergence of financial crises, climate change, and increasing numbers of conflicts has produced an air of uncertainty that grips governments and institutions around the world. What is still not commonly recognized is that all of these problems are linked and that population and consumption remain the twin horns of the dilemma that confronts humanity. Population pressures, increased consumption by wealthier countries, the understandable desire for a good quality of life among the 5 billion impoverished people on the planet, and the depletion of finite, nonrenewable resources are all factors creating the wide range of environmental, social, and financial crises that are characteristic of contemporary life in the early twenty-first century (see Figure 1.2).

These changing conditions are affecting the built environment in significant ways. First, there is an increased demand for buildings that are resource-efficient, that use minimal energy and water, and whose material content will have value for future populations. In 2000, the typical office building in the United States consumed over 300 kilowatt-hours per square meter per year (kWh/m^2/yr) or 100,000 BTU/square foot/year (BTU/ft^2/yr). Today's high-performance buildings are approaching 100 kWh/m^2/yr (33,000 BTU/ft^2/yr).[2] In Germany, the energy profiles of high-performance buildings are even more remarkable, in the range of 50 kWh/m^2/yr

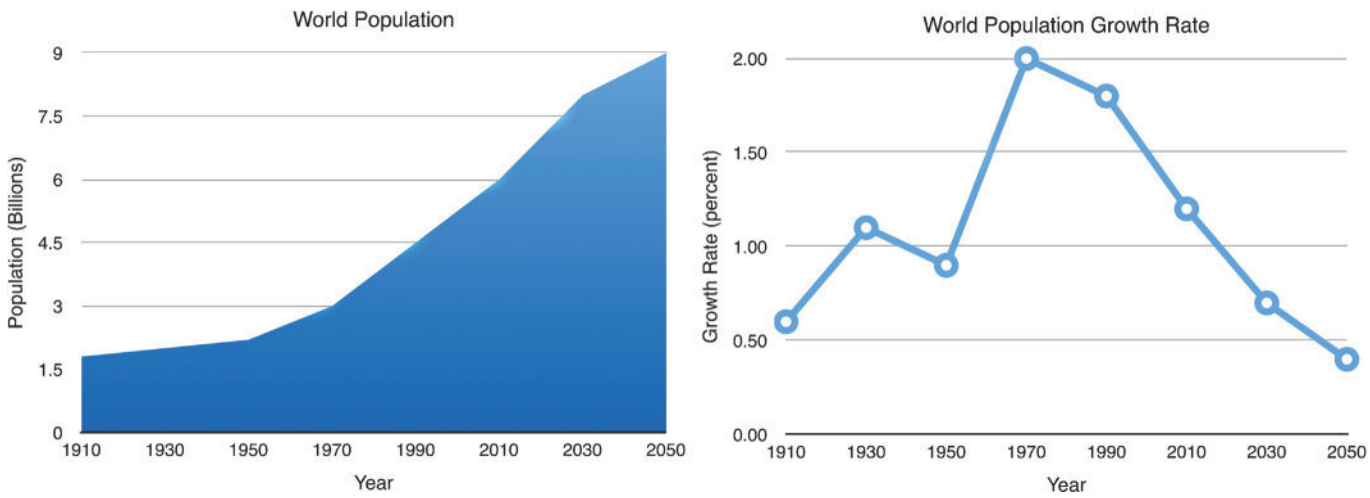


Figure 1.2 World population continues to increase, but the growth rate is declining, from about 1.2 percent in 2012 to a forecasted 0.5 percent in 2050. (*Source:* US Census Bureau, International Database, June 2011)

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(17,000 BTU/ft^2/yr). It is important to recognize that reduced energy consumption generally causes a proportional reduction in climate change impacts. Reductions in water consumption in high-performance buildings are also noteworthy. A high-performance building in the United States can reduce potable water consumption by 50 percent simply by opting for the most water-efficient fixtures available, including high-efficiency toilets and high-efficiency urinals. By using alternative sources of water, such as rainwater and graywater, potable water consumption can be reduced by another 50 percent, to one-fourth that of a conventionally designed building water system. This is also referred to as a Factor 4 reduction in potable water use. Similarly impressive impact reductions are emerging in materials consumption and waste generation.

Second, it has become clear over time that building location is a key factor in reducing energy consumption because transportation energy can amount to two times the operational energy of the building (Wilson and Navaro 2007). Not only does this significant level of energy for commuting have environmental impacts, but it also represents a significant cost for the employees who make the daily commute. It is clear that the lower the building's energy consumption, the greater is the proportion of energy used in commuting. For example, a building that consumes 300 kWh/m^2/yr of operational energy and 200 kWh/m^2/yr of commuting energy by its occupants has 40 percent of its total energy devoted to transportation. A high-performance building in the same location with an energy profile of 100 kWh/m^2/yr and the same commuting energy of 200 kWh/m^2/yr would have 67 percent of its total energy consumed by transportation. Clearly, it makes sense to reduce transportation energy along with building energy consumption to have a significant impact on total energy consumption (see Figure 1.3).

Third, the threat of climate change is enormous and must be addressed across the entire life cycle of a building, including the energy invested in producing its materials and products and in constructing the building, commonly referred to as

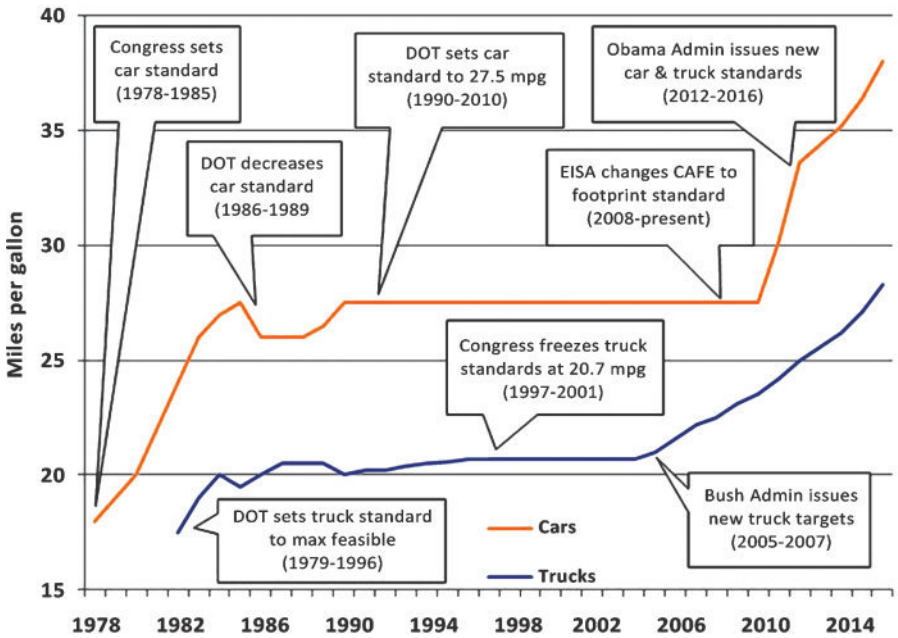


Figure 1.3 The fuel efficiency of US vehicles languished for decades before federal standards, due to the energy crises of the 1970s, demanded significant improvements in fuel performance. More recent requirements have increased dramatically the miles per gallon performance of both automobiles and trucks. (*Source:* Center for Climate and Energy Solutions)

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embodied energy. The energy invested in building materials and construction is significant, amounting to as much as 20 percent of the total life cycle energy of the facility. Furthermore, significant additional energy is invested by maintenance and renovation activities during the building's life cycle, sometimes exceeding the embodied energy of the construction materials. Perhaps the most noteworthy effort to address the built environment contribution to climate change is the *Architecture 2030 Challenge* whose goal is to achieve a dramatic reduction in the greenhouse gas (GHG) emissions of the built environment by changing the way buildings and developments are planned, designed, and constructed.[3] The 2030 Challenge asks the global architecture and building community to adopt the following targets:

- All new buildings, developments and major renovations shall be designed to meet a fossil fuel, GHG-emitting, energy consumption performance standard of 70 percent below the regional (or country) average/median for that building type.
- At a minimum, an equal amount of existing building area shall be renovated annually to meet a fossil fuel, GHG-emitting, energy consumption performance standard of 70 percent of the regional (or country) average/median for that building type.
- The fossil fuel reduction standard for all new buildings and major renovations shall be increased to 80 percent in 2020, 90 percent in 2025, and be carbon-neutral in 2030 (using no fossil fuel energy to operate).[4]

The *2030 Challenge for Product* addresses the GHG emissions of building materials and products and sets a goal of reducing the maximum carbon-equivalent footprint to 35 percent below the product category average by 2015 and eventually to 50 percent below the product category average by 2030.

The emerging concept of NZE, which, in its simplest form, suggests that buildings generate as much energy from renewables as they consume on an annual basis, also supports the goals of the 2030 Challenge. Every unit of energy generated by renewables that displaces energy generated from fossil fuels results in less climate change impact. An NZE building would, in effect, have no climate change impacts due to its operational energy. It is clear that influencing energy consumption and climate change requires a comprehensive approach that addresses all forms of energy consumption, including operational energy, embodied energy, and commuting energy.

In summary, high-performance building projects are now addressing three emerging challenges: (1) the demand for high-efficiency or *hyperefficient* buildings, (2) consideration of building location to minimize transportation energy, and (3) the challenges of climate change. These challenges are in addition to issues such as indoor environmental quality, protection of ecosystems and biodiversity, and risks associated with building materials. Building assessment systems such as LEED are being affected by these changes as is the very definition of green buildings. As time advances and more is learned about the future and its challenges, the design, construction, and operation of the built environment will adapt to meet this changing future landscape.

Sustainable Development and Sustainable Construction

The main impetus behind the high-performance green building movement is the sustainable development paradigm, which is changing not only physical structures but also the workings of the companies and organizations that populate the built environment, as well as the hearts and minds of the individuals who inhabit it.[5] Fueled by

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examples of personal and corporate irresponsibility and negative publicity resulting from events such as the collapse of the international finance system that triggered the Great Recession of 2008–2010, increased public concern about the behavior of private and public institutions has developed. As a result, accountability and transparency are becoming the watchwords of today's corporate world. Heightened corporate consciousness has embraced comprehensive sustainability reporting as the new standard for corporate transparency. The term *corporate transparency* refers to complete openness of companies about all financial transactions and all decisions that affect their employees and the communities in which they operate. Major companies, such as DuPont, the Ford Motor Company, and Hewlett-Packard, now employ triple bottom line reporting,[6] which involves a corporate refocus from mere financial results to a more comprehensive standard that includes environmental and social impacts. By adopting the cornerstone principles of sustainability in their annual reporting, corporations acknowledge their environmental and social impacts and ensure improvement in all arenas.

Still, other major forces, such as climate change and the rapid depletion of the world's oil reserves, threaten national economies and the quality of life in developed countries. Both are connected to our dependence on fossil fuels, especially oil. Climate change, caused at least in part by increasing concentrations of human-generated carbon dioxide (CO_2), methane, and other gases in Earth's atmosphere, is believed by many authoritative scientific institutions and Nobel laureates to profoundly affect our future temperature regimes and weather patterns.[7] Much of today's built environment will still exist during the coming era of rising temperatures and sea levels; however, little consideration has been given to how human activity and building construction should adapt to potentially significant climate alterations. Global temperature increases now must be considered when forming assumptions about passive design, the building envelope, materials selection, and the types of equipment required to cope with higher atmospheric energy levels.

The state of the global economy and consumption continue to significantly affect the state of Earth's environment. The Chinese economy grew at an official rate of 7 percent in 2015 with some estimates that it will continue to grow at or above this pace over the next few years. China produced about 2 million automobiles in 2000, about 6 million in 2005, and 14 million in 2015. China's burgeoning industries are in heavy competition with the United States and other major economies for oil and other key resources, such as steel and cement. The rapid economic growth in China and India and concerns over the contribution of fossil fuel consumption to climate change will inevitably force the price of gasoline and other fossil fuel–derived energy sources to increase rapidly in the coming decades. At present, there are no foreseeable technological substitutes for large-scale replacement of fossil fuels. Alternatives such as hydrogen or fuels derived from coal and tar sands threaten to be prohibitively expensive. The expense of operating buildings that are heated and cooled using fuel oil and natural gas will likely increase, as will industrial, commercial, and personal transportation that is fossil fuel dependent. A shift toward hyperefficient buildings and transportation cannot begin soon enough.

The Vocabulary of Sustainable Development and Sustainable Construction

A unique vocabulary is emerging to describe concepts related to sustainability and global environmental changes. Terms such as *Factor 4* and *Factor 10*, *ecological footprint*, *ecological rucksack*, *biomimicry*, the *Natural Step*, *eco-efficiency*, *ecological economics*, *biophilia*, and the *precautionary principle* describe the overarching

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philosophical and scientific concepts that apply to a paradigm shift toward sustainability. Complementary terms, such as *green building*, *building assessment*, *ecological design*, *life-cycle assessment (LCA)*, *life-cycle costing (LCC)*, *high-performance building*, and *charrette*, articulate specific techniques in the assessment and application of principles of sustainability to the built environment.

The sustainable development movement has been evolving worldwide for almost 25 years, causing significant changes in building delivery systems in a relatively short period. Sustainable construction, a subset of sustainable development, addresses the role of the built environment in contributing to the overarching vision of sustainability. The key vocabulary of this relatively new movement is discussed in the following sections and in Chapter 2. Additionally, a glossary of key terms and an index of abbreviations is included at the end of this book.

SUSTAINABLE CONSTRUCTION

The terms *high performance*, *green*, and *sustainable construction* often are used interchangeably; however, the term *sustainable construction* most comprehensively addresses the ecological, social, and economic issues of a building in the context of its community. In 1994, Task Group 16 of the Conseil International du Bâtiment (CIB), an international construction research networking organization, defined sustainable construction as "creating and operating a healthy built environment based on resource efficiency and ecological design."[8] Task Group 16 articulated seven Principles of Sustainable Construction that ideally would inform decision making during each phase of the design and construction process, continuing throughout the building's entire life cycle (see Table 1.1; see also Kibert 1994). These factors also apply when evaluating the components and other resources needed for construction (see Figure 1.4). The Principles of Sustainable Construction apply across the entire life cycle of construction, from planning to disposal (here referred to as *deconstruction* rather than *demolition*). Furthermore, the principles apply to the resources needed to create and operate the built environment during its entire life cycle: land, materials, water, energy, and ecosystems.

TABLE 1.1

Principles of Sustainable Construction

1. Reduce resource consumption (reduce).
2. Reuse resources (reuse).
3. Use recyclable resources (recycle).
4. Protect nature (nature).
5. Eliminate toxics (toxics).
6. Apply life-cycle costing (economics).
7. Focus on quality (quality).

Source: Kibert (1994)

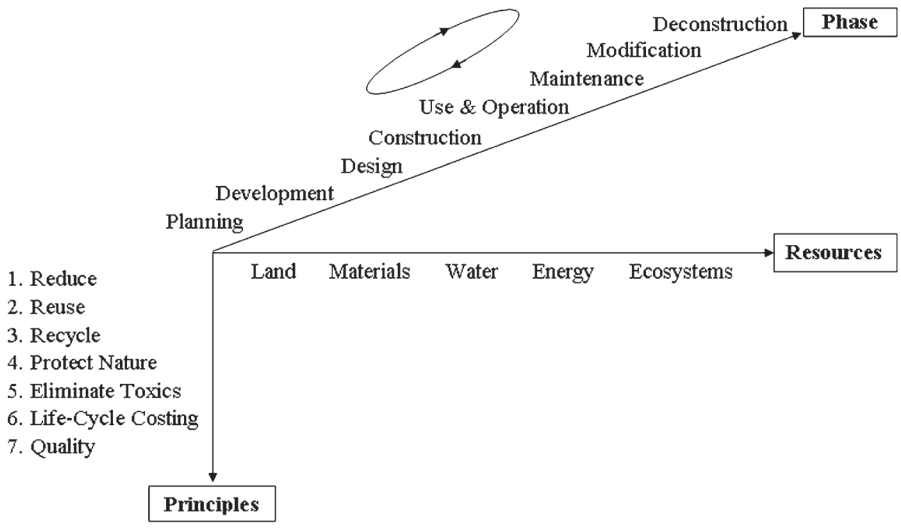


Figure 1.4 Framework for sustainable construction developed in 1994 by the CIB Task Group 16 (Sustainable Construction) for the purpose of articulating the potential contribution of the built environment to the attainment of sustainable development. (Illustration courtesy of Bilge Çelik)

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GREEN BUILDING

The term *green building* refers to the quality and characteristics of the actual structure created using the principles and methodologies of sustainable construction. Green buildings can be defined as "healthy facilities designed and built in a resource-efficient manner, using ecologically based principles" (Kibert 1994) Similarly, *ecological design*, *ecologically sustainable design*, and *green design* are terms that describe the application of sustainability principles to building design. Despite the prevalent use of these terms, truly sustainable green commercial buildings with renewable energy systems, closed materials loops, and full integration into the landscape are rare to nonexistent. Most existing green buildings feature incremental improvement over, rather than radical departure from, traditional construction methods. Nonetheless, this process of trial and error, along with the gradual incorporation of sustainability principles, continues to advance the industry's evolution toward the ultimate goal of achieving complete sustainability throughout all phases of the built environment's life cycle.

HIGH-PERFORMANCE BUILDINGS, SYSTEMS THINKING, AND WHOLE-BUILDING DESIGN

The term *high-performance building* recently has become popular as a synonym for green building in the United States. According to the Office of Energy Efficiency and Renewable Energy of the US Department of Energy, a high-performance commercial building "uses whole-building design to achieve energy, economic, and environmental performance that is substantially better than standard practice." This approach requires that the design team fully collaborate from the project's inception in a process often referred to as *integrated design*.

Whole-building design,[9] or integrated design, considers site, energy, materials, indoor air quality, acoustics, and natural resources as well as their interrelation with one another. In this process, a collaborative team of architects, engineers, building occupants, owners, and specialists in indoor air quality, materials, and energy and water efficiency uses systems thinking to consider the building structure and systems holistically, examining how they best work together to save energy and reduce the environmental impact. A common example of systems thinking is advanced daylighting strategy, which reduces the use of lighting fixtures during daylight, thereby decreasing daytime peak cooling loads and justifying a reduction in the size of the mechanical cooling system. This, in turn, results in reduced capital outlay and lower energy costs over the building's life cycle.

According to the Rocky Mountain Institute (RMI), a well-respected nonprofit organization specializing in energy and building issues, whole-systems thinking is a process through which the interconnections between systems are actively considered and solutions are sought that address multiple problems. Whole-systems thinking often is promoted as a cost-saving technique that allows additional capital to be invested in new building technology or systems. RMI cites developer Michael Corbett, who applied just such a concept in his 240-unit Village Homes subdivision in Davis, California, completed in 1981. Village Homes was one of the first modern-era developments to create an environmentally sensitive, human-scale residential community. The result of designing narrower streets was reduced stormwater runoff. Simple infiltration swales and on-site detention basins handled stormwater without the need for conventional stormwater infrastructure. The resulting $200,000 in savings was used to construct public parks, walkways, gardens, and other amenities that improved the quality of the community. Another example of systems thinking is Solaire, a 27-story luxury residential tower in New York City's Battery Park (see Figure 1.5) that, when completed in 2003, was the first green high-rise residential building in the United States. The façade of Solaire contains



Figure 1.5 Solaire, a 27-story residential tower on the Hudson River in New York City built in 2003, was the first high-rise residential building in the United States specifically designed to be environmentally responsible. (Photograph courtesy of the Albanese Development Corporation)

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PV cells that convert sunlight directly into electricity, and the building itself uses 35 percent less energy than a comparable residential building. Solaire provides its residents with abundant natural light and excellent indoor air quality. The building collects rainwater in a basement tank for watering roof gardens. Wastewater is processed for reuse in the air-conditioning system's cooling towers or for flushing toilets. The roof gardens not only provide a beautiful urban landscape but also assist in insulating the building to reduce heating and cooling loads. This interconnection of many of the green building measures in Solaire indicates that the project team carefully selected approaches that would have multiple layers of benefit, the core of systems thinking.[10]

Sustainable Design, Ecological Design, and Green Design

The issue of resource-conscious design is central to sustainable construction, which ultimately aims to minimize natural resource consumption and the resulting impact on ecological systems. Sustainable construction considers the role and potential interface with ecosystems to provide services in a synergistic fashion. With respect to materials selection, closing materials loops and eliminating solid, liquid, and gaseous emissions are key sustainability objectives. *Closed loop* describes a process of keeping materials in productive use by reuse and recycling rather than disposing of them as waste at the end of the product or building life cycle. Products in closed loops are easily disassembled, and the constituent materials are able to be recycled and worthy of recycling. Because recycling is not entirely thermodynamically efficient, dissipation of residue into the biosphere is inevitable. Thus, the recycled materials must be inherently nontoxic to biological systems. Most common construction materials are not completely recyclable but rather are *downcyclable* for lower-value reuse, such as for fill or road subbase. Fortunately, aggregates, concrete, fill dirt, block, brick, mortar, tiles, terrazzo, and similar low-technology materials are composed of inert substances with low ecological toxicity. In the United States, the 160 million tons (145 million metric tons [mt]) of construction and demolition waste produced annually make up about one-third of the total solid waste stream, consuming scarce landfill space, threatening water supplies, and driving up the costs of construction. As part of the green building delivery system, manufactured products are evaluated for their life-cycle impacts, to include energy consumption and emissions during resource extraction, transportation, product manufacturing, and installation during construction; operational impacts; and the effects of disposal.

LAND RESOURCES

Sustainable land use is based on the principle that land, particularly undeveloped, natural, or agricultural land (greenfields), is a precious finite resource and its development should be minimized. Effective planning is essential for creating efficient urban forms and minimizing urban sprawl, which leads to overdependence on automobiles for transportation, excessive fossil fuel consumption, and higher pollution levels. Like other resources, land is recyclable and should be restored to productive use whenever possible. Recycling disturbed land such as former industrial zones (brownfields) and blighted urban areas (grayfields) back to productive use facilitates land conservation and promotes economic and social revitalization in distressed areas.

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ENERGY AND ATMOSPHERE

Energy conservation is best addressed through effective building design, which integrates three general approaches: (1) fully implementing passive design, (2) designing a building envelope that is highly resistant to conductive, convective, and radiative heat transfer, and (3) employing renewable energy resources. Passive design employs the building's geometry, orientation, and mass to condition the structure using natural and climatologic features, such as the site's solar *insolation* (or incoming solar radiation), thermal chimney effects, prevailing winds, local topography, microclimate, and landscaping. Since buildings in the United States consume 40 percent of domestic primary energy,[11] increased energy efficiency and a shift to renewable energy sources can appreciably reduce CO_2 emissions and mitigate climate change.

WATER ISSUES

The availability of potable water is the limiting factor for development and construction in many areas of the world. In the high-growth Sun Belt and western regions of the United States, the demand for water threatens to rapidly outstrip the natural supply, even in normal, drought-free conditions.[12] California is experiencing an epic drought that threatens not only the most agriculturally productive region of the world but also the economy of the state and perhaps the United States. Climate alterations and erratic weather patterns precipitated by global warming threaten to further limit the availability of this most precious resource. Since only a small portion of Earth's hydrologic cycle yields potable water, protection of existing groundwater and surface water supplies is increasingly critical. Once water is contaminated, it is extremely difficult, if not impossible, to reverse the damage. Water conservation techniques include the use of low-flow plumbing fixtures, water recycling, rainwater harvesting, and xeriscaping, a landscaping method that utilizes drought- resistant plants and resource-conserving techniques.[13] Innovative approaches to wastewater processing and stormwater management are also necessary to address the full scope of the building hydrologic cycle.

ECOSYSTEMS: THE FORGOTTEN RESOURCE

Sustainable construction considers the role and potential interface of ecosystems in providing services in a synergistic fashion. Integration of ecosystems with the built environment can play an important role in resource-conscious design. Such integration can supplant conventional manufactured systems and complex technologies in controlling external building loads, processing waste, absorbing stormwater, growing food, and providing natural beauty, sometimes referred to as *environmental amenity*. For example, the Lewis Center for Environmental Studies at Oberlin College in Oberlin, Ohio, uses a built-in natural system, referred to as a "Living Machine," to break down waste from the building's occupants; the effluent then flows into a reconstructed wetland (see Figure 1.6). The wetland also functions as a stormwater retention system, allowing pulses of stormwater to be stored and thereby reducing the burden on stormwater infrastructure. The restored wetland also provides environmental amenity in the form of native Ohio plants and wildlife.[14]



Figure 1.6 The Lewis Center for Environmental Studies at Oberlin College in Oberlin, Ohio, was designed by a team led by William McDonough, a leading green building architect, and including John Todd, developer of the Living Machine. In addition to the superb design of the building's hydrologic strategy, the extensive PV system makes it an NZE building. (Photograph courtesy of Oberlin College)

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Rationale for High-Performance Green Buildings

High-performance green buildings marry the best features of conventional construction methods with emerging high-performance approaches. Green buildings are achieving rapid penetration in the US construction market for three primary reasons:

1. *Sustainable construction provides an ethical and practical response to issues of environmental impact and resource consumption.* Sustainability assumptions encompass the entire life cycle of the building and its constituent components, from resource extraction through disposal at the end of the useful life of the materials. Conditions and processes in factories are considered, along with the actual performance of their manufactured products in the completed building. High-performance green building design relies on renewable resources for energy systems; recycling and reuse of water and materials; integration of native and adapted species for landscaping; passive heating, cooling, and ventilation; and other approaches that minimize environmental impact and resource consumption.
2. *Green buildings virtually always make economic sense on an LCC basis, although they may be more expensive on a capital, or first-cost, basis.* Sophisticated energy-conserving lighting and air- conditioning systems with an exceptional response to interior and exterior climates will cost more than their conventional, code-compliant counterparts. Rainwater harvesting systems that collect and store rainwater for nonpotable uses will require additional piping, pumps, controls, storage tanks, and filtration components. However, most key green building systems will recoup their original investment within a relatively short time. As energy and water prices rise due to increasing demand and diminishing supply, the payback period will decrease (Kats 2003).[15]
3. *Sustainable design acknowledges the potential effect of the building, including its operation, on the health of its human occupants.* A 2012 report from the Global Indoor Health Network suggested that, globally, about 50 percent of all illnesses are caused by indoor air pollution.[16] Estimates peg the direct and indirect costs of building-related illnesses (BRIs), including lost worker productivity, as exceeding $150 billion per year (Zabarsky 2002). Conventional construction methods have traditionally paid little attention to sick building syndrome BRI, and multiple chemical sensitivity until prompted by lawsuits. In contrast, green buildings are designed to promote occupant health; they include measures such as protecting ductwork during installation to avoid contamination during construction; specifying finishes with low to zero volatile organic compounds to prevent potentially hazardous chemical off-gassing; more precise sizing of heating and cooling components to promote dehumidification, thereby reducing mold; and the use of ultraviolet radiation to kill mold and bacteria in ventilation systems.[17]

State and Local Guidelines for High-Performance Construction

At the onset of the green building movement, several state and local governments took the initiative in articulating guidelines aimed at facilitating high-performance construction. The Pennsylvania Governor's Green Government Council (GGGC) used mixed

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TABLE 1.2

High-Performance Green Building as Defined by the Pennsylvania GGGC
A project created via cooperation among building owners, facility managers, users, designers, and construction professionals through a collaborative team approach.
A project that engages the local and regional communities in all stages of the process, including design, construction, and occupancy.
A project that conceptualizes a number of systems that, when integrated, can bring efficiencies to mechanical operation and human performance.
A project that considers the true costs of a building's impact on the local and regional environment.
A project that considers the life-cycle costs of a product or system. These are costs associated with its manufacture, operation, maintenance, and disposal.
A building that creates opportunities for interaction with the natural environment and defers to contextual issues such as climate, orientation, and other influences.
A building that uses resources efficiently and maximizes use of local building materials.
A project that minimizes demolition and construction wastes and uses products that minimize waste in their production or disposal.
A building that is energy- and resource-efficient.
A building that can be easily reconfigured and reused.
A building with healthy indoor environments.
A project that uses appropriate technologies, including natural and low-tech products and systems, before applying complex or resource-intensive solutions.
A building that includes an environmentally sound operations and maintenance regimen.
A project that educates building occupants and users to the philosophies, strategies, and controls included in the design, construction, and maintenance of the project.

Source: Pennsylvania GGGC (1999).

but very appropriate terminology in its "Guidelines for Creating High-Performance Green Buildings." The lengthy but instructive definition of high-performance green building (see Table 1.2) focused as much on the collaborative involvement of the stakeholders as it did on the physical specifications of the structure itself.

Similar guidance was provided by the New York City Department of Design and Construction in its "High Performance Building Guidelines," in which the end product, the building, is hardly mentioned, and the emphasis is on the strong collaboration of the participants (see Table 1.3).

The "High Performance Guidelines: Triangle Region Public Facilities," published by the Triangle J Council of Governments in North Carolina in 2001, focused on three principles:

1. *Sustainability*, which is a long-term view that balances economics, equity, and environmental impacts
2. *An integrated approach*, which engages a multidisciplinary team at the outset of a project to work collaboratively throughout the process
3. *Feedback and data collection*, which quantifies both the finished facility and the process that created it and serves to generate improvements in future projects.

Like the other state and local guidelines, North Carolina's "High Performance Guidelines" emphasized the collaboration and process, rather than merely the physical characteristics of the completed building. Historically, building owners assumed that they were benefiting from this integrated approach as a matter of course. In

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TABLE 1.3

Goals for High-Performance Buildings According to the New York City Department of Design and Construction

Raise expectations for the facility's performance among the various participants.
Ensure that capital budgeting design and construction practices result in investments that make economic and environmental sense.
Mainstream these improved practices through (1) comprehensive pilot high-performance building efforts and (2) incremental use of individual high-performance strategies on projects of limited scope.
Create partnerships in the design and construction process around environmental and economic performance goals.
Save taxpayers money through reduced energy and material expenditures, waste disposal costs, and utility bills.
Improve the comfort, health, and well-being of building occupants and public visitors.
Design buildings with improved performance, which can be operated and maintained within the limits of existing resources.
Stimulate markets for sustainable technologies and products.

Source: Excerpted from "High Performance Building Guidelines" (1999).

practice, however, the lack of coordination among design professionals and their consultants often resulted in facilities that were problematic to build. Now the green building movement has begun to emphasize that strong coordination and collaboration is the true foundation of a high-quality building. This philosophy promises to influence the entire building industry and, ultimately, to enhance confidence in the design and construction professions.

Green Building Progress and Obstacles

Until recently considered a fringe movement, in the early twenty-first century, the green building concept has won industry acceptance, and it continues to influence building design, construction, operation, real estate development, and sales markets. Detailed knowledge of the options and procedures involved in "building green" is invaluable for any organization providing or procuring design or construction services. The number of commercial buildings registered with the USGBC for a LEED building assessment grew from just a few in 1999 to more than 6,000 registered and certified in late 2006. By 2015, the number of registered buildings had grown to over 69,000, and a total of over 27,000 buildings had been certified. The area of LEED certified buildings increased from a few thousand square feet in 1999 to 3.6 billion square feet (375 million m^2) in 2015 for commercial buildings alone. Federal and state governments, many cities, several universities, and a growing number of private-sector construction owners have declared sustainable or green materials and methods as their standard for procurement.

Despite the success of LEED and the US green building movement in general, challenges abound when implementing sustainability principles within the well-entrenched traditional construction industry. Although proponents of green buildings have argued that whole-systems thinking must underlie the design phase of this new class of buildings, conventional building design and procurement processes are very difficult to change on a large scale. Additional impediments also may apply. For example, most jurisdictions do not yet permit the elimination of stormwater

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infrastructure in favor of using natural systems for stormwater control. Daylighting systems do not eliminate the need for a full lighting system, since buildings generally must operate at night. Special low-emissivity (low-E) window glazing, skylights, light shelves, and other devices increase project cost. Controls that adjust lighting to compensate for varying amounts of available daylight, and occupancy sensors that turn lights on and off depending on occupancy, add additional expense and complexity. Rainwater harvesting systems require dedicated piping, a storage tank or cistern, controls, pumps, and valves, all of which add cost and complexity.

Green building materials often cost substantially more than the materials they replace. Compressed wheatboard, a green substitute for plywood, can cost as much as four times more than the plywood it replaces. The additional costs, and those associated with green building compliance and certification, often require owners to add a separate line item to the project budget. The danger is that, during the course of construction management, when costs must be brought under control, the sustainability line item is one of the first to be "value-engineered" out of the project. To avoid this result, it is essential that the project team and the building owner clearly understand that sustainability goals and principles are paramount and that LCC should be the applicable standard when evaluating a system's true cost. Yet even LCC does not guarantee that certain measures will be cost-effective in the short or long term. Where water is artificially cheap, systems that use rainwater or graywater are difficult to justify financially, even under the most favorable assumptions. Finally, more expensive environmentally friendly materials may never pay for themselves in an LCC sense.

A summary of trends in, and barriers to, green building is presented in Table 1.4. They were generated by the Green Building Roundtable, a forum held by the USGBC for members of the US Senate Committee on Environment and Public Works in April 2002, and most still apply today.

TABLE 1.4

Trends and Barriers to Green Building in the United States

Trends

1. Rapid penetration of the LEED green building rating system and growth of USGBC membership
2. Strong federal leadership
3. Public and private incentives
4. Expansion of state and local green building programs
5. Industry professionals taking action to educate members and integrate best practices
6. Corporate America capitalizing on green building benefits
7. Advances in green building technology

Barriers

1. Financial disincentives
   a. Lack of LCC analysis and use
   b. Real and perceived higher first costs
   c. Budget separation between capital and operating costs
   d. Security and sustainability perceived as trade-offs
   e. Inadequate funding for public school facilities
2. Insufficient research
   a. Inadequate research funding
   b. Insufficient research on indoor environments, productivity, and health
   c. Multiple research jurisdictions

Source: Adapted from US Green Building Council. 2003. *Building Momentum: National Trends and Prospects for High-Performance Green Buildings*. Available at www.usgbc.org/Docs/Resources/ 043003_hpgb_whitepaper.pdf.

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Trends in High-Performance Green Building

Even though the high-performance green building movement is relatively new, there have already been several shifts in direction as more is learned about the wider impacts of building and the accelerating effects of climate change. Fifteen years ago at the onset of this revolution, the use of the charrette was a relatively new concept, as were integrated design, building commissioning, the design- build delivery system, and performance-based fees. All of these are now familiar green building themes, and building industry professionals are familiar with their potential application.

Much has changed in a short span of time. Since 2008, energy prices have been erratic. Hydraulic fracturing (fracking) produced a rapid increase in oil and gas supplies in the United States. The result was equally rapid falling energy prices, which are causing havoc in the markets for renewable energy. Renewable energy had just become competitive with fossil fuel–based energy when the trend toward lower supplies of fossil fuel energy suddenly was reversed. However, the most significant environmental problem of our time, climate change, will only be exacerbated by short-term cheap energy. Within several decades, the world will be again faced with high energy prices plus the enormous and widespread impacts of climate change. This is a critical issue for green building, and thus the trend to NZE and net-zero-carbon buildings that rely on extremely high energy and very high energy performance.

Another major shift is the demand for and increased attention to transparency for the products that constitute the built environment. A wide range of new tools have become available, such as environmental product declarations (EPDs), health product declarations (HPDs), risk-based assessments (RBAs), and multiattribute standards. This is yet another indicator of the widening influence of the green building movement on the upstream activities of manufacturers and suppliers of built environment products.

New technologies, such as high-efficiency PV systems and building information modeling (BIM), are affecting approaches to project design and collaboration. Evidence is mounting that climate change is occurring significantly faster than even the most pessimistic models predicted. Some fundamental thinking about green building assessment has changed, and there is significant impetus toward integrating LCA far more deeply into project evaluation. The impacts of building location are being taken into account since it has become apparent that the energy and carbon associated with transportation is approaching the levels resulting from construction and operation of the built environment. The next sections address these emerging trends in more detail and provide some insights into how they are affecting high-performance green buildings.

TRANSPARENCY

The term *transparency*, when associated with the green building movement, is concerned with the open provision of information about: (1) building energy and water performance and (2) the impacts of the materials and products that compose the building. Building product transparency requires that manufacturers reveal product ingredients so that project teams will have information that allows them to decide if there are any potential toxicity problems with the chemicals that compose the product. Nonprofit organizations and industry associations are creating numerous tools designed to meet the demand of this relatively new movement. The trend toward product transparency and full disclosure is part of a larger trend in corporate sustainability in which large companies such as Walmart and Target are requiring their suppliers to disclose ingredients and to phase out certain chemicals of concern in their consumer products. HPDs, which became relatively mainstream tools in 2012, are one approach to addressing the demand for transparency. An HPD reports the

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materials or ingredients contents of a building product and the associated health effects. The content of this report and its format is governed by the HPD Open Standard™. HPDs have a standard format to allow users to become familiar with the location of key elements of information. It is voluntary and can be used by manufacturers to disclose information about product ingredients that they judge would be useful to the market. The HPD is designed to be flexible and allows manufacturers to deal with issues of intellectual property or supply chain communication gaps by letting them characterize the level of disclosure they able to achieve. In short this means that the HPD does not force the manufacturer to disclose proprietary or competitive trade information.

A complementary tool connected to transparency is the EPD. Whereas HPDs are designed to disclose human health impacts, EPDs provide detailed information on the environmental impacts of products. EPDs are third-party LCAs using a methodology spelled out in the international standards, ISO 14025. Similar to HPDs, EPDs have a standard format that makes them fairly easy to use by project teams or other stakeholders. Some of the impacts reported via EPDs include global warming potential, ozone depletion potential, and eutrophication. Although these tools provide enormous amounts of information about products, their actual utility is still being debated. The nub of the debate is about whether these products can be used to judge which products are best from a health and environmental standpoint and whether project teams have the knowledge and resources to utilize these tools effectively. HPDs generally are categorized as *hazard-based* tools because they use a hazard list to scan product chemicals for potential issues. An alternative to hazard-based approaches is RBA; such assessments include in the analysis standard toxicological approaches involving dose and exposure scenarios.

The other type of transparency that is rapidly emerging is building performance information. In the United States, large cities are leading the drive to make energy and water consumption data for all buildings openly available. In general, these cities require not only disclosure of the performance data but also require efforts to reduce energy consumption. On Earth Day 2009, Mayor Michael Bloomberg announced New York City's Greener, Greater Buildings Plan (GGBP), which requires the benchmarking and public disclosure of building energy performance and water consumption; periodic energy audits and building tune-ups known as *retro-commissioning*; lighting upgrades; submetering of large tenant spaces; and improvements to the city's building energy code. Roughly 80 percent of New York City's carbon footprint is connected to building operations, and the GGBP is designed to reduce the city's GHG emissions 30 percent by 2030.

In April 2015, Atlanta, Georgia, became the first southern city to pass legislation requiring the collection and reporting of energy use data in the city's commercial buildings. In Atlanta, the goal is a 20 percent reduction in energy consumption by commercial buildings by 2030, creation of more than 1,000 jobs annually for the first few years, and cutting carbon emissions in half from 2013 levels by 2030. The Atlanta Commercial Buildings Energy Efficiency Ordinance also encourages periodic energy audits and improvements to existing building equipment and functions (i.e., retro-commissioning).

A more extensive discussion of building product transparency can be found in Chapter 11; additional insights into energy reporting are included in Chapter 9.

CARBON ACCOUNTING

By virtually all accounts, climate change seems to be accelerating and lining up with the worst-case scenarios hypothesized by scientists. One unexpected event that is rapidly increasing levels of atmospheric CO_2, the primary cause of climate change, is drought, which causes, among other things, the death of rainforest trees. Researchers

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calculate that millions of trees died in 2010 in the Amazon due to what has been referred to as a 100-year drought. The result is that the Amazon is soaking up much less CO_2 from the atmosphere, and the dead trees are releasing all the carbon they accumulated over 300 or more years. The widespread 2010 drought followed a similar drought in 2005 (another 100-year drought), which itself put an additional 5.5 billion tons (5 billion mt) of CO_2 into the atmosphere (see Lewis et al. 2011). In comparison, the United States, the world's second largest producer of CO_2 behind China, emitted 6.0 billion tons (5.4 billion mt) of CO_2 from fossil fuel use in 2009. The two droughts added an estimated 14.3 billion tons (13 billion mt) to atmospheric carbon and likely accelerated global warming.

In the last major report by the Intergovernmental Panel on Climate Change in 2007, estimated sea level rises were just 7–23 inches (18–45 centimeters) by 2100. However, a mere four years later, a 2011 study presented by the International Arctic Monitoring and Assessment Program found that feedback loops are already accelerating warming in the Far North, which will rapidly increase the rate of ice melt. As a result, the panel now estimates that sea levels could rise by as much as 5.2 feet (1.7 m) by the end of the century. The only conclusion that can be reached by observing the many positive feedback loops influencing climate change is that all indicators point to a much higher rate of change than had been predicted.

The result of these alarming changes is that releases of CO_2 into the atmosphere are becoming an increasingly serious issue. Governments around the world are making plans to reduce carbon emissions, which entails tracking or accounting for carbon in order to limit its production. The built environment, with enormous quantities of *embodied energy*[18] and associated operational and transportation energy, is a ripe target for gaining control of global carbon emissions. It is likely that projects that can demonstrate significant reductions in total carbon emissions will be far better received than those with relatively high carbon footprints, which could conceivably be banned. New concepts, such as *low-carbon, carbon-neutral*, and *zero-carbon buildings*, are emerging in an effort to begin coping with the huge quantities of carbon emissions associated with the built environment. On the order of 40 percent of all carbon emissions are associated with building construction and operation, and it is likely that as much as another 20 percent could be attributable to transportation. Perhaps nowhere in the world has there been more interest and progress in low-carbon building than in the United Kingdom. The Carbon Trust was established by the government as a nonprofit company to take the lead in stimulating low-carbon actions, contributing to UK goals for lower carbon emissions, the development of low-carbon businesses, and increased energy security and associated jobs, with a vision of a low-carbon, competitive economy. We can expect to see control of carbon emissions and other measures to mitigate their impacts becoming an ever more prominent feature of high-performance green buildings. Chapter 12 provides details on how to account for the carbon footprint of the built environment.

NET-ZERO BUILDINGS

In the early 1990s, William McDonough, the noted American green building architect and thinker, suggested that buildings should, among other things, "live off current solar income". Today, what seemed a rash prediction is becoming reality as the combination of high-performance buildings and high-efficiency, low-cost renewable energy technologies are providing the potential for buildings that, in fact, can live off current solar income. These are commonly referred to as NZE buildings. In general, these are grid-connected buildings that export excess energy produced during the day and import energy in the evenings, such that there is an energy balance over the course of the year. As a result, NZE buildings have a zero annual energy bill. The added bonus is that they are considered carbon neutral with respect to their operational energy.

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An excellent example of an NZE building is the research support facility (RSF) designed and built for the National Renewable Energy Laboratory (NREL) in Golden, Colorado. The RSF, completed in 2011, is a 220,000-square-foot (20,450-m^2), four-story building with a PV system on-site. It is interesting to note that a 2007 NREL study concluded that one-story buildings could achieve NZE if the building roof alone were used for the PV system but that it would be extremely difficult for two-story buildings to meet this goal (Griffith et al. 2007). Clearly, much has been learned in a short time because the RSF has four stories, twice the limit suggested by NREL's own research. The Energy Use Intensity (EUI) of the RSF is just 32,000 BTU/ft^2/yr (101 kWh/m^2/yr), making it a very low energy building with the potential for producing enough PV energy to meet all its annual energy needs (see Figure 1.7A–D). The relatively narrow building floor plate, just 60 feet (19.4 m) wide, enables daylighting



Figure 1.7 (A) The NREL Research Support Facility in Golden, Colorado, is a four-story NZE building that combines low-energy design with high-efficiency photovoltaics to produce all the energy it requires over the course of a year. (*Source:* National Renewable Energy Laboratory)



Figure 1.7 (B) Ground view of the air intake structure that conducts outside air into the thermal storage labyrinth in the crawl space of the NREL RSF. (*Source:* National Renewable Energy Laboratory)

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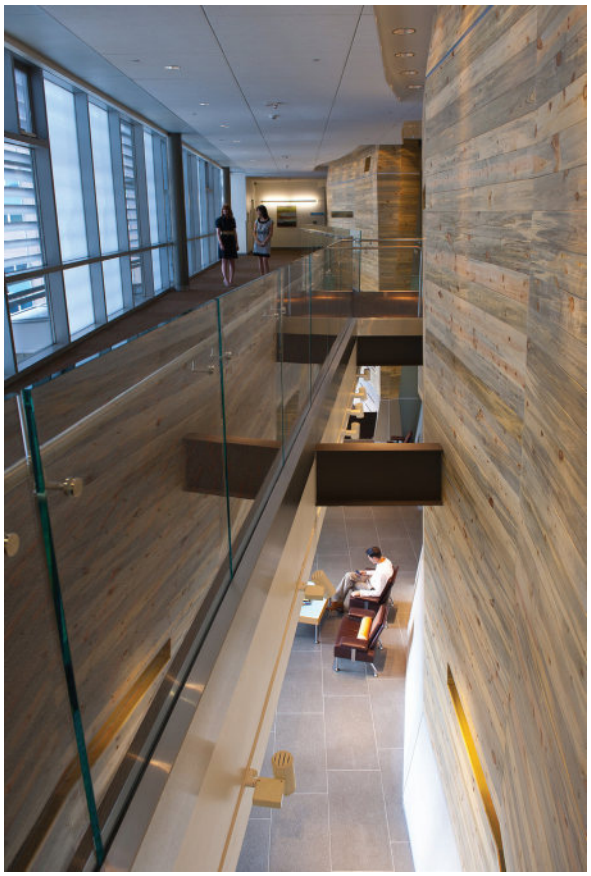


Figure 1.7 (C) The daylighting system for the NREL RSF was designed using extensive simulation. Shading devices were carefully placed on the exterior and interior to manage both direct and indirect sunlight, distributing it evenly to create a bright, pleasant working environment. (*Source:* National Renewable Energy Laboratory)



Figure 1.7 (D) The fenestration for the NREL RSF was designed to provide excellent daylighting while controlling glare and unwanted solar thermal gain through the use of shading devices, recessed windows, and electrochromic glass. Operable windows allow the occupants to control their thermal comfort and obtain fresh air. (*Source:* National Renewable Energy Laboratory)

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and natural ventilation for its 800 occupants, and 100 percent of the workstations are daylit. Building orientation and geometry minimize the need for east and west glazing. North and south glazing is optimally sized and shaded to provide daylighting while minimizing unwanted heat losses and gains. The building uses triple-glazed operable windows and window shading to address different orientations and positioning of its glazed openings. The operable windows can be used by the occupants to provide natural ventilation and cooling for the building. Electrochromic windows, which can be darkened using a small amount of electrical current, are used on the west side of the building to control glare and heat gain. The RSF has approximately 42 miles (67 kilometers) of radiant piping embedded in all floors of the building to provide water for radiant cooling and heating the majority of the work spaces. This radiant system provides thermal conditioning for the building at a fraction of the energy costs of the forced-air systems used in most office buildings. A thermal storage labyrinth under the RSF stores heating and cooling in its concrete structure and is integrated into the building energy recovery system. Outdoor air is heated by a transpired solar collector system located on the façade of the structure. Approximately 1.6 MW of on-site PVs are being installed and dedicated to RSF use. Rooftop PV power will be added through a power purchase agreement, and PV power from adjacent parking areas will be purchased by the building through arrangement with a local utility. The RSF was awarded a LEED platinum rating in recognition of the success of its integrated design and the holistic approach of the project team.

The implementation of NZE is now national policy, and the US Department of Energy has programs in place with the objective that all new buildings will be NZE by 2050. In some local jurisdictions, such as Austin, Texas, new homes are required to be NZE by 2015. The ASHRAE-proposed building energy label, known as Energy Quotient, reserves its highest rating for NZE buildings. This important new trend appears to have significant momentum and will influence the direction of green building evolution.

BUILDING INFORMATION MODELING

The emergence of BIM as a design and visualization tool is an important trend for the building industry. Its three-dimensional modeling promises to provide owners with a far better representation of their projects, increase the quality of both design and construction, and increase the speed of construction. BIM makes the handling of complex projects with enormous information requirements far easier. One of the attributes of high-performance green building projects is their reliance on significant additional modeling, additional specification requirements, and the need to track numerous aspects of the construction process, such as construction waste management, indoor air quality protection during construction, and erosion and sedimentation control. Additionally, quantities of recycled materials, emissions from materials, and other data must be gathered for green building certification. BIM has the capability of accepting plug-ins that can perform energy modeling and daylighting simulation and provide a platform for the data required by green building certification bodies. BIM software makes it relatively easy to select the optimum site and building orientation to maximize renewable energy generation and daylighting and minimize energy consumption. BIM is an important and potentially powerful tool that can further increase the uptake of green buildings by lowering costs. Although not strictly relevant to green building certification, it makes the process far easier and less costly by providing "one-stop shopping" for information.

LIFE-CYCLE ASSESSMENT

Although a mature concept, LCA is growing in importance because it allows the quantification of the environmental impacts of design decisions that span the entire life of the project. In the past, LCA was used to compare products and building assemblies, which provided some indication of how to improve decision making but did not

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provide information about the long-term effects resulting from building operation. With the emergence of the German DGNB building assessment system, the environmental performance of the whole building—its materials, construction, operation, disposal, and transportation impacts—can be quantified and compared to baselines that have been compiled to allow comparisons. Designers can quickly consider a wide variety of alternative building systems, materials, and sites and compare them to the norms for the type of building being considered. For example, the global warming and ozone depletion potentials for various alternatives per unit of building area can be compared to find the least damaging outcome. The Australian Green Star building assessment system considers energy not in energy units but in CO_2 equivalents to focus on the impact of climate change. LCA affords the design team the capability of quickly evaluating their energy strategies to find one that improves on the baselines established for carbon or other parameters. In North America, LCA is rewarded to some extent in the Green Globes rating system. It is part of ANSI/GBI 01-2016, Green Building Assessment Protocol for Commercial Buildings, a standard based on the Green Globes rating system and promulgated by ANSI and the GBI. LCA was also included as a pilot credit in the LEED system, and it appears in the latest version. The state of California also included LCA as a voluntary measure in its 2010 draft Green Building Standards Code. In the future, as governments struggle to cope with reducing GHG emissions because the effects of climate change are causing economic problems and social dislocations, it is likely that LCA will become a mandatory area of evaluation for building design.

Book Organization

This book describes the high-performance green building delivery system, a rapidly emerging building delivery system that satisfies the owner while addressing sustainability considerations of economic, environmental, and social impact, from design through the end of the building's life cycle. A building delivery system is the process used by building owners to ensure that a facility meeting their specific needs is designed, built, and handed over for operation in a cost-effective manner. This book examines the design and construction of state-of-the-art green buildings in the United States, considering the nation's unique design and building traditions, products, services, building codes, and other characteristics. Best practices, technologies, and approaches of other countries are used to illustrate alternative techniques. Although intended primarily for a US audience, the general approaches described could apply broadly to green building efforts worldwide.

Much more so than in conventional construction delivery systems, the high-performance green building delivery system requires close collaboration among building owners, developers, architects, engineers, constructors, facility managers, building code officials, bankers, and real estate professionals. New certification systems with unique requirements must be considered. This book focuses largely on practical solutions to the regulatory and logistical challenges posed in implementing sustainable construction principles, delving into background and theory as needed. The USGBC's green building certification program is covered in detail. Other complementary or alternative standards, such as the GBI's Green Globes building assessment system, the federal government's Energy Star program, and the United Kingdom's BREEAM building certification program, are discussed. Economic analysis and the application of LCC, which provides a more comprehensive assessment of the economic benefits of green construction, also are considered.

Following this introduction, the book is organized into four parts, each of which describes an aspect of this emerging building delivery system. Part I, "Green

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Building Foundations," covers the background and history of green buildings, the basic concepts, ethical principles, and ecological design. Part II, "Assessing High-Performance Green Buildings," addresses the important issue of assessing or rating green buildings, with special emphasis on the two major US rating systems, LEED and Green Globes. Part III, "Green Building Design," more closely examines several important subsystems of green buildings: siting and landscaping, energy and atmosphere, carbon accounting, the building hydrologic cycle, materials selection, and indoor environmental quality. In Part IV, "Green Building Implementation," addresses the subjects of construction operations, building commissioning, economic issues, and future directions of sustainable construction. Additionally, several appendices containing supplemental information on key concepts are provided. To support the readers, a website, www.wiley.com/go/sustainableconstruction, contains hyperlinks to relevant organizations, references, and resources. This website also references supplemental materials, lectures, and other information suitable for use in university courses on sustainable construction.

Case Study: The Pertamina Energy Tower: A Primer on Green Skyscraper Design

The world's population is likely to grow from 7 billion today to over 9 billion by 2050, with about 70 percent of the population dwelling in cities. Densely populated urban areas are the antithesis of the post–World War II era marked by suburban sprawl and migration away from the cities that dominated urban planning for over 60 years. Today economics and changes in people's attitudes toward lifestyle dictate a shift to large cities around the world. To meet the demand for built environment, whole ecosystems of skyscrapers are growing in the world's burgeoning urban areas and contributing to the emergence of a new urban form often referred to as vertical cities. The trend toward building more vertical cities is driven by global population growth, urbanization, and economics. Antony Wood, the executive director of the Council on Tall Buildings and Urban Habitat (CTBUH), a nonprofit organization that tracks skyscrapers, refers to this as **sustainable vertical urbanism**. Nowhere is this trend toward vertical urbanism more pronounced than in China, which has one-third of the world's largest buildings over 150 meters (492 feet). By 2020, China will boast six of the 10 tallest buildings in the world. In 2014, China dominated the growth in skyscrapers, with 58 of the 97 completed buildings being in Chinese cities. In their book *Vertical City: A Solution for Sustainable Living*, the architects Kenneth King and Kellogg Wong describe a future in which cities evolve into a complex array of skyscrapers, infrastructure, and services that include everything needed for a high quality of life. Space for parks, sports stadiums, libraries, theaters, restaurants, shopping malls, and even hospitals are provided, along with offices and work spaces for businesses.

The key to the vertical city is the skyscraper, and its design is being transformed by highly creative architects and developers who are helping propel the shift to a denser and taller built environment. The rate of construction, purpose, and approach to building skyscrapers are rapidly changing and evolving. Just after the 9/11 attacks on New York City in 2001, many pundits were forecasting that the formerly iconic skyscrapers would become obsolete because they were obvious targets for terrorists. However, in the period since the events of 2001, there has been a significant increase in the pace of skyscraper construction and a race to design and build ever taller structures. Between 1930 and 2001, the maximum skyscraper size increased by 230 feet (74 m). However, since 2001, due to the development of new materials, structural systems, and design tools, the height increase has been 1,234 feet (398 m) and led to the creation of a new category of skyscraper, the *supertall skyscraper*, a classification for buildings 984 feet (300 m) or more in height.

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Prior to the mid-1990s, skyscrapers were designed to contain office space. However, the skyscrapers developed since that time are filled with hotels, condominiums, shopping centers, restaurants, theaters, and other elements of a typical downtown urban environment but arranged vertically. The design of skyscrapers increasingly is shifting to emphasize the buildings' relationships with people and the environment. Rather than commercializing every square meter of area, significant space is devoted toward creating a positive experience for occupants, in terms of both green space and extensive daylighting. Skyscrapers enhance the experience of living and working in the city and often contain offices and apartments plus all the amenities found in several typical blocks of a large city. In 2000, just five of the world's 20 tallest buildings were mixed use. By 2020, all *but* five of the tallest will be mixed use. It is clear that architects are responding to the demand for verticality by creating compelling new forms, enormous in scale, that draw attention as they change the skylines of the world's great cities. Towers that were once monolithic and repetitive edifices are becoming far more diverse, integrated, and connected.

Skyscraper designers face enormous challenges; not least among them are the enormous forces resulting from the sheer mass of materials used, which increases significantly with height. However, advances in materials, such as extremely high-strength concrete and steel, and more precise design tools coupled with faster computers are resulting in buildings that are far lighter than their predecessors. For example, the current tallest building in the world, the Burj Khalifa in Dubai, United Arab Emirates, which is more than 2,717 feet (828 m) in height, weighs half as much as the Empire State Building, which at 1,250 feet (381 m) is less than half as tall. The newest skyscrapers often incorporate very high compressive strength concrete that contains lightweight microfibers instead of reinforcing steel, saving considerable weight. Concrete structures can also be thinner and, unlike steel structures, concrete does not require fireproofing. Designing to accommodate wind forces also can be very challenging because winds 1,000 feet (323 m) above the ground may be traveling at up to 100 miles (160 kilometers) per hour, creating significant and complex forces, such as vortex shedding, that pull the structure in random directions. Today's enormous computing power and improved structural models have eliminated the need for engineers to design buildings with large safety factors because they are able to accurately model external forces and materials behavior. Three-dimensional printing also has contributed to the ability of engineers to rapidly test a wide variety of structural configurations in specialized wind tunnels to determine the best approach to minimizing wind loads. As a result, the quantity of materials needed to support the skyscraper is minimized.

Parallel to the growth in skyscrapers has been an accelerating shift to designing high-performance or green skyscrapers. In 2015, the US GBC announced that there were a record five iconic global skyscrapers being designed for certification with the LEED rating system. The result is that many of the features found in smaller green buildings, such as high levels of energy efficiency, low construction waste, abundant natural light, carbon-neutral buildings, and even NZE buildings, are finding their way into skyscrapers. Perhaps most significant of the newer skyscrapers emerging from the world's great architecture firms is the Pertamina Energy Tower in Jakarta, Indonesia, designed by Skidmore, Owings and Merrill (SOM), considered one of the premier designers of supertall category buildings. A 99-story structure with a height of 1,740 feet (530 m), the Pertamina Energy Tower provides a primer on the design of high performance green buildings (see Figure 1.8).

As a result of their unmatched experience with skyscrapers and in particular green skyscrapers, SOM has developed a well-thought-out and tested template for the design of high-performance skyscrapers that the firm has tested in a variety of projects. Among the projects that contributed to the evolution of the SOM approach is the Pearl River Tower in Guangzhou, China, a 72-story, 1,015-foot-tall (309-m) building completed in 2011. The 2.3 million square-foot (213,700-square-meter) building helped advance the state of the art in sustainable design by incorporating and testing the latest green technologies and engineering advancements. Its sculpted body directs wind to a pair of openings at its mechanical floors where

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Figure 1.8 Rendering of the Pertamina Energy Tower, the world's first net-positive-energy building and an exemplar of high-performance buildings. (*Source:* SMILODON)

the prevailing winds drive vertical-axis wind turbines (VAWTs) that generate energy for the building. Other green features include solar PV panels, a double-skin curtain wall, a chilled ceiling system, under-floor ventilation, and daylight harvesting. The many lessons learned in its design and construction helped SOM further refine its green skyscraper design process. SOM applied the experience gained in the design of the Pearl River Tower and other green projects to the Pertamina Energy Tower, which was designed with a focus on high performance and sustainability. It is the first skyscraper that is net-positive energy—that is, on-site renewable energy provides more than 100 percent of the energy required to operate the building. Indeed, this building was designed with energy as the central criterion for measuring the success of its performance. As a result, the Pertamina Energy Tower's self-contained renewable energy system exceeds energy consumption by about 6 percent annually. This remarkable performance was achieved by reducing energy demand through a combination of active and passive strategies. The passive design strategies include a high-performance façade that allows daylight penetration while simultaneously minimizing cooling loads through optimized glazing and specially designed external shading fins. Natural light supplied by daylighting is important not only for reducing energy consumption but also for its positive benefits to human health. The active strategies include a high-efficiency ventilating and air conditioning system, high-efficiency light-emitting diode (LED) lighting fixtures, occupancy sensors that automatically dim or switch off luminaires, a demand-controlled ventilation system that provides the precise quantity of fresh outside air to meet occupant needs, a regenerative system that recovers energy during the braking cycle of the elevators, and double enthalpy wheels in the outside air-handling units that recover otherwise wasted energy.

The project team used a five-step process to design the Pertamina Tower. Step 1 was to design a baseline building to serve as a basis for testing ideas and hypotheses. Step 2 was to integrate passive strategies to reduce the project's energy demand. Step 3 focused on measures to increase efficiency and reduce energy demand through integrated active strategies. In Step 4, a central energy plant was designed to serve the energy needs of the building. Step 5 was to integrate on-site renewable energies into the building. This five-step process will be followed by the operational maintenance phase, which starts with the commissioning process and postoccupancy evaluation to optimize the building performance and to further reduce the building's energy consumption (see Figure 1.9).

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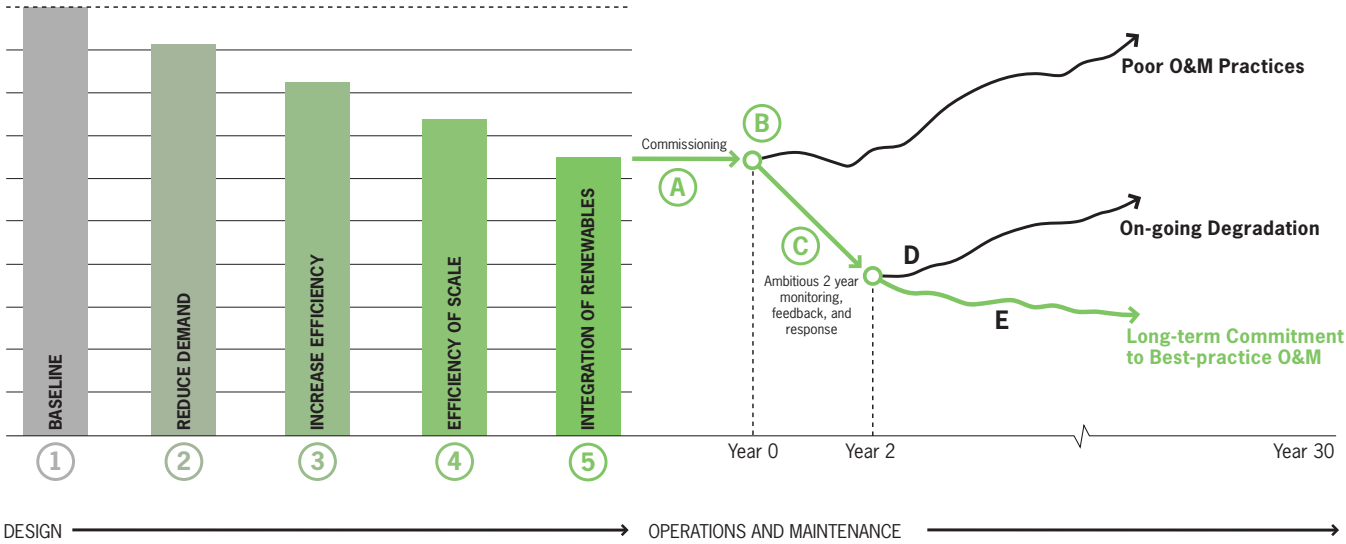


Figure 1.9 The five-step design process followed by SOM was applied to the design of the Pertamina Energy Tower. The period after occupancy is an enormous opportunity to capitalize on the building's high-performance design by fine-tuning and further improving the building's performance. (*Source:* SOM)

In Step 1 of the SOM design process, the project team calculated that the baseline energy consumption of the building was likely to be 250 kWh/m^2/yr (85,600 BTU/ft^2/yr). In this case, the base case is a building of the same type and size as the Pertamina Energy Tower that just meets the minimum requirements of the local building code. This level of performance is not atypical of skyscrapers, which tend to be more energy intensive than other building types. However, a high-performance skyscraper is expected to use considerably less energy through a process of integrated design, which requires extensive collaboration by all parties on the project team. In the case of the Pertamina Energy Tower, computer modeling of the actual building indicated that a reduction in energy demand of 60 percent to100 kWh/m^2/yr (34,000 BTU/ft^2/yr) could be achieved.

In Step 2, the incorporation of passive design features into the building, included detailed studies on how to best integrate the project with its environment to maximize energy savings. The Pertamina Tower is noteworthy for its rounded shape and notched corners on the east and west sides, the outcome of a parametric study to determine the form that would best minimize energy consumption. The idea was to study the relationship of the building to its environment to determine what shapes and features would produce the minimum energy demand. The analysis of the form of the building's footplate produced some significant and useful results. Starting with a conventional square shape as the base case for the 3,400-square-meter floor plate, the designers iterated through a variety of other options. A simple change in which the square shape of the base case building was rotated 90 degrees to a diamond configuration reduced peak cooling demand by 8 percent. Rounding the corners of the diamond reduced peak cooling by 8 percent, and also provided an overall savings of 9 percent in annual cooling. By shifting to the final notched and rounded shape, peak cooling was reduced by 49 percent and annual cooling was reduced by 30 percent, a truly significant decrease in energy demand (see Figure 1.10).

Passive design includes a detailed analysis of opportunities to harvest natural light and reduce solar loads through the design of the façade. The building is located about 6 degrees south of the equator. In this zone, the track of the sun directly over the building is virtually symmetrical over the course of a year. During the summer and winter solstices, the sun is directly overhead and does not cast a shadow. Day length does not vary much during the year and is always about 12 hours long. The location of the building produced some challenges but also some opportunities

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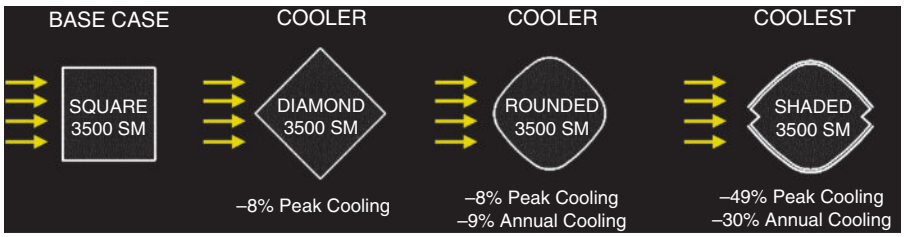


Figure 1.10 By optimizing the shape of the Pertamina Energy Tower's footplate, the design team was able to demonstrate enormous peak and annual energy savings. Note the notches on the rightmost shape, which are the east- and west-facing aspects of the tower. The façade in the notches is equipped with vertical fins to block intense early-morning and late-afternoon sun. (*Source:* SOM)

for passive design. The SOM design team ran an enormous number of calculations and simulations to determine the best approach to address the glare problem and minimize the solar thermal load (see Figure 1.11). The outcome of this effort was an external fin design that wraps around the building on each floor, controlling glare and solar loads (see Figure 1.12). The passive exterior fins are combined with automatic blinds controlled by sensors that open and close the blinds as the sun tracks across the building. The east and west ends of the buildings are equipped with vertical fins to counter the intense solar thermal radiation as the sun moves across the sky (see Figure 1.13).

Step 3 of the SOM design strategy initiates consideration of the cooling and electrical hardware of the building and components that complement the passive strategies. For example, an automated interior shading control system is used to optimize daylight harvesting, minimize artificial lighting, and maximize views. Zoned LED lighting is used throughout the building, along with occupancy sensors, to minimize electrical lighting energy. The core strategy for cooling the building is the use of active chilled beams on each floor in interior zones. Variable-volume fan coil units along the perimeter meet the varying solar thermal load and provide adequate control of humidity. Demand-controlled ventilation supplies the required ventilation air to the building in a precise manner based on the number of occupants present. Regenerative braking systems are used in the building's elevators to recover energy

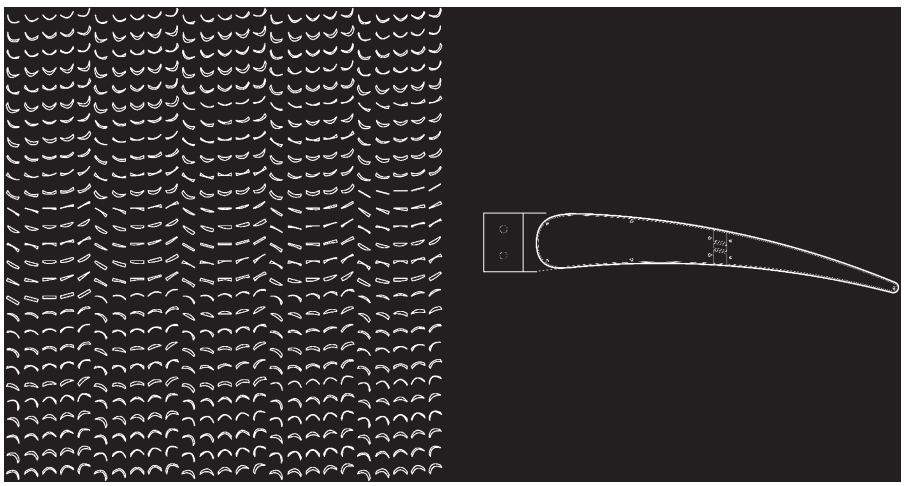


Figure 1.11 The SOM design team tested a wide variety of fin shapes to determine the optimum cross section for controlling glare and the solar thermal load for a building located on the equator. The selected shape is show on the right side of the illustration. (*Source:* SOM)

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Figure 1.12 The actual designed fixed external fin system wraps around each floor of the building, terminating at the east and west notches. (*Source:* SOM)

that would otherwise be dissipated as heat. Exhaust air leaving the building is used to cool and dry hot fresh outside air through the use of an energy recovery system equipped with double enthalpy wheels located in the outside air-handling unit. The net result of all the passive and active strategies is that the EUI will be 60 percent less than the baseline of 250 kWh/m^2/year, or 100 kWh/m^2/year (see Figure 1.14).

Steps 4 and 5 of the SOM design strategy were accomplished in tandem. These involve the design of a central energy plant for the project and the integration of on-site renewable energy. Because of the significant reduction in EUI, the building has the potential for being designed to be energy self-sufficient—that is, an NZE building. Jakarta is located in a very active volcanic area, making geothermal energy a viable option for generating electricity and providing thermal energy for use

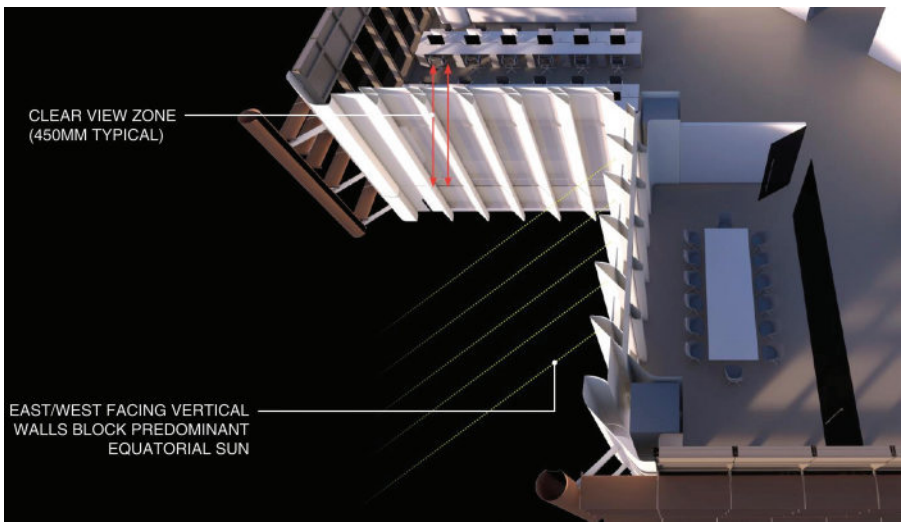


Figure 1.13 The fixed external fin system on the north and south faces of the building terminated at the notches on the east and west sides of the floor plate, where vertical fins block intense morning and afternoon heat. (*Source:* SOM)

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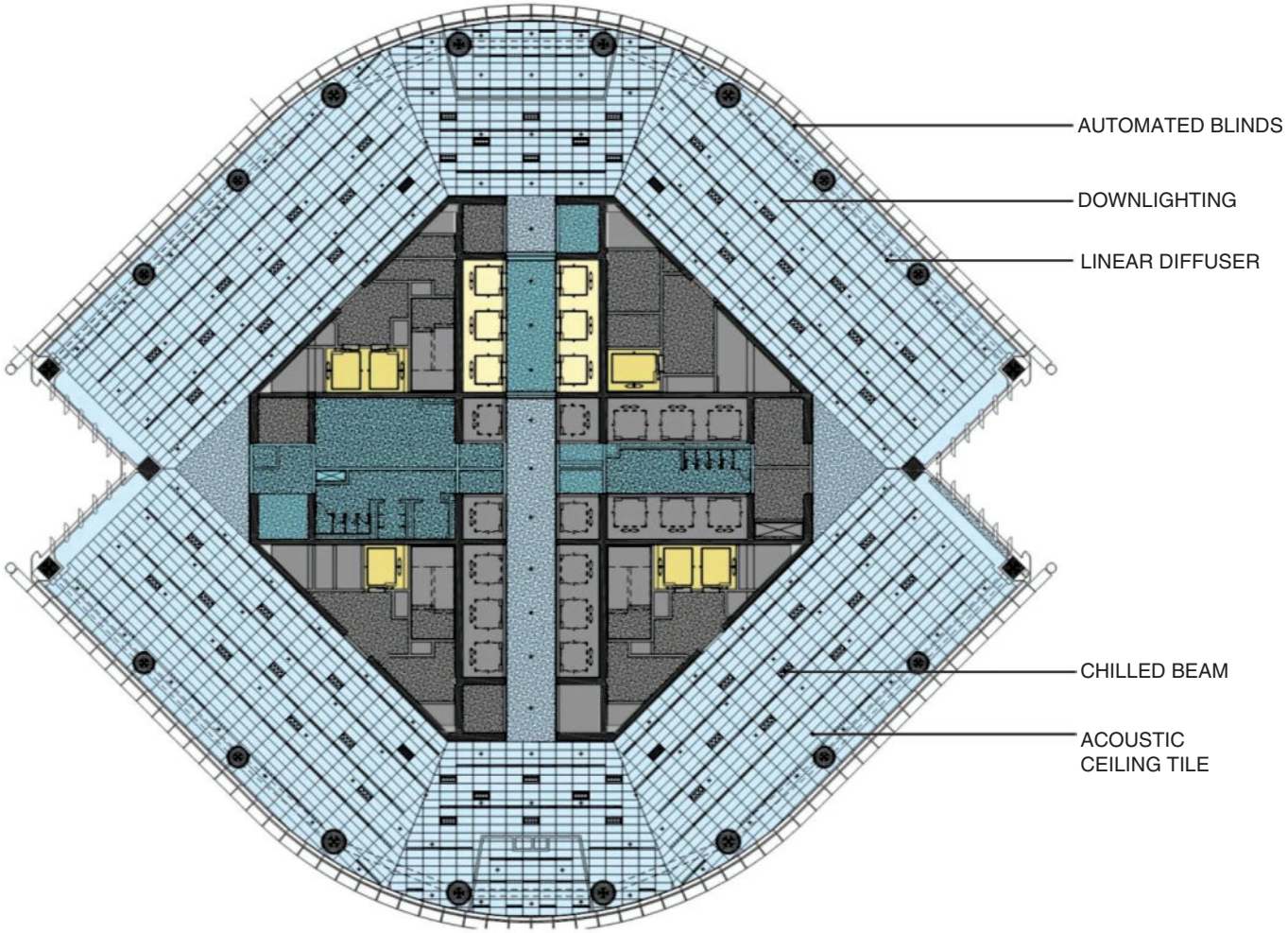


Figure 1.14 A combination of external and internal fins and blinds are used to control solar thermal energy and maximize daylighting during the course of the day. Three banks of chilled beams provide interior cooling, and perimeter fan coil units are employed to meet envelope loads and supply fresh outside air for ventilation. (*Source:* SOM)

in the building (see Figure 1.15). A geothermal binary cycle power plant is planned for implementation that will utilize a combined heat and power unit that can supply 4.2 MW of electricity and satisfy 100 percent of the site's annual electrical energy needs. High-efficiency centrifugal chillers that use green electricity produced by the binary cycle turbine will be tied into the geothermal fields and be used for cooling the tower. One thermal energy storage tank will be tied into the system so that the chillers can charge the tanks during low-cooling-demand hours for use when peak cooling is required, thereby maintaining a constant demand on the geothermal turbine that matches the 24/7 availability profile of the renewable resource (see Figure 1.16).

In addition to the geothermal energy, the Pertamina Energy Tower will capture energy from two other renewable sources, the prevailing winds and the sun. Solar PV panels that convert solar radiation into electricity will cover (18,800 ft^2 (1,750 m^2) of the pedestrian energy ribbon with state-of-the-art monocrystalline PV panels. Additional energy will be provided by VAWTs integrated into the building's crown and located at a height of 1,739 ft (530 m) to take advantage of the Venturi effect at this altitude. The crown design was developed using a comprehensive computational fluid dynamics study to thoroughly analyze the wind behavior at this elevation (see Figures 1.17 and 1.18). In short, in excess of 100 percent of the building's energy demand will be met by a combination of geothermal, wind, and solar radiation.

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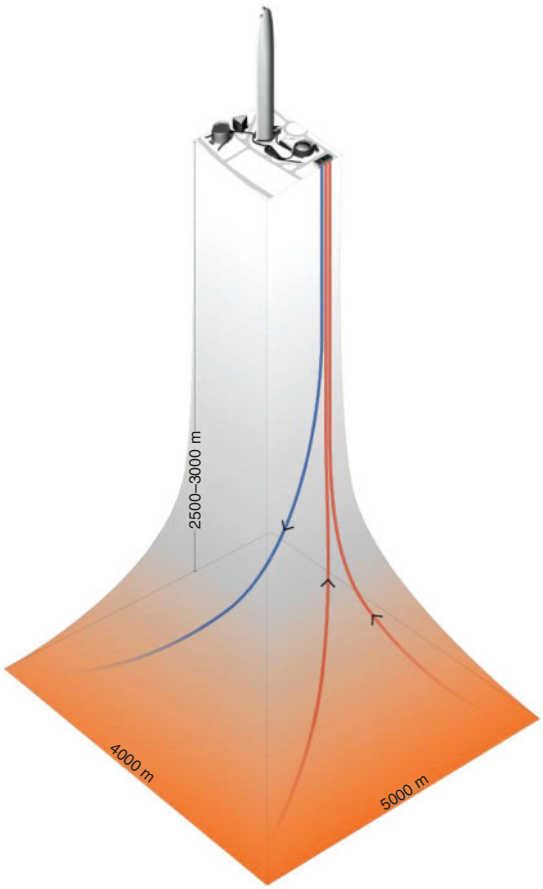


Figure 1.15 The Pertamina Tower will tap into the geothermal field located beneath the building and use heat exchangers to extract energy for electricity generation and cooling from the 150 ºC (300 ºF) energy source. (*Source:* SOM)

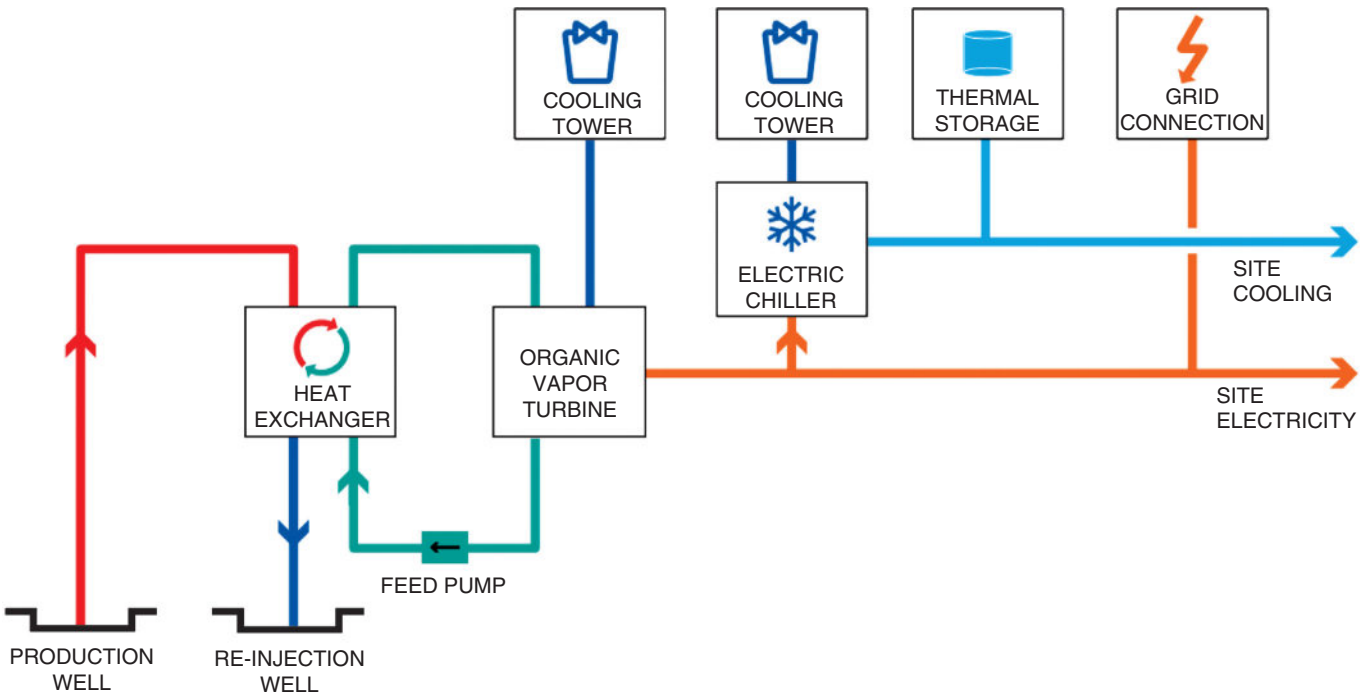


Figure 1.16 The geothermal energy system will use a 4.2 MW organic vapor turbine to generate electricity, electric chillers to generate chilled water, and a thermal storage system that will be charged during periods of low demand to meet high-demand peaks. (*Source:* SOM)

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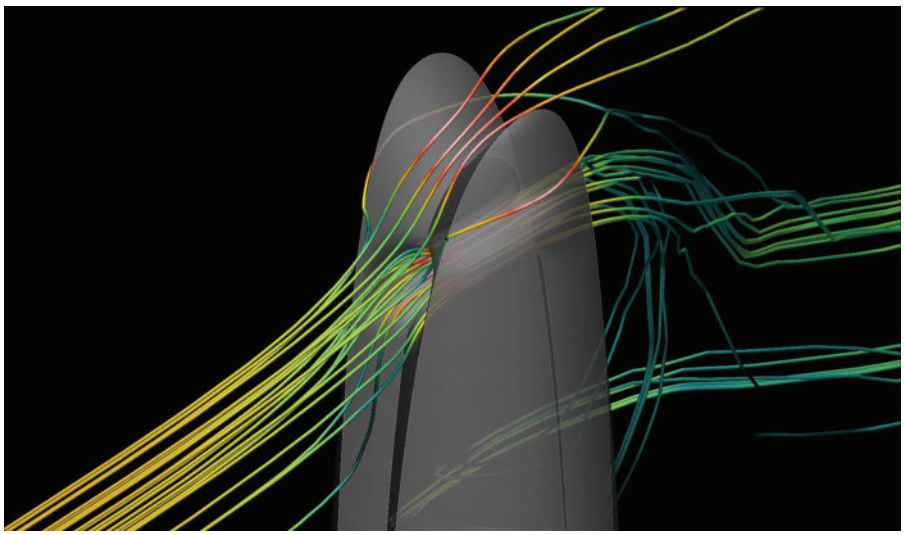


Figure 1.17 Winds at high levels above the ground present an opportunity to integrate wind turbines into skyscrapers. An opening in the, crown of the Pertamina Energy Tower is used to capture the energy of the prevailing wind and convert it into electricity using VAWTs. Computational fluid dynamics was used to model the behavior of wind around the building and design the wind energy system. (*Source:* SOM)

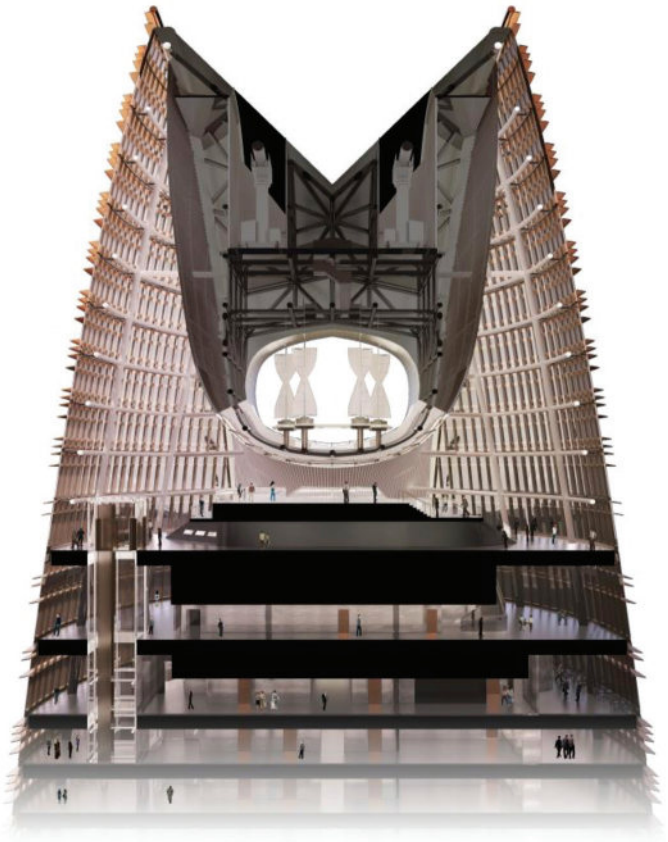


Figure 1.18 The opening in the crown of the building provides a platform for several VAWTs that provide significant renewable energy for the Pertamina Energy Tower. (*Source:* SOM)

The Pertamina Energy Tower represents a significant forward leap in the design of supertall skyscrapers. The design EUI of 100 kWH/m^2/year represents an enormous reduction in energy consumption—just 40 percent of the 250 kWh/m^2/year of a typical conventional, code-compliant building of this type. It is likely to be the first truly NZE skyscraper due to the strategy of tapping into the geothermal potential of its location in Indonesia. It also will have superior interior environmental qualities, such as excellent thermal comfort and views and extensive, glare-free natural light. The Pertamina project is the first to demonstrate that NZE is possible for very large buildings if an experienced team employs a disciplined design approach that uses past experience to inform future design.

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Summary and Conclusions

The rapidly evolving and exponentially growing green building movement is arguably the most successful environmental movement in the United States today. In contrast to many other areas of environmentalism that are stagnating, sustainable building has proven to yield substantial beneficial environmental and economic advantages. Despite this progress, however, there remain significant obstacles, caused by the inertia of the building professions and the construction industry and compounded by the difficulty of changing building codes. Industry professionals in both the design and construction disciplines are generally slow to change and tend to be risk-averse. Likewise, building codes are inherently difficult to change, and fears of liability and litigation over the performance of new products and systems pose considerable challenges. Furthermore, the environmental or economic benefit of some green building approaches has not been quantified scientifically, despite the often intuitive and anecdotal benefits. Finally, lack of a collective vision and guidance for future green buildings, including design, components, systems, and materials, may affect the current rapid progress in this arena.

Despite these difficulties, the robust US green building movement continues to gain momentum, and thousands of construction and design professionals have made it the mainstay of their practices. Numerous innovative products and tools are marketed each year, and, in general, this movement benefits from enormous energy and creativity. Like other processes, sustainable construction may one day become so common that its unique distinguishing terminology may be unnecessary. At that point, the green building movement will have accomplished its purpose: to transform fundamental human assumptions that create waste and inefficiency into a new paradigm of responsible behavior that supports both present and future generations.

Notes

1. UNHSP and World Bank statistics are as quoted in Zayed (2014).
2. The energy consumption figures for buildings in the United States refer to purchased or metered energy.
3. The Architecture 2030 Challenge was started by Ed Mazria in 2002. A parallel effort known as the 2030 Challenge for Products was initiated in 2011 to reduce the contributions of building materials to climate change.
4. The 2030 Challenge is described at the Architecture 2030 website, http://architecture2030.org/2030_challenges/2030-challenge/.
5. The origin of the word *sustainability* is controversial. In the United States, sustainability was first defined in 1981 by Lester Brown, a well-known American environmentalist and for many years the head of the Worldwatch Institute. In "Building a Sustainable Society," he defined a sustainable society as "one that is able to satisfy its needs without diminishing the chance of future generations." In 1987, the Brundtland Commission, headed by then prime minister of Norway, Gro Harlem Brundtland, adapted Brown's definition, referring to sustainable development as "meeting the needs of the present without compromising the ability of future generations to meet their needs." Sustainable development, or sustainability, strongly suggests a call for intergenerational justice and the realization that today's population is merely borrowing resources and environmental conditions from future generations. In 1987, the Brundtland Commission's report was published as a book, *Our Common Future*, by the UN World Commission on Environment and Development.
6. The World Business Council for Sustainable Development (WBCSD) promotes sustainable development reporting by its 170-member international companies. The WBCSD is committed to sustainable development via the three pillars of sustainability: economic growth, ecological balance, and social progress. Its website is www.wbcsd.org.

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7. In November 1992, more than 1,700 of the world's leading scientists, including the majority of the Nobel laureates in the sciences, issued the "World Scientists' Warning to Humanity." The preamble of this warning stated: "Human beings and the world are on a collision course. Human activities inflict harsh and often irreversible damage on the environment and critical resources. If not checked, many of our current practices put at serious risk the future that we wish for human society and the plant and animal kingdoms, and may so alter the living world that it may be unable to sustain life in the manner we know. Fundamental changes are urgent if we are to avoid the collision our present course will bring about." The remainder of this warning addresses specific issues, global warming among them, and calls for dramatic changes, especially on the part of the high-consuming developed countries, particularly the United States.
8. At the First International Conference on Sustainable Construction held in Tampa, Florida, in November 1994, Task Group 16 (Sustainable Construction) of the CIB formally defined the concept of sustainable construction and articulated six principles of sustainable construction, later amended to seven principles.
9. The *Whole Building Design Guide* can be found at www.wbdg.org.
10. Detailed information about Solaire can be found at www.thesolaire.com.
11. Primary energy accounts for energy in its raw state. The energy value of the coal or fuel oil being input to a power plant is primary energy. The generated electricity is metered or purchased energy. For a 40 percent efficient power plant, 1 kWh of purchased electricity requires 2.5 kWh of primary energy.
12. A description of the severe water resource problems beginning to emerge even in water-rich Florida can be found in the May/June 2003 issue of *Coastal Services*, an online publication of the National Oceanic and Atmospheric Administration Coastal Services Center, available at www.csc.noaa.gov/magazine/2003/03/florida.html. A similar overview of water problems in the western United States can be found in Young (2004).
13. An overview of xeriscaping and the seven basic principles of xeriscaping can be found at http://aggie-horticulture.tamu.edu/extension/xeriscape/xeriscape.html.
14. The Adam Joseph Lewis Center for Environmental Studies at Oberlin College was designed by a highly respected team of architects, engineers, and consultants and is a cutting-edge example of green buildings in the United States. An informative website, www.oberlin.edu/envs/ajlc, shows real-time performance of the building and its photovoltaic system.
15. "The Cost and Benefits of Green Buildings," a 2003 report to California's Sustainable Buildings Task Force, describes in detail the financial and economic benefits of green buildings. The principal author of this report is Greg Kats of Capital E. Several other reports on this theme by the same author are available online. See the references for more information.
16. See World Green Building Council (2015) for a detailed recent report on indoor air quality strategies in green buildings.
17. From "Ultra-Violet Radiation Can Cure 'Sick Buildings'" (2003).
18. The embodied energy of a product refers to the energy required to extract raw materials, manufacture the product, and install it in the building, and includes the transportation energy needed to move the materials comprising the product from extraction to installation.

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Part I

Green Building Foundations

This book is intended to guide construction and design professionals through the process of developing commercial and institutional high-performance green buildings. A green building can be defined as a facility that is designed, built, operated, and disposed of in a resource-efficient manner using ecologically sound approaches and with both human and ecosystem health as goals. The nonprofit US Green Building Council (USGBC) has defined the parameters of a nonresidential green building in the United States by means of a green building assessment system.[1] The organization's Leadership in Energy and Environmental Design (LEED) building assessment system provides design guidance for the vast majority of US buildings currently described as green and has been implemented in several other countries, such as Canada, Spain, and South Korea. From 1998 to the present, the number of LEED-certified buildings has almost doubled each year in both number and area. In 2011, the value of buildings registered for LEED certification equaled as much as 15 percent of the total value of commercial/institutional buildings in the United States and is expected to exceed 50 percent by 2016. More recently, an alternative to LEED, known as Green Globes, has been competing with LEED as a tool for assessing and certifying high-performance green buildings in the United States.[2]

This book addresses the application of building assessment systems such as LEED and Green Globes in the United States as well as several noteworthy building assessment systems used in other countries. Part I addresses the background and history of the sustainable construction movement, various green building rating systems, the concept of life-cycle assessment, and green building design strategies. It is intended to provide the working professional with sufficient information to implement the techniques necessary to create high-performance green buildings. This part contains the following chapters:

Chapter 2: Background

Chapter 3: Ecological Design

Chapter 2 describes the emergence of the green building movement, its rapid evolution and growth over the past decade, and current major influences. This chapter also addresses the unusual scale of resource extraction, waste, and energy consumption associated with construction, and it examines the resource and environmental impacts of the built environment. Although this book focuses on the United States, the context, organizations, and approaches of other countries are also mentioned.

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General design strategies for green building are covered in Chapter 3. Fundamentally, green design is based on an ecological model or metaphor commonly referred to as ecological design. The recent works of Sim Van der Ryn and Stuart Cowan, Ken Yeang, and David Orr, along with earlier works by R. Buckminster Fuller, Frank Lloyd Wright, Ian McHarg, Lewis Mumford, John Lyle, and Richard Neutra, are reviewed in this chapter.

In spite of the impulse to apply the highest ecological ideals to the built environment, a vast majority of contemporary designers lack an adequate understanding of ecology. Claims of a building's "ecological design" are often tenuous in fact, and greater participation by ecologists and industrial ecologists is necessary to reduce the gap between the ideal of ecological design and its expression in reality. To that end, the LEED and Green Globes building assessment systems are probably the first step in a long process of achieving truly ecological design. The products, systems, techniques, and services needed to create buildings in harmony and synergy with nature are rare. Buildings often are assembled from components produced by a variety of manufacturers that have paid little or no attention to the environmental impacts of their activities. Installation is performed by a workforce largely unaware of the impacts of the built environment and often results in enormous waste. Conventional buildings are designed by architects and engineers who often have little or no training in sustainable construction. In spite of these obstacles, certified green buildings are usually superior to conventional projects in terms of energy and water efficiency, materials selection, building health, waste generation, and site utilization. The USGBC has created an ambitious training and publicity program to disseminate LEED concepts. Innovative products for sustainable construction have become more prevalent, greatly easing the process of materials selection. Of equal importance, the green building process has necessitated a deeper integration of the client, the designer, and the general public. New projects generally are initiated via the charrette, which includes construction and design professionals as well as community members, who together brainstorm the project's initial design.

Exceeding the requirements of the contemporary assessment standards such as LEED and Green Globes is the next rung on the ladder of truly sustainable construction. Some of the features of future sustainable construction are described next.

- The built environment would fully adopt closed-loop materials practices, and the entire structure, envelope, systems, and interior would be composed of products easily disassembled to permit ready recycling. Waste material throughout the structure's life cycle would be capable of biological (composting) or technological recycling. The building itself would be deconstructable; in other words, it would be possible to disassemble it economically for reuse and recycling. Only materials with future value, either to human or to biological systems, would be incorporated into buildings.
- Buildings would have a synergistic relationship with their natural environment and blend with the surrounding environment. Materials exchanges across the building–nature interface would benefit both sides of the boundary. Building and occupant waste would be processed to provide nutrients to the surrounding biotic systems. Toxic or harmful emissions of air, water, and solid substances would be eliminated.
- The built environment would incorporate natural systems at various scales, ranging from individual buildings to bioregions. The underexplored integration of natural systems with the built environment has staggering potential to produce superior human habitats at lower cost. Landscaping would provide shade, food, amenities, and stormwater uptake for the built infrastructure. Wetlands would process wastewater and stormwater and often eliminate the need for enormous and expensive infrastructure. Currently the integration of

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nature, which is barely addressed in building assessment systems, is considered under the comprehensive category of design innovation. Ideally, the integration of human and natural systems would be standard practice rather than being considered an innovation.

- Energy use by buildings would be reduced by a Factor 10 or more below that of conventional buildings.[3] Rather than the typical 100,000 BTU/ft^2 (292 kWh/m^2) or more consumed by today's commercial and institutional structures, truly green buildings would be relatively deenergized, using no more than 10,000 BTU/ft^2 (29 kWh/m^2). The source of this energy would be the sun or other solar-derived sources, such as wind power or biomass. Alternatively, geothermal and tidal power, both nonsolar energy sources, also would be employed as renewable forms of energy derived from natural sources.

In summary, the green building movement has come a long way in a short time. Its exponential growth promises its longevity, and numerous public and private organizations support its agenda. It is exciting to contemplate the possibility of extending the boundaries of ecological design and construction as global environmental problems become exigent and as solutions, if not survival itself, demand a radical departure from conventional thinking. The evolution of products, tools, services, and, ultimately, Factor 10 buildings cannot occur soon enough. Only then may we alter the trajectory of the human quality of life from one of certain disaster to one that finally exists within the carrying capacity of nature. Although humanity is halfway through the race, the ultimate question remains unanswered: Can we change the built environment rapidly enough to save both nature and ourselves?

Notes

1. The USGBC (www.usgbc.org) is now the US leader in promoting commercial and institutional green buildings. The greening of single-family-home residential construction and land development is far more decentralized and varies from state to state. An example of an organization leading change at the state level in the residential and land development sectors is the Florida Green Building Coalition (FGBC) (www.floridagreenbuilding.org). The Florida Green Residential Standard and the Florida Green Development Standard can be downloaded from the FGBC website.
2. The genesis of Green Globes was the Building Research Establishment Environmental Assessment Method, which was developed in the United Kingdom in the early 1990s, brought to Canada in 1996, and eventually developed as an online assessment and rating tool. In 2004, the Green Building Initiative (GBI) acquired the rights to distribute Green Globes in the United States. In 2005, the GBI became the first green building organization to be accredited as a standards developer by the American National Standards Institute (ANSI) and began the process of establishing Green Globes as an official ANSI standard. The GBI ANSI technical committee was formed in early 2006, and the ANSI/GBI 01 standard based on Green Globes was published in 2010.
3. Factor 10, a concept developed by the Wuppertal Institute in Wuppertal, Germany (www.wupperinst.org), suggests that long-term sustainable development can be achieved only by reducing resource consumption (energy, water, and materials) to 10 percent of present levels. Another concept, Factor 4, suggests that technology currently exists to reduce resource consumption immediately by 75 percent. The book *Factor Four: Doubling Wealth, Halving Resource Use*, by Ernst von Weizsäcker, Amory Lovins, and L. Hunter Lovins (London: Earthscan, 1997), popularized this concept.

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Chapter 2

Background

On May 9, 2013, for the first time in the 200,000 years of existence of the species of bipedal primates known as humans, a pivotal event occurred that now threatens their future on Earth. On that date the Mauna Loa Observatory in Hawaii recorded that, for the first time in human history, atmospheric carbon dioxide (CO_2) levels exceeded 400 parts per million (ppm), an event that had last occurred over 800,000 years ago. In preindustrial times—that is, prior to 1760—CO_2 concentrations had averaged 280 ppm and had slowly increased to 310 ppm by 1958, the year that instruments at the observatory first began measurements (see Table 2.1). As of 2014, CO_2 levels averaged 400 ppm, and they are expected to continue to increase unless dramatic action is taken by the world's nations to limit greenhouse gas emissions from their power generating systems, industries, and transportation systems (see Figures 2.1 through 2.5).

Human activities have been identified as the cause of the shift in Earth's carbon cycle, which is trapping the sun's energy in the planet's atmosphere and oceans, with likely consequences for all life-forms.[1] Dr. Carmen Boening, a scientist with the Climate Physics Group of the NASA Jet Propulsion Laboratory, described the event in this way:

> Reaching the 400 ppm mark should be a reminder for us that CO_2 levels have been shooting up at an alarming rate in the recent past due to human activity. Levels that high have only been reached during the Pliocene era, when temperatures and sea level were higher. However, Earth's climate had never had to deal with such a drastic change as the current increase, which is, therefore, likely to have unexpected implications for our environment.[2]

Climate change, today's dominant environmental issue, is just one of many human-caused impacts plaguing both the planet and its inhabitants, both human and nonhuman. Eutrophication, acidification, deforestation, loss of biodiversity, and the activities of extractive industries such as mining are forcing countries to either shift onto a cleaner, softer path or face a wide range of negative consequences, among them threats to food and water resources. As the human industry that consumes the most resources and the most energy, construction clearly must undergo the most significant transformation.

TABLE 2.1

Atmospheric CO_2 concentrations are increasing at least 11 times faster from 1958 to the present compared with the period from 1760 to 1958.

Period	Years	Start CO_2 (ppm)	End CO_2 (ppm)	CO_2 (ppm) change	ppm/year change	Factor increase
1760–1958	198	280	310	30	0.15	----------
1958–2015	57	310	400	90	1.60	11

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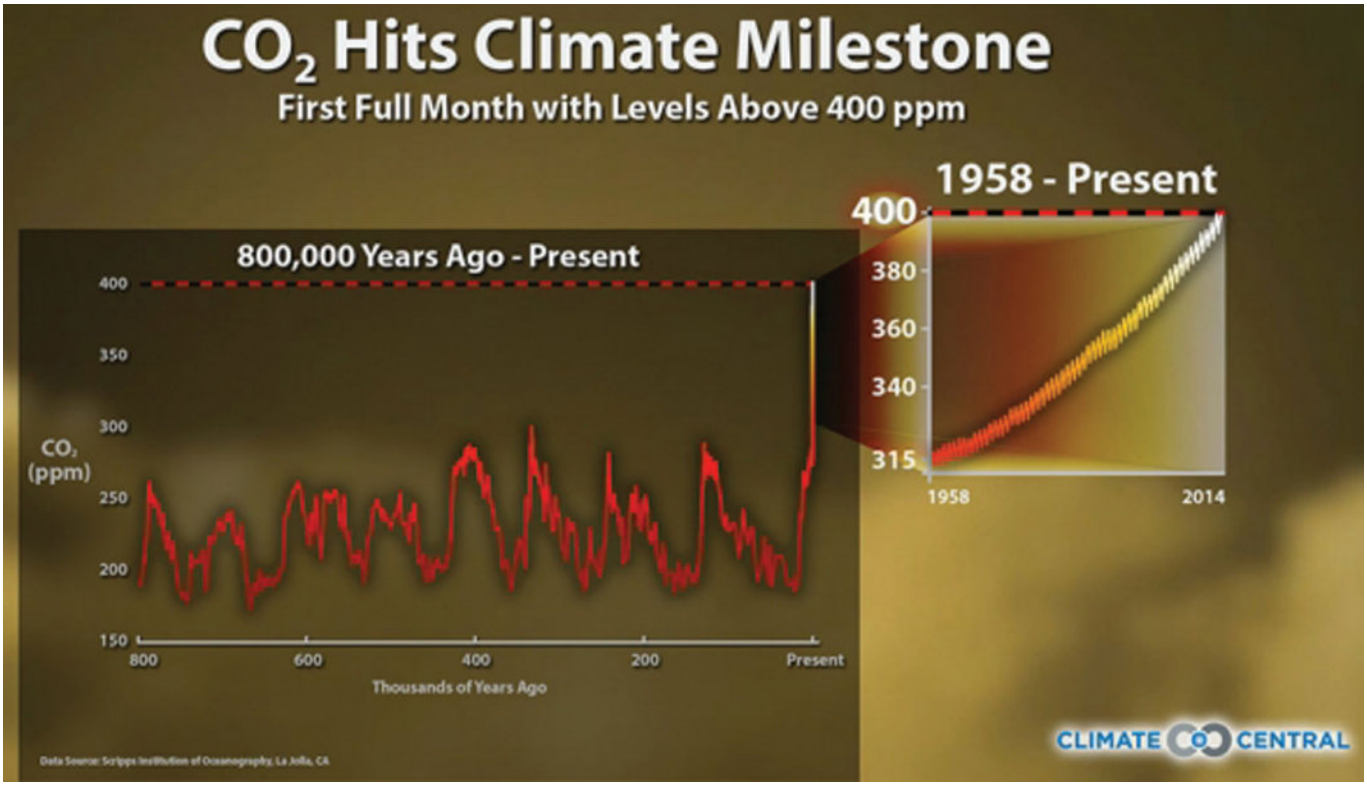


Figure 2.1 Climate Central's Internet announcement that CO_2 concentrations of 400 ppm had been exceeded for the first time. At the current rate of growth, atmospheric CO_2 will reach 500 ppm by 2065. (*Source:* Geoff Grant, Climate Central)

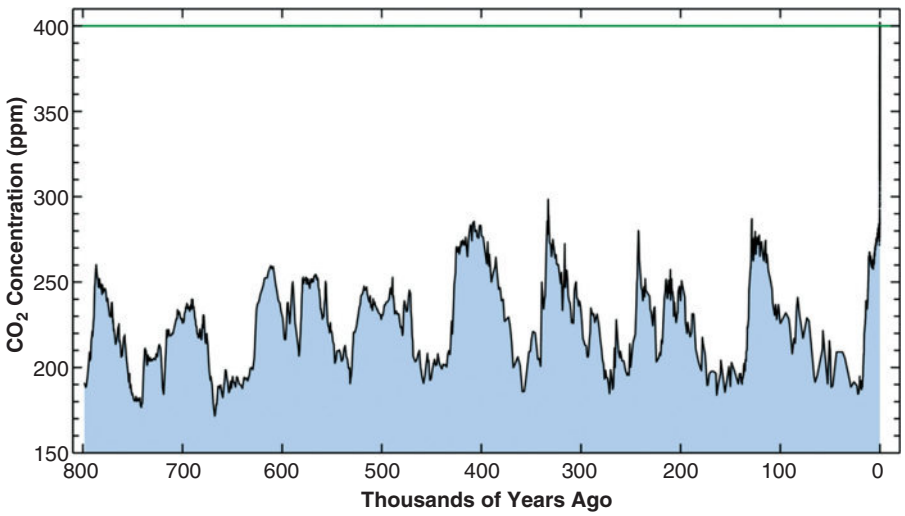


Figure 2.2 Concentration of CO_2 in Earth's atmosphere from the present (Year 0) to 800,000 years ago, the last time Earth's atmosphere experienced concentrations at or above 400 ppm. (Courtesy of Scripps Institution of Oceanography)

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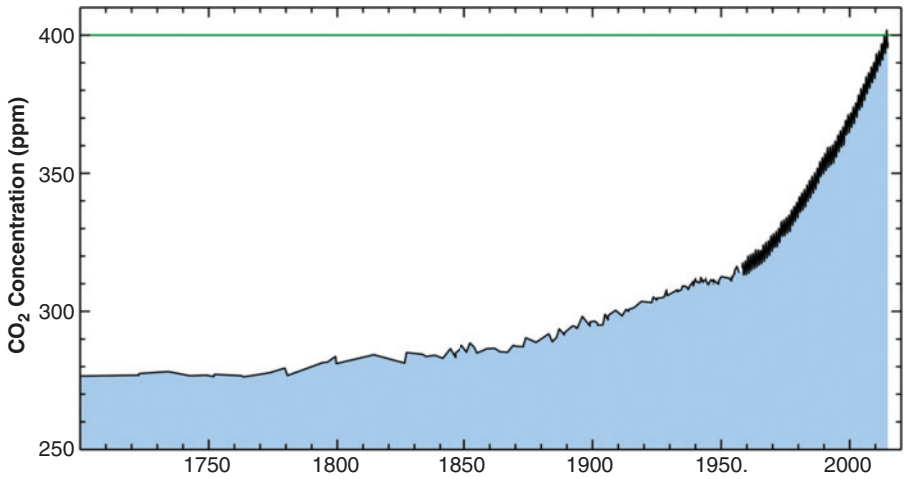


Figure 2.3 CO_2 concentrations in Earth's atmosphere from the year 1700 to the present, showing the increase in levels from about 280 ppm to 400 ppm. Note also the acceleration in CO_2 levels since the 1950s. (Courtesy of Scripps Institution of Oceanography)

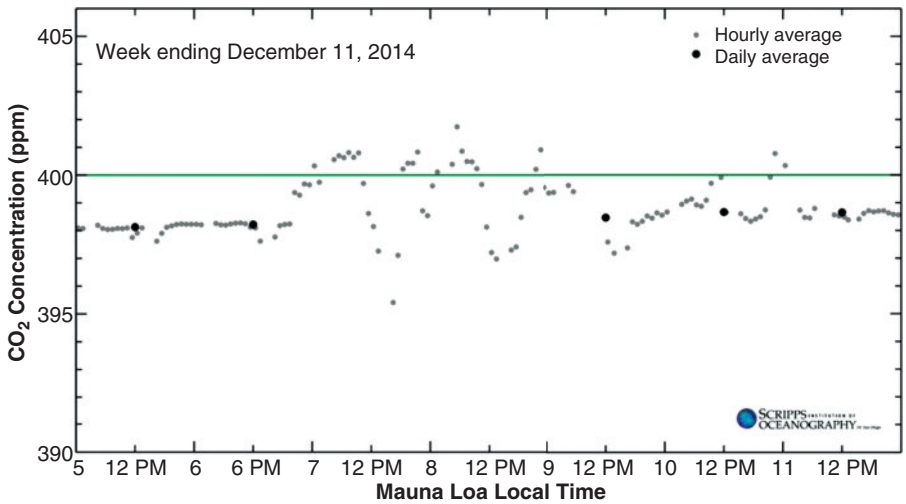


Figure 2.4 Measured CO_2 concentrations for the week ending December 11, 2014, on Mauna Loa exceeded 400 ppm during parts of the day. This has been the case since May 9, 2013, when the first 400 ppm concentrations were detected. (Courtesy of Scripps Institution of Oceanography)

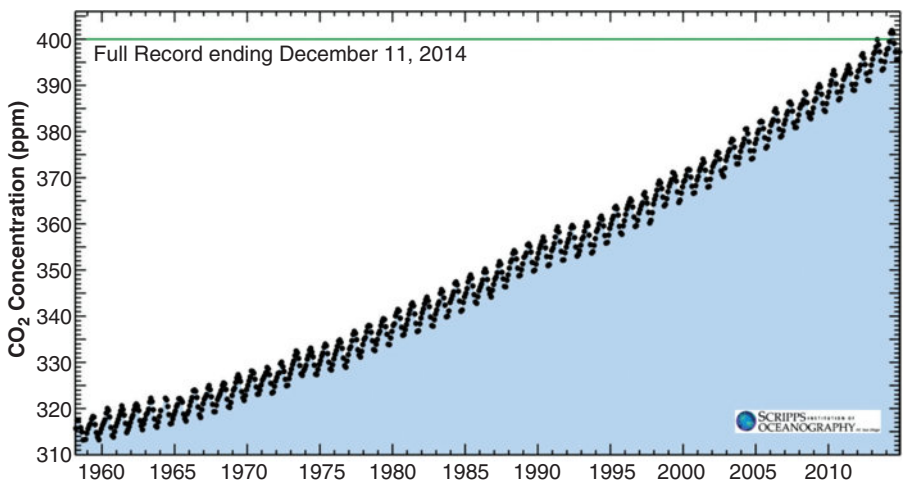


Figure 2.5 In the 55 years since 1960, concentrations of CO_2 in Earth's atmosphere increased from about 310 ppm to over 400 ppm, or by 90 ppm. In comparison, these concentrations increased just 30 ppm in the 210 years from the start of the Industrial Revolution. (Courtesy of Scripps Institution of Oceanography)

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The Driving Forces for Sustainable Construction

Sustainable construction is the response of the construction industry[3] response to the rapid negative changes in Earth's environment and its ecosystems. Three major changes are motivating the construction industry to develop an ethical response to several categories of impacts. First, there is growing evidence of accelerated destruction of planetary ecosystems, alteration of global biogeochemical cycles, and enormous increases in population and consumption. Human caused problems such as climate change, depletion of major fisheries, deforestation, and desertification are the prime cause of what some environmentalists have labeled the *Sixth Extinction*, referring to the human species' massive destruction of life and biodiversity on the planet.[4]

Second, increasing demand for natural resources by both developed and developing countries, such as the so-called BRIC (Brazil, Russia, India, and China) countries, is causing shortages and higher prices for materials and agricultural products. China adds about 8 million people each year to its population of 1.4 billion, and its economy has been expanding at a rate of about 7.0 percent annually. Worldwide economic turbulence in 2016 caused by Chinese overproduction is likely to impact this growth rate. In general, China's growing economy and improving standard of living have increased the demand for, and prices of, meat and grain. The negative consequences of rapid urban expansion in China have included water shortages and increasing desertification, leading to the growth of the Gobi Desert by 4,000 square miles (10,400 square kilometers [km^2]) per year.

The growing Chinese economy has a huge appetite for materials, which is contributing to shortages and driving up prices around the world. China produced over 46 percent of the world's steel in 2014 and is increasing production at a prodigious rate, from approximately 12 million tons (11 million metric tons [mt]) per month in 2001 to 69 million tons (60 million mt) per month in 2014, an annual rate increase of 768 million tons (720 million mt) and rising rapidly. In comparison, steel production in the United States has been relatively flat in the past decade, totaling 90 million tons (81 million mt) in 2014, a small fraction of the Chinese level of production. Chinese demand for fossil fuels is growing at a rate of 30 percent per year. Copper prices have increased 10-fold in 10 years. The manufacturing sector is experiencing higher prices for virtually every commodity used in the production system. Rare earths, which, as their name implies, are not abundant materials but indispensable elements such as lanthanum, neodymium, and europium, are essential for the magnets, motors, and batteries used in electric cars, wind generators, hard-disk drives, mobile phones, and other high-tech products. Their short supply is affecting industries worldwide. After prices spiked significantly in 2011–2012, recently prices for rare earths have stabilized.[5] In short, prices for nonrenewable materials and energy resources are on a strong upward trend that shows no sign of abating. The construction industry, a major consumer of these resources, must change in order to remain healthy and solvent.

Third, the green building movement is coinciding with similar transformations in manufacturing, tourism, agriculture, medicine, and the public sector, which have adopted various approaches toward greening their activities. From redesigning entire processes to implementing administrative efforts such as adopting green procurement policies, new concepts and approaches are emerging that deem the environment, ecological systems, and human welfare to be of equal importance to economic performance. For example, the Xerox Corporation has announced the strategic environmental goal of creating "waste-free products and waste-free facilities for waste-free workplaces." Xerox created just such a product, the DocuColor iGen4

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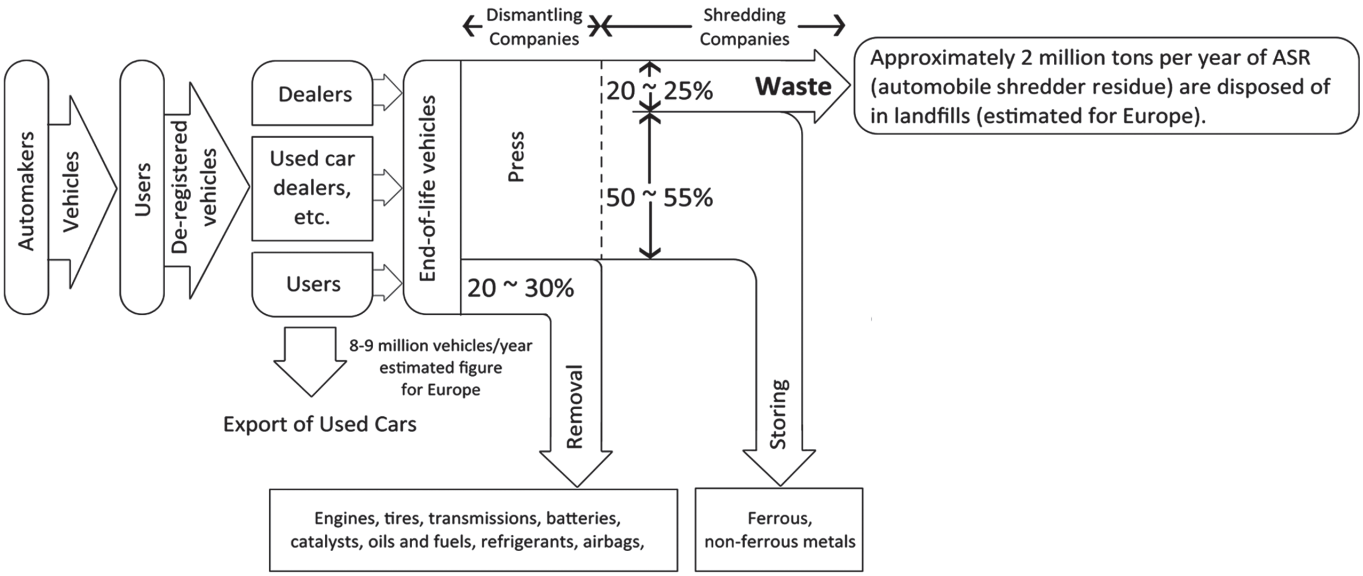


Figure 2.6 The European ELV directive requires manufacturers to accept the return of vehicles at the end of their useful life, with no charge to the consumer. This diagram shows the extensive recycling of returned vehicles and greatly reduced waste generation in automobile production.

EXP Press, which uses nontoxic dry inks and has a transfer efficiency of almost 100 percent. Up to 97 percent of the machine's parts and 80 percent of its generated waste can be reused or recycled. Furthermore, by reclaiming copy machines at the end of their useful life, recovering components for reuse and recycling, and instituting sophisticated remanufacturing processes, Xerox conserves materials and energy, dramatically reduces waste, and limits its potential liability by eliminating hazardous materials.[6]

In the automotive industry, the European end-of-life vehicles (ELV) directive has been in effect since the year 2000 (see Figure 2.6). This legislation requires manufacturers to accept the return of vehicles at the end of their useful life, with no charge to the consumer. The measure requires extensive recycling of the returned vehicles and minimizes the use of hazardous materials in automobile production. Spurred by European efforts, Ford Motor Company is using European engineering expertise at its research center in Aachen, Germany, to develop recycling technologies that will raise the recovery yield of recycled materials above their current 80 to 85 percent level. Construction is generally seen as a wasteful industry, and efforts to increase the reuse and recycling of building materials are beginning to emerge as part of the high-performance green building movement (see Figure 2.7). The European automobile industry, although a different economic sector, provides ample lessons for reducing waste and closing materials loops in construction.

This chapter describes the effect of these three forces on the green building movement and their influence on defining new directions for design and construction of the built environment. It lays out the ethical arguments supporting sustainability and, by extension, sustainable construction. It explores the relatively new vocabulary associated with various efforts that attempt to reduce human environmental impact, increase resource efficiency, and ethically confront the dilemmas of population growth and resource consumption. Finally, it covers the history of the green building movement in the United States, acknowledging that an understanding of its roots is necessary to appreciate its evolution and current status.

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Figure 2.7 The structural system for Rinker Hall, a Leadership in Energy and Environmental Design (LEED)–certified building at the University of Florida in Gainesville, is steel. Steel is an excellent material due to its high recycled content—almost 100 percent for some building components—and is readily deconstructable and recyclable. Rinker Hall is the only building out of the thousands certified by the US Green Building Council to have been awarded an innovation credit for its deconstructability. Although some would consider metals such as steel to be "green" building materials, their embodied energy—that is, the energy required for resource extraction, manufacturing, and transport—is fairly high and results in the consumption of nonrenewable fossil fuels and the generation of global warming gases and air pollution. Consequently, whether steel can truly be considered a green building material is controversial and depends on the criteria used in the evaluation. Of all the challenges in creating high-performance green buildings, finding or creating truly environmentally friendly building materials and products is the most difficult task facing construction industry professionals.

Ethics and Sustainability

In the context of sustainable development and sustainable construction, the idea of ethics must be broadened to address a wide range of concerns that are not usually considered. *Ethics* addresses relationships between people by providing rules of conduct that are generally agreed to govern the good behavior of contemporaries. Sustainable development requires a more extensive set of ethical principles to guide behavior because it addresses relationships between generations, calling for what is sometimes referred to as *intergenerational justice*. The classic definition of sustainable development, from the Brundtland Report, more commonly known as *Our Common Future* (UN World Commission on Environment and Development [WECD] 1987), is "meeting the needs of the present without compromising the ability of future generations to meet their needs." It is clear that *intertemporal* considerations—the responsibility of one generation to future generations, as well as the rights of future generations vis-à-vis a contemporary population—are fundamental concepts of sustainable development. The result of intertemporal or intergenerational considerations with respect to morality and justice must be an expanded concept of ethics that extends not only to future generations but also to the nonhuman living world and arguably to the nonliving world because the alteration or destruction of nonhuman living and nonliving systems affects the quality of life of future generations by reducing their choices. The result of destroying biodiversity today, for

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instance, is the removal of important information for future populations that could have been the basis for biomedicines, not to mention the removal of at least some portion of *environmental amenity*, or enjoyment that nature provides because of its many positive effects on human beings. It is clear that the choices of a given population in time will directly affect the quantity and quality of resources remaining for future inhabitants of Earth, impact the environmental quality they will experience, and alter their experience of the physical world. With this in mind, the purpose of this section is to expand on the foundations of classical ethics to provide a robust set of principles that can address questions of intergenerational equity.

THE ETHICAL CHALLENGES

Humans are unique among all species with respect to control over their destiny. Gary Peterson (2002), an ecologist, articulated this very well when he stated:

> Humans, individually or in groups, can anticipate and prepare for the future to a much greater degree than ecological systems. People use mental models of varying complexity and completeness to construct views of the future. People have developed elaborate ways of exchanging, influencing, and updating these models. This creates complicated dynamics based upon access to information, ability to organize, and power. In contrast, the organization of ecological systems is a product of the mutual reinforcement of many interacting structures and processes that have emerged over long periods of time. Similarly, the behavior of plants and animals is the product of successful evolutionary experimentation that has occurred in the past. Consequently, the arrangement and behavior of natural systems are based upon what has happened in the past, rather than looking forward in anticipation toward the future. The difference between forward-looking human systems and backward-looking natural systems is fundamental. It means that understanding the role of people in ecological systems requires not only understanding how people have acted in the past, but also how they think about the future. (p. 138)

Following this line of thinking, humans are certain to create materials and develop processes that have not evolved in a natural sense, which have no precedent in nature. The question then becomes: What constraints should society place on the development of new materials, products, and processes? The ongoing debates about genetically modified organisms (GMOs) and cloning are indicative of the uncertainty about the outcomes of human tinkering with the blueprints of life, not to mention the creation of materials that have uncertain long-term impacts. Other major developments such as biotechnology, genetic engineering, nanotechnology, robotics, and nuclear energy, to name but a few, present fundamental challenges to human society. Decisions about implementing technologies with no precedent in nature and with potentially unprecedented negative and irreversible impacts must be considered carefully, especially since, once a technology is deployed, it is extremely difficult to reverse course if negative consequences are discovered. Decisions about how to move forward must be based on (1) an ethical framework that represents society's general moral attitudes toward life and future generations, (2) an understanding of and willingness to accept risk, and (3) the economic costs of implementation and resulting impacts.[7]

INTERGENERATIONAL JUSTICE AND THE CHAIN OF OBLIGATION

There is an asymmetry of power between present and future generations because, while today's people can make choices that likely will severely affect people 100 to 200 years into the future—for example, ignoring the long-term impacts of climate change—the same cannot be said of future generations. There is simply no mechanism for future, remote generations to have an effect on the past.[8] Current

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generations can affect the health and quality of life of these remote generations. The choices of today's generations will directly affect the quality and quantity of resources remaining for future inhabitants of Earth and its environmental quality. This concept of obligation that crosses temporal boundaries is referred to as *intergenerational justice.* Furthermore, the concept of intergenerational justice implies a *chain of obligation* between generations that extends from today into the distant future. Richard Howarth (1992) expressed this obligation by stating that "unless we ensure conditions favourable to the welfare of future generations, we wrong existing children in the sense that they will be unable to fulfill their obligation to their children while enjoying a favourable way of life themselves" (p. 133). Howarth also suggested that the actions and decisions of the current generation affect not only the welfare but also the composition of future generations. He argued that when we create conditions that change resource availability or that alter the environment, future populations will be compositionally different than if the resource base and environmental conditions had been passed on, from one generation to future generations, unchanged. For instance, mutations caused by excessive ultraviolet radiation through an ozone layer depleted by human activities, or by synthetic toxic chemicals used without adequate safeguards, certainly will result in different people and conditions. Consequently, the chain of obligation that underpins the key sustainability concept of intergenerational justice includes parents' responsibility for enabling their offspring to meet their moral obligations to their children and beyond. Clearly, doing this would include educating the offspring about these obligations and the basis for them.

DISTRIBUTIONAL EQUITY

There is an obligation to ensure the fair distribution of resources among people currently alive so that the life prospects of all people are addressed. This obligation can be referred to as *distributional equity* or *distributive justice* and refers to the right of all people to an equal share of resources, including goods and services, such as materials, land, energy, water, and high environmental quality (see Figure 2.8). Distributional equity is based on principles of justice and the reasonable assumption that all individuals in a given generation are equal and that a uniform distribution of resources must be a consequence of *intragenerational equity.* The principle of distributional equity can be extended to relationships between generations because a given



Figure 2.8 One of the challenges of sustainability is increasing prosperity for the billions who are barely able to survive on a day-to-day basis. The principle of distributional equity requires that Earth's resources be more fairly allocated so that everyone has at least a decent quality of life. (Wikipedia Commons)

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generation has a moral responsibility to provide for their offspring, which is referred to as *intergenerational equity.* Thus, distributional equity also underpins the chain of obligation concept. Distributional equity is a complex concept, and a number of principles underpin and are related to it: (1) the difference principle, (2) resource-based principles, (3) welfare-based principles, (4) desert-based principles, (5) libertarian principles, and (6) feminist principles.

THE PRECAUTIONARY PRINCIPLE

The *precautionary principle* requires the exercise of caution when making decisions that may adversely affect nature, natural ecosystems, and global biogeochemical cycles. According to the Center for Community Action and Environmental Justice (CCAEJ), the precautionary principle states that "when an activity raises threats of harm to human health or the environment, precautionary measures should be taken even if some cause and effect relationships are not fully established scientifically." Global climate change is an excellent example of the need to act with caution. Notwithstanding debate about the effects of man-made carbon emissions on future planetary temperature regimes, the potentially catastrophic outcomes should motivate humankind to behave cautiously and attempt to limit the emissions of carbon-containing gases such as methane and CO_2. On its website (www.ccaej.org) the CCAEJ proposes four tenets of the precautionary principle:

1. People have a duty to take anticipatory action to prevent harm.
2. The burden of the proof of harmlessness of a new technology, process, activity, or chemical lies with the proponents, not the general public.
3. Before using a new technology, process, or chemical or starting a new activity, people have an obligation to examine a full range of alternatives including the alternative of not doing it.
4. Decisions applying the precautionary principle must be open, informed, and democratic and must include the affected parties.

As an example, a hypothetical danger of *nanotechnology* is the creation of so-called gray goo. Nanotechnology is an approach to building machines at the submicrometer level—that is, on an atomic scale. K. Eric Drexler (1987) suggested that one of the hallmarks of nanotechnology will be the ability of these invisible machines to self-replicate, with enormous potential benefits to humanity, but with the attendant danger that the replication will bring an out-of-control conversion of matter into machines. Drexler warned that "we cannot afford certain kinds of accidents with replicating assemblers," which can be restated as "we cannot afford the irresponsible use of powerful technologies." Thermodynamics and energy requirements will limit the effects of the gray goo conversion process, but significant harm still may be the consequence. This type of scenario requires consideration of the precautionary principle, even if the full consequences of self-replicating machines are not known, because of the potential catastrophic outcome if Drexler is correct. Similar concerns exist with regard to genetic engineering and nuclear engineering: They have a high probability of putting future generations at risk. Clearly, the precautionary principle should be applied to each of these scenarios to eliminate as much as possible risks to future populations, both human and nonhuman, from the consequences of technologies that are not fully understood.

Despite the wisdom of exercising caution when addressing complex issues that may have unknown, far-reaching effects, the precautionary principle is controversial and sometimes is perceived as a threat to progress, since it fails to consider the negative consequences of its application. For example, refusing to use new drugs because society has not fully established their effects on nature and people may foreclose

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options for advancing human health. Nonetheless, the consequences of not applying the precautionary principle are becoming apparent in several areas. Most notably, the widespread use of estrogen-mimicking chemicals is believed to damage the reproductive systems of animal species and probably of humans. With these concerns in mind, in 1999 the National Science Foundation developed the Biocomplexity in the Environment Priority Area to address the interaction of human activities with the environment and on climate change and biodiversity.[9] At least the debate surrounding the application of the precautionary principle has focused greater attention on the environmental impacts of technology and has pressured technologists to acknowledge the potential consequences of their efforts on humans and nature.

THE REVERSIBILITY PRINCIPLE

Making decisions that can be undone by future generations is the foundation of the *reversibility principle.* Renowned science fiction author Arthur C. Clarke (1965, cited in Goodin, 1983) suggested a rule that well describes this principle: "Do not commit the irrevocable." At its core, this principle calls for a wider range of options to be considered in decision making. Addressing the issue of energy choices is an excellent example because a rapidly growing global economy is faced with looming energy shortages, exacerbated by the depletion of finite oil supplies. In the United States, a shift is under way to reconsider nuclear plants as a major source of energy because they probably can generate electricity at an acceptable cost and also be a source of thermal energy for producing hydrogen from water for use in fuel cells. The reversibility principle would force today's society to confront the issue of whether the choice of nuclear energy as an option is reversible by a future society. Two questions would immediately emerge from this consideration. First, is the technology safe enough for widespread use? The nuclear industry suggests that over the past two decades of a national hiatus from building new plants, the technology has advanced to the point where a Chernobyl, Three Mile Island, or Fukushima Daiichi incident can be eliminated. The second question is: How would a future society cope with the nuclear waste from these plants? Converting the waste into harmless materials via a new technology is highly unlikely, and the power plants built today would force future generations to store and be put at risk by the radionuclides in the spent fuel rods. A subset of questions on this same subject would result as a consequence of assuming that, if storage of the radioactive waste for periods of time in the 10,000-year range is feasible, what are the storage options? (See Figure 2.9.) In addressing this question, Gene I. Rochlin (1978) suggested that there are two options. One is to deposit the waste deep in a stable rock formation where it could be recovered if, for example, leaks in the storage containers were detected by future generations. A second option is to deposit it in inaccessible locations—for example, by placing the waste deep in the ocean, where sliding continental plates would gradually cover it. The former solution allows future generations access to the waste to take corrective action, while the latter does not allow that option.

The reversibility principle is related to the precautionary principle because it lays out criteria that must be observed prior to the adoption of a new technology. It is less stringent than the precautionary principle in some respects because it suggests reversibility as the primary criterion for making a decision to employ the technology; the precautionary principle, in contrast, requires that a technology not be implemented if its effects are not fully understood and if the risks are unacceptable.

THE POLLUTER PAYS PRINCIPLE AND PRODUCER RESPONSIBILITY

The fundamental premise of the precautionary and reversibility principles is that those who are responsible for implementing technologies must be prepared to address the consequences of their implementation. The precautionary principle

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Figure 2.9 Nuclear waste storage is a challenging problem for the United States and other countries with nuclear energy or weapons systems and illustrates the potential application of both the precautionary and reversibility principles. The US Department of Energy constructed the underground Exploratory Studies Facility at Yucca Mountain, Nevada, to determine whether the location was suitable as a deep geological nuclear waste repository. The project was halted indefinitely in 2009, and the United States still has not found an acceptable solution for the increasing stockpiles of nuclear waste stored at nuclear reactor and weapons facilities around the country. (*Source:* US Department of Energy)

suggests that technologists should demonstrate the efficacy of their products and processes prior to allowing them to impact the biosphere. The reversibility principle permits implementation despite some level of risk as long as any negative effects can be undone. The *polluter pays principle* addresses existing technologies that have not been subject to these other principles and places the onus for mitigating damage and consequences on the individuals causing the impacts. The polluter pays principle originated with the Organisation for Economic Co-operation and Development in 1973 and is based on the premise that polluters should pay the costs of dealing with pollution for which they are responsible. Historically, the polluter pays principle has focused on retrospective liability for pollution; for example, an industry causing pollution would have to pay for the cleanup costs arising from it.

More recently, the focus of the polluter pays principle has shifted toward avoiding pollution and addressing wider environmental impacts through producer responsibility. Producer responsibility is an example of the extended version of the polluter pays principle, as it applies to waste and resource management, placing responsibility for the environmental impact associated with a product on the producers of that product. Producer responsibility is intended to address the whole life-cycle environmental problems of the production process, from initial minimization of resource use, through extended product life span, to recovery and recycling of products once they have been disposed of as waste. Producer responsibility is used increasingly throughout the world to address the environmental impacts of certain products. The European Union has applied producer responsibility through directives on packaging and packaging waste, waste electronic and electrical equipment, and ELV.

PROTECTING THE VULNERABLE

There are populations, including those of the animal world, that are vulnerable to the actions of portions of the human species, due to the destruction of ecosystems under the guise of development, introduction of technology (including toxic substances, endocrine disruptors, and GMOs), and general patterns of conduct (war,

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deforestation, soil erosion, eutrophication, desertification, and acid rain, to name a few). People who are essentially powerless due to governing and economic structures are vulnerable to the decisions of those who are powerful because of their wealth or influence. This asymmetrical power arrangement is governed by moral obligation. Those in power have a special obligation to *protect the vulnerable*, those dependent on them. In a family, children's dependence on their parents gives them rights against their parents. Future generations are also vulnerable because they are subject to the effects of decisions we make today. In a technological society, many portions of the human population and certainly the animal world can be exposed to harm by the actions of individuals or companies performing medical research or because the government that is charged with protecting them fails in its responsibilities when it comes to pollution, the use of toxic substances, and a wide variety of other poorly controlled actions. Breaches of ethics are not uncommon when it comes to vulnerable populations, such as prisoners, people with mental disabilities, women, and people in developing countries. And, as noted earlier, today's actions have consequences for future generations that have been considered only recently. Future people are certainly vulnerable to our actions, and both their existence and their quality of life are potentially compromised by short-term thinking and decisions based solely on the comfort and wealth of past populations. The ethical principle of protecting the vulnerable places an enormous responsibility on Earth's current population, one made even more difficult due to rampant global poverty.

PROTECTING THE RIGHTS OF THE NONHUMAN WORLD

The *nonhuman world* refers to plants and animals and could be extended to include bacteria, viruses, mold, and other living organisms. The principle of protecting this world is an extension of the principle of protecting the vulnerable, particularly animals but also plants that are in danger of extinction. Animal rights fall under this principle. The nonliving portion of Earth is essential in supporting life, and a set of sustainability principles should address the requirements for protecting this key element of the life support system. Some would argue that ethics should require the character of beautiful places, such as the Grand Canyon, be protected in perpetuity. This principle is an important one because humans have become disconnected from both the living and the nonliving nonhuman worlds when, in fact, we are utterly dependent on them for our survival. Indeed, the *biophilia hypothesis*, described later in this chapter, states that humans crave a connection with nature and that our health, at least in part, is dependent on being able to connect with nature on a routine basis. Human ingenuity in the form of technology is having quite the opposite effect. As noted by Andrew J. Angyal (2003):

> [T]his destructive myth of a technological wonderland in which nature is bent to every human whim is turning the Earth into a wasteland and threatening human survival. Western spiritual traditions have not been able to impede these lethal tendencies, but have encouraged them as part of God's plan for human domination of the Earth, and these traditions have understood human destiny as primarily involving a heavenly spiritual redemption.… With their preoccupation with redemption and their neglect of creation, modern religious traditions are unable to offer a spirituality adequate to experience the divine in ordinary life or in the natural world.

Thomas Berry (2002) described ten precepts based on nature deriving its rights from universal law, and not human law, which provide an ethical framework for the rights of the nonhuman world:

1. Rights originate where existence originates. That which determines existence determines rights.
2. Since it has no further context of existence in the phenomenal order, the universe is self-referent in its being and self-normative in its activities. It is

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also the primary referent in the being and activities of all derivative modes of being.

3. The universe is a communion of subjects, not a collection of objects. As subjects, the component members of the universe are capable of having rights.
4. The natural world on the planet earth gets its rights from the same source that humans get their rights, from the universe that brought them into being.
5. Every component of the Earth community has three rights: the right to be, the right to habitat, and the right to fulfill its role in the ever-renewing processes of the Earth community.
6. All rights are species-specific and limited. Rivers have river rights. Birds have bird rights. Insects have insect rights. Difference in rights is qualitative, not quantitative. The rights of an insect would be of no value to a tree or a fish.
7. Human rights do not cancel out the rights of other modes of being to exist in their natural state. Human property rights are not absolute. Property rights are simply a special relationship between a particular human "owner" and a particular piece of "property" so that both might fulfill their roles in the great community of existence.
8. Since species exist only in the form of individuals, rights refer to individuals and to their natural groupings of individuals into flocks, herds, packs, not simply in a general way to species.
9. These rights as presented here are based upon the intrinsic relations that the various components of Earth have to each other. The planet Earth is a single community bound together with interdependent relationships. No living being nourishes itself. Each component of the Earth community is immediately or mediately dependent on every other member of the community for the nourishment and assistance it needs for its own survival. This mutual nourishment, which includes the predator-prey relationships, is integral with the role that each component of the Earth has within the comprehensive community of existence.
10. In a special manner humans have not only a need for but a right of access to the natural world to provide not only the physical need of humans but also the wonder needed by human intelligence, the beauty needed by human imagination, and the intimacy needed by human emotions for fulfillment.

Clearly, putting nature on an equal footing with humans is a difficult leap for many people, but vigorously protecting nature is in the best interests of humanity. Indeed, simply protecting nature does not quite meet the imperatives of the principle of protecting the rights of the nonhuman world. Rather, humans should consider restoring nature in all activities, righting the wrongs of the past, and in the process restoring the badly damaged link between humans and nature. (Figure 2.10)

RESPECT FOR NATURE AND THE LAND ETHIC

Respect for nature follows from acknowledging the rights of the nonhuman world described in the previous sections. An ethics of respect for nature is based on the fundamental concepts that (1) humans are members of Earth's community of life, (2) all species are interconnected in a web of life, (3) each species is a teleological center of life pursuing good in its own way, and (4) human beings are not superior to other species. This last concept is based on the other three and shifts the focus from *anthropocentrism*, or a human-centered viewpoint, to a *biocentric* outlook (Taylor 1981).

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Figure 2.10 Protecting the rights of the nonhuman living world is important not only because each species or organism is a node in the web of life but also because each species is a *teleological center of life*, meaning each organism has a purpose and a reason for being and is therefore inherently good or valuable.

Humans are part of precisely the same evolutionary process as all other species. All other species that exist today faced the same survival challenges as humans. The same biological laws that govern other species—for example, the laws of genetics, natural selection, and adaptation—apply to all living creatures. Earth does not depend on humans for its existence. On the contrary, humans are the only species that has ever threatened the existence of the Earth itself. As relative latecomers, humans appeared on a planet that had contained life for 600 million years. Not only do humans have to share the planet with other species, but they are totally dependent on those species for survival. Human beings threaten the soundness and health of Earth's ecosystems by their behavior. Technology results in the release of toxic chemicals, radioactive materials, and endocrine disruptors. Forestry and agriculture destroy biologically dense and diverse forests. Emissions pollute land, water, and air. Unlike natural extinctions of the past from which Earth recovered, the current human-induced extinction is causing disruption, destruction, and alteration at such a high rate that, even if the human species causes its own extinction, the planet may never recover. An ethics based on biocentrism would result in humans realizing that the integrity of the entire biosphere would benefit all communities of life, humans and nonhumans. It is debatable whether this concept is merely an ethical one because it is also a biological fact that humans cannot survive without the ecosystems on which they depend. However, human beings have the capability to act and change behavior based on knowledge, in this case the awareness of the causal relationship of behavior to the survival of other species. An ethics of respect for nature consists not only of realizing this causal relationship but also of adopting behaviors that respect the rights of nonhuman species to both exist and thrive.

In addition to respecting the rights to survival of other species, as a consequence of careful observation and the application of scientific principles and the scientific method, humans understand the unique qualities and aspects of other organisms. These observations allow us humans to see these organisms as unique teleological centers of life, each struggling to survive and realize its good in its own way. This does not mean that organisms need to have the characteristic of consciousness, that is, self-awareness, to be "good," because each is oriented toward the same ends: self-preservation and well-being. The ethical concept here is that because each species is a teleological center of life, its universe or world can be viewed from the perspective of its life. Consequently, good (finding food), bad (being injured or killed), and indifferent (swimming in the ocean) events can be said to occur in each species' life, as is the case for the human species. Having respect for nature means that humans can

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Figure 2.11 Aldo Leopold advocated a relationship between humans and the land that he referred to as the land ethic. (Photo courtesy of The Aldo Leopold Foundation)

view life events for nonhuman species in much the same fashion as they would for other humans.

Aldo Leopold (1949) suggested that there should be an ethical relationship with the land and that this relationship should and must be based on love, respect, and admiration for the land. Furthermore, this ethical relationship, referred to as the *land ethic*, should exist not only because of economic value but should also be based on value in the philosophical sense (see Figure 2.11). The land ethic makes sense because of the close relationship and interdependence of humans with land, which provides food and amenities and contributes to good air and water quality. Humans have tended to become disconnected from the land because of technological developments that give us apparent (but not actual independence) from the land. Substitutes for natural material (e.g., polyester instead of cotton) further the notion that land is not essential for survival and that technology can provide suitable substitutes. Farm mechanization has also tended to separate the farmer from the land, resulting in less care and attention paid to a critical resource.

Basic Concepts and Vocabulary

Although probably the greatest success story of the contemporary American environmental movement, sustainable construction is only one part of a larger transformation taking place via a wide range of activities in numerous economic sectors. Progressive ideas articulated with new vocabulary serve as the intellectual foundation for this evolution. The most notable and important ideas include the concepts of sustainable development, industrial ecology, construction ecology, biomimicry, design for the environment, ecological economics, carrying capacity,

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Figure 2.12 The publication of *Our Common Future* in 1987 is generally accepted as marking the beginning of the contemporary sustainable development movement.

ecological footprint, ecological rucksack, embodied energy, the biophilia hypothesis, eco-efficiency, the Natural Step, life-cycle assessment, life-cycle costing, the precautionary principle, Factor 4, and Factor 10. These concepts are described briefly in the following sections.

SUSTAINABLE DEVELOPMENT

Sustainable development, or *sustainability*, is the foundational principle underlying various efforts to ensure a decent quality of life for future generations. *Our Common Future* (UN WECD, 1987), defined sustainable development as that which "meets the needs of the present without compromising the ability of future generations to meet their own needs" (p. 8) (see Figure 2.12). This classic definition implies that the environment and the quality of human life are as important as economic performance and suggests that human, natural, and economic systems are interdependent. It also implies intergenerational justice; highlights the responsibility of the current population for the welfare of millions yet unborn; and implies that we are borrowing the planet, its resources, and its environmental function and quality from future generations. Intergenerational justice raises the question of how far into the future we should consider the impacts of our actions. Although no clear answer to this important question is readily apparent, the Native American philosophy of thinking seven generations, or 200 years, into the future is instructive. If in two centuries few contemporary buildings will be standing, we must ask whether our current stock of materials will provide recyclable resources for future generations or saddle them with enormous and difficult waste disposal problems. This question, originating in the philosophy of sustainability, marks the fork in the road of our current industrial processes. Those on the path of business as usual will view the environment as an infinite source of materials and energy and a repository for waste. In contrast, those on the more ethical road less traveled will consider the quality of life of our descendants and question whether we are permanently stealing, versus temporarily borrowing, the environmental capital of future generations. At the philosophical core of the green building movement is the decision to embark on the latter path.

INDUSTRIAL ECOLOGY

The science of *industrial ecology*, which emerged in the late 1980s,[10] studies the physical, chemical, and biological interactions and interrelationships both within and among industrial and ecological systems (Garner and Keoleian 1995). Applications of industrial ecology involve identifying and implementing strategies for industrial systems to emulate more closely harmonious and sustainable ecological ecosystems. The first major effort of industrial ecology was to reduce the massive quantities of waste generated by traditional manufacturing processes, from which only an estimated 6 percent of extracted resources end up as final products.[11] The first well-known example of the resulting process, referred to as *industrial symbiosis*, is the industrial complex in Kalundborg, Denmark, where excess heat energy, waste, and water are shared among five major partners:

1. *The Asnaes power station*, Denmark's largest coal-fired power plant, with a 1,500-megawatt capacity
2. *The Statoil refinery*, Denmark's largest, with a current capacity of 4.8 million tons (4.4 million mt) per year
3. *Gyproc*, a plasterboard factory producing 150 million ft^2 (14 million m^2) of gypsum wallboard annually (roughly enough to build all the houses in six towns the size of Kalundborg)

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4. *Novo Nordisk*, an international biotechnological company, with annual sales of over $2 billion, which manufactures industrial enzymes and pharmaceuticals, including 40 percent of the world's supply of insulin
5. *The city of Kalundborg district heating system*, which supplies heating to 20,000 residents and water to its homes and industries

The Kalundborg complex (diagrammed in Figure 2.13) was the world's first eco-industrial park; since its inception, similar waste exchange complexes have been created around the world.[12] Since the early 1990s, the concept of industrial ecology has expanded to encompass issues of design for the environment, product design, closing materials loops, recycling, and other environmentally conscious practices. Industrial ecology is a comprehensive approach to implementing sustainable industrial behavior.

CONSTRUCTION ECOLOGY

Construction ecology is a subcategory of industrial ecology that applies specifically to the built environment. Construction ecology employs principles of industrial ecology combined with ecological theory that differentiates buildings from other industrial products, such as automobiles, refrigerators, and copying machines. Construction ecology also supports the design and construction of a built environment that (1) has a closed-loop materials system integrated with eco-industrial and natural systems, (2) depends solely on renewable energy sources, and (3) fosters the preservation of natural system functions. Application of these principles should result in buildings that:

1. Are readily deconstructable at the end of their useful lives
2. Have components that are decoupled from the building for easy replacement
3. Are composed of products designed for recycling
4. Are built using recyclable, bulk structural materials
5. Have slow "metabolisms" due to their durability and adaptability
6. Promote the health of their human occupants.[13]

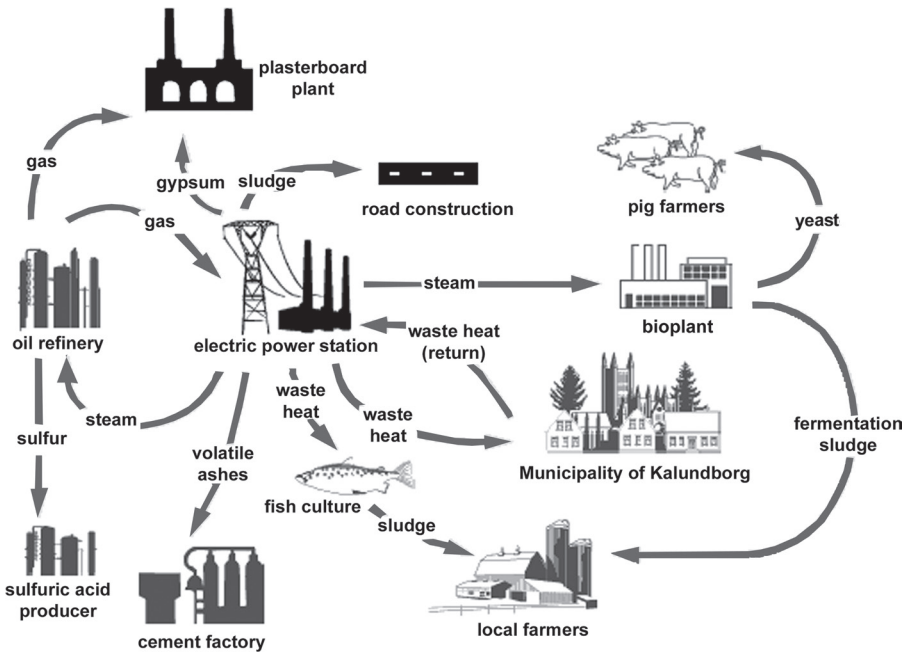


Figure 2.13 The industrial complex in Kalundborg, Denmark, exchanges energy, water, and materials among its member companies and organizations, demonstrating industrial symbiosis, one of the basic concepts of industrial ecology. (*Source: Ecodecision* (Spring 1996): 20

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BIOMIMICRY

The term *biomimicry* was popularized by Janine Benyus in her book, *Biomimicry: Innovation Inspired by Nature* (1997), and has since received widespread attention as a concept that demonstrates the direct application of ecological concepts to the production of industrial objects.[14] According to Benyus, biomimicry is the "conscious imitation of nature's genius," and it suggests that most of what we need to know about energy and materials use has been developed by natural systems over almost 4 billion years of trial and error. Biomimicry advocates the possibility of creating strong, tough, and intelligent materials from naturally occurring materials, at ambient temperatures, with no waste, and using current solar "income" (sunlight) to power the manufacturing process. For example, nature produces strong, elegant, functional, and beautiful seashells from materials in seawater at ambient temperatures. At the end of their useful lives as aquatic habitat, they degrade and provide future resources in a waste-free manner. In contrast, production of ceramic clay tiles requires high fire temperatures of at least 2,700° F (1,482° C) and the extraction and transport of clay and energy resources, and results in emissions and waste. Unlike their natural counterparts, clay tiles do not degrade into useful products and are likely to be disposed of in landfills at the end of their useful lives.

The subject of biomimicry and its application to the built environment in the form of biomimetic design are covered in more detail in Chapter 3.

DESIGN FOR THE ENVIRONMENT

Design for the environment (DfE), sometimes referred to as *green design*, is a practice that integrates environmental considerations into product and process engineering procedures and considers the entire product life cycle (Keoleian and Mereney 1994). The related concept of front-loaded design advocates the investment of greater effort during the design phase to ensure the recovery, reuse, and/or recycling of the product's components. Although DfE typically describes the process of designing products that can be disassembled and recycled, depending on the context, DfE may encompass design for disassembly, for recycling, for reuse, for remanufacturing, and for other approaches. DfE's application to building design implies that, to be considered green, significant effort must be made in product design to enable the reuse and recycling of the product's components. A window assembly designed using DfE strategies, for example, would be easy to remove from the building and to disassemble into its basic metal, glass, and plastic components. Furthermore, the materials must possess and maintain value in order to motivate the industrial system to keep them in productive use. As applied to the built environment, DfE implies that entire buildings should be designed to be taken apart, or deconstructed, to recover components for further disassembly, reuse, and recycling.

ECOLOGICAL ECONOMICS

Contemporary, or neoclassical, economics fails to consider or adequately address the problems of resource limitations or the environmental impact of waste and toxic substances on productive ecological systems. In contrast, ecological economics posits that healthy, natural systems and the free goods and services provided by nature are essential to economic success. *Ecological economics* is a fundamental requirement of sustainable development that specifically addresses the relationship between human economies and natural ecosystems. Since the human economy is embedded in the larger natural ecosystem and depends on it for exchanging matter and energy, both systems must coevolve. Ecological economic philosophy counters

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the human propensity to ignorantly or deliberately degrade ecosystems by extracting useful, high-quality matter and energy, which ultimately are transformed into useless, low-quality waste and heat. Ecological economics values nature's provision of goods, energy, services, and amenities as well as humanity's cultural and moral contributions.[15] Valuing nature—that is, assigning a monetary worth to its goods and services—although antithetical to some, is essential to appreciate and understand the worth of natural system resources and services in the human economy.

Unfortunately, obstacles exist to replacing the shortsighted approach of contemporary neoclassical economics with the ecological economics consideration of the contributions and limitations of natural systems. Our current limited understanding of complex nonlinear natural systems, as well as the difficulty of accurately representing these systems in relevant economic models, presents challenges. Nonetheless, ecological economics illuminates the dismal science of traditional economics and provides a more comprehensive framework for applying economic principles in the evolving, transformative era of sustainable development.

CARRYING CAPACITY

The term *carrying capacity* defines the limits of a specific land's capability to support people and their activities. According to the Carrying Capacity Network (www.carryingcapacity.org),

> Carrying capacity is the number of people who can be supported in a given area within natural resource limits, and without degrading the natural social, cultural, and economic environment for present and future generations. The carrying capacity for any given area is not fixed. It can be altered by improved technology, but mostly it is changed for the worse by pressures which accompany a population increase. As the environment is degraded, carrying capacity actually shrinks, leaving the environment no longer able to support even the number of people who could formerly have lived in the area on a sustainable basis. No population can live beyond the environment's carrying capacity for very long.

Carrying capacity focuses on the relationship between land area and human population growth and suggests the point at which the system may break down. Much debate surrounds the carrying capacity of the planet in general and the United States in particular. Although the United States may be able to carry 1 billion people with adequate resources, it is doubtful that a population of this magnitude is desirable. The concept of carrying capacity is also linked to the precautionary principle, discussed earlier in this chapter.

ECOLOGICAL FOOTPRINT

In the book *Our Ecological Footprint*, Mathis Wackernagel and William Rees (1996) suggested that an *ecological footprint*, referring to the land area required to support a certain population or activity, could serve as a surrogate measure for total resource consumption, thus allowing a simple comparison of the resource consumption of various lifestyles. The ecological footprint is the inverse of carrying capacity and represents the amount of land needed to support a given population. An ecological footprint calculation indicates that, for example, the Dutch need a land area 15 times larger than that of the Netherlands to support their population. The population of London requires a land area 125 times greater than its physical footprint. If everyone on Earth enjoyed a North American lifestyle, it would take up to five planet Earths (Figure 2.14), owing to the increasingly consumptive US lifestyle and the burgeoning world population, which exceeds 7 billion at the time of this writing. The ultimate

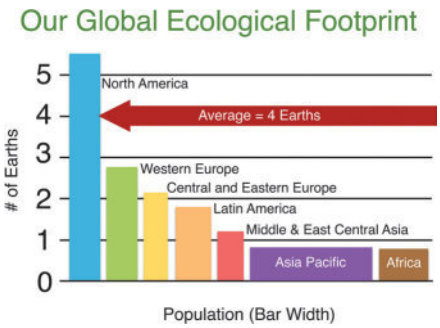


Figure 2.14 The ecological footprint often expressed as the number of planet Earth equivalents that would be needed to support the planet with various levels of consumption. If all 7.3 billion of Earth's people consumed at the same rate as the average American, it would take six planets to support them. There is only one planet Earth. Thus, it is likely that sometime in the 1980s, Earth's population and its consumption exceeded the planet's ability to support the average person. It is clear that planetary resources are being depleted at an unsustainable and accelerating rate. The graphic indicates that, except for the Asia Pacific and Africa, whose populations are living within the support limits of Earth, all other regions are consuming beyond the ability of planet to provide adequate resources. (Adapted from 8020vision.com)

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problem that must be solved, especially in the context of sustainable development, is how all people can have a decent quality of life without destroying the planetary systems that support life itself. A partial solution requires developed countries to reduce consumption dramatically and ensure that developing countries receive resources sufficient for more than mere survival. Such resource sharing lies at the heart of the original formulation of sustainable development, which values the goal of moving the developing world from mere survival to the ability to sustain a reasonably good quality of life. As William Rees noted in the preface to *Our Ecological Footprint*, "on a finite planet, at human carrying capacity, a society driven mainly by selfish individualism has all the potential for sustainability of a collection of angry scorpions in a bottle" (p. xi).

THE ECOLOGICAL RUCKSACK AND MATERIALS INTENSITY PER UNIT SERVICE

The term *ecological rucksack*, coined by Friedrich Schmidt-Bleek, formerly of the Wuppertal Institute in Wuppertal, Germany, attempts to quantify the mass of materials that must be moved in order to extract a specific resource. The concept of the ecological rucksack was developed to demonstrate that prosperity attributable to certain human activities has been achieved only by the destruction of natural resources through excavation, mining, channeling rivers and lakes, and processing gigatons (billions of tons) of materials to extract dilute resources. Schmidt-Bleek suggested that since these activities are responsible for significant environmental damage, extracted materials could be said to carry a "rucksack," or extraction burden. For example, the 10 grams of gold contained in a typical gold wedding band are extracted and concentrated from 300 tons (272 metric tons) of raw material.

The European Environment Agency defines *ecological rucksack* as the material input of a product or service minus the weight of the product itself.[16] The material input is defined as the life-cycle-wide total quantity (in pounds or kilograms) of natural material physically displaced in order to generate a particular product (see Table 2.2).[17] The environmental stress caused by an activity is proportional to the quantity of materials moved. The greater the mass moved, the higher is the environmental impact. The concept of ecological rucksack focuses on these large displacements of earth and rock rather than on minute quantities of toxic materials. It has been the large land transformations occasioned by increasing material demands, coupled with depleted deposits of rich materials, that have been historically neglected by environmentalists and policy makers.

Materials intensity per unit service (MIPS) is another concept originated by Schmidt-Bleek to assist in understanding the efficiency with which materials are used. MIPS measures how much service a given product delivers. The higher or greater the service, the lower is the MIPS value. MIPS is also an indicator of resource productivity, or eco-efficiency, and products with greater service are said to possess greater eco-efficiency and resource productivity.

TABLE 2.2

Ecological Rucksack* of Some Well-Known Materials

Material	Ecological Rucksack
Rubber	5
Aluminum	85
Recycled aluminum	4
Steel	21
Recycled steel	5
Platinum	350,000
Gold	540,000
Diamond	53,000,000

*The rucksack indicates how many units of mass must be moved to produce 1 unit mass of the material. For example, 1 kilogram [kg] (2.2 lb) of aluminum from bauxite requires displacing 85 kg (187 lb) of materials, compared to moving only 4 kg (9 lb) to produce 1 kg (2.2 lb.) of recycled aluminum.

THE BIOPHILIA HYPOTHESIS

E. O. Wilson, the eminent Harvard University entomologist, suggested that humans have a need and craving to be connected to nature and living things. He coined the term *biophilia hypothesis* to propose the concept that humans have an affinity for nature and that they "tend to focus on life and lifelike processes." The biophilia hypothesis asserts the existence of a fundamental genetically based human need and propensity to affiliate with life and lifelike processes. Various studies have shown that even minimal connection with nature, such as looking outdoors through a window, increases productivity and health in the workplace, promotes healing of patients in hospitals, and reduces the frequency of sickness

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in prisons. Prison inmates whose cells overlooked farmlands and forests needed fewer health-care services than inmates whose cells overlooked the prison yard (cited in Kahn, 1997).

In their book *The Biophilia Hypothesis*, Wilson and Stephen Kellert (1993), a professor in the School of Forestry and Environmental Studies at Yale University, collected invited papers to both support and refute this hypothesis. Kellert stated that for green buildings to eventually become truly successful, they must relate to natural processes and help humans achieve meaning and satisfaction. He suggested that there are nine values of biophilia, which offer a broad design template for sustainable building:

1. The utilitarian value emphasizes the material benefit that humans derive from exploiting nature to satisfy various needs and desires.
2. The naturalistic value emphasizes the many satisfactions people obtain from the direct experience of nature and wildlife.
3. The ecologistic-scientific value emphasizes the systematic study of the biophysical patterns, structures, and functions of nature.
4. The aesthetic value emphasizes a primarily emotional response of intense pleasure at the physical beauty of nature.
5. The symbolic value emphasizes the tendency for humans to use nature for communication and thought.
6. The humanistic value emphasizes the capacity for humans to care for and become intimate with animals.
7. The moralistic value emphasizes right and wrong conduct toward the nonhuman world.
8. The dominionistic value emphasizes the desire to subdue and control nature.
9. The negativistic value emphasizes feelings of aversion, fear, and dislike that humans have for nature. (p. 59)

Anecdotal evidence emerging about the effects of daylighting and views to the outside indicates that human health, productivity, and well-being are promoted by access to natural light and views of greenery. Hundreds of studies have demonstrated that stress reduction results from connecting humans to nature. Consequently, facilitating the ability of humans to interact with nature, even at a distance, from inside a building, is emerging as an issue for consideration in the creation of high-performance green buildings.

ECO-EFFICIENCY

Originated by the World Business Council for Sustainable Development (WBCSD) in 1992, the concept of *eco-efficiency* includes environmental impacts and costs as a factor in calculating business efficiency. The WBCSD considers the term *eco-efficiency* to describe the delivery of competitively priced goods and services that satisfy human needs and enhance the quality of life while progressively reducing ecological impacts and resource intensity throughout the products' life cycles to a level commensurate with Earth's estimated carrying capacity. The WBCSD (1996) has articulated seven elements of eco-efficiency (see Table 2.3).

Furthermore, the WBCSD identified four aspects of eco-efficiency that render it an indispensable strategic element in the contemporary knowledge-based economy:

1. Dematerialization: companies are developing ways of substituting knowledge flows for material flows.
2. Closing production loops: the biological designs of nature provide a role model for sustainability.

TABLE 2.3

Seven Elements of Eco-Efficiency as Defined by the WBCSD

1. Reducing the material requirements of goods and services
2. Reducing the energy intensity of goods and services
3. Reducing toxic dispersion
4. Enhancing materials recyclability
5. Maximizing sustainable use of renewable resources
6. Extending product durability
7. Increasing the service intensity of goods and services

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3. Service extension: the world is moving from a supply-driven economy to a demand-driven economy.
4. Functional extension: companies are manufacturing smarter products with new and enhanced functionality and are selling services to enhance the products' functional value.

The WBCSD suggested that business can achieve eco-efficiency gains through:

- Optimized processes: moving from costly end-of-pipe solutions to approaches that prevent pollution in the first place
- Waste recycling: using the by-products and wastes of one industry as raw materials and resources for another, thus creating zero waste
- Eco-innovation: manufacturing "smarter" by using new knowledge to make old products more resource-efficient to produce and use
- New services: for instance, leasing products rather than selling them, which changes companies' perceptions, spurring a shift to product durability and recycling
- Networks and virtual organizations: sharing resources to increase the effective use of physical assets

As a concept, eco-efficiency describes most of the foundational principles underpinning the concept of sustainable development. Its promotion by the WBCSD, essentially an association of major corporations, is a positive sign that the business community is beginning to take sustainability seriously.

THE NATURAL STEP

Developed by Swedish oncologist Karl-Henrik Robèrt in 1989, the *Natural Step* (www.naturalstep.org) provides a framework for considering the effects of materials selection on human health. Robèrt suggested that many human health problems, particularly those of children, result from materials we use in our daily lives. The extraction of resources such as fossil fuels and metal ores from the planet's crust produces carcinogens and results in heavy metals entering Earth's surface biosphere. The abundance of chemically produced synthetic substances that have no model in nature has similar deleterious effects on health. The Natural Step articulates the four systems conditions, or basic principles, that should be followed to eliminate the effects of materials practices on our health. The four systems conditions are listed next. (Their potential application to construction projects is described in greater detail in Chapter 11.)

1. In order for a society to be sustainable, nature's functions and diversity are not systematically subject to increasing concentrations of substances extracted from the Earth's crust.
2. In order for a society to be sustainable, nature's functions and diversity are not systematically subject to increasing concentrations of substances produced by society.
3. In order for a society to be sustainable, nature's functions and diversity are not systematically impoverished by overharvesting or other forms of ecosystem manipulation.
4. In a sustainable society, resources are used fairly and efficiently in order to meet basic human needs globally.

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LIFE-CYCLE ASSESSMENT

Life-cycle assessment (LCA) is a method for determining the environmental and resource impacts of a material, a product, or even a whole building over its entire life. All energy, water, and materials resources, as well as all emissions to air, water, and land, are tabulated over the entity's life cycle. The life cycle, or time period considered in this evaluation, can span the extraction of resources, the manufacturing process, the installation in a building, and the item's ultimate disposal. The assessment also considers the resources needed to transport components from extraction through disposal. LCA is an important, comprehensive approach that examines all impacts of material selection decisions, rather than simply an item's performance in the building. LCA and the tools used to produce an LCA are described in greater detail in Chapter 11.

LIFE-CYCLE COSTING

The ability to model a building's financial performance over its life cycle is necessary to justify measures that may require greater initial capital investment but yield significantly lower operational costs over time. Using *life-cycle costing* (LCC), a cost/benefit analysis is performed for each year of the building's probable life. The current worth of each year's net benefits is determined using an appropriate discount rate. Net benefits for each year are tabulated to calculate the total current worth of a particular feature. For example, the financial return for installation of a photovoltaic (PV) system would be determined by amortizing the system's costs over its probable life; the worth of the energy generated each year would then be calculated to determine the net annual benefit. Application of LCC may determine whether the payback for this system meets the owner's economic criteria. LCC analysis can also be combined with LCA results to weigh the combined financial and environmental impact of a particular system. LCC is covered in more detail in Chapter 14.

EMBODIED ENERGY

Embodied energy refers to the total energy consumed in the acquisition and processing of raw materials, including manufacturing, transportation, and final installation. Products with greater embodied energy usually have higher environmental impact due to the emissions and greenhouse gases associated with energy consumption. However, another calculation, which divides the embodied energy by the product's time in use, yields a truer indicator of the environmental impact. More durable products will have a lower embodied energy per time in use. For example, a product with high embodied energy, such as aluminum, could have a very low embodied energy per time in use because of the product's extremely high durability. In addition, certain products have relatively low embodied energy when recycled. Recycled aluminum has just 10 percent of the embodied energy of aluminum made from bauxite ore. Similarly, recycled steel has about 20 percent of the embodied energy of steel made from ores. A list of typical embodied energies for common construction materials is presented in Table 2.4.

FACTOR 4, FACTOR 5, AND FACTOR 10

The concepts of *Factor 4* and *Factor 10* provide a set of guidelines for comparing design options and for evaluating the performance of buildings and their component systems. The notion of Factor 4 was first suggested in the book *Factor Four: Doubling Wealth, Halving Resource Use*, written in 1997 by Ernst von Weizsäcker, Amory Lovins, and L. Hunter Lovins (see Figure 2.15).[18]

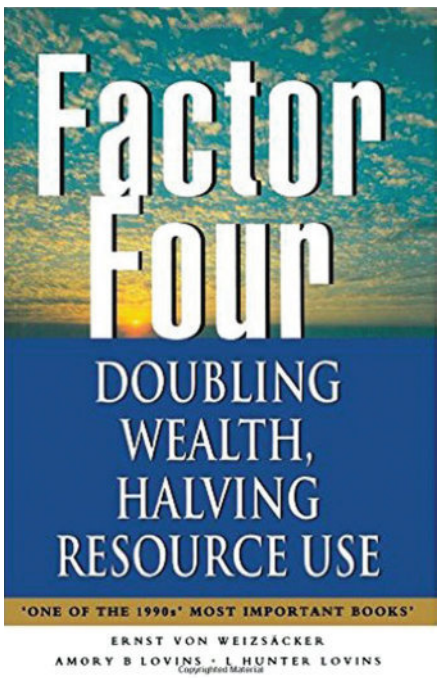


Figure 2.15 The Factor 4 concept originated in the book *Factor Four: Doubling Wealth, Halving Resource Use*, by Ernst von Weizsäcker, Amory Lovins, and L. Hunter Lovins.

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TABLE 2.4

Embodied Energy of Common Construction Materials

Material	Embodied Energy, BTU/lb	Embodied Energy MJ/kg	MJ/m^3
Aggregate	43	0.1	150
Concrete (30 MPa)	559	1.3	3,180
Lumber	1,075	2.5	1,380
Brick	1,075	2.5	5,170
Cellulose insulation	1,419	3.3	112
Mineral wool insulation	6,277	14.6	139
Fiberglass insulation	13,026	30.3	970
Polystyrene insulation	50,298	117.0	3,770
Gypsum wallboard	2,622	6.1	5,890
Particleboard	3,439	8.0	4,400
Plywood	4,471	10.4	5,720
Aluminum	97,587	227.0	515,700
Aluminum (recycled)	3,482	8.1	21,870
Steel	13,757	32.0	251,200
Steel (recycled)	3,826	8.9	37,210
Zinc	21,925	51.0	371,280
Copper	30,351	70.6	631,164
Polyvinyl chloride (PVC)	30,093	70.0	93,620
Linoleum	49,868	116.0	150,930
Carpet (synthetic)	63,625	148.0	84,900
Paint	40,110	93.3	117,500
Asphalt shingles	3,869	9.0	4,930

Source: Canadian Architect website, www.cdnarchitect.com
Note: MJ/kg = megajoules per kilogram of material
MJ/m^3 = megajoules per cubic meter of material

Factor 4 suggests that for humanity to live sustainably today, we must rapidly reduce resource consumption to one-quarter of its current levels. Fortunately, the technology to accomplish Factor 4 reductions in resource consumption already exists and requires only public policy prioritization and implementation. A parallel approach originated by Friedrich Schmidt-Bleek hypothesizes that, in order to achieve long-term sustainability, we must reduce resource consumption by a factor of 10 (see www.factor10-institute.org). An example of applying this principle to the built environment is provided by Lee Eng Lock, a Chinese engineer in Singapore. He has challenged many of the fundamental assumptions made by mechanical engineers in their systems design and layout. Rather than oversizing chillers, air handlers, pumps, and other equipment, he ensures that they are precisely the correct size for the job. This commonsense approach achieves the same cooling and comfort while using only 10 percent of the energy of conventional designs, thus accomplishing a Factor 10 reduction in energy.[19] The Factor 10 concept has had a significant effect internationally and is now being implemented by the European Union. The Factor 4 concept was revisited by Ernst von Weizsäcker and several Australian colleagues in 2009, and they concluded there was a potential Factor 5 of available efficiency improvements for entire sectors of the economy, without losing the quality of service or well-being.

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Major Environmental and Resource Concerns

Concerns about environmental degradation, resource shortages, and human health impacts are promoting widespread acceptance of green building, the ultimate goal of which is to mitigate the enormous pressures on planetary ecosystems caused by human activities. The major environmental issues to be addressed by sustainable construction methods are shown in Table 2.5. Some of these are covered in more detail in the sections that follow.

TABLE 2.5

Major Environmental Issues Connected to Built Environment Design and Construction

Climate change
Ozone depletion
Soil erosion
Desertification
Deforestation
Eutrophication
Acidification
Loss of biodiversity
Land, water, and air pollution
Dispersion of toxic substances
Depletion of fisheries

CLIMATE CHANGE

In addition to causing climate change, certain chemicals used in building construction and facility operations have been thinning the ozone layer, the protective sheath of the atmosphere consisting of three-molecule oxygen (O_3), which is located 10 to 25 miles (16–40 km) above Earth and serves to attenuate harmful ultraviolet radiation. In 1985, scientists discovered a vast hole the size of the continental United States in the ozone layer over Antarctica. By 1999], the size of the hole had doubled. Ozone depletion is caused by the interaction of halogens—chlorine- and bromine-containing gases, such as chlorofluorocarbons (CFCs) used in refrigeration and foam blowing and halons used for fire suppression. Table 2.6 provides a summary of the main contributors to the destruction of the ozone layer. In one of the few successful examples of international environmental cooperation, the UN Montreal Protocol of 1987 produced an international agreement to eventually halt the production of ozone-depleting chemicals. Assuming that the Montreal Protocol is faithfully adhered to by the international community, the ozone layer is projected to be fully restored by the year 2050.

DEFORESTATION, DESERTIFICATION, AND SOIL EROSION

Natural forests are estimated to contain half of the world's total biological diversity, possessing the greatest level of biodiversity of any type of ecosystem. Sadly, worldwide *deforestation* is occurring at a rapid rate, with 2 acres (0.8 hectare [ha]) of rainforest

TABLE 2.6

Gases Used for Typical Building Functions

Halogen Gas*	Lifetime (years)	Global Emissions (1,000s of metric tons/year)	Ozone Depletion Potential (ODP)‡
Chlorine			
CFC-12	100	130–160	1
CFC-113	85	10–25	1
CFC-11	45	70–110	1
HCFCs	1–26	340–370	0.02–0.12
Bromine			
Halon 1301	65	~3	12
Halon 1211	16	~10	6

Source: Excerpted from "Twenty Questions and Answers about the Ozone Layer" (2002) at www.esrl.noaa.gov/csd/assessments/ozone/2010/twentyquestions/

*The chlorine gases are used in refrigerants. The bromine gases in fire suppression systems.

†Lifetime refers to the duration of the gases in the atmosphere.

‡ODP is the ozone depletion impact of a gas. The ODP of CFC-11 is defined as 1. With an ODP of 12, halon 1301 depletes ozone at a rate 12 times greater than that of CFC-11.

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Figure 2.16 Deforestation, such as this clear-cut in northern Florida, destroys animal habitat, causes soil erosion, and affects biodiversity. Green building standards call for the use of wood products from sustainably managed forests. (Photograph courtesy of M. R. Moretti)

disappearing every second (see www.rainforest-alliance.org) and temperate zone forests losing about 10 million acres (4 million ha) per year. Although about one-third of the total land area is forested worldwide, about half of Earth's forests have disappeared. In the United States, only 1 to 2 percent of the original forest cover still remains. This pattern of large-scale forest removal, known as *deforestation*, is linked to negative environmental consequences such as biodiversity loss, global warming, soil erosion, and desertification (see Figure 2.16).

Deforestation defeats the capability of forests to "lock up," or sequester, the large quantities of CO_2 stored in tree mass; instead, it is released into the atmosphere as gaseous compounds, which contribute to accelerated climate change. Between 1850 and 1990, worldwide deforestation released 134 billion tons (122 billion mt) of carbon. Currently, deforestation releases about 1.8 billion tons (1.6 billion mt) of carbon per year, compared to the burning of fossil fuels, such as oil, coal, and gas, which releases about 6.6 billion tons (6 billion mt) per year. And because trees and their root systems are necessary to prevent soil erosion, landslides, and avalanches, their removal contributes to soil loss and changes the rate at which water enters the watershed. Forest-sustained freshwater supplies are an important source of oxygen, which fosters biodiversity, especially in rainforests. Additionally, large-scale deforestation affects the albedo, or reflectivity, of Earth, altering its surface temperature and energy, rate of surface water evaporation, and, ultimately, patterns and quantity of rainfall.

Deforestation also causes soil erosion, a key factor in land degradation. More than 2 billion tons (1.8 billion mt) of topsoil are lost annually due to human agricultural and forestry land development. More than 5 billion acres (2 billion ha) of land, an area equal to the United States and Mexico combined, is now considered degraded, according to the United Nations' *Global Environmental Outlook 2002 Report* (www.unep.org/geo/geo3). In arid and semiarid regions, degradation results in *desertification*, or the destruction of natural vegetative cover that prevents desert formation. The UN Convention to Combat Desertification (www.unccd.int), formed in 1996 and ratified by 179 countries, reports that over 250 million people are directly affected by desertification. Furthermore, drylands susceptible to desertification cover 40 percent of Earth's surface, putting at risk a further 1.1 billion people in more than 100 countries dependent on these lands for survival. China, with a rapidly growing population and economy, loses about 300,000 acres (121,000 ha) of land each year to drifting sand dunes (see Figure 2.17).

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Figure 2.17 Desertification in southern Niger is consuming not only land but also local villages. (Wikipedia Commons)

EUTROPHICATION AND ACIDIFICATION

Two environmental conditions that frequently threaten water supplies are eutrophication and acidification. *Eutrophication* refers to the overenrichment of water bodies with nutrients from agricultural and landscape fertilizer, urban runoff, sewage discharge, and eroded stream banks (see Figure 2.18). Nutrient oversupply fosters algae growth, or algae blooms, which block sunlight and cause underwater grasses to die. Decomposing algae further utilize dissolved oxygen necessary for the survival of aquatic species, such as fish and crabs. Eventually, decomposition in a completely oxygen-free, or *anoxic*, water body can release toxic hydrogen sulfide, poisoning organisms and making the lake or seabed lifeless. Eutrophication has led to the degradation of numerous waterways around the world. For example, in the Baltic Sea, huge algae blooms, now common after unusually warm summers, have decreased water visibility by 10 to 15 feet (3–4.6 meters [m]) in depth.



Figure 2.18 Agricultural runoff, urban runoff, leaking septic systems, sewage discharges, eroded streambeds, and similar sources can increase the flow of nutrients and organic substances into aquatic systems. The result is an overstimulation of algae growth, causing eutrophication that interferes with the recreational use of lakes and estuaries and adversely affects the health and diversity of indigenous fish and animal populations. (Photograph courtesy of M. R. Moretti)

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Acidification is the process whereby air pollution in the form of ammonia, sulfur dioxide, and nitrogen oxides, mainly released into the atmosphere by burning fossil fuels, is converted into acids. The resulting acid rain is well known for its damage to forests and lakes. Less obvious is the damage acid rain causes to freshwater and coastal ecosystems, soils, and even historical monuments. The acidity of polluted rain leaches minerals from soil, causing the release of heavy metals that harm microorganisms and affect the food chain. Many species of animals, fish, and other aquatic animal and plant life are sensitive to water acidity. As a result of European directives that forced the installation of desulfurization systems and discouraged the use of coal as a fossil fuel, Europe experienced a significant decrease in acid rain in the 1990s. Nonetheless, a 1999 survey of forests in Europe found that about 25 percent of all trees had been damaged, largely due to the effects of acidification.[20]

LOSS OF BIODIVERSITY

Biodiversity refers to the variety and variability of living organisms and the ecosystems in which they occur. The concept of biodiversity encompasses the number of different organisms, their relative frequencies, and their organization at many levels, ranging from complete ecosystems to the biochemical structures that form the molecular basis of heredity. Thus, biodiversity expresses the range of life on the planet, considering the relative abundances of ecosystems, species, and genes. Species biodiversity is the level of biodiversity most commonly discussed. An estimated 1.7 million species have been described out of a total estimated 5 to 100 million species. However, deforestation and climate change are causing such a rapid extinction of many species that some biologists are predicting the loss of 20 percent of existing species over the next 20 years.

Deforestation is particularly devastating, especially in rainforests, which comprise just 6 percent of the world's land but contain more than 500,000 of its species. Biodiversity preservation and protection is important to humanity since diverse ecosystems provide numerous services and resources, such as protection and formation of water and soil resources, nutrient storage and cycling, pollution breakdown and absorption, food, medicinal resources, wood products, aquatic habitat, and undoubtedly many undiscovered applications.[21] Once lost, species cannot be replaced by human technology, and potential sources of new foods, medicines, and other technologies may be forever forfeited.

Furthermore, destruction of ecosystems contributes to the emergence and spread of infectious diseases by interfering with natural control of disease vectors. For example, the fragmentation of North American forests has resulted in the elimination of the predators of the white-footed mouse, which is a major carrier of Lyme disease, now the leading vector-borne infectious illness in the United States. Finally, species extinction prevents discovery of potentially useful medicines, such as aspirin, morphine, vincristine, taxol, digitalis, and most antibiotics, all of which have been derived from natural models.[22]

TOXIC SUBSTANCES AND ENDOCRINE DISRUPTORS

One dangerous by-product of the human propensity to invent has been the creation of an enormous number of chemical compounds that have no analog in nature and often affect biological systems toxically. A *toxic substance* is a chemical that can cause death, disease, behavioral abnormalities, cancer, genetic mutations, physiological or reproductive malfunctions, or physical deformities in any organism or its offspring, or that can become poisonous after concentration in the food chain or in combination with any other substances.[23] Toxic substances can be carcinogenic or mutagenic, and they affect developmental, reproductive, neurological, or respiratory systems. Ignitable or corrosive substances are also classified as toxic. As an aside,

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toxins are biological poisons that are the by-products of living organisms. A toxin may be obtained naturally—that is, from secretions of various organisms—or it may be synthesized.

The rate of synthetically produced chemicals in the United States has increased from 1 million tons (0.9 million mt) per year in 1940 to over 850 million tons (765 million mt) per year in 2014, or 2.7 tons (2.4 mt) per capita. The chemical industry represents 25 percent of US gross domestic product (GDP) and 12 percent of exports. And in spite of the fact that, in 2014, approximately 91 million commercially available chemicals were listed with the Chemical Abstracts Service, the National Academy of Sciences stated that adequate information to assess public health hazards existed for only 2 percent of these chemicals. Each year, more than 6000 new chemical compounds are developed; however, industry is required to report the environmental release of only 320 specific substances. Over 3 billion pounds (1.4 billion kg) of toxic chemicals enter the environment each year, with official hazardous waste production amounting to 1400 trillion pounds (635 trillion kg) per year. Each year, US industry produces about 12 pounds (5.4 kg) of toxic waste per capita (www.ccaej.org). Since 1987, industries have been required to report the release of certain chemicals to the government through the Toxics Release Inventory, but the inventory does not cover all chemicals or all industries, and only the largest facilities are required to report. A report by Dutzik, Bouamann, and Purvis (2003) for the US Public Interest Research Group Education Fund found that the following amounts of chemicals were released into the atmosphere in the year 2000:

- Cancer-causing chemicals: 100 million pounds (45.4 million kg), with dichloromethane being the most frequent
- Chemicals, such as toluene, linked to developmental problems: 138 million pounds (63 million kg)
- Chemicals, such as carbon disulfide, related to reproductive disorders: 50 million pounds (23 million kg)
- Respiratory toxicants: 1.7 billion pounds (0.8 billion kg), most commonly acid aerosols of hydrochloric acid
- Dioxins: 15.4 pounds (7 kg)
- Persistent toxic substances: lead [275,000 pounds (125,000 kg)], lead compounds [1.3 million pounds (0.6 million kg), mercury [30,000 pounds (13,600 kg)], and mercury compounds [136,000 pounds (62,000 kg)]

During the past few decades, it has become apparent that many chemicals damage animal and human hormonal systems. *Endocrine-disrupting chemicals* (EDCs) interfere with the hormones produced by the endocrine system, a complex network of glands and hormones that regulates the development and function of bodily organs, physical growth, development, and maturation. Some commonly known EDCs are dioxin, polychlorinated biphenyls (PCBs), dichlorodiphenyltrichloroethane (DDT), and various pesticides and plasticizers. EDCs have been implicated in the occurrence of abnormally swollen thyroid glands in the eagles, terns, and gulls found in the fish-bird food chain of the Great Lakes. EDCs have contributed to the appearance of alligators with diminished reproductive organs and are blamed for the declining alligator populations in Lake Apopka, Florida. The most notorious example occurring in the human population was the use of diethylstilbestrol (DES), a synthetic estrogen prescribed until 1971 to prevent miscarriages in pregnant women. DES has since been linked to numerous health problems in offspring exposed to the drug in the womb, including reproductive complications and infertility in DES daughters.[24] Although a "better life through chemistry," the tagline of American industry of the 1950s, can still be claimed, the unexpectedly high price tag is still being tallied.

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DEPLETION OF METAL STOCKS

The depletion of key resources needed to support the energy and materials requirements of today's technological, developed world societies is a threat to the high quality of life enjoyed by North Americans, Europeans, Japanese, and members of other modern industrialized societies. The subject of oil depletion is covered in Chapter 1 of this book. Although oil production was thought to have reached its peak in about 2008, the advent of fracking technology for oil and gas extraction has temporarily increased production and lowered prices. The Earth is a finite object and increased consumption will likely result in an era of far higher prices for oil-based products, among them gasoline, diesel fuel, jet fuel, and oil-based polymers. A similar scenario is playing out with other key resources, most notably metals. A study by Gordon, Bertram, and Graedel (2006) of the supply and usage of copper, zinc, and other metals has determined that supplies of these resources—even if recycled—may fail to meet the needs of the global population. Even the full extraction of metals from Earth's crust and extensive recycling programs may not meet future demand if all countries try to attain the same standard of living enjoyed in developed nations. Gordon et al. based their study on metal still in the Earth, in use by people, and lost in landfills. Using copper stocks in North America as a starting point, they tracked the evolution of copper mining, use, and loss during the 20th century. They then applied their findings and additional data to an estimate of the global demand for copper and other metals if all nations were fully developed and used modern technologies. Their study found that all of the copper in ore, plus all of the copper currently in use, would be required to bring the world to the level of the developed nations for power transmission, construction, and other services and products that depend on copper. Globally, the researchers estimate that 26 percent of extractable copper in Earth's crust is now lost in nonrecycled wastes, while 19 percent of zinc is estimated to be lost. Interestingly, the researchers said that current prices do not reflect those losses because supplies are still large enough to meet the demand, and new methods have helped mines produce material more efficiently. Although copper and zinc are not at risk of depletion in the immediate future, the researchers believe that scarce metals, such as platinum, are at risk of depletion in this century because there is no suitable substitute for their use in devices such as catalytic converters and hydrogen fuel cells. And because the rate of use for metals continues to rise, even the more plentiful metals may face similar depletion risks in the not-too-distant future. The impact on metal prices due to a combination of demand and dwindling stocks has been dramatic. Between 2002 and 2012, copper rose 500 percent in price, and the prices of nickel, brass, and stainless steel rose by about 250 percent. In spite of the higher prices, the good news is that there is a renewed emphasis on recycling, using only the quantity of metals required, and ensuring that all in-plant scrap is recovered during manufacturing.[25]

The Green Building Movement

More than any other human endeavor, the built environment has direct, complex, and long-lasting impacts on the biosphere. In the United States, the production and manufacture of building components, along with the construction process itself, involves the extraction and movement of 6 billion tons (5.4 billion metric tons) of basic materials annually. The construction industry, representing about 8 percent of the US GDP, consumes 40 percent of extracted materials in the United States. Some estimates suggest that as much as 90 percent of all materials ever extracted reside in today's buildings and infrastructure. Construction waste is generated at a rate of about 0.5 ton (0.45 mt) per person each year in the United States, or about 5 to 10 pounds per square foot

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Figure 2.19 Annual construction and demolition waste in the United States is estimated to be about 160 million tons (145 million mt), or about 0.5 ton (0.45 mt) per capita. Buildings are not generally designed to be disassembled. As a result, only a small percentage of demolition materials can be recycled. The partial demolition of the Levin College of Law library at the University of Florida in Gainesville in mid-2004 illustrates the quantities of waste typically generated in renovation projects, on the order of 70 to 100 pounds per square foot (344–489 kg per m^2). (Photograph courtesy of M. R. Moretti)

(24–49 kg/m^2) of new construction. Waste from renovation occurs at a level of 70 to 100 pounds per square foot (344 –489 kg/m^2). The demolition process results in truly staggering quantities of waste, with little or no reuse or recycling occurring (see Figure 2.19). Of the approximately 145 million tons (132 million mt) of construction and demolition waste generated each year in the United States, about 92 percent is demolition waste, with the remainder being waste from construction activities. In addition to the enormous quantities of waste resulting from built environment activities, questionable urban planning and development practices also have far-reaching consequences. Since transportation consumes about 40 percent of primary energy consumption in the United States, the distribution of the built environment and the consequent need to rely on automobiles for movement between work, home, school, and shopping results in disproportionate energy consumption, air pollution, and the generation of CO_2, which contributes to global warming.

The green building movement is the response of the construction industry to the environmental and resource impacts of the built environment. As was noted in Chapter 1, the term *green building* refers to the quality and characteristics of the actual structure created using the principles and methodologies of sustainable construction. In the context of green buildings, *resource efficiency* means high levels of energy and water efficiency, appropriate use of land and landscaping, the use of environmentally friendly materials, and minimizing the life-cycle effects of the building's design and operation.

GREEN BUILDING ORGANIZATIONS—UNITED STATES

Key American organizations promoting the implementation of sustainable construction practices include the US Green Building Council, the Green Building Initiative, the US Department of Energy, the US Environmental Protection Agency, the National

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Figure 2.20 The late Ray Anderson, founder and former chairman of InterfaceFLOR, was considered one of the essential leaders of the US green building movement. His abiding belief that sustainability was an ethical imperative was supported by his strong actions to shift a major building products supplier from a business-as-usual mode to being the most sustainable company on Earth. (Photograph courtesy of Interface, Inc.; © Lynne Siller)

Association of Home Builders, the US Department of Defense, and other public agencies and nonprofit organizations. The private sector has been led by several manufacturers. Notably, the late Ray Anderson, founder and former chairman of InterfaceFLOR, guided the company's transition from a conventional carpet tile manufacturer to one with a corporate philosophy based on industrial ecology (see Figure 2.20). Anderson's efforts to move Interface toward sustainability prompted competition among other manufacturers, among them Milliken and Collins and Aikman, to produce "green" carpet tiles. In the commercial building arena, the prime green building organization is the USGBC, located in Washington, DC. A relatively new organization, the Green Building Initiative (GBI), which is headquartered in Portland, Oregon, acquired the rights to a Canadian building assessment standard known as Green Globes in 2004. The GBI has adapted Green Globes to the US building market and is offering it as an alternative to the USGBC LEED building rating systems.

Homebuilding and residential development are represented by a proliferation of organizations, many of which preceded the USGBC and arose independently in homebuilding organizations and municipalities across the United States. The city of Boulder, Colorado, took an aggressive stance in 1998 with respect to green building by passing an ordinance requiring specific measures. Pennsylvania established the Governor's Green Government Council in part to address the implementation of green building principles in the state. The city of Austin, Texas, is perhaps best known for its efforts in green building and was the recipient of an award at the first UN Conference on Sustainable Development in Rio de Janeiro, Brazil, in 1992. Local residential green building movements have emerged in Denver, Colorado; Kitsap County, Washington; Clark County, Washington; Baltimore, Maryland, with the suburban builders association; and, more recently, in Atlanta, Georgia, with the Earthcraft Houses program.

The National Association of Home Builders now provides guidance to its 800 state and local associations to assist in implementing green building programs. Reliable and independent information and critical analysis is published by BuildingGreen, Inc., in its monthly newsletter, *Environmental Building News.* BuildingGreen also publishes *GreenSpec*, a directory of products addressed to

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high-performance building needs, and provides the Green Building Advisor, computer software that facilitates green building design.

GREEN BUILDING ORGANIZATIONS—INTERNATIONAL

The international green building movement came of age in the early 1990s owing to the activities of task groups within the Conseil International du Bâtiment (CIB), a construction research networking organization based in Rotterdam, the Netherlands, and the International Union of Laboratories and Experts in Construction Materials, Systems, and Structures, based in Bagneux, France. In 1992, CIB Task Group 8 (Building Assessment) provided international impetus for the development and implementation of building assessment tools and standards. CIB Task Group 16 (Sustainable Construction) helped consolidate international standards regarding the application of sustainability principles to the built environment. And the relatively new International Initiative for a Sustainable Built Environment (iiSBE; www.iisbe.org) provides a clearinghouse for an extensive range of green building information. The iiSBE also organizes the biannual green building challenge and sustainable building conference and facilitates international sustainable building assessment with its main assessment method, the Sustainable Building Tool, which is used at biannual conferences to assess or rate entrant exemplary buildings worldwide.

HISTORY OF THE U.S. GREEN BUILDING MOVEMENT

The green building movement has a long history in the United States, with its philosophical roots traceable to the late nineteenth century. Subsequently, it developed in tandem with the country's environmental movement, and since the 1990s, it has been enjoying a renaissance. Notable dates include 1970, the year the first Earth Day was celebrated and the US Environmental Protection Agency was created, both events marking a major philosophical shift. Other influential events include the publication of Rachel Carson's landmark book *Silent Spring* in 1962 and the efforts of early environmentalists, such as Barry Commoner, Lester Brown, Denis Hayes, and Donella Meadows. Concern over resource availability, particularly reliance on fossil fuels, was magnified by the oil shocks of the early 1970s, which resulted from the Arab-Israeli conflict of the time. This further piqued public interest in energy efficiency, solar technologies, retrofitting homes and commercial buildings with insulation, and energy recovery systems. As a result, the federal government began to provide tax credits for investment in solar energy and funded development and testing of innovative technologies ranging from solar air conditioning to eutectic salt energy storage batteries. By the late 1970s, many new efficiency standards were embodied in the model energy codes adopted by the states. After this burst of activity, however, interest in energy conservation began to wane as energy prices began to decline.

The early 1990s saw a renewed interest in energy and resource conservation as humans began to seriously consider more complex global environmental issues, such as ozone depletion, global climate change, and destruction of major fisheries. Three events in the late 1980s and early 1990s helped to focus attention on problems associated with global environmental impacts: the publication in 1987 of *Our Common Future*; the 1989 meeting of the American Institute of Architects (AIA), at which it established its Committee on the Environment; and the UN Conference on Sustainable Development in 1992, commonly known as the Rio Conference.

The recent American resurgence in sustainable construction was precipitated in 1993 by a joint meeting of the International Union of Architects (Union Internationale des Architectes; UIA) and the AIA, known as "Architecture at the Crossroads." The UIA/AIA World Congress of Architects promulgated the Declaration of Interdependence for a Sustainable Future, which articulated a code of principles and practices to facilitate sustainable development (see Figure 2.21).

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DECLARATION OF INTERDEPENDENCE FOR A SUSTAINABLE FUTURE

UIA/AIA WORLD CONGRESS OF ARCHITECTS

CHICAGO, 18-21 JUNE 1993

RECOGNISING THAT:

A sustainable society restores, preserves, and enhances nature and culture for the benefit of life, present and future; ■ a diverse and healthy environment is intrinsically valuable and essential to a healthy society; ■ today's society is seriously degrading the environment and is not sustainable.

We are ecologically interdependent with the whole natural environment; ■ we are socially, culturally and economically interdependent with all of humanity; ■ sustainability, in the context of this interdependence, requires partnership, equity, and balance among all parties.

Building and the built environment play a major role in the human impact on the natural environment and on the quality of life; ■ a sustainable design integrates consideration of resources and energy efficiency, healthy buildings and materials, ecologically and socially sensitive land-use, and an aesthetic sensitivity that inspires, affirms, and ennobles; ■ a sustainable design can significantly reduce adverse human impacts on the natural environment while simultaneously improving quality of life and economic well-being.

WE COMMIT OURSELVES,

As members of the world's architectural and building-design professions, individually and through our professional organizations, to:

- place environmental and social sustainability at the core or our practices and professional responsibilities;
- develop and continually improve practices, procedures, products, curricula, services and standards that will enable the implementation of sustainable design;
- educate our fellow professionals, the building industry, clients, students and the general public about the critical importance and substantial opportunities of sustainable design;
- establish policies, regulations and practices in government and business that ensure sustainable design becomes normal practice; and
- bring all the existing and future elements of the built environment – in their design, production, use, and eventual reuse – up to sustainable design standards.

Olfemi Majekodunmi
President,
International Union of Architects

Susan A. Maxman
President,
American Institute of Architects

Figure 2.21 The joint Declaration of Interdependence for a Sustainable Future, promulgated by the UIA/AIA World Congress of Architects during a joint meeting in Chicago, Illinois, in 1993, was an important event in the history of the high-performance green building movement. (*Source:* International Union of Architects and American Institute of Architects)

Although many energy-efficient buildings emerged after the oil crises of the 1970s, the first US buildings that considered a wider range of environmental and resource issues did not emerge until the 1980s. The earliest examples of green buildings were the result of major US environmental organizations requiring holistic approaches to the design of their office buildings. In 1985, William McDonough was hired by the Environmental Defense Fund to design its New York offices. The design featured natural materials, daylighting, and excellent indoor air quality, all part of a green solution for then endemic sick building problems. In 1989, the Croxton Collaborative, a design firm founded by Randy Croxton, designed the offices of the Natural Resources Defense Council in the Flatiron District of New York City. In this project, natural lighting and energy-conserving technologies were employed to reduce energy consumption by two-thirds compared to conventional buildings. The 1992 renovation of Audubon House, also in New York City, was a significant early effort in the contemporary green building movement (see Figure 2.22). The organization sought to reflect its values as a leader of the environmental movement and directed architect Randy Croxton to design the building in the most environmentally

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friendly and energy-efficient manner possible. In the process of achieving that goal, the extensive collaboration required by the many building team members provided a model of cooperation that has now become a hallmark of the contemporary green building process in the United States.[26]

The first highly publicized green building project in the United States, the "Greening of the White House," was initiated in 1993 and included renovation of the Old Executive Office Building, a 600,000-square-foot (55,700-m^2) structure across from the White House (see Figure 2.23). The participation in this project of a wide array of architects, engineers, government officials, and environmentalists drew national attention and resulted in dramatic energy cost savings (about $300,000 per year), emissions reductions [845 tons (767 mt) of carbon per year], and significant reductions in water and solid waste associated costs. The success of the White House project spurred the federal government's sustainability efforts and prompted the US Postal Service, the Pentagon, the US Department of Energy, and the General Services Administration to address sustainability concerns within their organizations. The US National Park Service also opened green facilities at several national parks, including the Grand Canyon, Yellowstone, and Denali. The Naval Facilities Engineering Command, the US Navy's construction arm, began a series of eight pilot projects to address sustainability and energy conservation concerns. The highly visible effort at its 156,000-square-foot (14,500-m^2), 150-year-old headquarters in the Washington Navy Yard reduced energy consumption by 35 percent and resulted in annual savings of $58,000.[27]

In addition, several important guides to green building or sustainable design appeared in the early to mid-1990s. The *Environmental Building News*, first published in 1992, remains an independent, dispassionate, and authoritative guide to sustainable construction.[28] In 1994, the AIA first published its *Environmental Resource Guide*, a thorough guide to the environmental and resource implications of construction materials; a more detailed version, edited by Joseph Demkin, followed in 1996. The "Guiding Principles of Sustainable Design," produced by the National Park Service in 1994, provided one of the first overviews of green building production.[29]



Figure 2.22 (A) Audubon House in New York City was designed by the Croxton Collaborative as the headquarters of the Audubon Society. It is one of the projects marking the start of the contemporary US green building movement. (B) Desk illumination from a skylight in Audubon House. (Photographs courtesy of Croxton Collaborative Architects, P.C.)



Figure 2.23 The "Greening of the White House" project was the first widely publicized federal government green building project. (Illustration courtesy of View by View, Inc.)

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Similarly, the *Sustainable Building Technical Manual* was developed and published jointly by the US Department of Energy and Public Technology, Inc., in 1996.[30] The Rocky Mountain Institute's *Primer on Sustainable Building*, published in 1995, also contributed to the public understanding of sustainable construction.

Other international efforts and organizations interacted with and influenced the US movement during this period. The British green building rating system, the Building Research Establishment Environmental Assessment Method (BREEAM), was developed in 1992. As noted previously, the CIB convened Task Groups 8 and 16 in 1992, which held influential international conferences in 1994 in the United Kingdom and Tampa, Florida. Also, as noted earlier, the USGBC was formed in 1993 and held its first major meeting in March 1994.[31] Early articulations of the organization's LEED standard appeared at this time, along with green building standards developed by the American Society for Testing and Materials (ASTM). The ASTM standards were eventually set aside in favor of the USGBC's LEED assessment standard.

Development of the USGBC's LEED building rating system took four years and culminated in a 1998 test version known as LEED 1.0. It was enormously successful, and the Federal Energy Management Program sponsored a pilot effort to test its assumptions. Eighteen projects comprising more than 1 million square feet (93,000 m^2) were evaluated in the beta-testing phase. A greatly improved LEED 2.0 was launched in 2000 and provided for a maximum of 69 credits and four levels of building certification: platinum, gold, silver, and bronze. A further refined LEED was published in 2003 and labeled LEED for New Construction version 2.1 (LEED-NC 2.1). The name of the lowest level of certification, "bronze," was also changed to "certified." In 2005, further improvements, such as moving the rating system online, occurred, resulting in the issuance of LEED-NC 2.2. Major revisions to LEED occurred in 2009 (LEED v3) and 2013 (LEED v4), including reweighting credits and restructuring the rating system. The LEED rating system is covered in far more detail in Chapter 5.

New approaches, including the GBI's Green Globes for New Construction and Green Globes for Existing Buildings, as well as the International Code Council (ICC) 700 National Green Building Standard™, are reinforcing the enormous growth in green building by providing a variety of approaches to rating green buildings and creating competition to improve green building rating systems.

The first green building standards, as distinguished from green building rating systems such as LEED, began to emerge in 2010. The American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) issued ASHRAE 189.1-2009, *Standard for the Design of High-Performance Green Buildings Except Low-Rise Residential Buildings*. A more recent version of this standard is ASHRAE 189.1-2014. If adopted by a code body—for example, the Standard Building Code—it would be code- enforceable, effectively making green buildings standard practice.[32] Another similar standard was issued by the American National Standards Institute (ANSI) and the GBI in the form of ANSI/GBI 01-2010, *Green Building Assessment Protocol for Commercial Buildings*, which was derived from the Green Globes environmental design and assessment rating system for new construction.[33] The most recent version of this standard is ANSI-GB 01-2016.

The International Green Construction Code (IgCC) was also issued in 2010 and revised 2012. According to the International Code Council, the IgCC addresses site development and land use, including the preservation of natural and material resources, as part of the process. The code is designed to improve indoor air quality and support the use of energy-efficient appliances, renewable energy systems, water resource conservation, rainwater collection and distribution systems, and the recovery of used water, or graywater. The IgCC emphasizes building performance, including features such as a requirement for building system performance verification along with building owner education, to ensure the best energy-efficient practices are being carried out. The IgCC references ASHRAE 189.1 as an alternative jurisdictional

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compliance option within the IgCC. Governments across the United States and around the globe can adopt the code immediately to reduce energy usage and their jurisdiction's carbon footprint.

NEW DIRECTIONS IN HIGH-PERFORMANCE GREEN BUILDING

Perhaps the most interesting recent development in high-performance buildings in the United States is the emergence of two movements with the same basic approach, that is, they both call for a dramatic transformation of the requirements for green buildings. The first of these movements is the Living Building Challenge (LBC), which originated in the Cascadia Green Building Council, originally founded to represent the US Green Building Council in the northwestern United States and Vancouver, Canada. The LBC is exactly what its name implies, a challenging set of 20 prerequisites that a building project must attain in order to achieve certification from the International Living Future Institute as a green building. Unlike other green building rating systems, such as LEED, which bases a building rating on a point system, there are only mandatory requirements. Again, unlike LEED, which has several levels of certification ranging from certified to platinum, the LBC provides either certification or renewal certification. Among the mandatory requirements are that the building must be net-zero energy (NZE), net zero water, and nontoxic; provide for habitat restoration on sister sites; and incorporate urban agriculture. The 20 LBC imperatives, all of which must be addressed, go well beyond the efficiency standards that generally are used to declare a project "sustainable." The first two projects to achieve full LBC certification in late 2010 were the Omega Center for Sustainable Living in Rhinebeck, New York, and the Tyson Living Learning Center in Eureka, Missouri (see Figures 2.24 and 2.25). The latter project provides a good example of the choices that often must be made to meet the LBC mandates. Although it achieved NZE performance by the end of its first year in operation, producing almost 3,800 kilowatts (kWh) of electricity more than it needed, the Tyson Living Learning Center needed some adjustments to achieve the NZE level because the building was using more electricity than calculated. When commissioning had been completed and the dynamic behavior of the building indicated it would not achieve NZE performance, the team had the choice of adding more PV panels to the building or finding another solution. Choosing the latter route, the project team added insulation in several areas; retrofitted storm windows; and adjusted the heating, ventilation, and air conditioning (HVAC) system to improve the energy performance of the building. Approximately 82 other projects were pursuing LBC certification in early 2016. The Living Building Challenge is covered in more detail in Chapter 4.



Figure 2.24 The Omega Center for Sustainable Living in Rhinebeck, New York, was one of the first projects to achieve the Living Building Challenge certification in late 2010. (© Omega Institute for Holistic Studies)

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Figure 2.25 The Tyson Living Learning Center in Eureka, Missouri. Miscalculations initially resulted in this building falling short of energy performance goals. Due to the ambitious sustainability requirements of the Living Building Challenge, postconstruction adjustments were made by adding insulation in several areas, retrofitting storm windows, and adjusting the HVAC system. These improvements led to the project achieving the desired NZE performance by the end of its first year in operation. (*Source:* David Kilper, WUSTL)

Similarly, *Architecture 2030* was established by architect Edward Mazria in 2002 in response to the global climate change crisis. The mission of this organization is to rapidly transform the built environment in order to achieve enormous reductions in greenhouse gas emissions by changing the way buildings are planned, designed, and constructed. Specifically, the Architecture 2030 Challenge calls for rapid reductions in building energy consumption and associated greenhouse gas emissions such that, by the year 2030, all new buildings would be carbon neutral. Several local jurisdictions in the United States have adopted the targets set by Architecture 2030. In July 2006, Sarasota County, Florida, was the first county to formally adopt the Architecture 2030 Challenge as policy. In February 2007, two bills were introduced in the California legislature that duplicate the Architecture 2030 Challenge targets for energy consumption reductions for new residential and nonresidential buildings.

Case Study: OWP 11, Stuttgart, Germany

The Drees & Sommer (DS) Group is a top international engineering firm headquartered in Stuttgart, Germany, with 32 offices and 1,125 employees worldwide. For 40 years, DS has provided a wide range of services in project management, real estate consulting, and engineering for public- and private-sector owners and investors in all aspects of real estate. DS refers to its approach to business as the "blue way" because it combines the traditional services provided by full-service engineering companies, such as economy, functionality, and process quality, with considerations of ecology, architecture, and human comfort. By virtue of this approach, DS demonstrates a philosophy of ensuring client success by thinking and acting in an integrated and sustainable manner. This comprehensive approach is apparent in the design of its own office building, commonly referred to as OWP 11, in Stuttgart and which, for its exemplary design and performance, was awarded a gold certification by the German Sustainable Building Council (Deutsche Gesellschaft für Nachhaltiges Bauen; DGNB) for meeting the criteria of the DGNB building assessment system (see Chapter 4 for more about DGNB).

OWP 11 consists of the renovation and expansion of an existing building located on an awkwardly shaped site. The hallmark of the building's exterior is a metal façade that faces north onto Pascalstrasse, underscoring the high-tech nature of much of the company's business (see Figure 2.26). The foyer is the essential interior element and functions without dominating the ensemble of two buildings that it links (see Figure 2.27). The shared courtyard and grounds are integrated as a key element of the overall architectural design. The management of DS paid special

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Figure 2.26 The signature exterior of OWP 11 in Stuttgart, Germany, is its metal façade, which is the outer layer of a well-insulated wall system that reduces internal heating and cooling loads to very low levels. (*Source:* © Dietmar Straub, Besigheim, Germany, and © Martin Duckek, Ulm, Germany)

attention to the interaction of its workforce in the new facility. To ensure unexpected, chance meetings of colleagues to stimulate the generation of new ideas, the building was laid out to maximize the potential of these interactions. In addition, management was aware that employee self-esteem has a lot to do with where their offices are located within the building. Those who are located close to pedestrian traffic areas feel they are closer to the action and therefore important. The pedestrian traffic and the movement of workers throughout the building act as a sort of "brain wave," which enhances communication and interaction, increasing opportunities for innovation and new ideas. As a result, the building design maximizes placement of offices along the pedestrian corridors while at the same time providing the opportunity for workers to function in quiet areas at the appropriate time (see Figure 2.28).



Figure 2.27 The interior foyer of the building links the new and old wings and provides a spectacular entryway and circulation corridor for OWP 11. (*Source:* © Dietmar Straub, Besigheim, Germany, and © Martin Duckek, Ulm, Germany)



Figure 2.28 The work spaces of OWP 11 balance the desire to be at the center of the action with the need for quiet spaces for productive work. Note that there is no general lighting in the space; all lighting needs are provided by a floor-mounted indirect lighting system. (*Source:* © Dietmar Straub, Besigheim, Germany, and © Martin Duckek, Ulm, Germany)

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Figure 2.29 (A) The edge strip heating elements placed in the formwork. (B) Technical installation in the reinforced concrete floor prior to pouring. (C) Heating, cooling, and ventilation pipes are integrated into the reinforcement. (*Source:* © Dietmar Straub, Besigheim, Germany, and © Martin Duckek, Ulm, Germany)

Step 1 in saving energy was to minimize heating and cooling loads. This required optimal thermal insulation of the building and demand-driven external solar protection in the form of a combination of computer-controlled exterior blinds and manually controlled interior blinds. The building is heavily insulated, with a 6- to 11-inch (16- to 27-cm) layer of mineral fiber insulation in the walls. The aluminum-framed windows have triple-glazed, low-emissivity glazing. The U-value—that is, the thermal conductance of the window frames—is particularly low, some 20 percent lower than commercially available frames. During warmer seasons, operable windows under the control of the office workers are used for ventilating the work spaces. During the heating season, fresh air is pumped into the building by a mechanical ventilation system with heat recovery.

Step 2 in energy savings was heating and cooling the building with the minimum possible temperature difference between the required room temperature and the heating and cooling elements. In OWP 11, as a result of the optimum thermal insulation, heating and cooling loads are so low that energy-efficient, low-temperature heating (under 90°F [32°C]) and high-temperature cooling (64°F [18°C]) could be used (see Figure 2.29). Because this strategy requires large heat transfer surfaces, normal radiators could not be used. Instead, structural heating and cooling was installed in the office areas in the form of pipes that carry warm or cool water, depending on the season, through the reinforced concrete floors. The floors provide extremely effective and economical heating in winter and cooling in summer. The only downside of this arrangement is the thermal inertia of the system; because of the high thermal storage capacity of the structure, room temperature cannot be changed quickly. The DS engineers, in collaboration with their Zent-Frenger consultants, found the solution to this potential problem by using a supplemental system that responds rapidly to changing conditions. The structural heating and cooling within the reinforced concrete ceilings covers the base loads and is supplemented by additional heating elements with a fast response time that allows individual room temperature regulation. The fast-response system is composed of a 1.6 inch (4-centimeter) thick, prefabricated slab with a special, highly conductive concrete mix design with thermal insulation on top. These fast-response heating elements have a separate water supply network and are laid parallel to the façade. A simple control allows users to regulate their room temperature for responsive individualized heating or cooling.

Step 3 was to use alternative energy sources made possible by the low temperature differences required for heating and cooling, as described in step 2. Geothermal energy is tapped from rock underneath the building using ground-coupled heat exchangers. Eighteen holes, 8 inches (20 cm) in diameter, were drilled at least 19 feet (6 m) apart to a depth of 170 feet (55 m). At this depth, the ground temperature year-round is 52° to 54°F (11°–12°C). Plastic pipes were then inserted into the bore holes and a mixture of water and glycol circulated through the system. During the heating season, the glycol- water solution is first heated 6° to 9°F (3°–5°C) by the heat recovery system and then boosted by an electrically powered heat pump to about 90°F (32°C). The heating load requires primary energy of approximately 21 kWh per square meter per year (kWh/m^2/yr); a conventional office building in Germany would require 130 kWh/m^2/yr, more than six times as much. During the summer, the glycol-water solution, after passing through the ground-coupled heat exchangers, is pumped at a temperature of approximately 54 to 59°F (12°–15°C) and raised to a temperature of about 64°F (18°C) by a heat exchanger. The only electrical energy required for this cooling process is for pumping the heat exchange fluid and the cold water in the building cooling circuit. The entire building can be cooled at a cost of between 1.50 and 2.00 euros per day on an extremely hot summer day. The overall primary energy requirement for climate control—that is, for HVAC—is about 36 kWh/m^2/yr, less than a fifth the energy demand of a conventional office building with oil heating and compressor-driven cooling.

German buildings are required to display an "energy passport" in a public location that indicates the facility's primary energy consumption (see Figure 2.30). The passport for OWP 11 tells an interesting story: The building uses just 76.9 kWh/ m^2/yr

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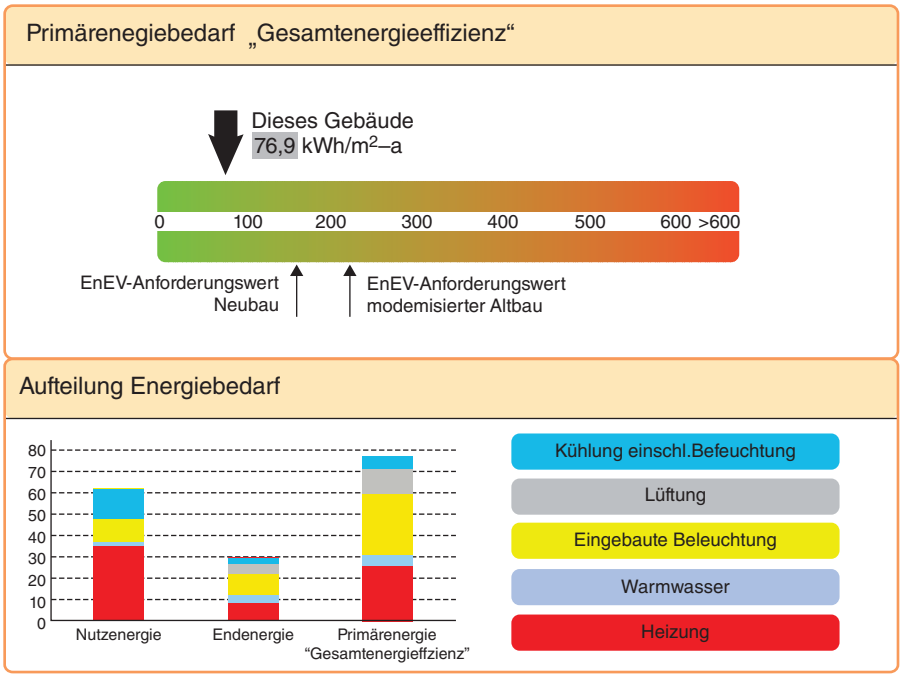


Figure 2.30 The *Energieausweis*, or energy passport, for OWP 11 indicates a primary energy consumption of 76.9 kWh/m^2/yr, which is far lower than the German energy code for new construction limit of about 160 kWh/m^2/yr. (*Source:* © Dietmar Straub, Besigheim, Germany, and © Martin Duckek, Ulm, Germany)

of primary energy. In comparison, the best US buildings consume about 100 kWh/m^2/yr of site or metered energy. *Primary energy* is the energy consumed at the power plant to produce the metered energy. For an all-electric building, primary energy is about three times the metered energy. As a result, 100 kWh/m^2/yr energy of metered energy is over 300 kWh/m^2/yr of primary energy. Therefore, OWP11 and other similar German buildings consume a small fraction of the energy consumed by the best US buildings.

Summary and Conclusions

Significant global environmental problems increasingly threaten food supplies, water and air quality, and the survival of ecosystems upon which humanity depends for a wide variety of goods and services. Because it uses enormous quantities of resources and replaces natural systems with human artifacts, the built environment sector of the economy has disproportionate environmental impacts on the planet. Consequently, the construction industry has a special obligation to behave proactively and shift rapidly from wasteful, harmful practices to a paradigm under which construction and nature work synergistically rather than antagonistically. This new model of sustainable construction is referred to as high-performance green building.

The green building movement is a relatively recent phenomenon, and in the United States, it is growing at an exponential rate. The USGBC's LEED building assessment standard has emerged as the definitive guideline. It articulates the parameters for green buildings in the United States and several other countries. Parallel efforts in other economic sectors are occurring simultaneously as manufacturers attempt to design and produce goods with low environmental impact. The concepts of closed materials loops, efficient resource use, and the redesign of products and buildings to emulate natural systems are indispensable to preserve humanity's quality of life, along with the constant acknowledgment that nature is the source of that quality.

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Notes

1. The Scripps Observatory has a website describing the Keeling Curve, the plot of CO_2 concentrations over time named in honor of the Keeling family, which initiated the recording of CO_2 concentrations on Mauna Loa in 1954. The Keeling Curve over various eras can be found at https://scripps.ucsd.edu/programs/keelingcurve/.
2. NASA provides climate change information on the NASA Vital Signs—Climate Change website at http://climate.nasa.gov/400ppmquotes/. The quote from Dr. Carmen Boening is from this website.
3. Construction industry is defined as the companies and individuals who plan, design, build, and decommission the built environment. It includes architects, landscape architects, interior designers, engineers, urban planners, construction managers, subcontractors, general contractors, and demolition contractors.
4. The five prior extinctions were the Ordovician (440 million years ago), Devonian (365 million years ago), Permian (245 million years ago), Triassic (210 million years ago), and Cretaceous (66 million years ago). The as-yet unnamed sixth extinction is not being caused by major geologic upheavals, as was the case for the previous five, but instead by the activities of just one of the millions of species inhabiting the planet: humans.
5. There are 17 rare earth elements, and 97 percent of global production is in China, giving China a stranglehold over the world's high-tech industries. See IBT (2011).
6. Xerox's activities to redesign its product line and incorporate sustainability into the company's philosophy are described by Maslennikova and Foley (2000).
7. For a far more detailed discussion of the ethics underpinning sustainability, see Kibert et al. (2011).
8. The notion of "remote generations" is from the Stanford Encyclopedia of Philosophy (2003 and 2008).
9. A description of the National Science Foundation's Biocomplexity in the Environment Priority Area can be found at www.nsf.gov/news/priority_areas/biocomplexity/index.jsp.
10. In Frosch and Gallopoulos (1989), the term industrial ecology was used for the first time in the popular scientific press. This marked the beginning of the widespread use of this phrase to describe a wide variety of environmentally responsible approaches to industrial production.
11. Robert Ayres has written extensively on the subject of industrial materials flows. More detailed information on the problem of enormous waste can be found in Ayres (1989).
12. An excellent summary of industrial ecology in general and the Kalundborg plant specifically can be found at the website of Indigo Development, www.indigodev.com. Several excellent references and handbooks are also available from the website. Indigo Development, founded by Ernie Lowe, is devoted to furthering the development of industrial ecology, which he refers to as "an interdisciplinary framework for designing and operating industrial systems as living systems that are interdependent with natural systems."
13. Construction ecology is defined in the context of industrial ecology and sustainable construction in Kibert, Sendzimir, and Guy (2002).
14. In addition to Janine Benyus's book on biomimicry, a useful website providing an overview of this concept is www.biomimicry.net.
15. An excellent short overview of ecological economics by Stephen Farber of the Graduate School of Public and International Affairs, University of Pittsburgh, can be found at www.fs.fed.us/eco/s21pre.htm.
16. The European Environment Agency has an excellent online glossary of environmental terms at http://glossary.eea.europa.eu/.
17. The ecological rucksack quantities are derived from a number of online and published sources. A good description of the concept, along with a diagram showing relative ecological rucksacks for a variety of materials, can be found in von Weizsäcker, Lovins, and Lovins (1997).
18. The book Factor Four: Doubling Wealth, Halving Resource Use was written as a report to the Club of Rome as a follow-up to the 1972 book The Limits to Growth, written by Donella Meadows, Dennis Meadows, Jorgen Randers, and William Behrens III, which was the original report to the club. Limits to Growth stated that exponential growth in population and the world's industrial system would force growth on the planet to be halted within a century, a result of environmental impacts and resource shortages.

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19. According to the authors of Factor Four, Lee Eng Lock's supply fans use 0.061 kW/ton of cooling versus 0.60 kW/ton in conventional practice. Similarly, his chilled-water pumps use 0.018 kW/ton versus 0.16 kW/ton for conventional water pumps, his condenser water pumps use 0.018 kW/ ton versus 0.14 kW/ton, and his cooling towers use 0.012 kW/ton versus 0.10 kW/ton.
20. A group of Swedish nongovernmental organizations maintains a website promoting knowledge about the effects of acid rain, www.acidrain.org.
21. See "Global Environmental Problems: Implications for U.S. Policy" (2003). Available at https://tforsgren.ipage.com/gyi/Lesson%20File/2Environment/environment.pdf
22. Excerpted from "The Loss of Biodiversity and Its Negative Effects on Human Health" (2004), from the website of Students for Environmental Awareness in Medicine, Seamglobal.com/lossofbiodiversity.html.
23. The definition of toxic substances is adapted from the definition provided on the Great Lakes website of Environment Canada, www.on.ec.gc.ca/water/raps.
24. Information on endocrine disruptors can be found on the website of the National Resources Defense Council (NRDC), www.nrdc.org/health/effects/qendoc.asp.
25. From "Materials Prices Dictate Creative Engineering" (2006).
26. The story of the Audubon House design process is recounted in Croxton Collaborative and the National Audubon Society (1992).
27. An excellent detailed overview of the history of the US green building movement can be found in the "White Paper on Sustainability" (2003). This publication also contains other important background information about the green building movement and suggests an action plan to help improve and ensure the quality and outcomes of green building design and construction. Available at http://archive.epa.gov/greenbuilding/web/pdf/bdcwhitepaperr2.pdf.
28. BuildingGreen, Inc., publishes Environmental Building News and produces a range of other useful products, including the GreenSpec directory. All of its publications are also available by subscription at www.buildinggreen.com.
29. The current National Park Service Sustainable Building Implementation Plan is available at www.nps.gov/sustainability/sustainable/implementation.html.
30. The "Sustainable Building Technical Manual" is available at http://smartcommunities.ncat.org/pdf/sbt.pdf.
31. The USGBC's earliest organizers were David Gottfried and Michael Italiano, and its first president was Rick Fedrizzi, who, at the time, was with Carrier Corporation. The keynote speakers at the first annual meeting were Paul Hawken, who had just completed the groundbreaking book Ecology of Commerce, and William McDonough, one of the major architectural figures in the US green building movement and the author of the Hannover Principles.
32. As described by ASHRAE, ASHRAE 189.1-2009 provides a "total building sustainability package" for those who strive to design, build, and operate green buildings. From site location to energy use to recycling, this standard sets the foundation for green buildings by addressing site sustainability; water use efficiency; energy efficiency; indoor environmental quality; and the building's impact on the atmosphere, materials, and resources. ASHRAE 189.1-2009 serves as a jurisdictional compliance option to the Public Version 2.0 of the International Green Construction Code published by the International Code Council. The IgCC regulates construction of new and remodeled commercial buildings.
33. According to the GBI, the ANSI/GBI 01-2010 standard was developed following ANSI's highly regarded consensus-based guidelines, which are among the world's most respected for the development of consensus standards and ensure a balanced, transparent, and inclusive process. A variety of stakeholders, including sustainability experts, architects, engineers, environmental nongovernment organizations (ENGOs), and industry groups, participated in its development. The current version of this standard is ANSI/GBI 01-2010.

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Chapter 3

Ecological Design

In their landmark book, *Ecological Design* (1996), Sim Van der Ryn and Stuart Cowan defined *ecological design* as "any form of design that minimizes environmentally destructive impacts by integrating itself with living processes" (p. 18). Although a design rooted in ecology and nature should be integral to creating a green building, ecological design is in the early stages of evolution, and it will take considerable time and experimentation before a robust version matures. Meanwhile, designers often must use their best judgment when making decisions from among the myriad choices available. The ability to minimize the direct impact of the project on the site due to the construction footprint and construction operations and landscape modifications, such as tree removal and alteration of natural habitats, requires a fairly high level of understanding of the available options, especially in the context of sustainability. Developing a low-energy scheme demands a significant level of knowledge and experience with maximizing the project's potential for passive heating, cooling, lighting, and ventilating; with understanding the best orientation and massing for storing and releasing energy on a time scale compatible with building operation; and with understanding the myriad energy tradeoffs that must be considered—for example, between daylighting and solar heat gain. When considering material and product selection, the best choices can be far from obvious. In addition to the environmental implications, performance and cost criteria must be addressed in the selection process. These are just a few of the many decisions a project team must make that are far better informed when the team has knowledge of, and experience with, ecological design as applied to high-performance green buildings.

One of the outcomes of the high-performance green building movement has been the advent of green building rating systems, such as Leadership in Energy and Environmental Design (LEED) and Green Globes in the United States and the Building Research Establishment Environmental Assessment Method (BREEAM) in the United Kingdom. These rating systems allow a project team simply to use a checklist of measures derived from one of the building rating systems that, if followed, produces a green building, at least in the eyes of the rating system proponent, without the need for a deeper understanding of ecological design being required. The proposed outcome is that the project team, without ever having studied or pondered the diverse and complex issues of the construction industry's environmental impact, can design and build a high-performance building. Using a standard building rating system as guidance for green building design is certainly an advantage in that this approach has rapidly increased the penetration of green buildings in the marketplace. Yet simple adherence to a checklist without deeper thinking ultimately could result in building stereotypes that stagnate rather than advance the art of green building. Commitment to a design approach that is rooted in an understanding of natural systems and in the behavior of ecosystems, and that is concerned with resource conservation, undoubtedly will produce a high-performance building of higher economic and aesthetic value. The bottom line is that high-performance green buildings that are truly exceptional beyond the points and certifications require an integration with nature that is not achievable with a mere checklist.

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Figure 3.1 The Federal Building in San Francisco, California, exemplifies ecological design by employing local natural forces, such as the prevailing winds and sunlight, to provide cooling and daylighting. Detailed analysis of natural airflows induced by wind and thermal processes was accomplished using sophisticated computational fluid dynamics modeling. (Illustration courtesy of Morphosis Architects)

In the short history of the green building movement, several design approaches have been articulated, including ecological design, *environmental design*, *green design*, *sustainable design*, and *ecologically sustainable design*. Fundamentally, each approach seeks to acknowledge, facilitate, and/or preserve the interrelationship of natural system components and buildings. As a result, a wide range of questions and problems have surfaced:

- What can be learned from nature and ecology that can be applied to buildings?
- Should ecology serve as *model* or *metaphor* for a sustainable built environment?
- How can natural systems be directly incorporated to improve the functioning of the built environment?
- How can the human-nature interface best be managed for the benefit of both systems?
- When does the natural system metaphor break down, and, if it does, what are the alternative approaches?

These challenging questions have no easy answers, yet responses to them are critical to the evolution of sustainable construction. Clearly, the green building movement requires greater understanding and consideration of the environmental and human impacts of the built environment as well as incorporation of nature's lessons into the building process. The striking lack of understanding of ecology among design and construction professionals is less surprising when one considers that the green building movement was not created by ecologists but by building professionals and policy makers with only glancing familiarity with the dynamic discipline of ecology. Yet, without greater understanding of ecology and ecological theory, green buildings may cease to evolve beyond merely fanciful, intuitive structures that are green in name only (see Figure 3.1). With this in mind, this chapter reviews fundamental principles of ecological, or green, design and explores the philosophy and rationale of practitioners and academics whose life's work has centered on these issues. An overview of the history and current efforts to connect ecological thinking to buildings provides a starting point; further study of ecology, industrial ecology, and related fields is recommended.

Design versus Ecological Design

According to Van der Ryn and Cowan (1996), *design*, in its simplest form, can be defined as "the intentional shaping of matter, energy, and process to meet a perceived end or desire" (p. 8). This broad definition means that literally everyone is a designer because we are all using resources to achieve some end; consequently, the responsibility for design does not rest solely with those who might be called the design professionals, the most prominent of whom are architects. The world we design collectively is a rather simple one compared to the design of nature. In our world, we use a limited number of models and templates to produce an impoverished urban and industrial landscape largely devoid of true imagination and creativity. It is clear that this human-designed and engineered landscape often replaces the natural landscape with unrecyclable and toxic products manufactured by wasteful industrial processes that were implemented with little regard for the consequences for humans or ecological systems. It is often said that the environmental problems we face today, such as climate change and biodiversity loss, reflect a failure of design. The disconnection of human design from nature is precisely the problem that high-performance green building, through the application of ecological design, seeks to redress.

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In contrast to their definition of design, Van der Ryn and Cowan defined *ecological design* as that which transforms matter and energy using processes that are compatible and synergistic with nature and that are modeled on natural systems. Thus, unlike design that destroys landscapes and nature, ecological design, in the context of the built environment, seeks solutions that integrate human-created structures with nature in a symbiotic manner; that mimic the behavior of natural systems; and that are harmless to humans and nonhumans in their production, use, and disposal. Some would widen the concept of ecological design to an even broader concept, that of sustainable design, which would address the triple bottom-line effects of creating buildings: environmental impacts, social consequences, and economic performance. Clearly, the larger context and impacts of building design and construction need to be kept in mind by all the players in the process. Ecological design focuses on the human-nature interface and uses nature rather than the machine as its metaphor.

The key problem facing ecological design is a lack of knowledge, experience, and understanding of how to apply ecology to design. Complicating the issue is that there are several major approaches to understanding ecology, even among ecologists. Systems ecology, for example, focuses on energy flows, whereas proponents of adaptive management study processes.[1] Nature functions across scales and time horizons that are virtually unimaginable to human designers, who continue to struggle to apply even relatively simple ecological concepts, such as resilience and adaptability, to their work. An even deeper flaw is that building professionals have little or no background or education in ecology; hence, any application of so-called ecological or green design is likely to be shallow and perhaps even trivial. Equally problematic is that an enormous legacy of machine-oriented design is in place in the form of buildings and infrastructure, and the industrial products comprising buildings are still being created based on concepts, design approaches, and processes that have their roots in the Industrial Revolution. Thus, contemporary ecological designers are engaged in a struggle on several fronts in their attempt to shift to a form of thinking that would reconnect humans and nature. These four "fronts" can be described as:

1. Understanding ecology and its applicability to the built environment
2. Determining how to use nature as the model and/or metaphor for design
3. Coping with an industrial production system that operates using conventional thinking
4. Reversing at least two centuries of design that used the machine as its model and metaphor

The classic approach to building design has been for the architect to define and lead the design effort, with input from the building owner but with scant input from other entities affected by the project. Contemporary ecological design changes this thinking dramatically by engaging a wide range of stakeholders in the design process from the onset of the effort. The key point of ecological design is to obtain the maximum amount of input from as many parties to the project as possible.

BENEFITS OF ECOLOGICAL DESIGN

For green buildings to be successful, the benefits of designing them must be known to those purchasing construction services and facilities. Because sustainability addresses a broad range of economic, environmental, and social issues, the benefits of ecological or sustainable design are potentially enormous. A list of these benefits published by the Federal Energy Management Program provides an overview of the promise of a shift to sustainable design (see Table 3.1).

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TABLE 3.1

Benefits of Sustainable Design

	Economic	Societal	Environmental
Siting	Reduced costs for site preparation, parking lots, roads	Improved aesthetics, more transportation options for employees	Land preservation, reduced resource use, protection of ecological resources, soil and water conservation, restoration of brownfields, reduced energy use, less air pollution
Water Efficiency	Lower first costs, reduced annual water and wastewater costs	Preservation of water resources for future generations and for agricultural and recreational uses, fewer wastewater treatment plants	Lower potable water use and reduced discharge to waterways, less strain on aquatic ecosystems in water-short areas, preservation of water resources for wildlife and agriculture
Energy Efficiency	Lower first costs, lower fuel and electricity costs, reduced peak power demand, reduced demand for new energy infrastructure	Improved comfort conditions for occupants, fewer new power plants and transmission lines	Lower electricity and fossil fuel use, less air pollution and fewer carbon dioxide emissions, lowered impacts from fossil fuel production and distribution
Materials and Resources	Decreased first costs for reused and recycled materials, lower waste disposal costs, reduced replacement costs for durable materials, reduced need for new landfills	Fewer landfills, greater markets for environmentally preferable products, decreased traffic due to the use of local/regional materials	Reduced strain on landfills, reduced use of virgin resources, better-managed forests, lower transportation, energy and pollution, increase in recycling markets
Indoor Environmental Quality	Higher productivity, lower incidence of absenteeism, reduced staff turnover, lower insurance costs, reduced litigation	Reduced adverse health impacts, improved occupant comfort and satisfaction, better individual productivity	Better indoor air quality, including reduced emissions of volatile organic compounds, carbon dioxide, and carbon monoxide
Commissioning; Operations and Maintenance	Lower energy costs, reduced occupant/owner complaints, longer building and equipment lifetimes	Improved occupant productivity, satisfaction, health, and safety	Lower energy consumption, reduced air pollution and other emissions

Source: Excerpted from Office of Energy Efficiency and Renewable Energy, 2003, *The Business Case for Sustainable Design in Federal Facilities* (Washington, DC: Federal Energy Management Program, US Department of Energy). Available at http://evanmills.lbl.gov/pubs/pdf/bcsddoc.pdf Historical Perspective

Although the green building movement is a relatively recent phenomenon, it has its roots in the work and thinking of several previous generations of architects and designers, dating back at least to the end of the nineteenth century. In the American context, several key figures laid the foundation for today's ecological or green design, among them R. Buckminster Fuller, Frank Lloyd Wright, Richard Neutra, Lewis Mumford, Ian McHarg, Malcolm Wells, and John Lyle.

A brief introduction to each of these thinkers is presented here. The following section, "Contemporary Ecological Design," covers the synthesis of this foundational thinking about ecological design into an emerging, coherent process for green building design. To articulate today's thinking, the efforts of William McDonough, Ken Yeang, Sim Van der Ryn, Stuart Cowan, and David Orr are described.

R. BUCKMINSTER FULLER

Perhaps more than any other figure, R. Buckminster Fuller (1895–1983) laid the foundation for the green building revolution in the United States (see Figure 3.2). His list of accomplishments is long; it includes the design of the autonomous Dymaxion House in the 1920s, one of which was built in Wichita, Kansas, in 1946; the design of the aluminum Dymaxion car in 1933; and, of course, the creation of the geodesic dome in the 1950s (see Figure 3.3). Fuller has been called an inventor, architect,

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engineer, mathematician, poet, and cosmologist. He was, at heart, an ecologist. His designs emphasized resource conservation: the use of renewable energy in the form of sun and wind; the use of lightweight, ephemeral materials such as bamboo, paper, and wood; and the concept of design for deconstruction. His geodesic dome has been called the lightest, strongest, and most cost-effective structure ever devised.

Fuller is also credited with originating the term *Spaceship Earth* to describe how dependent humans are on the planet and its ecosystems for their survival and how the waste we create ends up in the biosphere, to the peril of everyone. His Dymaxion Map and World Game were designed to allow players to conserve world resources and create strategies for solving global problems by matching human needs with the planet's resources. Fuller understood the issue of renewable and nonrenewable resources, and his research showed that renewables could provide all energy needs. In the United States, he showed that, at the time in the mid-1930s, wind energy alone could provide three and a half times the country's total energy needs.[2] His work influenced many of today's green building movement participants, so much so that he is sometimes referred to as the "father of environmental design."

Fuller was also a prolific author; he is credited with writing 28 books, among them *Operating Manual for Spaceship Earth* (1969), in which he imagines humans as the crew of the planet, all bound together by a shared fate on what amounts to a tiny spaceship in an infinite universe. The question he posed to his fellow planetary inhabitants was: How do we contribute to the safe operation of Spaceship Earth? In the book, he described many of his basic concepts, two of which are *synergy* and *ephemeralization*. Another notable book by Fuller was *Critical Path* (1981), in which he explored social issues, marking him as one of the first people to connect the issues of environment, economics, and humans, labeled many years later by Lester Brown as *sustainability*. In *Critical Path*, Fuller analyzed how humanity has found itself at the limits of the planet's resources and facing political, economic, environmental, and ethical crises. Fuller, labeled "the planet's friendly genius," was an extraordinary member of the planet's "crew."



Figure 3.2 The R. Buckminster Fuller postage stamp was issued by the US Postal Service in July 2004 to commemorate the 50th anniversary of Fuller's patents for the geodesic dome, said to be the lightest, strongest, and most cost-effective structure ever devised. (Stamp Designs © 2004 United States Postal Service. Displayed with permission. All rights reserved)



Figure 3.3 R. Buckminster Fuller's Dynamic Maximum Tension, or Dymaxion House, in Wichita, Kansas, was the first serious attempt to create an autonomous house. It was designed for mass production, weighed just 3,000 pounds (1364 kilograms) compared with the 150 tons (137 metric tons) of a typical house, featured a built-in wind turbine for generating power, and had a graywater system. (Courtesy of The Estate of R. Buckminster Fuller)

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Figure 3.4 Frank Lloyd Wright (1867–1958) laid some of the early foundations for the contemporary high-performance green building movement through his fusion of site, structure, and context. (*Source:* Library of Congress)

FRANK LLOYD WRIGHT

Frank Lloyd Wright (1867–1958) is well known as an important figure in architecture (see Figure 3.4). Less well known is that his thinking on nature and building laid some of the early foundations for the contemporary high-performance green building movement. His early exposure to nature had a profound effect on both his life and his architecture. Under the tutelage of his mother, who employed Friedrich Froebel's nature-based training, he learned about nature's forms and geometries. His architecture reflects this influence, relying on the underlying structure of nature. Wright's goal was to create buildings that were, as he put it, integral to the site, to the environment, to the life of the inhabitants, and to the nature of the materials. He also introduced the term *organic architecture* into the design vocabulary to reflect, at least in part, how his thinking had evolved from that of his mentor, Louis Sullivan. Sullivan's mantra, "form follows function," was modified by Wright to "form and function are one," a change inspired by his observations of nature. Wright preferred an approach that emulated rather than imitated nature. Nature is an integrated whole, with seamless design. However, people filter and reinterpret nature's principles and the result is outcomes that are like nature, but not precisely like nature. He advocated a similar outcome for architecture by integrating spaces into a coherent whole and fusing site, structure, and context into one idea (see Figure 3.5). The building's design should be carefully considered to make it an organic whole. Every element of the building should be designed to make it integral to this organic whole: windows, doors, chairs, floors, roof, walls, and spatial form, all related to one another, emulating the order in nature. Materials and motifs are repeated throughout the building, and geometries are selected for their compatibility with a central theme, again emulating nature. Wright's provocative thinking and writing on organic architecture are important cornerstones of today's greening revolution, and the frequent reference to him as "America's first green architect" is certainly well deserved.

RICHARD NEUTRA

Richard Neutra (1892–1970), a student of Frank Lloyd Wright's, recognized how flawed the products of human creation were compared with those of nature (see Figure 3.6). He noted that human artifacts were static and unable to self-regenerate or self-adjust, unlike nature's creations, which are dynamic and self-replicating. He observed that nature's form and function emerge simultaneously, whereas humans must first create a building's form and then allow it to function. Neutra was one of the first to recognize the concept of *biophilia*, the need or craving of humans to be connected to nature, a concept that has been expounded on more recently by E. O. Wilson and Stephen Kellert (1996).

Neutra advocated the close connection of living spaces to the "green world of the organic." According to Neutra, imitating nature is not simply flattery on the part of humans; it is the copying of systems that function in an extraordinarily successful fashion. He was also one of the first architects to recognize the connection between



Figure 3.5 Taliesin West in Scottsdale, Arizona, designed by Frank Lloyd Wright, illustrates organic architecture. (*Source:* National Register of Historic Places)

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Figure 3.6 Richard Neutra (1892–1970) recognized the need of humans to be connected to nature and was one of the originators of the concept of biophilia. (Photograph courtesy of the J. Paul Getty Trust)



Figure 3.7 Neutra explored the health relationship between nature and structure as evidenced in the Health House in Los Angeles, California. (*Source:* National Register of Historic Places)

human health and nature and the need to consider this relationship in building design. In designing what became known as the Health House, a Los Angeles residence for Dr. P. M. Lovell, a naturopath, or integrated medical practitioner, Neutra explored the health relationship between nature and structure (see Figure 3.7). In today's green buildings, health issues are of paramount importance, and connections between nature and health are again being explored in a wide variety of building experiments.

LEWIS MUMFORD

Lewis Mumford (1895–1990) was renowned for his writings on cities, architecture, technology, literature, and modern life (see Figure 3.8). His long-term connection with the built environment was forged over a 30-year stint as architectural critic for the *New Yorker*. He was also a cofounder of the Regional Planning Association of America, which advocated limited-scale development and the region as significant for city planning. He wrote *The Brown Decades* in 1931 to detail the architectural achievements of Henry Hobson Richardson, Louis Sullivan, and Frank Lloyd Wright. Mumford was particularly critical of technology, and in *The Myth of the Machine*, written in 1967, he argued that the development of machines threatened humanity itself, citing, for example, the design of nuclear weapons. He argued in *Values for Survival*, written in 1946, for the restoration of organic human purpose and for humankind to exert "primacy over its biological needs and technological pressures" and to "draw freely on the compost from many previous cultures." Mumford advocated the implementation of *ecotechnics*, technologies that rely on local sources of energy and indigenous materials in which variety and craftsmanship add ecological consciousness as well as beauty and aesthetics. He drew his conclusions from observations of how cities evolved, from preindustrial cities that respected nature to post–Industrial Revolution metropolises that sprawled and destroyed compact urban forms, caused resources to be wasted, and had virtually no connection to nature.



Figure 3.8 Lewis Mumford (1895–1990) was an architecture critic and advocate for ecological consciousness over technology. (Courtesy of the Estate of Lewis and Sophia Mumford)

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Figure 3.9 Ian McHarg (1920–2001) was an advocate of planning for a built environment that is responsive to nature. (*Source:* The Japan Prize Foundation)

IAN McHARG

The disconnect between buildings and nature in the Industrial Age was also noted and articulated by Ian McHarg (1920–2001), particularly the lack of a multidisciplinary effort to produce a built environment that was responsive to nature. McHarg decried the lack of environmental consideration in planning; the lack of interest on the part of scientists in planning; and the absence of consideration of life itself in many of the sciences, such as geology, meteorology, hydrology, and soil science (see Figure 3.9). According to McHarg, the compartmentalization and specialization of disciplines have created conditions that at present may make truly ecological design difficult or impossible to achieve.

McHarg's 1969 book, *Design with Nature*, is a modern classic, especially for the discipline of green building. McHarg called for environmental planning on a local level and advocated taking everything in the environment (such as humans, rocks, soils, plants, animals, and ecosystems) into account when planning the built environment. He was also one of the first people to realize that the best way to preserve open space is to sustain urban areas, which contain existing resources (such as sewer systems and streets) to handle human growth. He also noted that it was critical that everyone have an ecological education in order to be able to make the best-informed decisions about growth and development.

MALCOLM WELLS

Malcolm Wells (1926–2009) was generally critical of architects for failing to be aware of or moved by the biological foundations of both life and art. In his 1981 work, *Gentle Architecture*, he asked a key question: "Why is it that almost every architect can recognize and appreciate beauty in the natural world yet fail to endow his own work with it?" (p. 41) (see Figure 3.10). Wells's solution was a simple but very effective one: Leave the surface of the planet alone and submerge the built environment underground so that Earth's surface can continue to provide unimpeded services, as shown in the Wells art studio in Figure 3.11. Wells's approach

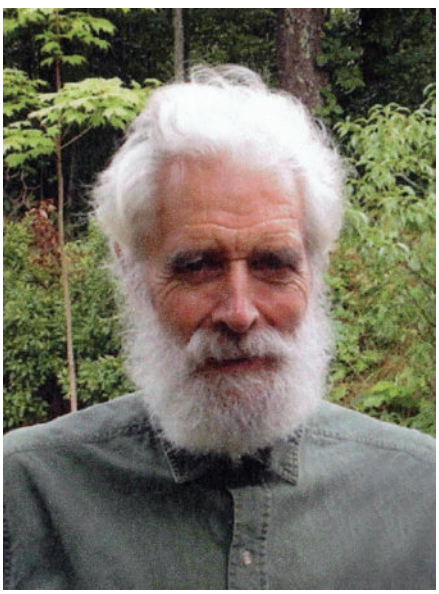


Figure 3.10 Malcolm Wells (1926–2009) significantly influenced today's green building movement through his "tread gently on the earth" approach. (Photograph courtesy of Karen Wells)



Figure 3.11 The underground art gallery of Karen Wells (wife of Malcolm Wells). (Photograph courtesy of Karen Wells)

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was to tread gently on Earth, minimize the use of asphalt and concrete, and use local natural resources and solar energy as the primary resources for the built environment. He is known as the "father of gentle architecture," or of earth-sheltered architecture, and although he claimed that his work had not had the effect he had hoped for, his thinking significantly influenced today's green building movement. He suggested that buildings should consume their own waste, maintain themselves, provide animal habitat, moderate their own climate, and match nature's pace—all notions that are presented frequently in the increasing number of green building forums throughout the United States.



Figure 3.12 John Lyle (1934–1998) promoted the idea of creating regenerative landscapes through ecological design. (Photograph courtesy of the Lyle Center for Regenerative Studies, California State Polytechnic University, Pomona)

JOHN LYLE

Landscape is perhaps the most neglected and underrated issue in green design, but one man, John Lyle (1934–1998), pursued the goal of creating regenerative landscapes. His book, *Design for Human Ecosystems*, originally published in 1985, is his classic text. In it, he explores methods of designing landscapes that function in the sustainable ways of natural ecosystems (see Figures 3.12 and 3.13). The book provides a framework for thinking about and understanding ecological design, highlighted by a wealth of real-world examples that bring Lyle's key ideas to life. Lyle traced the historical growth of design approaches involving natural processes and presented an introduction to the principles, methods, and techniques that can be used to shape landscape, land use, and natural resources in an ecologically sensitive and sustainable manner. He articulated the problems inherent in imposed and artificial infrastructures, which are part of a linear industrial system in which materials extracted from nature and the earth end up as useless waste.

Unlike its natural counterpart, the urban landscape does not produce food; store, process, or treat stormwater; or provide diverse habitat for wildlife. It is also not part of an ecological system and does not contribute to biological diversity. And the artificial landscape is not sustainable because it is highly dependent for its survival on fossil fuel, chemicals, and large quantities of water. In contrast, Lyle's regenerative landscape is characterized by the qualities of locality, fecundity, diversity, and continuity. A regenerative landscape grows out of a particular place (locality) in a manner unique



Figure 3.13 The Center for Regenerative Studies at the California State Polytechnic University in Pomona. (Photograph courtesy of the Lyle Center for Regenerative Studies, California State Polytechnic University, Pomona)

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to that place. It is fertile and continually grows and renews itself through reproduction, the heart of regeneration (fecundity). The regenerative landscape is composed of a wide variety of plants and organisms, each occupying a niche in its environment (diversity). And the regenerative landscape is not fragmented; it changes gradually over space and time (continuity).

Contemporary Ecological Design

The influence of these architects, designers, and philosophers on today's green building movement has been profound. In addition to establishing the foundations for ecological design, they influenced many of today's practitioners. Even though ecological design is still in development, the green building movement is driving efforts to refine its meaning and to explore in detail the connection between ecology and the built environment. Today's green building movement builds on the thoughts and work of figures like Fuller, Wright, Neutra, Mumford, Lyle, and McHarg. The intellectual capital and professional output of thousands of individuals, organizations, and companies can be added to the few voices on the subject of ecological design prior to 1990.

The process of discovery and implementation of ecological design will be a long but exciting journey as design, practices, materials, methods, and technologies adapt to a world that is truly in need of a refined approach to the built environment.

Perhaps the first step in describing where ecological design is today is to sort through the terminology being used in association with this concept. Christopher Theis, a professor of architecture at Louisiana State University, in a paper published in 2002 on the website of the Society of Building Science Educators (www.sbse.org), suggested that we first have to deal with several differing sets of nomenclature floating around in the building community. A variety of terms, including those already introduced in this book, are being used to describe the approach to delivering high-performance buildings: sustainable design, green design, ecological design, and ecologically sustainable design. Theis advocated the use of the term *ecological* to describe the design strategy needed to produce a high-performance green building. Although using the word *sustainable* to describe this design strategy may be more comprehensive, doing so leads to levels of complexity that are not resolvable in designing a building, because it is necessary to consider the three major aspects of sustainability: social, economic, and environmental. This is a nearly impossible task for the building team whose task is to take projects awarded to them by an owner or client and meet the requirements spelled out in their contract. This is not to say that the building team should be unaware of sustainability issues; as much as possible, they should consider the ramifications of all their decisions with respect to sustainability. In fact, the building team can exert a powerful influence on owners by educating them about these broad issues, both directly, through an articulation of their philosophy, and indirectly, by their approach to building design.

As for ecological design itself, Peter Wheelwright, chair of the Department of Architecture at the Parsons School of Design, described two often contradictory and conflicting approaches to ecological design currently taken in schools of architecture: the organic one, which combines an activist social agenda with a "Wrightian" design ethic, and the technological one, which is "futurist in orientation and scientific in method." In fact, they coexist, with designers seeking to create solutions rooted in nature, yet applying technology as appropriate.

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Key Green Building Publications: Early 1990s

The early 1990s marked the start of the green building movement in the United States. Three publications of this era provided an early articulation of green building design: *The Hannover Principles* in 1992, *The Local Government Sustainable Buildings Guidebook* in 1993, and *The Sustainable Building Technical Manual* in 1996. In addition, in 1992, *Environmental Building News*, the first and still the most authoritative publication on green building issues, was launched and featured a checklist for green design. Each of these key publications is reviewed briefly next.



Figure 3.14 William McDonough developed the principles of sustainable design commonly known as the Hannover Principles in 2000. (*Source:* Boise State University)

THE HANNOVER PRINCIPLES

In 1992, the city manager of Hannover, Germany, Jobst Fiedler, commissioned William McDonough, one of the early major figures in the emergence of green buildings, to work with the city to develop a set of principles for sustainable design for the 2000 Hannover World's Fair (see Figures 3.14 and 3.15). The principles were not intended to serve as a how-to for ecological design but as a foundation for ecological design. One of the contributions that emerged from this relatively early attempt to articulate principles for the green building movement was a definition of sustainable design as the "conception and realization of ecologically, economically, and ethically responsible expression as part of the evolving matrix of nature." These principles, commonly known as the *Hannover Principles*, are listed in Table 3.2.

THE LOCAL GOVERNMENT SUSTAINABLE BUILDINGS GUIDEBOOK AND *THE SUSTAINABLE BUILDING TECHNICAL MANUAL*

In the 1990s, several publications attempted to provide an orientation to the current era of ecological design, especially as driven by the emergence of the LEED building assessment system. Two of the first publications on the subject of designing a green building were produced by Public Technology, Inc.: *The Local Government Sustainable Buildings Guidebook*, in 1993, and *The Sustainable Building Technical Manual*, in 1996. At the time of their publication, the US Green Building Council (USGBC) was a very new organization, and the first drafts of the LEED standard were just beginning to emerge from its committees.

TABLE 3.2

The Hannover Principles

1. Insist on the rights of humanity and nature to coexist.
2. Recognize interdependence.
3. Respect relationships between spirit and matter.
4. Accept responsibility for the consequences of design.
5. Create safe objects of long-term value.
6. Eliminate the concept of waste.
7. Rely on natural energy flows.
8. Understand the limitations of design.
9. Seek constant improvement by the sharing of knowledge.

Source: Excerpted from Public Technology, 1996. *The Sustainable Building Technical Manual: Green Design, Construction and Operations* (Washington, DC: Author). Available from www.usgbc.org.



Figure 3.15 Holland Pavilion at the Hannover Expo 2000. (Hans Werlemann)

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TABLE 3.3

Design Considerations and Practices for Sustainable Building
Resources should be used only at the speed at which they naturally regenerate, and should be discarded only at the speed at which local ecosystems can absorb them.
Material and energy resources must be understood as a part of a balanced human/natural cycle. Waste occurs only to the extent that it is incorporated back into that cycle and used for the generation of more resources.
Site planning should incorporate resources naturally available on the site, such as solar and wind energy, natural shading, and drainage.
Resource-efficient materials should be used in construction of the building and in furnishings to lessen local and global impact.
Energy and materials waste should be minimized throughout the building's life cycle from design through reuse or demolition.
The building shell should be designed for energy efficiency.
Material and design strategies should strive to produce excellent total indoor environmental quality, of which indoor air quality is a major component.
The design should maximize occupant health and productivity.
Operation and maintenance systems should support waste reduction and recycling.
Location and systems should optimize employee commuting and customer transportation options and minimize the use of single-occupancy vehicles. These include using alternative work modes such as telecommuting and teleconferencing.
Water should be managed as a limited resource.

Source: Excerpted from Public Technology, 1993, *The Local Government Sustainable Buildings Guidebook* (Washington, DC: Author).

TABLE 3.4

Overview of Building Design Issues as Stated in *The Sustainable Building Technical Manual*
Passive Solar Design
Daylighting
Building envelope
Renewable energy
Building Systems and Indoor Environmental Quality
HVAC, electrical, and plumbing systems
Indoor air quality
Acoustics
Building commissioning
Materials and Specifications
Materials
Specifications

Source: Excerpted from Public Technology, 1996, The *Sustainable Building Technical Manual: Green Design, Construction and Operations* (Washington, DC: Author). Available from www.usgbc.org.

The Local Government Sustainable Buildings Guidebook revealed some of the very first thoughts on the direction of the US green building movement. A number of the guiding principles noted in the guidebook are shown in Table 3.3.

In contrast to the guidebook, *The Sustainable Building Technical Manual* was in essence a stopgap measure to serve the rapidly growing interest in green building. The manual provided a list of areas that should be considered in designing a green building. These are summarized in Table 3.4. The manual emphasized the need for an integrated, holistic approach to design, with the building being considered a system rather than an assemblage of parts. This marked one of the first public statements of this key aspect of green building. As noted previously, the notion of a systems approach has emerged as one of the dominant themes of green building, even though in practice it is difficult to achieve due to the large quantities of information being processed, the many actors involved, and the same difficulties in communication that occur in conventional design.

ENVIRONMENTAL BUILDING NEWS

The most prominent US publication on green building is *Environmental Building News*, a monthly newsletter/journal dedicated to the subject of high-performance buildings. Periodically, it has featured checklists on various subjects related to green building, among them one for environmentally responsible design. Although not considered a philosophical approach, *Environmental Building News* does provide an overview of the major issues that should be considered in designing green buildings. Table 3.5 presents this checklist.

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TABLE 3.5

***Environmental Building News* Checklist for Environmentally Responsible Design**

Smaller is better. Optimize use of interior space through careful design so that the overall building size—and the resources used in constructing and operating it—are kept to a minimum.
Design an energy-efficient building. Use high levels of insulation, high-performance windows, and tight construction. In southern climates, choose glazings with low solar heat gain.
Design buildings to use renewable energy. Passive solar heating, daylighting, and natural cooling can be incorporated cost-effectively into most buildings. Also consider solar water heating and photovoltaics—or design buildings for future solar installations.
Optimize material use. Minimize waste by designing for standard ceiling heights and building dimensions. Avoid waste from structural overdesign (use optimum-value engineering/advanced framing). Simplify building geometry.
Design water-efficient, low-maintenance landscaping. Conventional lawns have a high impact because of water use, pesticide use, and pollution generated from mowing. Landscape with drought-resistant native plants and perennial groundcovers.
Make it easy for occupants to recycle waste. Make provisions for storage and processing of recyclables—recycling bins near the kitchen, undersink compost receptacles, and the like.
Look into the feasibility of graywater. Water from sinks, showers, or clothes washers (graywater) can be recycled for irrigation in some areas. If current codes prevent graywater recycling, consider designing the plumbing for easy future adaptation.
Design for durability. To spread the environmental impacts of building over as long a period as possible, the structure must be durable. A building with a durable style ("timeless architecture") will be more likely to realize a long life.
Avoid potential health hazards—radon, mold, pesticides. Follow recommended practices to minimize radon entry into the building and provide for future mitigation if necessary. Provide detailing to avoid moisture problems, which could cause mold and mildew growth. Design insect-resistant detailing to make minimizing pesticide use a high priority.

Source: www.buildinggreen.com (paid subscription required).

Key Thinking about Ecological Design

In addition to the publications just described, in the mid-1990s, two landmark books on the subject of contemporary ecological design were published: *Designing with Nature*, written in 1995 by Ken Yeang, a Malaysian architect, and *Ecological Design*, authored by Sim Van der Ryn and Stuart Cowan in 1996. Although there are several other volumes on the subject of designing buildings in a manner that employs either the metaphor or model of nature, these two are particularly noteworthy for their deeper thinking on the subject of ecological design.

DESIGNING WITH NATURE: KEN YEANG

Designing with Nature was perhaps the first publication to attempt to tackle the tremendous challenge of how to apply ecology directly to architecture. Ken Yeang (see Figures 3.16 and 3.17) used the terms *green architecture* and *sustainable architecture* interchangeably, defining them as "designing with nature and designing with nature in an environmentally responsible way." Yeang (1995, chapter 1) approached this problem by making several important assumptions:

- The environment must be kept biologically viable for people.
- Environmental degradation by people is unacceptable.



Figure 3.16 Ken Yeang developed principles for applying ecology directly lto architecture. (Photograph courtesy of Ken Yeang)

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Figure 3.17 The National Library of Singapore designed by Ken Yeang. (Photograph courtesy of Ken Yeang)

- Destruction of ecosystems by humans must be minimized.
- Natural resources are limited.
- People are part of a larger closed system.
- Natural system processes must be considered in planning and design.
- Human and natural systems are interrelated and essentially one system.
- Changing anything in the system affects everything else.

Yeang also suggested several premises or bases for ecological design (see Table 3.6).

TABLE 3.6

Bases for Ecological Design as Suggested by Ken Yeang

1. Design must be integrated not only with the environment, but also with the ecosystems that are present.
2. Because Earth is essentially a closed system, matter, energy, and ecosystems must be conserved and the biosphere's waste assimilation capacity considered.
3. The context of the ecosystem, that is, its relationship with other ecosystems, must be considered.
4. Designers must analyze and use each site for its physical and natural structures to optimize the design.
5. The impact of the design must be considered over its entire life cycle.
6. Buildings displace ecosystems, and the matter–energy impacts must be considered.
7. Due to the complex impacts of built environments on nature, design must be approached holistically rather than in a fragmented manner.
8. The limited assimilative capacity of ecosystems for human-induced waste must be factored into design.
9. Design should be responsive and anticipatory, and as much as possible result in beneficial effects for natural systems.

Source: Adapted from Ken Yeang, 1995, *Designing with Nature: The Ecological Basis for Architectural Design* (New York: McGraw-Hill), chapter 1.

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In the actual implementation of ecological design, Yeang suggested that there are three major steps:

1. Define the building program as an ecological impact statement (analysis).
2. Produce a design solution that comes to grips with the probable environmental interactions (synthesis).
3. Establish the performance of the design solution by measuring inputs and outputs throughout the life cycle (appraisal).

Yeang continues his efforts to develop his concept of ecological design, and he is particularly well known for his work on tall green buildings. He has written several other books on the subject of ecological design and in 2008 published an updated work on the general subject of ecological design called *EcoDesign: A Manual for Ecological Design.* He has also written extensively on the greening of skyscrapers in *The Green Skyscraper: The Basis for Designing Sustainable Intensive Buildings* (1999), *Eco Skyscrapers* (2007), and *Eco Skyscrapers*, Volume 2 (2011).

ECOLOGICAL DESIGN: SIM VAN DER RYN AND STUART COWAN

Sim Van der Ryn and Stuart Cowan also delved deeply into the subject of ecological design in their book by the same name. They wrote *Ecological Design* to provide a context for green design rather than specific details. The main feature of the book is the articulation of five ecological design principles:

1. *Solutions grow from place.* Each location has its own character and resources; hence, design solutions are likely to differ accordingly. Solutions also should take advantage of local style, whether it is the adobe architecture of New Mexico or the cracker architecture of Florida. Sustainability has to be embedded in the process so that choices can be made about how a project can interact with local ecosystems and, ideally, improve on the conditions that presently exist—for example, to clean up contaminated industrial sites or brownfields for productive uses.
2. *Ecological accounting informs design.* For true ecological design to take place, the impact of all decisions must be taken into account. These include the effects of energy and water consumption; solid, liquid, and gaseous wastes; and toxic materials use and waste. Moreover, materials selection should support the design of facilities that minimize resource consumption and environmental effects. In regard to materials selection, life-cycle assessment is appropriate to determine the total resource consumption and emissions over the entire life of the building and to find the solution with the minimum total impact.
3. *Design with nature.* Ecological design should foster collaboration with natural systems, and the result should be buildings that coevolve with nature. Buildings should mimic nature, where, for example, there is essentially no waste because, in nature, waste equals food. Buildings are one stage in a complex industrial system that has to be redesigned with this strategy in mind to ensure that waste is minimized and closed-loop behavior rather than large-scale waste is the result. A synergistic relationship with nature is desirable, one in which matter–energy flows across the human-nature interface and is beneficial to both subsystems, human and natural. The heating and cooling systems in buildings can be assisted by landscaping, waste can be processed by wetlands, trees can take up vast quantities of stormwater, and waste generated by a building's occupants can provide nutrients for the landscape.

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4. *Everyone is a designer.* The participatory process is emerging as a key ingredient of ecological design; that is, including a wide array of people affected by a building provides more creative and interesting results. Schools of architecture need to be reinvigorated and reoriented to teach about building holistically and to include ecological design as a foundation for the curriculum. A new ecological design discipline should be created to address not only issues that may be connected to the built environment but also issues such as industrial product design and the materials supply chain.
5. *Make nature visible.* Having lost their connection with nature, humans have forgotten details as simple as where their water and food originate and how they are processed and moved to humans for consumption. Ecological design should reveal nature and its workings as much as possible, celebrate place, and reverse the trend from denatured cities to urban spaces with life and vitality. Drainage systems, normally hidden, might be exposed. The disposal areas for waste, sewage systems, wastewater treatment plants, and landfills should be located closer to the human waste generators to expose them to the consequences of wasteful behavior. By the same token, the elegant and complex behavior of natural systems in the form of natural wetlands that treat effluent can serve to educate people about integration with nature. As part of the design and construction process, the regenerative approaches advocated by John Lyle can be employed to restore areas once damaged by human activities to their natural state.



Figure 3.18 Sim Van der Ryn is considered one of the pioneers in applying the principles of both ecology and social ecology to architecture. (Photograph courtesy of Sim Van de Ryn)

Van der Ryn (see Figure 3.18) and Cowan provide a framework for designers—that is, everyone—for creating a nature- and ecology-based process that is flexible, adaptable, and useful for the building project and the place. Again, their framework does not give details on how to accomplish this process, because the details would be immense in scope and volume. Rather, it provides a strong philosophical underpinning for high-performance green building design that, if faithfully followed, will produce human-made structures that cooperate rather than compete with nature.

THE NATURE OF DESIGN: ECOLOGY, CULTURE, AND HUMAN INTENTION: DAVID ORR

In 2002, David Orr addressed ecological design in his book, *The Nature of Design: Ecology, Culture, and Human Intention.* Orr took a much broader view of ecological design than had been done previously, addressing the full array of human interaction with nature, to include how we acquire and use food, energy, and materials and what we do for a living (see Figure 3.19). Although he is not a professional in a built environment discipline, Orr has made a significant impact on today's green building movement by virtue of his ability to clearly elucidate a vision of ecological design. Orr broadens our thinking about ecological design by comparing it to the Enlightenment of the eighteenth century, with its connections to politics and ethics. He describes ecological design as an emerging field that seeks to recalibrate human behavior to, in effect, synchronize it with nature and connect people, places, ecologies, and future generations in ways that are fair, resilient, secure, and beautiful. According to Orr, changing the behavior of both the public and private sectors is badly needed to transform our production and consumption patterns.

In addition to his work as an author and as a proponent of environmental literacy, Orr raised funds for what is perhaps the most important green building project of the late 1990s: the Lewis Center for Environmental Studies at Oberlin College in Oberlin, Ohio (see Figures 3.20 and 3.21). The Lewis Center was designed by an elite team of architects and other professionals, among them William McDonough, one of

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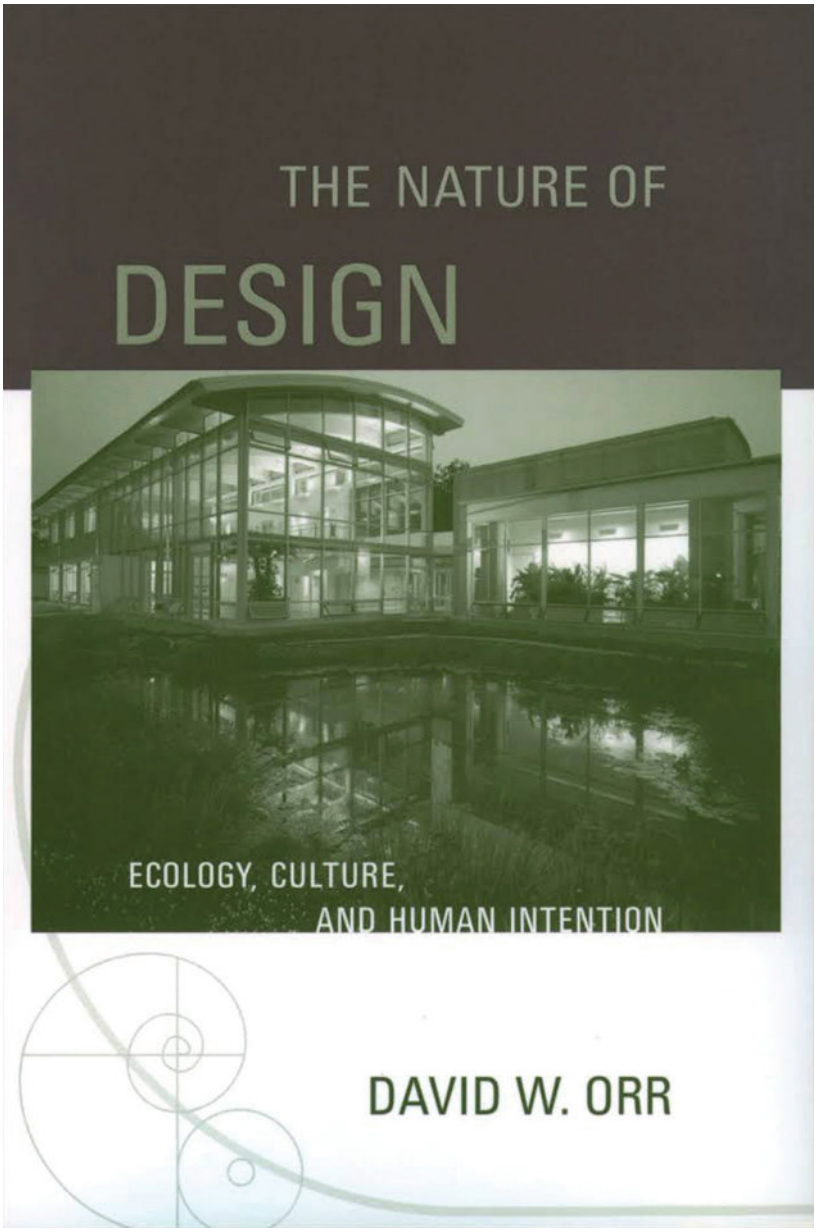


Figure 3.19 In his book *The Nature of Design: Ecology, Culture, and Human Intention*, David Orr addressed the full array of human interaction with nature, including how we acquire and use food, energy, and materials and what we do for a living.

the leading green building architects, and John Todd, creator of the Living Machine, a waste treatment system that uses natural processes to break down the components of the building's wastewater stream. Orr saw buildings as contributing to a pedagogy for environmental literacy and cites numerous examples of how designers can create structures that teach as well as function. For example, buildings can teach us how to conserve energy, recycle materials, integrate with nature, and contribute rather than detract from their surroundings. The landscape around the Lewis Center, by virtue of its design, helps teach ecological competence in horticulture, gardening, natural systems agriculture, forestry, and aquaculture as well as techniques to preserve biodiversity and ecological restoration. As Orr noted, we need a national effort to engage students of every discipline in ecological design because our current system of production and consumption is poorly designed. This is perhaps the key challenge facing us: understanding how nature can inform design of all types, building and urban design.

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Figure 3.20 The Lewis Center for Environmental Studies at Oberlin College in Oberlin, Ohio, was built in the late 1990s and designed by an elite team of architects and other professionals, among them William McDonough and John Todd, creator of the Living Machine, a waste treatment system that uses natural processes to break down the components of the building's wastewater stream. (Courtesy of Oberlin College)

Evolving the Concept of Ecological Design

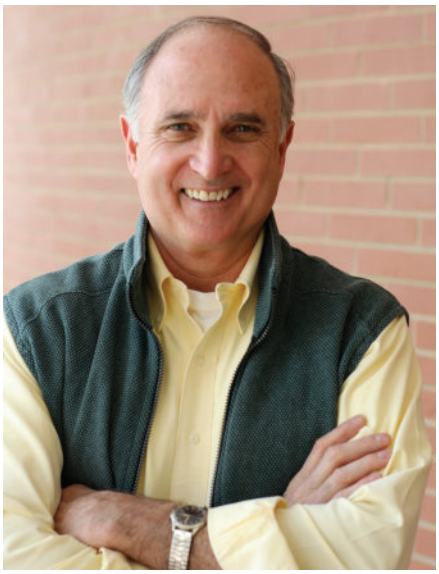


Figure 3.21 David Orr broadened our thinking about ecological design by comparing it to the Enlightenment of the 18th century, with its connections to politics and ethics. He described ecological design as an emerging field that seeks to recalibrate human behavior to synchronize it to nature and connect people, places, ecologies, and future generations in ways that are fair, resilient, secure, and beautiful. (Photograph courtesy of David Orr)

In the future, sustainable construction will require a deeper understanding of ecological design and what can and cannot be achieved through its application. For example, ecological design, by its very nature, is based on the observation of the chemistry and behavior of the living natural world. Clearly, the built environment is neither living nor natural, and although the notion of a strong role for ecology is associated with the concept of green high-performance buildings, the exact nature of this relationship is not yet well defined. This section presents a wide variety of hypotheses about ecological design to support the discussion of the relationship between ecology and design. Nine of the major hypotheses suggested by designers, industrial ecologists, and others are listed next.

1. General management rules for sustainability (Barbier 1989; Daly 1990)
2. Design principles for industrial ecology (Kay 2002)
3. The golden rules for ecodesign (Bringezu 2002)
4. Adaptive management (Peterson 2002)
5. Biomimicry (Benyus 1997; briefly described in Chapter 2)
6. Factor 4 and Factor 10 (von Weizsäcker, Lovins, and Lovins 1997; briefly described in Chapter 2)
7. Cradle to cradle (McDonough and Braungart 2002)
8. The Natural Step (Robèrt 1989; described in Chapter 2 and Chapter 11) (See Figure 3.22)
9. Natural capitalism (Hawken, Lovins, and Lovins 1999)

In the following sections, these major contributions to ecological design are presented as the basis for a future more robust and more refined version of ecological design that can serve as both a philosophical and a technical basis for sustainable construction.

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Figure 3.22 Karl Henrik Robèrt developed the Natural Step framework in Sweden. It provides a well-tested set of management principles for industry to use in support of sustainability. (Photograph courtesy of Karl Henrik Robèrt)

GENERAL MANAGEMENT RULES FOR SUSTAINABILITY

Herman Daly (1990; see Figure 3.23), the founder of ecological economics, and Edward Barbier (1989), an economist of ecological economics, formulated several pragmatic rules for "managing" sustainability. According to the first rule, the use of renewable resources should not exceed the regeneration rate. In order to operationalize this demand, one has to consider that the use of either naturally or technically renewable materials always requires some inputs of nonrenewables (e.g., mineral fertilizer for the loss of nutrients due to leaching in agriculture; the requirements for materials and energy for recycling processes). As a consequence, the total life cycle of products has to be checked for the use of renewables and nonrenewables. The former will have to be distinguished according to criteria on sustainable modes of production in agriculture, forestry, and fishery. An example in the construction sector would be the origin of timber products from sustainable cultivation.

The second rule states that nonrenewable resources may be used only if physical or functional substitutes are provided—for example, investments in solar energy systems from gains from fossil fuels. Here the basic assumption is that man-made capital may be substituted for natural capital (weak sustainability). The central requirement from an economic perspective is that the sum of natural and man-made capital is not reduced. However, from a natural systems perspective, it may be argued that there are minimum requirements of nature that may not be depleted without risk for life-support functions. Therefore, man-made capital should not be substituted (permanently) for natural capital (strong sustainability). Under this assumption, the second rule would require minimization of the use of nonrenewables.

The third rule states that the release of waste matter should not exceed the absorption capacity of nature. This rule can be operationalized by comparing critical loads of water, soil, and air compartments with actual levels of emission rates. After measures have been applied successfully to reduce pollution problems, the after-end-of-pipe approach to limit critical loads is also important. The implementation of the third rule usually is based on substance-specific analyses. This approach has some limitations. Generally, we must acknowledge that we are aware of only the tip of the iceberg with respect to the potential future impacts of all materials and substances released to the environment. Many natural functions react in a nonlinear manner. The complex interactions of natural substances like carbon dioxide, not to mention thousands of synthetic chemicals, cannot be foreseen in total.

From experience, we know that the effects of certain emissions become obvious after release and after environmental change takes place. There is a huge time



Figure 3.23 Herman Daly, often called the father or ecological economics, led the early 1970s effort to develop this field, which is often referred to as the science of sustainability. The emergence of ecological economics also supported the development of the General Management Rules for Sustainability. (Photograph courtesy of Herman Daly)

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lag between the scientific finding, public perception, and political reaction. Thus, the chances for comprehensive and precautionary materials management are extremely limited. A long-term effective implementation of the third rule should begin before the end of pipe and should aim to minimize the environmental impact potential of anthropogenic material flows. This impact potential is generally determined by the volume of the flow times the specific impacts per unit of flow. The second term is unknown for most materials released to the environment. The first term, the volume or weight used or released in a certain time period, can be made available for nearly every material handled. It may be used to indicate a generic environmental impact potential. As long as detailed information on specific impacts is lacking, it may be assumed that the impact potential is growing with the volume of the material flow. The overall volume of outputs from the *anthroposphere* (or *technosphere*), which is the portion of Earth affected by human activities to the biosphere, where life exists, can be reduced only when the inputs of inputs to the anthroposhere are diminished. Reducing these inputs is especially important due to the large-scale flow of construction materials, which are extracted from the biosphere and then retained for time on the order of decades to centuries within the anthroposphere. Starting from a situation in which the assimilation capacity of nature is overloaded by a variety of known substances, the long-term implementation of the third rule requires a reduction of the resource inputs from biosphere to anthroposphere in order to lower their throughput and ultimate output to the environment.

Another rule that has not yet attracted sufficient attention may be derived from the relation of inputs and outputs of the anthroposphere. Currently, the input of resources exceeds the output of wastes and emissions in both industrialized and developing countries. As a consequence, the economies of these countries are growing physically (in terms of new buildings and infrastructure). The stock of materials in the anthroposphere is therefore increasing. In Germany, for example, the rate of net addition to stock was about 10 tons (9.1 mt) per capita annually in the mid-1990s. Associated with this accumulation of stock is an increase in built-up land area and a consequent reduction in reproductive and ecologically buffering land. Due to the limited space on our planet, this development cannot continue infinitely. Thus, a flow of equilibrium between input and output must be expected. However, a question naturally arises: When will the economy stop growing physically and to what physical level?

DESIGN PRINCIPLES FOR INDUSTRIAL ECOLOGY

James Kay (2002), the late ecologist from the University of Waterloo, proposed a set of principles that would govern the production-consumption system. They are based on the premise that all man-made systems should contribute to the survival of natural systems.

1. *Interfacing.* The interface between societal systems and natural ecosystems reflects the limited ability of natural ecosystems to provide energy and absorb waste before their survival potential is significantly altered and the fact that the survival potential of natural ecosystems must be maintained.
2. *Bionics.* The behavior of large-scale societal systems should be as similar as possible to that exhibited by natural systems.
3. *Appropriate biotechnology.* Whenever feasible, the function of a societal system should be carried out by a subsystem of a natural biosphere.
4. *Nonrenewable resources.* Nonrenewable resources are used only as capital expenditures to bring renewable resources online.

The interfacing and appropriate biotechnology principles are related to intermediate ecological design in that they call for natural systems to interface with

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human systems in a synergistic manner to the benefit of both systems. Natural systems could provide services that otherwise would be performed by expensive engineered systems, such as stormwater control and waste processing. The bionics principle is closely related to strong ecological design for large-scale functions. The nonrenewable resources principle has its roots in ecological economics, where investing limited nonrenewables in transitioning to renewable resources is a key tenet. In effect, Kay's design principles are a mix of various levels of several types of ecological design, and he does not state that one version is most preferable.



Figure 3.24 Stefan Bringezu proposed the Golden Rules of Ecological Design to assist designers and planners in the design of an environmentally benign built environment. (Photo courtesy of Stefan Bringezu)

THE GOLDEN RULES FOR ECODESIGN

To assist engineers, architects, and planners in the production of an environmentally benign built environment, Stefan Bringezu (2002; see Figure 3.24) of the Wuppertal Institute suggested five "golden rules of ecological design":

1. Potential impacts to the environment should be considered on a life-cycle basis (from cradle to cradle).
2. The intensity of use of processes, products, and services should be maximized.
3. The intensity of resource use (material, energy, and land) should be minimized.
4. Hazardous materials should be eliminated.
5. Resource input should be shifted toward renewables.

The first golden rule aims to avoid shifting problems between different processes and actors. For instance, if the energy requirements for heating or cooling during the use phase of buildings were not considered in the planning phase, the options with the highest potential for energy efficiency would be neglected. And if one considers only the direct material inputs for construction, the environmental burden associated with the upstream flows will be hidden.

The second golden rule reflects the fact that most building products are not used much of the time. For a considerable part of each day and each week, homes, offices, and public buildings are essentially unoccupied. Nevertheless, economic, environmental, and probably also social costs have to be paid for maintenance. Multifunctionality and more flexible models of use may reduce the demand for additional construction and contribute to lower costs for the users. The model of car sharing also may be applied to construction. Part-time employees already share the same office. And there is even potential for more efficient building use beyond normal working hours. The third golden rule may be specified with the Factor 4 to 10 target for material requirements, including energy carriers, and should be applied to average products and services. In order to reach these goals, it seems essential to invest more intellectual power in the search for alternative options to provide the services and functions demanded by users. The fourth golden rule calls for the elimination of hazardous substances. At face value, this is a very sensible rule, but it is very difficult to implement from the perspective of today's economy. The use of nuclear energy violates this rule, and self-replicating nanomachines or genetically modified organisms may also be considered hazardous according to some criteria. The fifth and final golden rule is a restatement of a key concept of ecological economics; namely, that supplies of nonrenewables will clearly diminish over time as they are consumed. For example, recent studies of copper consumption in the United States indicate that only one-third of the original dowry of copper ore exists today. The logic is that as these resources disappear, a shift to renewable resources must occur and that, in fact, the consumption of nonrenewables should support the development of renewable resources. In the case of copper, a substitute renewable material may not be easy to develop.

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ADAPTIVE MANAGEMENT

Ecology, like other fields, has several distinct schools. One of them is adaptive management, as articulated by Gary Peterson (2002), who described it as an approach to ecosystem management that argues that ecosystem functioning can never be totally understood. As Peterson noted, ecosystems are continually changing due to internal and external forces. Internally, ecosystems change due to the growth and death of individual organisms as well as fluctuations in population size, local extinction, and the evolution of species traits. Ecosystems are also changed by external events, such as the immigration of species, alterations in disturbance frequency, and shifts in the diversity and amount of nutrients entering the ecosystems. To cope with these changes, management continually must adapt. Management becomes adaptive when it persistently identifies uncertainties in human-ecological understanding and then uses management intervention as a tool to strategically test the alternative hypotheses implicit in these uncertainties. Consequently, basing the design of human systems on ecosystem function means creating materials, products, and processes using models that are not very well understood. Clearly, this means that it is probably impossible to implement strong ecological design in other than one-dimensional, virtually trivial applications.

Adherents to this line of thinking are also responsible for posing the fundamental and crucial question: "Why are systems of people and nature not just ecosystems?" (Westley et al. 2002) As noted in the Chapter 2 discussion of ethics and sustainability, the qualities of humankind that make them the only forward-looking and thinking species on this planet can result in humans thinking of themselves as "apart" from nature rather than "a part" of nature. Coupled with humans' ability to infer the laws of nature and physics and to create materials and products that have no precedent in nature, the challenge is how to address the results of human inventiveness.

BIOMIMICRY

Janine Benyus (1997) described biomimicry as the conscious emulation of life's genius (see Figure 3.25). In her popular book on the subject, she stated: "'Doing it nature's way' has the potential to change the way we grow food, make materials, harness energy, heal ourselves, store information, and conduct business" (p. 2). She went on to say: "In a biomimetic world, we would manufacture the way animals and plants do, using sun and simple compounds to produce totally biodegradable fibers, ceramics, plastics, and chemicals" (p. 2). Farms would be modeled on prairies, new drugs would be based on plant and animal chemistry, and even computers would use carbon-based rather than silicon-based structures (see Figure 3.26). Proponents of biomimicry point to the 3.8 billion years of research and development that nature has invested in evolving a wide range of materials and processes that could benefit humans. Benyus also laid out 10 lessons for corporations that are based on the emulation of nature as the model for human-designed systems:



Figure 3.25 Janine Benyus described biomimicry as the conscious emulation of life's genius and outlines 10 lessons for corporations, based on the emulation of nature, as the model for human-designed systems. (Mark Bryant Photography, 2011)

1. Use waste as a resource.
2. Diversify and cooperate to fully use the habitat.
3. Gather and use energy efficiently.
4. Optimize rather than maximize.
5. Use materials sparingly.
6. Don't foul the nest.
7. Don't draw down resources
8. Remain in balance with the biosphere.
9. Run on information.
10. Shop locally. (pp. 253–254)

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Benyus also suggested "four steps to a biomimetic future" (pp. 287–292):

1. *Quieting.* Immerse ourselves in nature.
2. *Listening.* Interview the flora and fauna of our own planet.
3. *Echoing.* Encourage biologists and engineers to collaborate, using nature as a model and measure.
4. *Stewarding.* Preserve life's diversity and genius.

With respect to step 3, echoing, Benyus provided 10 questions for testing innovation or technology for its acceptability (Benyus 1997, 291–292). All 10, according to Benyus, should be answered affirmatively:

1. Does it run on sunlight?
2. Does it use only the energy it needs?
3. Does it fit form to function?
4. Does it recycle everything?
5. Does it reward cooperation?
6. Does it bank on diversity?
7. Does it utilize local expertise?
8. Does it curb excess from within?
9. Does it tap the power of limits?
10. Is it beautiful?

In the area of materials, Benyus stated that nature has four approaches:

1. Life-friendly manufacturing processes
2. An ordered hierarchy of structures
3. Self-assembly
4. Templating of crystals with proteins (p. 96)

As she pointed out, nature produces a wide range of complex and functional materials. Abalone (twice as tough as high-tech ceramics), silk (five times stronger than steel), mussel adhesive (works underwater), and many other natural materials are remarkable in their performance. Each is created out of the local environment and biodegrades back to the environment in a harmless manner at the end of its useful life.

Biomimicry has many drawbacks when it is applied to the design of products and materials in the human sphere. Nature manufactures its products at a built-in evolved rate that is a function of information and local resources. In contrast, humans have learned to make products at an astoundingly rapid pace and, over time, to dematerialize and deenergize their production systems. Humans can and do observe nature and natural phenomena and apply their observations to create all manner of products, not all of them beneficial. The strength of biomimicry is that it provides us with a deeper appreciation for the elegant designs of nature and instructs us about how to design systems that are materials and energy conserving, that largely close materials loops, that use renewable energy, and that are niche players in complex ecosystems. Biomimicry probably has far greater value as a teacher than as a provider of specific information about the chemical composition and structure of materials, and in this regard it should be part of the toolbox of ecological design.

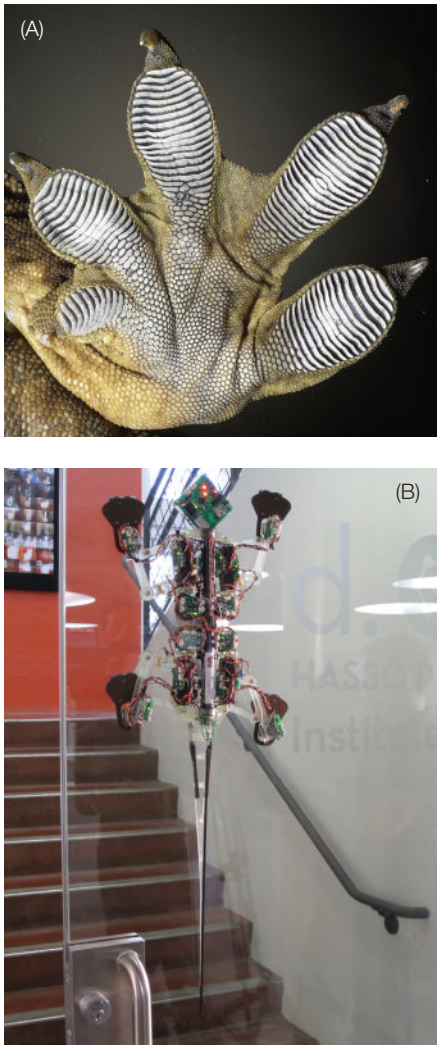


Figure 3.26 The "Stickybot" (A) is a biomimicry design developed at Stanford University with adhesive "feet" that mimic the setae on a gecko's feet (B), enabling it to climb vertical surfaces. (Photographs courtesy of (A) Mark Cutkosky, Stanford University, and (B) Ali Dhinojwala, University of Akron)

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BIOPHILIC DESIGN

Recently, the notion of the biophilia hypothesis has morphed into the concept of *biophilic design*. By introducing the wide variety of patterns present in nature into the built environment, designers can, at least partially, connect human occupants and passersby with the experience of nature (see Figure 3.27A and 3.27B). It is thought



Figure 3.27 (A) The Heart of School building at the Green School campus in Bali, Indonesia, is an example of the possibilities bamboo provides as a building material for creative, sustainable structures. It reflects Principle 9, Material Connection with Nature, of the *14 Patterns of Biophilic Design*. (Photo Courtesy of Green School Bali)



Figure 3.27 (B) Ceiling structure of the Allen Lambert Galleria and Atrium at Brookfield Place, illustrating Principle 10, Complexity & Order. (Photo Courtesy of Reto Fetz)

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that this approach can have positive effects on health by reducing stress, especially in urban environments, because it mimics the connection with nature. A recent synthesis of various approaches to biophilic design, *14 Patterns of Biophilic Design: Improving Health & Well-Being in the Built Environment*, describes three groups of biophilic patterns that can be used to promote a sense of well-being in the built environment (see Table 3.7).

TABLE 3.7

The 14 Patterns of Ecological Design

Nature in the Space Patterns

Nature in the space addresses the direct, physical and ephemeral presence of nature in a space or place. This includes plant life, water and animals, as well as breezes, sounds, scents and other natural elements. Common examples include potted plants, flowerbeds, bird feeders, butterfly gardens, water features, fountains, aquariums, courtyard gardens, and green walls or vegetated roofs.

1. *Visual connection with nature.* A view to elements of nature, living systems, and natural processes.
2. *Nonvisual connection with nature.* Auditory, haptic, olfactory, or gustatory stimuli that engender a deliberate and positive reference to nature, living systems or natural processes.
3. *Nonrhythmic sensory stimuli.* Stochastic and ephemeral connections with nature that may be analyzed statistically but may not be predicted precisely.
4. *Thermal and airflow variability.* Subtle changes in air temperature, relative humidity, airflow across the skin, and surface temperatures that mimic natural environments.
5. *Presence of water.* A condition that enhances the experience of a place through seeing, hearing or touching water.
6. *Dynamic and diffuse light.* Leverages varying intensities of light and shadow that change over time to create conditions that occur in nature.
7. *Connection with natural systems.* Awareness of natural processes, especially seasonal and temporal changes characteristic of a healthy ecosystem.

Natural Analogues Patterns

Natural analogues addresses organic, nonliving, and indirect evocations of nature. Objects, materials, colors, shapes, sequences, and patterns found in nature manifest as artwork, ornamentation, furniture, décor, and textiles in the built environment. Mimicry of shells and leaves, furniture with organic shapes, and natural materials that have been processed or extensively altered are examples of these patterns.

8. *Biomorphic forms and patterns.* Symbolic references to contoured, patterned, textured or numerical arrangements that persist in nature.
9. *Material connection with nature.* Materials and elements from nature that, through minimal processing, reflect the local ecology or geology and create a distinct sense of place.
10. *Complexity and order.* Rich sensory information that adheres to a spatial hierarchy similar to those encountered in nature.

Nature of the Space Patterns

Nature of the space addresses spatial configurations in nature. This includes our innate and learned desire to be able to see beyond our immediate surroundings, our fascination with the slightly dangerous or unknown, obscured views and revelatory moments, and sometimes even phobia inducing properties when they include a trusted element of safety.

11. *Prospect.* An unimpeded view over a distance, for surveillance and planning.
12. *Refuge.* A place for withdrawal from environmental conditions or the main flow of activity, in which the individual is protected from behind and overhead.
13. *Mystery.* The promise of more information, achieved through partially obscured views or other sensory devices that entice the individual to travel deeper into the environment.
14. *Risk/Peril.* An identifiable threat coupled with a reliable safeguard.

Source: William Browning, Catherine Ryan, and Joseph Clancy, 2014, *14 Patterns of Biophilic Design: Improving Health & Well-being in the Built Environment*, Terrapin Green LLC. Available at www.terrapinbrightgreen.com/reports/14-patterns/.

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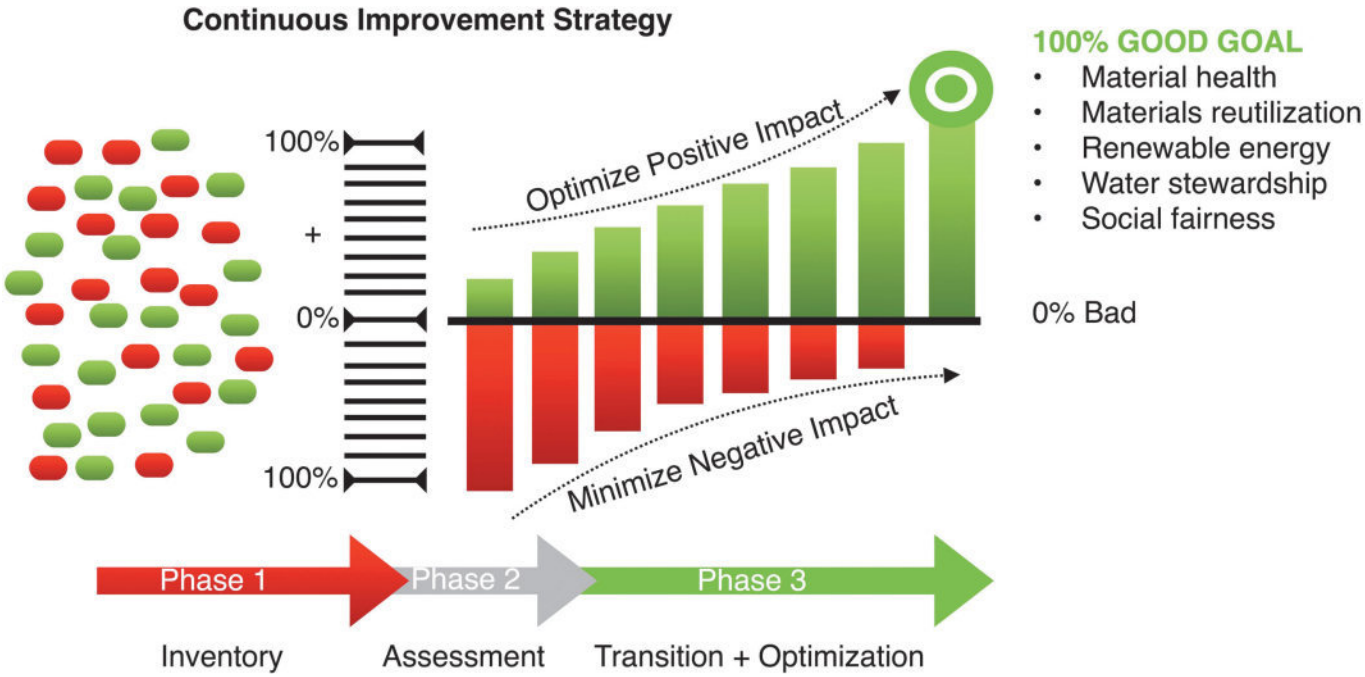


Figure 3.28 The cradle-to-cradle strategy is to remove the negative impacts of products by focusing on removing known problematic substances and to replace them with benign materials. (Photograph modified from McDonough Braungart Design Chemistry, LLC)

CRADLE-TO-CRADLE DESIGN

The concept of cradle-to-cradle design describes approaches that contrast to designs that employ a cradle-to-grave approach or mentality (see Figure 3.28). This concept has been popularized in *Cradle to Cradle: Remaking the Way We Make Things*, by William McDonough and Michael Braungart (2002). In laying the foundation for the cradle-to-cradle concept, they suggested that people and industry should set out to create:

- Buildings that, like trees, produce more energy than they consume and purify their own wastewater
- Factories that produce effluents that can be used as drinking water
- Products that, when their useful life is over, do not become useless waste but can be tossed on the ground to decompose and become food for plants and animals and nutrients for soil or, alternatively, that can return to industrial cycles to supply high-quality raw materials for new products
- Billions, even trillions, of dollars' worth of materials accrued for human and natural purposes each year
- A world of abundance, not one of limits, pollution, and waste

McDonough and Braungart (2002) suggested that the solution is to follow nature's model of eco-effectiveness. Doing this entails separating the materials we use in human activity into biological substances (which can be returned to the natural ecosystem, where they can benefit other creatures as nutrients) and technical substances (which can, with proper design, be 100 percent recollected and recycled or even upcycled, producing, in second use, products of greater value than their original use, with zero waste). Carpets and shoes, for example, could be made of two layers—a biological outer layer that abrades over time, whose fibers could serve as nutrients in the soil or compost, and a much more durable technical inner layer that would be 100 percent recyclable, after its long life, into another identical product. A biological

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nutrient is a material or product that is designed to return to the biological cycle. According to McDonough and Braungart, packaging, for example, can be designed as biological nutrients, so that, at the end of its use, it can be tossed on the ground or compost heap. A technical nutrient is a material or product that is designed to be returned to the technical cycle, the industrial metabolism from which it comes. The authors also defined a class of materials they refer to as the *unmarketables*, which are neither technical nor biological nutrients.

The cradle-to-cradle approach has a number of shortcomings that make it difficult to implement. The term *biological nutrients*, for example, is not easily defined. Is a biopolymer, produced from corn or cellulose and biodegradable, a biological nutrient? Is a biodegradable synthetic material a biological nutrient or a technical nutrient? The fact is that biomaterials such as biopolymers use natural materials as feedstock but result in alterations to the basic feedstock and produce materials that have no precedent in nature. Furthermore, the consequences of their biodegradation are not well known. Whether biodegradation results in nutrients or waste has not been firmly established.

McDonough and Braungart (2002) suggested implementing changes to products and systems based on five steps to eco-effectiveness:

Step 1. *Get rid of known culprits.* These include X substances (i.e., materials that are bioaccumulative): mercury, cadmium, lead, and polyvinyl chloride (PVC), to name a few.

Step 2. *Follow informed personal preferences.* Prefer ecological intelligence, being sure that a product or substance does not contain or support substances or practices that are blatantly harmful to human and environmental health. Doing this also includes admonitions to prefer respect and prefer delight, celebration, and fun.

Step 3. *Create a "passive positive" list concerning harm in manufacture or in use.* This is the X list, involving the X substances in step 1. It includes substances that are carcinogens or problematic as defined by the International Agency for Research on Cancer and Germany's Maximum Workplace Concentration (MAK) list. MAK defines two lists of substances, the gray list and the P list. The gray list includes problematic substances not urgently in need of phase-out. The P list consists of benign substances.

Step 4. *Activate the positive list.* Redesign products focusing on the P list substances.

Step 5. *Reinvent.* Totally reinvent products, such as the automobile, to be "nutrivehicles."

Dave Pollard described this process more elegantly in his blog:[3]

1. Free ourselves from the need to use harmful substances (e.g., PVC, lead, cadmium, and mercury).
2. Begin making informed design choices (materials and processes that are ecologically intelligent, respectful of all stakeholders, and which provide pleasure or delight).
3. Introduce substance triage: (a) phase out known and suspected toxins, (b) search for alternatives to problematic substances, and (c) substitute for them "known positive" substances.
4. Begin comprehensive redesigns to use only "known positives," separate materials into biological and technical, and ensure zero waste in all processes and products.
5. Reinvent entire processes and industries to produce "net positives"— activities and products that actually improve the environment.

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Figure 3.29 The Herman Miller Mirra chair, which was certified by the Cradle to Cradle Products Innovation Institute, is made with recycled content, and 96 percent of its components break down for easy recycling. (Photograph courtesy of Herman Miller)

Cradle-to-cradle design provides an interesting framework for designing materials and products and focuses attention on waste and on the proliferation of toxic substances used in the production system. Clearly, these are important issues that deserve significant attention when selecting building systems and products for a high-performance built environment. A Cradle-to-Cradle certification process has been developed by McDonough and Braungart, and several products, such as the Herman Miller Mirra chair, have been successfully assessed under this scheme (see Figure 3.29).

It should be noted that the general approach used in cradle-to-cradle design is known as health-based assessment (HBA), and it focuses on known toxic components. More recently, HBA is being challenged by a newly emerging approach known as risk-based assessment, which is a more scientific approach that addresses concentrations and doses of materials used in products and their transformation in the manufacturing process. Chapter 11 on materials addresses this issue in more detail.

Thermodynamics: Limits on Recycling and the Dissipation of Materials

One of the notions repeatedly suggested by McDonough is that human designs should behave like natural systems. One of his oft-stated principles is "There is no waste in nature," with the implication that human systems should be designed to eliminate the concept of waste. In fact, zero-waste systems are not possible due to the laws of physics, more specifically the laws of thermodynamics. Nicholas Georgescu-Roegen (1971, 1979) dealt with the implications of the entropy law and the second law of thermodynamics for economic analysis. He described the important difference between primary factors of production (energy and materials) and the agents (capital and labor) that transform those materials into goods and services. The agents are produced and sustained by a flow of energy and materials that enter the production process as high-quality, low-entropy inputs and ultimately exit as low-quality, high-entropy wastes. This process restricts the degree to which the agents of production (capital and labor) can substitute for depleted or lower-quality stocks and flows of energy and material inputs from the environment. Thermodynamics can inform

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us about ultimate limits. There are irreducible thermodynamic minimum amounts of energy and materials required to produce a unit of output that technical change cannot alter. In sectors that are largely concerned with processing and/or fabricating materials, technical change is subject to diminishing returns as it approaches these thermodynamic minimums. Matthias Ruth (1995) used equilibrium and nonequilibrium thermodynamics to describe the materials–energy–information relationship in the biosphere and in economic systems. In addition to illuminating the boundaries for material and energy conversions in economic systems, thermodynamic assessments of material and energy flows, particularly in the case of effluents, can provide information about depletion and degradation that are not reflected in market prices.

What are the implications of thermodynamics and the entropy law for materials recycling? Georgescu-Roegen (1971) argued that materials are dissipated in use, just as energy is, so complete recycling is impossible. He elevated this observation to a fourth law of thermodynamics—or law of matter entropy—describing the degradation of the organizational state of matter. The bottom line for Georgescu-Roegen is that due to material dissipation and the generally declining quality of resource utilization, materials in the end may become more crucial than energy. However, his fourth law has been criticized by a number of analysts in both economics and the physical sciences.

A paper by Reuter, van Schaik, Ignatenko, and de Haan (2005) addressed the dissipation of materials in recycling by examining the technical feasibility of a European Union mandate for 95 percent end-of-life vehicle recycling by 2015 (see Figure 3.30), with an intermediate goal of 85 percent by 2006. One of the conclusions was that while the 85 percent target is achievable, the basic constraints of thermodynamics make it virtually impossible to reach the 95 percent goal. Consequently, at least 5 percent of the automobile mass dissipates into the biosphere. This is true of all recycling activities; the materials being recycled are dissipated to background concentrations, as dictated by the second and perhaps the fourth (according to Georgescu-Roegen [1971]) laws of thermodynamics. Indeed, the dissipation of materials in the recycling process begs a number of questions; among them is: What are the health and ecological impacts of recycling as practiced and as envisioned for a sustainable future?



Figure 3.30 A Mercedes Benz can be quickly disassembled for end-of-vehicle life recycling. (Photograph courtesy of Mercedes Benz GmbH, Stuttgart, Germany)

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A 1998 US Geological Survey report by Michael Fenton indicated some of the practical problems with so-called cradle-to-cradle strategies. Steel and iron scrap, for which there is high demand, is not recycled at a very impressive rate. Fenton's report stated that, in 1998, an estimated 75 million metric tons of steel and iron scrap was generated. The recycling efficiency was 52 percent, and the recycling rate was 41 percent.

In short, materials will be lost in recycling processes and, due to entropy, will seek to return to background concentrations for naturally occurring substances and to very low concentrations for synthetic materials. Cradle-to-cradle and other approaches do not address this potentially difficult issue when suggesting that recycling of technical nutrients is desirable. Again, recycling, like most other issues involved in improving materials cycles, is a matter of ethics, risk, and economics.

NATURAL CAPITALISM

The concept of natural capitalism was articulated by Hawken, Lovins, and Lovins (1999) in a book with the same name. Implementing natural capitalism entails four basic shifts in business practice:

Shift 1. *Radical resource productivity.* Dramatically increase the productivity of natural resources.

Shift 2. *Ecological redesign.* Shift to biologically inspired models.

Shift 3. *Service and flow economy.* Move to solutions-based business models.

Shift 4. *Investment in natural capital.* Reinvest in natural capitalism.

Each of these shifts is echoed in the other previously mentioned sets of principles and approaches. Relative to Shift 1, the productivity of natural resources can certainly be increased. However, natural renewable resources have little role in the creation of buildings, the vast bulk of which are made of human-designed materials. Hawken et al. (1999) claimed that the industrial manufacturing system converts 94 percent of extracted materials into waste, with just 6 percent becoming product. It is unclear how accurate these numbers are or if they reflect what actually occurs. The ultimate goal is to reduce resource extraction, which can be accomplished in three ways:

1. Dematerialization of products
2. Increasing the recycling rate of products at the end of their life cycle
3. Increasing the durability of products

If the industrial system were to double each of these factors, a Factor 8 increase in resource productivity would occur. And each of these factors is achievable over the short term.

Shift 2, to biologically inspired models, is also echoed time and again and focuses on developing systems with closed-loop behavior. However, as pointed out by Reuter et al. (2005), the laws of thermodynamics and separation efficiency dictate that closed loops are not closed loops at all; some fraction of the materials being recycled will dissipate into the environment and ultimately, after many recycling loops, materials will for all practical purposes be totally dissipated.

Shift 3, to a service and flow economy, is a proposal that has been made numerous times over the past decade and has received little serious attention. Having manufacturers retain ownership of building components and maintain responsibility for reusing or recycling them makes good sense on paper. However,

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maintaining the link between manufacturer and product, even after decades of use, would be extremely difficult, and the logistics system that would be required to dismantle buildings and return materials to their originators would be enormously complicated.

Shift 4, reinvesting in natural capital, is an important point and its implementation in the built environment context can be strongly reinforced. It is indeed possible to restore damaged sites and to ensure that the net ecological value of many sites is greater than it was prior to the alterations caused by building.

BIOLOGICAL MATERIALS, BIOMATERIALS, AND OTHER NATURE-BASED MATERIALS

One of the shifts advocated by many of the approaches just described is a shift from nonrenewable to renewable resources. Natural capitalism, the Natural Step, and cradle-to-cradle design, for example, suggest that this shift is fundamental for sustainability in general. A shift to renewable resources implies a shift in the materials sector to biological materials, biomaterials, and other natural or nature-based materials. Biological materials and biomaterials are two distinct classes of materials. *Biological materials* are natural systems products such as wood, hemp, and bamboo, while *biomaterials* are materials with novel chemical, physical, mechanical, or "intelligent" properties, produced through processes that employ or mimic biological phenomena.[4] Biomaterials include several emerging classes of biopolymers, such as polylactic acid and polyhydroxyalkanoate. Long-chain molecules synthesized by living organisms, such as proteins, cellulose, and starch, are natural biopolymers. Synthetic biopolymers are generated from renewable natural sources, are often biodegradable, and are not toxic to produce. Synthetic biopolymers can be produced by biological systems (i.e., microorganisms, plants, and animals) or chemically synthesized from biological starting materials (e.g., sugars, starch, and natural fats or oils). Biopolymers are an alternative to petroleum-based polymers (traditional plastics). (Bio)polyesters have properties similar to those of traditional polyesters. Starch-based polymers are often a blend of starch and other plastics (e.g., polyethylene), which allows for enhanced environmental properties.

Biological materials, such as wood pulp and cotton, can pose environmental problems. Unsound agricultural or silvicultural practices can quickly turn a fertile tract into a disaster area. Because biological resources are renewable, there is a tendency to think of them as unlimited. Nothing could be further from the truth. If cultivated carefully, crops can be planted in perpetuity. But if the land is pushed past its carrying capacity or otherwise abused, permanent damage can be done (Hayes 1978).

A widespread shift to biological materials for both energy and materials has other implications because large quantities of land may be required to provide ethanol, biological materials, and the feedstock for biomaterials such as biopolymers. An ethical debate is shaping up over taking excess land from food production and shifting it to these other applications, causing increases in food prices and impacting the poor and hungry of the world.

The fact that these materials are biodegradable and compostable means that they are recyclable via a biological route. However, there is a great deal of uncertainty about the quality and utility of the degraded materials and the logistics for effectively using these nutrients of unknown quality in agriculture or the support of natural systems.

Finally, there is little evidence that biologically based materials can replace the synthetic materials that have become common in construction, especially structural materials such as steel and concrete, not to mention copper and aluminum wiring, glass, and the wide variety of polymers used in myriad applications.

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Case Study: Kroon Hall, Yale University, New Haven, Connecticut

Ten years after the onset of the green building revolution in the United States, there are numerous examples of outstanding high-performance buildings, many of which have been awarded the platinum LEED rating, the highest accolade awarded by the USGBC. Although it is difficult to pick the best from among this group of facilities, Kroon Hall at Yale University in New Haven, Connecticut, certainly would be a contender for outstanding high-performance green building. The $33.5 million building houses the School of Forestry and Environmental Studies at Yale University, the home of such luminaries as Tom Graedel and Stephen Kellert, leaders and provocative thinkers of the contemporary sustainability movement. Kroon Hall is located on the site of a decommissioned power plant, derelict parking lot, and network of service roads that have been transformed into a highly visible place for the study of the environment on Yale's Science Hill Campus. Native plants, shade trees, and walking paths were employed to create a parklike landscape on the site of a former brownfield (see Figure 3.31A–E).



Figure 3.31 (A) Kroon Hall at Yale University in New Haven, Connecticut, is located on a former industrial area that included a decommissioned power plant, a derelict parking lot, and a network of service roads. A 100-kilowatt (kW) photovoltaic (PV) array on the roof provides about 25 percent of the building's electricity needs. (Robert Benson Photography)





Figure 3.31 (B–C) The former industrial site was transformed into an attractive location to study environmental science. The new landscaping around Kroon Hall provides a connection to ecological systems and to the research and instructional missions of the Yale School of Forestry and Environmental Studies. (B: Michael Taylor, Hopkins Architects Partnership; C: © OLIN)

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Figure 3.31 (D) The south side of the building is recessed, and window overhangs are integrated into the building façade to control glare and thermal loads while maximizing daylighting. (Photograph by Morley Von Sternberg)



Figure 3.31 (E) The daylighting strategy for Kroon Hall produces spectacular results and creates a pleasant connection to the outdoors. (Robert Benson Photography)

According to Hopkins Architects, the London-based firm that has created a number of other noteworthy high-performance buildings around the world, the similarity to an elegant New England barn was not intentional, but the design certainly fits the character of its New England surroundings. The building has a narrow profile and east–west orientation that contributes to maximizing opportunities for daylighting and renewable energy generation while at the same time enabling passive heating and cooling. To maximize daylighting, the design team decided to locate the building in the middle of the block in which it sits rather than at the end in order to prevent shading from adjacent structures. Breyer Hill sandstone is used on the north and south façades, and the vaulted roof is supported by glue-laminated beams. The clever use of horizontal shading along the south façade allows solar heat gain in the winter while blocking the heat gain and glare in the summer. Spandrel panels consisting of low-emissivity insulated glass units at the exterior, a 3-inch (8-centimeter [cm]) airspace, and a 2.5-inch (6-cm) space filled with translucent aerogel insulation were used as part of the building's façade. These remarkable panels transmit 20 percent of visible light while offering an insulation value at their center of more than R-20. The average insulation value of the curtain wall is about R-8, about four times better than that of a conventional curtain wall.

Kroon Hall is designed to consume 50 percent of the energy of a conventionally designed academic building and to reduce greenhouse gas emissions by 62 percent. The building is conditioned by a displacement ventilation system that introduces air through the floor at low velocity, providing very quiet spaces. Low-velocity fans in the basement circulate air almost imperceptibly and use relatively little energy. A 100-kW PV array on the rooftop supplies 25 percent of the building's electricity needs; the remainder of the required electricity is purchased from renewable energy sources to help meet the goal of carbon neutrality. Four solar thermal panels are located in the south façade to help provide the building with hot water. Heating and cooling are provided by ground-source heat pumps

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connected to four 1,500-foot- (484-meter-) deep wells, located near the building. During the fall and spring, the mechanical systems of the building are shut down, and color-coded lights are used to prompt building occupants to open the windows for cooling and ventilation. Other strategies used to reduce energy consumption include evaporative cooling, operable windows, and exposed concrete slabs that serve as energy sinks to both buffer temperature swings and reduce energy consumption.

A rainwater harvesting system conducts water from the roof and grounds to a courtyard, where aquatic plants filter out sediment and contamination; the water is used for landscape irrigation and for toilet flushing. The building's hydrologic cycle strategy, which includes the rainwater harvesting system, is predicted to save more than 600,000 gallons (2.3 million liters) of potable water per year. Waterless urinals and low-flow faucets together with toilets flushed by rainwater result in an 81 percent reduction in total potable water consumption for the building. To reduce stormwater runoff, a green roof was installed on one of the galleries and porous asphalt was used for all the walkways on the site. The green roof also decreases the building's cooling load and limits the urban heat island effect of the project while providing a pleasant view for occupants and visitors.

Although it was not the primary goal of the project team, Kroon Hall achieved a platinum LEED rating from the USGBC. The result of an excellent integrated design process was that the team was able to weave green strategies throughout the project in an intelligent and fruitful manner. As a result, Kroon Hall is an exemplar not only of high-performance green building but also of architecture.

SYNTHESIS

After the range of principles and approaches that describe how to create an environmentally sound and sustainable built environment have been examined, and taking into account the orientation of the human species toward the future, the development and deployment of new materials and products will likely be based on ethics, risk, and economics. Clearly, many lessons have been learned about the introduction of toxins and estrogen mimickers into the environment, the impacts of emissions on human and natural systems, the effects of extraction on the environment and human communities, the impacts of waste, and all the other well-known negatives of the production system. Changing the decision system, screening all substances for a broad range of impacts, is badly needed to ensure that the risks to nature and humans are minimized. Certainly, nature's materials and processes provide inspiration for human-designed materials and products, and the behavior of natural systems can inform human systems. But many novel materials and products will continue to be produced, and a systematic approach to examining the extraction, production, use, recycling, and disposal of these resources is needed. This would include life-cycle assessment, but with application of toxicology and other screens to produce a fuller understanding of the risks associated with the entire life cycle of materials. Beyond the question of materials is responsibility for products and ensuring their potential for disassembly. In the context of the built environment, one other level of disassembly, that of the whole building, must be considered for closing materials loops. Economics, underpinned by policy in the form of taxes that penalize negative behavior in the production and consumption system, will also help dictate the future. In the final analysis, ethics will have to govern the decision system. It also must address how humans use knowledge of potential negative impacts and, ideally, require detailed screening of all new chemicals and processes to ensure that their effects are well understood. Knowledge of these effects would allow risk assessment and the ultimate decision as to whether the benefits outweigh the costs.

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THOUGHT PIECE: REGENERATIVE DESIGN

Bill Reed, an internationally known architect and thinker, suggests that we are at the beginning of a shift in thinking about the design of human systems that ultimately needs to be restorative and regenerative, that we are faced with the necessity of actually having to help revive nature after the enormous damage done by human activities over centuries. Bill's work with Regenesis Group is to lift building and community planning into full integration and coevolution with living systems—through an integrative, whole-, and living-systems design process. The purpose of this work is to improve the quality of the physical, social, and spiritual life of our living places.

Regenerative Development and Design: Working with the Whole

Bill Reed, AIA, LEED, Hon. FIGP, Integrative Design Collaborative



Regeneration is both a practice philosophy and a process. Success in regeneration means to evolve and continually develop new potential. Its dictionary definition addresses both the action and the source of this new potential (1) to create anew and (2) to be born of a new spirit.

In practical terms, regeneration means to contribute to the value-generating processes of the living systems of which we are part. Without adding value—with a conscious awareness of the ongoing, cocreative, and emergent processes of life—life shifts to a degenerating state. The imperative in any design process is to intentionally develop the understanding required to participate in improving the resiliency of living relationships such as ecosystems, human social systems, businesses, families, and so on. Without a process of continually adding value to living systems, sustainability is not possible.

In order to understand regeneration in the context of the sustainability movement, it is necessary to understand that the practice of targeting of conservation, zero, or neutral conditions—while worthy and necessary aims—will not address what is required for a sustainable condition (even if it is possible to reach this level of perfection). Zero damage is not the same as understanding how we interact with the complexities of life and how to avoid the inevitable, unintended consequences of our actions. Nor does zero damage address how to continually participate in the dance of evolution—the entry-level condition to join the game of life.

There are a few reasons behind why we approach sustainability from this zero-based perspective: These aims are seen primarily from a technical perspective; we perceive life as a mechanical process of interactive components rather than understanding that living wholes are greater than the sum of their parts; humans are seen as the doers, not participants; and the environment is seen as something other than us.

There is a distinction between environmental and ecological thinking. By definition, an environment is the context within which something exists. Environment contains an "us" and a "not us" in its meaning. Ecology, by contrast, sees all aspects as part of a working dynamic whole—it's all us.

There is a need to fill a significant gap in our culture's work toward achieving a sustainable condition. The gap: the development of a state of consciousness that has the ability to hold life, all life, as a living entity that works as a whole, integrated, and evolving living system. The whole, from a living-systems perspective, includes everything, every process, and every dimension of consciousness and existence—whether we can perceive these things or not.

It is difficult for a reductionist culture to understand that working with the complexity of a living system is possible in the first place, and second, how it can be addressed without reducing it to manageable parts. This is where working with pattern understanding comes into play. For practitioners familiar with working with patterns, it is actually easier to assess living patterns and reach definitive conclusions from these distinct patterns than it is to try to make sense of thousands of pieces.

We are quite good at this when it comes to assessing a whole person: We intuitively know that we will not be able to understand the distinct nature (or essence) of a friend if there are only a few organs and bones available for inspection. Even if all his or her component parts were available, all the genetic sequencing, and so on, it is obvious that the nature of the

(continued)

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person can only be described mechanically, if at all. Yet, with observation, we are able to describe the uniqueness of individuals. We do this by looking at the patterns of how they, as a whole entity, are in relation to other entities— friends, colleagues, family members, their community, a dog in the street, and so on. It is how they are in relationship, what value they add to the relationship, the role they serve and provide that begin to triangulate "who" they are, not just "what" they are.

Often practitioners mistake the "flows" of a system as the indicator of relationship. Flows of water, energy, habitat, and sun are certainly important, yet, continuing to use human relationship as an analog, we would not describe our relationship to a friend only in terms of flows. The aspects of relationship are energetic, often invisible, and full of extremely complex and nuanced exchanges.

A living system—or place, or watershed, or community—is a "being" or "organism." It is necessary to be in relationship with it; if we are not, then abuse, neglect, or misunderstood interventions are the result. This nature of relationship is the big leap for the design and building industry. The land is not simply dirt that we build upon. Various aboriginal peoples had this understanding; everything in space and time, including the consciousness of "who" they were, was inextricably part of the whole.

The Navajo term for mountain refers to a "whole set of relationships and the ongoing movement inherent in those relationships. These relationships include the life cycles of the animals and plants which grow at different elevations, the weather patterns affected by the mountain, as well as the human's experience of being with the mountain. All of these processes form the dynamic interrelationship and kinetic processes that regenerate and transform life." Since this notion of the mountain is not separate from the entire cosmic process, one can only really come to know the mountain by learning about "the kinetic dynamics of the whole."

All this is not to say that working in pieces and parts with quantitative measurement is wrong. It is just the wrong place to start. As Wendell Berry observes, "A good solution is good because it is in harmony with those larger patterns, solves more than one problem, and doesn't create new ones." He goes on to explain that health is to be valued above any cure, and coherence of pattern above almost any solution produced piecemeal or in isolation. Adopting one or two green or regenerative technologies into a green building practice without understanding the underlying principles that make the approach wholly regenerative is not as effective and, at worst, produces unintended counterproductive consequences.

Western and Eastern medicine practices may be a useful comparison. Neither is right nor wrong in itself. Green design, as it is practiced in a mechanical manner, can be compared to working on the heart or intestinal system as a specialist might—curing the particular issue but not addressing the overall systemic nature of the cause, whether it is diet, environment, stress, or genetics. Integrative design, an organized process to find synergies among building and living systems, has an analogy in integrative medicine—many specialists getting together to diagnose and address relatively complex cause and effects. Regeneration might be compared to naturopathic and Eastern medicine—cranial sacral therapy, acupuncture, and so on—these practices start with the energetic patterns of the whole body. In practice, all these practices should come into play. Yet, it is always better to start with the nature of the larger environmental influences and interrelationships before solving for the symptom and cutting the body open.

From the perspective of architecture and planning, our responsibility is not to design "things" but to positively support human and natural processes in order to achieve long-term quality of life—that is, evolution with the necessary corollary of positive potential for all life.

- This means that the act of creating a building is not a conclusion but a beginning and catalyst for positive change.
- This sets the building within and connects it to a larger system and is concerned with an overall systems approach to design.
- This considers "place"—an expression of integrated ecologies of climate, resources, and culture—critical to the shaping of building, human, and natural development.

There are current designs and policy practices that approach this nature of interrelationship with the places we inhabit. Ecosystems have been seen to recover their health and demonstrate even greater levels of potential than imagined—deserts being turned into food-producing gardens with minimal water use; water being brought back to the desert by appropriate planting and techniques of slowing down water flows; damaged, low-diversity, and desertified ecosystems brought back in to full flower along with increased animal and plant habitat by replicating preindustrial animal habitat patterns; urban areas brought back to civility and high quality of life through paying attention to the nature of human and natural patterns in each unique place. Examples include Jane Jacobs's work in New York City neighborhoods as noted in *The Death and Life of Great American Cities*, in which she uses the term *regeneration* for her work. Alan Savory's work in creating new health in damaged ecosystems is another example. Regenesis in Santa Fe, New Mexico, looks at the socioecological whole and unites these "sectors" as a whole system of healthy evolution.

There are many positive stories, evidenced around the world, about regenerative design. We have frequently seen the first glimmer of new health and wholeness in nature and human habitat appear within a span of 18 months—the qualifier is if we understand that every place (neighborhood, city, region) has a pattern of life and that these places are both unique and nested within each other, that the smallest unit of place-sourced design is the watershed (water activates soil health and therefore life), that humans are nature and not separate from it, and that becoming conscious of the need to be in caring relationship with all life is the foundation of a positive and thriving coexistence—and thus moves us into the realm of true coevolution.

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Summary and Conclusions

Clearly, a shift is afoot in the design of buildings in the United States. In 2005, just 2 percent of nonresidential new construction was green buildings; by 2008, this had increased to 12 percent, and by 2010, it had grown to between 28 and 35 percent. By 2015, an estimated 40 to 48 percent of new nonresidential construction by value will be green, equating to a $120 to $145 billion market. It is estimated that for the four-year period from 2009 to 2013, green building supported 7.9 million US jobs and pumped $554 million into the US economy (McGraw-Hill Construction 2010). At a minimum, it can be said that high-performance green building has been a tremendous success. Whether green building rating systems such as LEED can be said to be driving building design to be environmentally friendly and resource-efficient is another question. Certainly, considering the rapid deterioration of our planet's fragile health, any measures that help reduce the destruction of its ecological systems, minimize waste, and use resources more effectively are helpful.

At the very least, high-performance green building can be said to be making deep inroads in addressing the disproportionate impact of the built environment on Earth. In particular, this movement makes design and construction professionals more aware of their ethical responsibilities for providing high-quality, healthy buildings that have the potential for complementing and working synergistically with nature.

Notes

1. Coincidentally, the founder of systems ecology, Howard T. Odum (1924–2002), and the founder of adaptive management, Crawford "Buzz" Holling (1930), worked together at the University of Florida for an extended period of time in the last two decades of the twentieth century. Odum's book, *Systems Ecology* (1983), and Holling's book, *Adaptive Environmental Assessment and Management* (1978), are landmark works that redefined how scientists think about ecological systems.
2. Based on information from the Buckminster Fuller Institute website, www.bfi.org.
3. From a blogpost by David Pollard in his blog, *How to Save the World*, "Sustainability, Cradle-to-Cradle," February 12, 2006. Available at http://howtosavetheworld.ca/2006/02/12/sustainability-cradle-to-cradle/
4. As described at the US Department of Agriculture website, http://agclass.nal.usda.gov/glossary.shtml.

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Part II

Assessing High-Performance Green Buildings

At present, high-performance green buildings are defined by the assessment systems that rate and certify them. Building assessment systems simply score a building project on how well it lines up with the general philosophical approach developed by the designers of the system. As a result, a building assessment system provides a standard definition for green building for the country employing it. In the United States, for example, the Leadership in Energy and Environmental Design (LEED) building assessment system, its categories, and the allocation of points for various green attributes define green building for the American marketplace, both public and private. One advantage of relying on building assessment systems for this purpose is that it standardizes the boundaries of what constitutes a high-performance green building, what its important attributes are, and how the performance of the project across a wide variety of categories is measured. A significant disadvantage of these assessment systems is that each is simply one organization's vision of a green building, and often, because of time and financial constraints, assessment systems leave much to be desired. For example, many assessment systems rely on energy modeling to forecast energy consumption rather than using actual energy data as the arbiter of success. The result has been the occasional embarrassing report stating that the actual energy consumption is much higher than was originally forecast by the energy model. The rationale for not using real energy consumption data is that gathering the data takes time (generally a minimum of a year), and the cost of this effort is not insignificant. Another problem associated with overdependence on building assessment systems is that project teams risk losing the ability to think creatively and instead develop "LEED-brain." As clever and useful as LEED and other assessment systems may be, they leave a lot to be desired with respect to a wide range of important issues.

The types of ratings vary widely among assessment systems. LEED, for example, has four ratings based mostly on precious metals: platinum, gold, silver, and certified, from highest rating to lowest. In a similar fashion, Green Globes awards one to four green globes, and the Green Star system used in Australia, New Zealand, and South Africa provides one to six green stars. In Green Star, however, only the four- to six-star projects are really meaningful because one to three Green Stars does not result in certification. In Japan, the Comprehensive Assessment System for

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Building Environmental Efficiency (CASBEE) calculates a ratio of environmental benefits to environmental loadings such that a ratio of 3.0 or higher earns the project the top award. Most assessment systems have standards categories, such as energy, water, and indoor environmental quality, for rating the building. Some have a management category for rating the conduct of the building project while others do not feel this aspect is worthy of scoring. Clearly, there is no one single approach to building assessment, although recently there seems to be convergence on the need to provide a life-cycle assessment of the building's materials and operating impacts.

This part of the book addresses the general subject of building assessment, the major international building assessment systems, and the major building assessment systems used in the United States. The chapters covered in this part of the book are:

Chapter 4: Green Building Assessment

Chapter 5: The US Green Building Council LEED Building Rating System

Chapter 6: The Green Globes Building Assessment System

Chapter 4 is a general overview of green building assessment and covers the main issues relevant to building assessment. The two major building assessment systems used in the United States, LEED and Green Globes, are briefly described. The Living Building Challenge, a truly challenging building assessment system used in the United States and Canada, with stringent requirements for a wide range of green attributes, is covered in some detail because it provides some insights into what may be the shape of future rating systems. Additionally, this chapter provides an overview of each of the building assessment systems used in the United Kingdom, Japan, Australia, and Germany.

Chapter 5 focuses on the LEED building assessment system and includes a detailed description of LEED version 4 (LEED v4), the current version. It covers the history of the development of LEED, the structure of the LEED suite of rating systems, the structure of the major LEED rating systems, and a description of all the credits that are available for projects seeking certification under one of the rating systems in the category of LEED Building Design and Construction (LEED-BD&C). The importance of having people specially trained and experienced in the application of LEED to projects is discussed in this chapter. For the LEED building assessment system, the credential LEED Accredited Professional is awarded to individuals who have had appropriate training on green building and the LEED rating system and who have passed an examination on these topics. The Green Associate (GA) is another credential offered by the US Green Building Council, and it is a prerequisite for becoming a LEED AP. The GA credential identifies individuals who have taken and passed an examination on green building fundamentals. Because both LEED v4 and LEED v3 are available to project teams for the next few years, Appendix A provides information about LEED v3.

Chapter 6 addresses the Green Globes building assessment system, which is supported by the Green Building Initiative located in Portland, Oregon. The history, structure, and credits that are available in Green Globes are covered in this chapter. Similar to LEED, Green Globes offers a structured program for providing projects with individuals who have been accredited as being proficient in the application of Green Globes to building projects. This program includes two levels of accreditation: the Green Globes Professional (GGP) and the Green Globes Assessor (GGA). Similar to the LEED AP, the GGP is qualified to assist project teams navigate the Green Globes building assessment and certification system. The role of a GGA has no equivalent in LEED, because the GGA provides third-party verification that the project has met the requirements of the GBI for Green Globes certification.

Building assessment systems are evolving over time, and the various platforms, such as LEED, CASBEE, and Green Star, learn from each other and adopt the practices that have emerged as the most useful and best received by the international community.

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Chapter 4

Green Building Assessment

Prior to the advent of *building assessment* or *building rating systems*, environmentally friendly buildings were conceptualized by teams of architects and engineers who relied on their collective interpretation of what constituted green building. Beyond the understanding that green buildings should be resource efficient and environmentally friendly, no specific criteria existed to evaluate and compare the merits of green building design. In 1990, the UK's Building Research Establishment (BRE), the national building science research organization, developed the BRE Environmental Assessment Method (BREEAM), which is considered the first assessment system for buildings. BREEAM, similar to its counterparts in other countries, rates the performance of a building based on a set of criteria (see www.breeam.org). Building assessment systems are generally organized into categories, such as energy, water, and materials, and award points for criteria that are met by the project team in the design of the facility. These assessment systems also certify, often using a third-party assessor, that the project has achieved specified levels of performance. In 1998, the US Green Building Council (USGBC) launched its *Leadership in Energy and Environmental Design* (LEED) building assessment system for new construction. Versions of LEED are available for various building types and situations. For example, there are LEED tools available for schools, health care, and retail buildings, to name but a few. LEED employs a point system to award a platinum, gold, silver, or certified rating based on how many specific predetermined criteria in several categories the building successfully addresses. In addition to LEED, two other building assessment systems are currently in common use in the United States, Green Globes and the Living Building Challenge.

The generic term for LEED and similar systems used in other countries is *building assessment system* or *building rating system*. The Japanese building assessment system, the *Comprehensive Assessment System for Building Environmental Efficiency* (CASBEE), was developed by the Japan Sustainable Building Consortium.[1] In Australia, *Green Star* is the building assessment system advocated by the Green Building Council of Australia (GBCA) (www.gbcaus.org) and is fully implemented for a number of building types, including new and existing offices and office interiors. One of the newer building assessment systems is the Deutsche Gesellschaft für Nachhaltiges Bauen/Bewertungssystem Nachhaltiges Bauen für Bundesgebäude (DGNB/BNB), which was developed by the German Sustainable Building Council.

Purpose of Green Building Assessment Systems

Building assessment systems score or rate the environmental, resource, and health impacts of a building's design, construction, and operation against the criteria established by the assessment system. This determination can be complicated

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because each aspect of a building's performance can have different units of measurement which applied varying physical scales. Environmental effects can be evaluated at local, regional, national, and global scales. Resource impacts are measured in terms of mass, energy, volume, parts per million, density, and area. Building health can be inferred by the presence or absence of chemical and biological substances within circulating air as well as the relative health and well-being of the occupants. Comparing arrays of data for various building features presents further complications.

Another dimension that is important in building assessment is *time*. A building that is certified as being high performance at the start of its life cycle can eventually perform poorly if a program of continuous monitoring and assessment is lacking. Also, if during maintenance, alterations, and renovation, the new and replacement systems do not meet the high-performance requirements of the original building, it would be questionable whether the facility would maintain its green certification. For example, in replacing large mechanical system components such as chillers, if the new systems have lower efficiencies than the original equipment, then it may be difficult to justify the building retaining its certification as a green building. Although it would make sense for a building to lose its original certification as a result of degrading performance, this is not occurring yet, even though it probably is desirable. Thus, green buildings currently retain their original certification regardless of future conditions. To cope with this situation, the various building assessment schemes, such as LEED in the United States and BREEAM in the United Kingdom, have what are generally referred to as *existing building rating tools* for periodically assessing building performance across time. Although not mandatory, the shift to continual recertification is gaining momentum as owners are realizing the benefits of maintaining the building's high quality and performance.

One additional phenomenon regarding building assessment systems is the increasing specialization of these tools to tailor them more directly to the building's function. Thus, most systems have assessment tools for office buildings, schools, health care, hospitality, and an increasing number of building types. There are now assessment systems specifically for evaluating areas where groups of buildings, residential and/or nonresidential, are intended to be built. For example, LEED for Neighborhood Development (LEED-ND) is a tool for rating land development where a combination of residential and nonresidential buildings will be constructed.

Why consider a building assessment standard or rating at all? In general, building assessment systems are created for the purpose of promoting high-performance buildings, and some, like LEED, are specifically designed to increase market demand for sustainable construction. Building assessment systems generally offer a label and/or a plaque indicating a building's rating. The plaque is usually affixed to the building and provides a public statement of the building's performance. A superior assessment rating has been shown to increase a building's market value and can be attributed to the building's lower operating costs and the perceived positive health and productivity benefits for the occupants. Competition among owners and developers to achieve high building assessment ratings has resulted in the development of a significant stock of high-quality, high-performance buildings. Building assessment systems can also help facilitate otherwise difficult political goals, such as national requirements related to the Kyoto and other protocols on climate change, which, in effect, call on the United States to reduce fossil fuel consumption significantly.

Developers of building assessment systems generally face two major choices when designing a building assessment system: either use a single number to describe the building's overall performance or provide an array of numerical and qualitative information for the same purpose. A single number representing an overall score for

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the building has the virtue of being easy to understand. However, to produce a single score, the system must somehow convert the many different units describing the building's resource and environmental impacts (energy usage, water consumption, land area footprint, materials, and waste quantities) and conditions resulting from the building design (building health, built-in recycling systems, deconstructability, and percentage of products coming from within the local area) into a series of numbers that can be added together to produce a single overall score. This approach is difficult and arbitrary at best. Paradoxically, however, both the advantage and the disadvantage of the single-number assessment is its simplicity. The LEED rating system produces a single number that determines the building's assessment or rating based on an accumulation of points in various impact categories, which are then totaled to obtain a final score.

Alternatively, a building assessment system can utilize an array of numbers or graphs that depict the building's performance in major areas, such as environmental loadings or energy and water consumption, compared to conventional construction. Although this approach yields more detailed information, its complexity makes it difficult to compare buildings, depending on the range of factors considered. The Sustainable Building Tool (SBTool), a system used in the Green Building Challenge conferences to compare building performance in several countries, is an example of an assessment methodology that uses a relatively large quantity of information to assess the merits of a building's design.[3]

This chapter briefly describes the two major US building assessment standards, LEED and Green Globes, and one emerging system, the Living Building Challenge. LEED is described in much greater detail in Chapter 5, and Green Globes is covered in depth in Chapter 6. There are over 60 green building assessment systems worldwide (see Figure 4.1). This chapter also provides information about other major building assessment standards or systems used around the world, including BREEAM (United Kingdom), CASBEE (Japan), Green Star (Australia, New Zealand, and South Africa), DGNB/BNB (Germany), and the Green Building

Country	Rating System
Peru	EDGE
Philippines	BERDE/Philippine Green Building Council
Portugal	Linder A/SBToolPT®
Qatar	Qatar Sustainability Assessment System (QSAS)
Republic of China (Taiwan)	Green Building Label
Saudi Arabia	Saudi Arabia Accredited Fronds (Sa'af)
Singapore	Green Mark
South Africa	Green Star SA/Edge
Spain	Verde
Switzerland	Menergie
United States	LEED/Living Building Challenge/Green Globes/Build it Green/NAHB NGBS/International Green Construction Code (IGCC)/Energy Star
United Kingdom	BREEAM
United Arab Emirates	Esitdama
Turkey	CEDBIK
Thailand	TREES
Vietnam	LOTUS Rating Tools/EDGE
Czech Republic	SBToolCZ

Country	Rating System
Australia	Nabers/Green Star/BASIX (in NSW only)
Brazil	AQUA/LEED Brasil/EDGE
Canada	LEED Canada/Green Globes/Built Green Canada
China	GBAS
Colombia	EDGE
Egypt	Green Pyramid Rating System (GPRS)
Finland	PromisE
France	HQE
Germany	DGNB/CEPHEUS
Hong Kong	BEAM Plus
India	Indian Green Building Council (IGBC)/Green Building Construction India (GBCIndia)/ GRIHA/EDGE
Indonesia	Green Building Construction Indonesia (GBCI)/Greenship/EDGE
Italy	Protocollo Itaca/Green Building Council Italia
Japan	CASBEE
Republic of Korea	Green Building Certification Criteria/Korea Green Building Council
Malaysia	GBI Malaysia
Mexico	LEED Mexico
Netherlands	BREEAM Netherlands
New Zealand	Green Star NZ
Pakistan	Pakistan Green Building Council

Figure 4.1 Names of some of the green building assessment systems being used in over 60 countries

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TABLE 4.1

Issue Date and Awards for the Major International Building Assessment Systems

Country	Rating System	First Issue Date	Awards
United Kingdom	BREEAM	1989	Outstanding Excellent Very Good Good Pass Unclassified
United States	LEED	1998	Platinum Gold Silver Certified
United States	Green Globes	2005	4 Green Globes 3 Green Globes 2 Green Globes 1 Green Globe
Japan	CASBEE	2001	S (Excellent) A (Very Good) B+ (Good) B– (Rather Poor) C (Poor)
Australia	Green Star	2003	6 Stars 5 Stars 4 Stars*
Germany	DGNB/BNB	2006	Gold Silver Bronze
China	GBEL	2007	3 Stars 2 Stars 1 Star

*Green Star does not award projects 1, 2, or 3 stars.

Evaluation Label (GBEL) (China). Several families of rating systems are emerging (Table 4.1), some using LEED and others using BREEAM as their platform. Indeed, much of LEED is similar to BREEAM, implemented in 1989, which predates LEED by almost 10 years. Green Star, which was launched in 2003, and which has similarities to both LEED and BREEAM, is emerging as a unique platform with a number of innovative approaches to evaluating high-performance buildings. It is clear that the lineage of the major building assessment systems started with BREEAM, which provided the foundation for LEED and Green Star. Each of these three systems is the basis for several other assessment systems. CASBEE dates from 2001 and is currently used only in Japan and has little similarity to LEED. The German DGNB/BNB (2006) rating system is also unique and is emerging as a new potential platform for building assessment systems in other countries, for example, Denmark. In China, the Green Building Evaluation Label (GBEL) is a voluntary national rating system administered by the Ministry of Housing and Urban-Rural Development. GBEL is a green building certification program that evaluates projects based on six categories: land, energy, water, resource/material efficiency, indoor environmental quality, and operational management. The program utilizes a three-star rating system, with Three Stars being the highest achievable rating level, followed by Two Stars and One Star.

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Major Green Building Assessment Systems Used in the United States

There are two major green building assessment systems used in the United States, LEED and Green Globes, and one emerging system, the Living Building Challenge. LEED and Green Globes are described in far more detail in Chapters 5 and 6, respectively, while the Living Building Challenge (http://living-future.org/lbc/about) is addressed in this chapter. Although LEED is the most frequently used US building assessment system, Green Globes is gaining traction as an alternative and is being adopted on a large scale by, for example, the US Department of Veterans Affairs to assess the performance of its existing hospitals undergoing renovation. The Living Building Challenge is, as its name implies, a significant certification challenge because it raises the bar for high-performance buildings to a new high level that for the first time requires building projects to demonstrate they can generate all their energy needs from on-site renewable resources. This requirement represents just one of a number of difficult-to-achieve goals that the Living Building Challenge poses for project teams and owners. The Living Building Challenge is described in more detail next.

THE LIVING BUILDING CHALLENGE

The most demanding of all the North American building assessment systems is the *Living Building Challenge*, which originated in 2005 as an outgrowth of programs by the Cascadia Green Building Council in the northwestern United States and western Canada. Its intent was to push the envelope of high-performance building much farther than it was likely to be pressed by LEED and other building assessment systems. The Cascadia Green Building Council is unique among green building councils in North America because it represents both the USGBC and the Canada Green Building Council. There are now over 200 buildings registered and pursuing certification under the Living Building Challenge, yet only six buildings have completed the certification process.

The Living Building Challenge is based on a few simple but very powerful concepts, among them that a building should produce as much energy as it consumes, provide all the required water, and process all its sewage. One of the more recent projects undergoing Living Building Challenge certification is the Bullitt Center, a new office building located in the Capitol Hill neighborhood of Seattle, Washington, which earned Living Building certification in 2015 (see Figures 4.2 and 4.3). The Bullitt Center is the home of the Seattle-based Cascadia Green Building Council and will serve as an exemplar of the cutting edge of high-performance buildings in the Pacific Northwest. The Bullitt Center uses less than one-third the energy of a comparable building, and parking is provided for bikes but not for cars. The on-site solar power system meets all the energy requirements of the building yet has a payback of 8 to 10 years. Building materials considered hazardous, such as polyvinyl chloride (PVC) plastics, mercury, cadmium, and 360 other substances, were not used. The wooden timbers for the six-story frame originated in forests certified as sustainable by the Forest Stewardship Council. All steel, concrete, wood, and other heavy materials were sourced from within a 300-mile (480 km) radius to help reduce the building's carbon footprint. The stringent requirements of the Living Building Challenge resulted in a collaboration between the building's architect, Miller Hull Partnership, and the University of Washington's Integrated Design Lab, a unit of the Department of Architecture. Three years of brainstorming resulted in an innovative design that not only was able to meet the demands of the Living Building Challenge but was also cost-effective in spite of its higher initial costs.

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Figure 4.2 The Bullitt Center in Seattle, Washington, is the home of the Cascadia Green Building Council and is being designed for certification to the Living Building Challenge. Among its other purposes, it is an exemplar for future commercial buildings for low-impact and responsible construction. (Courtesy of the Miller Hull Partnership)

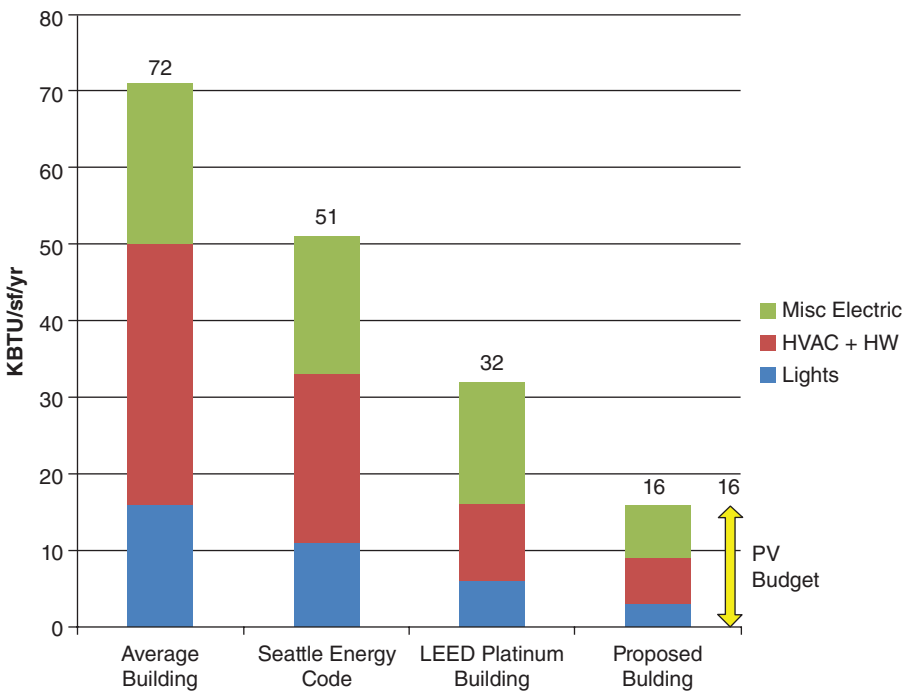


Figure 4.3 The path to net-zero energy for the Bullitt Center meant a thorough rethinking of building energy consumption. Energy was reduced from about 72,000 to 16,000 BTU/ft^2/yr (227–50 Kwh/m^2/yr), more than a Factor 4 reduction, to be within the energy budget provided by the sun and the capabilities of the photovoltaic system. Even the most ambitious LEED platinum building would likely have used twice the energy of the proposed design.

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The Living Building Challenge 3.0, the most recent version, is based on seven performance areas, or *petals*, consisting of Place, Water, Energy, Health and Happiness, Materials, Equity, and Beauty. Within the seven petals, there are 20 *imperatives* that provide specific guidance for achieving certification (see Table 4.2). Unlike other building assessment systems, the Living Building Challenge requires that the project meet all of the imperatives, not just a sufficient number to gain adequate points for certification. Living Building Challenge certification is awarded only after 12 months of continuous operation that demonstrate that the building has achieved its performance goals. The imperatives of the Living Building Challenge are all very demanding. For example, Imperative 06 of the Water Petal, Ecological Water Flow, requires that 100 percent of stormwater and building water discharge be managed on-site to meet the project's internal water demands or released onto adjacent sites for management through acceptable time-scale surface flow, groundwater recharge, agricultural use, or adjacent building reuse. The imperatives under the Equity Petal are unique and also demanding, requiring various measures that promote social justice and equity while also preserving the rights of nature. The Beauty Petal also is unique in requiring that the project produce an object of beauty and inspire and educate the community.

One of the outcomes of the Living Building Challenge has been the stimulation of interest in truly advanced, high-performance buildings (Figure 4.4). The Living

TABLE 4.2

Seven Categories(Petals) and 20 Imperatives of the Living Building Challenge

Petal	Imperatives
Place	1. Limits to Growth 2. Urban Agriculture 3. Habitat Exchange 4. Human-Powered Living
Water	5. Net Positive Water
Energy	6. Net Positive Energy
Health	7. Civilized Environment 8. Healthy Interior Environment 9. Biophilic Environment
Materials	10. Red List 11. Embodied Carbon Footprint 12. Responsible Industry 13. Living Economy Sourcing 14. Net Positive Waste
Equity	15. Human Scale and Humane Places 16. Universal Access to Nature and Place 17. Equitable Investment 18. Just Organizations
Beauty	19. Beauty and Spirit 20. Inspiration and Education



Figure 4.4 Among the innovative ideas emerging as a result of the Living Building Challenge is an off-grid building submitted by Mithun to Canada's Living Building Challenge. As required by the Living Building Challenge, the building is designed to be completely energy and water sufficient. It includes greenhouses, rooftop gardens, a chicken farm, and fields for growing produce. This integrated system of urban agriculture meets another imperative of the Living Building Challenge. (Rendering by Mithun)

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Building Challenge has significantly raised the bar for high-performance green buildings. There has been renewed interest in the high-performance green building movement to radically lower the impacts of the built environment on both humans and natural systems.

International Building Assessment Systems

Several significant building assessment systems are used in other countries and provide other perspectives on how to approach the problem of determining how environmentally friendly a given building design may be. In the following sections, five building assessment systems are described: BREEAM (United Kingdom), CASBEE (Japan), Green Star (Australia), DGNB/BNB (Germany), and the GBEL (China). SBTool, a building assessment method that is used by countries participating in the Green Building Challenge series of conferences to compare buildings using a uniform approach, is also described.

BREEAM (UNITED KINGDOM)

BREEAM is an acronym for the *Building Research Establishment Environmental Assessment Method* for buildings. This assessment system is designed to describe a building's environmental performance. Launched in 1989 in the United Kingdom, it is considered the first building assessment system and served as the foundation for many other rating systems, including LEED. Currently, there are over 200,000 BREEAM-certified buildings, 20 times the number of LEED-certified buildings, and 1 million buildings have been registered for BREEAM certification. BREEAM sets the standard for best practice for sustainable building performance in the United Kingdom. It can be used to rate any type of building, and there are several building-specific BREEAM building assessment systems, each designed for a defined type of building. BREEAM is also used in a country-specific format in the Netherlands, Norway, Sweden, and Spain.

At present, BREEAM has six different *schemes* that can be used to assess the performance of virtually all types of buildings including homes (see Table 4.3).

BREEAM UK for New Construction, one of the building-specific BREEAM rating systems, consists of 49 individual assessment issues spanning nine environmental categories, plus a 10th category titled Innovation. Each issue addresses a specific building-related environmental impact or issue and has a number of credits assigned to it. BREEAM credits are awarded when a building demonstrates that it

TABLE 4.3

Applicability of BREEAM Schemes

Standard BREEAM Schemes	Project Types
BREEM UK New Construction	All new buildings except homes
BREEAM UK Communities	Master planning phase of a development
BREEAM In-Use	Existing nondomestic buildings
EcoHomes	New and refurbished social housing
Code for Sustainable Homes	New homes
BREEAM UK Refurbishment	Domestic and nondomestic refurbishment projects

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TABLE 4.4

BREEAM Rating Benchmarks

BREEAM Rating	Percentage Score	Performance
Outstanding	85%	Less than 1% of new UK nondomestic buildings (innovator)
Excellent	70%	Top 10% of UK nondomestic buildings (best practice)
Very Good	55%	Top 25% of UK nondomestic buildings (advanced best practice)
Good	45%	Top 50% of UK nondomestic buildings (intermediate best practice)
Pass	30%	Top 75% of UK nondomestic buildings (standard best practice)
Unclassified	Under 30%	

meets the best-practice performance levels defined by that issue; for example, it has mitigated an impact or, in the case of health and well-being, addresses a specific building occupant-related issue, for example, good thermal comfort, daylight, or acoustics. Table 4.4 shows the ratings provided by BREEAM for a given building project. Table 4.5 indicates BREEAM's environmental section weightings and a sample calculation for a hypothetical building. The percentage benchmark or threshold for each level of rating is an example of a BREEAM score and rating calculation, and it indicates the BREEAM sections and the credits available for each of the sections. A BREEAM Assessor must determine the BREEAM rating using the appropriate assessment tools and calculators.

TABLE 4.5

BREEAM Environmental Section Weighting and Sample Rating Calculation

Environmental Section Weighting		Sample Score and Rating Calculation			
BREEAM Section	**Percentage of Weighting**	**Credits Achieved**	**Credits Available**	**Percentage of Credits Achieved**	**Section Score**
Management	12.0%	10	22	45.45%	5.45%
Health and Well-Being	15.0%	8	10	80.00%	12.00%
Energy	19.0%	16	30	53.33%	10.13%
Transport	8.0%	5	9	55.56%	4.44%
Water	6.0%	5	9	55.56%	3.33%
Materials	12.5%	6	12	50.00%	6.25%
Waste	7.5%	3	7	42.86%	3.21%
Land Use and Ecology	10.0%	5	10	50.00%	5.00%
Pollution	10.0%	5	13	38.50%	3.85%
Innovation	10.0%	2	10	20.00%	2.00%
		Final BREEAM Score:			**55.66%**
		BREEAM Rating:			**VERY GOOD**

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BREEAM Case Study: AHVLA Stores Building, Weybridge, United Kingdom

A new two-story stores building was developed to replace an existing building on the Animal Health and Veterinary Laboratories Agency (AHVLA) campus near Weybridge, United Kingdom (see Figure 4.5). For reasons of structural loading and accessibility, the primary storage, receiving, and shipping areas are located on the ground floor, and the office, lockers, and restrooms are located on the first floor. The building was designed for compact and economical space use and circulation flow in a minimum rectangular envelope. This shape achieves both a reduced volume of heated space in the building (and so of energy demand) and a reduced external surface area from which heat energy can be lost. The stores building was commissioned by the Department for Environment, Food and Rural Affairs as part of a wider redevelopment of the campus. The project was BREEAM assessed in accordance with the department's policy of achieving the highest environmental targets for developments on its estate.

KEY FACTS

- BREEAM rating: Excellent
- Score: 83.76%
- Size: 1,500 m^2
- BREEAM version: Industrial 2006

OVERVIEW OF ENVIRONMENTAL FEATURES

- Vertical-axis wind turbines mounted on the roof.
- Biofuel boiler.
- Compact building envelope with good thermal insulation.
- Solar shading.
- Surface water runoff from roof via "weir" cascade (instead of traditional downpipes) into underground storage and attenuation tank (due to local high water table).



Figure 4.5 AHVLA headquarters, located in Weybridge, United Kingdom, achieved a BREEAM score of excellent. (*Source:* Animal Health and Veterinary Laboratories Agency)

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- Rainwater harvested and used for toilet flushing.
- Good thermal insulation and airtightness. The site's relatively exposed and noisy location next to the M25 highway allowed for noise reduction through the building fabric to be combined with highly insulated external walls and roof. The nature of the building requires a largely windowless external envelope, which also presented opportunities for achieving a good thermal and airtight envelope.

THE BREEAM ASSESSMENT

The stores building performed very well across all categories with the top-scoring categories being:

- Water and Management: 100% of available credits
- Pollution: 92.31%
- Health and Well-Being: 85.71%
- Energy: 83.33%

BUILDING SERVICES

- Biofuel boiler—running on pure rapeseed oil, which has a low carbon dioxide emission factor
- 436 kW vertical-axis wind turbine units—feeding back into the site's electricity network when the building's use is less than the electricity generated
- Sun pipes—supplementing passive infrared controlled lighting to internal areas
- Solar thermal heating to supplement the low-temperature hot water system

GREEN STRATEGY

The client set out the objectives for this project from the very first briefing meetings and was emphatic in aiming for the highest achievable green strategy. As part of earlier initiatives for the Department for Environment, Food and Rural Affairs, the design team reviewed more than 30 possible options for environmentally sustainable improvements that could be used on the campus redevelopment. The team could quickly assess and incorporate the most appropriate elements into the new stores building during the briefing and design stages, so these elements were fully integrated into the design and not considered as later add-ons. This approach also enabled the maximum synergy between mutually contributing elements (e.g., water storage, stormwater attenuation, reduction of above- and belowground drainage, and optimization of the site area), giving added value to the BREEAM elements.

CASBEE (JAPAN)

The *Comprehensive Assessment System for Building Environmental Efficiency* is the Japanese building assessment system. CASBEE was developed by the *Japan Sustainable Building Consortium*, which is composed of academic, industrial, and government entities, specifically for Japanese cultural, social, and political conditions. The key concept in CASBEE is *building environmental efficiency* (BEE), which is a description of the *ecological efficiency*, or *eco-efficiency*, of the built environment. The World Business Council for Sustainable Development defines eco-efficiency as maximizing economic value while minimizing environmental impacts. Similarly, CASBEE defines BEE as maximizing the ratio of building quality to environmental loadings.

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Building quality (Q) is described by CASBEE as the amenities provided for building users and consists of several quantities:

Q1: Indoor environment
Q2: Quality of service
Q3: Outdoor environment on-site
Q: Total quality
Q = Q1+ Q2 + Q3

Similarly, there are several categories of *environmental loadings* (L) in CASBEE:

L1: Energy
L2: Resources and materials
L3: Off-site environment
L: Total loading
L = L1 + L2 + L3

As noted earlier, BEE is simply the ratio of building quality to building environmental loadings. The BEE rating calculation produces a number, generally in the range of 0.5 to 3, that corresponds to a building class, from class S (highest for a BEE rating of 3.0 or higher) to classes A (BEE of 1.5–3.0), B^1 (BEE of 1.0–1.5), B^2 (BEE of 0.5–1.0), and C (BEE less than 0.5). The relationship of quality (Q) to loading (L) in CASBEE and the resulting BEE letter scores are diagrammed in Figure 4.6. Clearly, it is desirable to have as high a BEE rating as possible. Although simple in concept in that it relies on mathematical reasoning, extensive data gathering and calculations are required to make a determination of the BEE rating. For the example shown in Figure 4.6, the BEE value is 1.4 based on a building quality (Q) value of 59 and a building environmental loading (L) value of 41.

CASBEE has been refined since its inception in 2004 and is now a suite of rating systems, as shown in Figure 4.7 and Table 4.6. Each CASBEE building

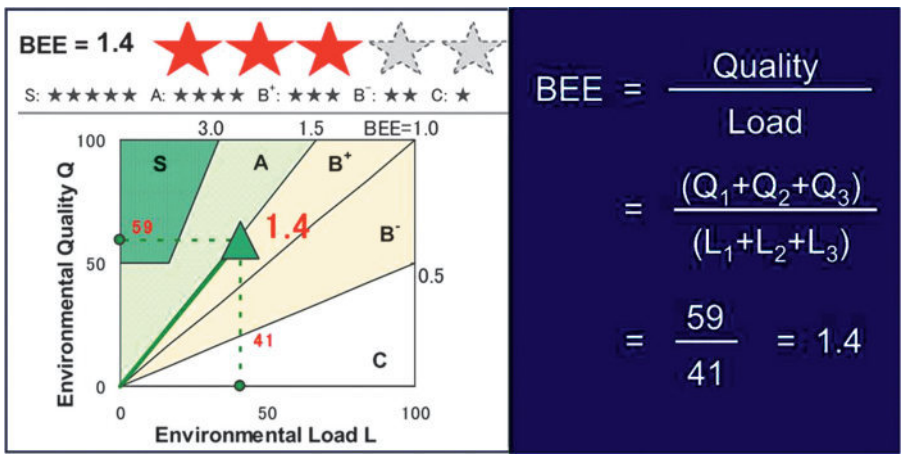


Figure 4.6 The BEE rating is determined by finding the intersection of Q (building quality) and L (building loadings). High ratings (S and A) are achieved by buildings with high environmental quality and performance and low environmental loadings. Higher resource consumption and lower environmental quality produce below-standard ratings (B^2 or C). (*Source:* Japan Sustainable Building Consortium)

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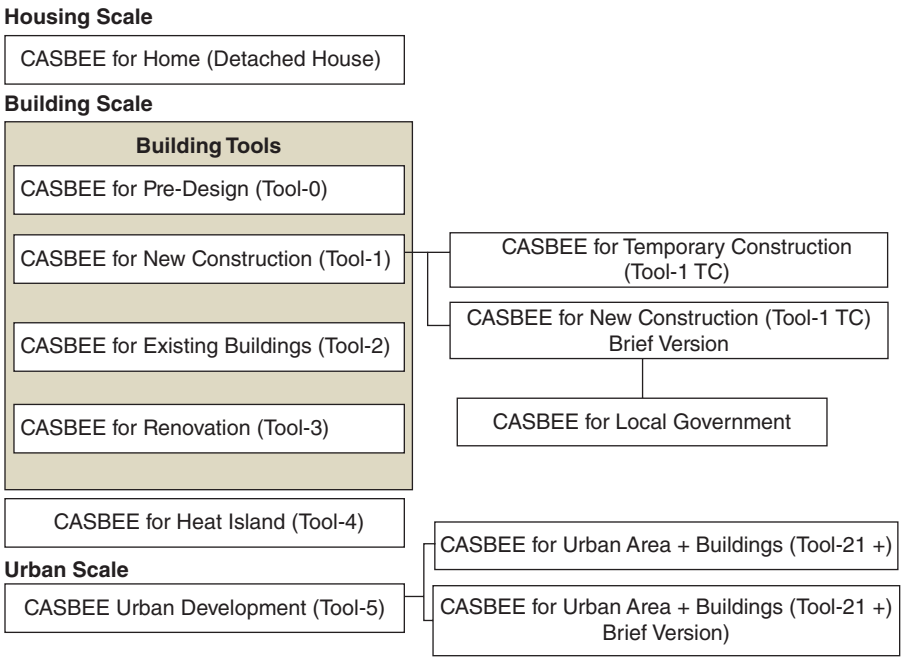


Figure 4.7 The CASBEE family of tools indicating the scaling and building stage assessments built into the system. This assessment system can be applied to individual homes and buildings up to urban scale. It can also be applied not only to new construction but also to existing buildings and renovations of existing buildings.

assessment system provides a numeric score and a one- to five-star rating for the building, depending on its BEE rating, as indicated in Table 4.7.

One interesting use of the BEE approach embedded in CASBEE is for renovation projects. Using the CASBEE-Renovation (CASBEE-RN) building assessment system, the BEE value can be calculated before and after renovation. In the example shown in Figure 4.8, the building had a BEE of 0.6 prior to renovation and a BEE of 1.4 after the renovation, increasing its rank from B^2 to B^1.

GREEN STAR (AUSTRALIA)

Green Star is the major Australian green building assessment scheme and is similar in many respects to BREEAM and LEED in its approach and structure. The Green

TABLE 4.6

CASBEE Building Assessment Systems

Name of CASBEE Building Assessment System	Short Name	Latest Version
New Construction	CASBEE-NC	2014
Temporary Construction	CASBEE-NC/TC	2005
Existing Buildings	CASBEE-EB	2010
Renovation	CASBEE-RN	2010
Heat Island	CASBEE-HI	2010
Detached Home	CASBEE-DH	2010
Urban Development	CASBEE-UD	2014
Site	CASBEE-S	2010
New Construction—Tenant	CASBEE-NC/T	2010

TABLE 4.7

CASBEE Grading System Based on BEE Value

CASBEE Grade	Stars	BEE Value
S (Excellent)	★★★★★	Over 3.0
A (Very Good)	★★★★	Under 3.0, over 1.5
B^1 (Good)	★★★	Under 1.5, over 1.0
B^2 (Rather Poor)	★★	Under 1.0, over 0.5
C (Poor)	★	Under 0.5

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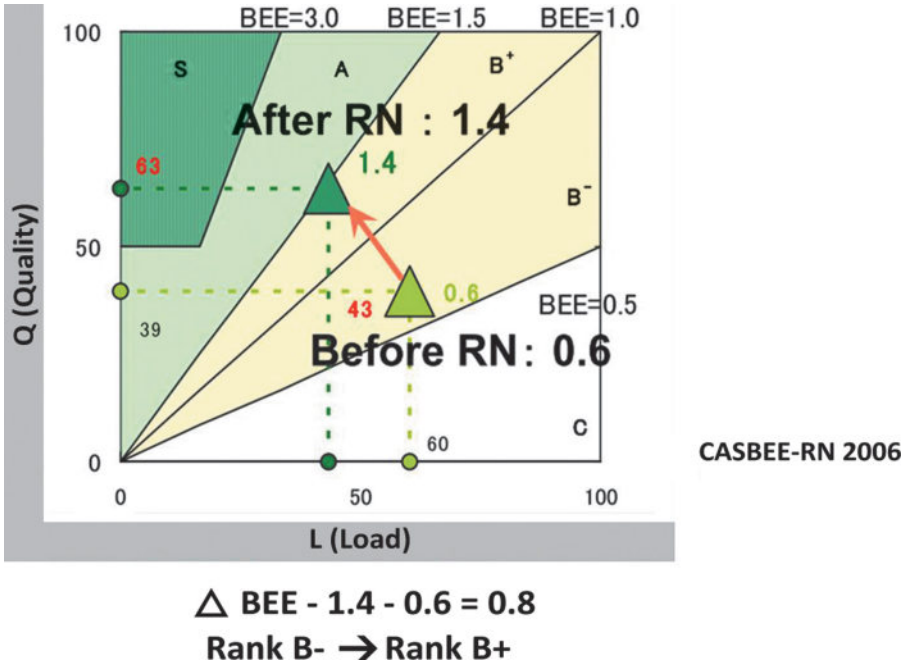


Figure 4.8 The BEE rating can be used to set goals for performance improvement for existing buildings. The building represented in this graphic increased its rating from 0.6 to 1.4. (*Source:* Japan Sustainable Building Consortium)

Table 4.8

Green Star Rating Tools

Green Star Rating Tool	Status
Communities	Active
Designed and As-Built	Active
Performance	Active

Building Council of Australia (GBCA) developed the Green Star Office rating tool in 2002, and now a variety of additional tools cover a wide range of building types (see Table 4.8). Green Star has been adopted by New Zealand and South Africa as the platform for their national building assessment systems.

The Green Star building assessment system awards from one to six green stars, but only those buildings with ratings of four to six green stars have significance with respect to being considered high-performance buildings. The GBCA describes the three highest levels of achievement in this way:

> *4 Star Green Star Certified Rating* (score 45–59) signifies "Best Practice" in environmentally sustainable design and/or construction.
>
> *5 Star Green Star Certified Rating* (score 60–74) signifies "Australian Excellence" in environmentally sustainable design and/or construction.
>
> *6 Star Green Star Certified Rating* (score 75–100) signifies "World Leadership" in environmentally sustainable design and/or construction.

Nine categories are assessed in a Green Star rating, and the number of green stars awarded to the project is based on the percentage of the total points available. Table 4.9 shows the points and percentages of total points for each of the nine categories for Green Star Office v3.

Each category has several issues associated with it, as indicated in Table 4.10 for *Green Star Designed and As-Built*. There are several *conditional requirements* in Green Star, one in the Energy category and one in Land Use and Ecology. These are similar to the prerequisites found in the USGBC LEED building assessment system.

Like all third-party certification systems, Green Star certification is a formal process that involves a project using a Green Star rating tool (e.g., Green Star Office v3) to guide the design or construction process. During that process, documentation is gathered for use in the two assessment phases of the project. The GBCA commissions a panel of third-party certified assessors to validate that the

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TABLE 4.9

Categories and Points in the rating tool, *Green Star Designed and As-Built*

Green Star Category	Points	Percentage of Total
Management	12	8.1%
Indoor Environment	27	18.2%
Energy	29	19.6%
Transport	11	7.4%
Water	12	8.1%
Materials	25	17.0%
Land Use and Ecology	8	5.4%
Emissions	19	12.8%
Innovation	5	3.4%
Total	**148**	**100.0%**

documentation for all claimed credits follows the compliance requirements for each rating tool. Project teams are notified of their score based on the recommendation of the assessment panel and, where applicable, of any innovation credits that have been awarded by the GBCA. If a certified rating is awarded, the project receives a framed certificate, award letter, and relevant Green Star logos.

TABLE 4.10

Issues in *Green Star Designed and As-Built*

1. Management	IEQ-11 Hazardous Materials
Man-1 Green Star Accredited Professional	IEQ-12 Internal Noise Levels
Man-2 Commissioning Clauses	IEQ-13 Volatile Organic Compounds
Man-3 Building Tuning	IEQ-14 Formaldehyde Minimization
Man-4 Independent Commissioning Agent	IEQ-15 Mold Prevention
Man-5 Building Users' Guide	IEQ-16 Tenant Exhaust Riser
Man-6 Environmental Management	
Man-7 Waste Management	**3. Energy**
	Ene-Conditional Requirement
2. Indoor Environment	Ene-1 Greenhouse Gas Emissions
IEQ-1 Ventilation Rates	Ene-2 Energy Submetering
IEQ-2 Indoor Air Quality	Ene-3 Lighting Power Density
IEQ-3 Carbon Dioxide Monitoring and Control	Ene-4 Lighting Zoning
IEQ-4 Daylight	Ene-5 Peak Energy Demand Reduction
IEQ-5 Daylight Glare Control	
IEQ-6 High Frequency Ballasts	**4. Transport**
IEQ-7 Electric Lighting Levels	Tra-1 Provision of Car Parking
IEQ-8 External Views	Tra-2 Fuel-Efficient Transportation
IEQ-9 Thermal Comfort	Tra-3 Cyclist Facilities
IEQ-10 Individual Comfort	Tra-4 Commuting Mass Transit

(continued)

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TABLE 4.10 *(continued)*

Issues in *Green Star Designed and As-Built*	
5. Water	Eco-2 Reuse of Land
Wat-1 Occupant Amenity Water	Eco-3 Reclaimed Contaminated Land
Wat-2 Water Meters	Eco-4 Change of Ecological Value
Wat-3 Landscape Irrigation	
Wat-4 Heat Rejection Water	**8. Emissions**
Wat-5 Fire Water System Consumption	Emi-1 Refrigerant ODP
	Emi-2 Refrigerant GWP
6. Materials	Emi-3 Refrigerant Leaks
Mat-1 Recycling Waste Storage	Emi-4 Insulant ODP
Mat-2 Building Reuse	Emi-5 Watercourse Pollution or Stormwater
Mat-3 Reused Materials	Emi-6 Discharge to Sewer
Mat-4 Shell and Core or Integrated Fit-Out	Emi-7 Light Pollution
Mat-5 Concrete	Emi-8 Legionella
Mat-6 Steel	
Mat-7 PVC Minimization or PVC	**9. Innovation**
Mat-8 Sustainable Timber or Timber	Inn-1 Innovative Strategies and Technologies
Mat-9 Design for Disassembly	
Mat-10 Dematerialization	Inn-2 Exceeding Green Star Benchmarks
7. Land Use and Ecology	
Eco-Conditional Requirement	
Eco-1 Topsoil	

Green Star Case Study

One of the recipients of the highest, six-star rating from Australia's Green Star building assessment system is 1 Bligh Street in Sydney, Australia, co-owned by DEXUS Property Group, DWPF, and Cbus Property (see Figure 4.9). The 28-story building is Australia's first high-rise with a double-skin façade, and it also has a full-building-height, naturally ventilated atrium that helps maximize daylighting at each office floor level. The double-skin façade has internal blinds and external louvers that are automatically adjusted depending on their orientation to the sun (see Figure 4.10). This system conserves energy, eliminates sky glare, and optimizes user comfort. The unique full-height atrium and elliptical-shaped floor plates enable 74 percent of the building to be within 8 meters of either the façade or the atrium, providing large amounts of natural light into the building and spectacular views in all directions. Its energy performance is outstanding, with a 42 percent carbon dioxide reduction when compared to a similar-size conventional office tower. On top of the building, 500 square meters of roof-mounted solar panels capture solar energy to directly power an absorption chiller to drive the cooling systems, an advanced hybrid of variable air volume and chilled-beam air-conditioning technology.

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Figure 4.9 (A) The property at 1 Bligh Street in Sydney, Australia, is one of the most advanced buildings in the world, with a double-skin façade, solar-powered air-conditioning system, and a blackwater recycling system. (B) The naturally ventilated 28-story atrium assists in providing spectacular daylighting for all floors. (Images supplied courtesy of ingenhoven + architectus [Sydney])

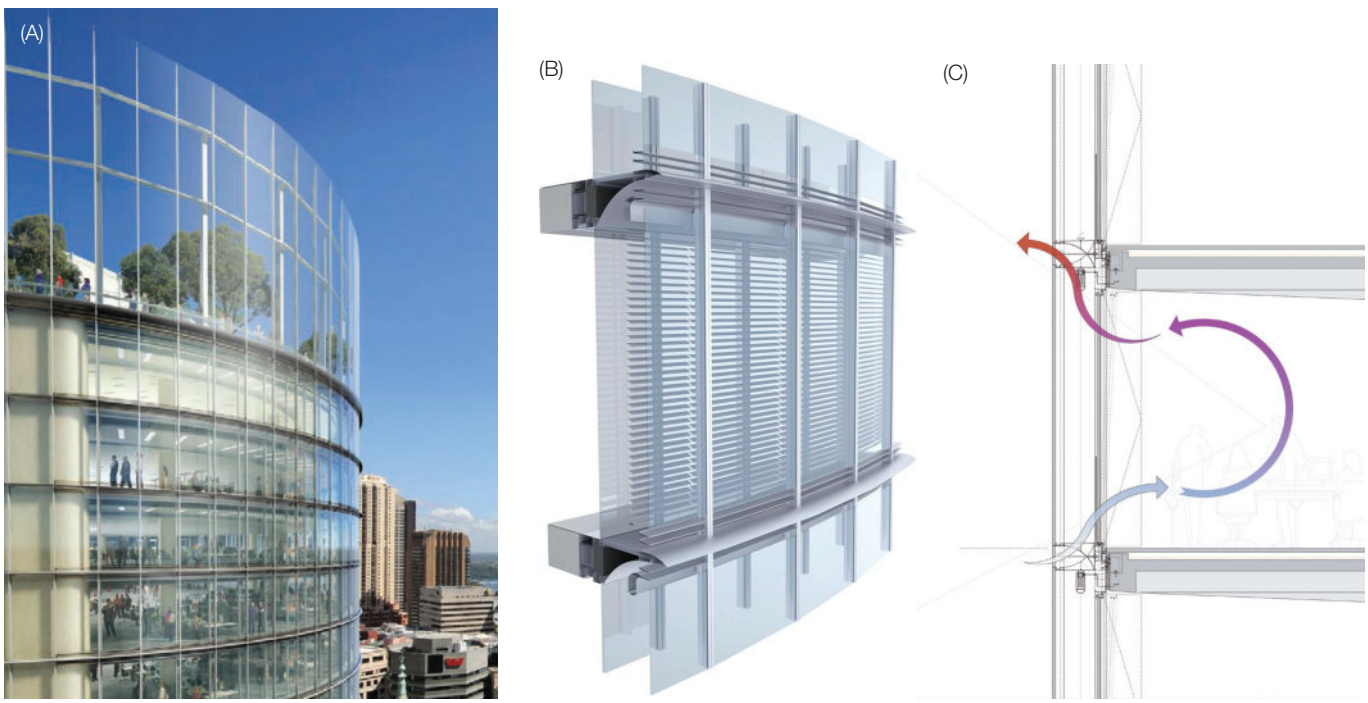


Figure 4.10 (A–B) The double-skin façade of 1 Bligh Street has a system of internal blinds that automatically deploy or adjust to optimize the combination of daylighting and energy transmission while protecting the occupants from glare. (C) Detail of air movement through the façade. (Images supplied courtesy of ingenhoven + architectus [Sydney])

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Water is a crucial resource everywhere, but nowhere is it more precious than in Australia, which is in the grip of a decade-long severe drought. New projects, such as 1 Bligh Street, provide an opportunity to demonstrate how to truly minimize potable water consumption. It has the first blackwater recycling system in a high-rise office building in Australia, and it will save 100,000 liters of drinking water a day, equivalent to filling an Olympic-size swimming pool every two weeks. Wastewater is mined from the building and nearby sewers, processed, and then distributed around the building for nondrinking purposes, with 75,000 liters used for cooling towers and 25,000 liters used for flushing toilets. The system provides 100 percent recycled water for toilet flushing as well as 90 percent of cooling tower makeup water. Sydney's goal is to have recycled water provide at least 15 percent of its water supply. One Bligh Street is an important example because it employs new blackwater recycling technology.

The use of specially formulated high-strength concrete reduces the number of columns and therefore minimizes the amount of concrete used. Timber and plywood used in the structure is recycled or from Forest Stewardship Council accredited sources. The steel used in the project comprises more than 50 percent recycled content. Over 80 percent of all PVC-type products have been replaced with non-PVC materials. Over 37,000 metric tons, amounting to 94 percent of all construction waste produced on the project, was recycled.

DGNB/BNB (GERMANY)

Germany has a long history of designing high-performance buildings, but only recently has there been an effort to develop a green building certification program. The first steps in developing such a program and building assessment system started in 2001 with the production of the German *Sustainable Building Technical Manual*. This served as the genesis of an effort that culminated in the formation of the German Sustainable Building Council (DGNB [Deutsche Gesellschaft für Nachhaltiges Bauen]) in 2007 and the emergence of a formal certification system.

There are actually two green building assessment systems in Germany. The first of these is the DGNB, which is directed at nonresidential, commercial buildings. The other building assessment system is the BNB (Bewertungssystem Nachhaltiges Bauen für Bundesgebäude, or Assessment System for Sustainable Construction for Government Buildings), which is used only to assess government buildings. The administration of the two systems is carried out by different organizations that cooperate to ensure uniformity in the application of the rating systems.

DGNB/BNB is the newest major building assessment system, and it differs substantially from systems employed by other countries. For most other building assessment systems, including LEED, BREEAM, and Green Star, the categories that the developers feel are important are the starting point for creation of the building assessment system. For example, in LEED, six categories were deemed important: Sustainable Sites, Water Efficiency, Energy and Atmosphere, Materials and Resources, Indoor Environmental Quality, and Innovation in Design. These were further subdivided into issues. For example, for the LEED Energy and Atmosphere category, energy consumption, renewable energy, building commissioning, and impacts of refrigerants are the issues that can be awarded points toward certification. This approach is sometimes referred to as a *bottom-up strategy.* In contrast, DGNB/BNB was developed using a *top-down strategy*; that is, the authors of DGNB/BNB based the allocation of points on the three major areas of consideration for sustainability: Ecology, Economy, and Socioculture (see Figure 4.11). The questions asked prior to producing the building assessment and certification system were: What are the sustainability issues relevant to construction? What needs to be protected? How does this protection occur? As shown in Figure 4.12,

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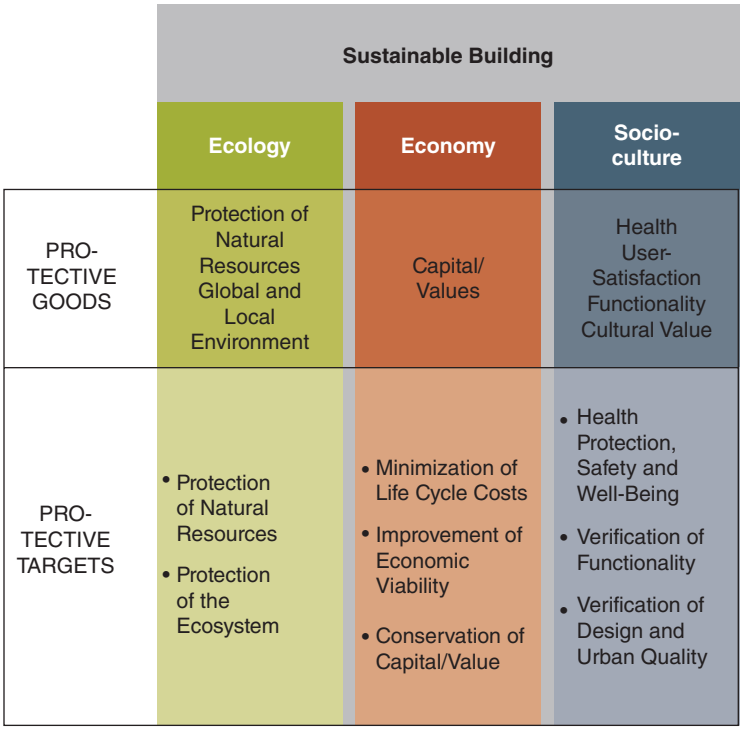


Figure 4.11 The developers of the DGNB/BNB assessment system used a top-down approach in its design with the three legs of sustainability as the major points of evaluation (ecology, economy, and socioculture). The process of developing the assessment system included considering what needed to be protected and the specific targets for protection.

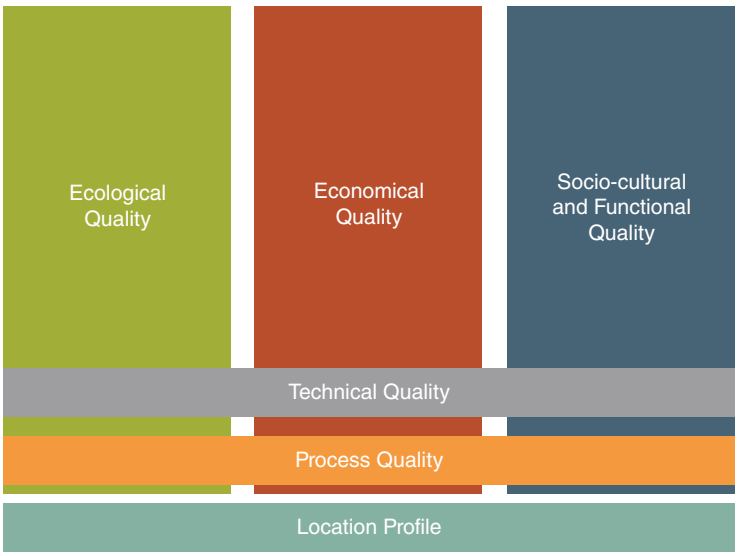


Figure 4.12 The three major sustainability areas of evaluation (ecological quality, economic quality, and sociocultural-functional quality) each carry 22.5 percent of the possible points in the DGNB/BNB. Technical quality carries 22.5 percent, and 10 percent of the points are allocated to process quality. The statement of the location profile is an administrative requirement that must be accomplished for certification.

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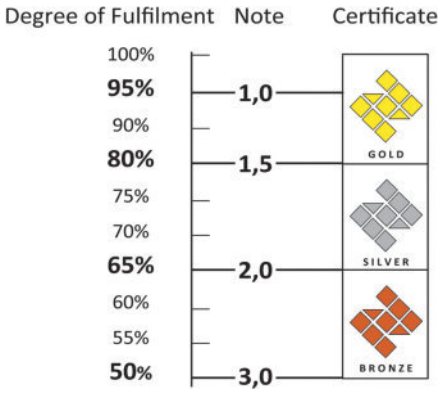


Figure 4.13 The DGNB provides for three levels of certification (gold, silver, and bronze) and a grade (labeled as "Note" in the figure) based on the percentage of points achieved.

the three major areas of sustainability were used as the basis for organizing the DGNB/BNB building assessment system, and three other issues were also considered: Technical Quality, Process Quality, and the project's Location Profile. The three major areas of sustainability were determined to be equally important along with Technical Quality, and each of these was allocated 22.5 percent of the available points, a total of 90 percent. The final 10 percent of the total points was allocated to Process Quality, issues such as Integrated Design, Commissioning, and Quality Assurance.

The final outcome of the project evaluation is the award of a certificate. As indicated in Figure 4.13, there are three certification levels: gold, corresponding to a minimum 80 percent score; silver, which requires at least 65 percent of the available points; and bronze, requiring a minimum of 50 percent of the total points available. The result of this approach is a very logical and comprehensive rating system that addresses a wide range of factors while also providing a balanced approach to assessing a building's performance. In the environmental impact section of the evaluation, there is extensive use of life-cycle assessment, more so than in any other contemporary rating system, and benchmarks have been established for impacts per square meter of building in order to determine the number of points to be awarded for each factor being evaluated. Typical German high-performance office buildings consume on the order of 100 kWh/m^2/yr of primary energy, a number that is not achievable without significant reductions in conventional mechanical cooling system energy consumption. It should be noted that, for the sake of comparison, this number includes all major building systems but does not include plug loads. This very low level of energy consumption is impressive and can be accomplished only with a well-integrated design process and with significant latitude given to architects and engineers to use creative approaches to develop this type of advanced building. One other significant factor that differs from the design of buildings in, for example, the United States is that the occupants in German buildings are willing to accept a significantly larger comfort zone. Due to the nature of naturally ventilated buildings, temperatures are difficult to maintain in a very narrow band; however, the German designers have demonstrated that they can keep temperatures within a reasonable comfort zone with very few annual cases where temperature drifts outside of this zone.

An example of a DGNB certified building, Theaterhaus in Stuttgart, Germany, is covered in detail in Chapter 7.

SBTooL

SBTool is a comprehensive and sophisticated building assessment tool developed for the biannual international Green Building Challenge, which was held in 1998 (Paris, France), 2000 (Maastricht, Netherlands), 2002 (Oslo, Norway), 2005 (Tokyo, Japan), 2008 (Melbourne, Australia), 2011 (Helsinki, Finland), and 2014 (Barcelona, Spain). SBTool provides a standard basis of comparison for the wide range of buildings being evaluated in the Green Building Challenge. It requires a comprehensive set of information not only on the building being assessed but also on a benchmark building for use in comparing how well the green building performs compared to the norm. SBTool requires the group using it to establish benchmark values and weights for the various impacts. The tool is implemented in the form of a sophisticated Excel spreadsheet that can be downloaded from the website of the International Initiative for a Sustainable Built Environment (iiSBE). The output from SBTool provides an assessment of the building in seven different categories: Resource Consumption, Environmental Loadings, Indoor Environmental Quality, Service Quality, Economics, Management, and Commuting Transport.

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Thought Piece: Building Assessment

Ray Cole is perhaps the leading international thinker on the subject of building assessment and has researched and written papers on the subject for about 20 years. In this thought piece, he discusses the role of performance assessment methods and advocates their use in helping to address global societal needs. He also points to regenerative design and its emphasis on "place" as an important subject for assessment because it ties together many of the key important aspects of sustainable construction, such as systems thinking, community engagement, and respect for place.

Shifting Emphasis in Green Building Performance Assessment

Raymond J. Cole, School of Architecture and Landscape Architecture, University of British Columbia, Canada



The term *green building* has been used fairly consistently over the past two decades to describe those buildings that have a higher environmental performance compared to that of typical buildings, and the term *green building performance assessment methods* has been used to describe approaches that provide an objective measure of their environmental strengths. The emphasis on green design has been primarily directed at creating buildings that "do less harm" or, more generally, play a key role in reducing the degenerative consequences of human activity on the health and integrity of ecological systems (McDonough and Braungart 2000; Reed 2007).

Performance assessment methods have unquestionably been instrumental in mainstreaming green building practice and have profoundly influenced the range of considerations deemed important in design. They are now embedded within the parlance of building procurement, design and construction, and operation. Given that the major systems are now global "brands" with considerable organizational support, they will continue to play a dominant role for the foreseeable future. While the maintenance of a brand can constrain the type and extent of changes that can be made to their structure and content, they clearly must evolve in terms of scope and emphasis. Indeed, while green building performance assessment tools were initially conceived to engage industry, encourage widespread adoption of green practices, and "transform the market," their scope and application has increasingly expanded. While initial versions were directed at the construction of new buildings—often office buildings—this was followed by an expansion into versions for other building types (hotels, factories, homes, etc.) and conditions (commercial interiors, existing buildings, renovations, etc.). The Japanese CASBEE building assessment system has versions specifically addressing property appraisal that map the performance criteria against increased revenue, reduced costs, reduced risks, and improved image. The focus of these developments was always the performance of individual buildings. With their maturation, the scope of assessment systems has been further extended in scale to embrace communities, urban design, and infrastructure planning, for example, LEED-ND, BREEAM Communities, and CASBEE Urban Design (see Japan Sustainable Building Consortium 2010). This shift in scale is perhaps the most significant development over the past decade and may be indicative of the increasing need to redefine the spatial and temporal boundaries of consideration and link the environmental performance of buildings more explicitly with their ecological and physical/infrastructure context. While the performance of the individual building clearly remains important, the scale and emphasis appears to be shifting toward what is considered meaningful, comprehensible, and manageable for society to collectively engage in effecting positive change.

(continued)

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Current building environmental assessment methods have a number of distinct characteristics, including that: criteria are technically framed and based on metrics that are quantifiable, measurable, and comparable and which, in aggregate, are assumed to offer an accurate measure and understanding of overall green building performance; and the overall success of a building is measured through the simple addition of the weighted (either implicitly or explicitly) scores attained for the individual performance issues. Moreover, the need for clear, unambiguous assessment and avoiding "double counting" has required the performance criteria to be kept discrete. The resulting simple listing of performance requirements and scoring inhibits the ability to see how they function as part of an integrated system, both internally and with the context in which they sit. Reed (2007) characterizes this attribute of green design and the associated assessment tools as indicative of the legacy of reductive and fragmented thinking.

In North America, the Living Building Challenge, launched in August 2006, is a recognized demanding and complementary performance aspiration to the LEED green building rating system (see International Living Building Institute 2010). All of its 20 "imperatives" must be met before the designation of "Living Building" is granted. This stands in contrast to LEED, where, particularly for the certified, silver, and gold levels, it is possible to select (or "cherry-pick") the credits to attain the necessary overall performance level. Although, similar to LEED, its structure is simply a list of performance requirements set within seven broad categories. The demanding performance requirements of the Living Building Challenge criteria are, however, challenging many norms and conventions and driving toward greater synergistic design. In a similar way that LEED and other major assessment methods have expanded from individual buildings to communities, the Living Building Challenge evolved to permit "scale jumping" in recognition that different performance issues are more easily or appropriately addressed at different scales, from individual buildings to an entire region.

The term *sustainable building* often is used synonymously with *green building*, although the former carries the expectation of extending the range of considerations to include broader social and economic issues. And, with this, "sustainability" assessment methods—such as Arup's Sustainable Project Assessment Routine (SpeAR; www.arup.com/Projects/SPeAR.aspx), iiSBE's SBTool (www.iisbe.org), the South African Green Star SA Rating System (www.gbcsa.org.za/green-star-sa-rating-system/), and the GSBC's Certificate Program have been introduced that explicitly acknowledge this expanded range of performance issues. As with green building assessment methods, sustainability tools have recognizable frameworks that convey their scope, structure, and organization, but these are typically presented graphically. Whereas SPeAR, SBTool, and the Sustainable Building Assessment Tool frame performance issues within a circle segmented into the key performance areas, the German Certificate Program distinguishes the three "sustainability" quality categories from the technical and process criteria that cut across them and then presents the output in a circular format. The representation of the criteria within a circular framework as distinct from the list format common to many green building assessment tools is, presumably, seen as evoking potential links and synergies among the various performance criteria. However, as with current green building assessment tools, they still remain discrete, and weighted scores are again simply aggregated.

Expanding the framework to include social, cultural, ecological, and economic considerations moves the assessment into areas where there is greater difficulty and less consensus regarding performance metrics. Perhaps more significantly, buildings, in and of themselves, cannot be sustainable but can only be designed to support sustainable patterns of living (Gibberd 2005). Such a responsibility clearly shifts the focus on building performance to the larger context in which they are situated. Rather than striving solely for an understanding of an individual building's performance, the potential contribution a building makes to the social, ecological, and economic health of the place within which it functions will perhaps become of equal, if not more, significance.

A number of historical threads that have either been latent or running parallel to green building discourse and practice over the past 40 years are now converging under the umbrella of regenerative design and development and, with it, the reframing of approaches to discuss and assess performance. While many of its core tenets—systems thinking, community engagement, respect for place—have long individual histories in architectural design, regenerative design begins to tie them together in a cogent manner. Regenerative design relates to approaches that support the coevolution of human and natural systems in a partnered relationship. Within regenerative development, built projects, stakeholder processes, and inhabitation are collectively focused on enhancing life in all its manifestations—human, other species, ecological systems—through an enduring responsibility of stewardship (du Plessis 2012; Pedersen Zari and Jenkin 2008; Mang and Reed 2012). Regeneration, in contrast to the emphasis on "doing less harm," which has dominated past green building practice—and is the emphasis of most environmental assessment methods—carries the positive message of considering the act of building as one that can give back more than it receives and thereby over time build social and natural capital. Such an approach requires design to acknowledge and respond to the unique attributes of "place" and secures sustained stakeholder engagement to ensure a project's future success.

The structure and emphasis of current green building assessment tools offer little instruction regarding understanding and engaging local ecosystems and their processes or, more generally, of the systems thinking emphasized in regenerative design. Regenerative design requires a fundamental reconceptualization of the act of building design primarily in terms of imagining, formulating, and enabling its role within a larger context (Mang and Reed 2012). It would therefore seem appropriate that the representation of regenerative design in support tools should reflect this interplay. Indeed, as the notion of regenerative design and development gains increased momentum, it is anticipated that there will be a commensurate demand for support tools to assist those practitioners wishing to engage with it. This could be considered a necessary step to both sharpen regenerative design's theoretical underpinnings and to further a broader discussion and practice (Cole et al. 2012).

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Capra (1996) illustrated how the reductive approaches to scientific inquiry dominant for over the past few centuries are gradually succumbing to the holistic nature of the disciplines of biology and ecology and how the machine metaphor is being replaced by one of networks. Such a whole-systems approach will invariably guide future building-related initiatives and strategies across all scales, and will clearly have consequences for the scope and emphasis of current assessment methods or the development of complementing approaches to describe and evaluate what constitutes successful performance.

A set of tools and frameworks is emerging directed at representing the priorities and emphasis of regenerative design. For example, the conceptual regenerative design framework—REGEN—proposed by the US architecture firm Berkebile Nelson Immenschuh McDowell for the USGBC (Svec, Berkebile, and Todd 2012); LENSES (living environments in natural, social, and economic systems), created by Colorado State University's Institute for the Built Environment to help communities and project teams create places where natural, social, and economic systems can mutually thrive and prosper (Plaut, Dunbar, Wackerman, and Hodgin 2012); and the Sustainable Design Initiative framework developed by Perkins +Will, which set the resource-related design strategies within cycles—from nature and back to nature—differentiating between those approaches that are primarily executed within the physical bounds of the site and largely within the purview of the design team and owner and those that extend beyond the bounds of the site and must be negotiated with other parties for the implementation and success (Cole et al. 2012). Such approaches can provide a necessary and complementary role to current green building assessment methods. Green building assessment systems were conceived to provide a measure of performance but are also used to guide design by communicating what are deemed priority environmental issues. Plaut et al. (2012) argue that these "offer little guidance in the way of guiding people through the creation, implementation, and operation of projects" and by focusing on "measuring the performance of an end result or product" and can be described as "product-based." By contrast, LENSES and the other regenerative frameworks can better be described as what Plaut et al. call "process-based" and are primarily directed at guiding design. Moreover, whereas the product-based tools keep individual environmental performance requirements discrete, the graphic organization of the emerging regenerative design tools expands the issues to include social, cultural, economic, and ecological systems and processes but also emphasizes the relationship between them. In short, they accept the built environment as a complex socioecological system and attempt to offer guidance to designers and other stakeholders in situating projects within it.

At this point, in addition to building new capabilities, other potential implications emerge from shifting from green to regenerative design and the development of associated assessment tools. First: reestablishing regional design practices. The architectural diversity and richness evidenced in the way that indigenous and vernacular practices offered regionally specific solutions is largely absent in current mainstream architectural practice. The central emphasis on "place" within regenerative design provides the necessary frame by which this collective knowledge can be rediscovered and reinterpreted within a contemporary context. Second: establishing common ground between the diverse stakeholders associated with the production and use of a building, something that has often eluded other design approaches. While the integrative design process has been an enormously valuable complement to green design, the more expansive dialogue central to regenerative design and development has the potential to engage and maintain stakeholder commitment. Third: change responsibilities and skills for designers. While green design has required design team members to gain familiarity with a host of environmental strategies and blur professional boundaries, regenerative design will drive designers toward positioning these within a whole-systems setting. In addition to having the potential of reframing what constitutes the nature of design and the role of designers, these and other shifts identified earlier (reductive/holistic, product/process, building/context) have profound consequences for what constitutes "performance" and what constitutes "assessment."

Acknowledgment

The issues and ideas presented in this thought piece are drawn from a *Building Research and Information Special Issue: Regenerative Design—Theory and Practice*, published in 2012 in *Building Research and Information*, Raymond J. Cole, guest editor.

Summary and Conclusions

The high-performance building movement worldwide is being propelled by the success of building assessment methods, in particular, LEED in the United States and BREEAM in the United Kingdom. Both methods take complex arrays of numerical and nonnumerical data and provide a score that indicates the performance of a building according to the scoring and weighting system built into the

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method. Newcomers to the marketplace, such as GBI's Green Globes and the Living Building Challenge, can help to bring the movement and these collective green building design concepts and strategies even further into the mainstream. Internationally, there are a host of green building assessment systems and methods, such as CASBEE in Japan, Green Star in Australia, and DGNB in Germany. Around the world, there are over 40 green building councils that promote green building and building assessment tools, many of which, like Green Mark in Singapore, are local products and not strictly based on other major assessment tools. In addition to creating a competitive atmosphere of promoting high-performance green building, these assessment systems also bring standard definitions of green building to their countries and a common vocabulary, which is essential for increasing the penetration of green buildings around the world.

Notes

1. A detailed description can be found at the consortium's website, http://www.ibec.or.jp/CASBEE/english/index.htm
2. From December 1 through December 11, 1997, more than 160 nations met in Kyoto, Japan, to negotiate binding limitations on greenhouse gases for the developed nations, pursuant to the objectives of the Framework Convention on Climate Change of 1992. The outcome of the meeting was the Kyoto Protocol, in which the developed nations agreed to limit their greenhouse gas emissions relative to the levels emitted in 1990. The United States agreed to reduce its emissions from 1990 levels by 7 percent during the period 2008 to 2012. After several additional meetings of the global community between 1992 and 2015, the effort culminated with the COP 21 Climate Summit held in Paris in December 2015. Over 150 countries pledged to limit climate warming to less than 2ºC (4ºF) using a wide variety of strategies that include a $100 billion fund to support the efforts of developing countries.
3. SBTool, developed by Natural Resources Canada in collaboration with a wide range of academics and practitioners worldwide, has been used by the Green Building Challenge to determine how well buildings compare to base or typical buildings in each category, for example, schools. The tool consists of an Excel spreadsheet. The most recent version is available for research and academic purposes at www.iisbe.org/sbmethod.

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Chapter 5

The U.S. Green Building Council LEED Building Rating System

Building rating systems or *building assessment systems* are frequently used to grade the performance of a building project based on a specific set of green or sustainable criteria. Chapter 4 addresses the topic of building rating in detail and covers the most common international systems used for this purpose. Three major rating systems are commonly used in the United States. The most widely known and applied system is the *Leadership in Energy and Environmental Design (LEED)* building rating system, which is described in detail in this chapter. The LEED system is actually a terminology that covers a number of rating systems that have been tailored for specific building types. In addition to its widespread use in the United States, LEED has been applied to projects in 150 countries. Green Globes, a rating system whose application is growing quickly, is described in Chapter 6. The third major system, the Living Building Challenge (see Chapter 4), is not currently being applied to a large number of projects but is having a significant impact on stimulating improvements to other rating systems.

The LEED rating system offers a wide number of rating tools that can be used to evaluate different types of projects, such as office buildings, schools, data centers, and hospitals. Other LEED variants are designed to score the performance of building interior fit-outs, homes, neighborhood developments, and the operation and maintenance of existing buildings. The success of LEED can be credited to the long, careful three-year (1995–1998) development process that created this method for determining the degree to which a building stacked up against the criteria used to provide a "green" score for the project. The earliest attempts at formulating an assessment system, dating from 1993, were conducted under the aegis of the standards structure of the American Society for Testing and Materials (ASTM). This first effort at developing a US rating system was handed over in 1995 to the then newly formed The U.S. Green Building Council (USGBC). A pilot version of LEED was issued for beta testing in 1998, and the first operational market version was published in 2000. Perhaps the most important decision of the USGBC members developing LEED that ensured its success was that green building demand should be market-driven rather than being required by regulation, meaning that the building owners would be the ultimate arbiters of the program's success. For commercial green buildings, this meant that they would have to distinguish themselves in the market by having higher resale value than comparable buildings.

A second significant decision made to guide the development of LEED was employing a broad, consensus-based process during its formulation. Building assessment systems are typically produced by national building research organizations, such as the Building Research Establishment in the United Kingdom. The standard is then "sold" to the respective building development market as a tool developed by a reputable institution that will help meet the public demand for more environmentally responsible behavior on the part of the building industry. In contrast, the USGBC was, and remains, a nongovernmental organization comprising a wide range

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of collaborators from industry, academia, and government. LEED was produced by this collaboration during a laborious process that sought to produce a green building rating system that would meet the needs of the wide range of participants in the building industry. The engagement of so many collaborators ensured acceptance when the rating system was completed. In addition, the US Department of Energy offered critical funding in the form of grants to support LEED's development. LEED building assessment products continue to enjoy a high degree of success, thanks to the collaborative, consensus-based development process.

Brief History of LEED

As noted, LEED was developed by the USGBC during a three-year process from 1995 to 1998 (see Table 5.1). The first version, known as LEED 1.0, was issued in 1998 as a beta or test version. Twenty buildings were certified using LEED 1.0 to attain a rating that originally was *platinum*, *gold*, *silver*, or *bronze*. The bronze designation was later changed to *certified*. LEED 2.0 was issued in 2000 as a dramatically changed version of LEED 1.0 and offered to the wider commercial and institutional building market as a final, operational building assessment system. LEED-NC 2.1, the next edition of LEED, issued in 2002, started the process of issuing rating products for specific building types. For example, in the case of the version for New Construction, the descriptor NC was appended to the title. LEED-NC 2.1 was virtually identical to LEED 2.0, except that it had greatly simplified documentation requirements. LEED-NC 2.2, issued in 2005, did away with manual documentation submissions and shifted to an Internet portal for this purpose, USGBC LEED-Online. For LEED v3, also referred to as LEED 2009 based on the year of its release, there were several major changes to its structure and several across-the-board changes for all of the LEED building assessment tools. In LEED v3, for the first time, additional points, referred to as *Regional Priority* (*RP*) *Credits*, were awarded to projects that focused on regional issues established by local USGBC chapters. A new version of LEED-Online was released to facilitate easier communication between the project teams and the certifying bodies. LEED-Online allows teams to better manage project details and upload supporting files in order to submit data for each of the credits they are seeking. The most recent version, LEED v4, was released in November 2013 and can accommodate a larger array of specific building types, including data centers, hospitality, and warehouse and distribution centers. This new version adopts the latest American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) standards and reshapes the overall structure and content of the LEED rating system. It should be noted that project teams could opt to use either LEED v3 and LEED v4 from 2014 through late 2016. Appendix A provides a quick reference guide for LEED v3.

TABLE 5.1

Historical Applicability of LEED Versions

Version	Years Applicable
1.0	1998–2000*
2.0	2000–2002
2.1	2002–2005
2.2	2005–2009
3***	2009–2016†*
4	2013–‡

*LEED v1.0 was a beta version tested on a select group of buildings.

†**Project teams have a choice of LEED v3 and LEED v4 between November 2013 and October 2016, thus the overlap.

‡ LEED v3 is alternatively referred to as LEED 2009, the year in which it was issued.

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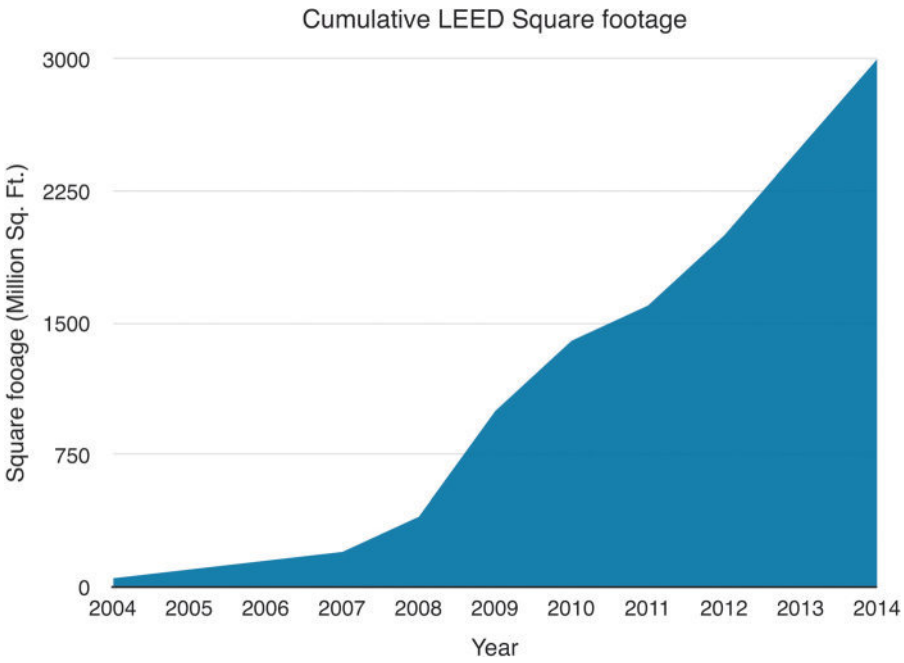


Figure 5.1 Cumulative square footage of LEED-certified projects through 2014. In March 2014, the USGBC announced that the total LEED-certified floor area for commercial construction projects exceeded 3.1 billion square feet.

The popularity of LEED certification has continued to grow since its appearance in 1998. As of 2010, a cumulative total of over 1 billion square feet of commercial construction projects had been LEED certified, while in 2011, the total had grown to 1.7 billion square feet and to 3.1 billion square feet as of early 2014 (see Figure 5.1). The majority of LEED-certified projects are from new construction activity that includes both public and private owners. Figure 5.2 represents the cumulative growth of commercial LEED-certified projects since the beta testing of LEED1.0 in 1998. LEED-certified residential projects increased the overall total to about 57,800 projects as of 2014.

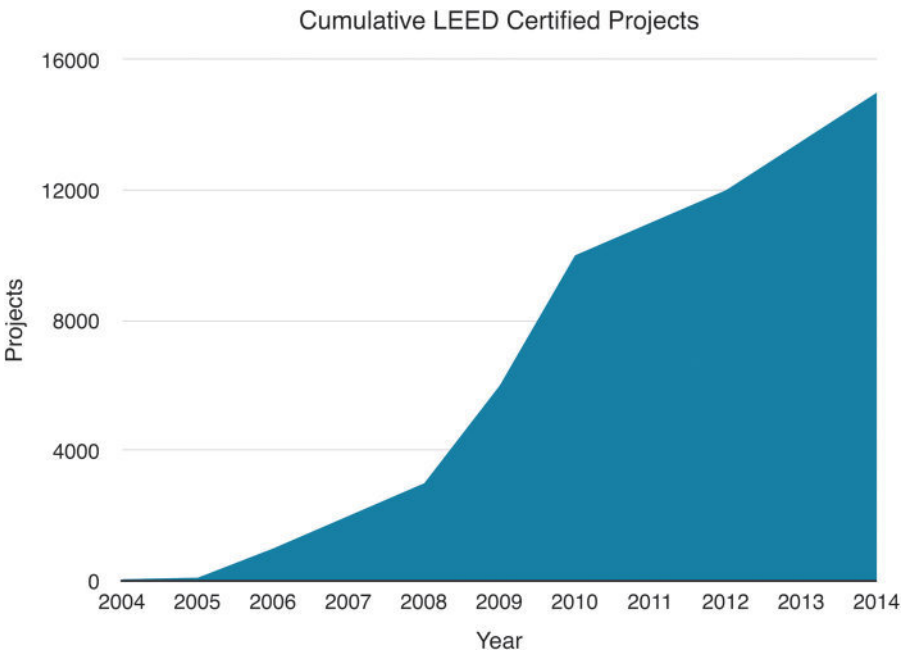


Figure 5.2 The total number of LEED-certified projects in the United States through 2014.

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Structure of the LEED Suite of Building Rating Systems

Although referred to in the singular, LEED is not a single rating system but a *suite* of systems, as shown in Figure 5.3. LEED is organized around five major groupings or rating systems: (1) Building Design and Construction (BD+C), (2) Interior Design and Construction (ID+C), (3) Building Operations and Maintenance (O+M), (4) Neighborhood Development (ND), and (5) Homes (H). Each rating system has one or more rating tools designed for specific building types. In this chapter, the focus is on LEED: BD+C, which addresses eight major building typologies: (1) New Construction (NC), (2) Core and Shell (CS), (3) Schools, (4) Retail, (5) Data Centers, (6) Warehouses and Distribution Centers, (7) Hospitality, and (8) Healthcare. Within the LEED: ID+C rating system, the Commercial Interiors (CI) rating tool, is also described in detail. LEED: O+M is applicable to buildings with commercial occupancies that involve building operations, minor space changes, system and process, upgrades, small additions, and facility alterations (see Table 5.2).

In general, the current full syntax for rating tools is:

LEED {System}: {Tool}

For example, the nomenclature for the Building Operations and Maintenance tool for data centers is LEED O+M: Data Centers.

Only one LEED rating can be awarded to a building as a whole, and the rating system employed depends on the use of the majority of the building. For example, to apply LEED BD+C: New Construction to a project, the owner must occupy more than 50 percent of the building. If tenant spaces occupy more than 50 percent of the building, then the LEED BD+C: CS rating tool should be used for owners and developers to provide tenants with a building shell that integrates sustainable design.

LEED BD+C: CS covers the core building elements, including the structure; building envelope; and heating, ventilation, and air conditioning (HVAC) systems. If tenants are interested in interior space improvement projects, they are to use the LEED ID+C: CI rating tool for assisting in greening their spaces. LEED BD+C: CS and LEED ID+C: CI are designed to complement one another, with

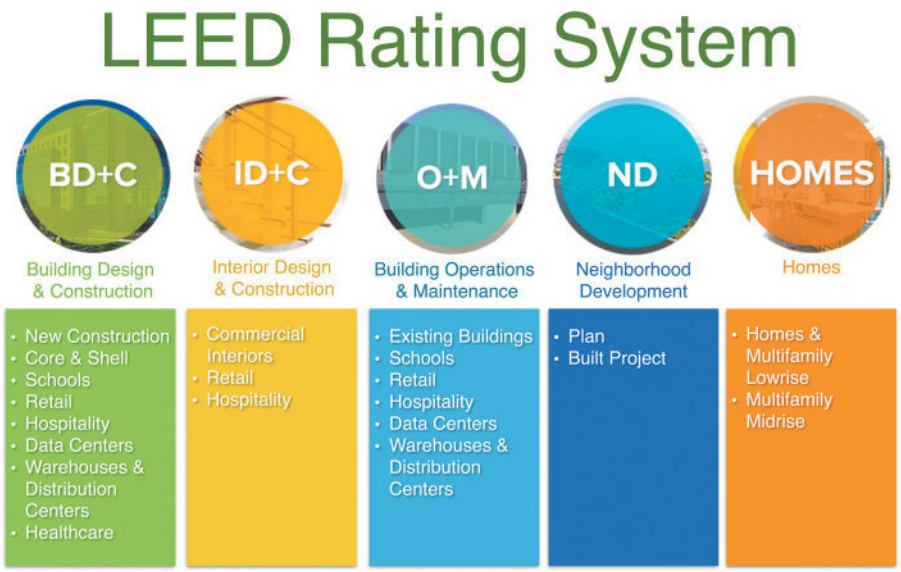


Figure 5.3 The various LEED building rating products address a wide variety of building types. In order to determine which rating product best suits the high-performance project, the project team should identify the construction type and space usage.

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TABLE 5.2

LEED Rating Systems and Associated LEED Rating Tools

Rating System	Associated Rating Tools
Building Design and Construction (BD+C)	New Construction and Major Renovation (NC) Core and Shell (CS) Schools (S) Retail Hospitality Data Centers Warehouses & Distribution Centers Healthcare
Interior Design and Construction (ID+C)	Commercial Interiors (CI) Retail Hospitality
Building Operations and Maintenance (O+M)	Existing Buildings (EB) Schools Retail Data Centers Warehouses and Distribution Centers
Neighborhood Development (ND)	Plan Built Project
Homes (H)	Homes and Multifamily Lowrise Multifamily Midrise

the Core and Shell tool addressing the building and the Commercial Interiors tool the tenant spaces. When both rating systems are applied in a project, the overall high-performance building would be equivalent to a LEED BD+C: New Construction project.

The various LEED rating systems can be applied to certain types of projects multiple times at several phases of their evolution. For example, for retail projects, the LEED BD+C: Retail can be applied to new retail buildings; the LEED ID+C: Retail tool can guide the fit out of their interiors; and for existing retail buildings, the LEED O+M: Retail can be used to maintain the building's performance over time. In general, the Retail tools are used to guide and distinguish high-performance retail projects, including banks, restaurants, grocery, and apparel, electronics, and big-box stores (see Table 5.3).

TABLE 5.3

LEED Rating System Applied to Certain Types of Projects at Several Phases in Their Evolution

	Type of Project		
Phase	**Schools**	**Retail**	**Commercial**
Construction	LEED BD+C: Schools	LEED BD+C: Retail	LEED BD+C: New Construction
Fit-out	___	LEED ID+C: Retail	LEED ID+C: Commercial Interiors
Operations	LEED O+M: Schools	LEED O+M: Retail	LEED O+M: Existing Buildings

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LEED BD+C: Schools is similar to LEED BD+C New Construction but focuses on K-12 schools by addressing issues such as classroom acoustics, master planning, mold prevention, and environmental site assessment. LEED BD+C: Healthcare can be applied to inpatient, outpatient, and licensed long-term care facilities, medical offices, assisted-living facilities, and medical education and research centers. LEED: Homes focuses on single-family, low-rise homes (less than four stories), affordable housing, and manufactured and modular homes. LEED for ND (LEED ND) is used for development projects such as neighborhoods, subdivisions, and larger mixed-use developments. LEED for Existing Buildings (EB): Operations and Maintenance is applicable to buildings that involve building operations, minor space changes, system and process, upgrades, small additions, and facility alterations.

LEED Credentials

The USGBC has developed a system of credentials to identify individuals who are knowledgeable in green building practices that support market transformation. Figure 5.4 illustrates these various credentials, which can be achieved through a combination of experience and examination. These credentials include the LEED Green Associate (LEED GA), LEED Accredited Professional (LEED AP) with specialty, and LEED AP Fellow. The LEED GA credential is the fundamental credential and can be pursued by anyone who is employed in a building or environmental field. LEED GAs must have basic knowledge of the LEED rating systems, LEED documentation process, sustainable design principles, standard terminology, and LEED resources that are available for identifying green strategies. No real-world experience is required to apply for the GA exam. The LEED rating systems provide a point for a project if a LEED AP is a member of the team. No point is awarded if a LEED GA is a team member.

For professionals in the industry, the option of taking the LEED AP with a specialty exam is available. Experience working on a LEED project is highly recommended. The specialty referred to in this context is the specific rating system that the individual is qualified to manage (see Figure 5.4). A LEED AP can opt for five specialties in terms of taking the LEED AP examination. A LEED AP with a

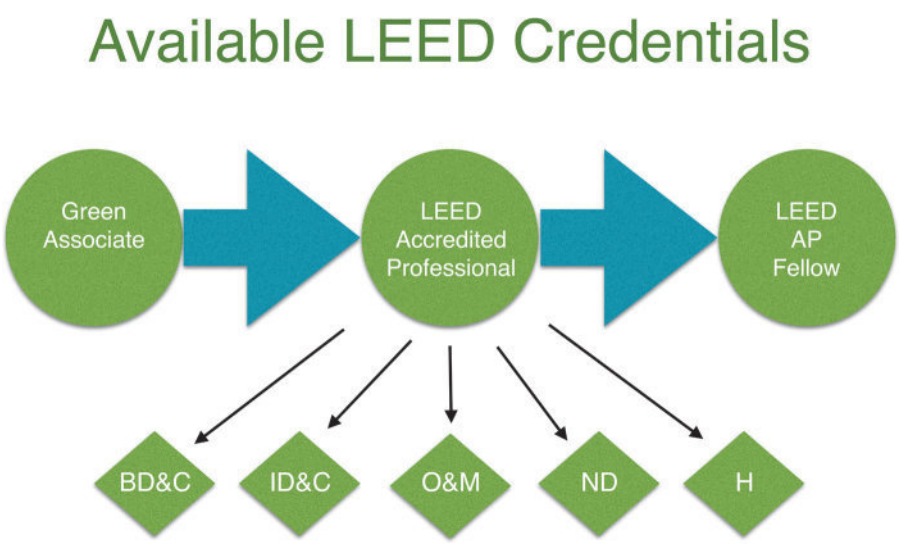


Figure 5.4 The available LEED credentials include the entry-level Green Associate, the five LEED AP specialty designations, and the LEED AP Fellow.

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BD+C specialty can manage projects that are using one of the rating tools in the LEED BD+C rating system. A LEED AP with a specialty of ID+C can manage interiors projects for commercial, retail, and hospitality buildings. Other LEED AP specialties include LEED AP O+M, Homes (LEED AP Homes), and LEED AP ND.

LEED APs are required to have in-depth of knowledge of green building practices and must specialize in a particular type of building rating system as described earlier—for example, LEED BD&C. The LEED AP test is divided into two sections: (1) general knowledge of green building and the LEED rating systems and (2) in-depth knowledge of the building rating systems for the specialty being tested. Holders of the LEED GA and LEED AP credentials must maintain their status by paying a $50 maintenance fee every two years as well as participating in the Credential Maintenance Program (CMP). The CMP is a structured system used to expand the knowledge and experience base for LEED Professionals. LEED APs are required to have at least 30 hours of coursework every two years. Six of those hours must be LEED-specific. LEED GAs are required to have 15 hours of coursework every two years, including 3 LEED-specific hours.

The most prestigious professional credential within the USGBC system is the LEED AP Fellow. The LEED Fellow Program was developed to honor and recognize distinguished LEED APs who have made a significant contribution to the field of green building and sustainability at a regional, national, or international level. In order to become a LEED Fellow, the individual must be nominated by another LEED AP who has a specialty and at least 10 years of experience in the green building field. The nominee must also be a LEED AP with a specialty and have at least 10 years' experience in the green building field. In addition, the nominee must have held the LEED AP credential for at least 8 cumulative years. The nominee is evaluated in four of five mastery elements: technical proficiency, education and mentoring, leadership, commitment and service, and advocacy.

LEED v4 Structure and Process

LEED v4 is the most recent version of the USGBC building rating system, and it can be applied to a wide variety of new and existing building types. It is structured with three minimum program requirements (MPRs) and a maximum of 110 points divided into 10 categories. The category structure and point allocation differ substantially between the LEED v3 and LEED v4. Table 5.4 shows a comparison for LEED BD+C: New Construction projects for these two recent versions. In order for a building to be considered for LEED certification, the requirements for all MPRs and all prerequisites must have been met. Additional information about MPRs and prerequisites is provided later in Table 5.5. Lists of these LEED v4 requirements are provided in Tables 5.5 and 5.6.

The number of points available in each category was established by the developers of LEED BD+C: NC v4 to indicate the weight they placed on the various major issues addressed by this rating system. As a result, the allocation of points to each category is arbitrary, based on the judgment and expert opinion of the developers. Clearly, it is arguable, for example, that Energy and Atmosphere (EA) (26 points) is more important than Sustainable Sites (SS) (13 points) and more than twice as important as Materials and Resources (MR) (10 points). The challenge of allocating points among various categories illustrates some of the pitfalls inherent in a building assessment system that attempts to reduce complex factors to a single number. Still, the system does provide a logical and rational, albeit arbitrary, approach to producing numerical scores in each category. It is important to keep in mind that LEED was

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TABLE 5.4

LEED Category Allocation for LEED BD+C: NC v3 and v4

LEED BD+C: NC v3 Categories	Maximum Points	LEED BD+C: NC v4 Categories	Maximum Points
1. Sustainable Sites (SS)	26	1. Integrative Process (IP)	3
2. Water Efficiency (WE)	10	2. Location and Transportation (LT)	16
3. Energy and Atmosphere (EA)	35	3. Sustainable Sites (SS)	13
4. Materials and Resources (MR)	14	4. Water Efficiency (WE)	11
5. Indoor Environmental Quality (EQ)	15	5. Energy and Atmosphere (EA)	26
6. Innovation and Design (ID)	6	6. Materials and Resources (MR)	10
7. Regional Priority (RP)	4	7. Indoor Environmental Quality (EQ)	14
		8. Performance (PF)	7
		9. Innovation (IN)	6
		10. Regional Priority (RP)	4
Total Possible Points	**110**	**Total Possible Points**	**110**

TABLE 5.5

LEED BD+C v4 Minimum Program Requirements

1. Must be in a permanent location on existing land.
2. Must use reasonable LEED boundaries.
3. Must comply with project size requirements.

TABLE 5.6

All Prerequisites Listed in LEED BD+C: NC v4

	Prerequisite	Name of Prerequisite
1.	Sustainable Sites (SS)	Construction Activity Pollution Prevention
2.	Water Efficiency (WE)	Outdoor Water Use Reduction
3.	WE	Indoor Water Use Reduction
4.	WE	Building-Level Water Metering
5.	Energy and Atmosphere (EA)	Fundamental Commissioning and Verification
6.	EA	Minimum Energy Performance
7.	EA	Building-Level Energy Metering
8.	EA	Fundamental Refrigerant Management
9.	Materials and Resources (MR)	Storage and Collection of Recyclables
10.	MR	Construction/Demolition Waster Management Planning
11.	Indoor Environmental Quality (EQ)	Minimum Indoor Air Quality Performance
12.	EQ	Environmental Tobacco Smoke Control

TABLE 5.7

Points Required for LEED v4 Ratings

Rating	Points Required
Platinum	80–110
Gold	60–79
Silver	50–59
Certified	40–49
No rating	39 or less

developed using an extensive collaborative process; hence, the outcome of this group thought process is probably on target with respect to weighting the points and categories. Thus, in spite of its relative simplicity, it does a good job of taking complex information and converting it into a single score and rating level.

The total score is computed by adding up the points earned in each category results in a building rating (see Table 5.7). The platinum rating is fairly difficult to achieve, and a silver rating represents a good assessment and a noteworthy accomplishment.

GREEN BUILDING CERTIFICATION INSTITUTE RELATIONSHIP TO THE USGBC AND LEED

Until 2008, the USGBC administered building certifications and professional designations in-house. In 2008, a nonprofit organization, the Green Building Certification Institute (GBCI), was founded to provide a balanced third-party certification in order

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to be recognized by the American National Standards Institute (ANSI). The GBCI is responsible for managing all aspects of LEED professional credentialing, including exam development, registration, delivery, and maintenance, to ensure ongoing excellence and that LEED professionals are proficient in the field. In addition, the GBCI is responsible for managing the LEED project certification program by conducting technical reviews and analysis of submissions to verify and evaluate projects based on how well they have met the requirements of the various LEED rating systems. Project document is submitted through the LEED-Online Internet portal, which is discussed later in this chapter.

The USGBC retains responsibility for creating and implementing new versions of the LEED building rating system by integrating new green building technologies, systems, and strategies into the latest requirements. This responsibility includes establishing new reference guides and educational resources and outlining certification and accreditation requirements, among other things. The GBCI is the arbiter of both building certification and LEED GA and AP accreditation, both of which are based on USGBC-generated rules. The relationship between the USGBC and the GBCI is visually depicted in Figure 5.5.

LEED CERTIFICATION PROCESS

Prior to certification, the building is referred to as a *LEED-registered project*. Achieving a LEED certification level requires significant dedication from professionals of the project team. This dedication must be maintained from design to the end of construction in order to successfully complete all steps in the certification process. These six steps include:

1. Ensuring that the building is eligible for certification
2. Registering the project with the GBCI
3. Ensuring and documenting that the project meets the MPRs and prerequisites and can attain at least the minimum number of points to achieve the LEED-certified level
4. Submitting the required documentation via LEED-Online
5. If necessary, appealing points denied by the GBCI
6. Receiving final notification from the GBCI that the project has achieved LEED certification

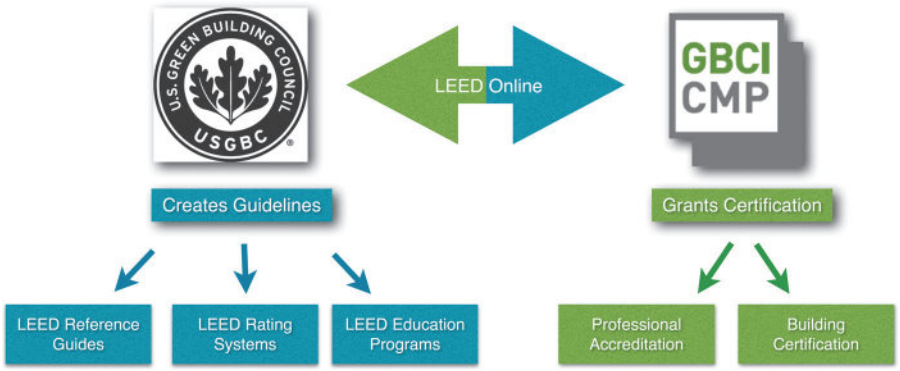


Figure 5.5 The relationship between the USGBC and the GBCI and their respective roles in the LEED green building rating system. The USGBC develops the requirements for LEED certification, and the GBCI ensures that the requirements have been met. The GBCI is also responsible for the testing and continuing education of LEED APs.

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LEED-ONLINE

Over time, the LEED building rating system has shifted from requiring hard-copy documentation for certification to an Internet-based system known as LEED-Online. Project teams can submit all of their documentation online in an easy-to-use format. LEED-Online stores all LEED information, resources, and support in one centralized location. It enables team members to upload credit templates, track Credit Interpretation Rulings (CIRs), view documented responses to questions posed by previous project teams, manage key project details, contact the customer service department, and communicate with reviewers throughout the design and construction review process.

REGISTRATION

The first step in LEED certification is project registration. Projects are registered by visiting the LEED Registration page of the USGBC website (www.usgbc.org), where information about the project is input and a registration fee is paid. Early registration is encouraged because starting the process as early as possible maximizes the potential for achieving certification. Registration establishes contact with the USGBC and provides access to essential information, software tools, and communications. Appointment of a Project Team Administrator occurs when the project is first registered at LEED-Online. The Project Team Administrator invites members of the project team to register with the project and then assigns roles to the individual project team members. Typical roles include architect, landscape architect, civil engineer, owner, and developer, to name just a few. The system also allows the Project Team Administrator to create new roles that are unique to the project, if needed. The Project Team Administrator develops a project description, assigns responsibility for LEED credits to the project team members, and then monitors the submission of documentation to support the LEED credits. The Project Team Administrator should be a LEED AP and is the project team member assigned to steer the project through the certification process. Once a project is registered and responsibilities are assigned, the project team begins to prepare documentation to satisfy the prerequisites and credit submittal requirements.

CREDIT INTERPRETATION RULINGS

If a project team encounters difficulties applying a LEED prerequisite or credit to a specific project, the USGBC encourages the team to sort out the issue themselves first and contact the GBCI only as a last resort. The CIR system ensures that rulings are consistent and available to other projects. If there is a gray area for which the project team requires clarification, the team can submit its query through LEED-Online and receive a ruling from the USGBC on the official interpretation of the situation. This latter response by the USGBC is the so-called CIR. All CIRs are contained in a database accessible from LEED-Online, and they can be used as precedents for addressing situations encountered by the project team.

DOCUMENTATION AND CERTIFICATION

To earn LEED certification, the project must meet all the MPRs, satisfy all of the prerequisites, and earn the minimum number of points to at least attain the LEED-certified rating level. For LEED BD+C projects, the project team has the option to divide their review process into two separate reviews, design review and construction review, also known as a split review. The benefit of a split review is

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that it helps the project team gauge whether the project is on track for achieving the anticipated LEED certification level. LEED-Online specifies which points are either design phase credits or construction phase credits, and the project team must submit complete documentation of design phase credits for the design review. The GBCI will then respond with the Preliminary Design Review, indicating which credits are "Anticipated," "Pending," or "Denied" and if any documentation was "Approved" or "Not Approved." The project team then has the option to accept the results of the Preliminary Design Review as final or submit a response. If the project team determines that a response is necessary, they must submit a clear response to the Preliminary Design Review as well as appropriate documentation within 25 business days. The GBCI then will review the submitted documents along with the team's response and within 25 business days reply with the Final Design Review. The Final Design Review addresses each credit as "Anticipated," "Pending," or "Denied." During this period, no points are awarded to the project. Closer to project completion, the project team can submit the remaining credits for the Preliminary Construction Review. The structure of this review is the same as the Preliminary Design Review. If project team members feel that they should be awarded a specific credit, whether from the Final Design Review or Final Construction Review, they have the option to appeal.

AWARD OF CERTIFICATION

Upon notification of LEED certification, the project team has 30 days to accept or appeal the awarded certification level of platinum, gold, bronze, or certified. Upon the project's acceptance, or if the project team has not appealed the rating within 30 days, the LEED certification is final. GBCI will refer to the project as a LEED-certified building, and the project team will receive an award letter and certificate specifying the LEED certification level. Although in the past LEED-certified projects were awarded plaques by the USGBC, currently a plaque can only be purchased online from an exclusive vendor (see www.greenplaque.com) (see Figure 5.6). The plaque exhibits the LEED certification level and year of achievement and typically is featured on either the exterior or interior of the high-performance building.



Figure 5.6 The certification plaque from the USGBC is made of recycled glass. (Photograph courtesy of Torii Mor Winery)

APPEALS

If the project team feels that sufficient grounds exist to appeal a credit denied in the Final LEED Review, it has the option to appeal. The appeal fee is $500 per credit appealed. A review of the documentation for the appealed credits occurs within 25 business days, at which time an Appeal LEED Review will be provided to the applicant. All appeals are submitted via LEED-Online. If an appeal is pursued, a different review team will assess the appeal documentation.

LEED REGISTRATION AND CERTIFICATION FEES

A registration fee must be paid for all LEED projects as part of the registration process. When the project team is prepared to initiate the review process, a certification fee must first be paid prior to action by the GBCI. As noted earlier, the project team has the option of submitting all documentation at the conclusion of the construction process or in two phases: (1) a design review, in which all credits that have been completely addressed by the design team are put forward for review, and (2) a construction review, in which all the remaining credits are reviewed. The advantage of the two-phase review process is that it speeds the certification process and allows the project team to decide on and act on appeals far earlier in the process.

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LEED Building Design and Construction Rating System

As noted earlier, LEED refers to a wide array of building assessment tools that are organized into five rating systems: (1) Building Design and Construction (BD+C), (2) Interior Design and Construction (ID+C), (3) Building Operations and Maintenance (O+M), (4) Neighborhood Development (ND), and (5) Homes (H). In this section, the most frequently used rating system, LEED BD+C, is described in more detail. The LEED BD+C rating system contains eight rating tools: New Construction, Core and Shell, Schools, Retail, Data Centers, Warehouses and Distribution Centers, Hospitality, and Healthcare. The prerequisites and credits listed in Tables 5.8 through 5.10 apply to these rating tools within the LEED BD+C rating system: (1) New Construction and Major Renovation, (2) Core and Shell, and (3) Schools. These three types of projects represent the most frequently used LEED rating tools. For other types of LEED BD+C projects, such as Healthcare, Data Centers, Warehouses and Distribution Centers, Hospitality, and Retail, plus projects in other LEED rating systems, such as LEED O+M or LEED ID+C, the project team should consult the appropriate technical manuals for the specific type of project. The layout of LEED BD+C with respect to credits and points for NC CS, and S projects is shown in Table 5.8. For all other BD+C project types, the LEED v4 *Technical Manual* should be consulted.

TABLE 5.8

Points Assigned to LEED BD+C Projects

Category or Credit Name	New Construction (NC)	Core and Shell (CS)	Schools (S)
Integrated Project Planning and Design	1	1	1
Location and Transportation (LT)	16	20	15
Sustainable Sites (SS)	10	11	12
Water Efficiency (WE)	11	11	12
Energy and Atmosphere (EA)	33	33	31
Materials and Resources (MR)	13	14	13
Indoor Environmental Quality (IEQ)	16	10	16
Innovation and Design (ID)	6	6	6
Regional Priority (RP)	4	4	4
Total Points Available	110	110	110
Certified	40–49	40–49	40–49
Silver	50–59	50–59	50–59
Gold	60–79	60–79	60–79
Platinum	>60	>60	>60

INTEGRATIVE PROJECT PLANNING AND DESIGN

One of the peculiarities of the newest version of LEED is that the first credit listed in LEED v4, Integrative Process (IP), is not identified as being in a major category and stands alone (see Table 5.9). This credit addresses the issue of collaboration among the project team members to enhance the sustainability qualities of the project. All other LEED credits are grouped together under specific categories, such as Location and Transportation (LT) or EA.

The project team is required to collaborate in reducing energy and water consumption and to document efforts to improve the performance of the project compared to specified baseline cases. A preliminary energy box, an estimate of the

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TABLE 5.9

Points Assigned to LEED BD+C Integrated Project Planning and Design Category

Category or Credit Name	New Construction	Core and Shell	Schools
Integrated Project Planning and Design	1	1	1

Source: Integrative Process

building's energy consumption at the schematic design stage, must be created to explore the reduction of energy loads and must include a passive energy design assessment and analysis of lighting levels, thermal comfort, and plug and process loads. Constraints due to programmatic and operational issues must be included in this analysis. A similar assessment of indoor, outdoor, and process water load reduction is required. These assessments must be included in both the Owners Project Requirements (OPR) and Basis of Design (BOD) to ensure their inclusion in the construction documents.

LOCATION AND TRANSPORTATION

The *Location and Transportation (LT)* category is a new category that first appeared in LEED v4. It focuses on the issue of building location relative to ecologically sensitive land and access to transportation. Table 5.10 lists the six LT credits that apply to LEED BD+C: NC, LEED BD+C: CS, and LEED BD+C: S projects.

Points can be earned if a project is located in a development that has been previously certified under LEED ND. The number of points earned varies depending on the rating (certified, silver, gold, or platinum) earned by the development. If a project team attempts this credit, the project is not eligible to earn points for other LT credits. In other words, this is an alternative path for the rest of the LT category.

LT Credit: Sensitive Land Protection

LEED BD+C projects that are not located on sensitive land earn points for avoiding impacts that otherwise would occur. Sensitive land includes prime farmland, floodplains, habitat for endangered and threatened species, and properties in close proximity to wetlands and water bodies.

TABLE 5.10

Points Assigned to LEED BD+C Location and Transportation

Category or Credit Name	New Construction	Core and Shell	Schools
Location and Transportation (LT)	16	20	15
LEED for Neighborhood Development*	16	20	15
Sensitive Land Protection	1	2	1
High-Priority Site	2	3	2
Surrounding Density and Diverse Uses	5	6	5
Access to Quality Transit	5	6	4
Bicycle Facilities	1	1	1
Reduced Parking Footprint	1	1	1
Green Vehicles	1	1	1

*A project within the boundaries of a LEED-ND certified development can opt to earn all its LT points by virtue of its LEED-ND certification.
Source: LEED-ND Location

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LT Credit: High-Priority Site

Locating the project in areas that support community development can receive points if they meet the requirements of this credit. There are three options for this credit.

Option 1 (Historic District). This option addresses infill projects in historic districts.

Option 2 (Priority Designation). This option includes a range of additional possibilities, such as Federal Empowerment Zones, Federal Enterprise or Renewal Community sites, certain US Department of Treasury Housing and Urban Development sites, and certain US Department of Treasury Low Income designated and local programs equivalent to the federal programs.

Option 3 (Brownfield Remediation). This option earns points for locating the project on a brownfield site.

LT Credit: Surrounding Density and Diverse Uses

Locating a project in a dense urban environment can earn points.

Option 1 (Surrounding Density). The points earned increase as the average density within ¼ mile of the project increases.

Option 2 (Diverse Uses). A project located near publicly diverse uses, such as schools, restaurants, dry cleaners, and other services, can earn points under this option. The idea is to promote development with existing infrastructure, walkability, and transportation efficiency.

LT Credit: Access to Quality Transit

Projects located within ¼ mile of bus, streetcar, or rideshare stops or within ½ mile of rail stations or bus rapid transit stops can earn credit if they meet specific daily levels of service requirements. School projects have an option if specified percentages of students live with a ¾-mile walking distance with pedestrian access.

LT Credit: Bicycle Facilities

If the project facilitates bicycle use, credit can be earned for this measure. Bicycle storage or a functional entry to the project must be within a 200-yard walking or bicycling distance from a bicycle network with connections to diverse uses, schools or employment centers, or mass transit.

LT Credit: Reduced Parking Footprint

Minimizing the consumption of resources and land for parking is the target of this credit. Projects cannot provide excess parking beyond local code requirements. If there is no local requirement, specific targets are provided for this purpose.

LE Credit: Green Vehicles

By designating a minimum of 5 percent of parking spaces as preferred parking for green vehicles, the project can earn points for encouraging the use of green vehicles. Green vehicles are defined as those earning a minimum score of 45 in the American Council for an Energy Efficient Economy annual evaluation of energy efficient automobiles.

SUSTAINABLE SITES

The *SS* category addresses issues of construction impacts on the building site, animal habitat, stormwater management, heat island effects, and the reduction of light pollution (see Table 5.11). Note that two SS prerequisite credits must be

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TABLE 5.11

Points Assigned to LEED BD+C SS

Category or Credit Name	New Construction	Core and Shell	Schools
Sustainable Sites (SS)	10	11	12
Construction Activity Pollution Prevention	P	P	P
Environmental Site Assessment	n/a	n/a	P
Site Assessment	1	1	1
Site Development-Protect or Restore Habitat	2	2	2
Open Space	1	1	1
Rainwater Management	3	3	3
Heat Island Reduction	2	2	2
Light Pollution Reduction	1	1	1
Site Master Plan	n/a	n/a	1
Tenant Design and Construction Guidelines	n/a	1	n/a
Joint use of Facilities	n/a	n/a	1

P = Prerequisite for the rating system
n/a = not applicable to the rating system

addressed successfully for building certification. No points are awarded for these or other prerequisites, but all of them must be addressed successfully.

SS Prerequisite:. Construction Activity Pollution Prevention

One of the prerequisites or mandatory requirements for LEED certification is that pollution caused by construction activities in the form of airborne dust, soil erosion, and sedimentation of waterways must be minimized. A plan for controlling erosion and sedimentation must be developed, implemented, and documented and must conform with the more stringent of either the US Environmental Protection Agency (EPA) Construction General Permit requirements or local requirements.

SS Prerequisite: Environmental Site Assessment

The second prerequisite or mandatory requirement in the SS category applies only to school (S) projects for which a Phase I Environmental Site Assessment per ASTM Standard E-1527-05 must be performed to check for environmental contamination of the site. If contamination is found, a Phase II Environmental Site Assessment per ASTM Standard E1903-11 must be conducted. If contaminated, the site must be remediated to the most stringent of federal, state, or local standards. If there are state or local equivalents of the Phase I and Phase II Environmental Site Assessments, these may be used in lieu of the ASTM Standards.

SS Credit: Site Assessment

Whereas Site Assessment is a mandatory requirement for S projects, for NC and CS projects, project team members can earn points toward certification if they successfully address the requirements of this credit. To earn the points associated with this credit, a Phase I Environmental Site Assessment per ASTM Standard E-1527-05 must be performed to check for environmental contamination of the site. If contamination is found, a Phase II Environmental Site Assessment per ASTM Standard E1903-11 must be conducted. If contaminated, the property must be remediated to the most stringent of federal, state, or local standards. If there are state or local equivalents of the Phase I and Phase II Environmental Site Assessments, these may be used in lieu of the ASTM Standards.

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SS Credit: Site Development—Protect or Restore Habitat

This SS credit addresses the protection of the existing ecology of the site or the restoration of degraded natural systems. A detailed assessment of site conditions is required and must include a survey of these site attributes: topography, hydrology, climate, vegetation, soils, human use, and human health effects. The survey must detail how these attributes influenced the project design, with an explanation being provided if any of these attributes and conditions that have not been considered in the design process.

SS Credit: Open Space

The project team must document that outdoor space at least equal to 30 percent of the site area has been provided for environmental and human purposes. At least 25 percent of this area must be vegetated, and the area can include pedestrian-oriented elements, recreation-oriented elements, garden space, community gardens, and animal habitat. In some cases, where there is high urban density with a floor area ratio of 1.5 or greater, a physically accessible green roof can be used to meet the 25 percent vegetated space requirement.

SS Credit: Rainwater Management

Rainwater runoff volume must be reduced and the quality of rainwater increased, with the goal of replicating the normal historical hydraulic behavior of the site. In general, low-impact development and green infrastructure are to be used to accomplish these objectives. A number of options based on the percentile of rainwater events or natural land cover conditions are provided.

SS Credit: Heat Island Reduction

Increasing the area of built environment tends to increase the heat island effect in which microclimates can occur in urban areas and affect both humans and wildlife. The project team is required to use design approaches that minimize this phenomenon, both for horizontal construction, such as parking and paving ("nonroof areas" in LEED nomenclature), and for the roof of the building project. A commonly used measure of how well a material reflects solar thermal energy and thus reduces the heat island effect is the solar reflectance index (SRI), which ranges from 0 to 100 in value. A value of 0 would mean that the material absorbs all the solar thermal energy striking it, while a value of 100 indicates that it reflects all incident solar thermal energy. A dark asphalt surface would have an SRI of 4, while a surface with white paint could have a value of 79. The nonroof areas can be addressed by using vegetation, shade from photovoltaic (PV) arrays, and/or materials that can maintain an SRI of at least 28 for three years. If the three-year data are not available, a more conservative SRI of 33 must be applied. For roof areas, the SRI must have an initial value of at least 82 for a low sloped roof, with a three-year value of at least 64. For steep roofs, the SRI must have an initial value of at least 39 and a minimum three-year value of 32.

SS Credit: Light Pollution Reduction

The stated purposes of the light pollution credit are to increase access to the night sky, improve nighttime visibility, and prevent the disturbance of both wildlife and people by excess lighting. A methodology known as backlight, uplight, and glare (BUG) is used for this purpose. The lighting strategy used is a function of where the project is located, with the most stringent efforts required near large natural and rural areas, and with less stringent requirements for urban areas. The lighting strategy also applies to the illumination of exterior signage and light trespass from luminaires in building interiors.

SS Credit: Site Master Plan

If future development is planned, school projects can earn points under this credit by creating a master plan that addresses the expansion of school buildings, other facilities,

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parking, paving, and utilities. In addition to the master plan, the credit requires the project to achieve four of six specific LT and SS credits, such as Heat Island Reduction and Light Pollution Reduction.

SS Credit: Tenant Design and Construction Guidelines

CS projects can earn points if they educate tenants regarding the potential implementation of sustainable design and construction features, such as reducing energy and water consumption and improving indoor environmental quality (IEQ).

SS Credit: Joint Use of Facilities

School projects can earn one point for collaborating with the community to share three types of school facilities, such as the building, cafeteria, and recreational fields for community events. Another option is to share at least two types of school spaces with the general public or via contracts with specific organizations, such as the health or police departments. Examples of this could be the school library and parking lots. A third option for credit is sharing at least two spaces owned by other organizations—for example, a YMCA-owned swimming pool for student physical training or athletic activities, an auditorium, or a stadium.

WATER EFFICIENCY

Reducing indoor and outdoor potable water consumption is becoming increasingly important as drought conditions persist around the world. The Water Efficiency (WE) category addresses water consumption for both outdoor and indoor uses and has two prerequisites that specifically address these two major water use areas (see Table 5.12). More recently, metering water consumption, both at whole building level and for high consumptive uses, has gained importance because it provides a better understanding of where water is being consumed and for what purposes. As a result, metering of water consumption is now covered by two WE credits.

WE Prerequisite: Outdoor Water Use Reduction

The first WE prerequisite requires either a landscape that does not require a permanent irrigation system beyond a two-year watering in period or one that is provided with an irrigation system that represents a 30 percent reduction in consumption below a baseline calculated for the peak watering month. The US EPA WaterSense Water Budget Tool (www3.epa.gov/watersense/water_budget/) must be used to calculate the effectiveness of a strategy of plant species selection and grouping and irrigation system design.

TABLE 5.12

Points Assigned to LEED BD+C Water Efficiency

Category or Credit Name	New Construction	Core and Shell	Schools
Water Efficiency (WE)	11	11	12
Outdoor Water Use Reduction	P	P	P
Indoor Water Use Reduction	P	P	P
Building-Level Water Metering	P	P	P
Outdoor Water Use Reduction	2	2	2
Indoor Water Use Reduction	6	6	7
Cooling Tower Water Use	2	2	2
Water Metering	1	1	1

P = Prerequisite for the rating system

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WE Prerequisite: Indoor Water Use Reduction

Total indoor potable water use must be reduced by at least 20 percent below a baseline calculated based on building code fixture requirements. Indoor water use reduction applies to appliances, such as dishwashers and clothes washers, and water used for processes such as heat rejection in the form of cooling towers and heat exchangers.

WE Prerequisite: Building-Level Water Metering

All buildings are required to be supplied with meters that determine monthly and annual water consumption. The meters can provide automated data or allow manual readings.

WE Credit: Outdoor Water Use Reduction

Similar to the WE Prerequisite for Outdoor Water Use Reduction, this credit requires either a landscape that does not require a permanent irrigation system beyond a two-year watering in period or one that is provided with an irrigation system that represents a 50 percent reduction in consumption below a baseline calculated for the peak watering month. The US EPA WaterSense Water Budget Tool must be used to calculate the effectiveness of plant species selection and grouping and irrigation system design.

WE Credit: Indoor Water Use Reduction

Further reductions below the baseline can earn increasing numbers of points by reducing potable water consumption from 25 to 50 percent. Additional performance requirements are specified for commercial washing machines and commercial kitchen equipment.

WE Credit: Cooling Tower Water Use

Projects with cooling towers can receive credit for conserving water while also controlling condenser water contaminants.

WE Credit: Water Metering

Additional water metering for two or more water subsystems, such as irrigation, domestic hot water, interior plumbing fixtures, boilers, reclaimed water, and process water, can earn points under this credit.

ENERGY AND ATMOSPHERE

The LEED: BD+C category EA, addresses the issues of energy for high-performance buildings; it also covers several issues that connect building systems to environmental impacts on air and the atmosphere—for example, the elimination of hydrochlorofluorocarbons, which, due to their presence in chillers and other mechanical equipment, are implicated in climate change and ozone depletion (see Table 5.13). The next sections discuss LEED v4 credits and reporting requirements in the EA category. Note that the four prerequisites do not carry points, and all must be met for a building to be considered for certification.

EA Prerequisite: Fundamental Commissioning and Verification

For all NC, CS, and S projects, the mechanical, electrical, plumbing, and renewable energy systems must be assessed and tested by a qualified Commissioning Authority (CxA) in accordance with ASHRAE Guideline 0-2005 and ASHRAE Guideline 1.1-2007 relative to their energy, water, indoor environmental quality, and durability performance. The OPR and BOD must include the building enclosure requirements in accordance with the guidance in National Institute of Building Sciences Guideline 3-2012 for Exterior Enclosures. The CxA must review the OPR and BOD and compare them to the project design for consistency. In addition, the CxA must develop

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TABLE 5.13

Points Assigned to LEED BD+C Energy and Atmosphere

Category or Credit Name	New Construction	Core and Shell	Schools
Energy and Atmosphere (EA)	33	33	31
Fundamental Commissioning and Verification	P	P	P
Minimum Energy Performance	P	P	P
Building-Level Energy Metering	P	P	P
Fundamental Refrigerant Management	P	P	P
Enhanced Commissioning	6	6	6
Optimize Energy Performance	18	18	16
Advanced Energy Metering	1	1	1
Demand Response	2	2	2
Renewable Energy Production	3	3	3
Enhanced Refrigerant Management	1	1	1
Green Power and Carbon Offsets	2	2	2

P = Prerequisite for the rating system

a commissioning (Cx) plan, develop construction checklists, develop a systems test procedure, verify test execution, maintain logs of activities, findings, and recommendations, and prepare a final Cx report. All results are reported directly to the owner. The CxA is also responsible for preparing a facilities operations and maintenance plan for the facility operators to use in operating the building at optimum efficiency.

EA Prerequisite: Minimum Energy Performance

There are three options available to fulfill the requirements of this prerequisite:

Option 1. A whole-building energy simulation must be performed and guide the design of NC, CS, and S facilities. The design must produce a minimum energy savings over the baseline case of 5 percent for new construction (NC or S), 3 percent for major renovations (NC or S), and 2 percent for CS projects. The simulation of both the baseline and designed facility must comply with the requirements of ANSI/ASHRAE/IESNA Standard 90.1-2010.

Option 2. In lieu of energy simulation, certain classes of buildings can apply the ASHRAE 50% Design Guides as follows:

(1) ASHRAE 50% Design Guide for Small to Medium Office Buildings smaller than 100,000 square feet (9,290 square meters [m^2]).

(2) ASHRAE 50% Design Guide for K-12 School Buildings

These prescriptive Design Guides spell out a path for achieving 50 percent energy savings over an ASHRAE Standard 90.1 baseline model without having to run the energy simulations. Versions of these Design Guides are also available for medium to large box retail stores and for large hospitals over 100,000 square feet (9,290 m^2).

Option 3. The project can apply specified Sections of the prescriptive Advanced Building Core Performance Guide for all buildings less than 100,000 square feet (9,290 m^2)

EA Prerequisite: Building-Level Energy Metering

Building-level energy meters or submeters than can be aggregated to determine total energy consumption are required. These meters include both meters that are the property of the building owners and meters owned by the utility. The energy data must be tracked at least monthly and be provided to the USGBC for a five-year period or until the ownership or lessee of the building changes.

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EA Prerequisite: Fundamental Refrigerant Management

Chlorofluorocarbons (CFCs), as previously noted, are ozone-depleting substances with a long history of use in building air-conditioning equipment. The EA prerequisite has the intent of eliminating CFCs from buildings, thereby protecting the ozone layer. It requires zero use of CFCs in new building HVAC and refrigeration (HVAC&R) systems. For a reuse project with existing equipment, a plan to phase out the CFCs must be submitted prior to project completion. Small existing HVAC&R systems, such as standard refrigerators or water coolers, containing 0.5 pounds (225 g) of refrigerant or less are exempted from this requirement.

EA Credit: Enhanced Commissioning

This credit addresses increasing the level of commissioning to include the building energy systems (Option 1) and envelope commissioning (Option 2).

Enhanced commissioning adds several additional requirements to the Fundamental Building Commissioning category and provides two paths for compliance.

Option 1.

Path 1. The requirements include reviewing the energy systems design, reviewing contractor submittals, creating a systems manual for building operators, verifying the training of operators, rechecking the building operation within 10 months of occupancy to verify performance, and developing an ongoing commissioning plan.

Path 2. The project can earn additional points by developing a monitoring procedure that includes the data points to be measured and evaluated for assessing the performance of energy and water systems.

Option 2. This option involves envelope commissioning and the requirements include reviewing contractor submittals, creating a systems manual for building operators, verifying training of operators, rechecking the building operation within 10 months of occupancy to verify performance, and developing an ongoing commissioning plan.

EA Credit: Optimize Energy Performance

Designing and building an energy-efficient building is important for sustainability reasons as well as for earning a LEED rating. Because Optimize Energy Performance has more than half of the EA credits assigned to it, it is by far the most important credit in the EA category—in fact, in the entire LEED rating system. ASHRAE 90.1-2010 is the basis for determining how well the high-performance building performs compared with the base case (i.e., the building that just meets the standard's minimum requirements). To be successful in obtaining a LEED rating for the building, the design team should ensure that the requirements of ASHRAE 90.1-2010 are exceeded by a substantial margin. The energy-related components of a typical building are its envelope (walls, roof, floor, windows, and doors); HVAC equipment; power distribution system; lighting system; and equipment such as pumps, appliances, refrigeration equipment, and elevators.

EA Credit 1 (EAc1) has three options for earning points toward LEED certification, as described below. Buildings must earn at least two points under EAc1 to be certified.

Option 1. Whole-Building Energy Simulation (1–18 points for NC and CS projects and 1–16 points for S projects). The project can earn points by running a whole-building energy simulation per ASHRAE 90.1-2010 using the performance rating method described in Appendix G of the standard. Table 5.14 shows the relationship between energy savings and points awarded under Option 1.

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TABLE 5.14

Points versus Percentage Energy Savings over Baseline

New Construction (NC)	Major Renovation	Core and Shell (CS)	NC and CS Points	S Points
6%	4%	3%	1	1
8%	6%	5%	2	2
10%	8%	7%	3	3
12%	10%	9%	4	4
14%	12%	11%	5	5
16%	14%	13%	6	6
18%	16%	15%	7	7
20%	18%	17%	8	8
22%	20%	19%	9	9
24%	22%	21%	10	10
26%	24%	23%	11	11
29%	27%	26%	12	12
18%	16%	15%	7	7
20%	18%	17%	8	8
22%	20%	19%	9	9
24%	22%	21%	10	10
26%	24%	23%	11	11
29%	27%	26%	12	12
32%	30%	29%	13	13
35%	33%	32%	14	14
38%	36%	35%	15	15
42%	40%	39%	16	16
46%	44%	43%	17	—
50%	48%	47%	18	—

The building must be designed, at a minimum, to meet the mandatory provisions of ASHRAE 90.1-2010. The proposed design must include all the energy costs of the proposed design, and the design must be compared with a baseline building as described in Appendix G of the standard. On-site renewable energy generation is included in the modeling to show a reduction in energy demand from external sources.

Option 2. Prescriptive Compliance Path: ASHRAE 50% Advanced Energy Design Guide (1–6 points). As was provided for in the Energy Performance prerequisite described earlier, projects can use the prescriptive ASHRAE 50 Percent Advanced Energy Design Guide for Small to Medium Office Buildings or the ASHRAE 50 Percent Advanced Energy Design Guide K-12 School Buildings in lieu of energy simulation. The number of points awarded varies from 1 to 6 based on the number of building components (envelope, glazing, interior lighting, exterior lighting, and plug loads) that follow the recommendations in these guides.

EA Credit: Advanced Energy Metering

Metering of energy consumption to support energy management is an important strategy for reducing building energy use. This credit requires the installation of advanced energy metering for the whole building and submeters for uses that consume 10 percent or more of total energy. The meters must be permanent and measure both energy use and peak power, referred to as *energy demand*. There must be a data collection system, and it must be remotely accessible, able to store 36 months of data, and capable or reporting hourly, daily, monthly, and annual energy use. For CS projects, the requirements are slightly different in that the whole building must be metered and provisions for tenant metering systems must be included.

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EA Credit: Demand Response

Enabling the facility to participate in demand response programs that use load shedding or load shifting strategies earns points under this credit. If the utility has a demand response program, the facility must be enrolled in the program for at least one year. If the utility does not have a demand response program, meters and communications must be installed to shed at least 10 percent of the building's estimated peak electricity demand.

EA Credit: Renewable Energy Production

LEED encourages the consumption of renewable rather than nonrenewable energy for buildings and provides points for on-site or site-recovered renewable energy systems. Eligible renewable energy systems include PV or solar thermal systems, active systems, biofuel-based electrical systems, geothermal heating/electrical systems, low-impact hydro, wave/tidal power systems, and wind-based electrical production systems. In order to receive points, projects using renewable systems must calculate project performance by expressing the energy produced as a percentage of the building annual energy cost. The building annual energy costs are calculated either by using an energy simulation or by using the US Department of Energy Commercial Buildings Energy Consumption Survey database to estimate electricity use. Table 5.15 indicates the relationship between renewable energy production and the number of points awarded.

EA Credit: Enhanced Refrigerant Management

The EA Prerequisite for Fundamental Refrigerant Management calls for zero use of CFC refrigerants in new building HVAC&R equipment. This credit provides for measures that further reduce the use of ozone-depleting refrigerants in buildings and addresses the climate change impacts of these substances. There are two options:

Option 1. Do not use refrigerants.

Option 2. Select refrigerants that minimize contributions to the life-cycle ozone depletion potential and the life-cycle direct global warming potential. In order to account for the potential damage of various refrigerants, a formula is used to quantify the combined impact in the building project.

EA Credit: Green Power and Carbon Offsets

Another approach to using renewable energy in a building is to contract for power from a utility that generates energy from renewable sources. This credit requires that the building owner engage in a minimum five-year contract for qualified resources that provides 50 percent (one point) or 100 percent (two points) of the project's energy needs from green power, carbon offsets, or renewable energy certificates (RECs). The renewable energy source must have come online since January 1, 2005. Green power and RECs must be Green-e certified or equivalent and can be used to

TABLE 5.15

Points versus Percentage Project Renewable Energy Generation

Percentage Renewable Energy	Points New Construction and Schools	Points Core and Shell
1%	1	1
3%	–	2
5%	2	3
10%	3	–

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mitigate only the project's electricity consumption. Carbon offsets can be used to mitigate the impacts of any energy source.

MATERIALS AND RESOURCES

The MR category addresses minimizing the impacts of the materials supply chain for construction. For the first time, LEED v4 provides for the use of life-cycle assessment and Environmental Product Declarations to earn points. It also addresses additional transparency measures on the part of manufacturers to stimulate the lowering of their contribution to environmental and human health impacts (see Table 5.16).

MR Prerequisite: Storage and Collection of Recyclables

An easily accessible area must be set aside for the separation, collection, and storage of recyclable materials, which at a minimum must include paper, corrugated cardboard, glass, plastics, and metals. The area must also have space for the proper disposal of at least two of the following electrical items: batteries, mercury-containing lamps, and electronic waste.

MR Prerequisite: Construction and Demolition Waste Planning

The project is required to develop and implement a construction and demolition waste plan that identifies at least five materials targeted for diversion and provides an estimate of the percentage of total construction and demolition waste that these materials represent. The plan must also specify how the waste will be separated or how the mixed or commingled waste will be handled by a recycling facility. A daily progress report addressing all waste streams must be generated and include both the total waste generated and the disposal and diversion rates.

MR Credit: Building Life-Cycle Impact Reduction

The project must demonstrate a strategy to minimize the environmental impacts of the building's materiality, either through reusing existing building resources or via life-cycle assessment. Four options are available:

> *Option 1. Historic Building Reuse.* Reuse a historic building by maintaining its structure, envelope, and interior nonstructural elements of a historical building. A qualified building must be listed on a local, state, or national register of historic places.

TABLE 5.16

Points Assigned to LEED BD+C Materials and Resources

Category or Credit Name	New Construction	Core and Shell	Schools
Materials and Resources (MR)	13	14	13
Storage and Collection of Recyclables	P	P	P
Construction/Demolition Waste Management Planning	P	P	P
Building Life-Cycle Impact Reduction	5	6	5
Building Product Disclosure and Optimization—Environmental Declarations	2	2	2
Building Product Disclosure and Optimization—Sourcing of Raw Materials	2	2	2
Building Product Disclosure and Optimization—Material Ingredients	2	2	2
Construction/Demolition Waste Management	2	2	2

P = Prerequisite for the rating system

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TABLE 5.17

Points Awarded versus Percentage Project Surface Area Reused

Percentage Surface Area Reuse	Points for New Construction, Schools	Points for Core and Shell
25%	2	2
50%	3	3
75%	4	5

Option 2. Renovation of Abandoned or Blighted Building. Renovate an abandoned or blighted building by maintaining at least 50 percent of exterior and interior elements. The building must be renovated to at least the degree that productive occupancy is possible.

Option 3. Building and Material Reuse. Reuse or salvage materials from on-site or off-site. Structural elements, such as floors and roof decking, enclosure materials, such as the building skin or framing, and permanently installed interior elements, such as walls and doors, are included. Table 5.17 lists the number of points earned versus percent of surface area reuse for this option.

Option 4. Whole-Building Life-Cycle Assessment. Perform a life-cycle assessment that is compliant with International Standards Organization ISO 14044 and select materials and products that demonstrate a 10 percent reduction in impact compared with the reference building. The reference building must closely resemble the designed building in size, function, and orientation with the energy performance of both reference and designed buildings the same as stated in the EA Prerequisite, Minimum Energy Performance. There must be reductions in at least three of the six environmental impact measures (global warming potential, stratospheric ozone depletion potential, acidification, eutrophication, formation of tropospheric ozone, and depletion of nonrenewable energy resources) by virtue of the materials/product selection process.

MR Credit: Product Disclosure and Optimization—Environmental Product Declarations

Environmental Product Declarations (EPDs) are life-cycle assessments of products performed in a format specified by ISO 14044. Multiattribute Standards are standards that specify multiple green attributes for products. This credit provides two options that can be used to earn two points for the project.

Option 1. EPDs. At least 20 different products must (1) have an ISO 14044 product-specific declaration, or (2) have an ISO compliant EPD that discloses impact information, or (3) comply with other USGBC-approved EPD frameworks.

Option 2. Multi-Attribute Optimization. Use products that comply with one of the following criteria for a minimum of 50 percent by cost of the total value of permanently installed products: (1) third-party certified products that have impacts below the industry average for three of the six environmental impacts measures (global warming potential, stratospheric ozone depletion potential, acidification, eutrophication, formation of tropospheric ozone, and depletion of nonrenewable energy resources), or (2c comply with some other USGBC-approved multiattribute framework.

MR Credit: Product Disclosure and Optimization—Sourcing of Raw Materials

Option 1. Raw Material Source and Extraction Reporting. Use a minimum of 20 products from at least five different manufacturers that have released a report

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regarding their raw materials that demonstrated responsible extraction procedures. These reports can be a combination of self-declarations by the manufacturer and third-party corporate social responsibility reports (CSRs) that contain information on raw materials extraction impacts. The CSRs must use one of the acceptable CSR frameworks, such as the UN Global Compact or the Global Reporting Initiative.

Option 2. Leadership Extraction Practices. Use products that meet the responsible extraction criteria from one of the following for at least 25 percent of the total value of permanently installed building products: extended producer responsibility, bio-based materials, wood products that are Forestry Stewardship Council certified, materials reuse, recycled content, or a USGBC-approved program.

MR Credit: Product Disclosure and Optimization—Material Ingredients

Option 1. Material Ingredient Reporting. Use at least 20 materials from manufacturers that use one of the following programs that indicate the chemical inventory of the product with at least 0.1 percent or 1,000 parts per million accuracy: Manufacturer Inventory, Health Product Declaration, Cradle to Cradle, or a USGBC-approved program.

Option 2. Material Ingredient Optimization. Use one of the following material ingredient optimization paths for at least 25 percent of the total value of permanently installed building products: GreenScreen v1.2 Benchmark, Cradle to Cradle Certified, REACH Optimization, or a USGBC-approved program.

Option 3. Product Manufacturer Supply Chain Optimization. Use products for at least 25 percent, by cost, of the total value of permanently installed building products that are sourced from manufacturers engaging in robust, validated safety, health, hazard, and risk programs that document at least 99 percent by weight of the ingredients in the product or material. The products also must be sourced from manufacturers with independent third-party verification that verify a variety of specified criteria are met for safety, health, hazard, and risk programs.

MR Credit: Construction and Demolition Waste Management

The project must recycle and/or salvage nonhazardous construction and demolition materials and measure the results by consistently using weight or volume units. Included are wood waste converted to biofuel. Excluded are excavated soil, land-clearing debris, and alternative daily cover. The two available options for this credit are described next.

Option 1. Divert 50 Percent and Three Material Streams. Divert at least 50 percent of the total construction and demolition waste stream from at least three different material streams.

Option 2. Reduction of Total Waste Material. Generate no more than 2.5 pounds per square foot (12.2 kilograms per m^2) of waste.

INDOOR ENVIRONMENTAL QUALITY

The Environmental Quality (EQ) category focuses heavily on indoor air quality and includes several other indoor environmental quality issues such as acoustical performance, lighting quality, daylighting and views, and thermal comfort (see Table 5.18).

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TABLE 5.18

Points Assigned to LEED BD+C Indoor Environmental Quality

Category or Credit Name	New Construction	Core and Shell	Schools
Indoor Environmental Quality (EQ)	16	10	16
Minimum IAQ Performance	P	P	P
Environmental Tobacco Smoke Control	P	P	P
Enhanced IAQ Strategies	2	2	2
Low-Emitting Materials	3	3	3
Construction IAQ Management Plan	1	1	1
IAQ Assessment	2	n/a	2
Thermal Comfort	1	n/a	1
Interior Lighting	2	n/a	2
Daylight	3	3	3
Quality Views	1	1	1
Acoustic Performance	1	n/a	1

P = Prerequisite for the rating system
n/a = not applicable to the rating system

EQ Prerequisite: Minimum Indoor Air Quality Performance

Buildings or building spaces that are mechanically ventilated must follow the requirements of the ventilation rate procedure in ASHRAE Standard 62.1-2010 or more stringent local equivalent. If outside the United States, the ventilation system design must adhere to the requirements of European Committee for Standardization (CEN) Standard EN 15251-2007, Indoor Environmental Quality. Similarly, for naturally ventilated buildings, the natural ventilation procedure in ASHRAE 62.1-2010 must be followed. For mechanical ventilation, the outdoor air flow must be monitored by direct airflow measurement. For natural ventilation, either direct airflow measurement or measurement of carbon dioxide (CO_2) concentrations is required.

EQ Prerequisite: Environmental Tobacco Smoke Control

Smoking must be prohibited inside the building and outside the building except in designated areas at least 25 feet (7.6 meters) from all building air intakes. Signage banning smoking must be posted near building entrances. For residential buildings, smoking is prohibited in all common areas, and excess leakage between units must be prevented by weather stripping and careful sealing of all penetrations between units.

EQ Prerequisite: Minimum Acoustic Performance

For school projects, a maximum background noise level of 40 decibels (dBA) must be achieved for HVAC systems in classrooms and other core learning spaces. ANSI Standard S12.60–2010, Part 1, Annex A.1; the 2011 HVAC Applications ASHRAE Handbook, Chapter 48, "Sound and Vibration Control"; and AHRI Standard 885–2008 provide best practices for preventing noise and sound transmission from HVAC equipment and components. For high-noise sites (those with peak-hour 60 dBA sound levels during school hours), acoustic treatment and other measures to minimize noise intrusion from exterior sources and control sound transmission between classrooms and other core learning spaces must be utilized.

EQ Credit: Enhanced Indoor Air Quality Strategies

There are two options for gaining points for additional measures to improve indoor air quality:

Option 1. Measures such as entryway systems, interior cross-contamination prevention, and filtration are required for this strategy. The entryway systems must

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be permanently installed and must be 10 feet (3 m) in length to capture dirt and particulates that enter the building, generally on the shoes of the building users or visitors. Grates, grilles, and slotted systems can be used for this purpose. Interior cross-contamination prevention measures must be used where hazardous gases and chemicals may be present. These areas must be negatively pressurized, have self-closing doors, be sealed with deck-to-deck partitions, and be safely exhausted to the building exterior. Outdoor air systems supplying air to occupied spaces must be equipped with Minimum Efficiency Reporting Value (MERV) 13 or higher filters per ASHRAE Standard 52.2-2007, which specifies how to test air filters or, if outside the United States, must have Class F7 or higher filters as defined by CEN Standard EN 779-2002. The CEN standard is the European equivalent of ASHRAE 52.2.

Option 2. An alternative set of requirements includes exterior contamination prevention, increasing ventilation, monitoring CO_2 levels, and providing additional source control and monitoring. Using advanced design strategies, such as employing computational fluid dynamics modeling, can result in entryways that inherently prevent pollutants from entering the building. Monitoring CO_2 concentrations for densely occupied spaces and providing indication of levels and alerting occupants to setpoints being exceeded provide additional assurance of a quality indoor air environment.

EQ Credit: Low-Emitting Materials

This credit covers volatile organic compound (VOC) emissions into indoor air, the VOC content of materials, and the means for testing indoor VOC levels. Seven categories of material are covered: (1) interior paints and coatings applied on site, (2) interior adhesives and sealants applied on site, (3) flooring, (4) composite wood, (5) acoustic insulation, (6) furniture, and (7) exterior products (School projects only). The dividing line between indoor and outdoor spaces is the weatherproofing barrier, for example, the waterproofing membrane and air or water resistant barriers. For school projects, there are restrictions on the VOC content of some classes of exterior materials such as coatings and roofing.

EQ Credit: Construction Indoor Air Quality Management Plan

The air quality during construction and the numerous potential contaminants resulting from sanding, painting, and finishing work can pose a threat to the health of future building occupants. To prevent these threats from occurring, several measures are required. First, control measures to protect air-handling system components from contamination are required as specified in Sheet Metal and Air Conditioning Contractors National Association *IAQ Guidelines for Occupied Buildings under Construction*, 2nd edition, 2007. Second, all absorptive materials to be used in construction must be stored in a manner that protects them from moisture damage. Third, air-handling equipment must be operated only with MERV 8 or better filters installed on all return air grilles and transfer duct inlets. These filters must be replaced or removed just prior to occupancy. Finally, the use of tobacco product inside or within 25 feet of the building is prohibited.

EQ Credit: Indoor Air Quality Assessment

Option 1. Just prior to occupancy and with all interior finishes installed and with new filtration media installed, flush out the building with 14,000 cubic feet of air per square foot of outdoor air. The flush-out also can occur during occupancy at specified airflow rates, interior temperatures, and durations.

Option 2. After construction is complete but prior to occupancy, conduct baseline IAQ testing for formaldehyde, particulates, ozone, total VOCs, carbon monoxide, and other specified chemicals.

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EQ Credit: Thermal Comfort

Option 1. Design the project in accordance with ASHRAE Standard 55-2010, *Thermal Comfort Conditions for Human Occupancy*.

Option 2. Design the HVAC systems and building envelope to meet the requirements of ISO 7730:2005, Ergonomics of the Thermal Environment, and CEN Standard EN 15251:2007, Indoor Environmental Input Parameters for Design and Assessment of Energy Performance of Buildings.

EQ Credit: Interior Lighting

Option 1. Lighting Control. At least 90 percent of individually occupied spaces must have lighting controls that allow the occupants to adjust lighting levels to suit their needs. For shared spaces, lighting must be able to be adjusted to meet group needs, lighting for presentations/projectors must be separately controlled, and the switches for luminaires must be in the spaces served by the luminaires.

Option 2. Lighting Quality. All spaces, with limited exceptions, must be provided with luminaires with a luminance of less than 2,500 foot-candles per square meter between 45 and 90 degrees from nadir. Light sources must have a color rendering index of 80 or higher, with some limited exceptions. For at least 75 percent of the connected load, light sources with a rated life of at least 24,000 hours must be used.

EQ Credit: Daylight

Option 1. Use computer simulation to demonstrate daylight autonomy for 55, 75, or 90 percent of normally occupied spaces. Additionally, show that an annual sunlight exposure of no more than 10 percent is achieved.

Option 2. Using computer simulation show that illuminance levels of between 300 and 3,000 lux are achieved between 9 A.M. and 3 P.M. for regularly occupied floor areas for 75 or 90 percent of normally occupied spaces.

Option 3. Use direct measurement to demonstrate that lighting levels between 300 and 3,000 lux are achieved for 75 or 90 percent of normally occupied spaces.

EQ Credit: Quality Views

By achieving line-of-sight view to the outdoors through vision glazing for 75 percent of all regularly occupied spaces, the building occupants are connected to the exterior outdoor environment and the project can earn points under this credit.

EQ Credit: Acoustic Performance

Strategies that promote high-quality acoustic design will address HVAC background noise, sound isolation, reverberation time, and sound reinforcement and masking. This credit requires minimum sound transmission class ratings between various types of interior spaces, minimizing HVAC noise and providing appropriate reverberation times depending on the uses for the space.

INNOVATION

IN Credit: Innovation

LEED v4 allows the awarding of points for this credit for innovations (IN), use of a pilot credit from the LEED Pilot Credit Library, or exemplary performance. In the context of LEED, innovation is the achievement of measurable environmental performance for a strategy not specifically addressed by LEED. For example, a green cleaning program implemented in the operation of the building could meet this requirement because this strategy is not addressed in any of the LEED credits. The LEED Pilot Credit Library is a set of credits that are being beta tested for eventual incorporation into future versions of LEED and that project teams can use to earn IN

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TABLE 5.19

Points Assigned to LEED BD+C Innovation and Design

Category or Credit Name	New Construction	Core and Shell	Schools
Innovation and Design (ID) (refers to innovative approaches not otherwise addressed in LEED)	6	6	6
Innovation (refers to exemplary performance)	5	5	5
LEED Accredited Professional	1	1	1

TABLE 5.20

Points Assigned to LEED BD+C Regional Priority

Category or Credit Name	New Construction	Core and Shell	Schools
Regional Priority	4	4	4
Regional Priority Credits	4	4	4

points. Exemplary performance provides points for specifically designated credits in other categories where the project either doubles the credit requirements or achieves the next incremental percentage threshold. For example, for the MR Credit addressing construction waste management, if the project team achieves both waste diversion and waste reduction targets, an extra point can be achieved under the IN credit (see Table 5.19).

ID Credit: LEED Accredited Professional

To assist in facilitating LEED certification, a LEED AP specialized in the rating system must be a principal participant of the project team.

REGIONAL PRIORITY

For any area of the world where there is a LEED project, additional credit can be earned depending on the priorities of the USGBC chapter in that region. These priorities are based on the existing credits from each LEED category and are selected based on input from the USGBC regional councils and chapters (see Table 5.20). Each region is assigned six RP credits for possible extra credit, and the project team can earn points for four of the six designated credits. The RP credits are available on the USGBC website (www.usgbc.org) according to zip code.

Case Study: University of Florida Research and Academic Center at Lake Nona in Orlando, Florida

Laboratories present a significant challenge to project teams designing and building a high-performance facility. Laboratory buildings typically have requirements for high rates of ventilation and must address the presence of potentially toxic chemicals and materials that not present in, for example, commercial office buildings. The University of Florida was the client for a new Research and Academic Center located at Lake Nona near Orlando, Florida, in collaboration with HOK Architects and AEI, the engineers for the project. The $44 million, 100,000 ft² (10,406 m^2) facility was designed to enable direct collaboration between University of Florida scientists and researchers with the Sanford–Burnham Medical Research Institute (see Figures 5.7 and 5.8).

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Figure 5.7 The University of Florida Research and Academic Center at Lake Nona in Orlando, Florida, is a high-performance research building that was awarded a LEED platinum award by the US Green Building Council for its outstanding energy and environmental design. The solar shading screen, which is made of metal mesh, is the dominant architectural feature of the building. Although its shape and the material comprising it posed numerous fabrication and construction challenges, the screen was properly installed and functions as intended. (Photo courtesy of HOK Architects)

The hoped-for outcome was that this research facility would create medical breakthroughs by harnessing the outstanding abilities of multidisciplinary teams consisting of researchers, clinicians, teachers, and students. The goal was to develop effective therapies to dramatically improve the health of patients. One of the key goals of the project team was outstanding daylighting that would both enhance the productivity of the researchers and contribute to reduce energy consumption. In the layout of the research laboratories, a glass wall was located along the inboard side of the research areas to provide ample views and to allow daylight penetration between labs and the research office zone (see Figure 5.9). Research areas include two floors of open laboratories made up of large, ballroom-plan island bench areas with mobile sinks and casework supported by fume hood and biosafety cabinets. Labs have views of a wooded preserve to the south. An internal glass wall provides visual connections to offices.



Figure 5.8 South view of the University of Florida's Lake Nona Research and Academic Center located near Orlando, Florida. (Photo courtesy of HOK Architects)

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Figure 5.9 The daylighting strategy used for the Lake Nona research building provides excellent levels of natural light, which is often difficult to achieve in research laboratories. (Photo courtesy of HOK Architects)

A motorized system of roller shades is used for window treatments in classrooms, labs, offices, and the main auditorium, blocking out the sun while still allowing natural light to filter through (see Figure 5.10). The result is a very pleasing teaching and learning environment for faculty and students. The exceptional architecture feature of the building is an exterior sunshade, which creates a striking appearance for the building while at the same time mitigating heat gains to direct sunlight, a necessity in Florida. The result of this approach to solar management is a reduction in the use of cooling capacity and a parallel reduction in energy consumption. The large glass curtain wall of the building is covered with the screen made of a metal mesh. Thus, the building occupants have both natural lighting and unobstructed views. The external sunshade is formed into a circular dome style structure (see Figure 5.11). It is made out of 10 trapezoidal panels that curve from the top of



Figure 5.10 A system of manual and motorized roller shades controls glare and daylighting. The window treatments, installed in classrooms, labs, offices, and the main auditorium block out the sun while still allowing natural light to filter through. This creates a more comfortable and pleasing learning environment for faculty and students. The curved west-facing wall of the auditorium required special measures in order to ensure that the shades were installed correctly. (Photo courtesy of HOK Architects)

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Figure 5.11 The metal mesh sunscreen is the signature architectural element of the University of Florida Research and Academic Center laboratory building. It reduces heat and glare while allowing daylighting and views through the often very challenging west façade of the building. (Photo courtesy of HOK Architects)

the building to the bottom, wrapping the exterior of the building and hugging intermediate supports. A center area in the panel cuts away to reveal the glass curtain wall behind. The sunshade panels are 68 feet (20.7 m) high and they extend 18 feet (5.5 m) from the building. The sunshade design was especially challenging because of the design criteria for heavy winds in Florida, which require that these elements withstand hurricane winds of 150 mph. Some of the other INs in this building that make it an exceptional high-performance green laboratory building are the system of active chilled beams, heat pump recovery for reheat, solar-heated domestic water, and a terra-cotta green screen that provides an outer layer of insulation to improve energy efficiency while preventing excess moisture.

The University of Florida's College of Pharmacy's Center for Pharmacometrics and Systems Pharmacology, housed in the Research and Academic Center, is among the first academic centers in the nation to adopt sophisticated mathematical modeling and computer simulations to mimic clinical trials of new drugs. Simulated trials allow researchers to avoid investing unnecessarily in drugs that are unlikely to be of benefit. The result is that resources and research efforts can be better targeted toward drugs that have the potential to help millions of people, and the drugs that emerge from the process will be more likely to receive quick approval from the U.S. Food and Drug Administration.

The Lake Nona Research and Academic Center was also deemed an outstanding project by the USGBC, which awarded the project a LEED platinum-level certification using LEED v2.2 (see Table 5.21).

TABLE 5.21

Points awarded for the LEED Platinum certification of the University of Florida Lake Nona Research and Academic Center

Credit	Points Achieved	Points Available
Sustainable Sites	14	14
Prerequisite: Construction Activity Pollution Prevention	yes	yes
Site Selection	1	1
Development density and community connectivity	0	1
Brownfield redevelopment	0	1

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Credit	Points Achieved	Points Available
Alternative transportation	3	4
Site development	1	2
Stormwater design	2	2
Heat island effect	1	2
Light pollution reduction	1	2
Water Efficiency	4	5
Water efficient landscaping	2	2
Innovative wastewater technologies	0	1
Water use reduction—20%	2	1
Energy and Atmosphere	13	17
Prerequisite: Fundamental Commissioning of the Building Energy Systems	yes	yes
Prerequisite: Minimum Energy Performance	yes	yes
Prerequisite: Fundamental Refrigerant Management	yes	yes
Optimize energy performance	9	10
On-site renewable energy	0	3
Enhanced commissioning	1	1
Enhanced refrigerant management	1	1
Measurement and verification	1	1
Green power	1	1
Materials and Resources	7	13
Prerequisite: Storage & Collection of Recyclables	yes	yes
Building reuse	0	3
Construction waste	2	2
Material reuse	0	2
Recycled content	2	2
Regional materials	2	2
Rapidly renewable materials	0	1
Certified wood	1	1
Indoor Environmental Quality	14	15
Prerequisite: Minimum IAQ Performance	yes	yes
Prerequisite: ETS Control	yes	yes
Outdoor air delivery monitoring	1	1
Increased ventilation	1	1
Construction IAQ management plan	1	2
Low-emitting materials	4	4
Indoor chemical and pollutant source control	1	1
Controllability of systems	2	2
Thermal comfort	2	2
Daylight and views	2	2
Innovation	5	5
Innovation and design	4	4
LEED Accredited Professional	1	1
TOTAL POINTS (LEED Platinum at least 50 points)	52	69

Summary and Conclusions

The LEED building assessment system is a suite of rating products that can be used to guide the life-cycle design, construction, and operation of a high-performance green building. The current version of the LEED assessment system is version 4. The various LEED rating products provide a wide variety of options, one of which is applicable to almost any type of project. A successful certification process results

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in one of four levels of certification: platinum, gold, silver, or certified. Construction industry professionals who are engaged in green building design and construction can earn a variety of LEED credentials, ranging from LEED Green Associate to LEED AP with specialty to LEED Fellow. The number of building projects certified by the GBCI is growing at an exponential rate, and it is expected in the near future almost half of all new, nonresidential buildings will be green buildings with the vast majority undergoing LEED certification.

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Chapter 6

The Green Globes Building Assessment System

Green Globes (www.thegbi.com) is a building assessment system with roots in the United Kingdom and Canada that has been making inroads in the United States as an alternative to the US Green Building Councils (USGBC) Leadership in Energy and Environmental Design (LEED). It provides a rating of one to four Green Globes for building projects, depending on the percentage of the maximum points that the project actually achieves (see Figure 6.1). The Green Building Initiative (GBI), the US proponent of Green Globes, describes the Green Globes building assessment system as a revolutionary green management tool that includes an assessment protocol, a rating system and a guide for integrating environmentally friendly design into commercial buildings. When the web-enabled assessment protocol has been completed by a project team, it also facilitates recognition of the project through third-party verification. It is designed to be an interactive, flexible, and affordable approach to environmental design and building assessment.

The Green Globes building rating system represents more than 20 years of research and refinement by a wide range of prominent international organizations and experts. The genesis of the system was the Building Research Establishment Environmental Assessment Method (BREEAM) in the United Kingdom, which was imported into Canada in 1996. In the same year, the Canadian Standards Association published BREEAM Canada for Existing Buildings. In 2004, the GBI acquired the rights to distribute Green Globes in the United States. The GBI mission is to accelerate the adoption of building practices that result in energy-efficient, healthier, and environmentally sustainable buildings by promoting credible and practical green building approaches. The GBI is committed to continually refining the system to ensure that it reflects changing opinions and ongoing advances in research and technology, as well as involving multiple stakeholders in an open and transparent process.

In 2005, the GBI became the first green building organization to be accredited as a standards developer by the American National Standards Institute (ANSI) and began the process of establishing Green Globes as an official ANSI standard. The GBI ANSI technical committee was formed in early 2006 to develop an environmental design and assessment protocol for commercial building under

85–100%		Reserved for select building designs which serve as national or world leaders in energy and environmental performance. The project introduces design practices that can be adopted and implemented by others.
70–84%		Demonstrates leadership in energy and environmental design practices and a commitment to continuous improvement and industry leadership.
55–69%		Demonstrates excellent progress in achieving eco-efficiency results through current best practices in energy and environmental design.
35–54%		Demonstrates movement beyond awareness and commitment to sound energy and environmental design practices by demonstrating good progress in reducing environmental impacts.

Figure 6.1 The Green Globes rating levels are based on the percentage of points achieved compared to the maximum available. Achieving a minimum of 35 percent of the available points would provide a certification level of one Green Globe. (Diagram courtesy of the Green Building Initiative, Inc.)

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new construction. This protocol, approved in March 2010, is ANSI/GBI 01-2010, *Green Building Assessment Protocol for Commercial Buildings*. This protocol is in the process of being updated to a new version, ANSI/GB01-2016, to reflect the latest thinking in green building assessment

Green Globes Building Rating Tools

The Green Globes building assessment system consists of three major assessment tools:

1. Green Globes for New Construction (NC)
2. Green Globes for Existing Buildings (EB)
3. Green Globes for Sustainable Interiors (SI)

Similar to the LEED building rating system, the Green Globes assessment tools each contain categories that have points assigned to them. Table 6.1 shows the major significant differences between the Green Globes and LEED systems. Green Globes has 10 times as many points assigned to issues compared to LEED; as a result, it is significantly more fine-grained compared to LEED. Green Globes does not have any mandatory requirements or prerequisites whereas LEED has a wide range of prerequisites. LEED allows consideration of only Forestry Stewardship Council certified wood products for awarding points while Green Globes has four certified wood options. Similarly, LEED has two possible paths for gaining points for energy performance while Green Globes has four paths. In contrast to LEED, where there is no physical visit to the project site by a member of the assessment team, a Green Globes Assessor (GGA) is assigned to the project, performs an inspection of the project at substantial completion, and verifies the measures documented by the project. With respect to earning points, Green Globes allows not applicable (NA) credits and partial credit while LEED does not have this provision. As noted, Green Globes projects are assigned a third-party assessor to both perform on-site verification and to respond to questions from the project team about technical issues of certification. Similar to LEED, Green Globes has four possible certification levels and awards from one to four Green Globes to a certified project.

TABLE 6.1

Key Differences between the Green Globes and LEED Building Assessment Systems

Program Feature	Green Globes	LEED
Total program points	1,000	110
Partial credit	Yes	No
Prerequisites	No	Yes
Not applicable credits	Yes	No
Energy performance	Four paths	Two paths
Forestry certifications accepted	4	1
Assessor visit to project	Yes	No
Ratings	4 Globes 3 Globes 2 Globes 1 Globe	LEED Platinum LEED Gold LEED Silver LEED Certified

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TABLE 6.2

Description of Green Globes Categories

Category	Description
Project/environmental management	Integrated design process, environmental management, commissioning
Site	Development area, ecological impacts, stormwater management, landscaping, exterior light pollution
Energy	Energy performance; energy demand; energy metering; measurement and verification; building opaque envelope; lighting; heating, ventilation, and air-conditioning (HVAC) systems and controls; efficient equipment; renewable energy; energy-efficient transportation
Water	Indoor and outdoor water consumption, cooling towers, boilers and water heaters, water-intensive applications, treatment, alternate sources, metering, irrigation
Materials and resources	Building assembly, interior fit-outs, materials reuse, building life service plan, resource conservation, building envelope
Emissions	Heating system emissions, ozone-depleting potential, global warming potential
Indoor environment	Ventilation, source control and measurement, lighting design and systems, thermal comfort, acoustic comfort

Table 6.2 shows the seven Green Globes categories and describes the issues addressed in each category. The Project Management and Emissions categories are unique to Green Globes, although LEED version 4 addresses integrated design. In general, Green Globes is more detailed than LEED and addresses far more specific issues than does LEED. For example, for the LEED BD+C: NC rating tool awards points for 60 different issues/credits; GG NC awards points for almost 300 issue/credits.

Green Globes currently has three building assessment tools:

1. Green Globes for New Construction (GG NC). Applies to new buildings that are designed for occupancy, have conditioned space, have had no more than 18 months of occupancy at the time the assessment is ordered, and are at least 400 square feet (37 square meters [m^2]) in gross area.
2. Green Globes for Existing Buildings (GG EB). Applies to existing buildings that have 12 consecutive months of operational energy and water data, have conditioned spaces, and are at least 400 gross square feet (37 m^2) in size.
3. Green Globes Sustainable Interiors (GG SI). Eligible spaces must be permanent and designed for occupancy with periodic refits of no less than a year, be contiguous within a single boundary (no checkerboard group of offices with noncertified spaces in between), and be at least 400 gross square feet (37 m^2) in size.

The point allocation among categories for the four Green Globes assessment tools varies somewhat because only the GG NC has a Site category. The Management category for the GG EB tool is referred to as *Environmental Management*; for the GG NC and SI tools, it is labeled the *Project Management* category. Table 6.3 shows the point allocations for the four Green Globes assessment tools. Note that the system provides a base of 1,000 points which can be decreased for not-applicable (NA)

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TABLE 6.3

Points Allocation by Category for Each of the Four Green Globes Rating Tools

Category	GG NC	GG CIEB	GG CIEB HC	GG SI
Project/environmental management	50	100	97	70
Site	115	—	—	—
Energy	390	350	350	300
Water	110	80	78	90
Materials and resources	125	110	110	
Emissions	50	175	175	250
Indoor environment	150	185	190	250
Total	1,000	1,000	1,000	1,000

situations. For example, many projects in Florida do not have boilers and, as a result, boiler-specific credits in the energy, water, and emissions categories would generally be considered as NA.

Structure of Green Globes for New Construction

Green Globes offers building assessment and certification for new buildings, major renovations, additions, existing buildings, and interiors. A variety of facilities, including government, education, health-care, industrial, multiunit residential, retail, office, and corporate facilities, have used either the Green Globes NC or the Green Globes Existing Buildings (EB) rating system. Once the project has been registered for Green Globes certification, a Green Design Facilitator (GDF) must be appointed to begin an internal Green Globes assessment by the project team. The role of the GDF is to outline the overall green design framework for the project by answering a logical sequence of questions that guides the project team in integrating important elements of sustainability (see Figure 6.2). The professional best suited to filling the GDF role would be a trained Green Globes Professional (GGP). GGPs are individuals who receive training at the Green Globes user level and are qualified to offer project management and technical support to clients undergoing the building assessment and certification process. GGPs can also assist the project team in developing measurable green design performance requirements to satisfy the overall objectives of the project.

The Green Globes Construction Online Survey is the foundation of the rating process. However, to benefit fully from the value-added design assistance features of the system—and to obtain a preliminary self-assessment of a building—the project should be registered and the preliminary and subsequent questionnaires should be completed. However, a building cannot be promoted as Green Globes certified until the final assessment site visit and verification report have been completed.

The structure and point allocation of the Green Globes NC rating system is shown in Table 6.4. Note that in Green Globes, although 1,000 points are achievable,

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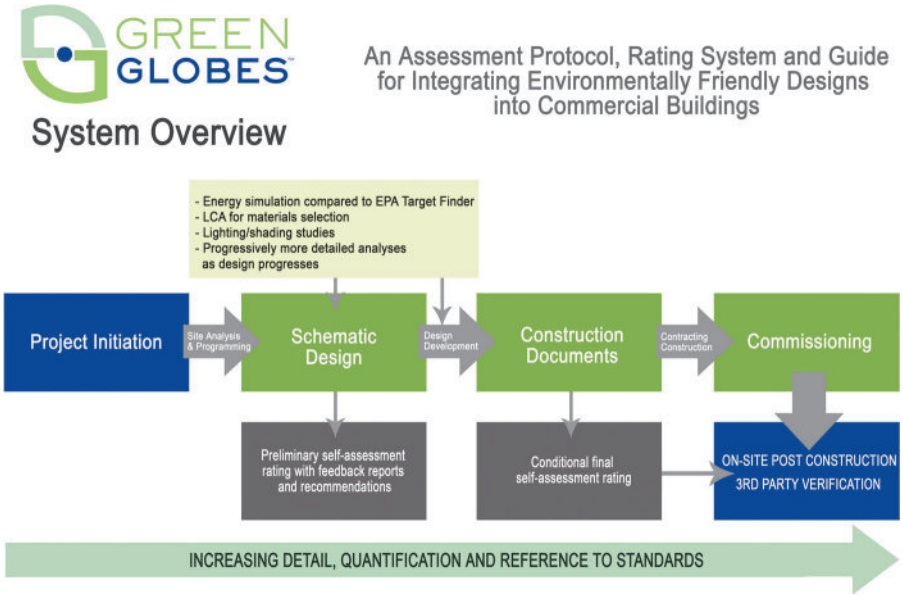


Figure 6.2 Overview of the Green Globes assessment protocol showing the assessment activities at each of the project stages. (Diagram courtesy of the Green Building Initiative, Inc.)

points can be indicated as NA, and the total achievable points are reduced by the points designated as NA. In the case study that follows, the project had 58 points indicated as NA. As a result, the achievable points were reduced from 1,000 to 942 points. In contrast, the LEED building rating systems do not permit points being indicated as NA.

The next sections provide more detail about the GG NC categories and the point allocations within each category.

TABLE 6.4

Structure of the Green Globes NC Rating System (Total Available Points = 1,000)

Description	Total Applicable Points Available
Section 1: Project Management	
1.1 Integrated Design Process	9
1.2 Environmental Management during Construction	12
1.3 Commissioning	29
Project Management Totals	50
Section 2: Site	
2.1 Development Area	30
2.2 Ecological Impacts	32
2.3 Stormwater Management	18
2.4 Landscaping	28
2.5 Exterior Light Pollution	7
Site Totals	115

(*continued*)

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TABLE 6.4 (*Continued*)

Structure of the Green Globes NC Rating System (Total Available Points = 1,000)

Description	Total Applicable Points Available
Section 3: Energy	
3.1 Energy Performance	100
3.2 Energy Demand	35
3.3 Metering, Measurement, and Verification	12
3.4 Building Opaque Envelope	31
3.5 Lighting	36
3.6 HVAC Systems and Controls	59
3.7 Other HVAC Systems and Controls	32
3.8 Other Energy-Efficient Equipment and Measures	11
3.9 Renewable Energy	50
3.10 Energy-Efficient Transportation	24
Energy Totals	390
Section 4: Water	
4.1 Water Consumption	42
4.2 Cooling Towers	9
4.3 Boilers and Water Heaters	4
4.4 Water Intensive Applications	18
4.5 Water Treatment	3
4.6 Alternate sources of water	5
4.7 Metering	11
4.8 Irrigation	18
Water Totals	110
Section 5: Resources	
5.1 Building Assembly (core and shell including envelope)	33
5.2 Interior Fit-out (including finishes and furnishings)	16
5.3 Reuse of Existing Structures	26
5.4 Waste	9
5.5 Building Service Life Plan	7
5.6 Resource Conservation	6
5.7 Building Envelope—Roofing/Openings	10
5.8 Envelope—Foundation, Waterproofing	6
5.9 Envelope—Cladding	5
5.10 Envelope—Barriers	7
Resources Totals	125
Section 6: Emissions	
6.1 Heating	18
6.2 Cooling	29
6.3 Janitorial Equipment	3
Emissions Totals	50
Section 7: Indoor Environment	
7.1 Ventilation	37
7.2 Source Control and Measurement of Indoor Pollutants	46
7.3 Lighting Design and Systems	30
7.4 Thermal Comfort	18
7.5 Acoustic Comfort	29
Indoor Environment Totals	160
TOTAL	1,000

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SECTION 1: PROJECT MANAGEMENT (50 POINTS)

The Project Management category is unique to Green Globes and addresses three major topics: (1) the integrated design process (IDP), (2) environmental management during construction, and (3) commissioning. Integrated design is one of the most important ingredients of green or sustainable design, and it is emphasized in virtually all of the most recent versions of green building rating systems, including LEED v4. Environmental management during construction is the province of the construction manager or general contractor and is directed at minimizing the project's impacts on the environment due to construction activities. The scope of building commissioning has been greatly expanded from consideration of just building service (HVAC, plumbing, electrical, fire protection, building automation, building transport systems, communications systems) to other systems, such as the building envelope, structural components, and noise isolation.

1.1 Integrated Design Process (IDP)	**9 pts**
IDP during predesign meetings with at least 5 disciplines	3
IDP Green Performance goals (quantitative) set in predesign	1
IDP Green Performance goals (metric) set in predesign	2
IDP Progress Meetings for 3 Design phases	1.5
IDP Progress meetings at completion of construction milestones	1.5
1.2 Environmental Management During Construction	**12 pts**
General contractors environmental management system (EMS)	3
General contractors clean diesel practices	2
Organic building materials protection	1
Building envelope complete before finishes and HVAC	1
IAQ during construction—14-day flush or positive IAQ results	2
IAQ for buildings occupied during construction	3
1.3 Commissioning	**29 pts**
Pre-Commissioning	
Owner Project Requirement (OPR) document	1
Basis of Design document	1
Commissioning authority requirement	1
Whole Building Commissioning	
HVAC and controls	4
Building envelope	3
Structural systems	2
Fire protection systems	2
Plumbing systems	1
Electrical system	1
Lighting systems and controls	1
Building automation system	1
Elevator and conveying systems	1
Communication systems	1
Field test partitions for noise isolation	1
Commissioning per ARHRAE Guidline-2005 Annex L	1
Training of building operator per ASHRAE Guideline 0-2005	1
Operations and Maintenance Manual	
Complete and user-friendly manual	6

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SECTION 2: SITE (110 POINTS)

The Site category addresses issues such as disturbance of the local ecology, stormwater management, appropriate landscaping strategies, and exterior light pollution. Land reuse is emphasized over using greenfield sites for construction purposes.

2.1 Development Area	**30**
Urban Infill and Urban Sprawl	
Located within 0.5 miles of a Commercial Zone	5
Site is served by existing utilities at least 1 year old	5
Greenfields, Brownfields, and Floodplains	
Is site on remediated brownfield or Superfund site?	10
Sensitive site avoidance (farm, park, woods, prairie, wetland)	6
Building higher than 100-year floodplain	4
2.2 Ecological Impacts	**32**
Site Disturbance and Erosion	5
Path A: Erosion and Sedimentation Control Plan OR	
Path B: Erosion and Sedimentation Control Specifications	
Limit construction activity to 40 feet from building and 5 feet from paved surfaces	3
Existing Tree Integration into Landscape Plan	
Large tree integration (12 inches in diameter or greater)	2
Cluster of existing trees	2
Existing undergrowth	1
Tree Preservation	4
Tree Preservation Plan by Certified Arborist OR	
Tree Protection Specification	
Heat Island Effect	
Percentage of roof that is vegetated or has a high Solar Reflectance Index (SRI) greater than 78 (low roof) or 29 (steep roof)	6
Vegetated area: 40–55% = 2 points, 56–70% = 4, >70% = 6	
Percentage of paving with SRI at least 25 (25–49% = 1 point, >50% = 2)	2
Percentage of paving shaded by 15 year trees (25–49% = 2 points, >50% = 3)	3
Percentage of East and West Walls with high SRI (75% of wall area must have SRI >= 29)	2
Bird Collisions	
Features or patterns on glass no more than 11 inches apart	1
Reflectance avoidance (overhangs, sunshades, screens)	1
2.3 Stormwater Management	**18**
Stormwater Management Plan—Flood and Erosion Control meet local targets	5
Stormwater Management Plan—Quality 80% total suspended solids removal	5
Stormwater Management Plan—Retain 50% Annual Rainfall	5
Site boundary is farther than 100 feet from a natural body of water	3
2.4 Landscaping	**28**
Professionally developed landscape and irrigation plan	6
Landscape plan notes soil type drainage and light conditions	2
Landscape plan notes structural limitation (shading, utilities, etc.)	1
Drought-tolerant plants, percentage (50–74% = 2 points, >=75% = 3)	3
Native, noninvasive plants, percent (50–74% = 2 points, >=75% = 4)	4
Minimal turf grass (only within 20 feet of building, 5 feet of paving, retention)	3
Tilled soil prior to planting	1
Organic mulch around plantings	1
Plants with similar water requirements are grouped together	2
Plants spaced to allow maturation after 5 years	1
Minimum 15% of paved areas are pervious	4
2.5 Exterior Light Pollution	**7**
Path A: Lighting Design Performance	
Lighting design that meets requirements of IES Model Lighting Ordinance OR	
Path B: Prescriptive Lighting Requirements	

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SECTION 3: ENERGY (390 POINTS)

The Energy category covers building energy consumption, control of energy demand, metering of energy consumption, the thermal performance of the building envelope, lighting energy, HVAC systems and control systems, energy-efficient equipment, renewable energy, and energy-efficient transportation.

3.1 Energy Performance	**100**
Assessing Energy Performance: One of four pathways	
Path A: Energy Star Target Finder	
Path B: ANSI/ASHRAE/IESA Standard 90.1, Appendix G	
Path C: Building Carbon Dioxide Equivalent Emissions	
Path D: ASHRAE Building Energy Quotient (bEQ)	
3.2 Energy Demand	**35**
Passive demand reduction (Thermal Mass)	
20% exterior walls 5 BTU/SF/oF light walls, 7 BTU/SF/oF heavy walls	3
20% internal mass walls 5 BTU/SF/oF light walls, 7 BTU/SF/oF heavy walls	3
50% return air plenum 5 BTU/SF/oF light walls, 7 BTU/SF/oF heavy walls	3
Thermal energy storage capable of reducing peak cooling demand	10
31–40% = 4 points, 41–50% = 7, >50% = 10	
Power demand reduction	
Modeled monthly power demand factor	8
(Demand factor 75–79% = 4 points, 80–85% = 6, 80–85% = 6, >85% = 8)	
Load shedding to reduce peak power demand	8
(by 15–19% = 4 points, 20–24% = 6, 25–30% = 7, >30% = 8)	
3.3 Metering, Measurement, and Verification	**12**
Metering	
Electricity	1
Heating fuel	1
Steam	1
Other	1
Submetering for specific equipment (building 20,000 SF or greater)	4
Measurement and verification (building 20,000 SF or greater)	4
3.4 Building Opaque Envelope	**31**
Thermal Resistance and Transmittance	
Meets or exceeds required R values for opaque elements	10
Orientation	
Ratio of north and south fenestration to east and west fenestration as high as possible	5
Fenestration Systems	
U factors of glazing meet requirements	8
SHGC of glazing meets requirements	8
3.5 Lighting	**36**
Total lighting power density	10
Interior automatic light shutoff controls for all spaces	3
Light reduction controls—dual switching in non-daylighted spaces	4
Daylighting—window areas equal to 10% of net building area	3
Effective Aperture for Vertical Fenestration (0.10 or more)	3
Percentage of roof that is skylights	2
(Up to 3% = 0.5 points, 3–4% = 1, 4–5% = 1.5, 5% or more = 2)	
Controls for daylighted zones	
Small spaces manual or automatic photocell	3
Large spaces manual or automatic photocell	3
Exterior luminaires and controls	
Average Lumens per watt—at least 60	1
LED lamps used for all exterior lighting	1
Lamp mercury content—compact fluorescent lights below 4 mg, T8 5 mg or less	1
Exterior lights controlled by photocell or time switch with 10-hour backup	2

(*continued*)

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3.6 HVAC Systems and Controls	**59**
Building automation system (BAS) for all energy-using systems	10
Cooling equipment—base efficiency meets ASHRAE 90.1-2010	5
Cooling equipment—base efficiency exceeds ASHRAE 90.1-2010	8
Cooling towers—two-speed or variable-speed fans	4
Waterside economizer that can use outside air for cooling water	4
Heat pumps —% exceeding ASHRAE 90.1-2010 standard (COP, HSPF)	6
Heating equipment—% exceeding ASHRAE 90.1-2010 standard (AFUE or Et or Ec)	8
Condensate Recovery—steam heating system with condensate recovery	3
Steam traps—design signed by a Professional Engineer	1
Steam traps—isolation valves provided to allow cleaning	1
Domestic hot water heaters—efficiency meets ASHRAE 90.1-2010	2
Domestic hot water heaters—electric igniters and low nitrous oxide (NOx) burners	1
Variable-speed control of pumps by % of pumping power	6
3.7 Other HVAC Systems and Controls	**32**
Minimize or eliminate reheat and recool	6
Air economizers	1
Controls to shut down outside air and exhaust after hours	1
Low-leakage dampers—less than	1
Diffusers, registers with full flow pressure drop of 0.01 inch or less	0.5
Noise criteria for duct distribution system 35 or less	0.5
Supply and return ductwork with pressure drop of 0.1inch /100 linear feet or less	0.5
Flexible ductwork no longer than 5 feet	0.5
Flex duct used only at diffusers and to variable air volume (VAV) boxes	0.5
Durable elbow support used	0.5
Duct joints are sealed and tested to verify leakage does not exceed 5%	1
HVAC motors meet NEMA Premium Energy Efficient Motor Program	1
Variable-speed fans controlled by duct pressure setpoint or emergency management control system	2
Occupancy or CO_2 sensors to control vent rates in varying occ. spaces	4
CO_2 sensors capable of maintaining calibration within 2% for 1 year	1
Does ERV system include: fan power controlled by pressure drop	1
Bypass for economizer operation	2
MERV 13 filtration	2
Variable Refrigerant Flow (VRF) Systems	6
3.8 Other Energy-Efficient Equipment and Measures	**11**
Elevators regenerative braking	3
Escalators/moving walkways able to slow down or stop without traffic	2
Other Energy Star equipment: plug-in lighting	2
Motors	2
Others (refrigerators, hand dryers, computers)	2
3.9 Renewable Sources of Energy	**50**
On-site renewable energy: Feasibility study for use of wind, solar, geothermal	9
Implementation of study (Yes 23, Partially 11, Not cost effective N/A, Not Implemented 0)	23
Off-site renewable energy: Renewable energy certificates or "green" power for 3-year term	18
3.10 Energy-Efficient Transportation	**24**
Site located ¼ mile or less from bus or train stop	10
Designated preferred parking for carpool and shelter for pickups	2
Electric vehicle recharge of alternate fuel station on-site or nearby	5
Site located ¼ mile or less from bike or multi-use path	3
Sheltered bike parking for 5% of office occupants or 50% residents	3
Building Walkability Index greater than 75%	1

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SECTION 4: WATER (110 POINTS)

The Water category covers the issues of both indoor and outdoor water consumption, cooling tower water use, water consumption by boilers and water heaters, the water efficiency of specialized equipment such as commercial dishwashers, laundries, and laboratory/medial equipment, water metering and submetering, and landscape irrigation.

4.1 Water Consumption	**42 pts**
Projected water consumption vs. baseline per Green Globes (GG) Calculator	24
EPA WaterSense: toilets	2
Urinals	2
Showerheads	2
Residential lavatory faucets	2
Residential kitchen faucets	2
Non-residential lavatory faucets	2
Non-EPA WaterSense fixtures entered into GG calculator	2
Clothes washers Energy Star	2
Dish washers Energy Star	2
4.2 Cooling Towers	**9 pts**
Minimize make-up water	2
Exceed minimum water quality by 20%	1
Flow meters on make-up and blow-down lines and conductance controllers	1
Percent dry cooling	3
Cooling towers equipped with drift eliminators	2
4.3 Boilers and Water Heaters	**4**
Greater than or = to 50 brake horsepower (bhp with boiler make-up meter)	1
Greater than or = to 50 bhp with condensate return	1
Boilers have conductivity controllers	1
Steam boilers have conductivity meters	1
4.4 Water-Intensive Applications	**18**
Commercial Food Service Equipment:	
No once through water-cooled equipment	1
No water-fed garbage disposal	1
Combination ovens consume 10 gal/hr or less	1
Pre-rinse valves for dish rinsing consume 1.5 gal/min or less	1
Food steamers consume 2 gal/hr or less	1
Dishwashers consume 5.8 gal/cycle or less	1
Laboratory and medical equipment—water consumption	5
Laundry equipment—water consumption	4
Special water features—water consumption	3
4.5 Water Treatment	**3**
4.6 Alternate Sources of Water	**5**
% of water for nonpotable uses harvested on-site or reclaimed (> = 50% = 5 points, 25–50% = 3, 10–24% = 1, <10% = 0)	5
4.7 Metering	**11**
Submetering for water-intensive applications (kitchen, etc.)	3
Potable water used for irrigation is metered	3
All water meters are linked to data management system	3
Chilled or hot water loops are equipped with make-up meters	2
4.8 Irrigation	**18**
% of exterior vegetated space not requiring irrigation (75–100% = 14, 50–74% = 11, 25–49% = 8, <25% = 0, NA)	14
Gutter downspouts directed into planted areas	1
Drip or low-volume irrigation	1
Smart meter components (rain sensors, soil moisture sensors, etc.)	1
Precipitation rate controls on heads	0.5
Flex pipes or swing joints for irrigation heads	0.5

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SECTION 5: RESOURCES (125 POINTS)

The Resources category addresses the materials used in construction and the waste generated in the construction process. It covers building reuse, either whole or partial, building service life planning, and the conservation of resources. It includes consideration of a variety of best practices, such as foundation design, waterproofing, envelope assembly, and the use of air barriers and vapor retarders.

5.1 Building Assembly (core and shell including envelope)	**33**
Path A: Performance Path for Building Assemblies (Athena or LCA) or Path B: Prescriptive Path for Building Assemblies	
5.2 Interior Fit-out (including Finishes and Furnishings)	**16**
Path A: Performance Path for Interior Fit-outs	
Path B: Prescriptive Path for Interior Fit-outs	
5.3 Reuse of Existing Structures	**26**
Facade reused—by wall area not including windows and doors (> = 60% = 6 points, 51–60% = 5, 41–50% = 4, 31– 40% = 3, 21–30% = 2, 10–20% = 1, <10% = 0)	6
Structural systems reused—by volume of structural components (> = 95% = 6 points, 81–95% = 5, 66–80% = 4, 41–65% = 3, 26–40% = 2, 10–25% = 1, <10% = 0)	6
Nonstructural elements—by area of ceilings, partitions, demountable walls (> = 95% = 6 points, 81–95% = 5, 66–80% = 4, 41–65% = 3, 26–40% = 2, 10–25% = 1, <10% = 0)	6
Furniture and furnishing reuse (> = 65% = 4 points, 41–65% = 3,26–40% = 2, 10–25% = 1, <10% = 0)	4
Project requirement to use reused and off-site salvaged material	4
5.4 Waste	**9**
Construction waste—% diverted from landfills (> = 75% = 6 points, 50–74% = 4, 25–49% = 2, <25% = 0)	6
Reuse of on-site material such as timber converted to mulch or concrete to aggregate	1
Operational waste:	
Operational flow for waste handling and recycling storage area	0.5
Storage area for recycling waste at point of service	0.5
Storage area for recycling waste at point pickup area	0.5
Operational flow for handling and storage for composting	0.5
5.5 Preliminary Building Service Life Plan	**7**
For the building	2
For the structural system, envelope, and hardscapes material needing replacement	2
For MEP systems that will require inspection or replacement	2
Schedule for maintenance, repair, and replacement of each building component	1
5.6 Resource Conservation	**6**
Minimized use of raw materials	
Prefabricated, preassembled, and/or modular products	2
Minimize use of raw materials compared to conventional practices	1
Multifunctional assemblies	
Assemblies that perform multiple functions	1
Deconstruction and disassembly	
Design facilitates future deconstruction, demounting, and disassembly	2
5.7 Building Envelope—Roofing/Openings	**10**
Roofing membrane assemblies and systems	
Installed per manufacturer's written instructions	1.5
Field inspection of roof system by 3rd party	1.5
Flashings	
Installed per prescribed industry best practices	1.5
Inspected as per prescribed industry protocols	1.5

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Roof and wall openings	
Comprise management design that meets industry performance requirements	1
Install as per prescribed industry best practices	1
Inspect as per industry protocols including testing for water penetration	2
5.8 Envelope—Foundation, Waterproofing	**6**
Foundation systems	
Slab on grade vapor retarder per ASTM E1745-11	0.5
Constructed with slab on grade on vapor retarder and capillary break base course	0.5
Field inspect vapor retarder per industry protocol	1
Minimum 5% grade slope away from building for minimum 10 feet	0.5
Roof drains to be directed at least 3 feet from building overhangs	0.5
Foundation drainage system	1
Below-grade wall slabs and above-grade horizontal assemblies	
Waterproof membrane assembly for all basement walls and slabs	1
Installed per manufacturer's written instructions and tested	1
5.9 Envelope—Cladding	**5**
Exterior wall cladding systems	
Cladding installed per manufacturer or industry standards—EIFS OR	1
Cladding installed per manufacturer or industry standards—Storefront OR	
Cladding installed per manufacturer or industry standards—Masonry	
Cladding inspection as per industry protocols—EIFS OR	1
Cladding inspection as per industry protocols—Storefront OR	
Cladding inspection as per industry protocols—masonry veneer	
Joints sealed and field inspected	1
Rainscreen wall cladding	
Primary and secondary line of defense	0.5
Air barrier installed	0.5
Means for incidental water to escape	0.5
Assemblies required to pass AAMA 508-07	0.5
5.10 Envelope—Barriers	**7**
Air barriers	
Flexible joint between air barrier and adjacent materials	0.5
Designed to withstand pressures without displacement	0.5
Designed to withstand structure movement without displacement	0.5
Air barrier connection details shown	0.5
Demonstrate compliance of air barrier	2
Vapor retarders	
Interior vapor retarder for zones 4,6,7,8, and Marine 4	3

SECTION 6: EMISSIONS (50 POINTS)

The Emissions category is unique to Green Globes and addresses selection of heating and cooling system equipment. Credit is provided for the installation of low-emission heating equipment, focusing on nitrous oxide (NOx) and carbon monoxide (CO). For cooling equipment the focus is on the elimination of substances with significant ozone depletion potential (ODP) and GWP.

6.1 Heating	**18**
Path A: District Heating—Used OR	
Path B: Low-Emission Boilers and Furnaces	
(Ultra-Low NOx = 9 points [<=12 ppm], Low NOx = 7 points[<= 30 ppm], or NA)	
(Ultra-Low CO = 9 points [<= 50 ppm], Low CO = 7 points [<= 100 ppm], or NA)	

(*continued*)

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6.2 Cooling	**29**
Ozone depletion potential (ODP)	10
(No Refrigerants or ODP <= 0.005 = 10 points, <= 0.01 = 8, <= 0.015 = 6, <= 0.02 = 4, <= 0.025 = 2, <= 0.03 = 1)	
Global warming potential (GWP)	
(No Refrigerants or GWP100 <= 100 earns 10 pts, <= 300 earns 8 points, <= 500 earns 6 pts, <= 700 earns 5 pts, <= 900 earns 4 pts, <= 1100 earns 3 pts, <= 1300 earns 2 pts, <= 1500 earns 1 pt, > 1500 earns 0 pts)	10
Leak detection	
Test remote commercial systems for leaks per GreenChill	3
Refrigerant leak detection down to 2% per year	3
Leak detection with alarm to alert building operations	3
6.3 Janitorial Equipment	**3**
Designated area for chemical storage with full height walls and exhaust	

SECTION 7: INDOOR ENVIRONMENT (110 POINTS)

The Indoor Environment category covers many of the generally accepted indoor environmental quality issues, such as ventilation, lighting, daylighting, and acoustics. Green Globes allows all the ventilation options provided for in ASHRAE Standard 62.1 while LEED allows only the ventilation rate procedure.

7.1 Ventilation	**37**
Ventilation air quantity	
Compliant with ASHRAE 62.1-2010, ICC 2009, IAPMO 2009 or ASHRAE 170-2008	7
OR Compliant with ASHRAE 62.1-2007 = 5	
Ventilation Schedules for all occupied spaces	4
Air exchange	8
Path A: Mechanical Ventilation Only—Zone Air Distribution Effectiveness (Ez) >= 0.9 OR	
Path B: Natural Ventilation Only—See *Reference Manual* OR	
Path C: Combination of Mechanical and Natural Ventilation	
Ventilation intakes and exhausts equipped with:	
Exhaust outlets and plumbing stacks at least 20 feet from air intakes	1
Air intakes at least 30 feet from sources of pollution	1
Air intakes protected with 0.3 inch or smaller mesh screen	1
Air handler filter compliant with ASHRAE 62.1-2010	2
Air intakes and outlets sized per ASHRAE 62.1-2012	1
No duct liner except for transfer air	1
Roof drainage slopes away from outside air intakes	1
CO_2 sensing and ventilation control equipment for variable occupancy rooms	5
Air handling equipment equipped with MERV 13 Filters	5
7.2 Source Control and Measurement of Indoor Pollutants	**46**
Volatile organic compounds (VOC)	
Adhesives and sealants VOC limits	2.5
Carpet and carpet adhesive—Carpet and Rug Institute Green Label Plus	2
Paint VOC limits	3
Floor and floor coverings VOC limits	2.5
Leakage, condensation, and humidity	
HVAC able to monitor and control dew point	4
Mold- and moisture-resistant finishes in high-humidity areas	2
Floor drains in all potentially "wet" areas	2
Access for HVAC maintenance	
Complies with ICC IMC 2009, IAPMO UMC 2009	1
Distribution systems installed per ANSI/ASHRAE 62.1-2010	1

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Architectural features related to access installed per International Building Code	1
Access doors to HVAC are removable and have full swing	1
CO monitoring—in enclosed areas with sources of combustion	4
Wet cooling towers (None = 2, with drift eliminators = 1, without drift eliminators = 0)	2
Domestic hot water systems (tankless or above 131°F = 2, below 131°F = 0)	2
Humidification and dehumidification systems	
Drain pan design	3
Pest and contamination control	
Outdoor air intakes with 18x14-inch screens	0.5
Openings fitted with permanent protection (screens, sealants)	0.5
Bird habitation protection on building	0.5
Mullions and ledges less than 1 inch deep to discourage bird roosting	0.5
Sealed storage area for food/kitchen solid waste	1
Other indoor pollutants (tobacco, radon)	
No smoking on construction site or within 25 feet with signage	1
No smoking signage at building entrances	1
Radon potential accessed with mitigation measures specified	5
Asbestos removal, if required, meets all state and federal regulations	1
Ventilation and physical isolation for specialized activities	
Separate ventilation for areas that generate pollutants	1
Separate areas maintain negative pressure of 5.0 pascals on average	1
7.3 Lighting Design and Systems	**30**
Daylighting	
Percentage of floor areas for critical visual tasks achieves daylight factor of 2	7
Percentage of task areas with view to exterior within 25 feet of window	
Shading devices on south, west, and east exposures	1
Shading devices to eliminate direct sun from task areas	1
Photo sensors to maintain consistent light levels with daylight and artificial light	3
Lighting design	
IESNA illuminance categories for different spaces met	7
Limited luminance ratio sign-off by engineer	3
Limited Luminaire Reflective Glare sign-off by engineer	3
7.4 Thermal Comfort	**88**
Thermal Comfort Strategies	
Limited thermal comfort zones for big box (<= 2,000 ft^2 = 3, <= 5,000 ft^2= 2, NA)	3
Large classrooms and auditoriums with zones (<= 1,500 ft^2 = 3, NA)	3
Open office or circulation areas with zones (<= 500 ft^2 = 3, <= 1,000 = 2, NA)	3
Offices, meeting rooms with zones (<= 750 ft^2 = 3, <=1,200 ft^2 = 2, NA)	3
Thermal comfort design: engineer sign-off of design to: ANSI/ASHRAE 55-2010 = 6, ANSI/ASHRAE 55-2004 = 4	6
7.5 Acoustic Comfort	**29**
Acoustic comfort design	
Toilets remote from acoustically separated areas	0.5
Loud areas located away from acoustically separated areas	1
Entry doors staggered across halls	0.5
Through-wall penetrations comply with ANSI S12.60-2010/Part 1	0.5
Full-height walls between acoustically separated areas	1
Quiet-area walls have joints sealed with acoustical sealant	0.5
High floor-impact areas not above acoustically separated areas	1
Mechanical, plumbing, and electrical Table 1: ASHRAE design guidelines OR Table 5: ANSI/ASA S12.60-2010 noise limits	24

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Green Globes Assessment and Certification Process

Figure 6.3 depicts the Green Globes assessment and certification process for both Green Globes NC and Green Globes CIEB. For new construction projects, at the onset of the project, the project team completes an online survey, which helps team members determine how the project is measuring up to the credits in the Green Globes NC rating system (Figure 6.3A). At the completion of the design phase, a GGA assigned to the project reviews the online survey and the documentation submitted by the project team and advises members regarding needs for additional documentation or issues that require resolution. The team is also advised of the number of Green Globes that the project is on track to achieve. At the end of construction, the project team finalizes the online survey along with the project documentation. The GGA reviews the survey and documentation, then visits the project for the Stage II Assessment and recommends a final Green Globes rating for the project. The GBI notifies the project team and owner of the final rating and provides a letter and an optional plaque for the building that indicates the project's rating. For existing building projects, the steps in the certification process are shown in Figure 6.3B.

The GGA is a unique feature of Green Globes, and it is the GGA that is responsible for the Stage I and Stage II Assessments. The GGA conducts an extensive third-party assessment of the project by thoroughly reviewing construction documents and conducting project site visit. The site visit consists of interviewing various project team members, reviewing any outstanding documentation, and a walk-through of the project to review the sustainability features and measures selected by the project team. The GGA is an experienced building design and construction industry professional who has been trained on the Green Globes protocol and who has been monitored and mentored by other GGAs prior to assessing a building on her or his own. In the USGBC LEED process, the project team completes documentation online and



Figure 6.3 (A) The Green Globes NC assessment and certification process for projects from start to finish

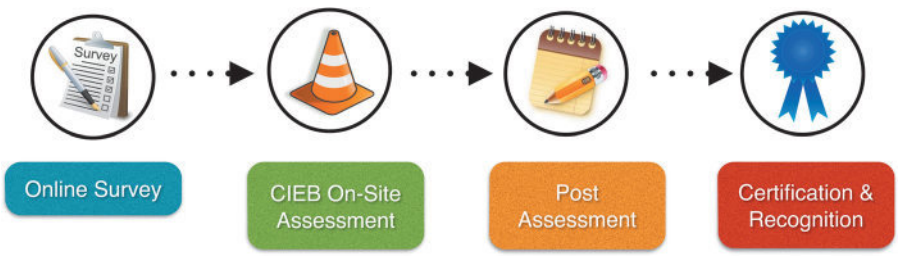


Figure 6.3 (B) The assessment and certification process for Green Globes CIEB or existing building projects.

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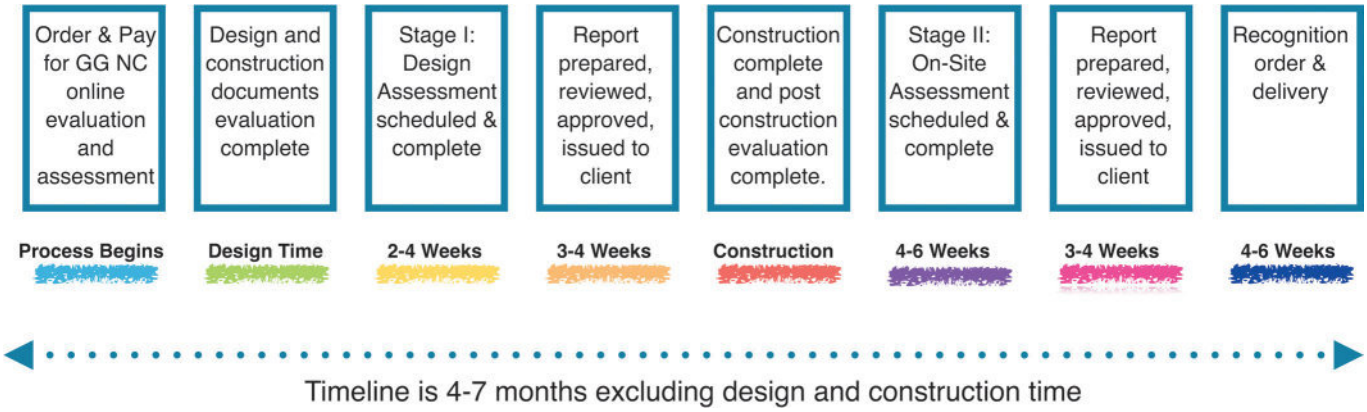


Figure 6.4 The assessment and certification timeline for typical Green Globes NC projects

submits it via LEED-Online, to be reviewed by a team that is not at any time in direct contact with the project team. Unlike LEED, the Green Globes system requires a GGA actually to visit the project, interact directly with the project team, and physically examine the project. At the end of this stage, the GGA verifies point allocation and sends his or her recommendation to the GBI concerning the appropriate certification level. This information is then communicated to the project leaders in the final certification report.

Every environmental assessment category of Green Globes may have criteria that a design and delivery team deems inapplicable or NA to the building. Allowing NA points is an important feature that ensures the standard protocol applies to a wide range of building types and geographic climate zones, and for buildings where codes or regulations may prohibit implementation of specific building enhancement items. For example, in Florida, buildings do not have boilers and these credits in Green Globes would be deemed NA and reduce the number of applicable points. In such situations, the NA points do not count. The total number of achievable points is adjusted accordingly, and certification levels still must fall under identified percentages. This approach is different from that of LEED in that it focuses on the work of the project team instead of addressing issues that are outside the project scope.

The timelines for the assessment and certification process for a Green Globes NC project are shown in Figure 6.4. In general, the assessment and certification process takes three to four months; this period can be shortened considerably for projects that maintain tight control of the construction process and have been diligent in documentation preparation. Figure 6.5 shows a similar timeline for Green Globes EB projects.

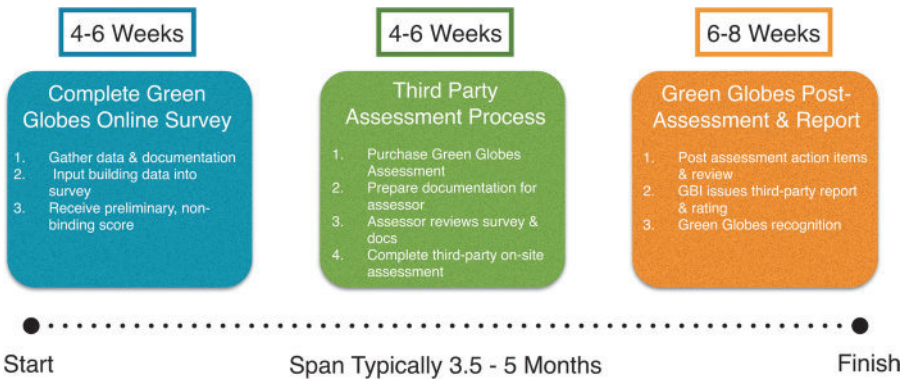


Figure 6.5 The timeline for assessment and certification of an existing building project using the Green Globes CIEB assessment system

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Green Globes Professional Credentials

The Green Globes building assessment system offers a credential similar to the LEED AP described in Chapter 5. The GGP is awarded based on education and industry experience, and its purpose is to train building industry professionals in the Green Globes assessment system so that they can guide the project team through the multistage building certification process. Green Globes also has a second credential, the GGA, which certifies third-party assessors and which is offered based on education, professional licensure, and relevant industry experience. These two credentials and the requirements for their award are shown in Table 6.5. Note that there are two different qualification paths for the GGA, depending on whether the assessor is evaluating NC or EB projects.

Award of the GGP or GGA credential requires that the applicant pass an examination regarding his or her knowledge of the NC or CIEB Green Globes building assessment system. The GGA, in addition to assessing the NC or CIEB project, provides support to the project team and addresses any gray areas that would be covered by the Credit Interpretation Request (CIR) process in LEED.

TABLE 6.5

Qualifications for Application for the Green Globes Professional and Green Globes Assessor Credential

Qualifications Requirements	Green Globes Professional	Green Globes Assessor CIEB	Green Globes Assessor NC
Industry experience	5 years	10 years or more total years of applicable industry experience directly pertaining to commercial buildings. 5 out of the 10 years of experience must fall within the specific functional areas listed for each assessor designation (CIEB/NC)	
Applicable functional categories for total industry experience	Facilities/operations management/maintenance Architecture/design/engineering/construction Inspections/auditing/appraisals building Materials/components/manufacturing energy analysis Commissioning		
Applicable categories for specific functional experience	N/A	Facilities management Operations/maintenance Architecture/design Engineering construction Inspections/auditing Commissioning	Architecture/design Engineering Construction Inspections/auditing Commissioning
Professional licensure	N/A	N/A	Licensed architect or licensed professional engineer
Education	N/A	Associates degree or higher in architecture, engineering, facilities/operations management, other relevant technical or building science program	Bachelor's degree or higher in architecture, engineering, other relevant technology, science, or environmental program
Building sustainability in practice	N/A	Involved in 3 or more projects where building sustainability principles were applied in the areas of energy, water, site, resources/materials, emissions, indoor environment, management	

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Case Study: Health Sciences Building, St. Johns River State College, St. Augustine, Florida

The growing campus of St. Johns River State College in St. Augustine, Florida, is phased for construction over the next few decades. The college planning goals require any new construction to be designed in an environmentally sensible manner, which led to the newly constructed Health Sciences Building receiving a three Green Globe rating from GBI's Green Globes building rating system (see Figure 6.6).

An integrated project management team was organized early in the design process to help identify the basis of design, prioritize goals, and create effective policies that allowed design and construction professionals to get on board in developing a high-performance building. Green products were specified for the project, as was a commissioning plan to verify the integrity of the building's operations before and during occupancy. The gross area is 32,000 ft^2 (2,973 m^2), and the project cost was $8.5 million.

Impact on the site and surrounding areas was reduced by avoiding disturbing nearby wetlands and through the implementation of an erosion control plan. The heat island in the parking lot was reduced by planting trees, which will shade the parking areas within five years, and through the use of light-colored roofing materials, including a highly reflective ethylene propylene diene monomer membrane. Stormwater runoff was minimized through the design of bioswales, pervious pavers, and a retention pond (see Figure 6.7). Native plants were used in the landscape to minimize irrigation and maintenance requirements.



Figure 6.6 The Health Sciences Building at St. Johns River State College in St. Augustine, Florida, received a rating of three Green Globes from the GBI's Green Globes building rating system. (Photograph courtesy of Glen Roberts, St. Johns River State College)



Figure 6.7 Bioswales surrounding the parking lot reduce stormwater runoff into nearby wetland areas. (*Source:* D. Stephany)

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Figure 6.8 A high-efficiency Smardt centrifugal chiller was installed to replace the outdated unit, providing cooling for the entire St. Johns River State College. The chiller is designed to meet future needs as the campus continues to expand. (Photograph courtesy of Glen Roberts, St. Johns River State College)



Figure 6.9 Pulsed electromagnetic technology is used to treat the cooling tower water. This technology helps reduce scaling, biological growth, and corrosion, all without the use of chemicals. It also helps reduce water consumption and makes water easier to treat compared to chemically treated systems.

Establishing an energy consumption target was the first step toward improving building energy efficiency. Once the target was established, a number of energy-efficient approaches were chosen to meet the energy performance goal. These include optimization of the building orientation, incorporation of high-performance glazing, increased thermal resistance in both walls and windows, incorporation of natural ventilation, and installation of daylight sensors in perimeter spaces to optimize natural lighting levels in spaces when occupied. High-efficiency HVAC systems, such as a VAV system, cooling towers, secondary chilled-water pumps, and a high-efficiency water-cooled chiller, are controlled by variable-frequency drives for optimum energy performance (see Figure 6.8). The water-cooled chiller contains only one moving part, which is frictionless because it has no bearings. Instead, it rotates in the chilled water itself, minimizing friction and resulting in an energy performance of 0.576 kilowatts per ton. The BAS controls the HVAC system, including the zoned VAV boxes, to continually optimize system operation. For zones with low cooling loads, the BAS adjusts the VAV system to reduce conditioned airflow, resulting in a reduction in pump and fan electrical energy consumption. Energy recovery ventilators are used to pretreat the incoming outside air by air-to-air heat and humidity exchange with the building's exhaust air. Solar tubes are used in some of the interior spaces on the second floor to aid in reducing energy consumption where direct sunlight is not available.

Targets were set for water efficiency and achieved by incorporating waterless urinals, low-flow toilets and faucets, and irrigation systems that use reclaimed water from roof and parking surfaces, coupled with drought-tolerant plants. Additionally, pulsed electromagnetic technology was used to clean cooling tower water, resulting in significant water savings (see Figure 6.9).

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Figure 6.10 Polished, stained concrete floors were specified instead of far less durable floor coverings. These provide a long-lasting, very attractive option and reduce the quantity of materials needed for construction. (Photograph courtesy of Glen Roberts, St. Johns River State College)



Figure 6.11 A storage room on the second floor of the Health Sciences Building uses natural light that is projected into the room through solar tubes installed on the roof. (Source: D. Stephany)

The project team reduced the impact of the building on the environment by specifying materials that are durable, capable of extending the life of the building, and sourced locally. For example, polished, stained concrete floors were selected instead of carpeting or other floor coverings (see Figure 6.10). Reclaimed materials or materials with recycled content were used wherever possible. In addition, space for recycling was integrated into the design.

The building reduces its air emissions through the elimination of ozone-depleting chemicals. In addition, the project addresses human health by reducing harmful chemicals and storing them in a manner that includes adequate ventilation. A vermin prevention plan is integrated into the design, along with a pollution control plan that includes proper gas and chemical prevention measures. Approximately 80 percent of the spaces in the Health Sciences Building are exposed to daylighting (see Figure 6.11). Daylight and occupancy sensors are incorporated to control daylight harvesting and solar exposure. High ventilation rates and zoned thermal controls aid in addressing potential human comfort issues. Acoustics are addressed by specifying an appropriate Sound Transmission Class for various spaces.

The Green Globes assessment of the Health Sciences Building resulted in 71 percent of the available points being achieved. The building was awarded three Green Globes, similar to a LEED gold rating. The scorecard for this project is shown in Table 6.6. Note that this assessment was made using GG NC, version 1, which has different features from the newer version 2 described in this chapter.

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TABLE 6.6

Points distribution for the Green Globes certification of the Health Sciences Building

	Description	Points
A.	Project Management—Policies and Practice (50 points applicable)	45
A.1	Integrated Design Process	20
A.2	Environmental Purchasing	10
A.3	Commissioning Plan—Documentation	15
A.4	Emergency Response Plan	0
B.	Site (115 points applicable)	95
B.1	Development Area	30
B.2	Minimize Ecological Impacts	30
B.3	Enhancement of Watershed Features	15
B.4	Enhancement of Site Ecology	20
C.	Energy (373 points applicable)	211
C.1	Building Energy Performance	30
C.2	Energy Demand Minimization	95
C.3	Energy-Efficient Systems	66
C.4	Renewable Sources of Energy	0
C.5	Energy-Efficient Transportation	20
D.	Water (81 points applicable)	67
D.1	Water Performance	30
D.2	Water-Conserving Features	37
D.3	Minimization of Off-Site Treatment of Water	0
E.	Resources, Building Materials, and Solid Waste (80 points applicable)	36
E.1	Systems and Materials with Low Environmental Impact	0
E.2	Materials that Minimize Consumption of Resources	12
E.3	Reuse of Existing Structures	0
E.4	Building Durability, Adaptability, and Disassembly	9
E.5	Reuse and Recycling of Construction/Demolition Waste	5
E.6	Facilities for Recycling and Composting	10
F.	Emissions and Effluents (68 points applicable)	66
F.1	Minimization of Air Emissions	15
F.2	Minimization of Ozone Depletion	25
F.3	Avoid Contamination of Sewers or Waterways	3
F.4	Pollution Minimization	23
G.	Indoor Environment (175 points applicable)	149
G.1	Ventilation	42
G.2	Source Control of Indoor Pollutants	32
G.3	Lighting	30
G.4	Thermal Comfort	20
G.5	Acoustic Comfort	25
	Summary Project Management—Policies and Practice (45/50 points)	90%
	Site (95/115 points)	83%
	Energy (211/373 points)	57%
	Water (67/81 points)	83%
	Resources, Building Materials, and Solid Waste (36/80 points)	45%
	Emissions and Effluents (66/68 points)	97%
	Indoor Environment (149/175 points)	85%
	Total points (669/942 points)	71%

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Summary and Conclusions

Green Globes is an alternative building assessment system for use in the United States for both new and existing buildings. It differs from LEED in several important ways. First, it has a rating category for project management that gives credit for integrated design and environmental purchasing. It also provides credit for conducting life-cycle assessments of building assemblies during the design process. It has a starting base of 1,000 points compared to the 110 points offered by LEED. Importantly, in cases where the situation does not apply, the starting base points can be reduced by the number of points that are not applicable. This is an important feature of Green Globes that is not available in LEED projects. The assessment of the project is conducted by third-party GGAs who review the construction documents at the end of the design stage and make recommendations to the project team regarding the project's green attributes. The GGA also visits the project at the end of construction to review the team's self-assessment and documentation for all the credits claimed by the project team. The assessor makes a physical inspection of the project to ensure that the as-built project is in compliance with the self-assessment. The assessor also serves as a resource for the project team and assists the team in resolving gray areas that are not directly covered by the Green Globes questionnaire and support systems. Finally, the Green Globes building assessment system is being revised so that the ANSI/GBI 01-2016 standard will serve as the template for the Green Globes assessment process.

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Part III
Green Building Design

This part of the book addresses the major categories of issues covered by most building assessment systems, including Leadership in Energy and Environmental Design (LEED) and Green Globes. These categories include site and landscaping, energy systems, materials and products, the building hydrologic cycle, and indoor environmental quality. Part III contains these chapters:

Chapter 7: The Green Building Design Process
Chapter 8: The Sustainable Site and Landscape
Chapter 9: Energy and Carbon Footprint Reduction
Chapter 10: Built Environment Hydrologic Cycle
Chapter 11: Closing Materials Loops
Chapter 12: Built Environment Carbon Footprint
Chapter 13: Indoor Environmental Quality

Chapter 7 addresses the high-performance green building delivery system as a distinctly identifiable construction delivery system, analogous to individually recognized design-build systems. A hallmark of the high-performance green building delivery system is the high level of coordination and integration required for the design and construction team members. Additional measures, such as building commissioning and the charrette, are necessary to fully implement this new delivery system. Performance-based design contracts provide financial incentives to implement certain sustainable design features, such as relying on nature for some building services, thus enabling a downsizing of mechanical and electrical systems to reduce energy consumption and cost. Documenting the green building process and gathering system performance data are necessary to demonstrate that the building has met all certification requirements.

Chapter 8 parallels the building assessment categories that include issues such as locating the building near mass transit, siting the building on a brownfield instead of a greenfield, minimizing the ecological footprint of the construction process, and other measures designed to ensure that the building is sited to have the lowest possible environmental impact. This category also covers the potential for enhancing ecosystems as a component of developing green buildings. Stormwater management and alternatives to conventional practices are addressed. The problem of urban heat islands and measures to reduce temperature buildup in urban areas are considered. Light pollution—a health, safety, and environmental problem—is covered, and as are techniques for preventing excessive light from affecting the surrounding areas.

Chapter 9 covers a range of energy issues, including passive design, design of the thermal envelope, equipment selection, renewable energy systems, green power,

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and emerging technologies, all of which can help achieve a very low building energy consumption profile. Energy-efficient lighting systems and lighting controls that sense occupancy and can be tied into the lighting system are covered. Innovative practices, such as radiant cooling and ground coupling, are used as examples of cutting-edge methods for addressing energy issues in green buildings. Smart buildings and building energy management systems are described to show how technology can be used in an effective manner to reduce a building's energy profile.

Chapter 10 focuses on minimizing potable water use, water recycling and reuse, and provisions for minimizing off-site stormwater flows. A strategy for the design of an effective building hydrologic cycle is provided. Technologies are described that can help provide alternative sources of water when potable water is not absolutely necessary. A wastewater strategy for high-performance buildings is also provided to minimize the need to move wastewater off-site for processing. Water-efficient landscaping is described, and its role in a green building hydrologic strategy is covered.

The selection of environmentally friendly construction materials is addressed in Chapter 11, which covers the use of recycled-content materials, used components, embodied energy due to transportation of material, and the minimization of construction waste. Defining green building materials remains the most difficult problem for designers of contemporary green buildings. For example, recycled-content materials are, in principle, green building materials, but many contain industrial and agricultural waste, so it is not clear that recycling these by-products into the built environment is the best solution. Consequently, one objective of this chapter is to promote an understanding of the broad range of issues and problems connected to building materials and products. The chapter also covers the topic of life-cycle assessment, a method for analyzing the resources, waste, and health effects associated with the entire life of a product or material, from its extraction as raw material to its ultimate disposal.

Chapter 12 is new to this edition and covers the carbon footprint of the built environment. It proposes an approach to built environment carbon footprint calculations that includes three sources of carbon: (1) embodied carbon in the products and materials used to construct the building, (2) operational carbon associated with the energy consumed by the building over its life cycle, and (3) the carbon associated with the transportation energy that moves building occupants to and from their daily activities. In the case of office buildings, the transportation carbon footprint would be calculated for the commuting energy of the transportation systems used by the workforce.

Indoor environmental quality (IEQ) is covered in Chapter 13. The various types of health-related building problems are described. Selecting low-emission materials; protecting heating, ventilation, and air conditioning systems during construction; monitoring indoor air quality (IAQ); and issues surrounding the health of the construction workforce and future building occupants are explored. Lighting quality, access to daylight and views, and noise as IEQ issues are covered. The subject of electromagnetic radiation in building is addressed and strategies for dealing with its health impacts are covered. Best practices for providing building IAQ are also addressed. Additional best practices and checklists that provide assistance in achieving building assessment system points or that address issues not covered in these systems are also provided.

In short, Part III addresses the core issues of the technical side of sustainable construction and discusses approaches that can be employed to limit resource depletion, negative environmental consequences, and impacts on human health that are too often the result of the creation, operation, and disposal of the built environment. Future buildings should contribute to the restoration and regeneration of ecological capacity, recycle water, and discharge potable water, generate the energy needed for their operation, contribute to the health of their human occupants, and serve as materials resources for future generations rather than as a disposal headache.

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Chapter 7

The Green Building Design Process

The high-performance building movement is changing both the nature of the built environment and the delivery systems used to design and construct the facility according to a client's needs. The result has been the emergence of the *high-performance green building delivery system*, introduced in Chapter 1. This delivery system is distinguishable from conventional practice by the selection of project team members based on their green building expertise, increased collaboration among the project team members, more focus on integrated building performance than on building systems, heavy emphasis on environmental protection during the construction process, careful consideration of occupant and worker health throughout all phases, scrutiny of all decisions for their resource and life-cycle implications, the added requirement of building commissioning, and the emphasis placed on reducing construction and demolition waste. Some of these differences are driven by certification requirements, while others are part of the evolving culture of green building.

This chapter more fully describes the differences between standard practice and the green building process, paying particular attention to the highly collaborative *charrette* process, probably one of the most distinguishing hallmarks of contemporary green building. New tools, such as building information modeling (BIM) that produce three-dimensional representations of the model that are linked to energy modeling, daylighting, and life-cycle assessment software, are increasing the quality of the collaboration and lowering the costs of green building. Plug-ins for BIM that create documentation for green building certification based on building assessment systems are also emerging to further reduce the challenges of creating a high-performance built environment.

Conventional versus Green Building Delivery Systems

Contemporary construction delivery systems in the United States fall into four major categories: design-bid-build, construction management at risk, design- build, and integrated project delivery (IPD). These four systems are described briefly in the next sections and then compared and contrasted with the emerging high-performance green building delivery systems.

DESIGN-BID-BUILD (HARD-BID)

The primary objective of a *design-bid-build*, or *hard-bid*, delivery system is low-cost delivery of the project to the owner by the general contractor. The design team is selected by the owner and works on the owner's behalf to produce construction documents that define the location, appearance, materials, and methods to be used in the creation of the building and its infrastructure. General contractors bid on the project, with the lowest qualified bidder receiving the job.

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Similarly, the general contractor selects subcontractors based on competitive bidding and awards the specific work—for example, steel erection or masonry—to the lowest qualified bidder. Although the project theoretically is delivered at the lowest cost to the owner, conflicts among the parties to the contract (owner, design team, general contractor, subcontractors, and materials suppliers) are frequent, and emotional tension and miscommunication generally permeate the process, often resulting in higher costs due to change orders, repairs, and lawsuits. Although some high-performance green buildings have been built using the hard-bid construction process, the degree of potential conflict and lack of a collaborative working atmosphere make it the least desirable construction delivery system for this purpose.

CONSTRUCTION MANAGEMENT AT RISK (NEGOTIATED WORK)

In the construction management at risk delivery system, the owner contracts separately with the design team and the contractor, or *construction manager*, who will work on the owner's behalf. This system also is referred to as *negotiated work* since the construction manager negotiates a fee for management services with the owner. Early in the design process, the construction manager is usually required to guarantee that the total construction cost will not exceed a maximum price, referred to as the *guaranteed maximum price*. Ideally, both the construction manager and the design team are selected at the start of the project. Then the construction manager can provide preconstruction services, such as cost analysis, constructability analysis, value engineering, and project scheduling, to facilitate an efficient and effective design process followed by a conflict-free construction phase.

Working together, the parties produce construction documents that meet the owner's requirements, schedule, and budget and that prevent physical conflicts among systems, missing information, and other products of miscommunication often found in the construction documents produced for hard-bid projects. Using a bidding process, the construction manager selects subcontractors based on their capabilities and the quality of their work, not merely the lowest bid. For this reason, the level of conflict in negotiated work is much lower because of the closer working relationships among the parties to the contract. Additionally, construction management firms undertaking negotiated work understand that current and past clients are the primary source of future projects. Consequently, client satisfaction becomes a primary objective.

DESIGN-BUILD

Although negotiated work reduces the frequency and intensity of conflicts present in a hard-bid construction delivery system, the classic tension between the design team and the construction manager still exists, albeit to a lesser degree. *Design-build* is a method of project delivery in which one entity (the designer-builder) forges a single contract with the owner to provide for architectural/engineering design services and construction services.[1] Design-build is also known as *design-construct* and provides the owner with single-source responsibility. In the typical design-bid-build, or hard-bid, project, the owner commissions an architect or engineer to prepare drawings and specifications under a design contract and then selects a construction contractor by competitive bidding to build the facility. In contrast, the design-build delivery system provides the owner with a single contractual relationship with an entity that combines both design and construction services. This entity may be a firm that possesses in-house design and construction

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capabilities or a partnership between a design firm and a construction firm. Thus, the design-build delivery system is more likely to reduce typical design–construction conflicts, provide a lower price for the owner, improve quality, speed the project to completion, and facilitate improved communication among project team members. The design-build delivery system is very compatible with the green building concept. Due to its emphasis on a high degree of collaboration between the design and construction phases, it is very consistent with the design approach required to produce high-performance buildings.

INTEGRATED PROJECT DELIVERY

Integrated project delivery (IPD) is a relatively new construction delivery system that originated in the mid-1990s when a group of construction companies in Orlando, Florida, were attempting to increase productivity and the speed of project delivery without the typical conflicts and stress of construction projects. In May 2007, the IPD Definition Task Group, composed of a variety of stakeholders such as owners, architects, contractors, engineers, and lawyers, collaborated to define the IPD system. This emerging construction delivery system takes advantage of several other relatively new ideas, such as integrated process, lean construction, BIM, and other technologies, that provide the potential for good collaboration on construction projects. Charles Thomsen, former chairman of 3D International, defined IPD in 2011 as:

> an approach to agreements and processes for design and construction, conceived to accommodate the intense intellectual collaboration that 21st century buildings require. The inspiring vision of IPD is that of a seamless project team, not portioned by economic self-interest or contractual silos of responsibility, but a collection of companies with a mutual responsibility to help one another meet an owner's goals. To support that vision, architect/engineers, construction managers, and lawyers are crafting management processes and contract terms intended to align the interests of the key project team with the project mission, increase efficiency, reduce waste, and make better buildings.[2]

Thomsen suggested that the main ingredients of IPD are:

- A legal relationship
- A management committee
- An incentive pool
- A no-fault working environment
- Design assistance
- Collaborative software
- Green construction
- Integrated leadership

The IPD process is designed to produce shorter delivery times than other construction delivery systems, such as design-bid-build. The emergence of collaborative software provides opportunities to improve the flow of documentation, communications, and work to ensure that all parties engaged in the project are working on the same set of documents and collaborating to the same end. *Relational contracts* are the key document in IPD because they define the relationships among all parties to the project. A relational contract is a single agreement signed by the owner, architect/engineer, and the contractor. Although commonly used in the United Kingdom and Australia, these types of contracts are relatively new to the US

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construction industry. Other contractors—for example, subcontractors—can also be parties to the contract in what is called an *integrated form of agreement* or *triparty collaborative agreement.* Relational contracts in the IPD process have incentive clauses such that any potential savings are shared among the IPD team members and with the owner. An incentive pool for this purpose is created and put at risk depending on the collaboration of the team. In regard to high-performance green building, IPD is an untested idea because it is relatively new. However, many of the key aspects of IPD dovetail with the leading edge of high-performance green building, such as an integrated collaborative process and the application of technology to support the development of truly high-performance buildings. Additionally, IPD has many of the traits of construction delivery systems that are far more compatible with green building certification systems, such as Leadership in Energy and Environmental Design (LEED) and Green Globes. Both lean construction and BIM are being merged into the cutting edge of green building, just as they are in IPD. One of the long-standing criticisms of green building has been its higher first cost. IPD, together with these tools such as BIM and lean construction, provides the potential to deliver high-performance buildings at the same or lower cost compared with conventional, code-compliant facilities.

HIGH-PERFORMANCE GREEN BUILDING DELIVERY SYSTEM

The evolving high-performance green building delivery system is similar to other construction delivery systems, such as negotiated work and design-build, but with additional responsibilities for the project team. Most notably, it requires much greater communication among the project team members. Consequently, initial team building, which engages the widest possible range of stakeholders, ensures that everyone understands the project's goals and the unique specifications. This delivery system also demands special qualifications from its participants, especially an understanding of, and commitment to, the concept of green building and, in the case of projects to be certified using LEED, Green Globes, or the Living Building Challenge, a strong familiarity with the assessment systems and their requirements. The team members also should have experience with the charrette process and be especially willing to engage a wide range of stakeholders, including some who are traditionally not included in building projects. An example would be the inclusion of community members in the charrette for the design of a corporate facility. Some recent projects have included local building officials who ultimately will have to approve any innovative, out-of-the-box solutions that a high-performance building team may propose.

Due to its adversarial nature, the hard-bid delivery system is exceptionally difficult to employ for a green building project. The collaborative spirit needed for a successful high-performance green building project is difficult to develop in this adversarial climate. The design-build delivery system has significant potential to deliver green buildings because, like negotiated work, it is designed to minimize adversarial relationships and simplify transactions among the parties. However, unlike conventional construction, the checks and balances provided by transparent interaction between the design team and the construction entity are virtually absent. And, as with other aspects of sustainable development, transparency is an important characteristic of green building projects. In spite of this potential problem, several successful green building projects have been executed using design-build. These include the Orthopaedics and Sports Medicine Institute at the University of Florida in Gainesville, completed by the design-build team of URS and Turner Construction (see Figure 7.1).[3] IPD is a relatively new delivery system, but with its high emphasis on collaboration, it seems to be an approach that is highly compatible with green building delivery.

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Figure 7.1 The project team for the Orthopaedics and Sports Medicine Institute at the University of Florida in Gainesville used the design-build delivery system to deliver this LEED-certified green building. (*Source:* T. Wyman)

Executing the Green Building Project

Because the high-performance green building delivery system is distinctly different in many ways from conventional delivery systems, the project team needs to be aware of these differences and where they occur in the building design and construction process. After the programming and budgeting of the proposed building project has been accomplished by or on behalf of the owner, the execution of a high-performance green building project has seven phases:

1. *Setting priorities for the green building project* by the owner in collaboration with the project team.
2. *Selecting the project team:* the design team and the construction manager or the design-build firm.
3. *Implementing an integrated design process (IDP)* by orienting the project team to the concept of the IDP and how it will be implemented during the design and construction processes. Note that the IDP is different from IPD. The IDP is covered in more detail in the section titled "Integrated Design Process" (p. 223).
4. *Conducting a charrette* to obtain input for the project from a wide variety of parties, including the project team, the owner and users, the community, and other stakeholders.
5. *Executing the design process*, consisting of schematic design, advanced schematic design, design development, construction documents, and documentation of green building measures for a project that is to be certified, all conducted using the IDP. Doing this involves full use of the IDP in the

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development of the design, marked by extensive interdisciplinary interaction to maximize design synergies.

6. *Constructing the building*, to include implementing green building measures that address soil and erosion control, minimizing site disturbance, protecting flora and fauna, minimizing and recycling construction waste, ensuring building health, and documenting the construction phase of green building measures.
7. *Final commissioning and handover to the owner.*

OWNER ISSUES IN HIGH-PERFORMANCE GREEN BUILDING PROJECTS

The decision to produce a high-performance green building brings with it a number of unique issues that have to be resolved by the owner prior to initiation of the design and construction of the building. Among the questions that must be answered are these:

- *Does the owner want the building to be a certified green building?* Although the LEED approach is the predominant method for producing a green building in the United States, a green building based on a different philosophical and technical approach may be desirable. For example, the Green Globes building assessment protocol and the Living Building Challenge are alternative approaches that may be a good choice in some situations. In at least one state, Florida, a commercial green building assessment standard can be used in lieu of the national standard.[4] The International Green Construction Code is being adopted by some jurisdictions; as a result, those jurisdictions may require high-performance green construction.[5]
- *If the building is to be certified, what level of certification is desired (a platinum, gold, silver, or certified rating for LEED or one to four Green Globes in the case of Green Globes)?* The building's owner may have a preconceived idea of the level of certification desired for the facility, in which case the task of the project team will be to design and build the facility to meet the owner's goals. Often the project team will have to address the cost/benefit issues involved in achieving different certification levels and provide life-cycle costing (LCC) analysis for each level to give the owner the data needed to make a decision.
- *If the building need not be certified, what design criteria should be followed by the design team?* The LEED and Green Globes assessment systems each provide a consistent framework that contains virtually all the criteria needed to produce a green building. If LEED or Green Globes is not to be the basis for creating the green building, the owner will have to provide the project team with a detailed description of the criteria the team members are to use in their work.
- *What are the desired qualifications of the design team and construction manager with respect to the high-performance building?* In the case of a design-build project, what background and training should the designers and construction professionals have? It is certainly advantageous for the owner to hire project team members who have green building experience. If certification is desired, significant documentation of numerous aspects of the project will be required. For example, if one of the credits being addressed is the recycled content of materials used in the project, the construction manager must be aware of the requirement to obtain information from most of the subcontractors about the quantity of recycled materials in the products they

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are using in the building, and then he or she must compile the data from all the subcontractors to determine the overall percentage of recycled content in the project.

- *What level of capital investment, beyond that required for conventional construction, will the owner provide to make the facility a high-performance green building?* And is the owner willing to consider trading off lower operational costs for higher front-end capital costs? Green buildings are designed specifically to have lower operational costs, which are often accompanied by higher front-end capital costs. An LCC analysis will provide a breakdown of costs versus savings on an annual basis and indicate where the break-even point, in years, for the investment occurs. It is up to the owner to decide whether the break-even point is satisfactory and, based on this information, whether the additional capital cost is warranted.

SETTING PRIORITIES AND MAKING OTHER KEY INITIAL DECISIONS

When the decision has been made to create a high-performance green facility, the owner must decide on the priorities for the building. For example, in water-short areas of the United States, water issues may be so important that the owner may decide to focus heavily on the building's hydrologic cycle (water conservation, water reuse, rainwater harvesting, graywater systems, and employment of reclaimed water) rather than, for example, to make an exceptional effort to reduce energy consumption. Another owner may opt for implementing an extensive and exceptional system of daylighting and lighting controls due to its energy-conserving possibilities and potential health benefits and, conversely, undertake minimal water conservation measures.

Another priority to be set and decisions to be made concern the financial investment the owner is willing to make in a high-performance building. Green buildings normally involve systems not commonly used in conventional buildings, for example, rainwater harvesting systems, with their associated piping, pumps, and cisterns, entail additional design effort. Many state governments are forced by law to operate within strict square footage cost guidelines. As a result, very simple, cost-effective measures must be considered. Other types of organizations may have revolving funds that can be used to invest in high-performance options that will pay back the fund over time. Harvard University, for example, has a $12 million revolving fund that can be used for investing in higher-capital projects that are repaid out of the savings. The federal government requires LCC to be employed to justify building investment decisions, a requirement that works in favor of high-performance building decisions. Private-sector owners have considerably more leeway, and their decisions can be based on LCC, as is the case for the federal government which requires the use of LCC. Certified green buildings will have additional documentation requirements, requirements for commissioning, fees for registration and certification review, and other costs that must be allocated in the building budget.

SELECTING THE GREEN BUILDING TEAM

When an owner has decided to produce a high-performance green building, the next order of business is to select the design and construction teams. The actual selection process proceeds in the conventional fashion with the issuance of a request for proposal (RFP) or request for qualifications (RFQ) by the owner to announce the upcoming selection of the architect and construction manager. The RFP/RFQ should specify the additional qualifications required for the architect, interior designers, landscape architects, civil engineers, structural engineers, electrical engineers, and mechanical engineers. One of the challenges in writing an RFP for a high-performance

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building is to ensure that the architects and construction managers understand the owner's green goals. To facilitate this effort, the Committee on the Environment of the American Institute of Architects has produced a guide to writing RFPs and RFQs for green buildings, "Writing the Green RFP."[6]

After reviewing the submissions by the architect and construction management firms or design-build firms that respond to the project's RFP/RFQ, the owner typically creates a list of three to five firms in each category and then organizes presentations by the short-listed design firms and construction management companies. The final selection is based on experience, qualifications, previous work, and demonstrated understanding of the owner's program and requirements, the building site, and the firm members' ability to work with other project team members. The architect and construction manager or design-build firm should be selected prior to the start of the design so that both will be on board during the entire project.

Clearly, it is important that the architect and engineers have a detailed understanding of the concept of green building and a commitment to investing creativity and energy to produce an exceptional building. Even though the high-performance green building movement is relatively new, many design professionals have designed one or more green buildings. Detailed knowledge of the LEED building assessment standard or the Green Globes building assessment protocol is absolutely essential if the owner decides that the goal is green building certification. It is also important to note that some outstanding architects have experience creating high-performance buildings that have not been submitted for LEED or Green Globes certification; thus, the owner must judge the ability of these firms to meet his or her requirements.

If the building is to be certified, the construction manager should have strong familiarity with, or staff trained in, the requirements of the LEED or Green Globes assessment system. The certification process imposes enormous responsibility on the construction manager; lack of experience with the standards could compromise the certification of the project.

ROLE OF THE LEED ACCREDITED PROFESSIONAL OR GREEN GLOBES PROFESSIONAL IN THE PROCESS

The inclusion of building industry professionals trained in the use of green building certification systems helps facilitate decision making and the flow of information required to navigate the relatively complex requirements of these systems. Both the US Green Building Council (USGBC) and the Green Building Initiative, the proponent of Green Globes, have training programs and designations for these individuals.

The USGBC offers training and testing that, if passed successfully, designates the individual as a LEED Accredited Professional (LEED AP). This designation provides the building owner with a high degree of assurance that the requirements of the USGBC certification programs will be understood and that the extensive documentation required for certification will be provided. The LEED AP examination tests the individual's knowledge of green building principles as well as familiarity with the LEED requirements. The LEED AP examination covers these points:

- In-depth familiarity with the LEED building assessment system
- Understanding of LEED project registration/technical support/certification process
- Demonstrated knowledge of design and construction industry standards and process
- General understanding of the various designs referenced in LEED
- Understanding of green and sustainable design strategies and practices, and corresponding credits in the LEED rating system
- Familiarity with key green and sustainable design resources and tools[7]

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One of the other benefits of having a LEED AP on the project team is that one credit is awarded for the certification of the project. One drawback of the current system of awarding this credential is that it does not require in-depth knowledge of the building design and construction process, nor does it require professional experience. One challenge for the USGBC has been to create a rigorous accreditation process with requirements either for periodic recertification or for continuing education to maintain currency on green building issues and the LEED system.

In a similar fashion, the GBI offers training and testing designed to produce Green Globes Professionals (GGPs) who have a detailed knowledge of Green Globes, the certification process, and documentation requirements. Like LEED, Green Globes provides credit for having a GGP as a member of the project team. Unlike the LEED AP, the GGP must be a qualified building industry professional prior to taking the accreditation examination to become a GGP. Green Globes also has a higher-level qualification, the Green Globes Assessor (GGA), for the third-party advisor to the GBI regarding certification. The requirements to become a GGA far exceed those to become a GGP. The GGA provides the actual third-party certification for the project, assists the project team through the certification process, and makes the final judgment regarding achievement of certification and the level of certification. Chapter 6 covers the qualifications of GGAs and GGPs in more detail.

Integrated Design Process

Although it is true that excellent teamwork is required for any building project, the level of interaction and communication needed to ensure the success of a green building project is significantly higher. Green buildings are a relatively new concept to the industry, and generally it is necessary to orient all members of the project team to the goals and objectives of the project that are related to issues such as resource efficiency, sustainability, certification, and building health, to name a few. This orientation can serve three purposes. First, it can fulfill its primary purpose of informing the project team about all project requirements. Second, it can familiarize the project team with the owner's priorities for the high-performance green building aspects of the project. Third, it can provide an opportunity to accomplish team building in the form of group exercises for familiarizing the group with the building, the building program, and the building's green building issues.

Integrated building design or integrated design is the name given to the high levels of collaboration and teamwork that help differentiate a green building design from the design process found in a conventional project. According to the US Department of Energy, integrated design is

> [a] process in which multiple disciplines and seemingly unrelated aspects of design are integrated in a manner that permits synergistic benefits to be realized. The goal is to achieve high performance and multiple benefits at a lower cost than the total for all the components combined. This process often includes integrating green design strategies into conventional design criteria for building form, function, performance, and cost. A key to successful integrated building design is the participation of people from different specialties of design: general architecture, HVAC [heating, ventilation, and air conditioning], lighting and electrical, interior design, and landscape design. By working together at key points in the design process, these participants can often identify highly attractive solutions to design needs that would otherwise not be found. In an integrated design approach, the mechanical engineer will calculate energy use and cost very early in the design, informing designers of the energy-use implications of building orientation, configuration, fenestration, mechanical systems, and lighting options.[8]

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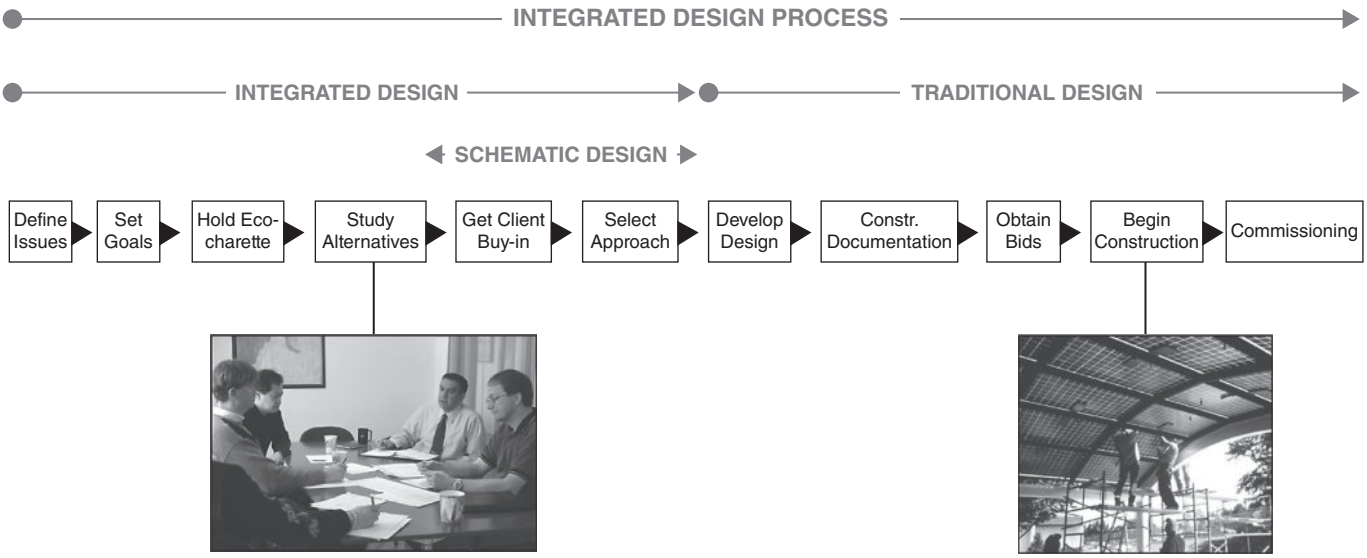


Figure 7.2 In green design, the integrated design starts much earlier in the project development process compared with conventional design, involving interaction with the owner to define issues and to set goals prior to schematic design and continuing through construction and commissioning (Diagram courtesy of Interface Engineering, Inc.)

The IDP is characterized by early significant collaboration in the design process. In conventional design, the team members begin their joint effort at the start of schematic design; in a green building project employing integrated design, the collaboration starts at the very beginning of the project, and all team members have input on design decisions during the entire cycle of design (see Figure 7.2). The earlier integrated design is implemented, the greater the benefits (see Figure 7.3).

There are numerous potential areas for integrated design in any building project: the building envelope, the daylighting scheme, green roofs, minimization of light pollution, indoor environmental quality, and the building hydrologic cycle, to name but a few. The Green Globes building assessment protocol spells out the requirements for integrated design in its project management section, where a team can achieve 20 points for demonstrating that it has indeed implemented integrated design

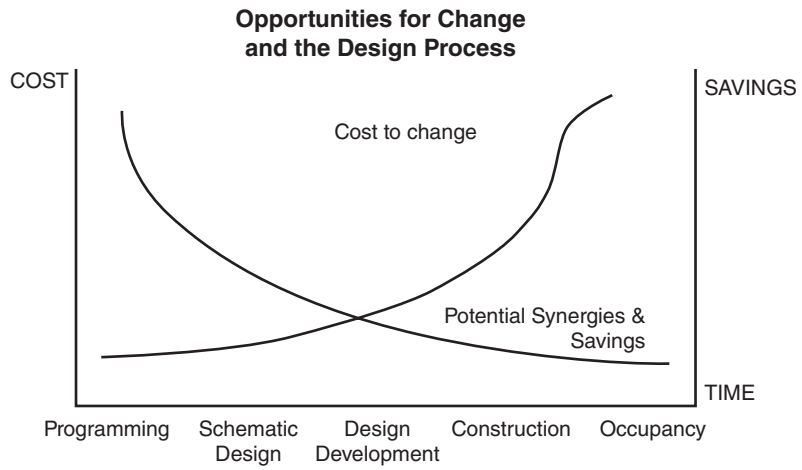


Figure 7.3 The earlier an integrated design is implemented, the greater the potential savings and the lower the cost of changes to the building design.

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in the process. In addition to appointing a green design coordinator, the team must demonstrate how it interacted by documenting the results of collaboration in the form of the minutes of goal-setting meetings and lists of items on which team members worked jointly for resolution.[9]

Another term that describes integrated design is *integrated design process*. Some of the foundational work on developing IDP occurred in Canada, and perhaps the most thorough definition was a result of a national workshop on IDP held in Toronto in 2001:

> IDP is a method for realizing high-performance buildings that contribute to sustainable communities. It is a collaborative process that focuses on the design, construction, operation and occupancy of a building over its complete life cycle. The IDP is designed to allow the client and other stakeholders to develop and realize clearly defined and challenging functional, environmental and economic goals and objectives. The IDP requires a multi-disciplinary design team that includes or acquires the skills required to address all design issues flowing from the objectives. The IDP proceeds from whole building system strategies, working through increasing levels of specificity, to realize more optimally integrated solutions.[10]

In addition to this extensive definition of IDP, the main elements of the IDP were identified as:

- Interdisciplinary work between architects, engineers, costing specialists, operations people, and other relevant actors right from the beginning of the design process.
- Discussion of the relative importance of various performance issues and the establishment of a consensus on this matter between client and designers.
- The addition of an energy specialist to test various design assumptions through the use of energy simulations throughout the process and to provide relatively objective information on a key aspect of performance.
- The addition of subject specialists (e.g., for daylighting, thermal storage, etc.) for short consultations with the design team.
- Clear articulation of performance targets and strategies, to be updated throughout the process by the design team.
- In some cases, a design facilitator may be added to the team, to raise performance issues throughout the process and to bring specialized knowledge to the table.

It was also noted that it may be useful to launch the IDP with a charrette, which is described in more detail in the next section of the chapter.

Traditional design could be said to have three steps:

1. The client and architect agree to a design concept that includes the general massing of the building, its orientation, its fenestration, and probably its general appearance and basic materials.
2. The mechanical and electrical engineers are engaged to design systems based on the building design concept agreed to in step 1. The civil engineer and landscape architect develop a concept for landscaping, parking, paving, and infrastructure based on the building design concept and the owner's wishes.
3. Each phase of design (schematic, design development, and construction documents) is carried out employing the same pattern, with minimal interaction between disciplines, little or no interdisciplinary collaboration, and great attention to the speed and efficiency of executing each discipline's design.

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The result of traditional design is a linear, noncollaborative process with little attempt to set goals beyond meeting the owner's basic needs. The building meets the building code but is not optimized. Each discipline functions in isolation, with interdisciplinary communications kept to a minimum. As is the case with every other system, optimizing each subsystem of the project results in a suboptimal building. The most likely outcome is not only a suboptimal project but also a range of other potential problems caused by a lack of strong coordination among disciplines.

In contrast to traditional design, the point of the IDP is to optimize the entire building project. The requirements for communication are intense, nonstop, and at all stages of the project, from design through construction, commissioning, handover to the owner, and postoccupancy analysis. Integrated design starts prior to the actual design process, with the project team articulating goals for the project and determining the opportunities for synergies in which design solutions have multiple benefits for the project. A typical sequence of events that is indicative of integrated design is listed next.

- The project team establishes performance targets and preliminary strategies to achieve the targets for a broad range of parameters, to include energy, water, wastewater, landscape performance, heat island issues, indoor environmental quality, and construction and demolition waste generation, to name a few. The IDP should bring engineering skills and perspectives to bear at the concept design stage, thereby helping the owner and architect avoid becoming committed to a suboptimal design solution. It also should involve all members of the team bringing their skills to bear on designing the optimal building. Mechanical engineers are better placed in terms of their background in thermodynamics and heat transfer than the architect, and it makes sense to engage them in the design of the building envelope.
- The team minimizes heating and cooling loads and maximizes daylighting potential through orientation; building configuration; an efficient building envelope; and careful consideration of the amount, type, and location of fenestration. A wide variety of plug loads should be addressed due to the effects of large numbers of computers, printers, fax machines, sound systems, and other equipment on building performance. Minimizing these loads and selecting equipment with the lowest possible energy consumption is needed so that the intent of the high-performance building is not compromised by neglecting to account for this consumption. The broad range of indoor environmental quality issues should be addressed, to include air quality, noise, lighting quality and daylighting, temperature and humidity, and odors. The team also should collaborate on site issues to maximize the use of natural systems; minimize hardscape; use trees to assist heating and cooling of the building; and integrate rainwater harvesting, graywater systems, and reclaimed water into the design of the building's hydrologic cycle.
- The team maximizes the use of solar and other renewable forms of energy, and use efficient HVAC systems while maintaining performance targets for indoor air quality, thermal comfort, illumination levels and quality, and noise control.
- The results of the process are several concept design alternatives, employing energy, daylighting, and other simulations to try out the alternatives, and then the selection of the most promising of these for further development.

The earlier IDP is instituted, the greater its effect on the design process. The maximum benefit occurs when the decision to employ the IDP is made prior to the start of the design process and the project team has the opportunity to set goals for the project that guide the design process.

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The result of the IDP should be a full understanding of the potential design synergies and the connection of the project goals to the resulting building design. A truly collaborative process will use these project goals as the basis for wide-ranging, dynamic interaction among the project team members to capitalize on the potential for reducing resource consumption, limiting environmental impacts, and restoring the site to its maximum ecological potential. Figure 7.4 is a schematic that demonstrates how project goals can be used in conjunction with IDP to produce a wide range of benefits, both for the project and for the environment.

Another term related to integrated design is *whole-building design*, a concept advocated by the National Institute of Building Sciences and described as consisting of two components: an integrated design approach and an integrated team process.[11] Whole-building design has been adopted by a group of federal agencies as the core concept of high-performance green buildings, and the emphasis is on collaboration and life-cycle performance. The concept of collaboration is extended outside the project team to include all stakeholders in the building process. In the integrated team process, the design team and all affected stakeholders work together throughout the project phases to evaluate the design for cost, quality of life, future flexibility, and efficiency; overall environmental impact; productivity and creativity; and the effect on the building's occupants. Whole-building design, as described by the National Institute of Building Sciences, draws from the knowledge pool of all the stakeholders across the project's life cycle, from defining the need for a building through planning, design, construction, building occupancy, and operations. The process does not conclude at the end of construction and handover to the owner. During operation, the building should be evaluated to ensure that it has met its high-performance design objectives. Furthermore, the building should be recommissioned periodically to maintain its high-performance character throughout its life cycle.

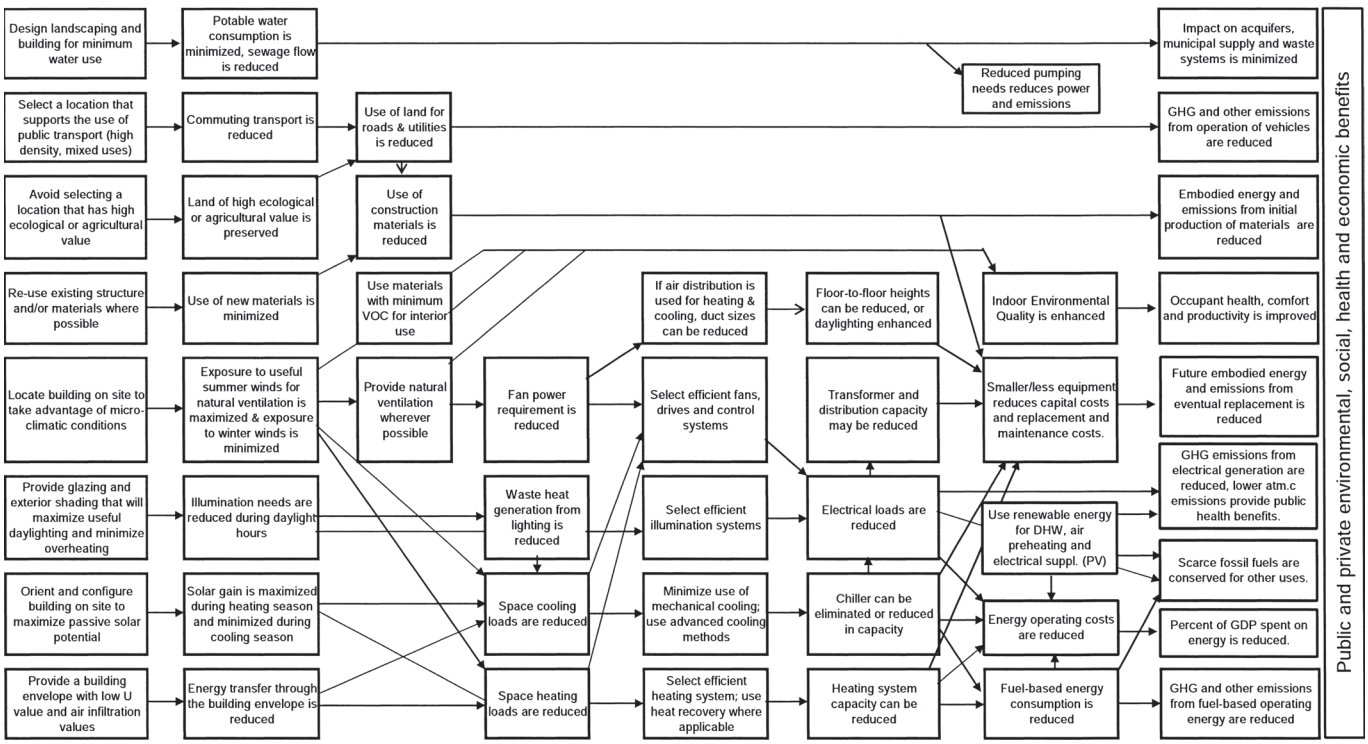


Figure 7.4 An IDP can assist in achieving design synergies by stimulating interdisciplinary collaboration. The result can be green strategies, such as those listed in the leftmost column of this example project, being translated into benefits for the building owner and occupants as well as for the global environment. (Illustration courtesy of Nils Larsson, Natural Resources Canada, and the United Nations Environmental Program)

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Role of the Charrette in the Design Process

Creating a green, sustainable building implies that the widest range of possible stakeholders will be engaged in the process because buildings ultimately affect a large variety of people and, in fact, affect future buildings. As the predominant artifacts of modern society, and due to their relative longevity, buildings are important cultural symbols; hence, they affect enormous numbers of people every day. Passersby are affected either positively or negatively by the appearance of a building based on its design, materials, color, location, and function. The stakeholders in a building vary widely depending on its type and its ownership. For example, a public building, such as a library or city administration building, affects not only the employees who use the building directly but also virtually all persons in the local jurisdiction, who, as taxpayers, have contributed to its realization. In the case of a corporate building, although its impact may not be as widespread, a savvy owner nevertheless engages a wide range of users, customers, local government, and citizens to obtain the maximum input. The process of gathering this input is referred to as a *charrette.* This section provides a general overview of the charrette concept. The next section covers the detailed integration of the charrette into the design process.

The word *charrette* is derived from the French term meaning "little cart." This concept has its roots in French architectural education when proctors at the École des Beaux-Arts in 19th-century Paris collected student projects on wheeled carts, literally pulling the drawings from the students' hands at the end of their final frenzied efforts on a design project. Today the term is used to refer to an effort to create a plan. According to the National Charrette Institute (NCI), there are four guiding principles for a charrette (see Table 7.1). Note that these principles are meant to apply to a community planning charrette, not specifically to the design of a single building. Consequently, they are presented here in a modified form from the actual NCI guiding principles.

TABLE 7.1

Four Guiding Principles for a Built Environment Charrette

1. *Involve everyone from the start.* The identification and solicitation of stakeholders to provide input to a project is of the utmost importance because the participants in the charrette process will feel a sense of ownership for the outcomes. The broader the range of input, the more likely the project is to be successful and accepted by the community. It is also important to note that people or organizations that may potentially play a role in blocking a project should be invited to participate.
2. *Work concurrently and cross-functionally.* All disciplines engaged in a project should work together at the same time during the charrette and with the other stakeholders to generate alternative designs under the guidance of a facilitator. The level of design detail that emerges from the charrette will be a function of the time available and the complexity of the project. In general, a building design charrette produces a wide range of potential solutions and approaches that not only cover green issues but also address the function of the building and its relationship to the community. For larger, more complex projects, the participants can divide into groups to tackle specific issues, then return to a caucus or plenary meeting for each group to share its progress with other groups and to make decisions on how to proceed.
3. *Work in short feedback loops.* For a building project, proposed solutions and measures are laid out in a brainstorming session during which the participants, guided by a facilitator, cover all aspects of the building, its infrastructure, and its relationship to the community. This approach produces far more alternatives and engages far more creativity than a conventional design process. This is an advantage in that many more ideas and options are presented. That said, the information also must be processed efficiently and rapidly to provide useful input to the actual design process. The result of the brainstorming sessions must be distilled to the essential outcomes, and duplications must be eliminated and priorities established. For example, it would certainly be advantageous if all buildings had photovoltaics, but few owners have the resources at present to incorporate them into their facilities. The feedback loops between initial brainstorming sessions and design decisions should be as rapid as possible so that more than one iteration is possible during the charrette.
4. *Work in detail.* The more detail in a charrette, the better. Alternatives for building appearance, orientation, massing, and electrical and mechanical systems should be sketched out in as much detail as possible. The NCI recommends working on problems at different scales during the charrette. Larger-scale issues of drainage, paving, and relationships to other buildings and the street should be addressed, as should details such as entrance location, window selection, and roof type.

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TABLE 7.2

Four Steps for a Built Environment Charrette

1. *Start-up.* In the context of a building project, the start-up for a charrette is very simple. It involves determining who the stakeholders are, engaging the stakeholders in the process, establishing the goals for the charrette, determining the time and place for holding the charrette, and notifying the participants of the details.
2. *Research, education, and concepts.* Prior to the charrette, the building owner, the charrette facilitator, and design team members should discuss the information needs for the charrette. The owner's directions, the building program, site details, utility information, and other pertinent data should be gathered and readied for the charrette. Information on specific technologies may be useful. For example, if a fuel cell is a strong-candidate technology for the project, technical information about the device, issues of connecting the fuel cell to the grid, and information about fuel and emissions should be gathered for use during the process. In some cases, the process of gathering information for the charrette may highlight the need to engage other organizations in the process. In the example of a fuel cell, the local utility company could provide valuable input as to how best to incorporate the fuel cell into the project. The location of the charrette should be selected to best facilitate its conduct. Generally, it is best to hold the charrette at the owner's location if adequate space and facilities are available. A large room with blackboards or whiteboards, space for large-paper tripods, and a projector and projector screen should be available.
3. *The charrette.* Generally, the charrette should be conducted by a facilitator familiar with the green building process. A typical building charrette might occur over several days and continue in phases until complete. The first step should be an effort to educate all the participants on the owner's requirements and the concept of high-performance green building. The second step would be to review the building program, previously generated architectural schemes, building siting, proposed construction budget, and construction schedule. The third step would be to lay out the goals of the project with respect to its green high-performance aspects. The owner may desire a specific level of certification—for example, a LEED gold certification—that will affect many of the decisions made during the charrette. When these steps have been completed and the project team and stakeholders understand the context of the project, the actual charrette begins. The facilitator conducts a guided brainstorming session that draws out input from the group about every aspect of the project, with a special emphasis on the sustainability of the building. During the conduct of the charrette, the team should keep a running scorecard on how the decisions made during the process are affecting the building assessment score. The economics of each decision also need to be taken into account, and the construction manager should ensure that enough data are available to provide a conceptual cost estimate for review by the owner.
4. *Review, revise, and finalize.* After the charrette is complete, the design team reviews the results with the owner, makes any appropriate adjustments and changes, and then produces a report of the charrette to guide the balance of the design process.

Source: Adapted from the four-step charrette process proposed by the National Charrette Institute, available at www.charretteinstitute.org.

The NCI has also proposed a four-step charrette process that, although designed for a community planning charrette, is also applicable to a building project charrette. These steps are outlined in Table 7.2.

At the conclusion of the charrette, it is the responsibility of the project team to transform the results into a report that can be used to guide the design of the project. A final review of the outcome of the brainstorming sessions should be conducted to ensure that the measures selected for implementation meet cost and other criteria that may be important. Communications may need to be established with entities or groups external to the charrette to ensure that they act to maximize the high-performance aspects of the project. For example, Rinker Hall, a LEED gold building at the University of Florida in Gainesville, is connected to a central plant that provides its heating and cooling. The project team decided that the LEED Energy and Atmosphere point for eliminating hydrochlorofluorocarbon (HCFC) use could be justified only by obtaining a commitment from the university to implement a program to replace its older, HCFC-based chillers with efficient hydrofluorocarbon refrigerant chillers. Another point, for maintaining open space, was acquired by obtaining a letter from the university administration stating that specific property contiguous to Rinker Hall would be maintained as open space for the life of the building. In the private sector, cooperation of municipal officials may be necessary to obtain points for proximity of mass transit.

The final version of the charrette report becomes one of the guiding documents for the launch of the schematic design phase of the project and ultimately serves to help steer the project through design development, construction documents, and the actual construction process.

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Green Building Documentation Requirements

Certifying a green building using one of the major building assessment systems requires that a great deal of attention be paid to gathering information throughout the project's design and construction process. The two main building assessment systems in the United States, LEED and Green Globes, have different approaches to how the documentation ultimately is reviewed, and the project team should review the requirements for each approach carefully.

LEED DOCUMENTATION

In the case of a project for which the owner is seeking USGBC certification, careful documentation of the efforts to achieve credits is needed. As noted earlier, the documentation requirements for the first versions of the LEED building assessment standard were relatively complex and difficult. For LEED-NC and other LEED products, the documentation requirements, while far simpler, are by no means easy to meet. The advent of LEED-Online, a sophisticated Web portal for posting of documentation and exchange of information, has made the entire process paperless. The documentation may be submitted in two batches: the design phase and the construction phase. The design phase submission is for those credits that are essentially complete during design and do not require any documentation during the construction phase. For instance, LEED Materials and Resources (MR) Prerequisite 1 requires that a space be set aside for the storage and collection of recyclables in the building. The required documentation is a drawing that shows this area and the location of the containers required for recycling. This prerequisite is completed during design and can be submitted with other design phase credits for review by the USGBC via LEED-Online. Most credits are documented at least in part by means of the LEED-Online Templates. A LEED-Online Template is to be filled out for each credit the project team is claiming for the building. For example, to demonstrate that the LEED-NC Prerequisite 1 for Construction Activity Pollution Prevention in the Sustainable Sites category has been addressed adequately, the civil engineer or other responsible party must fill out the LEED-Online Template designated for this purpose, stating that the project followed US Environmental Protection Agency (EPA) Document EPA 832/R-92-005 (September 1992), *Storm Water Management for Construction Activities*, or local erosion and sedimentation control standards and codes, whichever is more stringent. A brief list of the measures actually implemented also must be provided, along with a description of how they meet or exceed the local or EPA standards. The effort to document that this prerequisite has been met should be factored into the overall design and construction process to ensure that all the documentation has been prepared by the completion of construction.

Another example of required documentation is LEED MR Credit 4 for Recycled Content. This credit is achieved if the project team can demonstrate that 10 percent of the value of the nonmechanical and nonelectrical materials in the building have a combination of postconsumer and preconsumer recycled content. Only one-half of the preconsumer content can be included in the calculation. For this credit, the architect, owner, or other responsible party must state that these requirements have been met and include details about products, product value, postconsumer and preconsumer recycled content, and the resulting overall recycled content for the project.

The project team must also decide at the start of the project how information will flow among the various parties and who will compile and produce the information for the appropriate LEED-Online Template. For the MR credit, the calculations provided with the Online Template must clearly demonstrate that a requirement has

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been met by indicating the product or material, its value, and its postconsumer and preconsumer recycled content. The final computation should demonstrate that at least 10 percent of the total value of the materials, excluding mechanical and electrical systems, is recycled content, counting postconsumer content at its full percentage and preconsumer at half of its percentage in each product. This requirement can be challenging for products such as glass and aluminum storefronts, where part of the aluminum components may have recycled content but the glass will not. Additionally, because the product is likely to be assembled by a local glass subcontractor, that firm must research this information for its product. The contractor then compiles the information on the recycled content for all products to produce a final picture of the total recycled content of the project. Finally, either the contractor or the architect submits these data along with the MR Template for the project at LEED-Online.

It should also be noted that the USGBC audits submissions, meaning that much more extensive backup information may be required to verify the assertions made in the templates. Therefore, it is good practice to ensure that full documentation is maintained throughout the design and construction processes and that all assumptions are clearly stated in the backup materials.

The LEED building assessment system is covered in detail in Chapter 5.

GREEN GLOBES DOCUMENTATION

Green Globes relies on an online questionnaire that the project team should utilize to guide the green aspects of the design and construction process. A careful review of the questionnaire should alert the team that, for example, as an indicator of Integrated Design, meetings should be held and documented to demonstrate that Integrated Design was indeed being fostered. Another indicator of integrated design is the appointment of a GGP who must be assigned duties such as:

- Outlining the overall green design framework for the project
- Communicating the client's/user's intentions to the project team
- Developing measurable green design performance requirements
- Assisting in evaluating responses against the green design objectives

A careful review of the questionnaire will provide the project team with valuable information about the required documentation and what the GGA, who audits the project documentation in an on-site visit at the conclusion of construction, will be reviewing to determine if the documentation is adequate.

Case Study: Theaterhaus, Stuttgart, Germany

Theaterhaus represents some of the most advanced building engineering in Germany, a country where innovative design is the norm. It is a center for culture and arts in the Feuerbach area of Stuttgart and a meeting place for artists and literati to converse and collaborate about the state of music, literature, theater, and a wide range of other fine arts. In addition to being a theater complex and concert hall, the facility serves as a place for teaching music, as a gathering place for youth, and as a sports hall (see Figures 7.5–7.7). Theaterhaus is perhaps the largest naturally ventilated theater complex in the world and was designed with the dual goals of meeting the needs of the arts community while also producing an exemplar of ecologically responsive building and construction. It is a restoration of an industrial building known as the Rhein Stahlwerk, or Rhine Steelworks, which was built in the eastern section of Feuerbach in 1923. In spite of the industrial nature of the building, it was

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Figure 7.5 The entry to Theaterhaus in Stuttgart, Germany, is marked by an overhead shipping container with its name and logo.



Figure 7.6 The beautiful brickwork of the 1920s era Rhein Stahlwerk was preserved in its restoration and conversion into a cultural center.



Figure 7.7 The interior of Theaterhaus just inside the entrance, showing the staircase leading to the four performance halls. Extensive effort was made to preserve as much of the industrial character of the building as possible.

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quickly recognized as an exceptional work of architecture and art, and in 1986, it was declared an official cultural monument of Stuttgart. In the process of restoration and conversion to a cultural complex, the beautiful brick walls of the former Rhein Stahlwerk were meticulously preserved and have become a focal point upon approach. The renovation of the Rhein Stahlwerk into the Theaterhaus resulted in a total floor area of 122,000 square feet (ft^2) (12,200 square meters [m^2]), with 82,000 ft^2 (7,618 m^2), for the four performance spaces. About 10,000 ft^2 (1,000 m^2) is provided for an organization called Musik der Jahrhundert (Music of the Century) and 30,000 ft^2 (3,000 m^2) for an administrative area. In the theater zone, Hall 1 has a floor area of 7,500 ft^2 (750 m^2) and seating for 1,050 spectators. Hall 2 seats 450; Hall 3 seats 350; and Hall 4, the smallest performance space, seats 150. There are also several rehearsal spaces located throughout the theater zone in the building. The budget for the project, which was completed in 2003, was €17 million.

In addition to the remarkable restoration effort with respect to the building façade and interior structure, significant effort was invested in the design of a hyperefficient HVAC system that has resulted in remarkable energy performance. The energy required for moving air through the building was reduced 90 percent through the use of a natural ventilation system connected between the four theater spaces and the outside. A large exhaust chimney was appended to the top of the structure, and its shape and size induces airflow through the building by taking advantage of the buoyancy of warming air, the so-called chimney effect. Large intake louvers on the exterior of the building are connected to the chimney via a pathway that includes an earth-coupled canal, which cools the outside air in summer and warms it in winter. Air rising in the exhaust chimney induces this airflow, which, after passing through the earth canal, flows into each of the four theaters to meet their heating and cooling requirements (see Figures 7.8–7.13). In summer, no additional cooling is provided to temper the air flowing through the building, and the air cooled by ground contact is the sole medium provided for cooling. In winter, additional heating is provided as needed to boost the air warmed by the earth canal to suitable temperatures for conveyance into the building spaces. Additionally, in winter, a heat exchanger moves energy from the large exhaust chimney airstream to the intake air to warm it from an outside air temperature of 22° to 46°F (25°–8°C). If needed,



Figure 7.8 The key element of the Theaterhaus natural ventilation system is a 93-foot (30-m) chimney, which induces airflow from outside the building, through the building interior space, to be exhausted by the stack, or chimney, effect. The chimney was a feature that was added to the building and that adds to the industrial appeal and appearance of the former steelworks.



Figure 7.9 The grilles for the outside air intake for Theaterhaus are located on the side of the building. Air is induced to flow through the building by the rising warm air in the exhaust air chimney located on the top of the building.

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Figure 7.10 After entering the building through the outside air intake grilles, air flows through the earth canal, which cools the air via ground contact in summer and heats it in winter.

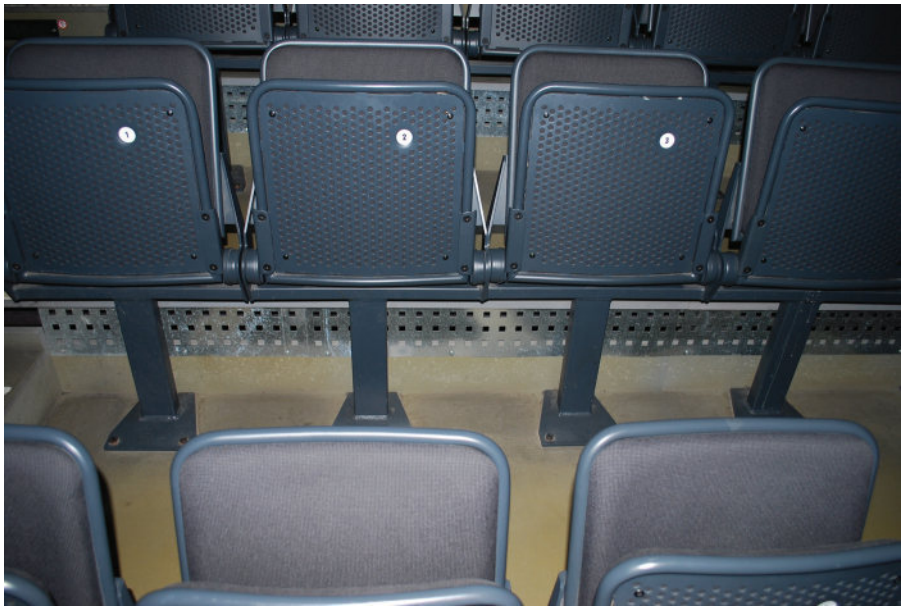


Figure 7.11 Grilles located under the seats in the performance halls are the locations where air flows into the spaces for heating, ventilating, and cooling. The main mode of operation is natural ventilation, with airflow being induced by the buoyancy or rising warm air in the exhaust air chimney.

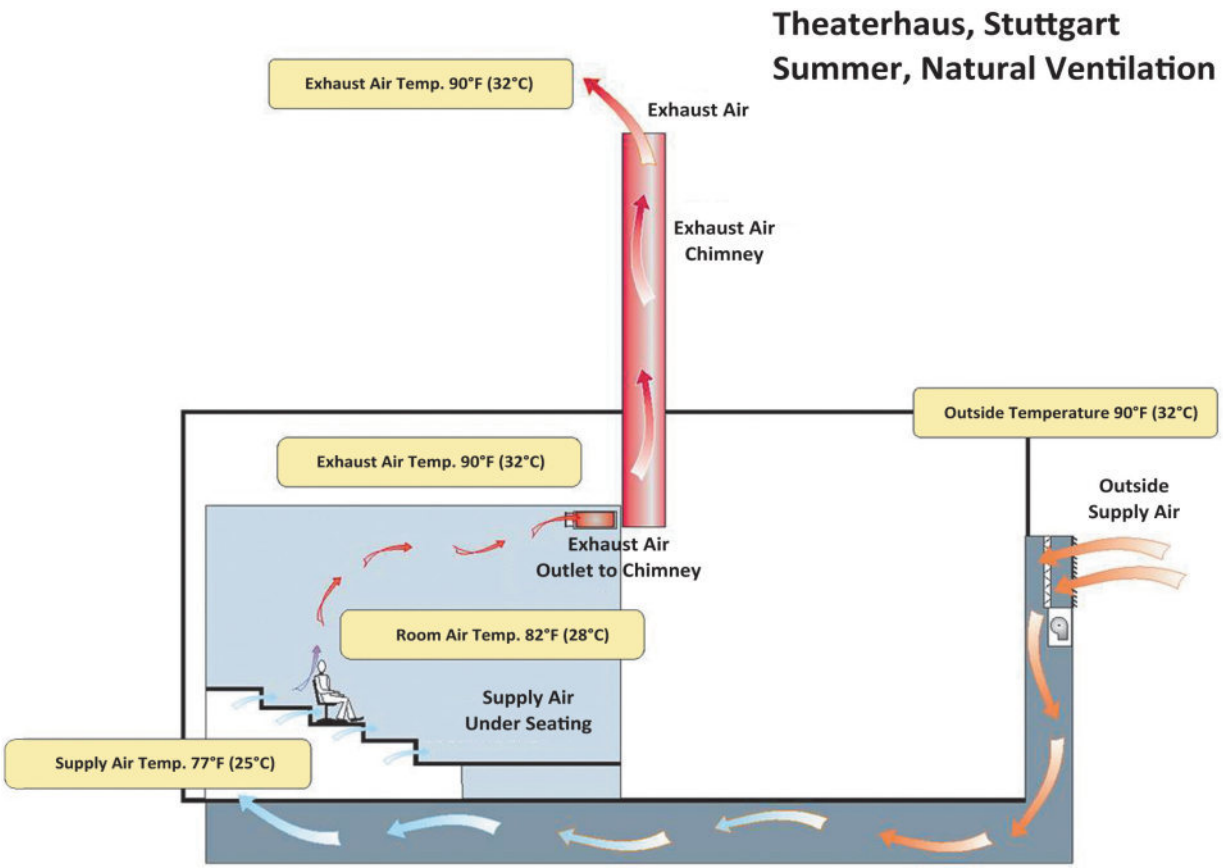


Figure 7.12 The summer natural ventilation scheme for Theaterhaus brings warm to hot air from outside and cools it in an underground tunnel by ground contact. The air then moves into the theater spaces and is exhausted to the large 66 ft (20 m) chimney located on the roof of the building. When the natural ventilation system is active, the entire airflow is induced by the warm air rising in the chimney. (Illustration courtesy of Transsolar Energietechnik GmbH)

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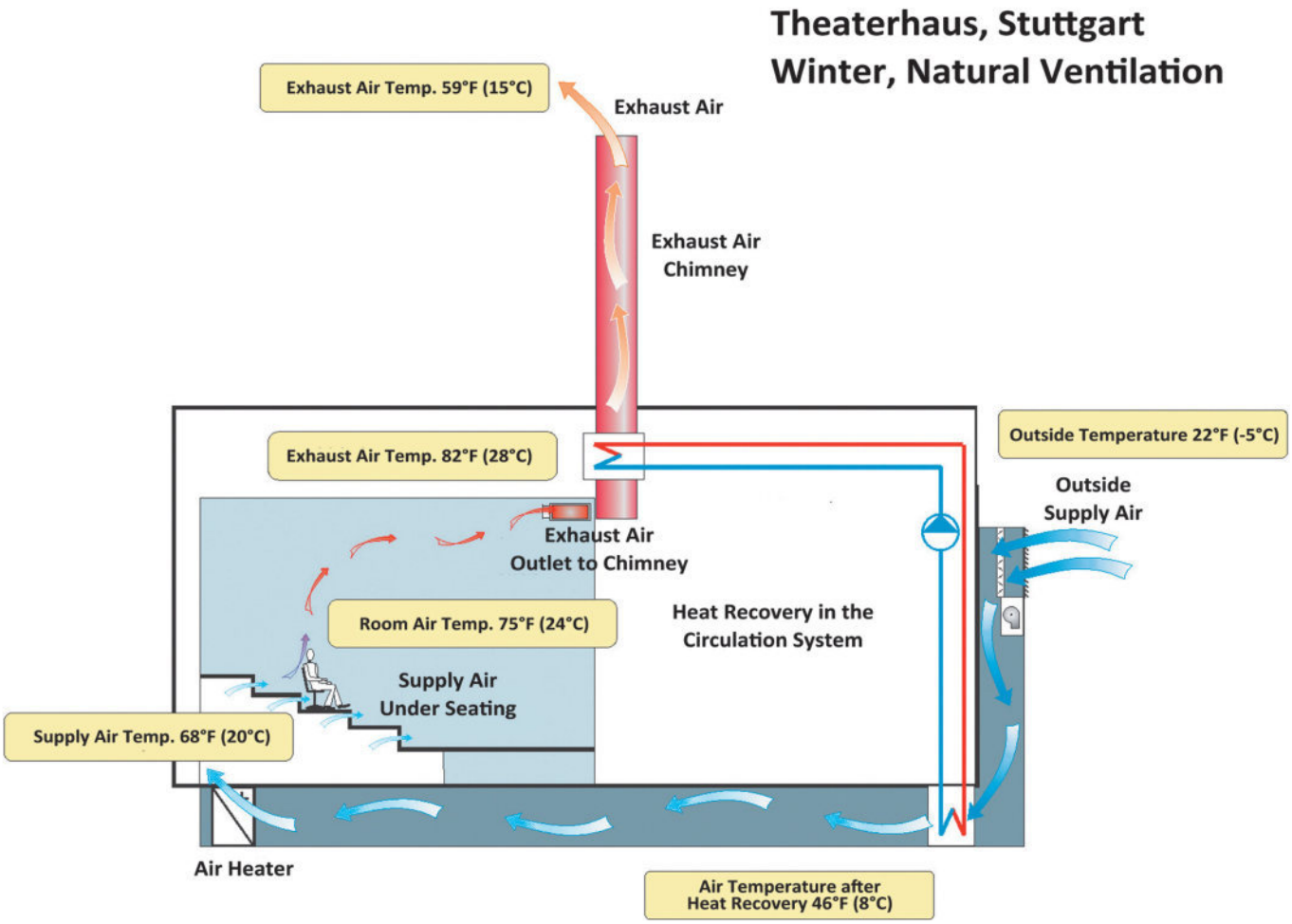


Figure 7.13 In the winter natural ventilation mode, air is conducted from the outside through the underground tunnel, which, together with a heat recovery system, warms the outside air. Additional heating is provided, if needed, to raise the supply air temperature into the theater to about 68°F (20°C). The heat recovery system is used to move energy from the air leaving the theater spaces to the outside air supply stream. (Illustration courtesy of Transsolar Energietechnik GmbH)

an air heater boosts the temperature to about 68°F (20°C) before it is conducted into the theater spaces. If higher airflows are needed, fans can be used to move additional air through the facility. Similarly, in summer, the outside air, which may be as warm as 90°F (32°C), is cooled to 77°F (25°C) before it is conducted into the spaces. Transsolar Energietechnik Engineering GmbH in Stuttgart, the designers of the natural ventilation-based HVAC system, predicts that, in addition to the ventilation energy savings of 90 percent, heating demand is reduced by about 20 percent and cooling demand by 100 percent.

Summary and Conclusions

Green building and its delivery system are unique in that they provide not only improved buildings to owners but also an improved process. In a short time, this movement has developed several key elements that will undoubtedly find their way into mainstream construction; among them are better teamwork among project team members, the use of the charrette to maximize input and creativity at the start of the design process, and the extensive use of building commissioning as a tool for

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ensuring that owners receive precisely the buildings they anticipated. In effect, this delivery system is based on the conventional construction management-at-risk delivery system, with significant improvements in the areas of collaboration and communication among the project team members. The design-build delivery system can also be modified to a green building delivery system by selecting a team with familiarity with green building and an orientation to environmentally friendly design and construction practices. IPD is a much newer construction delivery system with many attributes that make it highly compatible with the green building delivery process. The end result in either case, construction management-at-risk or design-build, should be a vastly superior end product, not only in environmental attributes but also in the quality of design and construction, due to the improved working atmosphere fostered by the green building concept.

Notes

1. The definition of design-build is from the website of the Design-Build Institute of America, www.dbia.org.
2. A white paper on IPD written by Charles Thomsen (2011) of the Construction Management Association of America can be found at http://charlesthomsen.com/essays/IPD%20summary.pdf.
3. As of January 2016, there were 69 green building projects at the University of Florida registered or certified by the USGBC LEED building rating system. More on these projects can be found at www.facilities.ufl.edu/leed/index.php.
4. The Florida Green Building Coalition Green Commercial Building Designation Standard can be found at www.floridagreenbuilding.org/standard.
5. On July 5, 2011, the city council of Scottsdale, Arizona, adopted the International Green Construction Code as the core component of its voluntary Commercial Green Building Program. This significant step makes it easier for developers of commercial and multifamily housing to be green certified. The code provides flexibility to adapt to Scottsdale's geographic conditions and environmental quality of life while promoting uniformity and consistency from city to city. By integrating the voluntary code into the city's plan review and inspection process, green certification is streamlined and a Green Certificate of Occupancy is issued following the final building inspection. A report on this development can be found at www.scottsdaleaz.gov/greenbuilding.
6. "Writing the Green RFP" can be found at the American Institute of Architects Committee on the Environment website, www.aia.org/practicing/groups/kc/AIAS074658?dvid=&recspec=AIAS074658. The guide also provides examples of green RFPs/RFQs and highlights the experience of some people who have had a role in writing this type of document. It also contains "Sustainable Design Basics" and "Frequently Asked Questions (FAQs)" sections.
7. Current information about the LEED Accredited Professional Exam and the latest requirements can be found at the Green Building Certification Institute (GBCI) website, www.usgbc.org/credentials#taking.
8. As found in the Building Toolbox section of the US Department of Energy's Building Technology Program at http://energy.gov/eere/amo/toolbox-and-expertise.
9. The potential Project Management points of Green Globes can be found at www.thegbi.org/files/training_resources/Green_Globes_NC_Technical_Reference_Manual.pdf.
10. The national workshop on IDP was held in Toronto, Canada, in October 2001. An excellent document describing the Canadian perspective on IDP is "Integrated Design Process Guide," written by Alex Zimmerman in 2006, available at www.aaa.ab.ca/aaa/AAA/AAA_Professional_Development/04BII_CMHC_ARTICLES.aspx?WebsiteKey=a00e67d1-4685-4a29-8c7c-ae3e7d253f29.
11. The concept of whole-building design and an online reference, "The Whole Building Design Guide," can be found at www.wbdg.org.

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Chapter 8

The Sustainable Site and Landscape

Land use and landscape design are closely coupled—and offer perhaps the greatest opportunity for innovation in the application of resources needed to create the built environment. Buildings, while altering the local ecosystem, can contribute to the ecosystem and function synergistically with nature. Carefully designed and executed work by architects, landscape architects, civil engineers, and construction managers is required to produce a building that:

- Optimizes the use of the site
- Is highly integrated with the local ecosystem
- Carefully considers the site's geology, topography, solar insolation, hydrology, and wind patterns
- Minimizes impacts during construction and operation
- Employs landscaping as a powerful adjunct to its technical systems

Other members of the project team must also have a voice in the decisions made about land. The location of the facility on the site, the type and color of exterior finishes, and the materials used in parking and paving all affect the thermal load on the building and hence the design of the heating and cooling systems by the mechanical engineer. Minimizing the impact of light pollution requires the electrical engineer to design exterior lighting systems carefully to eliminate unnecessary illumination of the building's surroundings. Providing access to mass transportation, encouraging bicycling and alternative-fuel vehicles, or accommodating alternative-fuel vehicles ensures that the greater context beyond the building is not neglected. Collaboration among all the members of the project team marks high-performance green building as a distinct delivery system and is essential to make optimal use of the site and landscape.

Site and landscape also provide the opportunity to move beyond mere greening to the potential restoration of the land as an integral part of the building project. Until the advent of the green building movement, scant attention was paid to the impacts of construction on the environment, particularly on the land. Buildings alter the ecology, biodiversity, fecundity, and hydrology of the site, leaving it in a degraded state. Contemporary green building approaches call for the reuse of land, its cleanup in the case of contaminated land, and increasing density to minimize the need for greenfield development.

In the context of green buildings, the role of the landscape architect perhaps should be redefined from that of simply providing exterior amenities for the project to serving as the integrator of ecology and nature within the built environment. Because they are probably the best-equipped members of the project team to deal with natural systems, landscape architects also should provide expertise to the rest of the project team on the relationship between buildings and natural systems.

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Historically, there has not necessarily been a recognizable connection between landscape architecture and the environment. As noted by Robert France in a 2003 critique of landscape architecture, "[T]he desire of planners to make their personal mark on the landscape, and of ecologists to understand the workings of nature, can be at odds with a desire to preserve, protect, and restore environmental integrity."[1] It might even be useful at this point in the evolution of the green building delivery system for members of this profession to review the term *landscape architect* and consider a more appropriate one, perhaps *ecological architect.* At present, there is no professional on the conventional project team with the knowledge of buildings, ecology, and the flow of matter and energy across the human–nature interface. New, emerging topics for landscape design include stormwater uptake, wastewater treatment, food production, contaminant remediation, and assisting in heating and cooling buildings. New approaches that include a robust role for natural systems in buildings are at the cutting edge of high-performance building and point to areas where their design eventually must evolve.

The appropriate use of land is a major issue in green building, if for no other reason than a building designed and constructed to the most exacting green building standards will be badly compromised if users or occupants must drive long distances to reach it. Other land issues include building on environmentally sensitive property, in flood-prone areas, or on greenfields, or agricultural land, instead of on land already affected by human activities. Putting formerly contaminated land, or brownfields, back into productive use in a building project has the dual advantage of improving the local environment and recycling land, as opposed to employing greenfields. Contemporary green building approaches also require far more care in the use of the building site. In a green building project, the construction footprint typically is minimized, and the construction manager plans the construction process to minimize the destruction of plants and animal habitat from soil compaction. Erosion and sedimentation control are emphasized, and detailed planning of systems to minimize soil flows during construction is part of the green building delivery system. The potential for so-called heat islands, caused by the use of energy-storing materials in the building and on the site, is addressed. Likewise, the issue of light pollution from buildings is addressed in the design of a high-performance green building.

Land and Landscape Approaches for Green Buildings

Buildings require several categories of resources for their creation and operation: materials, energy, water, and land. Land, obviously, is an essential and valuable resource, so its appropriate use is a prime consideration in the development of a high-performance building. Several general approaches to land use fit in with the concept of high-performance green buildings:

- Building on land that has been previously utilized instead of on land that is valuable from an ecological point of view
- Protecting and preserving wetlands and other features that are key elements of existing ecosystems
- Using native and adapted, drought-tolerant plants, trees, and turf for landscaping
- Using brownfields, properties that are contaminated or perceived to be contaminated
- Developing grayfields, areas that were once building sites in urban areas

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- Reusing existing buildings instead of constructing new ones
- Protecting key natural features and integrating them into the building project for both amenity and function
- Minimizing the impacts of construction on the site by minimizing the building footprint and carefully planning construction operations
- Minimizing earth moving and compaction of soil during construction
- Fully using the sun, prevailing winds, and foliage on the site in the passive solar design scheme
- Maintaining as much as possible the natural hydroperiod of the site
- Minimizing the impervious areas on the site through appropriate location of the building, parking, and other paving
- Using alternative stormwater management technologies, such as green roofs, pervious pavement, bioretention, rainwater gardens, and others, which assist on-site or regional groundwater and aquifer recharge
- Minimizing heat island effects on the site by using light-colored paving and roofing, shading, and green roofs
- Eliminating light pollution through careful design of exterior lighting systems
- Using natural wetlands to the maximum extent possible in the stormwater management scheme and minimizing the use of dry-type retention ponds
- Using alternative stormwater management technologies, such as pervious concrete and asphalt for paved surfaces.

These approaches cover a wide range of possibilities. Their general purpose is to integrate nature and buildings, reuse sites that already have been impacted by human activities, and minimize disturbances caused by the building project.

Land Use Issues

The selection of a building site is generally the purview of the building owner, but often it may be affected by input from members of the project team. Rinker Hall at the University of Florida in Gainesville, a green building that achieved a gold certification under the US Green Building Council (USGBC) Leadership in Energy and Environmental Design (LEED) rating system, originally was slated for construction in an open space on the campus that had previously provided environmental amenity and recreation. However, following interaction between the project user group and the university administrators, the building was relocated to a plot of used land—in this case, a parking lot. The general population of the university benefited by this move in that it did not lose the environmental amenity of the open space. As it turned out, Rinker Hall's new location was a far more prominent site than its original location. One of the most important green measures in siting a new building is to locate it where the need for automobiles is minimized while conserving open space and amenities. Consequently, urban locations reasonably close to mass transit are highly desirable. In some cases, additional discussion with local government and the local transit authority may be required to articulate the need for bus service to what would otherwise be a good location for the facility.

In this section, several issues related to land use and siting are covered: the loss of prime farmland; building in 100-year-flood zones; using land that is habitat for endangered species; and reusing brownfields, grayfields, and blackfields. These topics are addressed in the USGBC LEED and the Green Globes building assessment standards.

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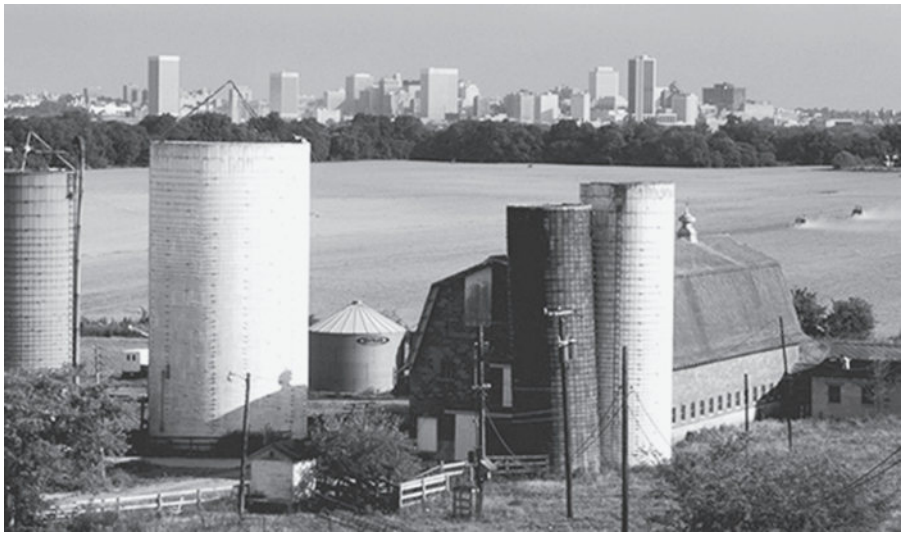


Figure 8.1 In the United States, farmland is being lost at the rate of 2 acres (0.8 hectare) per minute, with the most fertile, productive land being lost most rapidly. Farms abutting urban areas, as shown here, are especially threatened by land development and urban sprawl.

LOSS OF PRIME FARMLAND

In addition to addressing concerns over the loss of ecosystems, the green building effort considers the loss of agricultural land that, although impacted by human activities, is an important renewable resource (see Figure 8.1). Of the various categories of agricultural land, prime farmland is especially important to preserve. The US Department of Agriculture defines *prime farmland* as:

> land on which crops can be produced for the least cost and with the least damage to the resource base. Prime farmland has an adequate and dependable supply of moisture from precipitation or irrigation and favorable temperature and growing season. The soils have acceptable acidity or alkalinity, acceptable salt and sodium content, and a few rocks. They are not excessively eroded. They are flooded less often than once in two years during the growing season and are not saturated with water for a long period. The water table is maintained at a sufficient depth during the growing season to allow cultivated crops common to the area to be grown. The slope ranges mainly from 0 percent to 5 percent. To be classified as prime, land must meet these criteria and must be available for use in agriculture. Land committed to nonagricultural uses is not classified as prime farmland.[2]

In the 2012 and 2015 National Resources Inventory reports compiled by the American Farmland Trust, these observations about the impacts of development on the nation's farmland were made:

- Between 2002 and 2012, 44 million acres of land were newly developed, a 59% increase.
- Between 1982 and 2007, 41,324,800 acres of rural land (i.e., crop, pasture, range, land formerly enrolled in the Conservation Reserve Program, forest and other rural land) were converted to developed uses. This represents an area about the size of Illinois and New Jersey combined. During this same 25-year span, every state lost prime farmland.
- States with the biggest losses included Texas (1.5 million acres), Ohio (796,000 acres), North Carolina (766,000 acres), California (616,000 acres) and Georgia (566,000 acres).
- Between 2002 and 2007, 7,491,300 acres of rural land were converted to developed uses—an area nearly the size of Maryland. This amounts to an average annual conversion rate of 1,498,200 acres.

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- Our food is increasingly in the path of development. An astounding 91 percent of our fruit and 78 percent of our vegetables are produced in urban-influenced areas.
- Wasteful land use is the problem, not development itself. From 1982 to 2007, the U.S. population grew by 30 percent. During the same time period, developed land increased 57 percent.[3]

Redirecting development away from prime farmland is addressed in the USGBC LEED-NC and Green Globes building assessment standards and by the Sites program of the Sustainable Sites Initiative™ (SITES). In each case, these assessment systems are prioritizing the preservation of these valuable resources during the process of implementing green building projects.

GREENFIELDS, BROWNFIELDS, GRAYFIELDS, AND BLACKFIELDS

Greenfields are properties that have experienced little or no impact from human development activities. Greenfields also can be defined to include agricultural land that has had no activity other than farming. Like recycling in general, recycling of land is an important objective in creating high-performance green buildings. *Land recycling* refers to reusing land impacted by human activities instead of using greenfields. There are at least three identifiable categories of potentially recyclable land: brownfields, grayfields, and blackfields.

The US Environmental Protection Agency (EPA) defines brownfields as abandoned, idled, or underused industrial and commercial facilities where expansion or redevelopment is complicated by real or perceived environmental contamination.[4] The official definition of a brownfield site, according to Public Law 107-118 (H.R. 2869), the Small Business Liability Relief and Brownfields Revitalization Act, signed into law January 11, 2002, is: "With certain legal exclusions and additions, the term 'brownfield site' means real property, the expansion, redevelopment, or reuse of which may be complicated by the presence or potential presence of a hazardous substance, pollutant, or contaminant." The key word in the first definition is *perceived*; the key phrase in the second is *potential presence.* Former industrial properties often are thought to be contaminated because of the activities that occurred on the site—for example, metal plating or leather tanning. In fact, not infrequently, these properties are fairly clean, requiring minimal cleanup. In many US cities, brownfields are now valuable real estate because of their proximity to extensive infrastructure and a potential workforce. Industries that formerly fled to greenfields outside urban areas, thereby causing impoverishment of minority communities due to job loss, are returning to former industrial sites because the economics dictate the return to the city. A prime example of the potential success of a well-developed brownfields strategy is the Chicago Brownfields Initiative, which since 1993 has been assisting in the cleanup and transfer of 12 major former industrial sites in the city. An interesting aspect of the Chicago strategy has been to emphasize the return of these zones to industrial use, thus bringing jobs back into the city.[5]

The LEED and Green Globes building assessment systems and SITES provide credit for the use of a former brownfield as a building site. According to a USGBC credit ruling on brownfields, the project team can consider a site not officially designated a brownfield by the EPA if the team can convince the EPA that the site fulfills the requirements of a brownfield and the EPA agrees in writing.

Grayfields, another form of urban property, can be defined as blighted or obsolete buildings sitting on land that is not necessarily contaminated (see Figure 8.2).

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Figure 8.2 Grayfields are urban properties that are underperforming or declining in value for technological, economic, or social reasons. Strip malls throughout the United States, such as the one shown here, often become outmoded, and their tenants move on to larger facilities or to more profitable locations. Potential outcomes are blighted areas and impacts on the local economy and property values, creating challenges for local government.

The term *grayfield* is actually an expanded definition of *brownfield.* The state of Michigan, for example, embeds the term *grayfield* in the concept of *core community*, areas that are economically blighted and need investment to restore them to economic health. A grayfield could be a former machine shop that has become obsolete perhaps because it lacks a fire suppression system, had a septic system and old fuel tanks, or contains asbestos. Boarded-up housing can be an indication of a grayfield. The Congress for the New Urbanism (www.cnu.org) points out that former or declining malls can be classified as grayfields because they occupy impacted land that can be returned to productive use. Declining malls are caused by a number of factors: population shifts, increasing numbers of big-box stores, surging online purchases, changing demographics, and a failure of developers to reinvest in upgrades and modernization of older malls. Changes in the retail environment are also affecting the big-box stores as they continue to increase the size of their facilities. Larger abandoned big-box stores are now referred to as *ghost boxes.* Some of the strategies communities are using to deal with these types of properties are:

- *Adaptive reuse.* Turning ghost boxes into office space, entertainment space, or space for light manufacturing.
- *Demalling.* Reversing storefronts to face the street; converting the property to give it a "Main Street" look; and making connections to nearby housing, using pedestrian-friendly planning.
- *Razing and reuse.* Older malls are being demolished to make room for new retail developments.
- *Passing community ordinances to prevent future grayfields and ghost boxes.* Some communities are setting a maximum size for big-box stores or requiring that an escrow account covering future demolition costs be established for the construction of a big-box store.

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Both grayfields and brownfields are becoming valuable properties because of the presence of good infrastructure in urban areas; a trend toward urban living prompted by a perceived higher quality of life; and incentives offered by local and state governments in the form of tax rebates, tax credits, tax increment district financing, and other innovative strategies. In addition to access to infrastructure and a willing workforce for business, cities ultimately receive far greater tax revenues, creating a true win–win scenario. Although grayfields are not explicitly addressed in either LEED-NC or Green Globes, credits and points are awarded for building in a dense urban environment.

Yet another category of blighted land is *blackfields.* These properties are abandoned coal mines and are found in former coal-mining areas such as eastern Pennsylvania, where abandoned strip mines and subsurface mines comprise an area three times the size of Philadelphia and which will require an estimated $16 billion to clean up. Surface waters in these zones have a very low pH and are contaminated with iron, aluminum, manganese, and sulfates. The term *blackfields* also can be considered as an expanded definition of *brownfields.* There is a potential for obtaining LEED-NC points for using a blackfield for a building project.[6]

BUILDING IN 100-YEAR-FLOOD ZONES

Clearly, buildings should not be constructed in flood-prone areas, due to the high potential for disasters that result not only in human suffering but also in enormous environmental and resource impacts caused by the cycle of destruction and rebuilding. This is such a vital matter that the Federal Emergency Management Agency (FEMA) has become deeply involved in issues of flood mapping and insurance. Specifically, in support of the National Flood Insurance Program (NFIP), FEMA has undertaken a massive program of flood hazard identification and mapping to produce Flood Hazard Boundary Maps, Flood Insurance Rate Maps, and Flood Boundary and Floodway Maps. Several areas of flood hazards are identified on these maps. One of these areas is the *special flood hazard area* (SFHA), which is defined as an area of land that would be inundated by a flood having a 1 percent chance of occurring in any given year (previously referred to as the *base flood* or *100-year flood*). The 1 percent annual chance standard was decided after considering various alternatives. The standard constitutes a reasonable compromise between the need for building restrictions to minimize potential loss of life and property and the economic benefits to be derived from floodplain development. Development may take place within the SFHA, provided that it complies with local floodplain management ordinances, which must meet the minimum federal requirements. Flood insurance is required for insurable structures within the SFHA to protect federally funded or federally backed investments and assistance used for acquisition and/or construction purposes within communities participating in the NFIP.[7]

Before continuing with this discussion, it is important to point out that the term *100-year flood* is misleading. It is not the flood that will occur once every 100 years; rather, it is the flood *elevation* that has a 1 percent chance of being equaled or exceeded each year. Thus, the 100-year flood could occur more than once in a relatively short period of time. The 100-year flood, which is the standard used by most federal and state agencies, is also used by the NFIP as its standard for floodplain management and to determine the need for flood insurance. A structure located within an SFHA shown on an NFIP map has a 26 percent chance of suffering flood damage during the term of a 30-year mortgage.

To earn points when attempting to certify a green building using either LEED or Green Globes, the elevation of the building site must be at least 5 feet (1.52 m) above the 100-year floodplain.

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THREATENED AND ENDANGERED SPECIES

Passed in 1973 and reauthorized in 1988, the Endangered Species Act (ESA) regulates a wide range of activities affecting plants and animals designated as endangered or threatened. By definition, an *endangered species* is an animal or plant listed by regulation as being in danger of extinction. A *threatened species* is any animal or plant that is likely to become endangered within the foreseeable future. A species must be listed in the *Federal Register* as endangered or threatened for the provisions of the act to apply.

The ESA prohibits these activities involving endangered species:

- Importing into or exporting from the United States
- Taking (which includes harassing, harming, pursuing, hunting, shooting, wounding, trapping, killing, capturing, or collecting) within the United States and its territorial seas
- Taking on the high seas
- Possessing, selling, delivering, carrying, transporting, or shipping any such species unlawfully taken within the United States or on the high seas
- Delivering, receiving, carrying, transporting, or shipping in interstate or foreign commerce in the course of a commercial activity
- Selling or offering for sale in interstate or foreign commerce

The ESA also provides for protection of critical habitat (habitat required for the survival and recovery of the species) and creation of a recovery plan for each listed species.

The US Fish and Wildlife Service reported these statistics for endangered and threatened species in the United States, as of January 2016:

- 692 US species of animals are listed.
- 898 US species of plants are listed.
- 84 US species of plants and animals currently are proposed for listing.

As is the case with construction within a 100-year-flood zone, LEED and Green Globes do not provide credit if the project site is on land identified as habitat for species that are on state or federal lists of threatened or endangered species.

SOIL EROSION AND SEDIMENT CONTROL

Sediment is eroded soil that is suspended, transported, and/or deposited by moving water or wind. *Erosion* is the process of displacing and transporting soil particles by the action of gravity. Some general principles and best management practices that should be used in sediment and erosion control are indicated in Table 8.1.

For high-performance green buildings, care must be taken to ensure that soil loss is minimized. The construction manager and subcontractors must pay attention to soil loss in the form of airborne dust and stormwater runoff. Additionally, the contemporary green building delivery system requires that measures be put in place to prevent the sedimentation of both stormwater systems and receiving water bodies. An erosion and sedimentation control plan is a prerequisite for certification under LEED-NC, meaning that this plan is required for the building to be considered for even the lowest level of certification. Green Globes awards a range of points for erosion and sedimentation control measures. Similarly, SITES awards credit for minimizing soil disturbance during construction.

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TABLE 8.1

Principles and Best Practices for Sedimentation and Erosion Control
Design the project to fit the site's context: its topography, soils, drainage patterns, and natural vegetation.
Minimize the area of construction disturbance and limit the removal of vegetative cover.
Remove viable topsoil for temporary stockpiling and reuse when the landscape is installed.
Reduce the duration of bare-area exposure by scheduling construction such that bare areas of the site are exposed only during the dry season or for as short a time as possible.
Decrease the amount of bare area exposed at any one time.
Shield soil from the impact of rain or runoff by using temporary vegetation, mulch, or groundcover on exposed areas.
Divert run-on and runoff water away from exposed areas.
Prevent off-site runoff from entering the site.
Inspect and maintain the erosion and sediment control practices that have been put in place.
Use vegetative buffer strips, mulching and temporary seeding, surface roughening, erosion control blankets, permanent vegetation, and gravel-surfaced construction areas for erosion control.
Use silt fences, fiber wattles, and logs; check dams in swales, sediment traps and basins, detention/retention ponds, and silt filters/inlet traps for sedimentation control.
Where high winds are likely to transport soil, use sand or wind fences as a barrier to soil movement.
When restoring or replacing soil, use native soil from nearby so that type, composition, microbes, and hydrologic characteristics are compatible with the region and are suitable for plants that will be used, especially native or adapted plants of the region.

Sustainable Landscapes

The advent of high-performance green buildings is causing noteworthy changes to the traditional notion of the constructed landscape. Landscape design typically has been an afterthought in the conventional building delivery system, and in many cases, it is given very low priority. As funding for a project becomes tighter near the end of construction, the budget for the constructed landscape is likely to be reduced to the bare minimum. The outcome of such conventional thinking is that landscape design is given short shrift, treated *apart* from the building rather than as *integral* to it. Today, the role of landscape design in high-performance building is in a state of transition; some projects treat it conventionally, while others realize that the role of the site is critical to the performance of the buildings, both individually and collectively. Among these new roles for landscape design are assisting in building heating and cooling, helping control stormwater and eliminate stormwater infrastructure, treating waste, providing food, and contributing to biodiversity.

The concept of *sustainable landscape* predates the contemporary high-performance green building movement. The term emerged in the vocabulary of landscape architecture in 1988, when the Council of Educators in Landscape Architecture defined it as landscapes that contribute

> to human well-being and at the same time are in harmony with the natural environment. They do not deplete or damage other ecosystems. While human activity will have altered native patterns, a sustainable landscape will work with native conditions in its structure and functions. Valuable resources—water, nutrients, soil, etc.—and energy will be conserved, diversity of species will be maintained and increased" (Thayer 1989, p. 101)

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The movement to reconsider the role of landscape architecture was initiated by John Tillman Lyle with the publication of his 1985 book, *Design for Human Ecosystems: Landscape, Land Use, and Natural Resources.* It was almost a decade, however, before more was heard on the subject of sustainable landscapes. In 1994, two volumes appeared, coincidentally at the onset of the American green building movement: Robert Thayer's *Gray World, Green Heart: Technology, Nature and the Sustainable Landscape*, and another book by Lyle, *Regenerative Design for Sustainable Development.*

In *Design for Human Ecosystems*, Lyle considered how landscape, land use, and natural resources could be shaped to make the human ecosystem function in the sustainable ways of natural ecosystems. He suggested that designers must understand ecological order and how it operates at a wide variety of scales, from minute to global. The understanding of ecological order has to be linked with human values in order to develop solutions that are long-lasting, beneficial, and responsible.

In *Gray World, Green Heart*, Thayer (1994) noted that landscape is the place where "the conflict between technology and nature is most easily sensed." A sustainable landscape, according to Thayer, would have these properties:

- An alternative landscape where natural systems are dominant
- A landscape where resources are regenerated and energy is conserved
- A landscape that allows us to see, understand, and resolve the battle between the forces of technology and nature
- A landscape where essential life functions are undertaken, revealed, and celebrated
- A landscape where the incorporated technology is sustainable, the best of all possible choices, and can be considered part of nature
- A landscape that counters the frontier ethic of discovery, exploitation, exhaustion, and abandonment with one where we plant ourselves firmly, nurture the land, and prevent ecological impoverishment
- A landscape that responds to the loss of place with reliance on local resources, celebration of local cultures, and preservation of local ecosystems
- A landscape that responds to the view that landscape is irrelevant by making the physical landscape pivotal to our existence

Thayer admitted that this vision was utopian but suggested that such a vision is needed to give us direction. He went on to list five characteristics of a sustainable landscape that are based on the function and organization of natural landscapes:

1. Sustainable landscapes use primarily renewable, horizontal energy[8] at rates that can be regenerated without ecological destabilization.
2. Sustainable landscapes maximize the recycling of resources, nutrients, and by-products, and produce minimum waste or conversion of materials to unusable locations or forms.
3. Sustainable landscapes maintain local structure and function and do not reduce the diversity or stability of the surrounding ecosystems.
4. Sustainable landscapes preserve and serve local human communities rather than change or destroy them.
5. Sustainable landscapes incorporate technologies that support these goals and treat technology as secondary and subservient, not primary and dominant.

As a cautionary note, Thayer (1994) also stated: "Without sustainable values, landscapes designed to be sustainable will be misused, become unsustainable, and

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fail." Contemporary American culture does not have a sense of, nor does it value, place, and it is oriented toward consumption, profit, and waste. Creating a sustainable landscape in the face of these values is challenging but necessary to at least launch a countermovement that values nature and ecosystems and that helps increase human awareness of their role in daily life (see Figure 8.3).

In *Regenerative Design for Sustainable Development*, Lyle (1994) introduced designers of the built environment to the concept of regenerative landscape, reminding them, as John Dewey did in 1916, that "the most notable distinction between living and inanimate things is that the former maintain themselves by renewal" (Dewey, [1916] 1944, p. 1) Lyle maintained that the developed landscape—the one



Figure 8.3 (A) The landscape design for NASA's Space Life Sciences Laboratory at Kennedy Space Center in Florida is self-maintaining and was envisioned as a model of environmental site design, with over 60,000 square feet of native grasses and wildflowers. (B) The building orientation reduces heat load and minimizes encroachment into isolated wetlands. (Photos from Zamia Design, Inc.)

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created and built by humans—should be able to survive within the bounds of local energy and materials flows and that, in order to be sustainable, it must be *regenerative*, which, in the case of landscape, means being capable of *organic self-renewal.* Landscapes must be created using regenerative design (i.e., design that creates cyclical flows of matter and energy within the landscape). According to Lyle, a regenerative system is one that provides for continuous replacement, through its own functional processes, of the energy and materials used in its operation. A regenerative system has these characteristics:

- Operational integration with natural processes and, by extension, with social processes
- Minimum use of fossil fuels and man-made chemicals, except for backup applications
- Minimum use of nonrenewable resources, except where future reuse or recycling is possible and likely
- Use of renewable resources within their capacities for renewal
- Composition and volume of wastes within the capacity of the environment to reassimilate them without damage

Lyle gained considerable experience with regenerative landscapes as a professor at the one-acre Center for Regenerative Studies that he founded at California State Polytechnic University in Pomona, where faculty and students worked with regenerative landscapes and technology to try to solve the daily problems of providing shelter, food, energy, and water and dealing with waste. He and his students took what was then a compacted cow pasture within sight of a large landfill and created what a former center director, Joan Stafford, described as a landscape that "now yields armfuls of scented, exuberant lavender, sage, [and] rosemary, growing from rejuvenated soils" (Lyle 1999, p. v).

In Sustainable Landscape Construction: *A Guide to Green Building Outdoors*, J. William Thompson and Kim Sorvig (2000) provide a set of principles to guide landscape design and construction for green buildings. These principles are outlined in Table 8.2. In general, they are fairly straightforward and parallel the logic of LEED, which addresses many of these issues.

Some of the innovations emerging in today's high-performance green buildings include the application of landscaping directly to buildings in the form of green roofs, or living or eco-roofs, and the use of vertical landscaping, especially for skyscrapers. These two emerging landscaping concepts are described in the next sections.

GREEN, OR LIVING, ROOFS

A *green*, or *living*, *roof* is nothing more than an updated version of the ancient sod roof used in Europe that is making a comeback in today's green building movement. An alternative term used by some practitioners is *eco-roof.* The total area of green roofs in North America has been growing at a rapid pace, and in 2013 over 6.4 million square feet (595,000 m^2) of new green roofs were installed on buildings, an increase of 14 percent over the previous year. In the decade 2003–2013, the area of green roofs in North America increased tenfold. As of 2015, 33 cities in North America had policies, incentive programs, or guidelines for green roofs. This growth is propelled at least in part by the number of municipalities with policies or incentive programs that support green roof implementation. Over time, there has been a shift from prescriptive policies that specify technical details of the green roof, such as the growing medium, to performance policies focused on stormwater management objectives. In addition to their environmental benefits, green roofs can have strong positive economic impacts. A cost/benefit analysis conducted by

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TABLE 8.2

Principles of Sustainable Landscape Construction

Principle 1: Keep sites healthy. Ensure that biologically productive sites with healthy ecosystems are not harmed by the building project. Special attention must be paid to utility installation and road construction, which can be especially destructive to natural systems.

Principle 2: Heal injured sites. Using grayfields, brownfields, or blackfields reduces pressures on biologically productive sites and can result in restoration of blighted properties to productive ecosystems.

Principle 3: Favor living, flexible materials. Slope erosion can be controlled with living structures rather than artificial physical structures. Greenwalls, artificial structures that provide a support system for living matter, may be needed in especially steep terrain. Living materials on roofs create eco-roofs that provide additional green area and assist heating and cooling.

Principle 4: Respect the waters of life. Water bodies, including wetlands, should be protected and even restored. Rainwater can be harvested from roofs, stored in cisterns, and used for nonpotable applications. Landscape irrigation should be minimized and landscape designed to be durable and drought-tolerant.

Principle 5: Pave less. Paving destroys natural systems and should be minimized. Stormwater should be quickly infiltrated through the use of porous concrete and asphalt paving and through the use of pavers. Heat islands should be minimized by appropriate landscaping.

Principle 6: Consider the origin and fate of materials. Minimize the impact of landscape materials by carefully analyzing their embodied energy and other effects. Emphasize reused and recycled materials and avoid toxic materials.

Principle 7: Know the costs of energy over time. Landscape construction requires considerable energy in the form of work by machinery, the embodied energy of materials. The total energy consumption for all purposes, including maintenance, should be minimized.

Principle 8: Celebrate light, respect darkness. Landscape lighting should be accomplished such that plants are unaffected by lighting schemes, and lighting should be energy-efficient. Lighting should not spill over to areas where it is not wanted. Low-voltage lighting, fiber-optic lighting, and solar lighting should be considered.

Source: Thompson and Sorvig (2000).

the Philadelphia Water Department showed that $2.4 billion over 25 years invested in the green infrastructure approach would have an equivalent cost of $8 billion for conventional stormwater treatment. The city of Philadelphia created a Green Roof Tax Credit program that provides up to 25 percent of all costs incurred to construct a green roof to a maximum of $100,000 per project (Green Roofs 2014; Liu 2015; Rugh and Liu 2014) A wide variety of both public and private now have green roofs (see Figure 8.4). In Dearborn, Michigan, the Ford Motor Company has a 10-acre (4 hectare) living roof on its Rouge Center assembly plant; county buildings in Anne Arundel County, Maryland, also have grassy roofs.

Portland, Oregon, goes much further than most jurisdictions owing to the financial commitment the city has made to eco-roofs, in the form of tax breaks, grants, building code waivers, and the variety of private and public buildings with rooftop gardens (Flaccus 2002). Portland provides incentives for living roofs because they have been found to reduce building energy costs by 10 percent and to decrease summer roof temperatures by 70°F (21°C); furthermore, these roofs can reduce storm runoff by 90 percent and delay the flow of stormwater for several hours, thereby reducing the probability of stormwater and sewer system overflow. In an area like Portland, which suffers chronic stormwater and sewage system overflows that affect the Willamette and Columbia Rivers, an extensive array of eco-roofs on buildings may help mitigate this problem. Living roofs also can filter pollution and heavy metals from rainwater and help protect the regional water supply.

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Figure 8.4 A roof garden on the Chicago City Hall containing over 20,000 plants and more than 150 species. (*Source:* City of Chicago)

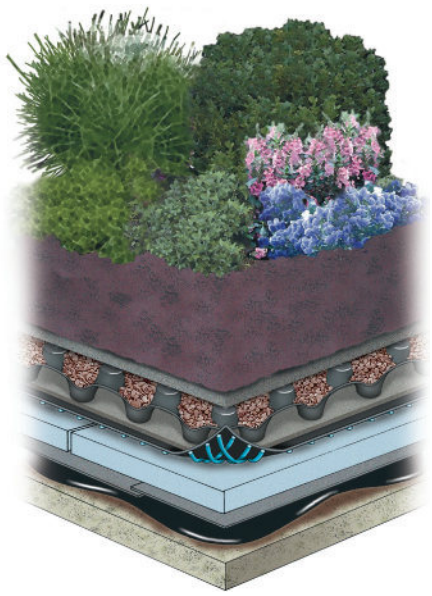


Figure 8.5 Cross section of an extensive eco-roof system that provides structure and drainage. (Image courtesy of American Hydrotech, Inc.)

An eco-roof can fulfill several distinct roles: serving as an aesthetic feature, helping the building blend into its environment, and supporting climatic stabilization. An eco-roof is particularly useful in wet, snowy areas but has more limited potential in dry climates. Green roofs must be built on a sufficiently strong frame with carefully applied waterproofing, because it is very difficult to locate leaks once the growing medium is in place. The living aspect of the roof is a compost-based system, usually composed of a base of straw that is left to decompose, within which native or introduced plants can then take root. As might be expected, a living roof requires ongoing care; another disadvantage is that it could be a fire hazard in hot, dry climates. In contrast, it is advantageous in that it protects the waterproofing from damage by ultraviolet radiation, and it precludes the need for tiles or other shingles.

According to the Living Systems Design Guild, green roofs are generally classified as either *extensive* or *intensive*:

Extensive eco-roof systems. Extensive landscaped roofs are defined as low-maintenance, drought-tolerant, self-seeding vegetated roof covers that incorporate colorful sedums, grasses, mosses, and meadow flowers that require little or no irrigation, fertilization, or maintenance (see Figure 8.5). The types of plants suitable for extensive landscaping are those native mainly from locations with dry and semidry grassy conditions or with rocky surfaces, such as an alpine environment. Extensive systems can be placed on low-slope and pitched roofs with up to a 40 percent slope.

Intensive eco-roof systems. If there is adequate load-bearing capacity, it is possible to create actual roof gardens on many buildings. This type of eco-roof system may include lawns, meadows, bushes, trees, ponds, and terraced surfaces. Intensive systems are far more complex and heavy than extensive eco-roof systems and hence require far more maintenance.

Eco-roof systems are made up of 6–10 individual components, as shown in Table 8.3. The soil substrate differentiates the extensive from the intensive system.

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TABLE 8.3

Components of Eco-Roof Systems

Plants. Extensive eco-roof systems include shallow root systems; regenerative qualities; and resistance to direct radiation, drought, frost, and wind. A much larger variety of plant selections is available for intensive roofscapes due to their greater soil depths.
Soil mix. The planting mix is a specially formulated, lightweight, moisture-retaining mix that is enriched with organic material.
Filter fabric. The filter fabric prevents fine particles from being washed out of the substrate soil, ensuring efficiency of the drainage layer.
Water retention layer. This layer is sometimes used, commonly in the form of a fabric mat, to provide mechanical protection and retain moisture and nutrients. Profiled drainage elements retain rainwater for dry periods in troughs or cups on the upper side of this layer.
Drainage layer. Eco-roofs must have a drainage layer to carry away excess water; on very shallow, extensive eco-roofs, the drainage layer may be combined with the filter layer.
Root barrier. The root barrier prevents roots from affecting the efficiency of the waterproofing membrane in case it is not root-resistant.
Waterproof membrane. An eco-roof system may consist of a liquid-applied membrane or a specially designed sheet membrane.
Insulation layer. An insulation layer is optional and prevents water stored in the eco-roof system from extracting heat in the winter or cool air in the summer.

Source: As described on the website of Living Systems Design, www.livingsystemsdesign.net/.

The extensive system has a soil substrate of 4–6 inches (10–15 centimeters [cm]) of formulated, lightweight growing medium, whereas an intensive system may have as much as 18–24 inches (46–61 cm) of a heavier soil mix.

As should be obvious from this discussion, an eco-roof is far more complex than a conventional roof and requires significantly more research and planning. Additionally, eco-roofs generally cost twice as much as conventional roofs, or $10–$15 per square foot ($107–$162 per m^2). However, the payback due to energy savings alone can be fairly rapid, and the benefits of reduced stormwater infrastructure and natural water cleaning make eco-roofs an attractive option.

VERTICAL LANDSCAPING

The French designer Patrick Blanc is generally considered to have developed the notion of a *vertical garden* or *green wall* that takes advantage of vertical surfaces to provide buildings with some degree of ecological capacity. Skyscrapers are not normally thought of as candidates for landscaping. However, Ken Yeang, a Malaysian architect, has been advocating what he calls *vertical landscaping* to at least in part render these very large structures green. He also advocates vertical landscaping for reducing energy consumption, stating that a 10 percent increase in vegetated area can produce annual cooling load savings of 8 percent. He described vertical landscaping as "greening the skyscraper" (Yeang 1996), which he said involves introducing plants and ecosystem components at a high level, in addition to the ground-level landscaping.

The vertical landscape creates a microclimate at the façade on each floor, can be used as a windbreak, absorbs carbon dioxide and generates oxygen, and improves the well-being of occupants by providing greenery throughout the building (see Figure 8.6). This strategy also helps counterbalance the enormous mass of concrete, glass, and steel with plants and soil. In addition to these benefits, a vertical landscape that is well integrated with the building can provide architectural visual relief from otherwise uninteresting, nondescript surfaces. In order for the vertical

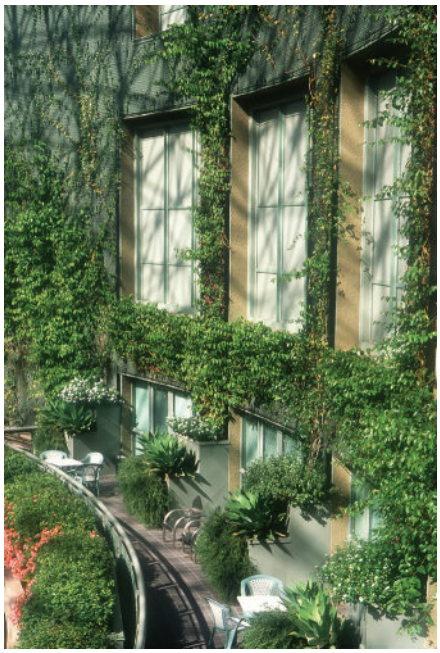


Figure 8.6 A vertical landscape at Universal City Walk in Universal City, California, provides a changing evergreen façade, which extends to a height of 75 feet (23 m). (Image courtesy of Greenscreen) (Photograph courtesy of Greenscreen®)

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landscaping to make visual sense, Yeang suggested that a series of stepped and linked planter boxes be designed into the building. The use of trellises also allows for vertical growth and interaction of the landscape from ground level to the roof. But because wind speeds at roof level often are twice their ground-level speed, plants at upper levels may need protection, which can be provided by side louvers that allow the landscape to be seen yet deflect the wind from around the plants.

Enhancing Ecosystems

A desired outcome of any building project would be a landscape and an ecosystem that are regenerated and improved as a consequence of the project. *Environmental Building News* (*EBN*) provides a checklist for owners and designers to use in helping restore the vitality of natural ecosystems (see Table 8.4). Although directed primarily at enhancing the presence of wildlife on a site, it is very useful for general ecosystem restoration or to regenerate or reconnect system components.

TABLE 8.4

***EBN* Checklist for Wildlife Habitat Enhancement of Developed Land**

1. **Research and Planning**
   Hire a qualified consultant specializing in natural landscaping and ecosystem restoration. Test soils for contaminants. Inventory existing ecosystems.
   Research ecosystems that may have been on the site prior to European settlement. Inventory current landscape management practices. Develop an ecosystem restoration plan.

2. **Ecosystem Restoration**
   Reduce turf area.
   Eliminate invasive plants.
   Establish native ecosystems.
   Ensure diversity in plantings.
   Provide wildlife corridors.
   Use bioengineering for erosion control.

3. **Enhancements for Wildlife**
   Select native plant species that attract wildlife.
   Encourage birds to "plant" seeds of species they like.
   Provide edible landscaping. Provide "edge" areas.
   Establish a bird feeding program, if desired.
   Provide bird nesting boxes and platforms.
   Provide bat houses.
   Provide water features.
   Avoid chemical usage in the landscape.

4. **Helping People Appreciate Natural Areas and Wildlife**
   Provide wildlife viewing areas.
   Provide easy and inviting access to the outdoors.
   Provide for easy management of bird feeders and nesting boxes.
   Provide clear signage in public spaces.
   Provide features that will get people outside.

Source: Excerpted from *Environmental Building News* (February 2001), pp. 8–12. The original checklist provides a detailed description of each of the points in the table. *EBN* is a publication of Building Green, Inc., www.buildinggreen.com.

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Stormwater Management

Transforming the natural environment by development dramatically affects the quantity and flows of stormwater across the surface of the Earth. Covering natural landscapes with buildings and infrastructure replaces largely pervious surfaces with impervious materials, thereby increasing the volume and velocity of horizontal water flows. Moreover, these same construction activities can modify or destroy ecosystems, most prominently wetlands, which function to absorb pulses of stormwater and return it in a controlled manner to bodies of water and aquifers. One of the functions of green building is to address the issue of stormwater management by protecting ecosystems and the pervious character of the landscape as well as to carefully consider how to affect as little as possible the site's natural hydroperiod. *EBN* provides a useful checklist for dealing with stormwater issues; it is presented in Table 8.5.

TABLE 8.5

***EBN* Checklist for Stormwater Management**

Reduce the Amount of Stormwater Created

1. Minimize the impact area in a development.
2. Minimize directly connected impervious areas.
3. Do not install gutters unless rainwater is collected for use.
4. Reduce paved areas through cluster development and narrower streets.
5. Install porous paving where appropriate.
6. Where possible, eliminate curbs along driveways and streets.
7. Plant trees, shrubs, and groundcovers to encourage infiltration.

Keep Pollutants Out of Stormwater

8. Design and lay out communities to reduce reliance on cars.
9. Provide greens where people can exercise pets.
10. Incorporate low-maintenance landscaping.
11. Design and lay out streets to facilitate easy cleaning.
12. Control high-pollution commercial and industrial sites.
13. Label storm drains to discourage dumping of hazardous wastes into them.

Managing Stormwater Runoff at Construction Sites

14. Work only with reputable excavation contractors.
15. Minimize the impact area during construction.
16. Avoid soil compaction.
17. Stabilize disturbed areas as soon as possible.
18. Minimize slope modifications.
19. Construct temporary erosion barriers.

Permanent On-Site Facilities for Stormwater Control and Treatment

20. Rooftop water catchment systems
21. Vegetated filter strips
22. Vegetated swales for stormwater conveyance
23. Check dams for vegetated swales
24. Infiltration basins
25. Infiltration trenches
26. Dry detention ponds with vegetation
27. Retention ponds with vegetation
28. Constructed wetlands
29. Filtration systems

Source: Excerpted from *EBN* (September/October 1994), pp. 1, 8–13. The original checklist provides a detailed description of each of the points in the table.

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Low-Impact Development

Low-impact development (LID) is a relatively new strategy that integrates ecological systems with landscape design to manage stormwater runoff effectively. LID techniques minimize runoff to prevent pollutants from adversely impacting water quality and can decrease the required size of traditional retention and detention basins, resulting in cost savings over conventional stormwater control mechanisms. LID can be applied to new development, redevelopment, or as retrofits of existing development. LID has been applied to a range of land uses, from high-density ultra-urban settings to low-density development. An alternative terminology being used by the EPA for LID is *green infrastructure.*

In general, the terms *LID* and *green infrastructure* refer to systems and practices of land development that use natural processes to infiltrate, evapotranspirate (return water to the atmosphere either through evaporation or by plants), or reuse stormwater runoff on the site where it is generated. LID employs principles such as preserving and re-creating natural landscape features, minimizing imperviousness, creating functional and appealing site drainage, and treating stormwater as a resource rather than as a waste product. Many practices can be used to implement LID, including bioretention facilities, rain gardens, vegetated roofs, rain barrels, and permeable pavements. By implementing LID principles and practices, water can be managed in a way that reduces the impact of built areas and promotes the natural movement of water within the system or watershed. Applied on an urban scale, LID can maintain or restore the watershed's hydrologic and ecological functions.

Another concept of LID in the urban setting is *artful rainwater design*. This idea is based on the premises that stormwater management techniques designed in conjunction with natural systems can provide site amenities with a strong aesthetic quality and even compel human interaction.

The LID approach to stormwater management is an enormous change from conventional practices, which historically divert stormwater through engineered conduit systems to natural water bodies or costly treatment plants. In contrast, the LID approach carefully considers the rate, volume, frequency, duration, and quality of discharge so as to allow for groundwater and aquifer recharge and the overall health of ecological systems.

The Nature Conservancy described six principles for successful LID. These are stated next and should be used to guide the design of a LID system:

1. *Use existing and valuable features.* Identify and work with all cultural and natural features that will immediately add value to the development: hedgerows, mature trees, wildlife habitats, streams, rural/architectural character, and heritage features.
2. *Let natural resources work for the project.* Use natural drainage by mimicking the existing systems and patterns. Minimizing construction disturbance and changes within the watershed will benefit the environment and reduce costs.
3. *Increase the value of the site with open spaces.* Clustering homes or buildings in the development enables the provision of open spaces and scenic views. Connections to open spaces within a larger city network can provide natural amenity, resulting in higher property values.
4. *Reduce the size of the water management needs on the site.* By limiting impervious surfaces, the amount of stormwater infrastructure can be greatly reduced. Buildings with smaller footprints, green roofs, permeable pavement, and narrow roads make stormwater management manageable.

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5. *Treat stormwater close to the source.* Instead of expensive underground infrastructure, catch basins, piping, and stormwater ponds, use low-cost, low-maintenance, low-tech, nonstructural rain gardens and bioswales to infiltrate runoff.
6. *Smart landscaping can save money.* There is no question that good landscaping increases property values and that smart landscaping can also save money. Money is wasted on techniques such as clear-cutting, grading, and costly stormwater ponds that only address one problem. With a multifunctional landscape, it is possible to manage runoff, improve water quality, reduce power bills, increase property value, and save money.

The Nature Conservancy also described 10 implementation measures that can help manage runoff while at the same time providing a landscape with natural amenity. These 10 techniques are not meaningful individually but can be highly effective as part of a larger LID strategy:

1. *Impervious surface reduction.* Some techniques for reducing impervious surfaces include reducing the number of parking spaces, sharing parking with adjacent uses when possible, creating center landscape islands and cul-de-sacs, and reducing setbacks from the street to shorten driveway lengths.
2. *Tree preservation.* Not only do trees increase property value, but they are also excellent landscape features for the uptake of stormwater. Trees act as mini-reservoirs that absorb and store large quantities of water. They are excellent for controlling runoff at the source, reducing soil erosion, decreasing temperatures, absorbing carbon dioxide, and providing habitat for wildlife. A 12-inch-caliper oak tree can intercept roughly 2,000 gallons of rain per year while a 30-inch-caliper maple can intercept as much as 12,000 gallons a year.
3. *Reduce lawn area/increase planted areas.* Lawns require a lot of watering, mowing, aerating, and chemicals and are not effective at absorbing water. Native grasses, shrubs, trees, and wildflowers are excellent species for absorbing stormwater. As is the case with trees, increasing the size of planting areas can result in higher property values while at the same time enhancing biodiversity.
4. *Bioswales and vegetated swales.* Bioswales assist in capturing rainwater runoff and then filter the runoff through prepared soil medium with suitable plants. They are ideal for median strips and parking lots along streets. The preferred depth of a bioswale is about 6 inches and with an overall size of 25×50 feet.
5. *Permeable pavement.* A wide range of permeable pavements are available, including interlocking pavers, grass pavers, porous asphalt, and porous concrete. These materials allow water to permeate the surface to an underlying stone or sand bed.
6. *Buffers and filter strips.* Buffers and filter strips are barriers between surfaces such as roads and parking lots, and waterways and sensitive aquatic environments. These buffers contain trees, bushes, wild grasses, and other natural plant species to remove particulates and other pollutants from stormwater crossing between the paved surfaces and sensitive bodies of water. Buffers can be linked to create a network of green infrastructure and provide opportunities and benefits to wildlife corridors. These buffers are also referred to as *conservation easements* and, like many other components of LID, can contribute to the present value of a property.

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7. *Rain gardens.* A rain garden is a shallow depression planted with suitable trees, shrubs, flowers, and other species to capture stormwater runoff from impervious areas. They can be used as a buffer to capture runoff from landscaped areas before it enters a lake, pond, or river.
8. *Soil quality management.* Active soils can create standing water if the surface is impenetrable. To prevent soils from being overly compacted, driving on wet soils beyond the parking area and over tree roots should be prevented.
9. *Green roofs.* Green roofs can absorb rainwater, provide insulation, create wildlife habitat, and reduce the heat island effect. [This chapter discusses the use of green roofs in high-performance green building projects.]
10. *Rain barrels and rainwater harvesting systems.* A rainwater collection system can help capture and store stormwater from the roof for future use, reducing stormwater flows and decreasing water costs.

LID strategies inevitably save money. Table 8.6 provides four examples of LID projects and the economic effects of taking this approach. Figures 8.7 to 8.9 illustrate several LID projects.



Figure 8.7 Designed in partnership with the Housing Authority of Seattle, Washington, this natural drainage system for the High Point neighborhood of West Seattle treats about 10 percent of the watershed feeding Longfellow Creek—one of Seattle's priority watersheds. The natural drainage system mimics nature in many ways by using features such as swales to capture and naturally filter stormwater and open, landscaped ponds or small wetland ponds to hold an overflow of stormwater. (Photo by Stuart Patton Echols)

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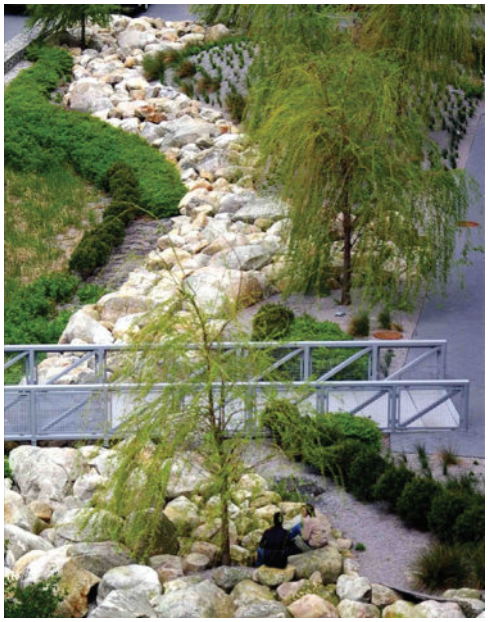


Figure 8.8 The stormwater bioretention system for the Stata Center, a Frank Gehry–designed building on the Massachusetts Institute of Technology campus in Cambridge, Massachusetts, is a multifunctional constructed wetland that detains runoff to reduce peak downstream flow. The plants and planting medium of the wetland clean the runoff and allow some groundwater infiltration. (Photo by Stuart Patton Echols)



Figure 8.9 The stormwater system design for Chambers, Washington, employs a long water trail that exhibits a variety of water treatments. These include a wetland and a lined bed with river stone and plants interspersed with pieces of driftwood to emphasize the water theme. (Photo by Stuart Patton Echols)

TABLE 8.6

Residential and Commercial Examples of LID Savings

Location	Description	LID Cost Savings
Madera Residential Subdivision, Gainesville, Florida	44-acre, 80-lot development, used natural drainage depressions instead of new stormwater ponds	$40,000, or $500 per lot
Gap Creek Residential Subdivision, Sherwood, Alaska	130-acre, 72-lot development, reduced street width and preserved natural topography and drainage networks	$200,021, or $4,819 per lot
OMSI Parking Lot Commercial Development, Portland, Oregon	6-acre parking lot, incorporated bioswales and reduced piping and catch basin infrastructure	$78,000, or $13,000 per acre
Tellabs Corporate Campus Commercial Development, Naperville, Illinois	55-acre site developed into office space, minimized site grading, preserved natural topography, eliminated storm sewer piping, and added bioswales	$564,473, or $10,623 per acre

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Heat Island Mitigation

An issue that is not normally considered in site and landscape design but that is a matter for consideration in high-performance green buildings is the *urban heat island effect.* Temperatures in cities are substantially higher than those in surrounding rural areas, usually in the range of 2° to 10°F (1°– 6°C) hotter (see Figure 8.10). The result is that cooling requirements for buildings in urban areas will be higher than for those in a rural setting. The additional energy required to support the higher cooling loads results in more air pollution, greater resource extraction impacts, and higher costs. Reducing or mitigating urban heat islands can counter these negative effects and result in a more pleasant urban lifestyle.

Heat islands are caused by the removal of vegetation and its replacement with asphalt and concrete roads, buildings, and other structures. The shading effect of trees and the evapotranspiration, or natural cooling effect, of vegetation are replaced by human-made structures that store and release solar energy.

According to the USEPA Heat Island Effect website (www.epi.gov/hiri/), in addition to their negative energy impacts, heat islands are problematic for these reasons:

- Heat islands contribute to global warming by increasing fossil fuel consumption by power plants.
- Heat islands increase ground-level ozone pollution by increasing the reaction rate between nitrogen oxides and volatile organic compounds.
- Heat islands adversely affect human health, especially that of children and older people, by increasing temperatures and ground-level ozone levels.

Heat island effects can be reduced by several measures:

- Installing highly reflective (or high-albedo) and emissive roofs that reflect solar energy back into the atmosphere
- Planting shade trees near homes and buildings to reduce surface and ambient air temperatures
- Using light-colored construction materials where possible to reflect rather than absorb solar radiation

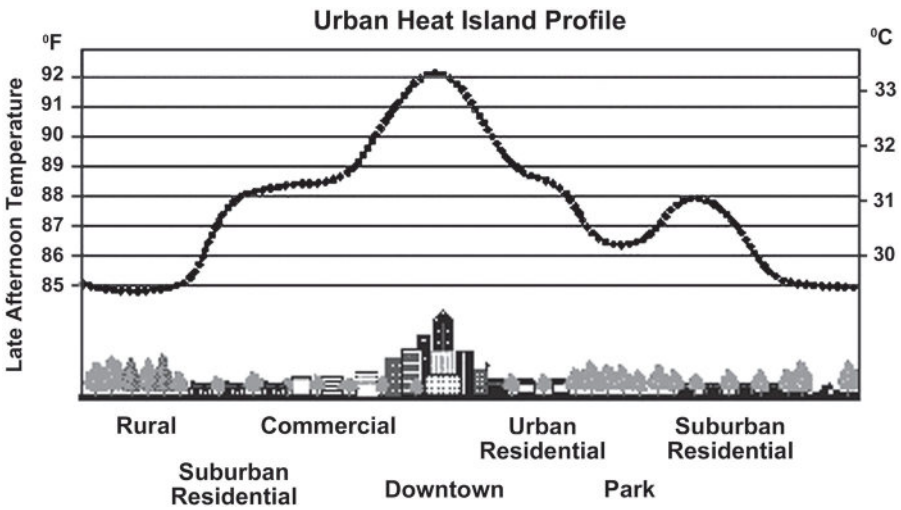


Figure 8.10 The removal of vegetation in urban areas and its replacement with buildings and infrastructure produces a heat island effect and results in urban temperatures that are 2° to 10°F (1°–5°C) higher than those in nearby rural areas. (Illustration by Bilge Çelik)

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The EPA launched the Urban Heat Island Pilot Project in 1998 to quantify the potential benefits of reducing heat islands. For the city of Sacramento, California, a Lawrence Berkeley National Laboratory study showed:

- Citywide energy bill reduction of $26.1 million per year, assuming high penetration of reduction measures
- Savings of 468 million watts of peak power and 92,000 tons (83,600 metric tons) of carbon annually
- An improvement in air quality caused by a decrease in ozone of 10 parts per billion
- Cooling-energy savings of 46 percent and peak power savings of 20 percent by increasing roof albedo, or reflectivity, on two school buildings

The LEED rating system provides points for mitigating heat islands in the Sustainable Sites category. For nonroof areas, LEED gives credit for creating shade or reducing heat islands for the site's impervious surfaces, such as parking lots, walkways, and plazas. Credit is also given for providing a high-albedo (high-reflectivity) or vegetated roof. Similarly, Green Globes awards points on a sliding scale, depending on how much of the project hardscape and roof area include heat island mitigation measures.

Light Trespass and Pollution Reduction

Exterior lighting systems on buildings frequently emit light that, in addition to performing their primary role of illuminating the buildings and their walkways and parking areas, illuminate areas off-site. This condition is sometimes referred to as *light trespass*, defined as unwanted light from a neighboring property. This unwanted light poses a number of problems, ranging from being a nuisance to causing safety problems when it "blinds" pedestrians and automobile drivers. Nuisance light also can negatively affect wildlife as well as human health, because it can interrupt normal daily light cycles that are needed for the average person's well-being. For example, chicken farmers have discovered that 24-hour lighting disturbs the growth of chicks. Bright lights can affect the migration patterns of birds and baby sea turtles.

Another negative lighting condition is *light pollution*, which prevents views of the night sky by the general population and astronomers. The solution to both light trespass and light pollution is proper lighting system design. The location, mounting height, and aim of exterior luminaires must all be taken into account to ensure that lighting energy is used efficiently and for its intended purposes. To prevent light pollution:

- Parking area and street lighting should be designed to minimize upward transmission of light.
- Exterior building and sign lighting should be reduced or turned off when not needed.
- Computer modeling of exterior lighting systems should be used to design exactly the level and quality of lighting needed to meet the project's requirements without straying off-site and causing undesirable conditions (see Figure 8.11).

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Figure 8.11 The exterior lighting system for Rinker Hall, a LEED-NC gold-certified building at the University of Florida in Gainesville, was designed to minimize light pollution. The result is a pleasant evening view of the building that enhances the experience of passersby. (Photograph courtesy of Gould Evans Associates and Timothy Hursley)

Assessment of Sustainable Sites: The Sustainable Sites Initiative

Building assessment systems, such as LEED and Green Globes, focus on the building as the object of assessment. The building site and its location typically are evaluated as part of the building assessment, and the site ecology, stormwater, landscaping, and other factors are considered in this process. However, a wide range of projects are not eligible for assessment by these well-known tools. For example, parking lots, athletic fields, plazas, streetscapes, and botanical gardens are just a few of the types of projects involving construction that do not necessarily involve a building. Also, open space requirements for developments often result in requirements for easements, buffer zones, and transportation rights-of-way. SITES was created to promote sustainable land development and management practices that can apply to sites with and without buildings, including the types of projects mentioned previously that are not routinely considered for environmental assessment along the lines of conventional building projects. SITES is a collaboration of the American Society of Landscape Architects, the United States Botanic Garden, and the Lady Bird Johnson Wildflower Center. The USGBC is an active stakeholder in the development of SITES, and some SITES credits have been incorporated into LEED. In a similar fashion, SITES has adapted some LEED credits into the current SITES v2 Rating System.

SITES is developing tools for those who influence land development and management practices to assist them in addressing increasingly urgent global concerns, such as climate change, loss of biodiversity, and resource depletion. These tools can be used by teams who design, construct, operate, and maintain landscapes, including planners, landscape architects, engineers, developers, builders, maintenance crews, horticulturists, governments, land stewards, and organizations offering building standards. The main objectives of SITES (2009) are to:

- Elevate the value of landscapes by outlining the economic, environmental, and human well-being benefits of sustainable sites

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- Connect buildings and landscapes to contribute to environmental and community health
- Provide performance benchmarks for site sustainability
- Link research and practice associated with the most sustainable materials and techniques for site development construction and maintenance
- Provide recognition for high performance in sustainable site design, development, and maintenance
- Encourage innovation

As part of a three-year-long stakeholder process, SITES engaged a wide variety of the country's leading sustainability experts, design professionals, and scientists and gathered public input from hundreds of individuals and dozens of organizations. The latest version of this cumulative effort was issued in 2012 in the form of an assessment tool, *SITES v2 Rating System for Sustainable Land Design and Development.* Since 2012, 46 projects have achieved SITES certification, including the Lady Bird Johnson Wildflower Center in Austin, Texas. The SITES guidelines and performance benchmarks offer four certification levels based on a four-star rating system, which works on a 200-point scale allocated among 48 credits. For certification, a project must achieve all 19 of the prerequisites and at least 100 credit points to become certified with a rating of up to four stars as shown next:

Certification Levels (200 Total Points)	
Certified	70
Silver	85
Gold	100
Platinum	135

The SITES v2 Rating system has emerged as a noteworthy assessment system that is especially important because it addresses construction projects that do not include buildings and for which there is no certification scheme. Additionally, it provides many areas of advanced thinking on site utilization, and its integration into the major building assessment systems in the United States will significantly improve the site and landscaping categories of these rating systems. An index of the SITES rating system, including its 19 prerequisites and 48 credits, can be found in Appendix B.

Case Study: Iowa Utilities Board/Consumer Advocate Office

With a lengthy name but an outstanding design that makes it one of the top high-performance green buildings of the last several years, the 44,640-square-foot (4,645 m^2) Iowa Utilities Board/Consumer Advocate Office (IUB/OCA) Building is a LEED Platinum building with a remarkably low energy use intensity of 28 kBTU/ft^2/year (64.2 kWh/m^2/year), a 60 percent reduction from the baseline energy code as defined by ASHRAE Standard 90.1–2004 (see Figure 8.12). At the onset of the design, BNIM and the other members of the project team, together with the owner, laid out four visionary goals that would guide the design of the facility to make it as sustainable as possible:

Visionary Goal 1: Minimize energy consumption
Visionary Goal 2: Serve as demonstration project
Visionary Goal 3: High performance on a modest budget
Visionary Goal 4: Monitoring building performance

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Figure 8.12 The IUB/OCA Building is on the grounds of the Iowa State Capitol in Ames, Iowa, and incorporates native prairie species as part of the site restoration, harking back to the area's predevelopment conditions. (Copyright Assassi, Courtesy of BNIM)

According to the architects, BNIM, the building was designed using a mix of innovative new strategies plus off-the-shelf approaches to maximize its performance while creating a very strong visual appeal. To accomplish this remarkable feat, the architects focused on integrated design and extensive computer modeling of every aspect of the building to assess all the available energy-efficiency opportunities. Optimal orientation with massing and a hyperefficient envelope with continuous insulation and other measures that eliminate thermal bridging and help modulate temperatures and reduce loads were a significant passive design strategy. A range of other energy-conserving features were employed, including geothermal heat pumps, an energy recovery unit, and a 45-kilowatt roof-mounted photovoltaic array. Also included in the design is a daylight harvesting system that is integrated with the building's low power density lighting system (0.75 watts per ft^2 [8.1 watts per m^2]) equipped with automated dimmers and occupancy sensors (see Figures 8.13 and 8.14).

Louvered sunscreens located on the south side of the building block summer heat and glare while allowing daylight indoors in a controlled fashion during the year (see Figure 8.15). Operable windows are common in the building, and 53 percent of all spaces are within 15 feet (4.6 m) of an operable window. The building automation system monitors outside conditions. When conditions are suitable for the windows to be opened or closed, the system emails occupants with instructions. The system also automatically shuts down zone heat pumps once windows are open to reduce energy loss.

Among the many remarkable strategies applied in this building was an absolutely strong focus on minimizing plug loads, which represent an ever-increasing fraction of an office building's energy consumption. The building was designed so that two types of plugs are available: one for critical equipment that has to run continuously, such as computers, and a second plug for everything else, which is then connected to occupancy sensors. Personal items, such as space heaters and refrigerators, were banned from being used in the building. An advanced building automation system was incorporated into the design for both controlling and monitoring the building's energy performance (see Figure 8.16)

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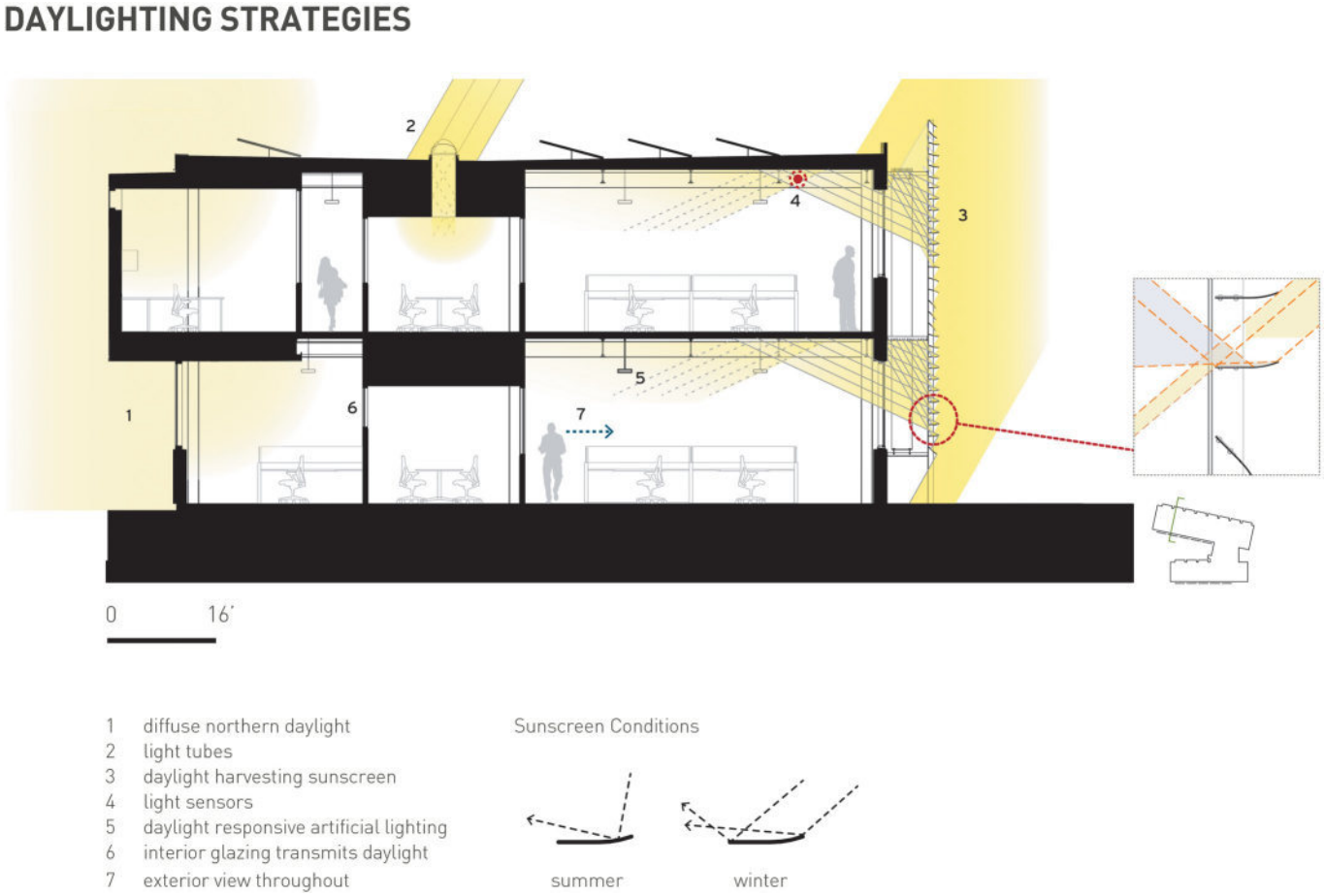


Figure 8.13 A comprehensive yet simple daylighting scheme harvests daylight from the north and south faces of the building and via solar tubes in the roof. Interior office and meeting rooms are also outfitted with windows to allow daylight penetration into offices and conference rooms located in the building's core. Coupled with occupancy and daylight sensors, the lighting strategy results in minimal artificial lighting. Just over 98 percent of the occupied spaces have adequate daylighting for common office tasks. (Copyright BNIM)



Figure 8.14 The daylight harvesting system functions at such a high level that it allows lights to be shut off during 98 percent of daytime hours. The operable windows provide local thermal comfort control and are also part of a cross-ventilation scheme activated by the building automation system, which emails occupants when conditions are suitable for opening windows. (Copyright Assassi, Courtesy of BNIM)

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Figure 8.15 The louvers on the south façade of the IUB/OCA Building contribute to the passive design of the facility by controlling solar glare and heat gain while admitting daylight. (Photo courtesy of iub.iowa.gov)

In addition to energy performance, the building also features high levels of performance in other green aspects. Potable water consumption was reduced 46 percent from baseline models. Integration of the building with local public transit and other multimodal transportation system components resulted in approximately 22 percent of the building occupants using public transit, cycling, or walking.

Iowa has significant issues with water quality and flooding. The IUB/OCA building is an opportunity to demonstrate sound approaches to stormwater management from both the project site and from adjoining sites. The stormwater system is comprised of a series of components including a stormwater interceptor, infiltration basin, rainwater gardens, bioswales, and pervious pavement (see Figure 8.17). Stormwater enters the landscape via sediment traps constructed of limestone that both help control erosion and slow down the water. The water then moves across the newly restored native prairie into infiltration basins planted with native grasses that remove suspended pollutants. The idea was to develop a replicable strategy that could be repeated across the state. The typical Iowa farm terraces were used as the model for this process of controlling water movement, with the additional benefit of moderating steeper slopes to slow down water flow. Water management inside the building was also important. The selection of low-flow fixtures and sensors reduces water consumption by 45 percent compared to a baseline office building.

Materials conservation was also given top priority in the design. As much as possible, all material elements serve at least two functions. The envelope was designed with white precast concrete as the main element, and thorough detailing eliminated thermal bridges at roof interfaces, foundation, and wall openings. A significant innovation was the development of details that permitted the installation of a continuous insulation wrap from the roof down to and around the underside of the foundation. Interior finishes were emissions free, and the precast panels were sandblasted on the interior to serve as the finished surface, eliminating the need for significant quantities of other materials, such as drywall. High levels of recycled content materials, on the order of 35 percent of the total materials value, were specified and utilized in the project. Attention was also paid to construction waste management with about 89 percent of the waste being diverted from being landfilled (see Figure 8.18).

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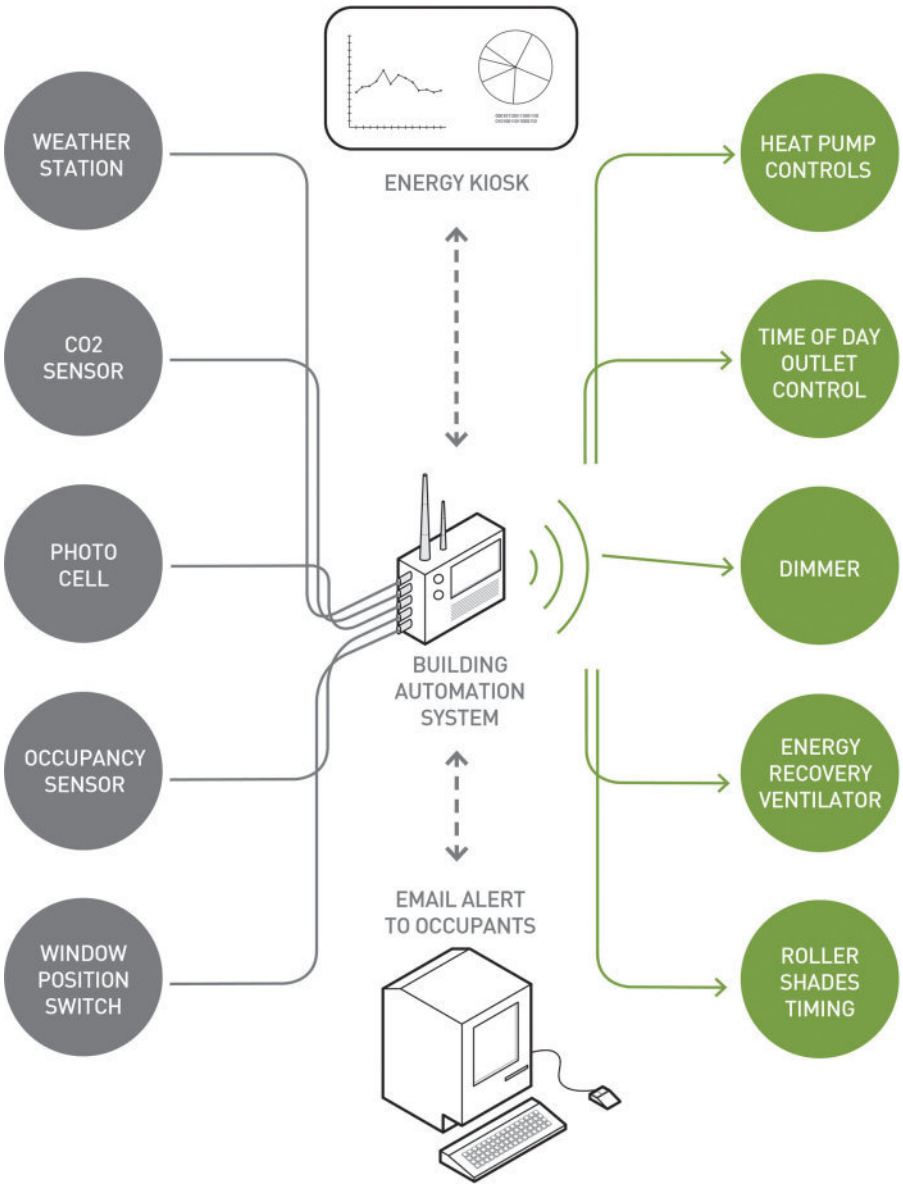
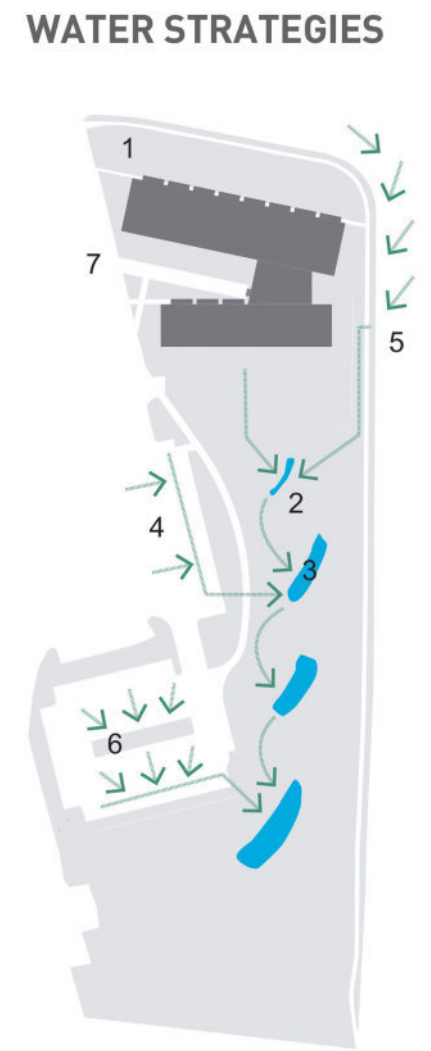


Figure 8.16 One of the visionary goals of the team designing the building was to monitor its performance. The building automation system not only measures performance but also optimizes energy consumption by controlling the blinds, energy recovery system, heat pumps, and plug loads. It even notifies the occupants by e-mail when conditions are suitable to open the building's operable windows. (Copyright © BNIM)



1. Rain Garden
2. Sediment Basin
3. Water Infiltration Basin
4. Pervious Pavement
5. Off-site Storm Diverter
6. Bioswale
7. On-street Parking (minimizes impervious surface)

Figure 8.17 A simple yet highly effective system of stormwater management mimics the natural flow of water across Iowa prairie. One purpose of including it in the IUC/OCA building was to demonstrate how stormwater could be better handled to both enhance native natural ecosystems and prevent flooding. (Copyright BNIM)

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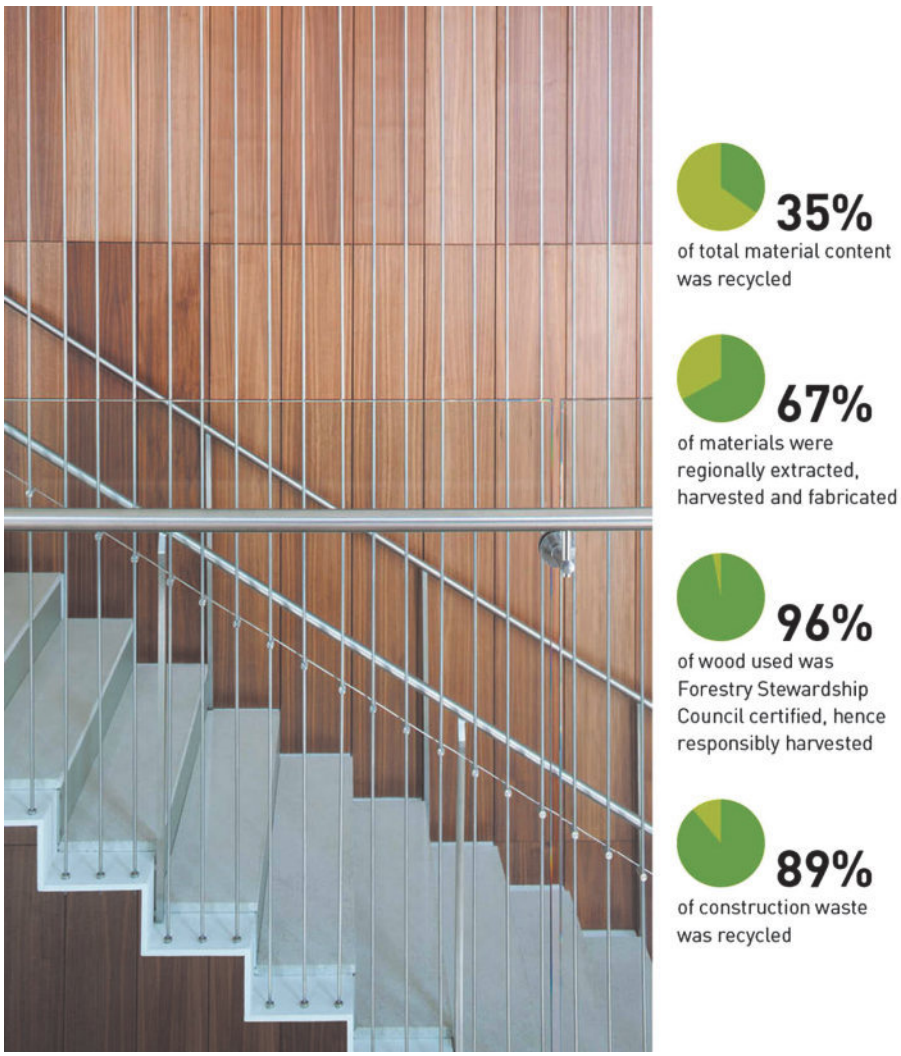


Figure 8.18 The materials strategy for the IUC/OCA Building minimized resource consumption, minimized waste, and promoted the responsible sourcing of products for the project. (Copyright Assassi, Courtesy of BNIM)

The IUC/OCA Building was selected as one of the American Institute of Architects' Committee on the Environment's Top 10 Green Projects in 2012 and has been successful in achieving the visionary goals set by the project team.

Summary and Conclusions

The most exciting and underutilized resources for creating high-performance green buildings are natural systems, and they should be employed as more than superficial components of the project. The ultimate green building will undoubtedly feature a much deeper integration of ecosystems with buildings, and exchanges of matter-energy between human systems and natural systems, in ways that are beneficial to both. The need to dramatically reduce building and infrastructure energy consumption will motivate designers to better understand the processing of waste by natural or constructed wetlands, which contribute to their sustainability and to that of the human systems with which they cooperate. Natural systems can shade and cool buildings yet allow sunlight through for heating during appropriate seasons. They also can provide calories and nutrition for people and may be able to take up large

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quantities of stormwater, thus allowing the downsizing of conventional stormwater handling systems.

The high-level integration of ecosystems and the built environment is slowly becoming a reality. But a future of high energy costs inevitably will force changes that decentralize many of the waste-processing functions currently performed at distant wastewater treatment plants to which building waste must be pumped, often through miles of piping, with motive energy provided by a series of lift stations. By integrating buildings with ecosystems, an alternative framework can be designed to ensure a future with a low energy profile. Although today's green building designers make only a minimal effort to use natural systems for anything other than amenities, in the future they will have much more detailed knowledge of ecology and ecological systems, enabling them to weave nature into the built environment.

Notes

1. France provides an insightful analysis of how landscape architecture must change to participate in ecological design. He points out the possibility of landscape as "functional art," most prominently in the form of wetlands that, in addition to being pleasing to the human eye, provide numerous services, such as stormwater uptake and wastewater processing. He adds that the shift to multifunctional wetlands is a success story for sustainable landscape architecture.
2. As defined by the US Department of Agriculture and listed on the website of the American Farmland Trust, www.farmland.org.
3. The 2010 and 2015 National Resources Inventory compiled by the American Farmland Trust is at www.farmlandinfo.org/statistics#National Resources Inventory.
4. The US EPA brownfields website is www.epa.gov/brownfields.
5. The Chicago Brownfields Initiative was a partnership of private and public sector institutions that advocates and assists in the conversion of formerly contaminated industrial zones to productive use.
6. The Eastern Pennsylvania Coalition for Abandoned Mine Reclamation has an excellent website that describes the extent of the problem with blackfields or abandoned mine properties: www.orangewaternetwork.org.
7. Detailed information about the NFIP, SFHA, and flood mapping can be found at the FEMA website, www.fema.gov/national-flood-insurance-program-flood-hazard-mapping.
8. According to Robert Thayer (1989), horizontal energy is low-intensity, widely dispersed, renewable energy in the form of sunlight, wind, water moving by tides or gravity, and energy fixed by plants. Horizontal energy is limited by its location and the rate of its natural generation, and landscape must exist within the limits of its availability.
9. Lawrence Berkeley National Laboratory has a website devoted to heat island issues: http://eetd.lbl.gov/newsletter/nl08/eetd-nl08-5-meteorology.html.

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Chapter 9

Low-Energy Building Strategies

Of all the challenges facing the development of high-performance green buildings, significantly reducing the energy and carbon footprints of the built environment is perhaps both the most important and the most daunting. This chapter addresses the design of low-energy buildings and strategies for carbon footprint reduction are covered in chapter 12. The environmental impacts of extracting and consuming nonrenewable energy resources, such as fossil and nuclear fuels, are profound. The major contribution to climate change—land impacts from coal and uranium mining, acid rain, nitrous oxides, particulates, radiation, ash disposal problems, and long-term storage of nuclear waste—are just some of the consequences of energy consumption by the built environment. Building energy consumption in the United States is at about the same scale as energy consumption by automobiles, with about 40 percent of primary energy being consumed by buildings and about the same quantity by transportation.[1] In fact, much automotive energy consumption is affected by the distribution of buildings on the landscape.

The rollover point for oil production—the point at which oil production will decline—has been delayed from its predicted peak in about 2010 due to the advent of fracking and, more recently, refracking.[2] Ultimately fossil fuel reserves are finite because the planet is finite in size and the rollover point is sure to occur at some point in time. Considerable additional energy and financial resources will be needed to extract Earth's fossil fuel resources. At the same time, economies around the world continue to grow, all of them dependent on abundant, cheap energy, none of them more so than the United States. H. T. Odum, the eminent ecologist who founded the branch of ecology known as *systems ecology*, forecasted that, at the rollover point, the energy required to extract the oil would be greater than its energy value.[3] Technological optimists who believe that an engineering solution always will be found to solve our energy, water, or materials problems have not yet found a cheap substitute for energy derived from fossil fuel. For the built environment, truly dramatic reductions in building energy consumption, accompanied by tremendous progress in passive design and the implementation of large-scale renewable energy systems, will be needed to meet a potentially costly energy future.

As we approach the day of reckoning when energy costs are likely to rise dramatically as a result of fierce international demand and competition, we still have time to make some very important decisions with respect to how we live and the types of buildings we create. The green building movement and allied efforts to improve building energy performance are attempting to influence a major shift in the way buildings are designed. A fundamental transformation must occur that involves a total rethinking of building design. Advocates of just such a radical change believe that buildings should be *energy-neutral* or even net *exporters* of energy. Advancing the use of solar energy, ground coupling, radiant cooling, and other radical approaches may indeed enable buildings to generate at least as much energy as they consume. In the interim, however, we must learn how to cut building energy use by a marked quantity, perhaps by as much as 90 percent—a daunting challenge, to be sure.

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Building Energy Issues

US energy demand is staggering, with Americans consuming 88 *quads* of primary energy in 2015. One quad alone is an enormous unit of energy, equaling 1 quadrillion (or 10^{15}), BTUs. The United States, with 5 percent of the world's population, accounts for 20 percent of the world's total primary energy consumption (see Figure 9.1A). *Primary* energy is the best measure of energy consumption because it is the energy in fuel sources such as coal, oil, and natural gas before they are converted into electricity and other forms of *secondary* or *site* energy. Total Chinese energy consumption surpassed US consumption in 2009 and reached 120 quads in 2014 (see Figure 9.1B). It is useful to note that total US energy consumption has been falling for almost 10 years and that Chinese consumption is flattening out. In the United States, buildings consume 40 percent of energy or about 8 percent of global primary energy (see Figure 9.2). Commercial buildings have the smallest fraction of energy consumption, at 18 percent, but this number is growing the most rapidly. Although at first glance transportation and industrial energy appear to be unrelated to building energy, they are, in fact, coupled together. The relationships of buildings and the distances between them are a major contributor to transportation energy. In addition, a considerable amount of industrial energy is invested in building products and infrastructure materials, and it is likely that the total energy, including the

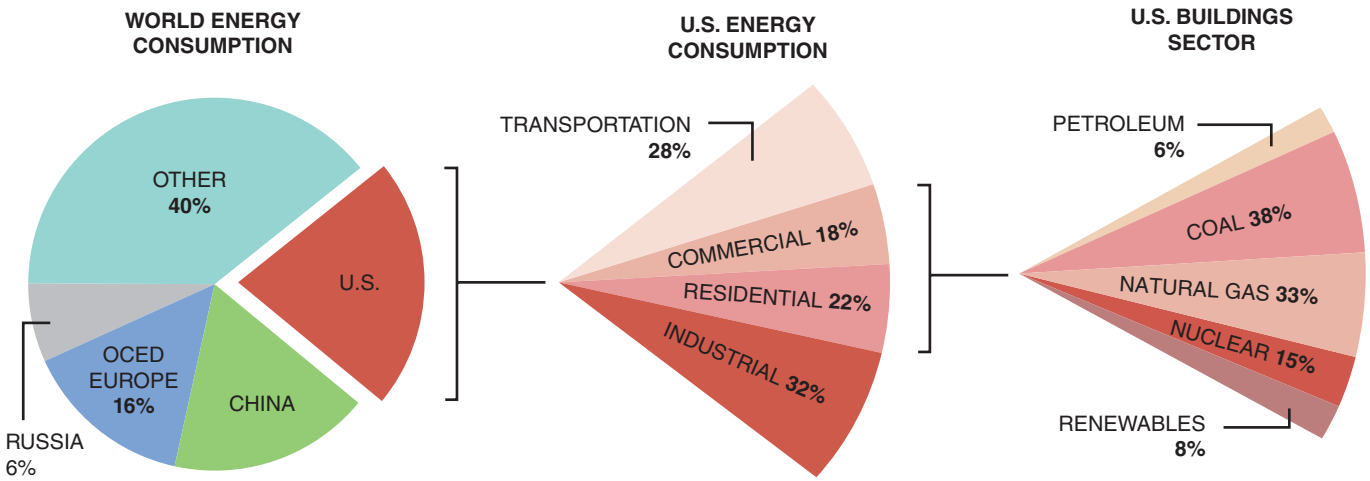


Figure 9.1 (A) Energy consumption patterns worldwide, in the United States, and for US buildings. (*Source:* US Energy Information Administration)

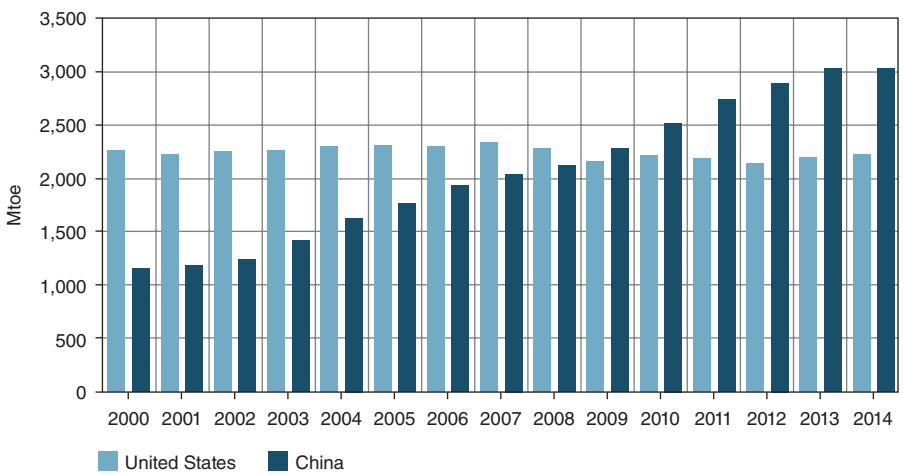


Figure 9.1 (B) Comparison of total energy consumption between the United States and China, 2000 and 2014. The units in this figure are millions of tons of oil (MTOEs) equivalent. One quad of energy is the equivalent of 25 MTOEs. (*Source:* Enerdata)

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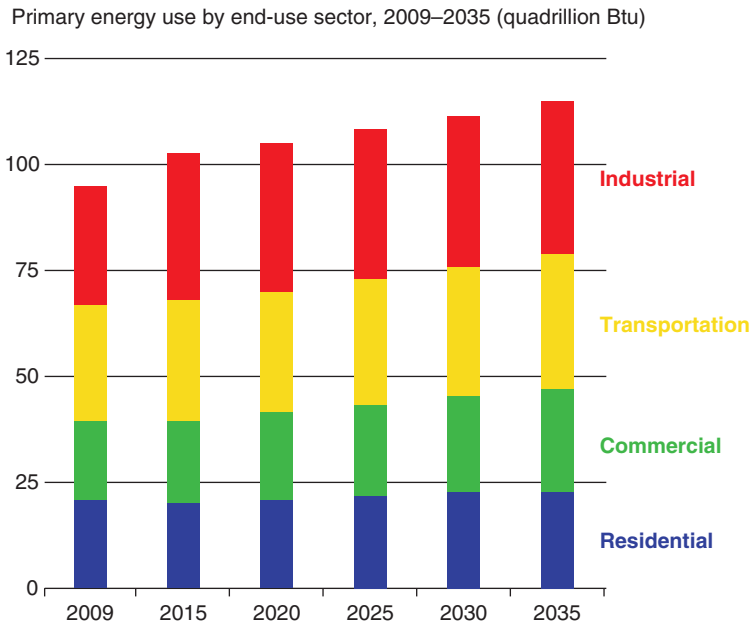


Figure 9.2 Primary energy use by end-use sector, 2009 to 2035, in quads. Energy use by buildings in the United States is growing, from about 40 percent in 2009 to a forecasted 48 percent in 2035. Commercial building energy consumption is growing at the fastest rate of the four sectors depicted in this diagram. (*Source:* US Energy Information Administration)

embodied energy of materials and the transportation energy attributable to buildings, is well over 60 percent of total primary energy. Energy consumed to support the built environment is dominated by coal at 33 percent of primary energy, but natural gas consumption is growing rapidly, and nuclear energy is a growing fraction of electrical energy generation.

There is some good news with respect to energy, namely, energy use per capita and per unit of economic production is falling and will continue to decrease for the foreseeable future (see Figure 9.3). However, total energy consumption is still rising due to an increasing population and a growing economy, a problem at several levels. First, energy prices affect economic production, and higher demand drives prices higher, thereby putting a damper on the economy. Second, the vast majority of energy consumption is via fossil fuel combustion, which has human health impacts. Finally, greater energy production generally means higher greenhouse gas production, contributing even more to climate change. To meet the challenges of the future, per capita and per gross domestic product (GDP) energy consumption must

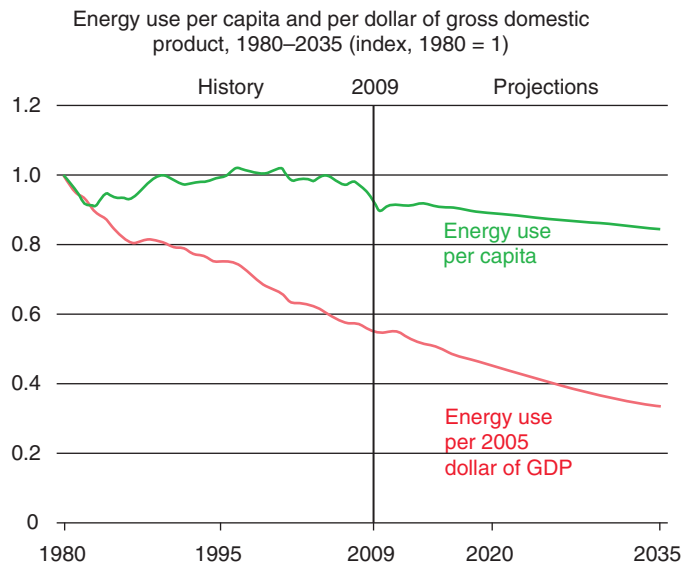


Figure 9.3 Index of energy use per capita and per dollar of GDP from 1980 to 2035 (the index for 1980 is set equal to 1). (*Source:* US Energy Information Administration)

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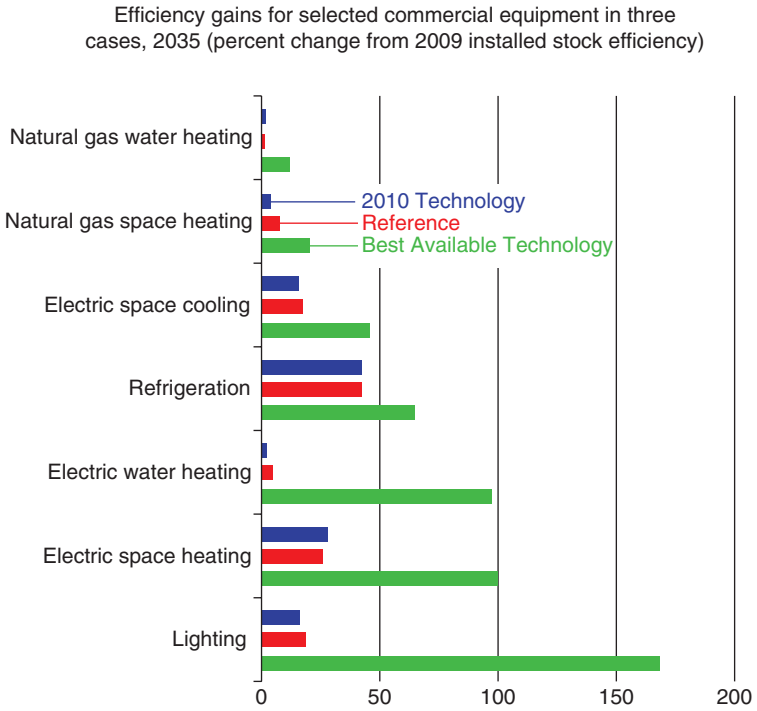


Figure 9.4 Building energy consumption can be significantly lowered by employing the best available technology for the major energy-consuming systems in buildings. (*Source:* US Energy Information Administration)

decline far more rapidly by developing more efficient manufacturing processes, reconfiguring cities to be more compact, and designing high-performance buildings and retrofitting existing buildings to consume far less energy. This last point is especially important because more than 99 percent of the building stock at any time is composed of existing buildings. Shifting to renewable energy systems such as solar, wind, and biomass systems is also important because renewable energy is considered to be part of a clean energy production system without the negative health and climate change impacts.

Building energy consumption can be reduced through the use of better design backed up by more stringent national and state energy standards and codes. Truly low-energy buildings are achievable by using passive energy strategies that take into account the orientation and mass of the building to maximize daylighting and minimize heat gain except when needed. Coupled with the best emerging technologies (see Figure 9.4), significant reductions in building energy use can be realized. Energy consumption in US buildings is declining due to these very reasons, driven by a combination of rising energy costs and more stringent standards (see Figure 9.5). A survey of buildings by the US Department of Energy (DOE), known as the Commercial Buildings Energy Consumption Survey (CBECS), was conducted in 2003 and found that building energy consumption averaged about 91,000 BTU per square foot (ft^2) per year (287 kWh/m^2 per year[kWh/m^2/yr]). Since this survey, building consumption has been pushed lower by ever more stringent standards, such that the 2010 version of American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) Standard 90.1, *Energy Standard for Buildings Except Low-Rise Residential Buildings*, (set a ceiling on commercial building energy consumption of about 36,000 BTU/ft^2/yr (114 kWh/m^2/yr), a 60 percent reduction since 2003.

Recent programs in Germany indicate that buildings can be designed to use far lower levels of energy than even the most ambitious US high-performance buildings. As part of a 10-year demonstration program, a group of 23 office buildings throughout Germany were designed, built, and monitored with a goal of using 32,000 BTU/ft^2 (100 kWh/m^2) of *primary energy* annually. Primary energy is the source energy for the energy delivered to the building (e.g., the energy value of coal

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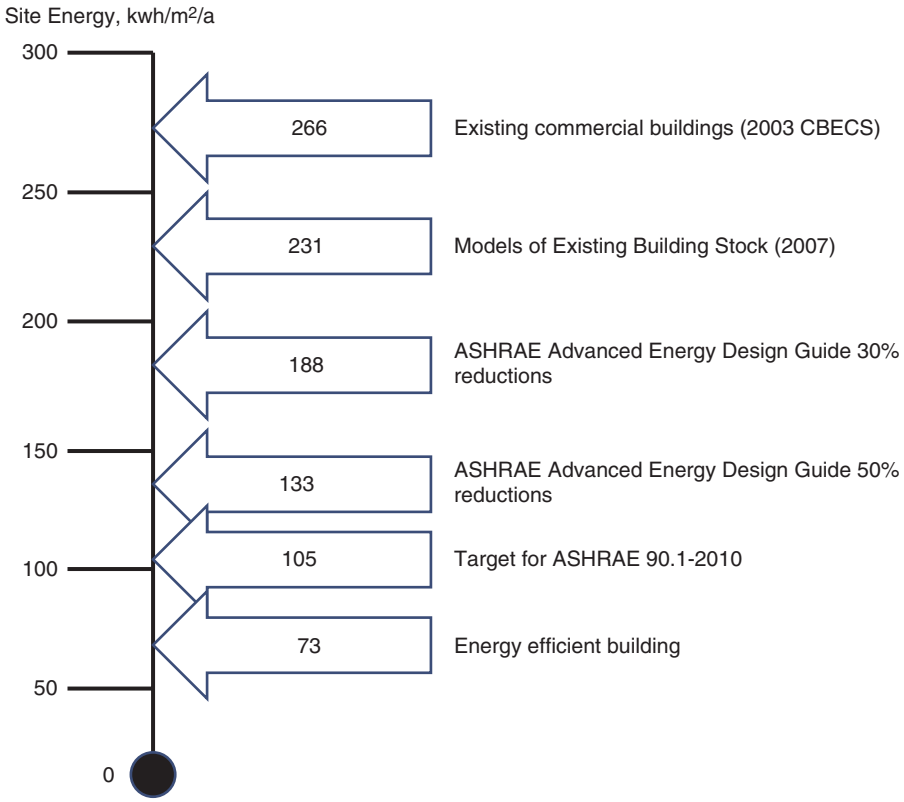


Figure 9.5 Energy use in US buildings has been dropping rapidly since the DOE CBECS found that building energy consumption averaged 287 kWh/m^2/yr in 2003. Since that time, standards such as ASHRAE 90.1-2010 are pushing energy far lower, to 114 kWh/m^2/yr at present. (*Source:* US Department of Energy)

before it is combusted to produce electricity). The efficiency of coal-fired electrical generating plants is such that only one-third of the coal energy becomes electrical energy. Consequently, the electrical energy used in the building, referred to as the *site energy*, is multiplied by a factor of 3 to account for the primary energy. A code-compliant US office building consumes on the order of 80,000 BTU/ft^2/yr (252 kWh/m^2/yr) of site energy. For an all-electric building in the United States, this would equate to 240,000 BTU/ft^2/yr (756 kWh/m^2/yr). For a building that derives 80 percent of its energy from electricity and the remainder from natural gas, the primary energy would be about 208,000 BTU/ft^2/yr (656 kWh/m^2/yr). Note that the best German buildings now have a primary energy target of 100 kWh/m^2/yr. An energy-efficient, high-performance building in the United States would have to use one-fifth to one-seventh of the energy of a conventional US building to match today's best practices in Germany (Löhnert et al. 2006). Even the best US practices, which cut energy consumption by 50 percent, result in the typical office building using at least twice the primary energy of a German building, pointing to a need for dramatic changes in the way buildings are designed in the United States.

A green building ideally would use very little energy, and renewable energy would be the source of most of the energy needed to heat, cool, and ventilate it. Today's green buildings include a wide range of innovations that are starting to change the energy profile of typical buildings. Many organizations are committed to investing in innovative strategies to help create buildings with Factor 10 performance, notably the federal government, which has been the leader in requiring life-cycle costing (LCC) analysis as the basis for decision making with respect to building procurement. Some state governments have followed suit, notably those of Pennsylvania, New York, and California; in contrast, others, such as Florida, have passed legislation requiring decisions based solely on the capital or first cost of a particular strategy. This latter, shortsighted approach will result in enormous expenditures of energy as we approach the rollover point.

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Green building advocates often note that the strategies used to heat, cool, ventilate, and illuminate high-performance buildings allow a significant downsizing of the mechanical plant and a parallel reduction in the overall capital costs of the building. This is clearly the ideal outcome, wherein both capital and operating costs are lower than those of a comparable base-case building. However, there are very few of these buildings in typical US climactic zones for a variety of reasons, including building code constraints. LCC analysis of a building's performance is key for giving designers the creative freedom to optimize a given building's energy consumption.

High-Performance Building Energy Design Strategy

Over the past decade, a process for designing low-energy buildings has emerged that can produce 100-k kWh/m^2/yr primary energy buildings. Listed next are the 10 steps involved in designing energy systems with low-energy and low-carbon footprints:

1. Use building energy simulation tools throughout the design process.
2. Optimize the passive solar design of the building.
3. Maximize the thermal performance of the building envelope.
4. Minimize internal building loads.
5. Maximize daylighting and integrate with a high-efficiency lighting system.
6. Design a hyperefficient heating, ventilation, and air conditioning (HVAC) system that minimizes energy use.
7. Select high-efficiency appliances and motors.
8. Maximize the use of renewable energy systems.
9. Harvest and use waste energy.
10. Incorporate innovative emerging strategies, such as ground coupling and radiant cooling.

The design of an energy-efficient building is a complex undertaking, and these steps cannot just be performed in sequence; they are, in effect, part of an iterative process that starts with passive design. Trade-offs inevitably must be made, often because of the client's requirements and budget. Designed properly, a building with a low-energy and a low-carbon footprint should provide greatly reduced operational costs for minimal or no increase in capital costs. In some cases, a well-executed passive design strategy can markedly reduce the costs of HVAC equipment due to the reduction in heating, cooling, ventilation, and lighting loads that can occur.

GOAL SETTING FOR HIGH-PERFORMANCE BUILDINGS

The design of the energy strategy for a high-performance building should involve an examination of energy targets for the building based on a combination of reviewing the performance of similar conventional buildings, an understanding of contemporary high-performance building best practices, and building energy simulations. The two major US building assessment systems, Leadership in Energy and Environmental Design (LEED) and Green Globes, take similar approaches to energy goal setting. The latest version of LEED relies on ASHRAE Standard 90.1-2010, *Energy Standard for Buildings Except Low-Rise Residential Buildings*, for direction on how to establish the baseline design for the building and compare it to the proposed

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design. The baseline design generally is thought of as a building designed to minimal building code requirements, with no special effort made to achieve energy efficiency. Green Globes relies on several approaches including ASHRAE 90.1-2010 to predict building energy performance. These approaches are described in more detail later in this chapter.

As noted, building assessment systems, such as LEED, rely on ASHRAE 90.1-2010 to provide a standard set of instructions that dictate how the baseline design is to be defined and how the design of the high-performance building, referred to as the *proposed design*, is to be compared to the baseline design. The baseline design is simply a version of the building being designed but with minimal efforts to reduce its energy consumption below building code requirements. Appendix G of the ASHRAE 90.1-2010 standard describes the performance rating method, which is a modification of the energy cost budget method. The baseline design is simulated for each of four orientations, with specified opaque assemblies, limits on vertical fenestration, and HVAC systems as defined in Appendix G. This approach uses energy cost as the basis for determining savings, with the cost of energy based on actual local utility rates or on state average prices published by the DOE's Energy Information Administration (www.eia.gov).

Green Globes defines several paths for setting goals and predicting building energy performance:

Path A: Energy Star Target Finder

Path B: ASHRAE 90.1, Appendix G

Path C: Building Carbon Dioxide Equivalent (CO_2e) Emissions

Path D: ASHRAE Building Energy Quotient (bEQ)

The *Energy Star Target Finder* is an online tool developed by the EPA to help set goals for building energy performance.[4] It provides a percentile score that predicts performance compared to the same type of buildings in the same location. To earn an Energy Star certification, a building must meet the 75 percent target, meaning that the building has to be in the top 25 percent of buildings of that type, in the specific area, as contained in the Target Finder database. This target is the threshold performance for points in Green Globes (i.e., it earns the minimum 10 points out of the maximum 100 points that can be awarded for minimizing energy consumption). The maximum number, 100 points, is achieved by buildings in the 96th percentile or higher. The advantage of this approach is that the target is based on actual buildings, and the designed building is compared to like structures in the immediate area. The drawback of Target Finder is that the database lists a limited range of building types. Target Finder does have the capability of taking mixed-use buildings into account; for example, a building combining office and residential space can be analyzed to determine the appropriate target.

Building Energy Quotient (bEQ) is a building energy labeling program developed by ASHRAE. Similar to the EPA's Target Finder and Energy Star Portfolio Manager, it predicts and scores energy performance based on a comparison to similar buildings. It can be used both to design the building and to improve its energy performance during actual operations. This energy performance is referred to as the *as-designed* performance and *in-operation* performance respectively. Points are awarded based on the bEQ score attained in the modeling process.

The *Building Carbon Dioxide Equivalent (CO_2e) Emissions* approach rates the building based on emissions of CO_2 relative to other buildings based on the protocol in ANSI/GB01 Standard 01-2010, Green Building Assessment Protocol for Commercial Buildings. It employs a model that converts the building's energy use intensity in energy per square meter annually to kilograms of CO_2e per square meter annually.

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BUILDING ENERGY SIMULATION AND DAYLIGHTING SIMULATION

Building energy simulation is an important tool in the design of a high-performance building. Contemporary building energy simulation tools allow the building to be modeled in great physical detail and to be operated on an hourly basis in a given configuration for an entire year. It is important to employ building energy simulation at a very early stage in the design process, when decisions about building shape, number of stories, and orientation are being made. Today's simulation tools allow the integration of active and passive building systems and can easily examine the interplay and trade-offs among heating and cooling systems, walls and roof choices, insulation, lighting, windows and doors, exterior and interior shading, and skylights. Perhaps the best-known whole-building energy simulation tool is DOE-2.2, which now has user-friendly interfaces and wizards to speed the energy simulation process (see www.doe2.com). Daylighting is a key component of an energy-efficient building, and performing simulations that optimize daylighting is important to understand the trade-offs among fenestration, envelope thermal resistance, and energy use for artificial lighting. Some building energy simulation tools, such as Energy-10, allow the integrated evaluation of daylighting, passive solar heating, low-energy heating and cooling strategies, and envelope design.[5] Daylighting also can be evaluated with sophisticated software such as Radiance (radsite.lbl.gov/radiance), developed by the Lawrence Berkeley National Laboratory (LBNL). Radiance contains libraries of materials, glazings, electric lighting luminaires, and furniture to facilitate the daylighting analysis. The simulation provides a quantitative check on the intuitive guesswork of the design team about the interrelationship of the building systems. Typical tools for whole-building energy simulation include eQUEST (www.doe2.com/equest/), DOE-2.2 (www.doe2.com/), and Energy-10.

To determine how well energy modeling represents the actual performance of buildings, LBNL conducted a study of 21 buildings certified under LEED 2.0 or LEED 2.1, with about half located in the Pacific Northwest and the others from areas throughout the United States. Part of the study separated federal from nonfederal buildings and considered only nonlaboratory buildings. A summary of this study is shown in Table 9.1. It indicates a wide range of results when comparing modeling to actual performance. In some cases, the modeling is quite accurate while in others it is far off. The real value of modeling is to find the relative importance of changes to the building's envelope and energy systems; providing an accurate prediction of building energy performance is less important. The modeling of plug loads (computers, printers, fax machines, copiers, appliances) is notoriously inaccurate because the behavior of the building users is unpredictable. Actual plug loads often are substantially higher than those simulated in the energy model. Additionally, with the continual addition of new electrically powered devices in office buildings, plug loads tend to increase over time. The issues of plug loads and techniques for reducing them are addressed later in this chapter in the section "Plug Load Reduction."

VERIFYING BUILDING ENERGY PERFORMANCE

The International Performance Measurement and Verification Protocol (IPMVP) provides an overview of current best practices for verifying energy efficiency, water efficiency, and renewable energy performance for commercial and industrial facilities. It also can be used by facility operators to assess and improve facility performance. Energy conservation measures (ECMs) covered in the protocol include fuel-saving measures, water efficiency measures, load shifting, and energy reductions through installation or retrofit of equipment and/or modification of operating procedures. The IPMVP is maintained with the sponsorship of the DOE by a broad

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TABLE 9.1

Comparison of Energy Models of LEED Buildings and Their Associated Base Cases Compared to Actual Energy Consumption

Building Type	Modeled Base Case	Modeled LEED Case	Savings of LEED Case Based on Modeling	Actual Energy Use*	Actual Energy Compared to Modeled†
Federal	131	117	21%	81	30%
Nonfederal	105	61	42%	57	7%

Source: Adapted from Diamond, Opitz, Hicks, Vonneida, and Herrera 2006
Note: For this study, nine federal and eight nonfederal, nonlaboratory buildings were compared.
*Thousands of BTU per square foot per year.
†A negative number indicates that the actual energy consumption was less than the modeled energy consumption.

international coalition of facility owners/operators, financiers, energy services companies, and other stakeholders.

The IPMVP was first published in 1996 and contained methodologies that were compiled by a technical committee composed of hundreds of industry experts, initially from the United States, Canada, and Mexico. Twenty national organizations from a dozen countries worked together to revise, extend, and publish a new version of the IPMVP in December 1997. The 2014 version, the latest edition, has been widely adopted internationally and has become the standard measurement and verification (M&V) document in countries ranging from Brazil to Romania. Volume 3 of the IPMVP applies to new construction, and its purpose is to provide a description of best practices for verifying the energy performance of new construction.[6] The IPMVP requires the user to develop an M&V plan that includes defining the ECMs employed in the building, identifying the boundary conditions for measurement, establishing base year data, defining conditions to which all data will be adjusted for comparison, and meeting a range of other requirements that establish a standardized method for comparing information. The LEED-NC point that can be earned for M&V requires that the IPMVP be used for measuring both energy and water consumption data.

Passive Design Strategy

Due to the complexity of designing the energy systems for a high-performance green building, the starting point must be full consideration of *passive solar design*, or *passive design*. Passive design is the design of the building's heating, cooling, lighting, and ventilation systems, relying on sunlight, wind, vegetation, and other naturally occurring resources on the building site. Passive design includes the use of all possible measures to reduce energy consumption prior to the consideration of any external energy source other than the sun and wind. Thus, it defines the energy character of the building prior to the consideration of active or powered systems (chillers, boilers, air handlers, pumps, and other powered equipment). Randy Croxton, one of the pioneers of contemporary ecological design, describes a good passive design as one that allows a building to "default to nature."[7] A building that has been well designed in a passive sense could be disconnected from its active energy sources and still be reasonably functional because daylighting, adequate passive heating and cooling, and ventilation are provided by the chimney effect, cross-ventilation, operable windows, and prevailing winds. A successful passive design scheme creates a truly climate-responsive, energy-conserving building with a wide range of benefits.

Passive design has two major aspects: (1) the use of the building's location and site to reduce the building's energy profile and (2) the design of the building

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itself—its orientation, aspect ratio, massing, fenestration, ventilation paths, and other measures. Passive design is complex, as it depends on many factors, including latitude, altitude, solar insolation (incoming solar radiation), heating degree days (HDDs) and cooling degree days (CDDs),[8] humidity patterns, annual wind strength and direction, the presence of trees and vegetation, and the presence of other buildings. An optimized passive design can greatly reduce the energy costs of heating, cooling, ventilation, and lighting.

Some of the factors that should be included in the development of a passive design strategy are listed next:

- *Local climate.* Sun angles and solar insolation, wind velocity and direction, air temperature, and humidity throughout the year
- *Site conditions.* Terrain, vegetation, soil conditions, water table, microclimate, relationship to other buildings
- *Building aspect ratio.* Ratio of the building's length to its width
- *Building orientation.* Long axis oriented east–west, room layout, glazing
- *Building massing.* Energy storage potential of materials, fenestration, color
- *Building use.* Occupancy schedule and use profile
- *Daylighting strategy.* Fenestration, daylighting devices (light shelves, skylights, internal and external louvers)
- *Building envelope.* Geometry, insulation, fenestration, doors, air leakage, ventilation, shading, thermal mass, color
- *Internal loads.* Lighting, equipment, appliances, people
- *Ventilation strategy.* Cross-ventilation potential, paths for routine ventilation, chimney effect potential

Like any concept, passive design can be applied improperly to building design. Its success is highly dependent on the wide range of factors just listed, and its application differs widely from New York to California, Colorado, or Florida. For example, using thermal mass as a passive design strategy, an excellent choice in the high desert altitudes found in New Mexico, with its abundant sunlight and wide daily temperature swings, would not be an appropriate choice in a hot, humid climate with generally narrow daily temperature differences, as would be found in Tampa, Florida. The optimum building orientation, the location and types of windows, the use of daylighting, and many other decisions must be based on a careful examination of the situation found in each locale.

SHAPE, ORIENTATION, AND MASSING

The classic passive design approach to orienting a building on its site is to locate the long side on a true east–west axis to minimize solar loads on the east and west surfaces, particularly during the summer. The *aspect ratio* is the ratio of a building's length to its width, which is an indicator of the general shape of a building. Passive design dictates that a building in the northern United States should have an aspect ratio close to 1.0; that is, it should be virtually square in shape. For buildings in the warmer southerly latitudes, the aspect ratio increases, with the building becoming longer and narrower. The reasoning behind this shift in aspect ratio is that a square building will have the minimum skin surface area compared to its volume. In colder climates, it is important to minimize the surface area through which heat can be transmitted. Temperature differentials for heating are generally much greater than for cooling; thus, the total skin area of the building is more important in heating situations. The long, narrow building favored by passive design experts for warmer climates minimizes the relative exposure of east and west surfaces that experience the greatest sun load. Windows on east and

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west surfaces typically are minimized to eliminate as much as possible the potential high morning and afternoon solar loads. South-facing walls will experience a variable sun load during the day, and windows are easily protected from solar loads through the use of roof overhangs, shading devices, or recessed windows.

Thermal mass is an important aspect of passive design. In cases where passive solar heating is desired, the geometry of the building should be arranged to allow materials with high heat capacity and significant mass to store solar energy during the day. Materials such as brick, concrete masonry, concrete, and adobe, used for floors and walls, can absorb solar energy during the day and release it in the evening, when internal temperatures begin to drop. For passive solar cooling, buildings in climates such as that of Florida should have minimal mass for storing energy and generally should be lightweight and well insulated. Preventing solar energy transmission into the structure is the desired strategy for passive cooling. The ideal design, which would consider both passive heating and passive cooling, could provide heating in winter and promote cooling in summer. This design requires careful consideration of orientation, fenestration, shading, and massing.

Because large commercial and institutional buildings are complex and often are restricted with respect to siting, trying out various passive design approaches using computer simulations is necessary to sort through the wide array of possibilities. The integration of landscaping with the building also has enormous potential for contributing to natural heating and cooling by shielding windows during the summer and allowing solar energy through in winter.

DAYLIGHTING

Using natural light or daylight for illumination is one of the hallmarks of a high-performance building. In addition to the benefits of supplying substantial light for free, natural lighting has been shown to provide great physical and psychological benefits to building occupants. The first comprehensive scientific studies of the benefits of daylighting were conducted by the Pacific Gas and Electric Company in California in the late 1990s for two general types of buildings: retail stores and schools ("Skylighting and Retail Sales" 1999). Daylighting in stores was shown to increase sales per square unit area of retail space from 30 to 50 percent, while the learning rate of students was 20 to 26 percent higher in classrooms with daylighting compared to those with only artificial lighting ("Daylighting in Schools" 1999). Clearly, daylighting produces a win-win situation, marked by lower energy costs and better school performance. Most likely, the same is true in offices. Although not yet proven by scientific methods, it is thought that a 10 to 15 percent increase in office worker productivity can be expected as a consequence of daylighting. A 10 percent increase in employee productivity due to decreased illness and absenteeism or an improved sense of well-being translates into savings that far exceed the energy costs of a typical office building. If the connections between daylighting and human health could be proven with a high degree of certainty, this alone would cause an enormous transformation in the way buildings are designed and built. At present, productivity and health effects are not fully taken into account in the LCC analysis of high-performance buildings. However, if and when science catches up with speculation and the benefits are verified, daylighting will leap past its use as a green building strategy to near-universal incorporation. (Chapter 15 addresses LCC for green buildings in more detail.)

Developing an effective daylighting strategy can, however, be a complex undertaking due to the trade-offs that must occur between admitting light and cooling the building. The cost of windows, skylights, light shelves, and other features that function to transmit light versus conventional construction, where daylighting is not much of an issue, also must be factored in. Fortunately, experience with daylighting is growing at an exponential rate, along with the green building movement itself; consequently, the information from these efforts is becoming available to a wider

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TABLE 9.2

Key Ideas for Daylight Feasibility

Windows must see the light of day. A high-density urban site may make daylighting difficult if the windows will not see much sky.

Glazing must transmit light. A strong desire for very dark glazing generally diminishes the capacity to daylight in all but very sunny climates.

Install daylight-activated controls. To save energy, lights are dimmed or turned off with controls. Automated lighting controls in a daylit building can have other cost-saving applications (occupancy, scheduling, etc.) and benefits.

Design daylight for the task. If the occupants require very bright light, darkness, or a highly controllable lighting environment, tailor the design to meet their needs.

Assess daylight feasibility for each portion of the building. Spaces with similar orientation, sky views, ground reflectance, and design can be treated together. Within a single building, the feasibility and cost effectiveness of daylighting may vary greatly.

Source: Excerpted from "Tips for Daylighting with Windows" (1997).

audience of designers and owners. A list of key ideas for assessing daylight feasibility from LBNL is shown in Table 9.2. An excellent checklist for daylighting from *Environmental Building News* (*EBN*) is shown in Table 9.3.

The energy and health benefits of daylighting are maximized in the design for Smith Middle School in Chapel Hill, North Carolina (see Figure 9.6). The strategy allows for multiple anidolic lighting systems, which use mirrors to direct the sunlight, to capture the south-facing sunlight and transmit it deep into the classrooms, gymnasium, media center, and main corridor, providing the most daylighting with the least

TABLE 9.3

Checklist for Daylighting

General Daylighting

- ☐ Provide a daylighting scheme that will work under the range of sky conditions expected at that location.
- ☐ Orient the building on an east–west axis.
- ☐ Brighten interior surfaces.
- ☐ Organize electric lighting to complement daylighting.
- ☐ Provide daylight controls on electric lighting.
- ☐ Commission the daylight controls.

Perimeter Wall Daylighting

- ☐ Provide perimeter daylight zones.
- ☐ Extend windows high on perimeter walls.
- ☐ Provide light shelves on south-facing windows.
- ☐ Minimize direct-beam sunlight penetration into work spaces.
- ☐ Choose the right glazing.
- ☐ Arrange interior spaces to optimize the use of daylighting.

Roof Daylighting

- ☐ Provide roof apertures for daylighting.
- ☐ Optimize skylight spacing.
- ☐ Consider extending skylight performance with trackers.
- ☐ Use reflective roofing on sawtooth clerestories.
- ☐ Diffuse daylight entering the building through roof apertures.

Core Daylighting

- ☐ Provide a central well or atrium for daylighting.

Source: "Daylighting: Energy and Productivity Benefits" (1999).

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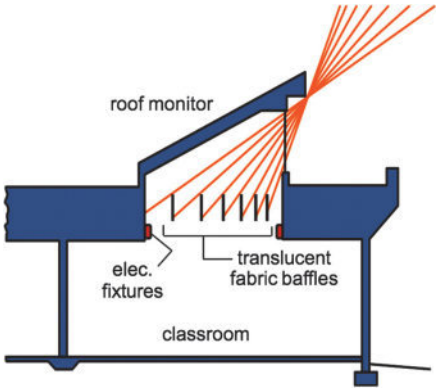






Figure 9.6 The daylighting strategy for Smith Middle School in Chapel Hill, North Carolina, employs (A) south-facing roof monitors with high-visible light transmission glazing and interior vertical baffles to provide for optimum controlled daylighting without glare throughout the entire classroom depth, (B) integrated lighting controls, and (C) exterior lighting shelves with high-visible light transmission glazing above to enhance daylighting and low-E glass for view windows below. (*Sources:* (A) Image courtesy of Lighting Research Center/Rensselaer Polytechnic Institute; (B–C) Innovative Design)

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amount of skylight glazing. The natural light is distributed through translucent, ultraviolet-resistant cloth baffles to scatter direct rays and avoid glare. Recessed south-facing windows prevent glare by incorporating both anodized aluminum light shelves and low-emissivity (low-E) double glazing. These light shelves reflect daylight onto the ceiling surface and deep into the room, while low-E glazing reduces internal solar heat gain. The daylighting strategy is integrated with the lighting systems controls through occupancy sensors, passive infrared technology, and a manual light switch. To turn on internal lights, three conditions must be satisfied: The manual switch must be on, occupant motion must be detected, and the lighting level within the room must be below a predetermined set point. Once these conditions are met, the lights come on and a photosensor adjusts the lighting down to 10 percent in response to daylight levels. An energy simulation indicated that the incorporation of daylighting technologies makes energy efficiency achievable through smaller cooling system sizing, resulting in cost savings and an enhanced indoor experience. The emerging consensus is that learning environments enlivened by subtle and natural variation of light intensity, color, and direction throughout the day are healthier environments, leading to higher productivity.[9]

PASSIVE VENTILATION

Providing ventilation to building occupants normally is accomplished by using fans, dampers, and controls to move outside air into the building while at the same time removing an equal amount of interior air to the outside. In more advanced designs, an economizer cycle uses outside air for cooling, providing significant savings. Ventilation air using natural forces to move the air, rather than mechanical systems, also can be provided, greatly reducing the energy needed to move air. Passive ventilation can be accomplished by using either a thermal chimney effect, whereby air normally rises due to heating, inducing airflow in a generally vertical direction, or a Venturi effect, whereby air movement is induced by the development of a low-pressure zone created by wind flow.



Figure 9.7 Wind catcher (upper right) on the Jubilee Campus of the University of Nottingham in the United Kingdom. The wind catcher pivots in the wind, with the vane indicating the direction of airflow. Wind flowing past the vane induces the convection of air through the structure. (Photograph courtesy of Hopkins Architects and Ian Lawson)

The Jubilee Campus of the University of Nottingham in the United Kingdom, designed by Sir Michael Hopkins and partners and built in 1999, still has one of the most advanced passive ventilation strategies among modern buildings. Wind catchers are used to position the air exhaust stacks for optimal ventilation. The wind catchers automatically turn in the direction of the wind, creating suction behind them and driving the ventilation system for the buildings. Cool, clean air is brought in at a high level and fanned down to the floor levels, where it starts to rise with the sunlight, body heat, and equipment. This intricate pattern of environmental cause and effect is echoed throughout the building's staircases and corridors. Thermal wheels are used in conjunction with the wind catchers to exchange energy between exiting exhaust air and incoming fresh air. The innovations in this design resulted in the Jubilee Campus winning the Royal Institute of British Architects sustainability award in 2001. Figures 9.7 and 9.8 show the passively ventilated building on the Jubilee Campus and depict the ventilation pattern through the building.

In a typical European passive ventilation design, the first determinant is the quantity of air required for ventilation. In England, the Chartered Institution of Building Services Engineers publishes standards and guidelines requiring these ventilation rates:

- Classrooms: 2 to 4 air changes per hour
- Offices: 4 to 6 air changes per hour
- Theaters: 6 to 10 air changes per hour
- Storage areas: 1 to 2 air changes per hour

The outside wind speed, which is generally in the range of 3 to 19 feet per second (1–6 meters/second [m/sec]) in England, is factored into the design, and

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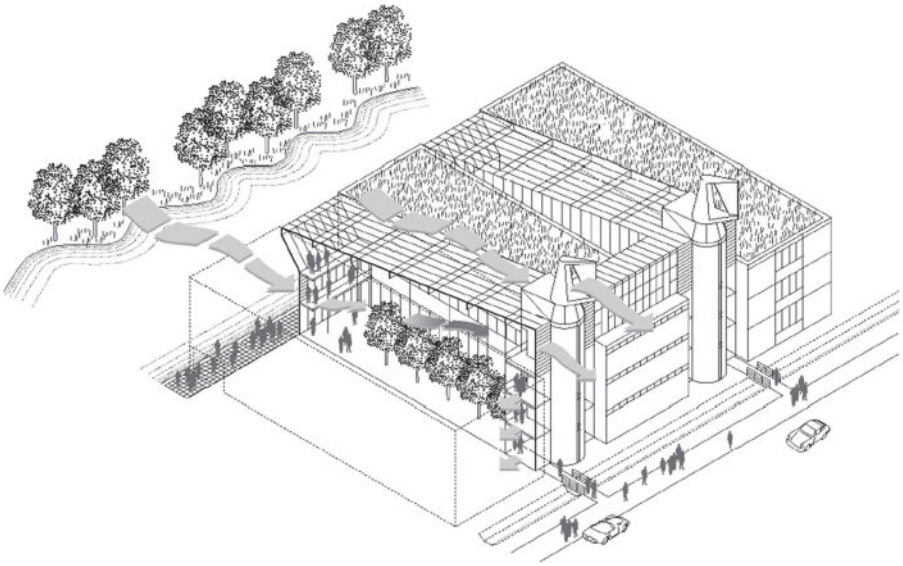


Figure 9.8 Schematic of the natural ventilation strategy for the Jubilee Campus of the University of Nottingham. Air flows from a low level at the rear of the building, moves gradually upward, and then exits through the pivoting wind catchers on the front of the building. A Venturi effect is induced in the wind catcher by the wind flowing past the vanes. (Illustration courtesy of Hopkins Architects)

the number of passive ventilation stacks required to move the calculated amount of ventilation air are designed into the structure. In the base of the stack, dampers connected to the building's energy management system (EMS), and possibly to carbon dioxide (CO_2), humidity, and/or temperature sensors, control the rate of ventilation. Diffusers at ceiling level introduce the ventilation air into the occupied spaces. Solar tubes that bring in light as well as air are incorporated into some passive ventilation stacks.

In contrast to Europe, which has a wide range of examples of passive ventilation systems, the concept has not had much success in the United States. One of the best US examples is the Federal Building in San Francisco, California. A sample computational fluid dynamics (CFD) simulation for this building is shown in Figure 9.9.

PASSIVE COOLING

Earlier in this chapter, it was noted that today's German office buildings achieve substantially better energy performance than their US high-performance counterparts. An obvious question is: How do the Germans achieve such exceptional energy

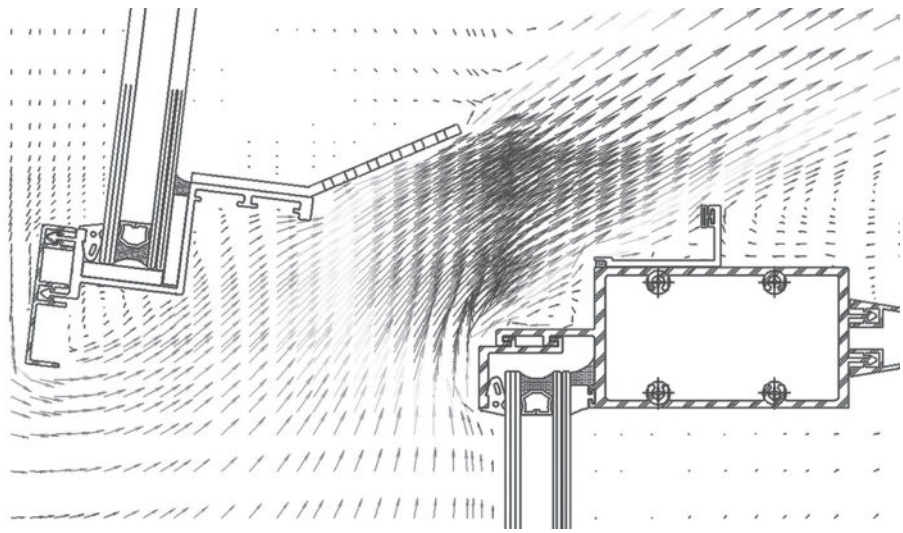


Figure 9.9 Design of passive ventilation systems requires the use of tools not traditionally used in building designs, such as the CFD modeling of wind and airflows around the Federal Building in San Francisco, California. The illustration shows a simulation of the design of an air deflector for the building's windows that helps accelerate airflows, propelling them deep into the building's spaces. (Illustration courtesy of Natural Works)

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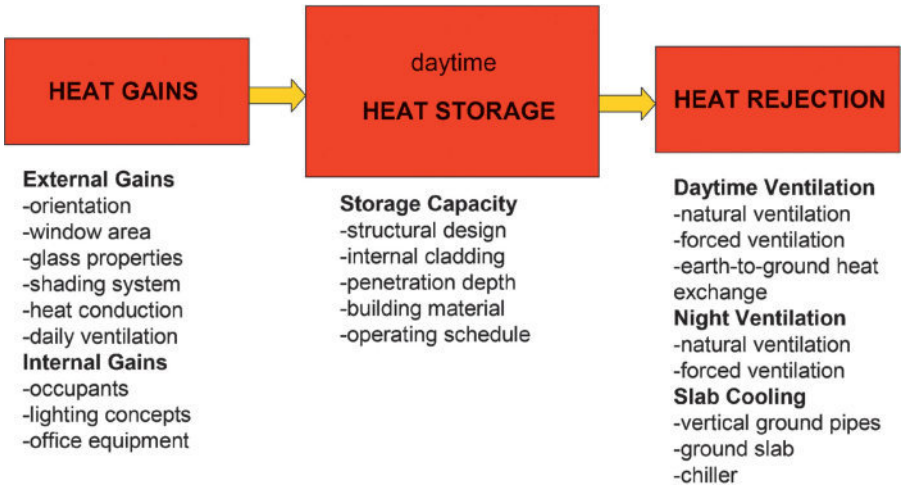


Figure 9.10 Passive cooling strategies use heat gain avoidance to minimize external thermal loads, minimize internal gains from occupants and electrical equipment, and use the building structure for storing residual heat gains, which are then removed by a combination of natural and forced ventilation with ground coupling.

performance in their buildings? The answer is that they are changing some of the basic assumptions of the past several decades about how buildings should operate. Rather than completely isolating the building occupants from outdoor conditions, designers now assume moderate interaction by means of natural ventilation, daylighting, and passive cooling. This concept, called *lean building*, results in smaller building service equipment for heating and cooling. In the German context, passive cooling is the interaction of all measures that reduce heat gains and render natural heat sinks—night air and the ground—accessible (see Figure 9.10).

Heat loads are transferred to the surrounding environment with some time delays, and heat storage in the building mass itself is substantial. The main design priority is to restrict the amplitude and dynamics of external heat gains. Limiting glazing while maintaining daylighting is the key to this strategy, and the ratio of glazing to façade area is less than 43 percent for the 23 German demonstration buildings mentioned previously. Almost all buildings use externally adjustable sun-shading devices, and total solar energy transmittance is kept below 15 percent. Cooling is accomplished by using night ventilation in which the building mass is cooled using earth-to-air heat exchangers, which are simply underground metal ducts through which the air is brought into the building, or by slab cooling in which groundwater is pumped through cavities in the slab. The coefficient of performance (COP) for mechanical and hybrid night ventilation ranges between 4.5 and 14, far higher than that of conventional cooling.[10] The earth-to-air heat exchangers have extremely high COPs, ranging from 20 to 280. Note that today's best-performing chillers, the heart of many air-conditioning systems, have a maximum COP of about 8.

By eliminating conventional cooling systems, the project has the resources to perform a technical analysis to design a lean building appropriate to the bioregion, one that transfers daytime internal energy to the structure and minimizes the intrusion of external heat energy into the building. Even if the outdoor conditions vary, indoor conditions remain within a well-defined comfort zone, meeting the needs of the occupants (Löhnert et al. 2006).

The result of using this approach is an enormous reduction in the cooling capacity typically needed for office buildings. In monitoring these buildings, the researchers found that the upper desirable temperature limit of 77°F (25°C) was exceeded less than 10 percent of the working hours. During the unusually warm summer of 2002 in Germany, the naturally ventilated buildings exceeded the temperature criterion only 5 percent of the time, the equivalent of 1 hour every 2.5 days—a remarkable outcome (see Figure 9.11). The one drawback of relying on a passive cooling strategy is that the mechanical plant will be unable to cope with extreme weather conditions that occasionally occur.

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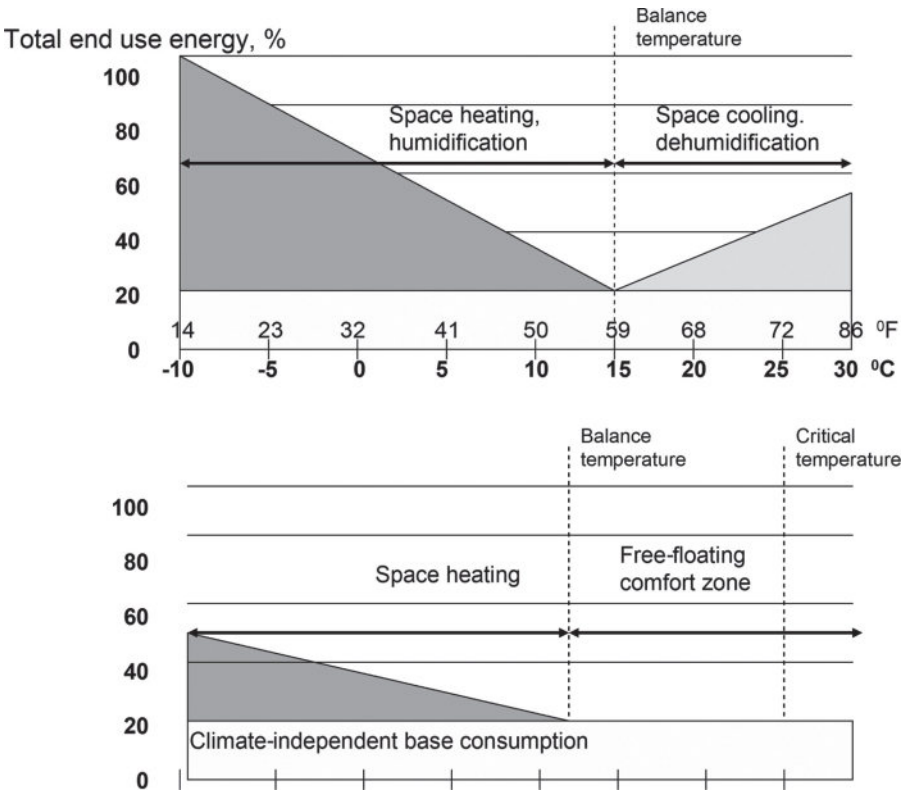


Figure 9.11 Low-energy German buildings use passive ventilation and cooling to eliminate much or all of the need for conventional mechanical cooling. Studies indicate that this strategy results in interior temperatures that rarely exceed acceptable space conditions for offices. As a consequence, buildings that use 100 kWh/m^2 (31,700 BTU/ft2) of primary energy annually are achievable, a fraction of the energy of today's US high-performance green buildings.

Building Envelope

After passive design is considered to minimize the need for external energy inputs, energy transmission through the building skin should be minimized through a tight, thermally resistant envelope. The building envelope must control solar heat gain, conduction or direct heat transmission, and infiltration or leakage heat transmission. The three major building envelope issues that need to be addressed are thermal resistance of the walls, window selection, and roof strategy. These are covered in the next sections. (The environmental impacts of materials selection are covered in Chapter 11.)

WALL SYSTEMS

The thermal conductance, or *U-value*, of building walls is an important factor in building energy efficiency because walls are generally the dominant component of the envelope. U-values are measured in units of BTU/hr-ft^2-°F (W/m^2-°C). The lower the U-value of an assembly, the greater is its resistance to heat transfer. Maximum U-values are set by state building energy codes and by ASHRAE 90.1-2010. The maximum U-value is a function of the number of HDDs and CDDs for the various climate zones in the United States (see Figure 9.12 and Table 9.4). Both HDD and CDD are measures of how much heating or cooling probably will be required in a given climatic zone. In general, wall thermal resistance becomes more important the farther north the building is located in the United States. Two other considerations in selecting wall systems are the thermal mass of the exterior surface that receives direct sunlight during the day and the placement of insulation with respect to the building façade. Placing insulation closer to the exterior nearest the outdoor conditions and having the thermal mass closest to the interior provides ideal conditions for using the mass beneficially and for minimizing

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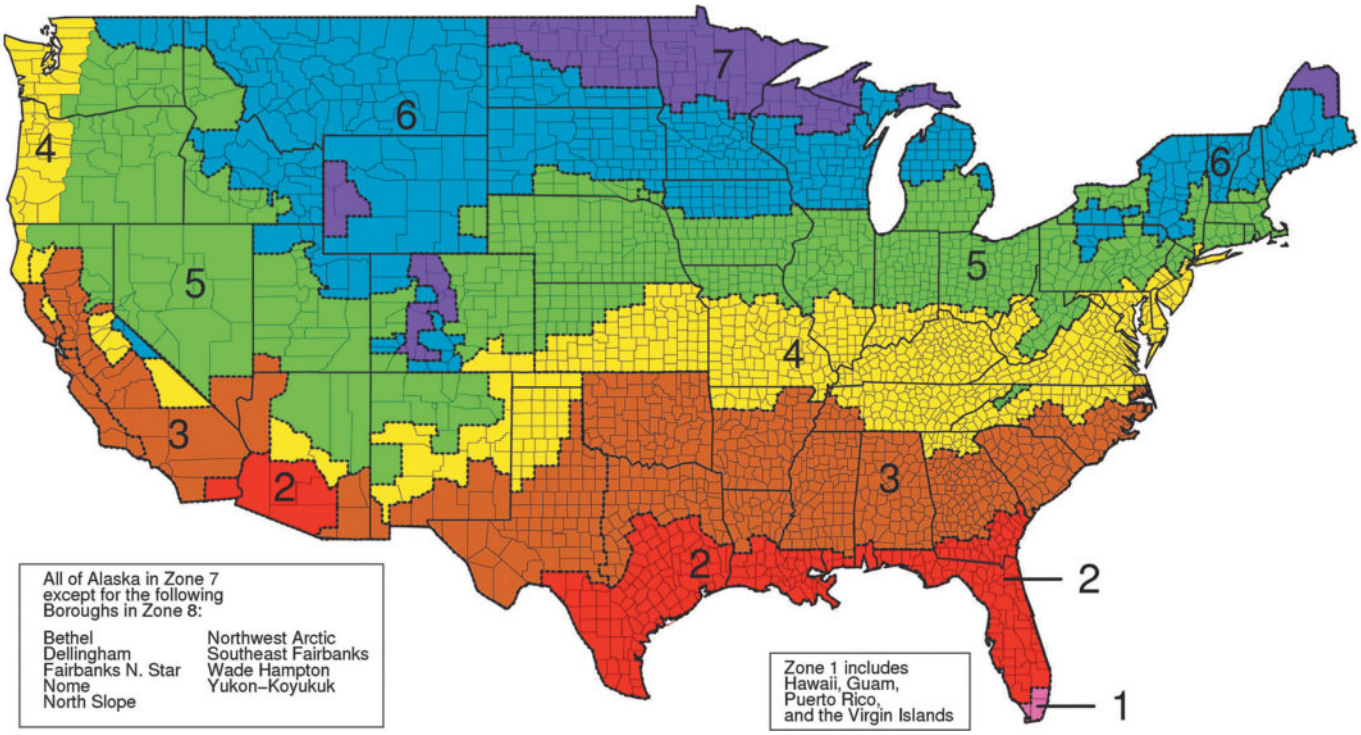


Figure 9.12 Climate zones by county in the United States based on the International Energy Conservation Code. (*Source:* Pacific Northwest National Laboratory)

the thermal loads transmitted into the building's interior that must be removed by air conditioning. In southern climates, it is generally important to design energy-shading façades that will reflect energy or are ventilated to carry away energy that is absorbed on the building's skin.

TABLE 9.4

US Climate Zones Defined by HDDs and CDDs

	Thermal Criteria	
Zone Number	**IP Units**	**SI Units**
1	9000<CDD50F	5000<CDD10C
2	6300 CDD50F ≤ 9000	3500<CDD10C ≤ 5000
3A and 3B	4500 CDD50F ≤ 6300 and HDD65F ≤ 5400	2500<CDD10C ≤ 3500 and HDD18C ≤ 3000
4A and 4B	CDD50F ≤ 4500 and HDD65F ≤ 5400	CDD10C ≤ 2500 and HDD18C ≤ 3000
3C	HDD65F ≤ 3600	HDD18C ≤ 2000
4C	3600<HDD65F ≤ 5400	2000<HDD18C ≤ 3000
5	5400<HDD65F ≤ 7200	3000<HDD18C ≤ 4000
6	7200<HDD65F ≤ 9000	4000<HDD18C ≤ 5000
7	9000<HDD65F ≤ 12600	5000<HDD18C ≤ 7000
8	12600<HDD65F	7000<HDD18C

Note: Heating degree days (HDDs) and cooling degree days (CDDs) are defined as the differences of daily average temperature from a base temperature, summed over the entire year. CDD50°F means the baseline for calculating CDD is 50°F. When the mean daily temperature is above 50°F, CDDs are calculated. A day with a mean temperature of 75°F would have (75°F 50°F) = 25 CDDs. These are totaled for the full year in a given climate zone to establish the annual CDDs for that zone. HDD are based on a baseline of 65°F

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WINDOW SELECTION

Windows play a variety of roles in the building envelope. They allow light into the room spaces, permit the occupants to admit air into the space (in the case of operable windows), and provide a thermally resistant layer to energy movement. Windows must be installed so as to balance the amount of light admitted into the structure with the control of solar heat gain and conduction of energy through the window assembly. Window performance is a combination of several factors: the *solar heat gain coefficient* (SHGC), the *visible transmittance* (VT) of the glass, the *thermal conductance* (U-value), and the infiltration or leakiness character of the window assembly.

Solar heat gain is largely a function of where windows are placed in the building and the types of glass used. SHGC and VT are used to express the radiation performance of windows in the building envelope. SHGC, with a value between 0 and 1, is the fraction of solar heat that enters the window and becomes heat; it includes both directly transmitted and absorbed solar radiation. The lower the SHGC, the less solar heat the window transmits through the glazing from the exterior to the interior and the greater its shading capability. In general, south-facing windows in buildings designed for passive solar heating should have windows with a high SHGC to allow beneficial solar heat gain in the winter. East- or west-facing windows encounter high levels of solar energy in the morning and afternoon and generally should have lower SHGC assemblies.

The VT, ranging in value from 0 to 1, refers to the percentage of the visible spectrum (380–720 nanometers) that is transmitted through the glazing. When daylight in a space is desirable, high-VT glazing would be the logical choice. However, lower-VT glazing may be more applicable for office buildings or where reduced interior glare is desirable. A typical clear, single-pane window has a VT of 0.90, meaning that it admits 90 percent of the visible light.

The ratio of SHGC to VT, known as the *light-to-solar-gain (LSG) ratio*, provides a gauge of the relative efficiency of different glass types in transmitting daylight while blocking heat gains. The higher the LSG, the brighter the room is without adding excessive amounts of heat. Table 9.5 shows average values of SHGC, VT, and LSG for typical windows. Figure 9.13 is a diagram of the characteristics of a contemporary high-performance window that is optimized for heating climates. Windows that are filled with argon or krypton gas have more thermal resistance than those filled with air. Argon is inert, relatively abundant, and less costly than krypton, which provides higher thermal resistance but at a higher cost. Windows with a low SHGC were used in the relatively high-temperature climate of northern Florida, as shown in Figure 9.14.

Low-emissivity (low-E) and reflective coatings are applied to glazing to control the light passing through the glass and usually consist of a layer of metal a few molecules thick. The thickness and reflectivity of the metal layer (low-E coating) and the location of the glass to which it is attached directly affect the amount of solar heat

TABLE 9.5

Typical Values of SHGC, VT, and LSG for Total Window (Center of Glass) for Different Types of Windows

Window Type	Glazing	SHGC	VT	LSG
Single-glazed	Clear	0.79 (0.86)	0.69 (0.90)	0.97 (1.04)
Double-glazed	Clear	0.58 (0.86)	0.57 (0.81)	0.98 (1.07)
Double-glazed	Bronze	0.48 (0.62)	0.43 (0.61)	0.89 (0.98)
Double-glazed	Spectrally selective	0.31 (0.41)	0.51 (0.72)	1.65 (1.75)
Triple-glazed	Low-E	0.37 (0.49)	0.48 (0.68)	1.29 (1.39)

Source: From "Solar Heat Gain Control for Windows" (2006).

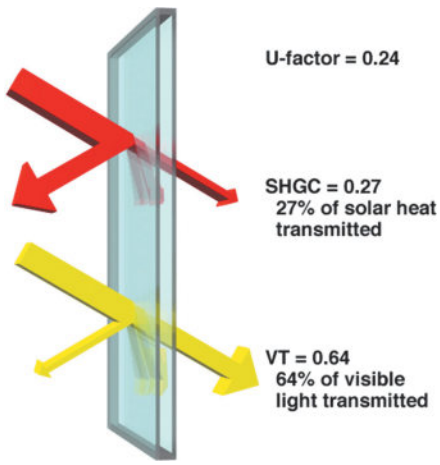


Figure 9.13 Characteristics of a typical double-glazed window with a low SHGC, low-E glass, filled with argon gas. These windows are often referred to as *spectrally selective low-E glass* due to their ability to reduce solar heat gain while retaining high visible transmittance. Such coatings reduce heat loss and transmit less solar heat gain, making them suitable for climates with both heating and cooling concerns. (Illustration courtesy of Efficient Windows Collaborative)

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Figure 9.14 Low-E glazing on the Orthopaedics and Sports Medicine Institute at the University of Florida in Gainesville. High-technology glazing allows the design of buildings that admit visible light for daylighting but reflect infrared radiation. DOE-2.1 and daylighting simulations confirmed that daylighting and low-E glass produced greater savings than focusing solely on the thermal resistance of the building envelope. (*Source:* T. Wyman)

gain in the room. Coating technology is advancing rapidly, and there are now low-E2 and low-E3 windows, with two and three silver coatings, respectively, that greatly improve glass performance. The low-E3 windows have a remarkably low SHGC of 0.30 or lower.

Any low-E coating is roughly equivalent to adding an additional pane of glass to a window. Low-E coatings reduce long-wave radiation heat transfer by 5 to 10 times. The lower the emissivity value (a measure of the amount of heat transmission through the glazing), the better the material reduces the heat transfer from the inside to the outside. Most low-E coatings also slightly reduce the amount of visible light transmitted through the glazing relative to clear glass. Representative emissivity values for different types of glass are listed next.

- Clear glass, uncoated: 0.84
- Glass with single hard-coat low-E: 0.15
- Glass with single soft-coat low-E2: 0.10

Increasing the window area to maximize daylighting has the effect of replacing a highly thermally resistant wall with far less thermally resistant glass, creating an opportunity for the infrared or heating component of light to enter the envelope and also creating the potential for infiltration around the window frame. In trading off daylighting to optimize the thermal envelope, controlling solar heat gain through windows is critically important. Prior to the development of today's window glazing and film technologies, 75 to 85 percent of infrared energy could pass through typical single- or double-paned glass.

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A standardized national system for rating windows is important to enable performance comparisons of these important components of the building envelope. The National Fenestration Rating Council (NFRC; www.nfrc.org) operates a uniform national rating system for measuring the energy performance of fenestration products, including windows, doors, skylights, and similar products. The key to the rating system is a procedure for determining the thermal transmittance (U-factor) of a product. The U-factor rating procedure is supplemented by procedures for rating products for SHGC, visible transmittance, air leakage, and annual energy performance. Together, these rating procedures, as set forth in documents published by the NFRC, comprise the NFRC rating system. This system is expected to be supplemented by additional procedures for rating energy performance characteristics, including long-term energy performance and condensation resistance. The NFRC rating system employs computer simulation and physical testing by NFRC-accredited laboratories to establish energy performance ratings for fenestration products and product lines (see Figure 9.15). The system is reinforced by a certification program under which a window and door manufacturer may label and certify its products to indicate those energy performance ratings.

EBN suggests the approach to window selection depicted in Table 9.6. *EBN* also provides these additional recommendations:

- Use modeling software such as RESFEN and WINDOW to optimize the building fenestration system.
- As a minimum, select double-glazed, low-E, argon-filled windows for most US climate zones.
- For colder climates, select higher-performance windows with triple glazing, low-E2 coatings, and gas fill. In Germany, triple-glazed windows are mandatory.
- Tune the windows to their orientation and climate. For east and west orientations when heat gain is not desirable, select low-SHGC windows. If passive solar heating is desired, high-SHGC windows on the south side may be desirable. For north-side windows in most climate zones, maximum thermal resistance is best, and SHGC is not necessarily important.



Figure 9.15 The NFRC label for windows lists the manufacturer, describes the product, provides a source for additional information, and includes ratings for one or more energy performance characteristics.
(*Source:* National Fenestration Rating Council)

ROOF SELECTION: THERMAL RESISTANCE AND COLOR

The roof of a high-performance building is especially important because it is a major area for heat transmission due to its generally large area and exposure to the sun. According to Cool Communities (www.coolcommunities.org), a nonprofit

TABLE 9.6

Window Selection Approach Based on Climate and Solar Heat Gain

		Whole-Window U-Factor	Whole-Window SHGC	Whole-Window SHGC for South Orientations When Solar Gain Is Desired
Hot Climate (Double or Triple Glazing)		0.16–0.30 Lower is better	0.25–0.37 Lower is better	0.36–0.63 Very dependent on location
	Double Glazing	0.27–0.39	0.42–0.55	0.42–0.63
Cold Climate	Triple Glazing	0.17–0.26	0.33–0.49	0.42–0.63

Source: The original table on which this is based is from "Choosing Windows: Looking through the Options" (2010).

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TABLE 9.7

Reflectance of Roof Materials and Air Temperatures above Roof

Material	Solar Reflectance	Temperature of Roof over Air Temperature (F°/C°)
Bright white coating (ceramic, elastomeric) on smooth surface	80%	15°/8°
White membrane	70%–80%	15°–25°/8°–14°
White metal	60%–70%	25°–36°/14°–20°
Bright white coating (ceramic, elastomeric) on rough surface	60%	36°/20°
Bright aluminum coating	55%	51°/28°
Premium white shingle	35%	60°/33°
Generic white shingle	25%	70°/39°
Light brown/gray shingle	20%	75°/42°
Dark red tile	18%–33%	62°–77°/34°–43°
Dark shingle	8%–19%	76°–87°/42°–48°
Black shingle or materials	5%	90°/50°

Source: Parker, McIlvaine, Barkaszi, Beal, and Anello (2000).

organization that advocates for measures that prevent urban heat islands and is based in Rome, Georgia, the roofs of structures such as shopping malls, warehouses, and office buildings can reach 150°F (83°C) in the summer, enough to affect whole neighborhoods. Using surfaces with high albedo (a measure of the reflectivity of solar radiation) for roofing can reduce the ambient air temperature so that the entire area is cooler. Light-colored roofs have high albedo, or high reflectivity, which helps reduce the thermal load on the building as well as the surrounding neighborhood. Both the LBNL and the Florida Solar Energy Center estimate that buildings with light-colored, reflective roofs use 40 percent less energy than similar buildings with dark roofs (Parker et al, 2000).

The Solar Reflectance Index (SRI), which measures how hot materials are in the sun, is used to easily describe the amount of solar energy reflected by roofing materials. A building with light-colored shingles and an SRI of 54 would reflect 54 percent of incident solar energy and would be very cool relative to a building with conventional dark shingles. Manufacturers have developed clean, "self-washing" white shingles with an even higher SRI, up to 62 percent. This is useful because the labor costs of maintaining the white color and high reflectivity of a conventional roof may exceed the worth of the energy being saved; consequently, a self-washing roof system significantly reduces maintenance costs and improves energy performance. The reflectance of commonly used roofing materials is shown in Table 9.7. As can be seen, dark-colored roofs have a tendency to absorb solar radiation, and they can be as much as 90°F (50°C) hotter than the air just above the roof. Because heat transmission is a function of temperature difference, a dark-colored, hot roof will have proportionately more heat conduction than a light-colored, relatively cool roof. Figure 9.16 shows the highly reflective, high-SRI roof used on a building in Hollywood, California.

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Figure 9.16 In a renovation project, the roof of this art studio in Hollywood, California, was coated for waterproofing with SureCoat, a white finish, which could be applied to the mechanical system as well, giving it a very high reflectivity, or albedo. Research by the Lawrence Berkeley National Laboratory and the Florida Solar Energy Center has demonstrated that light-colored roofs with a high SRI use 40 percent less energy than dark roofs. (All rights reserved. SureCoat Systems)

Internal Load Reduction

Excellence in passive design and in the design of a high-performance building envelope needs to be combined with a significant effort to address the internal heat loads of the building. This is achieved in part by a good daylighting strategy, which has the dual benefit of reducing energy consumption for lighting and removing the lighting power saved from the total building cooling load. People constitute a major fraction of the building's internal heat load, and we generally can assume that reducing the number of people in a building is not a viable strategy. Reducing loads due to computers, peripherals, copiers, and other miscellaneous equipment is a promising strategy because it has been found that these loads constitute a substantial fraction of a building's energy consumption. Increasing wiring sizes beyond those required by code has the benefit of reducing energy losses in the wiring system and proportionately reducing the impact of these heat losses on the building's cooling system.

PLUG LOAD REDUCTION

Designers of high-performance buildings typically do not closely examine one of the major internal building loads, *plug loads*, a name for devices plugged into electrical outlets around the building that not only consume substantial energy but also increase cooling loads due to their heat emissions. The DOE estimates that office equipment loads make up about 18 percent of a US commercial building's electrical load, exceeded only by HVAC and lighting loads. In a study of plug loads for its newly renovated 6700-square-foot (622-m^2) office building, IDeAs Z^2, a consulting engineering firm located in San Jose, California, estimated that plug loads would consume in excess of 40,000 kWh per year, or almost 7 kWh per square foot (75 kWh per m^2) each year. In many office buildings, the largest plug loads are due to desktop computers, typically averaging about 160 watts (W) per unit (Kaneda et al. 2006). One alternative that should be considered for reducing desktop computer plug loads is to replace them with laptops designed for energy efficiency to maximize battery life. Laptops generally consume 40 W, or about 25 percent of the power of

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desktops. The economics of replacing desktops with laptops will depend largely on the processing power required. In the case of IDeAs Z^2, which requires high-speed processors and large amounts of software to run its computational and graphics software, the cost difference between a desktop and a laptop with equivalent processing speed and storage was about $1,835. An analysis indicated that the additional cost for high-end laptops would be greater than the cost of photovoltaics (PVs) to offset the additional load; that is, it would be cheaper to buy PVs than to replace desktops with laptops. In cases where exceptional computing capability is not needed, the cost differential and payback will be more favorable.

MISCELLANEOUS PLUG LOADS

Electrical loads for printers, scanners, copiers, and fax machines also contribute to higher building energy consumption. Energy Star–rated equipment costs 20 to 100 percent more than existing equipment, with energy savings of less than 10 percent. There appears to be a very high premium for the highest-efficiency Energy Star–rated equipment. IDeAs Z^2 concluded that immediate replacement of existing devices was not cost-effective. Instead, its strategy was to replace old equipment with Energy Star–rated devices as much as possible and to evaluate replacements on an individual basis. It also researched energy-efficient dishwashers and concluded that, unlike refrigerators, which run round-the-clock 365 days a year, dishwashers run infrequently; therefore, the energy savings resulting from purchasing a high-efficiency dishwasher would be minimal. A final item that was evaluated was the existing coffeemaker, which stayed on "warm" all day (and occasionally all night), holding half a pot of coffee. The firm purchased a single-cup coffeemaker for daily staff use, which heats one cup at a time and has no warming element. The old coffeemaker would be used only in conjunction with a Thermos for large meetings.

PLUG LOAD CONTROL

Several types of control strategies are employed to reduce plug loads. Some equipment needs to be left on 24 hours a day, 7 days a week. This includes fax machines, main servers, and security systems. In these cases, high energy efficiency will be a key criterion when selecting equipment. Control of "phantom loads" in office equipment is another key strategy for conserving power. For equipment that has infrequent duty cycles, such as microwave ovens, the energy consumed during long hours of standby can be more than the energy consumed while in use. A second group of items, including printers, plotters, and copiers, need to be turned on only during working hours. These items typically have a long start-up time and would be inconvenient to turn on prior to each use, so they cannot be turned off between uses. However, there is no reason for these items to continue to run when the office is unoccupied, regardless of whether they are active or in sleep mode. IDeAs Z^2 found that the worst case was a laser plotter, which consumed 1,440 W when plotting, 30 W in the sleep mode, and 25 W when manually switched to standby. Oddly enough, the plotter had no true off switch. To ensure that this equipment is not left on, the security system automatically turns off the electrical circuits to it when armed and turns on the circuits the next day when disarmed, reducing phantom loads. Occupancy sensor-controlled surge protectors are used at each workstation to turn off the power to task lights, computer monitors, speakers, and other nonessential peripherals when a user leaves his or her desk. Desktops are routinely left on all day but are set to go into sleep mode when not in use. Sleep mode saves energy and allows for fast restart times compared to the hibernate mode. However, if power is lost, data will also be lost. Hibernate mode saves data to the hard drive, so if power is lost, data will not be lost. However, computers in hibernate take much longer to restart when they come back to active mode. IDeAs Z^2 currently is working with EPA-sponsored researchers and experimenting with personal computer settings and individual occupancy sensors to determine how

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TABLE 9.8

Example of the Energy and Cost Benefits of Sizing Wiring in Electrical Circuits to Be Larger Than Code Minimum Requirements

	#8 AWG	#6 AWG
Conduit size	¾ in	1 in
Estimated loss (100% load, 75C conductor temperature)	423 W	272 W
Wire cost*	$700	$800
Conduit cost*	$182	$259
Incremental cost		$177
Energy savings		604 kWh/yr
Dollar savings at $0.15/kWh, payback period		$90.60/yr, 2.0 years
Dollar Savings at $0.11/kWh, payback period		$66.45/yr, 2.7 years

*Wire and conduit costs in these examples are based on those found at a large Nevada retailer in April 2009.

best to minimize energy consumption without significantly reducing productivity or creating inconvenience. There is a debate within IDeAs Z^2 as to whether it is wise to shut off power to personal computers automatically when the building is unoccupied. The argument against it is that risking the loss of work left unsaved on the computer is not worth the attempt to save a few watts. However, most software has a built-in autosave feature, reducing the potential to lose a significant amount of work. IDeAs Z^2 currently is experimenting to determine if using the security system to turn off computer circuits is worth saving additional phantom losses.

UPSIZED ELECTRICAL WIRING

All circuits lose small amounts of energy through resistance as power flows through the wiring. Wire sizes recommended by code are based on keeping the heat generated from wiring losses below temperatures that would damage wire insulation. If wires are upsized, resistance in the wires is lower, and losses are reduced. IDeAs Z^2 estimated losses for sample circuits and compared the value of saved electricity with the additional cost to increase wire sizes one size above code recommendations. The paybacks were as low as four years for circuits that were highly loaded. All branch circuits carrying large, continuous loads were upsized to reduce wiring losses. In addition to reducing the electrical energy consumption of a circuit, this upsizing reduced the cooling loads associated with those losses.

Table 9.8 is an example of the energy benefits found on a lighting circuit for a large retailer in Nevada. By upsizing one wire size—from #8 American Wire Gauge (AWG) to #6 AWG—rapid payback of just two to three years was achievable (Lindsay 2009). IDeAs Z^2 used upsized wiring in the design of its own LEED platinum, net zero energy office building (see Figure 9.17).



Figure 9.17 The IDeAs Z^2 office building in San Jose, California, is an NZE facility that was achievable through well-conceived approaches to reducing plug loads and upsizing electrical wiring. (Photograph courtesy of Integrated Design Associates, Inc.)

Active Mechanical Systems

After the passive solar design of the building is optimized, the internal thermal loads in the building should be minimized. The thermal load of some buildings will be people-dominated; that is, the bulk of the load will be due to the number of people in the facility, so little can be done to reduce the load. A classroom building at a university is a good example of this situation. In other buildings, the load may be dominated by equipment, lighting, and other powered devices. In this situation, energy-efficient appliances, lighting, computers, and other systems can contribute to a significant

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reduction in cooling load. Office buildings may have equipment-dominated loads if they have relatively large quantities of powered devices, such as computers and copy machines, and a moderate to low population.

A wide variety of HVAC systems can be used to meet the needs of a facility's occupants. The type of system selected is a function of the size of the building, the climatic conditions, and the load profile of the building. A typical building HVAC system will have an air side that delivers conditioned air into the spaces and a fluid side that creates chilled and hot water for use in the HVAC system, so equipment with the highest possible efficiency should be selected for all roles. The next sections contain information about selecting some of the major types of equipment in an HVAC system: chillers, air distribution system components, and energy recovery systems.

CHILLERS

According to LBNL's Environmental Energy Technologies Division, chillers are the single largest energy users in commercial buildings, consuming 23 percent of total building energy. Chillers also have the unfortunate characteristic of increasing their power consumption during the day, contributing to peak demand and forcing utilities to build new power plants to meet high daytime power demand. Consequently, chillers are responsible for large portions of peak power charges for commercial customers. In addition to these problems, most chiller plants tend to be oversized during the design process. Chillers operate at peak efficiency when they operate at peak load. However, chillers tend to operate at part load during much of the day. Even those that are correctly sized operate most of the time at low, part-load efficiencies.

Four types of chillers are commonly available today (note that 1 ton equals 12,000 BTU/hour of cooling capacity, or 3.4 kW):

1. Centrifugal, primarily large tonnage above 300 tons (1,000 kW)
2. Screw (50–400 tons [170 to 1360 kW])
3. Scroll (up to 50 tons [170 kW])
4. Reciprocating (up to 150 tons [510 kW])

Manufacturers have been working to produce high-efficiency chillers that meet the needs of high-performance green buildings. For example, the Trane CVHE/F EarthWise centrifugal chiller was awarded the EPA's Stratospheric Ozone Protection Award. "Rated at 0.45 kWh/ton of cooling, the EarthWise centrifugal chiller is one of the highest efficiency devices in this major category of HVAC equipment."

Chiller plant efficiency can be improved by more than 50 percent while improving reliability by combining new technologies such as direct digital control (DDC) and variable-frequency drives (VFDs) with improved design, commissioning, and operation. California tends to lead the nation in developing energy performance standards, and the latest version of California Title 24 Energy Efficiency Standards has substantially increased requirements for chiller efficiency ("Chiller Plant Efficiency" 2010. Several different chiller technologies can be considered for a building. In general, water-cooled rotary screw or scroll chillers have the highest COP of all types of chillers. (COP is the ratio of cooling power delivered by a chiller to the input power.) A COP of 3.0, for example, indicates that the chiller provides 3 kWh of cooling for 1 kWh of input energy (see Figure 9.18). Note that a high capacity screw or scroll water-cooled chiller has a COP of over 6, a very high level of performance and more than double the COP of 2.50 for an electrically operated, air-cooled chiller. One significant disadvantage of a water-cooled chiller is the need to provide a cooling tower to reject the energy absorbed from the building.

Absorption chillers tend to have a comparatively low COP, normally less than 1.0, which appears to indicate a very low level of performance. However, absorption chillers can use heat energy that normally would be wasted to provide cooling.

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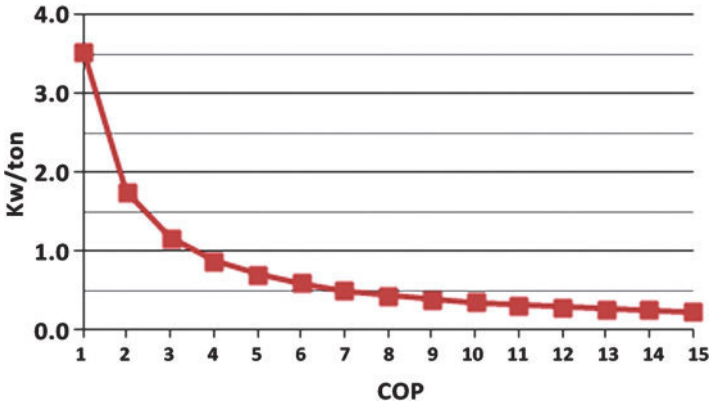


Figure 9.18 *COP* and *kilowatt/ton* are terms used to describe the performance of air-conditioning and cooling systems. COP is similar to the concept of efficiency, except it can be greater than 1.0 due to the nature of the refrigeration cycle. Specifically, COP is the ratio of cooling energy to input energy and has no units or dimensions. Kilowatt/ton is the inverse of COP; that is, it is the power required to produce 1 ton (12,000 BTU/hr) of cooling. A higher COP or a lower kilowatt/ton indicates a higher-efficiency system. A COP of 6 or higher represents a relatively high-efficiency piece of air-conditioning equipment or a system. A COP of 6 corresponds to a kilowatt/ton value of 0.59 or lower. The highest-performing systems and equipment today have COPs of about 9, corresponding to about 0.40 kW/ton.

A steam-driven screw chiller could reject its waste energy to an absorption chiller to provide additional cooling, thus increasing the COP of the overall system. Absorption chillers can also use relatively low-temperature heat to produce chilled water. Thus, they work well with solar thermal energy and waste heat from some varieties of fuel cells, such as phosphoric acid fuel cells (PAFCs). Table 9.9 describes the characteristics of a high-performance chiller plant, and Table 9.10 provides several design strategies for achieving a relatively low-cost, high-efficiency chiller plant.

AIR DISTRIBUTION SYSTEMS

Another major consumer of energy in modern buildings is the air distribution system, composed of air handlers, electric motors, ductwork, air diffusers, registers and grilles, energy and humidity exchangers, control boxes, and a control system. The air distribution system should be designed using much the same approach as for the chiller plant to deliver the precise capability needed and to do so efficiently across a wide range of operating conditions. According to *Greening Federal Facilities* (2001), a guide developed for use by federal government facility managers to use

TABLE 9.9

Characteristics of a High-Efficiency Chiller Plant

Efficient design concept. Selecting an appropriate design concept that is responsive to the anticipated operating conditions is essential to achieving efficiency. Examples include using a variable-flow pumping system for large campus applications and selecting the quantity, type, and configuration of chillers based on the expected load profile.

Efficient components. Chillers, pumps, fans, and motors should all be selected for stand-alone as well as systemic efficiency. Examples include premium-efficiency motors, pumps that have high efficiency under the anticipated operating conditions, chillers that are efficient with both full and partial loads, and induced-draft cooling towers.

Proper installation, commissioning, and operation. A chiller plant that meets the first two criteria still can waste a lot of energy—and provide poor comfort to building occupants— if it is not installed or operated properly. For this reason, following a formal commissioning process that functionally tests the plant under all modes of operation can provide some assurance that the potential efficiency of the system will be realized.

Source: "Chiller Plant Efficiency" (2010).

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TABLE 9.10

Design Strategies for a High-Efficiency Chiller Plant

1. *Improve chiller plant load efficiency.* Three methods for improving chiller plant load efficiency are: specify a chiller that can operate with reduced condenser water temperatures, specify a variable-speed drive for the compressor motor, and select the number and size of chillers based on anticipated operating conditions.
2. *Design efficient pumping systems.* Energy use in pumping systems can be reduced by sizing pumps based on the actual pressure drop through each component in the system as well as the actual peak water flow requirements, accurately itemizing the pressure losses through the system, and then applying a realistic safety factor to the total.
3. *Properly select the cooling tower.* Proper sizing and control of cooling towers is essential to efficient chiller operation. Cooling towers often are insufficiently sized for the task. An efficient cooling tower should be specified based on using realistic wet-bulb sizing criteria; an induced-draft tower, if space permits; intelligent controls; and sequences of operation that minimize overall energy use.
4. *Integrate chiller controls with building energy management system.* Although modern chillers are computer-controlled and have considerable intelligence to assist their operations, they should be integrated with the building's EMS to provide the capability to optimally operate the entire building energy plant. To accomplish this integration, the designers should specify an "open" communications protocol, use a hardware gateway, measure the power of ancillary equipment, and analyze the resultant data.
5. *Commission the system.* Commissioning a chiller system—that is, functionally testing it under all anticipated operating modes to ensure that it performs as intended—can improve efficiency and reliability and ensure that the owners are getting the level of efficiency they paid for.

Source: Adapted from "Chiller Plant Efficiency" (2010).

in greening their buildings during the course of routine operations and maintenance, design options for improving air distribution efficiency include: (1) variable air volume (VAV) systems, (2) VAV diffusers, (3) low-pressure ductwork design, (4) low-face velocity air handlers, (5) proper fan sizing with VFD motors, and (6) positive-displacement ventilation systems. VFD motors permit the speed of the motors to be matched to the exact amount of air required, which can produce enormous savings when the system is operating at less than peak load.

ENERGY RECOVERY SYSTEMS

Fresh air requirements for buildings mean that substantial quantities of fresh air are being brought into the facility while approximately the same amount of inside air is being exhausted to the outside. ASHRAE 62.1-2010, *Ventilation for Acceptable Air Quality*, governs the quantity of fresh air that is required for building operation. The energy costs for this exchange of air can be considerable. For example, on a 90°F (32°C) summer day in New York City, with 80 to 90 percent relative humidity, the hot, humid outside air is being brought into buildings for ventilation purposes. At the same time, inside air at 72°F (22°C), with 50 percent relative humidity, is being exhausted to the outside. Clearly, it would be useful to have devices that could cool down the outside airstream in summer with the air being exhausted and, conversely, heat outside air being brought into the building during the winter by using the energy in the relatively warm air being exhausted. Another approach is simply to use outside air directly for conditioning the building when outside air conditions are just right for that purpose. Two technologies, economizers and energy recovery ventilators (ERVs), have been developed to use outside air for conditioning and to exchange energy between fresh intake air and exhaust air streams. These approaches are described in the next sections.

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Economizers

One rather obvious way to save energy in a typical building is to use outside air to cool the building when weather conditions are appropriate. The concept is quite simple: Determine when the outside air temperature and humidity are in the same range as conditioned air delivered to the space would be, then duct the outside air to replace the conditioned airstream. The ductwork and dampers in the system are designed so that all the return air can be exhausted from the building. Chillers and chilled-water pumps can be turned off, thus saving as much as 20 to 30 percent of the energy that ordinarily would be invested in cooling.

Unfortunately, economizers have a rather high rate of operational failure. Dampers become corroded and stick in place, temperature sensors fail, actuators fail, and linkages malfunction. Estimates of the failure rate of economizers vary widely, but the consensus of experts, according to Energy Design Resources, is that only 25 percent may be functioning properly within a few years. Malfunctioning economizers actually can cause significant energy waste. For example, a system mistakenly being operated in economizer mode in the middle of summer in a hot climate, such as Florida or inland California, can increase the cooling load by over 80 percent due to the large quantities of outside air that must be cooled. In spite of this, economizers have huge potential if properly installed, commissioned, and maintained ("Economizers" 2000).

Energy Recovery Ventilators

Properly integrated desiccant dehumidification systems are cost-effective additions to many innovative high-performance building designs. An ERV is an energy and humidity exchanger that employs desiccant technology for its functioning. ERV devices are placed between fresh air and exhaust airstreams, moving energy and humidity between the two streams to save significant quantities of energy. Additionally, indoor air quality can be improved by higher ventilation rates, and desiccant systems can help to increase fresh air makeup rates economically. In low load conditions, outdoor air used for ventilation and recirculated air from the building must be dehumidified more than cooled (see Figure 9.19).

Desiccants are materials that attract and hold moisture, and desiccant air-conditioning systems provide a method of drying air before it enters a conditioned space. With the high levels of fresh air now required for building ventilation, removing moisture is exceptionally important. Desiccant dehumidification systems are growing in popularity because of their ability to remove moisture from outdoor ventilation air while allowing conventional air-conditioning systems to deal primarily with control temperature (sensible cooling loads).

The Air-Conditioning and Refrigeration Institute (ARI) developed a standard for ERVs, ARI 1060-2001, *Rating Air-to-Air Heat Exchangers for Energy Recovery Ventilation Equipment*, and ERV manufacturers should provide performance data in accordance with this standard. The device consists of a metal wheel coated with desiccant that rotates between the intake fresh air and exhaust airstreams. In summer, it dries and cools the hot, humid intake air with the cool, dry exhaust air from the building, saving significant quantities of energy, especially because the removal of moisture is accomplished via the desiccant, a very energy-efficient strategy.



Figure 9.19 The ERV manufactured by Greenheck, Inc., houses a desiccant wheel that rotates between fresh and exhaust air streams, exchanging energy and humidity and providing enormous energy conservation benefits. (Photograph courtesy of Greenheck, Inc.)

VENTILATION AIR AND CARBON DIOXIDE SENSORS

A healthy indoor environment is an important goal of green buildings. Creating a healthy interior requires that fresh outside air be brought into the building to dilute the buildup of potentially toxic components of indoor air. These toxic components include CO_2 from respiration, carbon monoxide from incomplete combustion of fuel, volatile organic compounds from building materials, and potentially others. The quantity of outside air required by ASHRAE 62.1-2010 for ventilation air is significant, and it must be either heated or cooled to allow it to remix with the supply airstream.

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Contemporary US buildings have two basic methods for providing fresh or ventilation air for their occupants. First, the system can be designed to provide a constant quantity of fresh air based on a conservative evaluation of the number of occupants and the building's operating conditions. This approach has the advantage of being fairly simple, but the problem is that in a building with a variable population, substantial quantities of energy are wasted to condition the fresh air. A better approach would be to determine how many people are in the building and introduce the appropriate quantity of ventilation air based on the number of occupants. The concentration of CO_2 provides an indicator of how many people are in the building. CO_2 is used as a surrogate ventilation index for diagnosing ventilation inefficiency or distribution problems. As the number of people in the space or the level of activity increases, so will the CO_2concentration. Increased concentration of CO_2 in a space is also linked to discomfort and an increased perception of odors. Sensors are available to detect the concentration of CO_2 in building spaces, and the data can be used as a surrogate for indoor air quality. The precise quantity of ventilation air needed to dilute the CO_2 to an appropriate level can be admitted to the space based on the measured CO_2 concentration. Buildings with populations that vary greatly can benefit from the use of this sensor technology because they can admit the exact amount of ventilation air needed, not the large quantities that would be required without this detection system.

Water-Heating Systems

In some buildings, water heating can consume large amounts of energy. In facilities with kitchens, cafeterias, health club facilities, or residences, there is heavy demand for hot water. Solar water heating and tankless water heaters are technologies that can be used to reduce the hot water demand; these are described in the next sections.

SOLAR WATER-HEATING SYSTEMS

An estimated 1 million residential and 200,000 commercial solar water-heating systems have been installed in the United States. Although there are many different types of solar water-heating systems, the basic technology is very simple. Sunlight strikes and heats an absorber surface within a solar collector or an actual storage tank. Either a heat transfer fluid or the actual potable water to be used flows through tubes attached to the absorber and picks up the heat from it. Systems with a separate heat transfer fluid loop must utilize a heat exchanger to heat the potable water. The heated water is stored in a separate preheat tank or a conventional water heater tank until needed. If additional heat is needed, it is provided by electricity or fossil fuel energy by the conventional water-heating system. By reducing the amount of heat that must be provided by conventional water heating, solar water-heating systems directly substitute renewable energy for conventional energy, reducing the use of electricity or fossil fuels by as much as 80 percent.

Today's solar water-heating systems are well proven and reliable when correctly matched to climate and load. The current market consists of a relatively small number of manufacturers and installers that provide reliable equipment and quality system design. A quality assurance and performance rating program for solar water-heating systems, instituted by a voluntary association of the solar industry and various consumer groups, makes it easier to select reliable equipment with confidence.

Solar water-heating systems are most likely to be cost-effective for facilities with water-heating systems that are expensive to operate or with operations such as laundries or kitchens that require large quantities of hot water. A need for hot water that is relatively constant throughout the week and throughout the year, or that is

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higher in the summer, is also helpful for solar water-heating economics. Conversely, hard water is a negative factor, particularly for certain types of solar water-heating systems, because it can increase maintenance costs and cause systems to wear out prematurely.

Although solar water-heating systems all use the same basic method for capturing and transferring solar energy, they use a wide variety of technologies. Systems can be either active or passive, direct or indirect, pressurized or nonpressurized. As a rough guide, the solar system should have 10 square feet (1 m^2) of collector area for every 14 gallons (50 liters [L]) of daily hot water usage, and the storage tank should have 1.4 gallons per square foot (50 L/m^2) of collector area. This corresponds to 40 square feet (4 m^2) of collector for every apartment suite in multiunit residential buildings and 10 square feet (1 m^2) of collector for every five office workers in an office building.

TANKLESS (INSTANTANEOUS) WATER-HEATING SYSTEMS

Tankless, or instantaneous, water heaters eliminate the need for hot water storage by supplying energy at the point of demand to heat water as it is being used. Clearly, this takes high energy input, either electric or gas, at the point of use, but energy losses from storage tanks are eliminated. Unlike storage water heaters, tankless water-heating systems theoretically can provide an endless supply of hot water. The actual maximum hot water flow is limited by the size of the heating element or thermal input of the gas heater.

Demand water heaters, common in Japan and Europe, began appearing in the United States about 30 years ago. Unlike conventional tank water heaters, tankless water heaters heat water only as it is used, or on demand. A tankless unit has a heating device that is activated by the flow of water when a hot water valve is opened. Once activated, the heater delivers a constant supply of hot water. The output of the heater limits the rate of flow of the heated water.

Gas tankless hot water units typically heat more gallons per minute than electric units, but in both cases, the rate of flow is limited. Electric tankless heaters should use less energy than electric storage systems. But gas-fired tankless heaters are available only with standing pilot lights, which lower their efficiency. In fact, the pilot light can waste as much energy as is saved by eliminating the storage tank.

Tankless heaters have either modulating or fixed output control. The modulating type delivers water at a constant temperature, regardless of flow rate. The fixed type adds the same amount of heat, regardless of flow rate and inlet temperature.

Electrical Power Systems

In addition to the building's air-conditioning and heating systems, the lighting system and electric motors are major consumers of electrical energy. Major advances have been made in lighting fixture and lighting control technologies that can dramatically reduce energy consumption. Because electric motors in buildings drive fans, pumps, and other devices, using the most energy-efficient motor can result in substantial energy savings. The next sections describe advances in lighting and motor technology that can produce substantial energy savings in buildings.

LIGHTING SYSTEMS

Lighting is a voracious consumer of electrical energy, consuming on the order of 30 percent of total building electrical energy in the United States; thus, a primary goal of all designs should be to reduce dependence on artificial light and to maximize

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the use of daylighting. These efforts should become an integrated strategy (i.e., natural and powered lighting should be combined to provide high-quality, low-energy illumination for the building's spaces).

When specifying lighting, several technical terms are used for selecting the most energy-efficient and effective system for the application: efficacy, Color Rendering Index (CRI), and color temperature. These three terms are defined next.

Efficacy is used as the measure of lighting efficiency, and it is measured in lumens per watt (lm/W) or light output per energy input. Clearly, higher efficacy means a more energy-efficient lighting system. Fluorescent lamps have efficacies that range from 80 to 93 lm/W, while light-emitting diode (LED) technology has a maximum efficacy of 200 lm/W.

CRI describes how a light source affects the appearance of a standardized set of colored patches under standard conditions. A lamp with a CRI of 100 will not distort the appearance of the patches in comparison to a reference lamp, while a lamp with a CRI of 50 will distort colors significantly. The minimum acceptable CRI for most indoor applications is 70; levels above 80 are recommended.

Color temperature influences the appearance of luminaires and the general "feel" in the space and is expressed in kelvins (K). Low color temperature (e.g., 2,700 K) provides a warm feel similar to that of light from incandescent lamps; 3,500 K provides a balanced color; and 4,100 K emits "cooler," bluish light. Standardizing the color temperature of all lamps in a room or facility is recommended.

FLUORESCENT LIGHTING

Fluorescent lighting is still used for many building lighting applications because it is efficient and can be switched and controlled easily. Modern linear fluorescent lamps have good color rendering and are available in many styles. Lamps are classified by length, form (straight or U-bend), tube diameter (e.g., T-8 or T-5), wattage, pin configuration, electrical type (rapid or instant start), CRI, and color temperature. When specifying a lighting system, it is important that the lamp and ballast are electrically matched and the lamp and fixture are optically matched.

Fluorescent lamp diameters are measured in ⅛-inch (0.3-centimeter [cm]) increments—for example, T-12s are 12/8 inch (3.2 cm) or 11/2 inch (3.8 cm) in diameter, and T-8s are 1 inch (2.5 cm) in diameter. Typical linear fluorescent lamps are compared in Table 9.11; note that efficacy (lumens per watt) is higher with smaller-diameter lamps.

T-5 lamps are designed to replace T-8 fluorescent lamps. The T-5 lamp operates exclusively with electronic ballasts and offers continuous dimming. It has an efficacy of about 93 lm/W, compared to the 89 lm/W achievable with T-8 lamps. Most manufacturers use internal protective shield technology to minimize light depreciation to a

TABLE 9.11

Fluorescent Light Fixture Characteristics

Lamp Type	T-12	T-12 ES	T-8	T-5*
Watts	40	34	32	54
Initial lumens	3200	2850	2850	5000
Efficacy (lumens/watt)	80	84	89	93
Lumen depreciation†	10%	10%	5%	5%

*High-output T-5 in metric length.
†Change from initial lumens to design lumens.
Source: From Philips Lighting; excerpted from *Greening Federal Facilities* (2001).

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predicted 5 percent over the life of the lamp. This technology has made it possible to reduce the mercury content of lamps to about 3 milligrams, compared to the previous 15 milligrams.

Color rendering of fluorescent lamps is very important. Modern, efficient fluorescent lamps use rare-earth phosphors to provide good color rendition. T-8 and T-5 lamps are available only with high-quality phosphors that provide CRIs greater than 80. Electronic ballasts with linear fluorescent lighting should be specified. Electronic ballasts are significantly more energy efficient than magnetic ballasts and eliminate the hum and flicker associated with older fluorescent lighting. Dimmable electronic ballasts are widely available.

Luminaires should be selected based on the tasks being performed. Reflectorized and white industrial fixtures are very efficient and good for production and assembly areas but are usually inappropriate for office applications. Lensed fluorescent fixtures (prismatic lens style) typically result in too much reflected glare off computer screens to be a good choice for offices. In areas with extensive computer use, the common practice is to install parabolic luminaires, which minimize high-angle light that can cause reflected glare off computer screens; however, these luminaires may result in unpleasant illumination in rooms with dark ceilings and walls. Instead, for ceilings over 9 feet (2.7 m) in height, direct/indirect pendant luminaries should be used. For lower ceilings—8 feet 6 inches (2.6 m) in height—parabolic luminaires with semi-specular louvers should be considered.

Luminaires should not be selected solely on the basis of efficiency. A very high-efficiency luminaire can have inferior photometric performance. The most effective luminaires are usually not the most efficient, but they deliver light where it is most needed and minimize glare. The Luminaire Efficiency Rating (LER) used by some fluorescent fixture manufacturers makes it easier to compare products. Since the LER includes the effect of the lamp and ballast type as well as the optical properties of the fixture, it is a better indicator of the overall energy efficiency than simple fixture efficiency. An LER of 60 is good for a modern electronically ballasted T-8 fluorescent fixture; 75 is very good and is close to state of the art.

Fiber-Optic Lighting

Fiber-optic lighting utilizes light-transmitting cable fed from a light source in a remote location. A fiber-optic lighting system consists of an illuminator (light source), fiber-optic tubing, and possibly fixtures for end-emitting uses. When light strikes the interface between the core and the cladding of the cable, total internal reflection occurs, and light bounces or reflects down the fiber within the core. Two types of fiber are used: small-diameter strands bundled together or a solid core (the latter type is more limited in application). The lighting source is generally a halogen or metal halide lamp. Fiber-optic lighting is generally energy-efficient and provides illumination over a given area. The only electrical connection needed for the system is at the illuminator. No wiring or electrical connection is required along any part, either at the fiber-optic cable or at the actual point source fixture.

Fiber-optic lighting systems provide many benefits and eliminate many problems encountered with conventional lighting systems. Infrared and ultraviolet wavelengths produced by a given light source are undesirable by-products, and fiber-optic systems can filter these out, eliminating the damaging effect of ultraviolet and infrared radiation. Fiber-optic lighting requires no voltage at the fixture, is completely safe, emits no heat, and is virtually maintenance-free. This lighting technology is especially useful for retail settings, supermarkets, and museums because it emits no heat or ultraviolet radiation (see Figure 9.20).

Light-Emitting Diodes

LEDs for lighting systems are evolving very rapidly, and white-light LEDs are now being produced that can be used in many building applications. LEDs are based on

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Figure 9.20 Fiberstars' Efficient Fiber Optic (EFO) lighting, shown in Trammell Crow's office in Houston, Texas, is low energy, lightweight, and ultrasafe because it does not conduct electricity. The manufacturer claims that a single EFO lamp uses 68 W and replaces about 400 W of halogen lamps. (Photograph courtesy of Fiberstars, Inc.)

semiconductors that emit light when current is passed through them, converting electricity to light with virtually no heat generation. Until the early 1990s, red, yellow, and green LEDs were being produced. In the early 1990s, blue LEDs and then white LEDs were developed.

LEDs have an efficacy of up to 200 lm/W, compared to about 52 lm/W for incandescent bulbs. At present, linear fluorescent lights produce 80 to 93 lm/W and compact fluorescent light bulbs produce about 65 lm/W. LEDs are also very tough and durable and can absorb large shocks without malfunctioning. The color temperature appearance of LEDs has improved, with warm-white (2,700–3,000 K) and neutral-white (3,500–4,000 K) versions available. The CRI cited by leading LED manufacturers is now at least 80, which is the minimum recommended for indoor applications. With a projected lifetime of 50,000 hours, LEDs last 20 times longer than incandescent light bulbs and two to three times longer than fluorescent lights. However, LEDs become dimmer over time, and the actual useful life—defined as when the LED is emitting just 70 percent of its initial light output—is about 30,000 hours. This dimming phenomenon is known as *LED depreciation* and is caused by the heat generated at the internal junction in the LED. Costs of LED lights declined by half from 2009 to 2010, from $36 to $18 per thousand lumens (kilolumens, or klm), and prices were about $2/klm in 2016. Some forecasts are that, by 2020, LED technology will be in 70 to 80 percent of all building lighting applications (see Figures 9.21 and 9.22).

LIGHTING CONTROLS

Ideally, lighting controls should comprise an integrated system that performs two basic functions:

1. Detects occupancy and turns lights on or off in response to the presence or absence of occupants.
2. Throttles lights up and down or turns lights on and off to compensate for levels of natural light provided by the daylighting system.

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Figure 9.21 An intelligent LED lighting system by Color Kinetics and 4 Wall Entertainment illuminates the exterior of the Hard Rock Hotel and Casino in Las Vegas, Nevada, cutting annual energy costs by 90 percent. (Photograph courtesy of 4Wall Entertainment)

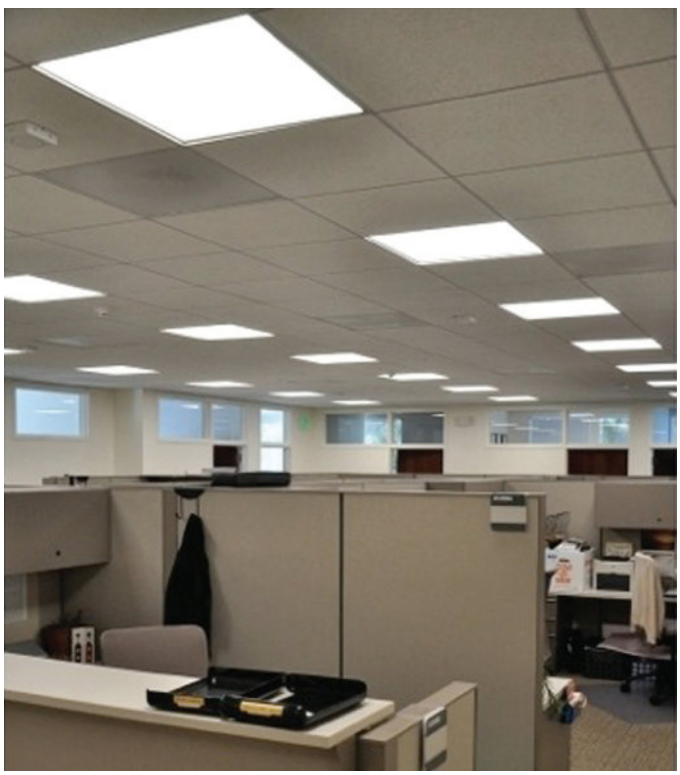


Figure 9.22 LED lighting is now available as architectural grid lay-in lighting that measures 2 feet by 2 feet. (Photograph courtesy of Lunera Lighting, Inc.)

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Research has shown that daylight-linked electrical lighting systems—such as automatic on/off and continuous dimming systems—have the potential to reduce the electrical energy consumption in office buildings by as much as 50 percent.

There are two basic types of daylighting control systems: dimming and switching. Dimming controls vary the light output over a wide range to provide the desired light level. Switching controls turn individual lamps off or on as required. In a conventional two-lamp fixture, there are three settings: both lamps off, one lamp on, both lamps on. The same strategy can be used with three- and four-lamp fixtures. Dimming systems, which require electronic dimmable ballasts, are more expensive than switching systems; however, they achieve greater savings and do not have the abrupt changes in light level characteristic of switching systems. Dimming systems are best suited to offices and schools and those areas where deskwork is being performed. Switching systems can be used in areas with high natural light levels (e.g., atria and entranceways) and where noncritical visual tasks are being performed (e.g., cafeterias and hallways).

Of course, neither system is appropriate in nondaylit areas. The lighting control zones and number of sensors need to be carefully designed. At least one sensor is required for each building orientation. The lighting control zone should be only as deep into the building as is effectively daylit—about 16 feet (5 m) from windows in conventional office plans. Light shelves can extend the daylit zone deeper into the building's interior.

In addition to energy savings, electric light dimming systems offer two other advantages over conventional lighting systems. First, conventional lighting systems typically are designed to initially overilluminate rooms, to account for the 30 percent drop in lighting output over time. Electric light dimming systems automatically compensate for this reduced output to give a constant light level over time. Second, daylighting controls can be adjusted to give the desired light level for any space. Thus, when floor plans are changed, it is easy to adjust the light levels to meet the lighting needs of each area, provided that the system is properly zoned and has adequate lighting capacity.

The cost of switching controls is quite modest, and these systems should be considered in all applications where changes in light level can be tolerated. Dimming lighting controls are approximately twice the price of switching controls and require electronic dimmable ballasts.

ELECTRIC MOTORS

Electric motors are important components of modern buildings, as they drive fans, pumps, elevators, and a host of other devices. Over half of all electrical energy in the United States is consumed by electric motors. Motors typically consume 4 to 10 times their purchase cost in energy each year, so energy-efficient models often make economic sense. For example, a typical 20-horsepower, continuously running motor uses almost $8,000 worth of electricity annually at 6 cents per kWh, about nine times its initial purchase price. Improving the efficiency of electric motors and the equipment they drive can save energy and reduce operating costs.

The construction materials and the mechanical and electrical design of a motor dictate its final efficiency. Energy-efficient motors utilize high-quality materials and employ optimized design to achieve higher efficiencies. Large- diameter copper wire in the stator and more aluminum in the rotor reduce resistance losses of the energy-efficient motor. An improved rotor configuration and an optimized rotor-to-stator air gap reduce stray load losses. An optimized cooling fan design provides ample motor cooling with a minimum of windage loss. Thinner and higher-quality steel laminations in the rotor and stator core allow the energy-efficient motor to operate with substantially lower magnetization losses. High-quality bearings result in reduced friction losses.

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Innovative Energy Optimization Strategies

At least partially because of the green building revolution, a wide variety of innovations in building systems are emerging. Four of the more innovative approaches are described here: (1) radiant cooling, (2) ground coupling, (3) renewable energy systems, and (4) fuel cells. Each of these is a cutting-edge strategy that can have a marked effect on energy consumption if used properly in a building.

RADIANT COOLING

In the United States, cooling generally is delivered to conditioned spaces using air that is pressurized by fans and delivered via ductwork to the various spaces. Because air has a very low heat capacity, rather large quantities of air must be delivered to a space to provide the needed cooling effect. Additionally, air, a compressible medium, is relatively energy-intensive to move, compared to water, which is incompressible, has very high heat capacity, and can be moved comparatively cheaply via pumping. That is why, in Europe, radiant cooling often is used for cooling spaces. These systems use water, which has 3,000 times the energy transport capacity of air, as the medium for delivering cooling to the space. In Germany, radiant cooling systems have become the new standard.

Radiant cooling systems circulate cool water through tubes in ceiling, wall, or floor elements or panels. The water temperature does not differ noticeably from the room temperature, so care must be exercised to ensure that the temperature of the circulated water does not reach the dew point of the air in the space. Otherwise, condensation will occur, resulting in moisture problems. The cost of a radiant cooling system is approximately the same as that of a VAV system, but the life-cycle savings are 25 percent higher compared to those of a VAV system. Moreover, the energy required for circulating water is only about 5 percent of the energy needed to circulate a comparable capacity of air.

There are three main types of radiant cooling systems (see Figure 9.23):

1. *Concrete core.* Plastic tubes are buried in concrete floor and ceiling slabs.
2. *Metal panels.* Metal tubes are connected to aluminum panels.
3. *Cooling grids.* Plastic tubes are embedded in plaster or gypsum.



Figure 9.23 Radiant cooling panels provide a low-energy solution for cooling, requiring only a fraction of the energy of a conventional system based on air handling and ductwork. (A) A dropped-panel installation showing a radiant cooling panel installation and ease of maintenance. (B) Installing a cooling mat: grids of plastic tubing carrying chilled water are placed under the ceiling drywall. (Photographs courtesy of Juan Rudek, Karo Systems)

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The metal panel system is the most commonly used radiant cooling system. Due to its metal construction, it has a relatively fast response time to changing conditions. Cooling grids are generally the choice for retrofit projects because the grid of plastic cooling tubes can be placed easily in plaster or gypsum in existing walls. As a guide to system sizing, the total heat transfer rate (combined radiation and convection) is about 11 W/m^2/°C (0.7 W/ft^2/°F) temperature difference for cooled ceilings.

Five design guidelines for radiant cooling systems are listed next.

1. The building should be well sealed.
2. In humid areas, the intake fresh air should be dehumidified prior to its entry into conditioned spaces.
3. Radiant cooling requires a large surface area due to the relatively small temperature difference between the cooling surface and the room air.
4. The set points for cooling and heating must be considered carefully to deliver maximum conditioning without causing moisture problems. For instance, for a typical system in Germany, during the cooling season, the room temperature set point is about 80°F (27°C), with cold or chilled water entering the radiant cooling panels at 61°F (16°C) and leaving at 66°F (19°C). For heating, the room set point is 68°F (20°C), with heated water delivered at 95°F (35°C) and leaving the radiant panels at 88°F (31°C).
5. Humidity sensors should be used to detect when the temperature of the supply water is approaching the dew point to activate valves that will prevent condensation from occurring.

GROUND COUPLING

One innovative method for reducing energy consumption in a building is ground coupling, in which the thermal characteristics of Earth and groundwater in the vicinity of the building are used for cooling and heating purposes. There are two major methods for applying ground coupling for building conditioning: (1) direct and (2) indirect. In the direct approach, groundwater is employed in radiant cooling systems, and fresh air is cooled through ground contact. The indirect approach employs heat pumps in conjunction with the ground or groundwater to move heating and cooling energy between the building and Earth. It is feasible, for example, to use groundwater in the 60°F (16°C) range in a radiant cooling system for a building and virtually eliminate the need for a chilled-water plant. The next sections describe these two approaches.

Ground Source Heat Pumps

Ground source heat pump systems use the ground as a heat source in the heating mode and as a heat sink in the cooling mode. The ground is an attractive heat source or sink compared to outdoor air because of its relatively stable temperature. In many locations, the soil temperature does not vary significantly over the annual cycle below a depth of about 6.5 feet (2 m). For example, in Louisiana, outdoor air temperatures may range from wintertime lows of 32°F (0°C) or lower to summertime highs of about 95°F (33°C), while the soil temperature at depths greater than 6.5 feet (2 m) never falls below about 64°F (18°C) or rises to approximately 77°F (25°C), averaging around 68°F (20°C). A number of different methods have evolved for thermally connecting, or coupling, the heat pump systems with the ground, but the two major methods are horizontal systems and vertical systems. These systems depend on how the piping that makes ground contact is laid out.

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The *horizontal* ground coupling system uses plastic piping placed in horizontal trenches to exchange heat with the ground. Piping may be placed in the trenches either singly or in multiple-pipe arrangements. The primary advantage of horizontal systems is lower cost due to fewer requirements for special skills and equipment, combined with less uncertainty about subsurface site conditions. The disadvantages of the horizontal ground coupling system are its high land area requirements, its limited potential for heat exchange with groundwater, and the wider temperature swings of the soil at typical burial depths.

Vertical ground coupling is the most common system used in commercial- scale systems. Vertical U-tube plastic piping is placed in boreholes and manifolded in shallow trenches at the surface. Vertical ground coupling has several advantages: low land area requirements, stable deep-soil temperatures with greater potential for heat exchange with groundwater, and adaptability to most sites. Among the disadvantages of vertical ground coupling are potentially higher costs, problems in some geological formations, and the need for an experienced driller/installer. The regulatory requirements for vertical boreholes used for ground coupling heat exchangers vary widely by state. One note of caution to the designer is that some regulations, installation manuals, and/or local practices call for partial or full grouting of the borehole. The thermal conductivity of materials normally used for grouting is very low compared to the thermal conductivity of most native soil formations. Thus, grouting tends to act as insulation and hinders heat transfer to the ground.

In addition to ground-coupled heat pumps, systems that use both surface water and groundwater have been successful. In fact, for commercial-scale applications, if groundwater is available in sufficient quantities, it should be considered as the first alternative, as it often turns out to be the least costly method.

Direct Ground Coupling for Fresh Air and Chilled Water

It is also possible to heat and cool fresh air being introduced into a building by bringing it in underground through large-diameter, 3- to 7-ft (1- to 2-m) galvanized steel tubes, known as *earth-to-air heat exchangers*. Additionally, groundwater sometimes can be used as the source of chilled water, reducing or eliminating the need for mechanical chilled-water systems. Both of these practices are becoming common in Germany, where buildings are routinely conditioned using a comprehensive ground coupling scheme. For example, a 50,000-square-meter (538,000-ft^2) Mercedes showroom in Stuttgart has all of its fresh air brought in at a velocity of about 155 meters (500 ft) per minute through a corrugated steel tube with a diameter of 1.8 meters (6 ft), the top of which is located 2 meters (6.6 ft) underground (see Figure 9.24). The ground temperature at this depth is a stable 60°F (16°C). In winter, cold outside air is warmed up to approximately the ground temperature prior to introduction into the building. In summer, hot outside air is significantly cooled prior to its introduction into the facility.

Where permitted by local jurisdictions, groundwater can be used directly in a radiant cooling system. The water temperature is adjusted by mixing valves or by employing a relatively small heat pumping system to move energy to and from the groundwater stream. The groundwater is pumped into the radiant cooling system and discharged back to the ground with only a few degrees of temperature change.

It is also feasible to design and install a ground coupling system that both conditions the fresh air being brought into the building and uses groundwater for a radiant cooling system. A well-designed ground-coupled HVAC system can provide significant savings by greatly reducing the requirements for equipment, ductwork, and air handlers.

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Figure 9.24 Ground-coupled system showing an air intake tube, 1.8 meters (6 ft) in diameter, under a Mercedes showroom in Stuttgart, Germany. The galvanized steel tube, which is 100 meters (325 ft) long, heats cold air via ground contact in winter and cools hot air in summer. The tube is located in a zone under the building where the temperature is a constant 16°C (60°F).

Renewable Energy Systems

Renewable energy can be generated on-site by three different techniques: PVs, wind energy, and biomass. Each of these has advantages and disadvantages and varying levels of complexity. A brief summary of each is provided in Table 9.12.

PHOTOVOLTAICS AND BUILDING-INTEGRATED PHOTOVOLTAICS

PV cells are semiconductor devices that convert sunlight into electricity. They have no moving parts. Energy storage, if needed, is provided by batteries. PV modules

TABLE 9.12

Advantages and Disadvantages of Renewable Energy Systems

Renewable Energy Type	Advantages	Disadvantages
Photovoltaics (PVs)	New technologies allow integration into building façade	Remains relatively expensive
	Price of PV modules is dropping as demand increases	Potential metering problems with local utility
Wind	Lowest kilowatt-hour cost of any renewable energy source	Generally large, unsightly generators
		Significant annual wind speed needed
Biomass	Can use local vegetation for fuel Potentially low-cost energy source	Systems for buildings are not readily available

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currently are providing electricity at hundreds of thousands of installations throughout the world. Especially exciting are building-integrated photovoltaic (BIPV) technologies that integrate PV cells directly into building materials, such as semitransparent insulated glass windows, skylights, spandrel panels, flexible shingles, and raised-seam metal roofing. PV elements can be fabricated in different forms. They can be used on or be integrated into roofs and façades as part of the outer building cladding, or they can be used as part of a window, skylight, or shading device. PV laminates provide long-lasting weather protection. Their expected life span is in excess of 30 years. Warranties currently are available for 20-year periods.

PV systems are modular in nature; hence, they can be adapted to changing situations. They usually can be added, removed, and reused in other applications. Typical modules consist of glass laminates, plastic Tedlar® bounding material, and silicon cells with trace amounts of boron and phosphorus. Their disposal or recycling after the end of their life span should not create any environmental problems.

A variety of attractive BIPV products are available that allow building surfaces, such as the roof, walls, skylights, and sunshades, to double as solar collectors. Integrating these products into the building envelope creates a large solar collection area, enabling solar power to displace more of the electricity used in the building. The cost of the PV system is offset by the fact that the BIPV products displace standard building envelope components. PVs can be integrated into the roofing system through PV roof shingles, roof tiles, and metal roof products, all of which can replace the standard roof. Alternatively, framed PV modules can be incorporated into the roofing system. BIPV glazing systems are available that allow sloped and overhead glazing to capture solar energy. These glazing systems are insulated and can be specified to provide the desired level of light transmission for daylighting, typically as needed per kilowatt of capacity.

Curtain walls offer considerable potential for BIPVs. A wide variety of PV products can be used in place of architectural spandrel glass and vision glass. Sunshades and skylights, common BIPV applications, have become popular in Europe. BIPV systems are available for sunshades and skylights that are visually transparent or provide partial shading. It is an easy upgrade to substitute preengineered BIPV sunshades for conventional sunshades. The look and color of these building-integrated PV products vary with the application and the type of solar collector technology. The most efficient solar collectors are deep blue to black in color, although BIPV products also are available in dark gray and medium blue; some manufacturers may produce custom-colored BIPV products for large orders.

Depending on the type of collection medium, BIPV can generate approximately 5 to 10 W of power per square foot (50–100 W/ m^2) of collector area in full sunlight. That means that a collector area of 100 to 200 square feet (10–20 m^2) typically is needed per kilowatt of capacity. The annual power output varies with the latitude and climate as well as with the orientation of the building surface that comprises the PV material. The annual energy output ranges from 1,400 to 2,000 kWh per kilowatt of installed system capacity. Figure 9.25 shows the BIPV system installed on the façade of Solaire, a 27-story luxury residential tower in New York City's Battery Park.



Figure 9.25 BIPVs in the Solaire building in New York City's Battery Park. The BIPVs are the specked surfaces between the windows. (Photograph courtesy of the Albanese Development Corporation)

WIND ENERGY

Wind energy is the fastest-growing form of energy production, with an estimated year-on-year growth of 25 percent. According to the DOE's National Renewable Energy Laboratory, the cost of wind energy to a utility has declined from $0.40/kWh in the 1980s to less than $0.025/kWh today. In 2002, the United States doubled the 1,700 megawatts (MW) of additional wind-generating capacity brought online in 2001. By the beginning of 2002, installed capacity in this country was over 4,200 MW, reaching over 10,000 MW in 2006. As of the end of 2014, the United States had 7,000 MW of cumulative installed wind capacity, 18 percent of the world's installed wind power. In

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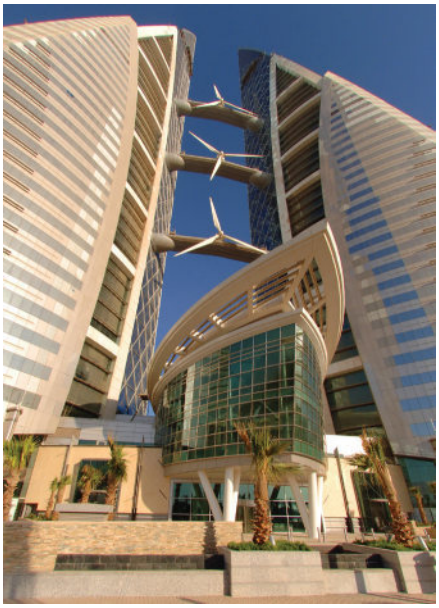




Figure 9.26 Three wind turbines, each 29 meters in diameter, provide 10 to 15 percent of the power needed to operate the Bahrain World Trade Center, which opened in 2007 in Manama, Bahrain. (Courtesy of Atkins)

the past few years, wind energy constituted 30 percent of all new installed capacity, and there are over 8,300 MW of wind energy projects under construction. The American Wind Energy Association has estimated that, with the support of the government and utilities, wind energy could provide at least 6 percent of the nation's electricity supply by 2020. The association estimates that ultimately 20 percent of US electricity demand could be met by wind energy. Texas has the highest wind energy capacity in the United States, about 12,400 MW in 2016, adding new capacity at the rate of over 1,000 MW per year. The reasons for this high installation rate was the Texas Renewable Portfolio Standard, which was available between 2005 and 2015, and which mandated installation of wind energy by utilities, and federal tax credits, which provide a $0.015/kWh write-off for the first 10 years of a project's operation.

Small wind turbines (those with less than 100 kW output) suitable for building-scale applications are available, and there are innovative programs that can make their incorporation into a building project financially feasible (see Figure 9.26). In 2015 a pair of vertical axis wind turbines were installed on the iconic Eiffel Tower in Paris. They are mounted about 400 feet (122 m) above the ground inside the metalwork of the tower and were painted to camouflage their appearance. These turbines produce about 10,000 kWh per year, enough to power many of the tourist areas in the tower, including restaurants, a souvenir shop, and history exhibits (see Figure 9.27).



Figure 9.27 Eiffel Tower wind turbine. (Courtesy of UGE International Ltd.)

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BIOMASS ENERGY

The term *biomass* refers to any plant-derived organic matter available on a renewable basis, including dedicated energy crops and trees, agricultural food and feed crops, agricultural crop wastes and residues, wood wastes and residues, aquatic plants, animal wastes, municipal wastes, and other waste materials. Handling technologies, collection logistics, and infrastructure are important aspects of the biomass resource supply chain.

Shifting part of the $50 billion now spent for oil imports and other petroleum products to rural areas would have a profoundly positive effect on the economy in terms of jobs created (for production, harvesting, and use) and industrial growth (facilities for conversion into fuels and power). David Morris of the Institute for Local Self-Reliance refers to using biomass as moving partway from a "hydrocarbon economy to a carbohydrate economy."[11]

Fuel Cells

Fuel cells are devices that generate electricity in a process that can be described as the reverse of electrolysis. In electrolysis, electricity is input to electrodes to decompose water into hydrogen and oxygen. In a fuel cell, hydrogen and oxygen molecules are brought back together to create water and generate electricity. The principle behind fuel cells was discovered in 1839, but it took almost 130 years before the technology began to emerge, first in the US space program and more recently in a host of new technologies and applications. Fuel cells provided power for onboard electronics for the *Gemini* and *Apollo* spacecraft and electricity and water for the space shuttles.

Fuel cells generally consist of a fuel electrode (anode) and an oxidant electrode (cathode) separated by an ion-conducting membrane. Fuel cells must take in hydrogen as a fuel, but any hydrogen-rich fuel can be processed to extract its hydrogen for fuel cell use. A device called a *reformer* is used to process nonhydrogen fuels to extract the hydrogen. This device reformulates nonhydrogen fuels such as gasoline, methane, diesel fuel, and ethanol to extract hydrogen from them. Due to their complexity, reformers are still very expensive. Some higher-temperature fuel cells can process some nonhydrogen fuels—methane, gasoline, and ethanol—directly without using the reformer.

There are several different types of fuel cells, including phosphoric acid, alkaline, molten carbonate, solid oxide, and proton exchange membrane (PEM) fuel cells. PEM fuel cells are of great interest because they operate at relatively low temperatures (below 200°F/93°C), have high power density, and can vary their output quickly to meet shifts in power demand. Current-generation fuel cells last anywhere from one to six years before they wear out or need an overhaul. Fuel cells are currently expensive to manufacture and depend on ongoing technological innovations to ensure their eventual economic viability. And, as noted, unless hydrogen is available as a fuel, a reformer must be utilized to process hydrogen-rich fuels to extract the hydrogen, an expensive additional component that adds considerable complexity to the fuel cell system.

For buildings and utilities, fuel cell power plants are beginning to make economic sense. The potential for home and commercial building power systems to use fuel cells, particularly in the United States in an era of utility deregulation, is quite high. An additional positive feature is that heat produced by some types of fuel cells can be used for thermal cogeneration in building power systems (see Figure 9.28).

Fuel cells specifically designed for building use are beginning to emerge. Plug Power is developing the GenSys fuel cell, which will produce electricity by using the

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Figure 9.28 An array of five PC25 PAFCs manufactured by UTC Power, Inc., powering a postal facility in Anchorage, Alaska. The PC25 provides about 200 kW of power, using natural gas as the fuel source. Waste heat generated by the PC25 can be used for heating applications or to create cooling using an absorption cycle chiller. (Photograph courtesy of UTC Power, Inc.)

hydrogen contained in natural gas or liquid petroleum gas (LPG).[12] For most building applications, this system has three major components:

1. A reformer that extracts hydrogen from the natural gas or LPG
2. A fuel cell that changes the hydrogen to electricity
3. A power conditioner that converts the fuel cell's electricity to the type and quality of power required for use in the building

Smart Buildings and Energy Management Systems

In its simplest form, a building's EMS is a computer with software that controls energy-consuming equipment to ensure that the building operates efficiently and effectively.[13] Many EMS are integrated with fire protection and security systems. A newer innovation, *smart buildings*, uses the concept of information exchange to provide a work environment that is productive and flexible. In each building zone, a building automation system and high-bandwidth cabling connect all building telecommunications; HVAC and refrigeration (HVAC&R) components; fire, life, and safety systems; lighting; emergency or redundant power; and security systems. The smart building concept is important for consideration in green buildings because of the enormous demand for flexible layout and responsiveness, both afforded by smart buildings. A survey of building owners conducted by the Building Owners and Managers Association found that there were 13 systems desired by tenants of smart buildings (see Table 9.13). In addition to the items on this list, also in demand today is the capability for wireless technologies to enable telecommunications and Internet connections. EMS can produce substantial energy savings, on the order of 10 percent of building energy consumption.

Modern smart buildings also use DDCs to control the growing variety of devices and control systems in the building's HVAC&R systems. In addition to controlling systems based on temperature and humidity, DDCs permit the integration of information about air quality and CO_2levels. Digital systems can process and store

TABLE 9.13

Building Systems Typically Found in a Smart Building
Fiber-optics capability
Built-in wiring for Internet access
Wiring for high-speed networks
Local area network and wide area network capability
Satellite accessibility
Integrated digital services network
Redundant power source
Conduits for power/data/voice
High-tech, energy-efficient HVAC system
Automatic on/off sensor in the lighting system
Smart elevators that group passengers by floor designation
Automatic sensors installed in faucets/toilets
Computerized/interactive building directory

Source: Adapted from "What Office Tenants Want" (2000)

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information and manage complex interrelationships between components and systems. Control of lighting systems can be accomplished with DDC systems that allow occupant control of lighting, a prime feature of smart buildings.

Ozone-Depleting Chemicals in HVAC&R Systems

Of the many building systems, mechanical systems used for generating cooling and for fire protection employ the largest quantity of ozone-depleting chemicals. Removing these chemicals from building inventories and replacing systems with new products that use non-ozone-depleting chemicals are priorities. This section describes the replacement of refrigerants in air-conditioning systems with newer technologies that do not impact the ozone layer.

Before 1986, the chemicals known as chlorofluorocarbons (CFCs) were commonly used as refrigerants in chillers, mechanical devices that are used to generate cooling; CFC-11 and CFC-12 were the two most common CFCs used. Then, in 1986, their release into the atmosphere was found to be a major cause of destruction of the ozone layer, and international treaties soon called for their phase-out. The impact of CFCs on the ozone layer is indicated in terms of a quantity called the *ozone depletion potential* (ODP). The ODP is defined as 1.0 for CFC-11, meaning that a substance with an ODP of 10.0 depletes ozone at 10 times the rate of CFC-11. Other typical CFCs have a value of 1.0. For hydrochlorofluorocarbons (HCFCs), the ODP ranges from about 0.02 to 0.11 (or about 10–50 times less impact than that caused by CFCs).

Several families of chemicals have been used to replace CFCs, among them HCFCs and hydrofluorocarbons (HFCs). Although HCFCs are a great improvement over CFCs, they still have relatively high ODPs. HFCs, in contrast, have a zero ODP and, as a result, have no impact on the ozone layer. HFC-containing equipment is available from all major manufacturers. HFC-134a has become the dominant refrigerant, replacing HCFC-123 and HCFC-22 in most chillers designed for building use. HCFC-22 currently is used in a large proportion of positive-displacement compressor-based chillers and in some larger-tonnage centrifugal chillers. These uses predate the 1987 Montreal Protocol, which banned the use of ozone depleting chemicals, but will be phased out as part of the overall HCFC phase-out. In the United States, HCFC-22 was phased out for use in new equipment as of January 1, 2010.

According to the Carrier Corporation, HFC-134a has proven to be an optimal refrigerant in chiller applications because it has no chlorine molecules and does not contribute to ozone depletion. HFC-134a is a highly efficient thermodynamic refrigerant in application. Current centrifugal chillers using HFC-134a are 21 percent more efficient than chillers sold just six years ago and 35 percent more efficient than the chillers installed during the 1970s and 1980s. Because HFC-134a is a positive-pressure refrigerant, pressure vessels using it must conform to the American Society of Mechanical Engineers pressure code, and every step in their construction must be inspected by third-party insurance companies. As a result of the stringent testing and applied technology, chiller leak rates can be lowered to less than 0.1 percent annually. Existing chillers have a leak rate of 2 to 15 percent. HFC-134a also has a smaller molecular mass than the past CFCs and HCFCs. This is an important feature, as it results in an overall product size that is 35 to 40 percent smaller, a size reduction that helps offset the cost of construction and facilitates the use of smaller interconnecting pipes. This advantage has led to the addition of isolation valves to the chiller piping connection so that the HFC-134a can be stored in the chiller during service. This feature gives the end user the option of never having to remove the refrigerant from the vessels once charged, a real "no emissions" feature. An additional advantage of HFC-134a chillers is their smaller size, requiring much less plant space than the CFC-11 chillers they replaced.

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Case Study: River Campus Building One, Oregon Health and Science University, Portland

Medical facilities pose significant challenges and provide enormous opportunities for high-performance building project teams. Although they generally are far more complex than other building types and have special requirements for controlling the movement of viruses and other pathogens that can result in the transmission of disease, they also have the potential for contributing to health and well-being by virtue of their design. In expanding its main campus in Portland, the Oregon Health and Science University required a new 400,000-square-foot, 16-story medical office and wellness building, which was named River Campus Building One. In addition to a two-story wellness center, the building houses several different types of university operations, including biomedical research, clinical space, an outpatient surgery, and educational space. The medical offices are built atop a three-level, below-grade parking structure (see Figure 9.29).

The project team included the Portland office of Interface Engineering, Inc., a multidisciplinary engineering firm that provided HVAC, plumbing, electrical, power and backup power distribution, lighting, security, energy, telecommunications, data, and fire alarm systems design as well as all tenant improvements and basic commissioning. Interface Engineering's project team was instrumental in River Campus Building One's receiving a LEED platinum certification from the US Green Building Council. How this project team helped achieve this rating through a holistic approach to the design of these technical systems is an excellent case study on how to create a low-energy building.

PROJECT BUDGET

The total project was initially budgeted at $145.4 million, with $30 million allocated for the building's mechanical, electrical, and plumbing (MEP) systems. Interface's MEP design approach resulted in savings of nearly $4 million of the initial $30 million budget. What was truly remarkable in this project is that energy consumption was reduced about 60 percent compared to the baseline model while at the same time the capital cost of the MEP systems was reduced 10 percent. Conventional wisdom is that high-performance MEP systems will cost more than their code-compliant alternatives. For River Campus Building One, Interface's engineering team did indeed "tunnel through the cost barrier," as Paul Hawken, Amory Lovins, and L. Hunter Lovins suggested was possible in their book *Natural Capitalism* (1999).



Figure 9.29 The Oregon Health and Science University's River Campus Building One, shown in the late stages of construction, is a LEED-NC 2.1 platinum certified building. (Courtesy of Interface Engineering)

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STRATEGY: INTEGRATED DESIGN

Achieving a win-win combination of lower energy consumption and lower capital costs for energy systems is a difficult but clearly achievable strategy. Interface was able to reach this holy grail of sustainable design using an integrated design approach. As articulated for the River Campus Building One project, integrated design is different from conventional design in two key respects:

1. Goal setting starts early in the sustainable design process, during the programming and conceptual design phases and
2. The entire design team is involved in the process much earlier than is usually the case so that engineers can provide inputs to architectural decisions that affect energy and water consumption, as well as indoor air quality.

For River Campus Building One, this meant that several disciplines were able to collaborate early in the design regarding the green roof, PV, and rainwater harvesting system. This early collaboration started with an eco-charrette in which participants and stakeholders from diverse backgrounds helped craft ambitious goals for the project. One of the goals that emerged was a 60 percent reduction in energy consumption relative to that of a comparable building (see Table 9.14).

Making key decisions early in the design process allowed the design team to focus on collaboration to ensure their implementation. The abundant rainfall in Portland and the facility's large roof area meant that rainwater could be used for nonpotable water uses, including cooling tower makeup water. Moderate temperatures allowed the use of outside air to flush and precondition the building at night. Due to Oregon's generous tax credits for renewable and alternative energy systems, the team also opted for PV panels on the south side of the building and a microturbine system in the central utility plant. Integrated design also allowed the design team to eliminate solutions that were not feasible early on—for example, roof-mounted, vertical-axis wind turbines.

DETAILS—HOW INTERFACE APPROACHED THE MECHANICAL SYSTEMS DESIGN

The Interface team had two core principles guiding the mechanical design: (1) optimum health and (2) reduced energy use. To achieve this, the engineers followed the basic sustainable engineering dictum laid out by Amory Lovins: optimize the system, not the subsystems. Doing otherwise—that is, optimizing the subsystems without considering the system as a whole—inevitably produces suboptimal results. Applied to buildings, the system includes all components of the building that affect energy consumption: the mass and orientation of the building, its envelope (thermal resistance, fenestration, roof, infiltration, shading), its plug loads (computers, printers, copiers, and other plug-in devices), its air delivery systems, the lighting system

TABLE 9.14

The Interface Team's Back-of-the-Envelope Goals for River Campus Building One

Load	Oregon Energy Code kBTU/SF/yr*	Percent	Target Savings, kBTU/SF/yr*
Heating	35	27	22
Cooling	10	7.7	5
Fans	6	4.6	2
Hot water	30	23	28
Lighting	30	23	15
Equipment	15	11.5	5
Exterior lighting	4	3	1
Totals	**130**	**100%**	**78**

*Thousands of BTU per square foot per year.

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(lights and lighting controls), the cooling and heating plant, fans, motors, pumps, piping and duct sizing, and layout. In many cases, energy efficicent system design calls for challenging conventional wisdom. For example, mechanical engineers use tables that assume an embedded level of friction loss for fluids such as air and water circulated in pipes or ductwork. Lowering the acceptable friction loss may result in the use of larger-diameter pipes and larger cross-sectional ducts or the selection of smoother pipes with less friction per unit length.

Early on, the team examined the building's energy profile and worked with the architects to optimize the building's envelope. The team used the BetterBricks Integrated Design Lab in Portland to study year-round shading, including the shading effects of adjacent buildings. As a result, River Campus Building One was designed so that windows were shaded in the summer but sunlight was allowed to warm the interior during the winter. Sunshades and building PV panels were used to assist in the shading above the fourth floor.

Plug loads from computers, printers, and other devices were examined to ensure that the selection of these components contributed to the 60 percent energy reduction goal. Similarly, all fans, water heaters, pumps, and motors were selected to support the energy-conserving goals of the team.

Computational fluid dynamics (CFD) models were used extensively to explore approaches to natural ventilation and the building's air distribution approach. A whole-building CFD model allowed the team to determine wind pressures on each face and optimize a natural ventilation strategy. CFD models also were used in making the decision to select a positive-displacement ventilation system for patient examination rooms (see Figure 9.30). Similarly, the supply air temperature for the examination rooms was selected based on CFD modeling, allowing the temperature to be raised from a typical 55° to 60°F (13°–16°C). In addition to lower energy costs, this permits the more extensive use of the typically temperate outside air in the Pacific Northwest to cool the building (see Figure 9.31).

In short, the Interface team, by collaborating with the project architects, was able to design a downsized mechanical system. As part of this process, the engineers also bought into the notion of right-sizing the mechanical system rather than oversizing the system to accommodate hypothetical unknowns. The team accomplished this by: (1) eliminating excessive safety factors, (2) calculating heating and cooling demands

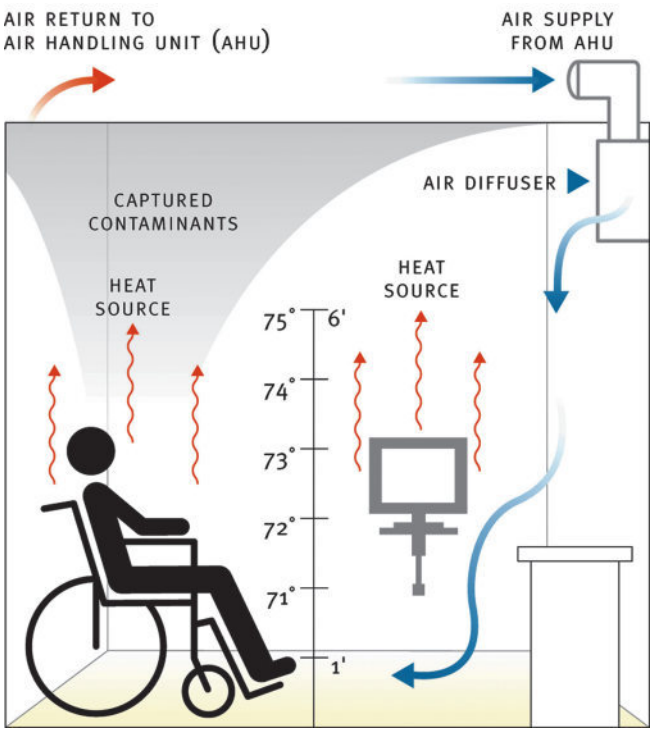


Figure 9.30 CFD modeling of patient examination rooms indicates the waterfall effect of cool incoming air falling down the walls, pooling on the floor, and then rising as it is heated by people, computers, and lights. (Courtesy of Interface Engineering)

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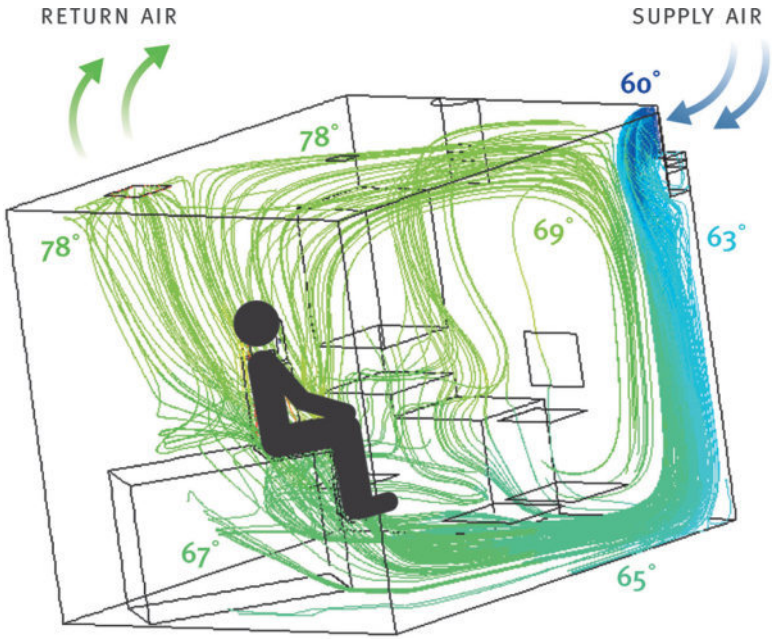


Figure 9.31 Modeling of patient examination room temperatures aided the Interface team in deciding to raise the supply temperature to 63°F (17°C), creating a more comfortable examination room with less air movement. (Courtesy of Interface Engineering)

using basic physics rather than simply applying conventional HVAC rules of thumb, (3) assuming nothing and proving everything, (4) building in expansion capabilities rather than trying to accomplish everything at the beginning, and (5) challenging restrictive codes that add cost without benefit by making successful appeals.

Right-sizing is just one of eight design points articulated by Andy Frichtl, PE, the lead engineer for River Campus Building One. The other seven design points he advocates are:

1. Transferring savings in HVAC systems to other important aspects of the project
2. Using free resources, such as the sun, wind, ground temperature, and groundwater to reduce building energy consumption
3. Reducing the demand for heating and cooling by superior envelope design, reduction in plug loads, and providing high-efficiency appliances and other devices
4. Shifting loads from peak to off-peak periods by using energy storage strategies
5. Challenging standard practice by emphasizing comfort and health, which may also involve challenging building codes
6. Utilizing radiant space conditioning, which uses radiative rather than convective heat transfer, with significantly lower energy consumption
7. Relaxing comfort standards by allowing temperature and humidity set points to float within a specified comfort zone

The result of applying these strategies was a variety of energy-efficient design measures to achieve the high-performance goals of the project:

- Radiant cooling of the atrium and lobby ground floor using reclaimed rainwater and groundwater in the concrete slab
- Radiant cooling with an overhead chilled beam (see Figure 9.32)
- High-efficiency boilers and chillers
- Double-fan VAV air handlers and VFDs on most pumps and motors
- Demand-controlled ventilation using CO_2 sensors and occupancy sensors to prevent overventilating and overlighting unoccupied spaces
- Heat recovery systems, including laboratory and general exhaust
- Displacement ventilation for core exam and office areas
- Load shifting using a system of hot and cold water storage to reduce peak demand

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Figure 9.32 Chilled-beam systems are aluminum-finned copper assemblies through which water circulates, providing radiative cooling or heating and inducing airflow by convective effects. (Courtesy of Interface Engineering)

- Energy-efficient lighting fixtures and controls, incorporating daylighting where feasible
- Night-flush precooling with outside air
- Economizers for free cooling using outside air when outside temperatures permit

Chilled beams represent a potential breakthrough strategy for conditioning buildings. The HVAC systems employing this technology can be one-third the size of systems using forced air as the heat transfer medium. Although relatively new to the United States, radiant cooling systems are fairly standard practice in Germany. They can function passively using only radiant effects for cooling or, with the assistance of a fan passing air through the beam, provide convective cooling. The compact size of the chilled beams allows reduced floor-to-floor heights because larger ductwork is eliminated and the space required for mechanical rooms and shafts can be reduced. Although the beams cost $100 to $250 a lineal foot ($328–$820/m), the net result is reduced HVAC system costs and lower costs for architectural and structural elements.

INTEGRATING LIGHTING AND DAYLIGHTING SYSTEMS

A properly designed lighting system for a high-performance building should integrate daylighting, lighting fixtures, and lighting controls to provide a low-energy lighting solution. For River Campus Building One, the Interface team's goal was to reduce the typical lighting system's 23 percent share of the total energy use by 50 percent. Team members managed to achieve a 45 percent reduction in the actual building, a savings of 16 percent in total energy use. In the exam rooms, the standard two 1- to 4-foot (0.3- to 1.2-m) lensed fluorescent luminaires were replaced by a single lensed skydome, 48 inches (122 cm) in diameter, that mimics natural light. Combined wall switch/occupancy sensors turn on only half of the exam room lights, permitting the other half to switch on automatically when needed. Reduced lighting levels were specified for lobbies and other pass-through spaces. When there is adequate natural light, hallway daylight sensors switch off normal and emergency lighting. Outdoor lighting was significantly reduced using cutoff fixtures that also eliminate unnecessary light pollution. In the high-bay athletic club, lighting levels automatically switch down as more daylight becomes available. Occupancy sensors in stairwells switch lighting on and off to follow an occupant up or down, allowing the lighting to stay on for the minimum time needed for passage. Perimeter offices also have occupancy sensors and daylighting sensors.

INNOVATIVE SOLAR ENERGY APPLICATIONS: BIPV AND SOLAR AIR HEATER

The project team for River Campus Building One specified sunshades in the design of the south façade and used the sunshade surface for PV panels (see Figure 9.33).



Figure 9.33 The PV panels used in River Campus Building One were assembled at Benson Industries, a major supplier of curtain walls and exterior cladding systems for larger buildings. (Courtesy of Interface Engineering)

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In addition to using renewable energy for the building, PVs are subsidized by generous federal and many state incentives, such as tax credits, accelerated depreciation, and, in the case of Oregon, bonuses from the Oregon Energy Trust. These BIPV panels have a peak of 60 kW and produce about 66,000 kWh annually.

On the 15th and 16th floors of the building, the façade serves as a giant solar heater, 190 feet (58 m) long by 32 feet (9.8 m) high. Sheets of low-iron glass are located 4 feet (1.2 m) from the building skin. The air between the skin and glass is warmed by solar energy and then moved by air-handling units across a heat exchanger for use in preheating water for use in bathroom sinks and exam rooms. The integrated design approach used by the project team allowed the fusion of architecture and engineering to create this innovative water heating system. This system has the added benefit of serving as a Trombe wall, warming clinic and lab spaces in winter and reducing the amount of total heating energy. It requires almost no maintenance and has no replacement costs over time.

Acknowledgment

The River Campus Building One Case Study is used with the permission of Interface Engineering, Inc. It is also available from Interface Engineering in a comprehensive booklet, "Engineering a Sustainable World," published in October 2005.

THOUGHT PIECE: ADVANCING THE STATE OF THE ART IN BUILDING ENERGY MODELING

One of the key elements in developing very low-energy and carbon buildings is being able to accurately and dynamically simulate the energy performance of a facility and to be able to use this model to optimize its design. The emergence of building information modeling (BIM) as the best current construction documents tool for building design and construction is bringing with it a new era with new potential for creating plug-in energy models that use what amounts to the design drawings and data to create the model. In this thought piece, Ravi Srinivasan, an international expert on both BIM and energy modeling, discusses this new direction and the exciting outcomes that can be expected as a result of the fusion of these two ideas.

Building Energy Analysis: The Present and Future

Ravi Srinivasan, College of Design Construction and Planning, University of Florida, Gainesville



Building energy analysis (BEA) is widely used for both new and existing buildings nowadays. Several BEA tools are available to develop building ECMs for greater energy efficiency. BEA requires extensive data gathering of model inputs. It is essential to bypass arbitrary and/or incorrect inputs when using BEA tools. Quality inputs to BEA tools are central to energy estimating. This may be achieved through integrating quality control mechanisms in BEA procedures. The possibility of erroneous inputs increases when modeling large buildings as it involves tedious, oftentimes iterative and repetitive data inputs. Among other model inputs, plug load density values and building occupancy schedules are important. *Plug load density* relates to equipment energy use per unit area. Plug load densities can be calculated by using equipment nominal power data and diversity (or utilization) factors. Benchmarking plug load densities is not as easy as it may seem. The reason is that not

(continued)

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all equipment peaks at the same time as some may be in idle mode. Only a few building energy standards, guidelines, and technical reports discuss such densities. As more simulationists play a decision-making role for the design team, they tend to lean on building energy standards and guidelines for plug load densities. However, the recommended values of standards and guidelines vary, posing a challenge for early design decision making. Such discrepancies may lead to unrealistic determinations of energy use. Benchmarking of plug load densities will pave the way for instituting targets for trimming plug load densities in new and retrofit building projects. Recently plug load densities for K–12 schools were benchmarked under two new categories—classrooms with computers and classrooms without computers (Srinivasan, Lakshmanan, Santosa, and Srivastav 2011). Eighteen K–12 schools, including nine elementary, two middle, and seven high schools, were assessed for actual plug load densities. Additionally, for the same case study buildings, four existing approaches—National Renewable Energy Laboratory, Commercial Energy Services Network, ASHRAE 90.1-1989, and California Title 24—were evaluated for plug load densities. Results show under- and overestimation of plug load densities over actual densities calculated.

Similarly, the importance of building operating schedules cannot be understated. Any changes in operating schedules will significantly change the results. Among other building types, convention centers are complex to model with BEA tools owing to both their mix of spaces and their occupancy patterns. For one such BEA, the building operating schedules were developed based on the convention center's event calendar (Srinivasan, Lakshmanan, and Srivastav 2011). The model adapted adjusted ASHRAE hourly operating schedules for event, nonevent, and move in, move out days, and used the event calendar and actual occupancy data. This drilldown approach of replicating the event calendar proved effective in model calibration. Calibration revealed that the energy model had a monthly variance of less than 8 percent for electricity. The calibrated model was then used to evaluate an array of energy efficiency measures.

Although several BEA tools are available on the market, a single tool with up-to-date algorithms representing new, state-of-the-art technologies for building systems and controls is not available. Currently, it is the modeler who selects the "right" tool that closely attempts to represent the building systems and controls. Workarounds are developed to represent unavailable systems and controls wherever applicable. These workarounds are also limited to the capability of the selected tool. Moreover, rapid prototyping of new building systems and controls using current BEA tools is cumbersome as the entire simulation code needs to be executed rather than just portions of it. Wetter's (2011) argument of component-based modeling using Modelica (Mattson and Elmqvist 1997), an open-source language, offers a solution to this inherent modeling problem. The concept behind this type of modeling approach is the use of equation-based object-oriented modeling that allows the design and analysis of building energy and controls systems. The Buildings library contains dynamic and steady-state component models that are applicable for analyzing control algorithms to assess energy performance.* Using this library, rapid prototyping and improved representation of advanced building energy and control systems can be achieved. The Building Controls Virtual Test Bed (BCVTB), developed by the Building Technologies Department at Lawrence Berkeley National Laboratory (LBNL), may be used for enhanced collaboration. This test bed enables data exchange between simulation programs such as EnergyPlus and Radiance, allows integration with physical sensors polling real-time data, and accesses the Modelica-based Buildings library. Using this platform, manufacturers and advanced simulationists can develop new building energy and controls systems. The BCVTB platform can also be used to update the simulation algorithms using simple state machines. A few experiments were conducted to utilize the power of the Buildings library, BCTVB, and BEA tools by LBNL. Notable is the implementation of model predictive control (MPC) of the University of California's Merced chilled-water plant to reduce peak demand reduction (Haves et al. 2010). With the use of physical sensors, MPC predicts optimal solutions in real time. Results show improvement in chiller performance over the baseline policy. This investigation also revealed the significance of rapid development of new control algorithms and their implementation in real-world scenarios to improve actual performance.

Yet, in today's building design-construction-operation realm, there is still an impasse in sharing project files. One may recall two notable developments this past decade—the Industry Foundation Classes (IFCs), developed by the International Alliance for Interoperability, to describe building and construction industry data, and the green building XML (gbXML), originally developed by Green Building Studio, to facilitate the transfer of building properties stored in building information models (BIMs) to engineering analysis tools. In spite of such developments, the transfer of data from BIM to BEA tools has not materialized in its entirety. In other words, gbXML data exported from BIM tools are not fully compatible for executing whole-building energy simulation as one would develop and conduct in a BEA tool directly. At present, gbXML exported from BIM software, such as Revit Architecture 2012, Revit MEP 2012, and ArchiCAD 10, can be directly imported to BEA tools, such as Ecotect Analysis and Trane Trace 700. However, the gbXML exported from BIM software is not robust enough to populate all necessary model inputs to run a BEA tool without additional involvement of the designer. Well, then, whatever happened to the goals of interoperability? It is more than a decade since IFC and gbXML have been in development, and yet we notice this partial disconnect—a crucial component for any green building integrated project design and delivery. This enormously affects the seamless work process from design to analysis, documentation, construction, and measurement and verification. What is fundamentally required is not only a seamless and effective project data transfer between project team members but also a unified approach toward sustainability that deals not only with building operative energy but also with information related to the overall building life cycle, including emissions, embodied energy, carbon, renewable energy balance (Srinivasan, Braham, Campbell, and Curcija 2011), and so forth. Rather than work in silos, such a unified approach will allow us to effectively simulate sustainability scientifically.

*A Buildings library following the Modelica Fluid library (Casella, Otter, Proelss, Richter, and Tummescheit 2006; Elmqvist, Tummescheit, and Otter 2003) is available for download at www.modelica.org/libraries/Buildings.

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Summary and Conclusions

As might be expected, energy receives the most emphasis in both the LEED and Green Globes building assessment systems. Clearly, improving building performance through the application of passive solar design techniques that use the materials, fenestration, and orientation of the building to maximize the amount of free energy that can be used is the key. Passive solar design addresses heating, cooling, daylighting, and ventilation of the building to minimize the employment of active mechanical and electrical systems, especially those powered by nonrenewable energy systems. The other measures called for in the energy categories of building assessment systems help round out the concept of a building that is both energy-efficient and environmentally responsible. The elimination of atmospheric ozone-depleting chemicals is a very worthwhile objective of any building rating scheme, and reducing energy consumption helps to lower the incidence of a wide range of power plant emissions.

One innovation in building assessment is the incorporation of strict requirements for building commissioning, ensuring that the building not only functions as designed but is also built to the highest-quality standards. Both LEED and Green Globes also provide impetus for the development of renewable energy sources on a large scale by providing a possible credit for using energy from renewable energy power plants.

Notes

1. *Primary energy* refers to raw energy in the form of oil, coal, and natural gas that is input to a process. It does not refer to electricity leaving a generating plant, which accounts for only a fraction of the input, primary energy.
2. *Fracking* is an acronym for *hydraulic fracturing*. It is the process of drilling down into shale rock layers and using a high-pressure mixture of water and other chemicals to force gas trapped inside the rock to be released and captured. *Refracking* describes repeated episodes of fracking in which the well, which lasts a short time, is repeatedly subjected to hydraulic fracking after periods of rest. Cases of refracking up to eight times or more have been reported.
3. Systems ecology was developed into a full-fledged ecological theory by H. T. Odum during his five decades at the University of Florida. The current program in systems ecology in the Department of Environmental Engineering at the University of Florida is described at www.ees.ufl.edu/research/area.asp?AID=3.
4. The EPA Target Finder website is www.energystar.gov/buildings/service-providers/design/step-step-process/evaluate-target/epa%E2%80%99s-target-finder-calculator.
5. Energy-10 was developed by the National Renewable Energy Laboratory and is available from the Sustainable Buildings Industry Council under license to the Midwest Research Institute.
6. The 2014 version of the IPMVP Protocol, "Concepts and Practices for Determining Energy Savings in New Construction," Volume 3, Part 1, plus other IPMVP references, are available from the Efficiency Valuation Organization website: www.evo-world.org/en/products-services-mainmenu-en/products-ipmvp-mainmenu-en.
7. Personal communication with author.
8. A heating degree day (HDD) or a cooling degree day (CDD) is a measure of the deviation of the site's temperature profile from the average temperature in a building. For heating, the average temperature is 65°F (18°C); for cooling, the average temperature used for calculations is 75°F (24°C). For example, a day with an average temperature of 60°F (16°C) would result in five Fahrenheit-based (two Celsius-based) HDDs [(65°F–60°F) (18°C–16°C) 1 day]. The number of HDDs or CDDs is an indicator of how extreme the temperature profile of a site is and how much energy may be required to provide heating or cooling.

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9. A description of the daylighting and other strategies employed to make Rinker Hall a high-performance building can be found at the American Institute of Architects (AIA), Committee on the Environment (COTE) website: http://www2.aiatopten.org/hpb/energy.cfm?ProjectID=286.
10. COP is a measure of the performance of heat pumps and air-conditioning systems and is defined as the ratio of energy removed or added to the energy input to the system. Both energy removed and energy input must have the same units—for example, BTUs per hour or kilowatts. Unlike efficiency, which has a maximum value of 1, COP can be greater than 1 and indeed should be much greater than 1. For example, efficient screw chillers can have a COP of 7 or higher. Another related term is *Seasonal Energy Efficiency Ratio* (SEER), which describes the ratio of energy removed, in BTU to watts of input power, and is used to describe the performance of smaller residential-scale air-conditioning systems. An air-conditioning unit with a SEER 14 rating would have an equivalent COP of 4.
11. The Carbohydrate Economy Clearinghouse was sponsored by the Institute for Local Self-Reliance (ILSR) and covered the broad range of issues associated with shifting to bio-based renewables**.**
12. Information about fuel cell applications can be found at www.fuelcells.org.
13. An excellent overview of building EMS is available from Energy Design Resources in the form of a design brief, "Energy Management Systems."

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Chapter 10
Built Environment Hydrologic Cycle

Of the various resources needed for the built environment, water is arguably the most critical. In his book *The Bioneers*, Kenny Ausubel (1997) noted that biologists occasionally refer to this resource as "Cleopatra's water" because, like all other materials on the planet, water stays in a closed loop. The water you sip from a drinking fountain may have once been used by the Egyptian queen in her bath. The human body is 97 percent water, and water is more crucial to survival than food. It serves as a buffer in human metabolism for the transfer of oxygen at small scale, as a damper on rapid changes in the planet's environment at large scale, and as a shock absorber in cellular function at microscopic scale. Water plays a role in most of the world's spiritual traditions and religions, from baptism in the Christian faiths, to sweat lodges in Native American rituals, to the cleanliness traditions of the Baha'i faith. Water is the source of life for both humans and other species, yet it also has the power to destroy. It is used as a metaphor for truth and as a symbol for redemption and the washing away of sin. Water serves as habitat for a substantial fraction of Earth's living organisms, and the remainder are totally dependent on it for their survival.

In spite of water's symbolic and practical values, water resources throughout the planet are badly stressed. On July 28, 2010, the United Nations passed a resolution affirming the right of all people to safe and clean water and sanitation.[1] At present, nearly 2 billion people live in water-stressed areas of the world, and 3 billion have no running water within about 0.6 mile (1 kilometer) of their homes. Every eight seconds, a child dies of a waterborne disease, which would be preventable if families had adequate financial resources. The world is running out of water, and the future will likely be grim for populations that cannot afford the technology and energy needed to produce clean water from seawater or polluted water. A 2009 McKinsey & Company report stated that, by 2030, global demand for water will exceed supply by more than 40 percent, a foreshadowing of the dire predicament that the human population of the planet will face in the near future. The report also forecasted that of the new demand between now and 2030, about 42 percent would be from just four countries: China, India, Brazil, and South Africa.

It is important to note the actual amount of water needed by a population because this defines the limits of supply and consumption for a region. For bare survival, the World Health Organization suggests that 0.5 to 1 gallon (2–4.5 liters [L]) of water is needed per person for drinking and another 1 gallon (4 L) for cooking and food preparation. The US Agency for International Development states that 26.4 gallons (100 L) a day per person are required to maintain a reasonably good quality of life. In the United States, direct per capita daily water use is approximately four times higher, about 100 gallons (400 L); and if agricultural and industrial water use is included, the amount per person per day is approximately 1,800 gallons (7,000 L)—an enormous quantity of a limited and precious resource.

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In addition to problems of water supply, public health and hygiene are important issues. Waterborne diseases, including diarrhea, typhoid, and cholera, are responsible for 80 percent of the illnesses and death in developing countries. Some 15 million children per year die from these diseases. Raw sewage and toxic materials, including industrial and chemical wastes, human waste, and agricultural waste, are dumped into water systems at the rate of 2 million tons per day. About 300,000 gallons (1.1 million L) of raw sewage are dumped every minute into the Ganges River in India, which is also a primary source of water for many Indians. Wastewater treatment lags in most of the world: only 35 percent is treated in Asia and approximately 14 percent in Latin America.

Global Water Resource Depletion

Of all Earth's water, only 2.75 percent is freshwater, and of that, three-quarters, or about 2 percent, is sequestered, or locked up, in glaciers and permanent snow cover. Only a tiny fraction of planetary water, about 0.01 percent, is surface water found in rivers and lakes and thus readily accessible (see Table 10.1). The remainder is buried deep in the ground. In some cases, if that water is removed, it can be replenished only over hundreds of years. In much of the world, freshwater removed from both ground and surface sources is being used up far faster than it is being replenished. Western Asia has the most severe water supply problem in the world, with over 90 percent of its population experiencing severe water stress. In Spain, over half of its approximately 100 aquifers are overexploited. In the United States, the situation is better but not significantly and perhaps not for long. In Arizona alone, more than 520 million cubic yards (400 million cubic meters [m^3]) of water are removed from aquifers each year, double the replenishment rate from rainwater.

Perhaps the best-known case of water supply depletion is the Aral Sea, which in the 1960s began supplying water to Soviet collective farms for the production of cotton. Formerly, it was a source of large fish; by the early 1980s, they had been virtually eliminated. By the 1990s, the Aral Sea occupied half of its original area, and it had shrunk in volume by 75 percent. A once-beautiful, large, rich, and deep lake with complex ecosystems had been largely destroyed in about 40 years due to human activities (see Figure 10.1).

TABLE 10.1

Inventory of Water on Earth's Surface

Reservoir	Volume ($km^3 \times 1{,}000{,}000$)	Percentage of Total
Oceans	1,370	97.25
Ice caps and glaciers	29	2.05
Groundwater	9.5	0.68
Lakes	0.125	0.01
Soil moisture	0.065	0.005
Atmosphere	0.013	0.001
Streams and rivers	0.0017	0.0001
Biosphere	0.0006	0.00004

Source: Fundamentals eBook, www.physicalgeography.net/fundamentals/contents.html.

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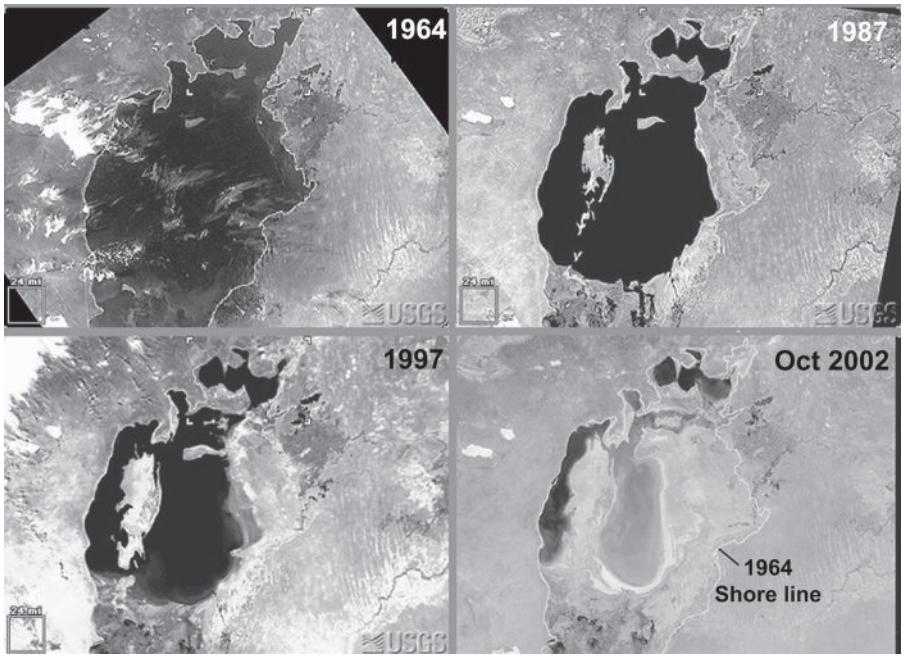


Figure 10.1 The Aral Sea has all but disappeared and its ecosystems have been totally destroyed in the 40-year period from the 1960s to the 1990s, a victim of withdrawals for growing cotton and industrialization. (*Source:* US Geological Survey)

Water Distribution and Shortages in the United States

In the United States, water crises are occurring almost everywhere. The Florida Panhandle's ecologically significant Apalachicola, located at the southern end of a complex watershed comprising the Apalachicola, Flint, and Chattahoochee Rivers, is under threat due to issues far from Apalachicola Bay into which the system flows. At the far north of this watershed lies Atlanta, Georgia, a growing city of 5 million that draws most of its water from the Chattahoochee River and competes with the sparsely populated rural and fishing communities farther south along the Alabama border and into Florida for the limited water in this system. A three-year drought ending in 2009 resulted in a three-state water war that pitted the urban interests of Atlanta against the rural needs of Georgia in a conflict that is being mirrored many times over in the United States alone (see Figure 10.2). In October 2007, Georgia governor Sonny Perdue declared a state of emergency for the northern third of the state of Georgia and asked President George W. Bush to declare it a major disaster area. At that time, Georgia officials warned that Lake Lanier, a 38,000-acre reservoir that supplies more than 3 million residents with water, was less than three months from depletion. Smaller reservoirs were dropping even lower. The competition for the limited water is refereed by the US Army Corps of Engineers, which releases more than 1 billion gallons of water from Lake Lanier every day. The water releases are based on two requirements that the Corps of Engineers is mandated to meet: the minimum flow needed for a coal-fired power plant in Florida and mandates to protect two mussel species in a Florida river. Consequently, the needs of Atlanta are pitted against the downstream needs of a largely rural region and the protection of natural species that support the livelihood of Gulf Coast fishermen. Governor Perdue asked a federal judge to significantly reduce the outflows from the lake and set aside more

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Figure 10.2 Lake Lanier, northeast of Atlanta, Georgia, supplies water to its burgeoning population of 5 million, competing with, among others, Gulf of Mexico oystermen, for critical and increasingly scarce water. The picture shows Lake Lanier during the October 2007 drought when water levels were 14.4 feet below normal. (Dick McMichael, dicksworld.wordpress.com)

water for the residents of northern Georgia. Similar dramas have occurred several times, and the three-state water war among Florida, Georgia, and Alabama continues.

Water crises are also apparent in the moratoriums imposed on development and growth because of either a shortage of water supplies or insufficient wastewater treatment capacity. A growth moratorium in Las Vegas, Nevada, currently one of the fastest-growing municipalities in the United States, has been under active discussion several times since 2004. In the Diamond Valley, near Las Vegas, water levels dropped over 100 feet (30 m) during the 1970s and 1980s and have never recovered (see Figures 10.3 and 10.4).[2] In January 2004, the town commissioners of Emmitsburg, Maryland, passed an ordinance that invoked a growth moratorium for lots not already approved for development until the maximum design capacity of the city's wastewater treatment plant (WWTP), which is 800,000 gallons (3 million L) per day, is not exceeded for 180 days.[3]

The sheer scale of water consumption is enormous but has flattened out over time, with over 410 billion gallons (1,552 billion liters [L]) extracted each day in the United States for all uses in 2010 with the same level of consumption estimated for 2015.[4]

The rate of water consumption is over 40 times that of gasoline, and some argue that one day in the not-too-distant future, water may be more expensive than gasoline. In fact, the equivalent price of bottled water in a convenience store is already at least $5.80 per gallon ($1.50/L). The bright side of this picture is that in 1980 US water use was even higher—450 billion gallons a day—meaning that total and per capita water use dropped in spite of an additional 70 million people and a doubling of US gross domestic product. Thus, less water was used in an economy of $14 trillion than in an economy of $6 trillion. Although direct consumption by people in buildings is not a large fraction of total water use in the United States, water shortages

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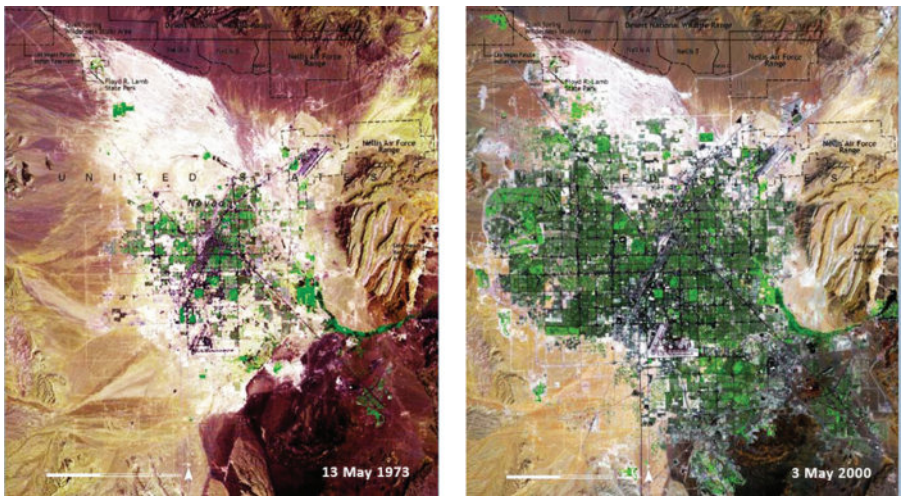


Figure 10.3 The enormous growth of Las Vegas, Nevada, has contributed to significant aquifer depletion in less than 30 years. The satellite imagery of Las Vegas illustrates the spatial patterns and rates of change resulting from the city's urban sprawl. (*Source:* United Nations Environment Programme)

in many areas of the country are having an impact on development and construction (see Figures 10.5 and 10.6).

Agriculture is the cause of serious water supply problems because it is responsible for over 80 percent of water consumption, and 60 percent of irrigation water is wasted because of leaky canals, evaporation, and mismanagement. Similar problems occur in the cities of many developing countries, with about 40 percent of the water in large cities being lost to leaky systems.

Buildings account for about 12 percent of freshwater withdrawals. The built environment hydrologic cycle, characterized by the input of high-quality potable



Figure 10.4 Most areas in Las Vegas, Nevada, require water irrigation for golf courses, country clubs, and other landscaping to further attract people to this region of the Mojave Desert. (Paul Francis, www.lasvegasrealestatehome.com)

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Figure 10.5 The water demands of the United States are causing significant water level drops in various aquifers throughout the region. Southern Arizona is one of many areas that extract extensive quantities of water from the aquifer, causing land subsidence. These areas are vulnerable to runoff contaminating basin aquifers. (*Source:* Arizona Department of Water Resources)



Figure 10.6 Sinkholes are an example of land subsidence due to groundwater extraction. Since groundwater serves partly as a structural component to the rock, its depletion results in voids and eventual collapse, sometimes sudden and unpredictable, creating a substantial hazard to people and infrastructure. (Photograph courtesy of Ildar Sagdejev)

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water and the release of used, contaminated water, is inefficient, wasteful, and illogical. In its more extended context, the built environment hydrologic cycle also includes the irrigation of landscaping and the handling of stormwater (see the discussion in Chapter 8 on stormwater, which is included with the general topic of the building site). As pointed out by Hawken, Lovins, and Lovins (1999), the invention of the water closet by Thomas Crapper was perhaps the start of an unfortunate trend in decision making with respect to building water use.[5] In order to dispense with the human waste generated in buildings, water closets dilute high-quality potable water with disease-ridden feces and relatively clean urine. Consequently, enormous quantities of water are wasted, and a potentially useful source of fertilizer is released into sanitary sewer systems to combine with industrial waste. The end result is a complex, chemically intense, energy-consuming, pollution-producing system of WWTPs. Major rethinking of the built environment hydrologic system is clearly needed to make better use of increasingly scarce and expensive potable water and to reduce the impact and cost of treating effluent from buildings.

In this chapter, we address how high-performance buildings can help contribute to reducing pressure on the increasingly scarce water resource and to improving the health of local ecosystems. We also discuss strategies for selecting water sources, employing recent technological improvements in plumbing fixtures, evaluating alternative wastewater strategies, implementing sustainable stormwater management, and optimizing landscape water consumption. Additionally, this chapter covers the subject of setting targets for water use and modeling building water consumption to assess progress in meeting these targets.

Hydrologic Cycle Terminology

Before discussing a high-performance building hydrologic strategy, it is important to define common terms used in the context of the built environment water cycle. Definitions of the more important concepts that should be understood in any discussion of the design of high-performance building water systems are provided next.

Hydrologic cycle. The continuous cycling of water between planetary reservoirs, such as the ground, water bodies, and the atmosphere. The hydrologic cycle is also referred to as the *water cycle.* Table 10.1 shows the distribution of water on Earth's surface and in the atmosphere. The residence time for water on Earth's surface varies from as little as 1 month for soil moisture to as much as 10,000 years for deep groundwater (see Table 10.2).

Built environment hydrologic cycle. The flow and storage of all types of water on sites altered from their natural state for the purpose of building and infrastructure. Water types include potable water, rainwater, stormwater, graywater, blackwater, and reclaimed water that are used, processed, stored, and moved by employing a variety of technologies that, in the case of high-performance buildings, are coupled with natural systems.

Potable water. Water that is safe for human consumption (i.e., has high quality and low risk of harm). Potable water generally is obtained from groundwater or surface water sources and then processed to increase its quality to drinking water standards.

Groundwater. Water that is found underground in rock formations, such as aquifers and in soils. Groundwater is extracted for human consumption using shallow wells or deep, artesian wells. Water that seeps into the ground to add to the supply of groundwater is referred to as *recharge water.*

TABLE 10.2

Typical Residence Times of Water Found in Various Reservoirs

Reservoir	Average Residence Time
Groundwater: deep (fossil)	**10,000 years**
Groundwater: shallow	**100–200 years**
Lakes	50–100 years
Glaciers	20–100 years
Rivers	2–6 months
Seasonal snow cover	2–6 months
Soil moisture	1–2 months

Source: Fundamentals eBook, www.physicalgeography.net/fundamentals/contents.html

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Surface water. Water that collects on Earth's surface in rivers, streams, lakes, and ponds, and which serves as a source of replenishment for groundwater.

Fossil water. Deep groundwater that has a long residence time, sometimes on the order of thousands of years. Although this water source has existed for a long period in underground aquifers, it is being depleted rapidly because it is not readily replenished and is essentially a nonrenewable resource. In the United States, the US Department of Agriculture reported that in parts of three leading grain-producing states that draw water from the Ogallala Aquifer—Texas, Oklahoma, and Kansas—the underground water table has dropped by more than 30 meters (100 feet); as a result, wells have gone dry on thousands of farms in the southern Great Plains.

Stormwater. Water that does not infiltrate into the ground and either runs off into bodies of water or enters the stormwater system. Includes water from the precipitation of rain and snow, water from melting snow, and water from overwatering.

Rainwater. Water from liquid precipitation, excluding water from snow, hail, and sleet, that has not entered a stream, lake, or other body of water.

Rainwater harvesting. The collection, storage, and use of rainwater. Most systems use the roof surface as the collection area and a large galvanized steel, fiberglass, polyethylene, or ferrocement tank as the storage cistern. When the water is to be used just for landscape irrigation, typically only sediment filtration is required. When water is being collected and stored for potable uses, additional measures are required to purify it and ensure its safety. Rainwater harvesting offers several important environmental benefits, including reducing pressure on limited water supplies and reducing stormwater runoff and flooding. It also can be a better-quality source of water than conventional sources. After purification, rainwater is usually very safe and of high quality.

Reclaimed water. Water from a WWTP that has been treated and can be used for nonpotable purposes, such as landscape irrigation, cooling towers, industrial process uses, toilet flushing, and fire protection. In some areas of the United States, reclaimed water may be referred to as irrigation quality water, but potential uses can extend well beyond irrigation.

Blackwater. Water containing human waste. Wastewater from kitchen sinks and dishwashers sometimes is considered blackwater because it contains oil, grease, and food scraps, which can burden the treatment and disposal processes.

Graywater. Water from showers, bathtubs, bathroom sinks, washing machines, and drinking fountains. Graywater may also include condensation water from refrigeration equipment and air conditioners, hot tub drainwater, pond and fountain drainwater, and cistern drainwater. Graywater contains a minimum amount of contamination and can be reused for certain landscape applications. Although graywater reuse still is being debated by public health officials, no case of illness has ever been traced to such reuse. Both graywater and blackwater contain pathogens—humans should avoid contact with either—but blackwater is considered a much higher risk medium for the transmission of waterborne diseases. Although they are not blackwater, these water sources should not be included in graywater that is to be used for irrigation: garden and greenhouse sinks, water softener backflush, floor drains, and swimming pool water. In buildings served exclusively by composting toilets and thus producing no true blackwater, it may be useful to include kitchen wastewater in graywater by taking special precautions to eliminate organic matter.

Xeriscaping. A landscaping strategy that focuses on using drought-tolerant native and adapted species that require minimal to no water for their maintenance. The term is derived from the Greek word *xeri*, meaning "dry"; the strategy is also referred to as *enviroscaping*.

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Living Machine. A trademark and brand name for a form of ecological wastewater treatment designed to mimic the cleaning functions of wetlands. The system is an intensive bioremediation system that can also produce beneficial by-products, such as reuse quality water, ornamental plants, and plant products usable for building materials, energy, or animal feed.

High-Performance Building Hydrologic Cycle Strategy

One of the key issues that the green building movement is attempting to include in the dialogue about the future direction of high-performance buildings is the interaction of the natural water cycle with the built environment. The built environment hydrologic cycle involves the handling and use of water both internal and external to buildings. Water is imported into the built environment for consumption and other uses and then exported as wastewater. Water used inside the building can be potable water from the municipal water system or from wells; rainwater from cisterns; or, when permitted, graywater recycled within the building. Outside the building, the built environment hydrologic cycle can be extraordinarily complex due to the challenges of handling sometimes large volumes of rainwater and providing water for landscape irrigation. Rainwater falling on the building site can have several fates. On a greenfield or previously undeveloped site, most rainwater infiltrates into the ground, and the remainder flows off into streams or other bodies of water. On a developed site, the situation can be reversed, with relatively little water infiltrating into the ground. Buildings and hardscape, such as sidewalks and roads, cover the ground, preventing infiltration of rainwater and inducing water flow across parking lots and roads. Rainwater must be either collected and conducted into municipal stormwater systems that receive and process this water or stored on-site in retention and detention ponds.

Designers of high-performance buildings have developed novel built environment hydrologic strategies that are having significant positive impacts on water consumption. The focus of these approaches is threefold: (1) to minimize the consumption of potable or drinking-quality water from wells or the municipal wastewater system, (2) to minimize wastewater generation, and (3) to maximize rainwater infiltration into the ground.

These strategies, together with the emergence of several key technologies, are resulting in high-performance buildings with enormous reductions in their water consumption and wastewater generation profiles. These innovative strategies and technologies are described next.

BENEFITS OF WATER EFFICIENCY

Reducing building water consumption and rethinking the wastewater strategy employed for the built environment can dramatically extend the available supply of water, improve human health, and reduce threats to ecological systems. In addition to these benefits, the Rocky Mountain Institute (www.rmi.org), a nonprofit organization that provides a wide range of services on energy, water, development, and green building issues, suggests that water efficiency can have these other tangible and calculable benefits:

- *Energy savings.* More money can be saved by reducing the energy needed to move, process, and treat water than the actual value of the saved water.

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- *Reduced wastewater production.* Reducing water consumption also reduces wastewater generation, lowering costs for building owners. Wastewater costs are significantly higher than the cost of potable water.
- *Lower facilities services investments.* Designing water-efficient buildings reduces the costs of water and wastewater infrastructure.
- *Industrial processes.* Innovations in water use in production systems can result in new processes and approaches.
- *Higher worker productivity.* Facilities that incorporate resource efficiency measures are known to have a more productive workforce.
- *Reduced financial risk.* Implementing water efficiency can be accomplished as needed, thus reducing costs and risks for large facilities.
- *Environmental benefits.* Lowering water consumption results in reduced impact on natural systems.
- *Public relations value.* Protecting the environment is looked upon favorably by the general public and clients.

The building hydrologic cycle and energy use are tightly coupled, with very little of the impact being apparent to the building owner. Complex and expensive systems extract potable water from surface water and groundwater sources, then pump it for treatment and distribution, requiring large quantities of energy that are generally subsidized by the low cost of water. Similarly, wastewater must be pumped through an extensive system of sanitary sewers and lift stations to central (WWTPs), consuming relatively large amounts of energy. (The term *watergy* sometimes is used to describe the tightly intertwined relationship of water and energy.) The good news is that reducing water consumption reaps numerous positive benefits, not only by reducing flows through the system but also by lowering overall energy consumption and associated pollution from energy sources.

STEPS IN DEVELOPING A HIGH-PERFORMANCE HYDROLOGIC STRATEGY

The next eight logical steps can be used to develop a hydrologic strategy for high-performance buildings:

1. *Select the appropriate water sources for each consumption purpose.* Potable water must be used only for those applications that involve human consumption or ingestion. In addition to potable water, other water sources include rainwater, graywater, and reclaimed water. These alternative sources of water can be used for landscape irrigation, fire protection, cooling towers, chilled and hot water, toilet and urinal flushing, and other applications for which valuable potable water can be minimized. In each case, the availability of each alternative water source should be analyzed to determine which mix is optimum for the particular project and its forecasted water use profile.
2. *For each purpose, employ technologies that minimize water consumption.* This strategy can include a combination of low-flow fixtures (toilets, urinals, faucets, and showerheads), no-flow fixtures (composting toilets, waterless urinals), and controls (infrared sensors). For cooling towers, chemical-free electromagnetic technology can reduce scaling caused by biological contaminants and corrosion, both of which can reduce the system performance. For landscaping, highly efficient drip irrigation systems use far less water and deliver the water to the plant roots with more than 90 percent efficiency. Additionally, drought-tolerant native and adapted species can be employed in the landscape scheme, an approach that often can eliminate the need for an irrigation system.

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3. *Evaluate the potential for a dual wastewater system.* Such a system separates lightly contaminated water from sinks, drinking fountains, showers, dishwashers, and washing machines from human waste—contaminated sources such as toilets and urinals. This dual piping system separates graywater from blackwater, thus providing the capability for water recycling within the building.
4. *Analyze the potential for innovative wastewater treatment strategies.* For example, constructed wetlands or Living Machines can be employed to process effluent. These approaches are rapidly evolving and beginning to appear in more high-performance building projects each year as the practice of using nature in symbiosis with the building process becomes more refined.
5. *Apply life-cycle costing* (LCC) to analyze the costs and benefits of adapting practices that reduce water flow through the building and its landscape beyond the levels mandated by the Energy Policy Act of 1992 (EPAct 1992). A simple LCC that examines nothing more than the cost of potable water generally provides long payback times, perhaps in the 10- to 20-year range. Including reductions in wastewater generation and the costs associated with its treatment provides an accelerated payback. A more liberal interpretation of costs, such as the actual energy cost of moving water and wastewater, emissions associated with energy generation, worker productivity improvements, and general environmental benefits, shortens the payback time of the initial investment. Finally, it can be reasonably expected that the price of potable water in most regions will increase at a greater rate than the general inflation rate and perhaps dramatically faster. Including this factor in the LCC evaluation, along with other indirect cost factors, should bring the paybacks into the same range as those for good energy conservation measures (i.e., seven years or less).
6. *Design landscaping to use minimal water* for its maintenance and upkeep, and consider the restoration of ecological systems as an important part of the building design.
7. *Design parking, paving, roads, and landscaping to maximize the infiltration of stormwater.* Prior to buildings being present on the site, a natural hydrologic cycle functioned to move water among the atmosphere, ground, bodies of water, and ecological systems. Restoring the natural hydrologic cycle can benefit natural systems and reduce the need for complex and expensive stormwater infrastructure.
8. *Incorporate green roofs* into buildings to store and naturally process stormwater and contribute to the regeneration of the ecology of the building location.

ESTABLISHING WATER CONSUMPTION TARGETS

Limits on water consumption in buildings are set by building codes, which are, in turn, based on legislation. Table 10.3 shows the progress in setting maximum water consumption levels for typical building plumbing fixtures. One of the landmark pieces of legislation concerning potable water consumption is the Energy Policy Act of 1992. EPAct 1992 requires all plumbing fixtures used in the United States to meet ambitious targets for reducing water consumption; as a result, building codes mandate these dramatically lower levels of water consumption. Additional requirements for water efficiency for prerinse spray valves used in commercial kitchens were set by the Energy Policy Act of 2005 (EPAct 2005). In 2007, California passed legislation that established even more stringent requirements for toilets and urinals, reducing toilet water consumption from 1.6 gallons (6 L) per flush to 1.28 gallons (4.8 L)

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TABLE 10.3

Water Efficiency Standards and Best Technology for Typical Building Plumbing Fixtures

Fixture Type	Units	EPAct 1992	EPAct 2005	WaterSense 2006	California 2007	Best Technology
Water closet, flushing	gpf	1.6		1.28	1.28	0.8*
	lpf	6.0		4.8	4.8	3.0
Urinal	gpf	1.0		0.8	0.5	0.0/0.13†
	lpf	3.8		3.0	1.9	0.0/0.47†
Showerhead	gpm at 80 psi gpm at 60 psi	2.5/2.2		2.0/1.8		0.57/0.49
	lpm at 450 kPa lpm at 410 kPa	9.5/8.5		7.6/6.8		2.2/1.9
Faucet	gpm at 80 psi gpm at 60 psi	2.5/2.0		2.0/1.6		0.5
	lpm at 450 kPa lpm at 410 kPa	9.5/7.6		7.6/6.1		1.9
Replacement aerator	gpm	2.5				0.5
	lpm	9.8				1.9
Metering faucet	gpc	0.25				0.09
	lpc	0.98				0.34
Prerinse spray valves	gpm at 60 psi		1.6			
	lpm at 410 kPa		6.0			

Key:
gpf = gallons per flush; gpm = gallons per minute; gpc = gallons per cycle
lpf = liters per flush; lpm = liters per minute; lpc = liters per cycle
psi = pounds per square inch pressure; kPa = thousand pascals pressure
*The best technology in this case is the water closet with the lowest water flush rate. Composting toilets use no water but generally have limited application.
†For urinals, the best technology is the waterless urinal, which has no water use. Ultra-low-flow urinals use about one-eighth of a gallon per flush and can be selected in cases where a waterless urinal is not appropriate or desirable.



Figure 10.7 The EPA created the WaterSense label to stimulate the development of technologies that improve on the EPAct 1992 requirements by at least 20 percent. (*Source:* US Environmental Protection Agency)

per flush and urinal water consumption from 1.0 gallon (3.8 L) per flush to 0.5 gallon (1.9 L) per flush.

Beyond legislation and code requirements, the US Environmental Protection Agency (EPA) created the voluntary WaterSense label in 2006, which required that WaterSense-certified fixtures use at least 20 percent less water than the requirements of EPAct 1992. The WaterSense label is awarded based on third-party certification that the fixture meets EPA requirements (see Figure 10.7).

Setting goals for a building's water consumption that exceed code requirements is an important first step in designing a strategy that makes sense. If the Factor 10 concept described in Chapter 2 is applied to the issue of water consumption, potable water—and, by inference, wastewater—should be reduced by 90 percent for the purpose of producing a sustainable future. This means that typical per capita household consumption of potable water in this country must be reduced from 100 gallons (380 L) per day to about 10 gallons (40 L) per day. To accomplish this remarkable reduction requires that water be reused and recycled at high rates. For example, per capita consumption of water is almost evenly divided between outdoor and indoor uses. If only recycled water were used outdoors for irrigating landscaping, per capita consumption of potable water would drop to 50 gallons (190 l) per day. Indoors, almost half of the water consumed is for toilet and urinal Flushing, and using only recycled water for this purpose would further reduce water consumption to 25 gallons (85 L) per day. These relatively straightforward measures produce an immediate Factor 4 reduction. Additional measures that incorporate low-flow fixtures and electronic controls can nearly produce the desired Factor 10 reduction.

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As an alternative to using Factor 4 or Factor 10 strategies to set targets for building water consumption, a more recent approach known as the *net zero built environment* is emerging. In addition to addressing energy, the net zero strategy addresses water consumption by setting limits to water usage based on annual precipitation and water recycled within the building (Sisolak and Spataro 2011).[6] This is referred to as *net zero water* and is required for certification under the Living Building Challenge. A number of US military installations such the Aberdeen Proving Grounds in Maryland and Fort Hood in Texas are participating in net zero water pilot programs. As an example, if a net zero water target were established as a criterion for a building in Gainesville, Florida, where the average annual rainfall is 36 inches (0.91 m), each square foot of roof would provide 3 cubic feet, or about 22.5 gallons (85 L), of water. For Rinker Hall, a Leadership in Energy and Environmental Design (LEED) gold certified building at the University of Florida in Gainesville, with three stories and a 15,000 ft^2 roof (1,394 m^2), the water budget would be about 330,000 gallons per year. The section below on Designing the High Performance Building Hydologic Cycle delves further into the issue of water modeling and budgeting.

WATER SUPPLY STRATEGY

The basic strategy for the water supply of a high-performance building is to reduce potable water consumption to the maximum extent possible. Thus, the first two steps in the high-performance building hydrologic cycle strategy just given also apply to the water supply strategy. The first step is to assess the potential for using nonpotable water sources to replace potable water in a wide range of applications. In this context, nonpotable water includes rainwater, graywater, and reclaimed water. When the feasibility of using each of these nonpotable sources has been assessed, the next step is to ensure that consumption of both potable and nonpotable water is minimized. A wide range of high-efficiency fixtures are available that provide flow rates well below the EPAct 1992 requirements. Waterless plumbing fixtures are becoming more widely available and price- competitive as manufacturers begin offering more alternatives. EPAct 1992 set relatively ambitious limits on water use for water fixtures. However, water use by high-performance green buildings normally exceeds the EPAct 1992 requirements. For example, the LEED requires at least a reduction of 20 percent in potable water consumption over the EPAct 1992 requirements.

BUILDING PLUMBING FIXTURES AND CONTROLS

The next sections describe the main types of plumbing fixtures currently in use and their low-flow/high-efficiency alternatives (*Greening Federal Facilities* 2001, sections 6.1–6.6). Note that, in this context, the term *low flow* refers to fixtures that meet the EPAct 1992 requirements and *high efficiency* refers to fixtures that meet the EPA requirements of using 20 percent less water than the EPAct 1992 requirements.

Toilets and Urinals

Toilets account for almost half of a typical building's water consumption. Americans flush about 4.8 billion gallons (18.2 billion L) of water down toilets each day, according to the EPA. According to the Plumbing Foundation, replacing all existing toilets with models that use 1.6 gallons (6 L) per flush would save almost 5,500 gallons (25,000 L) of water per person each year. A widespread toilet replacement program in New York City apartment buildings found an average 29 percent reduction in total water use for the buildings studied. The entire program, in which 1.3 million toilets were replaced, is estimated to be saving 60–80 million gallons (230–300 million L) per day. However, there is a common perception that low-flow toilets do not perform

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adequately. The reason is that a number of early 1.6-gallon (6-L) per flush gravity flush toilets that were adapted from the 3.5-gallon (16-L) per flush model (rather than being engineered to operate effectively with the lower volume) performed very poorly, and some low-flow toilets still may suffer from this problem. But studies show that most 1.6-gallon (6-L) per flush toilets work very well.

Several technologies of 1.6-gallon (6-L) toilets are available:

- *Gravity tank toilets.* Use basically the same design as for older toilets, but with steeper sides to allow more rapid cleaning during the flush cycle.
- *Dual-flush toilets.* Have two handles for flushing, one for minimal needs such as urine, which uses 1.0 gallon (3.8 L) per flush; the second for a maximum flow of 1.6 gallons (6 L).
- *Flushometer toilets.* Capture pressure developed in the flush cycle to assist in the subsequent flush.
- *Vacuum-assisted toilets.* Use the reverse principle of a flushometer toilet by employing a vacuum, which is regenerated by flushing action, to pull the wastewater from the toilet.

For toilets, a high-efficiency toilet (HET) fixture would consume 20 percent less water than a toilet that uses 1.6 gallons (6 L) per flush (i.e., less than 1.28 gallons [4.8 L] per flush). Where flush performance is a particular concern or where water conservation beyond that of a model that uses 1.28 gallons (4.8 L) per flush is required, electromechanical flush toilets and dual-flush toilets should be considered. Electromechanical toilets use electrically powered mechanical devices, such as pumps and compressors, to assist the removal of wastewater from toilets and use less than 1.0 gallon (3.8 L) of water per flush.

Even greater water conservation can be achieved in certain (limited) applications with composting toilets. Because of the size of composting tanks, lack of knowledge about performance, local regulatory restrictions, and higher first costs, composting toilets are rarely an option except in certain unique applications, such as national park facilities. Composting toilets are being used very successfully, for example, at Grand Canyon National Park in Arizona.

For urinals, water conservation well beyond the standard 1.0 gallon (4.5 L) per flush can be obtained using high-efficiency urinals (HEUs) or waterless urinals that use no water. HEUs use at least 20 percent less water than a code-compliant urinal and typically use about 0.5 gallon (1.9 L) per flush, or 50 percent less than the federal requirements. Waterless urinals use a special trap with a lightweight biodegradable oil that allows urine and water to pass through but prevents odors from escaping into the restroom; there are no valves to fail, and clogging does not cause flooding. The water and wastewater savings that can be achieved are truly remarkable. For example, Falcon Waterfree Technologies cites an annual net savings of $12,600 for a 75-unit installation, or about $168 per installed urinal. The payback for this rate of savings is less than three years at today's water and wastewater prices, and will be far greater in the future as pressure mounts to optimize the use of increasingly scarce sources of potable water (see Figure 10.8).



Figure 10.8 Waterless urinals save about 40,000 gallons (151,400 l) of water per year per fixture. (Courtesy of Sloan Valve Company)

Showers

EPAct 1992 requires that showerheads deliver a maximum of 2.5 gallons (9.5 L) per minute at a pressure of 80 pounds per square inch (psi; or 550 kilopascals (kPa). Prior to this legislation, showerheads used 3 to 7 gallons (11–27 L) per minute at normal water pressure, about 80 psi. A five-minute shower now uses about 12.5 gallons (47 L) of water while an older showerhead typically consumed 15 to 35 gallons (60–130 L). High-quality replacement showerheads that deliver 1.0 to 2.5 gallons (3.8–9.5 L) per minute can save many gallons per shower when used to replace conventional

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showerheads. Products vary in price from $3 to $95, and many good models are available for $10 to $20. A variety of spray patterns are also available, ranging from misty to pulsing and massaging. These showerheads typically have narrower spray jets and a greater mix of air and water than conventional showerheads, enabling them to provide what feels like a full-volume shower while using far less water.

Flow regulators on the shower controls and temporary cutoff buttons or levers incorporated into the showerhead reduce or stop water flow when the individual is soaping or shampooing, further lowering water use. When the water flow is reactivated, it emerges at the same temperature, eliminating the need to remix the hot and cold water. Flow restrictors are washerlike disks that fit inside existing showerheads, and they are tempting retrofits. Flow restrictor disks were given away by many water conservation programs; however, they provide poor water pressure in most showerheads, leading to poor acceptance of water conservation in general. Permanent water savings are better provided through the installation of well-engineered showerheads.

Faucets

Faucets generally are found in bathrooms, kitchens, and workrooms. Bathroom faucets need no more than 1.5 gallons (5.7 L) per minute, and residential kitchens rarely need more than 2.5 gallons (9.5 L) per minute. Institutional bathroom faucets may include automated controls and premixed temperatures. Institutional kitchen faucets may include special features, such as swivel heads and foot-activated on/off controls. Older faucets with flow rates of 3 to 5 gallons (11–19 l) per minute wasted tremendous quantities of water. Federal guidelines Mandated that all lavatory and kitchen faucets and replacement faucet tips (including aerators) consume no more than 2.5 gallons (9.5 L) per minute at 80 psi (550 kPa).

Metered-valve faucets are now restricted to a discharge rate of 0.25 gallon (0.95 L) per cycle. Metered-valve faucets usually have push buttons and deliver a preset amount of water and then shut off. For water management purposes, the preset amount of water can be reduced by adjusting the flow valve. The Americans with Disabilities Act requires a 10-second minimum on-cycle time.

Variations in water pressure can occur in buildings, and pressure- compensating faucets can be used to automatically maintain 2.5 gallons (9.5 L) per minute at varying water pressures. For kitchens, devices are available to maintain the water pressure at 2.2 to 2.5 gallons (8.3–9.5 L) per minute. In washrooms, 0.5 to 1.25 gallons (1.9–4.7 L) per minute often proves adequate for personal washing purposes.

Foot controls for kitchen faucets provide both water savings and hands-free convenience. The hot water mix is set, and the foot valve turns the water on and off at the set temperature. Hot water recirculation systems reduce water wasted while users wait for water to warm up as it flows from the faucet. To prevent these water-saving systems from wasting large amounts of energy, hot water pipes should be well insulated.

Drinking Fountains

Drinking fountains can be metered or nonmetered. Due to the design of water supply systems, drinking fountains vary with respect to discharge rate. In order to meet EPA WaterSense requirements, metered drinking fountains are limited to 0.25 gallon (0.95 L) per cycle and nonmetered to 0.7 gallon (2.65 L) per cycle. Self-contained drinking fountains have an internal refrigeration system. Adjusting the exit water temperature to 70°F (21°C) versus the typical 65°F (18°C) will result in substantial energy savings. Insulating the piping, chiller, and storage tank will save energy. If appropriate, adding an automatic timer to shut off the unit during evenings and weekends will add to the savings. Remote chillers or central systems are used in some facilities to supply cold drinking water to multiple locations. Sensor faucets require either electrical wiring for the connection of alternating current (AC) power or regular replacement of battery power supplies.

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ELECTRONIC CONTROLS FOR FIXTURES

Automated controls for faucets, toilets, and urinals can lower water consumption dramatically and potentially eliminate disease transmission via contact with bathroom surfaces and fixtures. These controls are rapidly gaining popularity in all types of commercial and institutional facilities, although the driver is generally hygiene rather than water or energy savings.

Electronic controls can be installed with new plumbing fixtures or retrofitted onto many types of existing fixtures. Although water savings depend greatly on the type of facility and the particular controls used, some facilities report 70 percent water savings. This type of on-demand system also can produce proportional savings in water heating (for faucets) and sewage treatment. Electronic controls for plumbing fixtures usually function by transmitting a continuous beam of infrared (IR) light. With faucet controls, when a user interrupts this IR beam, a solenoid is activated, turning on the water flow. Dual-beam IR sensors or multispectrum sensors generally are recommended because they perform better for a wider range of users. With toilets and urinals, the flush is actuated when the user moves away and the IR beam is no longer blocked. Some brands of no-hands faucets are equipped with timers to defeat attempts to alter their operation or to provide a maximum on cycle—usually 30 seconds. Depending on the faucet, a 10-second handwash typical of an electronic unit will consume as little as 1⅓ cups (0.3 L) of water.

Electronic controls also can be used for other purposes in restrooms. Sensor-operated hand dryers are hygienic and save energy by automatically shutting off when the user steps away. Soap dispensers can be controlled electronically. Electronic door openers can be employed to further reduce contact with bathroom surfaces. Even showers sometimes are being controlled with electronic sensors—for example, in prisons and military barracks. Electronic fixtures are particularly useful for installations for the disabled and for hospitals, greatly reducing the need to manipulate awkward fixture handles and removing the possibility of scalding caused by improper water control. Three types of no-touch faucets are available: with the sensor mounted in the wall behind the sink, the sensor integrated into the faucet, or the sensor mounted in an existing hot or cold water handle hole and the faucet body in the center hole. For new installations, the first or second option is usually best; for retrofit installations, the last option may be the only one feasible. At sports facilities where urinals experience heavy use, the entire restroom can be set up and treated as if it were a single fixture. Traffic can be detected and the urinals flushed periodically based on traffic rather than per person. This method can reduce water use significantly. Computer controls can be used to coordinate water usage to divert water for fire protection when necessary. Thermostatic valves can be used with electronic faucets to deliver water at a preset temperature. Reducing hot water consumption saves a considerable amount of energy. A 24-volt transformer operating off a 120-volt AC power supply typically is used for electronic controls, at least with new installations. The transformer should be listed by Underwriters Laboratories, and for security reasons, the transformer and the solenoid valve should be remotely located in a chase.

NONPOTABLE WATER SOURCES

Rainwater Harvesting

Rainwater has been considered a crucial source of water for survival for all of human existence. For building applications, rain typically was collected from the roofs of homes and other buildings and conducted into a storage tank or cistern. With the advent of centralized potable water systems, rainwater systems all but disappeared until the emergence of the modern high-performance green building movement. *The Texas Guide to Rainwater Harvesting* (2005), which provides an excellent overview

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of rainwater harvesting, cites three factors that are propelling rainwater back into the picture as a viable water source:

1. The escalating environmental and economic costs of providing water by centralized water systems or by well drilling
2. Health concerns regarding the source and treatment of polluted waters
3. The perception that there are cost efficiencies associated with reliance on rainwater

Rainwater systems are appropriate when one or more of the following factors is present:

- Groundwater or aquifer water supplies are limited or fragile. Fragile aquifer systems are those that, when pumped, can threaten ecologically valuable surface waters and springs.
- Groundwater supplies are polluted or significantly mineralized, requiring expensive treatment.
- Stormwater runoff is a major concern.

A rainwater harvesting system generally has seven key components:

1. *Catchment area.* With most rainwater harvesting systems, the catchment area is the building's roof. The best roof surface for rainwater harvesting does not support biological growth (e.g., algae, mold, moss), is fairly smooth so that pollutants deposited on the roof are quickly removed by the roof wash system, and has a minimal number of overhanging tree branches above it. Galvanized metal is the roofing material most commonly used for rainwater harvesting.
2. *Roof wash system.* This is a system for keeping dust and pollutants that have settled on the roof out of the cistern. It is necessary for systems used as a source of potable water but also is recommended for other systems, as it keeps potential contaminants out of the tank. A roof wash system is designed to purge the initial water flowing off a roof during rainfall.
3. *Prestorage filtration.* To keep large particulates, leaves, and other debris out of the cistern, a domed stainless steel screen should be secured over each inlet leading to the cistern. Leaf guards over gutters can be added in areas with significant windblown debris or overhanging trees.
4. *Rainwater conveyance.* This is the system of gutters, downspouts, and piping used to carry water from the roof to the cistern.
5. *Cistern.* This is usually the largest single investment required for a rainwater harvesting system. Typical materials used include galvanized steel, concrete, ferrocement, fiberglass, polyethylene, and durable wood (e.g., redwood or cypress). Costs and expected lifetimes vary considerably among these options. Tanks may be located in a basement, buried outdoors, or located aboveground outdoors. Light should be kept out to prevent algae growth. Cistern capacity should be sized to meet the expected demand. Particularly for systems designed as the sole water supply, sizing should be modeled on the basis of 30-year precipitation records, with sufficient storage to meet the demand during times of the year having little or no rainfall (see Figure 10.9).
6. *Water delivery.* A pump generally is required to deliver water from the cistern to its point of use, although occasionally gravity-fed systems are possible with appropriate placement of system components.

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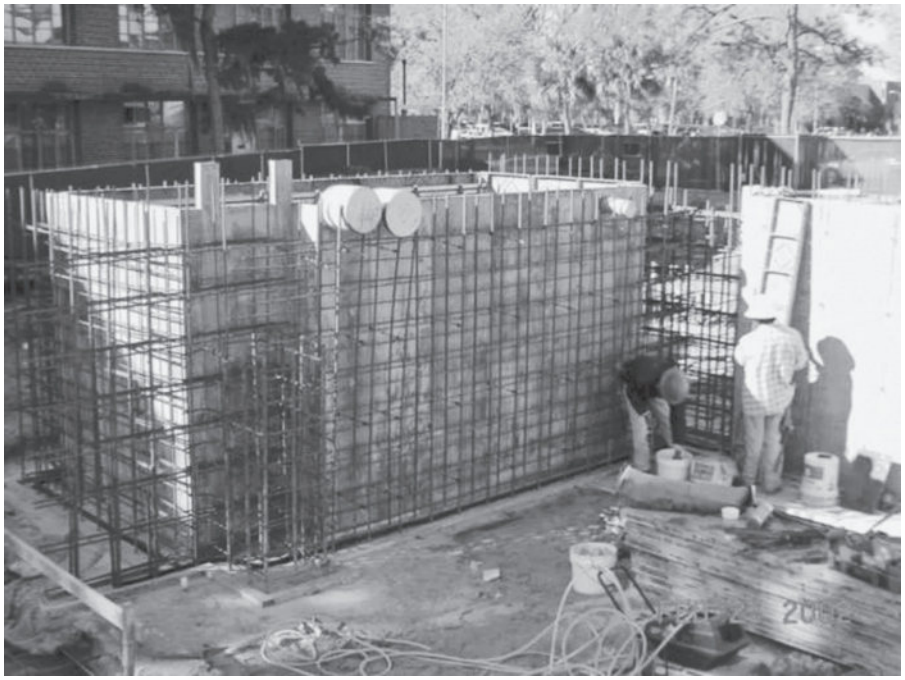


Figure 10.9 The rainwater harvesting system for Rinker Hall at the University of Florida in Gainesville has a cast-in-place cistern (shown here under construction) located under the south stairwell of the building. The rainwater is used for flushing the building's toilets. (Photograph courtesy of Centex-Rooney, Inc.)



Figure 10.10 Rainwater is harvested in a cistern system consisting of these 12 components: (1) nontoxic, noncorrosive roofing material; (2) nontoxic, noncorrosive gutters and downspouts; (3) first-flush diverter with a cleanout trap and bleed valve; (4) debris traps and sediment filter; (5) easily accessible but locked passageway; (6) engineered cistern that avoids direct-sunlight exposure to the collected rainwater; (7) automatic water refill with air gap supplied from the building; (8) cistern; (9) pump electrical supply; (10) pump start/stop relay; and (11) backflow prevention valve. The submersible pump is located inside the cistern while the overflow system is located behind the cistern. (H_2Options, Inc.)

7. *Water treatment system.* To protect plumbing and irrigation lines (especially with drip irrigation), water should be filtered through sediment cartridges to remove particulates, preferably down to 5 micrometers. For systems providing potable water, additional treatment is required to ensure a safe water supply. This can be provided with microfiltration, ultraviolet sterilization, reverse osmosis, or ozonation (or a combination of these methods). With some systems, higher levels of treatment are provided only at a single faucet where potable water is drawn.

Rainwater harvesting systems have immense potential for reducing potable water consumption by introducing a water source that is readily obtainable in many regions of the United States (see Figures 10.10 and 10.11). In spite of this advantage, there are no standard designs or approaches to designing a rainwater harvesting system; hence, currently, each system designed for a building is unique. Factors to include in the design include the roof material and slope, rainfall intensity, airborne pollutants (such as smoke, dust, and automobile exhaust), and debris generated from trees and other nearby vegetation. As a consequence of the wide range of factors affecting the design of a rainwater harvesting system, they can be prone to failure and unreliable, resulting in a potential erosion of interest in rainwater as a substitute for potable water. The creation of clear standards, designs, and standard components would go a long way toward resolving this problem and making the implementation of these systems standard practice.

Graywater Systems

Graywater generally is considered to comprise the nonhuman waste fraction of wastewater. Graywater collection involves separating graywater from blackwater, which, as defined previously, is the human waste–contaminated water from toilets and urinals. Graywater generally is used for landscape irrigation, but it also can be used to flush toilets and urinals.

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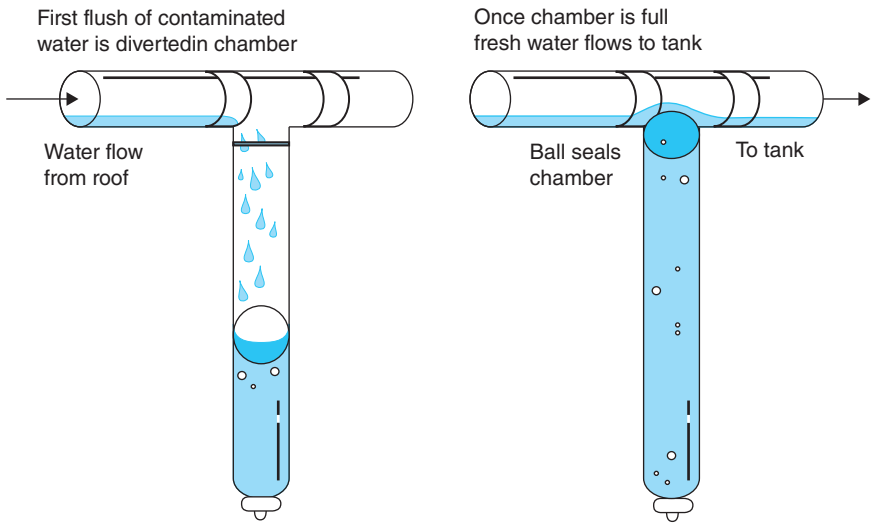


Figure 10.11 The simplest first-flush diverter is a standpipe that captures and diverts contaminants washed from the roof. Rainwater fills the standpipe, backs up, and then allows water to flow into the main collection piping after the contaminants have been flushed out. (*Source:* Texas Water Development Board)

Buildings with graywater systems must have dual waste piping systems, one for each type of water. Graywater waste lines should run to a central location where a surge tank can collect and hold the water until it drains or is pumped into an irrigation system or for other appropriate end uses. An overflow for the graywater collection system should be provided that feeds directly into the sewer line. If excess graywater fills the system due to a mismatch between supply and outflow or due to a filter or pumping malfunction, the overflow conducts the excess flow to the sewer system. A controllable valve also should be included so that graywater can be shunted into the sewer line when the area(s) being irrigated become too wet or other reasons preclude the use of graywater (see Figure 10.12).

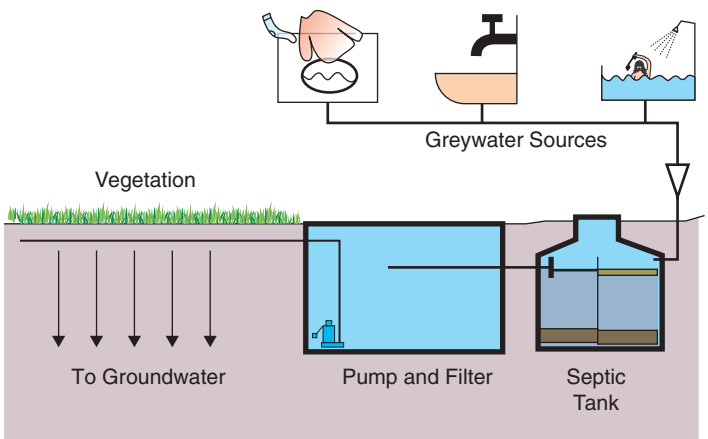


Figure 10.12 A graywater system collects water from showers, sinks, and washing machines into a septic system. The water then is filtered, pumped, and reclaimed for irrigation before seeping into the groundwater. (D. Stephany)

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Graywater should not be stored for extended periods of time before use. Decomposition of the organic material in the water by microorganisms will quickly use up available oxygen, and anaerobic bacteria will take over, producing unpleasant odors. Some graywater systems are designed to dose irrigation pipes with a large, sudden flow of water instead of allowing the water to trickle out as soon as it enters the surge tank. For a dosing system, holding the water for some amount of time will be necessary, but it should be limited to no more than a few hours. If a filter is used in the graywater system, it should be one that is easy to clean or self-cleaning. Filter maintenance is a major problem with many graywater systems. For complete protection from pathogens, graywater should flow by gravity or be pumped to a belowground disposal field (subsurface irrigation). Perforated plastic pipe—with a minimum diameter of 3 inches (76 millimeters [mm])—is called for in California's graywater regulations, although, with filtering, smaller-diameter drip irrigation tubing can be used. The California standards require that untreated graywater be disposed of at least 9 inches (about 230 mm) below the surface of the ground. Some graywater systems discharge into planter beds—sometimes even beds located inside buildings. Some ready-made systems are available by mail order, but these should be modified for specific soil and climate conditions. As a general rule, graywater can be used for subsurface irrigation of lawns, flowers, trees, and shrubs, but it should not be used for vegetable gardens. Drip irrigation systems have not yet proven to be effective for graywater discharge because of clogging or high maintenance costs.

Reclaimed Water

Reclaimed water is wastewater that has been treated for reuse. The use of reclaimed water for nonpotable purposes can reduce the demand on potable water sources greatly. Municipal wastewater reuse now amounts to about 4.8 billion gallons (18 million m^3) per day (about 1 percent of all freshwater withdrawals). Industrial wastewater reuse is far greater—about 865 billion gallons (3.2 billion m^3) per day.

In areas of chronic water shortage, the design team should check with the local water utility and inquire whether it has a program to provide reclaimed water to the building's location. Reclaimed water programs are particularly popular in California, Florida, Arizona, Nevada, and Texas.

There are a host of potential applications for reclaimed water: landscaping; golf course or agricultural irrigation; decorative features, such as fountains; cooling tower makeup; boiler feed; once-through cooling; concrete mixing; snowmaking; and fire main water. Making use of reclaimed water is easiest if the system is planned for at the outset of building a new facility, but major renovations or changes to a facility's plumbing system provide opportunities as well. For certain uses, such as landscape irrigation, required modifications to the plumbing system may be quite modest. It is important to note, however, that the use of reclaimed water may be restricted by state and local regulations. For locations such as universities or military bases that often have their own WWTP, there may be an opportunity to modify the plant to provide on-site reclaimed water (see Figure 10.13).

To consider using reclaimed water for a building, one or more of these situations should be present: (1) high-cost water or a need to extend the drinking water supply, (2) local public policy encouraging or mandating water conservation, (3) availability of high-quality effluent from a WWTP, or (4) recognition by the building owner of environmental benefits of water reuse.

Technologies vary with end uses. A modern WWTP has three stages of treatment—primary, secondary, and tertiary—with each succeeding stage requiring more energy and chemicals than the previous stage. In general, tertiary or advanced secondary treatment is required, either of which usually includes a combination of coagulation, flocculation, sedimentation, and filtration. Virus inactivation is attained

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Figure 10.13 (A) Reclaimed water is former wastewater that is cleaned and redistributed through a clearly coded system of bright purple pipes. Reclaimed water is used when the application does not require potable water. (B) Posting is mandated where the water comes in contact with the public so as to prevent human consumption. (*Source:* City of Clermont, Florida)

by granular carbon adsorption plus chlorination or by reverse osmosis, ozonation, or ultraviolet exposure. Dual water systems are beginning to appear in some parts of the country where the water supply is limited or where water shortages may constrain development. Buildings may have two water lines coming in, one for potable water and the other for reclaimed water. The former is for all potable uses, the latter for nonpotable uses. Piping and valves used in reclaimed water systems should be color-coded with purple tags or tape to minimize piping identification and cross-connection problems when installing systems. Liberal use of warning signs at all meters, valves, and fixtures also is recommended. (Note that potable water mains usually are color-coded blue, while sanitary sewers are green.) Reclaimed water should be maintained at 10 psi (70 kPa) lower pressure than potable water mains to prevent backflow and siphonage in the event of accidental cross-connection. Although it is feasible to use backflow prevention devices for safety, it is imperative never to connect reclaimed and potable water piping directly. One additional precaution is to run reclaimed water mains at least 12 inches (30 cm) lower (in elevation) than potable water mains and to separate them from potable or sewer mains by a minimum of 10 feet (3 m) horizontally.

Although water prices vary greatly throughout the country, reclaimed water costs significantly less than potable water. For example, in Gainesville, Florida, the price of potable water is now \$4.26 per 1,000 gallons (\$1.12/m^3) versus \$0.70 per 1,000 gallons (\$0.08/m^3) for reclaimed water. Similar pricing differences occur wherever reclaimed water is available.

WASTEWATER STRATEGIES

Reducing potable water consumption is relatively straightforward compared to the effort needed to change wastewater treatment strategies. Contemporary WWTPs are large, centralized, energy- and chemical-intensive operations designed to ensure that public health is protected. However, future high energy costs and increasing public resistance to chemical use are motivating building owners to

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consider other options for treating wastewater. The fundamental approaches being used today rely on nature, either directly or indirectly, for these alternative approaches. In the direct approach, effluent from buildings is treated by surface or subsurface wetlands. In the indirect approach, nature is brought into the building and enclosed in tanks and vats through which wastewater is passed and cleaned up by plants, light, and bacteria. The next sections describe two natural system–based approaches to wastewater treatment, constructed wetlands and the Living Machine concept.

Constructed Wetlands

One of the ultimate goals of green building is the application of ecological design to the greatest extent possible, including a synergistic relationship among natural systems, buildings, and the humans occupying them. Using nature to perform tasks that would otherwise be accomplished by energy-intense mechanical and electrical systems has four distinct advantages (Campbell and Ogden 1999):[7]

1. Nature is self-maintaining, self-regulating, and self-organizing.
2. Nature is powered by solar energy and chemical energy stored in organic materials.
3. Natural systems can degrade and absorb undesirable toxic and metal compounds, converting them into stable compounds.
4. Natural systems are easy to build and operate.

The use of wetlands to treat wastewater from buildings provides precisely this type of opportunity because these ecological systems can break down organic waste, minimizing the need for complex infrastructure and creating nutrients that benefit the species performing these services. Constructed wetlands can be characterized as passive systems for wastewater treatment. They mimic natural wetlands by using the same filtration processes to remove contaminants from wastewater (see Figure 10.14A). In addition to removing organic nutrients, constructed wetlands have the ability to remove inorganic substances; thus, they can be used to treat industrial wastewater, landfill leachate, agricultural wastewater, acid mine drainage, and airport runoff. Constructed wetlands also provide the added benefit of an environmental

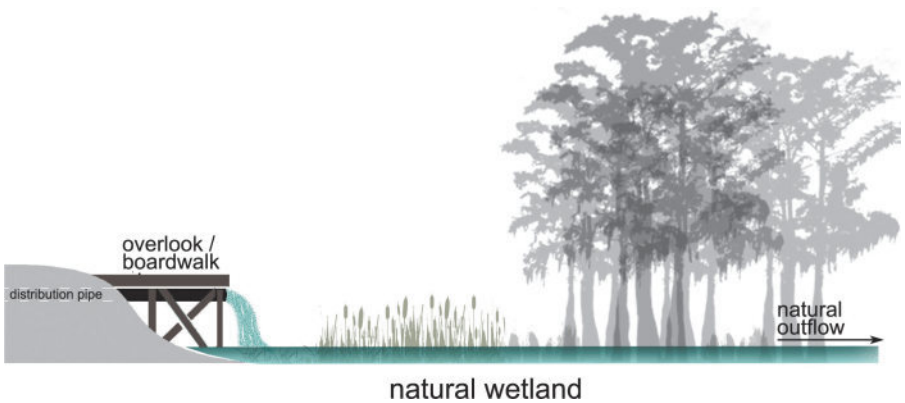


Figure 10.14 (A) Wetlands, sometimes referred to as nature's kidneys, are natural habitats with distinct characteristics of soil percolation, vegetation, and wildlife habitat. They play an important role in the ecosystem while providing a filtering process whereby contaminants in stormwater runoff are degraded before entering the groundwater. Wastewater can be purposely directed to natural wetlands for the highest cost benefit in terms of both conventional economic and natural capital. (T. Wyman)

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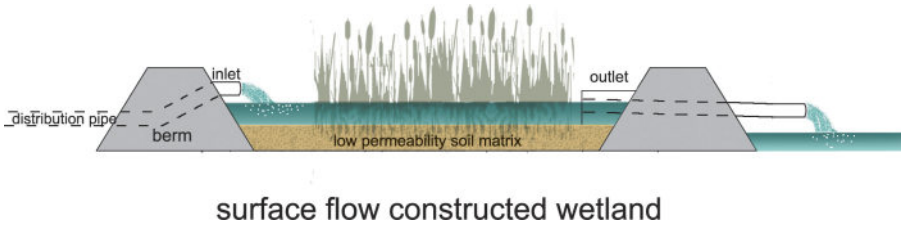


Figure 10.14 (B) Surface flow in constructed wetlands mimics natural wetlands because the water flows aboveground as sheet flow. Wetland plants are selected to provide attachment areas for microbes, which are essential for water quality improvement. The outlet receives water from the wetland cell and directs it either to downstream wetland cells or to a natural water system. (T. Wyman)

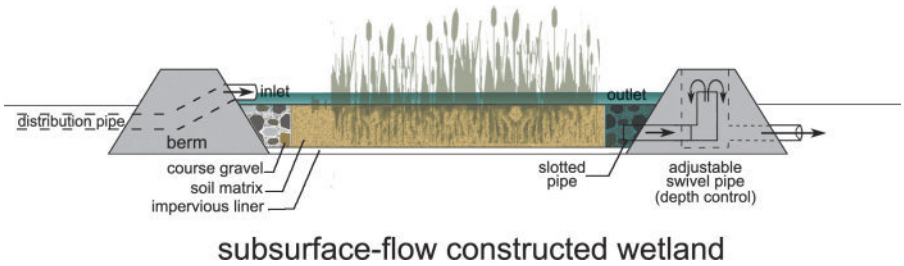


Figure 10.14 (C) Subsurface-flow constructed wetlands closely resemble WWTPs and must initiate and maintain all surface flow through the bed media to the outlet where water is collected from the base of the media. (T. Wyman)

amenity and can blend into natural or rural landscapes. Moreover, in addition to treating wastewater, constructed wetlands can provide surge areas for stormwater and treat this often contaminated runoff (see Lorion 2001 for an excellent summary of constructed wetlands technology).

Wetlands remove contaminants from water by several mechanisms, including nutrient removal and recycling, sedimentation, biological oxygen demand, metals precipitation, pathogen removal, and toxic compound degradation.

A number of site-specific factors must be taken into account when considering the use of a constructed wetland for wastewater treatment: hydrology (groundwater, surface water, permeability of ground), native plant species, climate, seasonal temperature fluctuations, local soils, site topography, and available area. Constructed wetlands are built for either surface or subsurface flow. Surface flow systems (see Figure 10.14B) consist of shallow basins with wetland plants that are able to tolerate saturated soil and aerobic conditions. The wastewater entering the surface system slowly moves via sheet flow through the basin and is released as clean water. Subsurface systems (see Figure 10.14C), where the wastewater flows through a substrate such as gravel, have the advantages of higher rates of contaminant removal, compared to surface flow systems, and limited contact for humans and animals. They also work especially well in cold climates due to the ground's insulating properties. Cost is an important factor in deciding which approach is best for a particular situation. The good news about constructed wetlands is that both the capital and operating costs are far lower than for conventional WWTPs, with the added benefit of reduced direct and indirect environmental impacts associated with materials extraction, processing, and manufacturing.

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Living Machines

In addition to using constructed wetlands to treat wastewater from the built environment, nature can be brought directly into a building in order to break down the materials in the wastewater system. Although there are several approaches, the best known is the Living Machine, created by John Todd (1999, chapter 8), a pioneer in the development of natural wastewater processing systems. The Living Machine differs from a conventional WWTP in four basic respects:

1. The vast majority of the Living Machine's working parts are live organisms, including hundreds of species of bacteria, plants, and vertebrates such as fish and reptiles.
2. The Living Machine has the ability to design its internal ecology in relation to the energy and nutrient streams to which it is exposed.
3. The Living Machine can repair itself when damaged by toxics or when shocked by interruption of energy or nutrient sources.
4. The Living Machine can self-replicate through reproduction of the organisms in the system.

The concept of the Living Machine can be applied not only to an alternative WWTP but also to a range of other systems that can generate fuel, grow food, restore degraded environments, and even heat and cool buildings. Several successful examples of the Living Machine have been integrated into buildings. An example of a Living Machine is the one located in the Lewis Center for Environmental Studies at Oberlin College in Oberlin, Ohio, which processes wastewater from the occupants of this 14,000-square-foot (1,400-m^2) building (see Figure 10.15).



Figure 10.15 The Living Machine built into the Lewis Center for Environmental Studies at Oberlin College in Oberlin, Ohio, contains biological organisms that break down wastewater components into nutrients that are then fed into a constructed wetland inside the building. (Photograph courtesy of Oberlin College)

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Designing the High-Performance Building Hydrologic Cycle

Designing the water, wastewater, and stormwater systems for a high-performance building is a challenging task. In general, the first objective is to minimize potable water consumption. To determine how well a given strategy is working and to meet the requirements for most green building certification schemes, a baseline model of the building water and wastewater systems is created to allow comparisons. Both the types of plumbing fixtures and the alternative sources of water (rainwater, reclaimed water, and graywater) can be varied in the baseline model to determine how much potable water has been saved. Table 10.4 shows the flow rates for flush and flow fixtures. Flush fixtures, as the name implies, are plumbing fixtures that use a fixed quantity of water for their function, while flow fixtures use a quantity of water that depends on the length of time the fixture is use. The water use and flow rates shown in the table are the starting point for determining the water use of a building.

Establishing the population and occupant type is the next step in identifying a baseline. Along with the population, the female-to-male ratio must be known in order to quantify water consumption through fixture types. For projects that have either unknown ratios or ratios that are relatively the same, it is best to model with an even gender distribution. Occupant type classifies the people who use the facility's

TABLE 10.4

Water Use by Various Types of Plumbing Fixtures

Flush Fixture Type	**Water Use (gpf)**
Conventional low-flow water closet	1.60
High-efficiency toilet (HET), single-flush gravity	1.28
HET, single-flush pressure assist	1.00
HET, dual-flush (full-flush)	1.28
HET, dual-flush (low-flush)	1.00
HET, foam flush	0.05
Waterless toilet	0.00
Composting toilet	0.00
Conventional low-flow urinal	1.00
High-efficiency urinal (HEU)	0.50
Waterless urinal	0.00
Flow Fixture Type	**Water Use (gpm)**
Conventional low-flow lavatory faucet	2.20
High-efficiency lavatory faucet	1.80
Conventional low-flow kitchen sink faucet	2.20
High-efficiency kitchen sink faucet	1.80
Conventional low-flow showerhead	2.50
High-efficiency showerhead	Max 2.00
Low-flow janitor sink faucet	2.50
Low-flow handwash fountain	0.50
Conventional low-flow self-closing faucet	0.25 gallons/cycle
High-efficiency self-closing faucet	Max 0.20 gallons/cycle

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TABLE 10.5

Uses per Day for Plumbing Fixtures by Gender and Type of Building Occupants

	Uses per Day			
Fixture Type				
Gender, Duration, Application	**FTE**	**Student Visitor**	**Retail Customer**	**Resident**
Water closet				
Female	3.0	0.5	2.0	5.0
Male	1.0	0.1	0.1	5.0
Urinal	2.0	0.4	0.1	n/a
Lavatory faucet	3.0	0.5	0.2	5.0
Commercial at 15 sec, 12 sec with autocontrol; residential at 60 sec				
Shower	0.1	0.0	0.0	1.0
Commercial at 300 sec; residential at 480 sec				
Kitchen sink	1.0	0.0	0.0	4.0
Commercial at 15 sec; residential at 60 sec				

plumbing system. The largest occupant type difference is between a full-time equivalent (FTE) and a transient or someone temporarily visiting the facility. An FTE refers to a person who occupies the building in the equivalent of an eight-hour day. Table 10.5 shows the typical daily use patterns of plumbing fixtures based on gender and type of occupant.

BASELINE WATER MODEL EXAMPLE

To best understand how to generate a baseline water model, we start with a few pieces of information. As an example, we will use an academic building designed to have a total of 50 full-time male and 30 full-time female occupants. The building is assumed to have 300 transient male visitors and 200 transient female visitors per day. The baseline water model assumes that the fixtures used in the building meet the EPAct 1992 requirements for maximum flow rates for plumbing fixtures. Fixture performances are selected from Table 10.4, and the number of uses per person per day can be found in Table 10.5. Each fixture type must be modeled in order to identify a total water use (in gallons or liters) per day. This value is determined by identifying the product of multiplying the appropriate occupant type by the number of daily uses per person and by the total water consumed per fixture use. This calculation can be found in Table 10.6. The rightmost column indicates the estimated fixture water use per day, which is then summed for both flush and flow fixtures.

To model the annual water consumption from the facility accurately, the number of workdays must be multiplied by the daily total water use; in this case, 260 days was determined. In this particular example, the total annual potable water use is predicted to be 277,030 gallons per year. Note that the estimated water quantity for a conventional water system can be used to estimate the wastewater quantity for the building.

USE OF LOW-FLOW FIXTURE STRATEGY

The most straightforward strategy for reducing potable water consumption in buildings is to incorporate plumbing fixtures that use significantly less water than

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TABLE 10.6

Example of a Baseline Water Model

Occupant Type	Flush Fixture	Daily Uses	Potable Water (gpf)	No. of Occupants		Water Use (gal)
FTE	Conventional low-flow water closet (male)	1.0	1.6	50		80
FTE	Conventional low-flow water closet (female)	3.0	1.6	30		144
FTE	Conventional low-flow urinal	2.0	1.0	50		100
Transient	Conventional low-flow water closet (male)	0.1	1.6	300		48
Transient	Conventional low-flow water closet (female)	0.5	1.6	200		160
Transient	Conventional low-flow urinal	0.4	1.0	300		120
	Total Flush Fixture Potable Water Use (gal)					**652**
Occupant Type	**Flow Fixture**	**Daily Uses**	**Potable Water (gpm)**	**Duration (sec)**	**No. of Occupants**	**Water Use (gal)**
FTE	Conventional low-flow lavatory faucet	3.0	2.2	15	80	132
FTE	Conventional low-flow kitchen sink faucet	1.0	2.2	15	80	44
FTE	Conventional low-flow showerhead	0.1	2.5	300	80	100
Transient	Conventional low-flow lavatory faucet	0.5	2.2	15	500	138
Transient	Conventional low-flow kitchen sink faucet	0.0	2.2	15	500	0
Transient	Conventional low-flow showerhead	0.0	2.5	300	500	0
	Total flow fixture potable water use (gal)					**414**
	Total daily potable water use (gal)					**1,066**
	Annual workdays					**260**
	Total annual potable water use (gal)					**277,030**
	Total annual wastewater generation (gal)					**277,030**

code-compliant fixtures. For example, while a code-compliant urinal has a maximum water use of 1 gallon per flush, a HET is required to have a maximum potable water use of 0.5 gallon per flush; furthermore, a waterless urinal uses no water at all. Table 10.7 shows the same baseline water consumption calculations with the modification of installing HETs and HEUs instead of their conventional counterparts. The results of this modification indicate a water use reduction of almost half. It is now possible to determine the feasibility of such a retrofit by associating costs savings in both water consumption and wastewater treatment.

USE OF ALTERNATIVE WATER SOURCES STRATEGY

Further significant savings in potable water consumption can be achieved by substituting other suitable water sources for potable water. Table 10.8 shows the impact of incorporating rainwater catchment and graywater systems. In this case, we are assuming that the size of the rainwater harvesting system is sufficient enough to supply graywater to be used for flushing toilets and urinals. By comparing the potable water consumption in this scenario to the baseline model, a water use reduction of 82 percent can be achieved.

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TABLE 10.7

Water Model for a Low-Flow Fixture Scenario

Occupant Type	Flush Fixture	Daily Uses	Potable Water (gpf)	No. of Occupants		Water Use (gal)
FTE	HET, single-flush gravity (male)	1.0	1.28	50		64
FTE	HET, single-flush gravity (female)	3.0	1.28	30		115
FTE	Waterless urinal	2.0	0.0	50		0
Transient	HET, single-flush gravity (male)	0.1	1.28	300		38
Transient	HET, single-flush gravity (female)	0.5	1.28	200		128
Transient	Waterless urinal	0.4	0.0	300		0
	Total flush fixture potable water use (gal)					**346**
Occupant Type	**Flow Fixture**	**Daily Uses**	**Water Use (gpm)**	**Duration (sec)**	**No. of Occupants**	**Water Use (gal)**
FTE	High-efficiency lavatory faucet	3.0	1.8	15	50	68
FTE	High-efficiency kitchen sink faucet	1.0	1.8	15	30	14
FTE	High-efficiency showerhead	0.1	1.8	300	50	45
Transient	High-efficiency lavatory faucet	0.5	1.8	15	300	68
Transient	High-efficiency kitchen sink faucet	0.0	1.8	15	200	0
Transient	High-efficiency showerhead	0.0	1.8	300	300	0
	Total flow fixture potable water use (gal)					**194**
	Total daily potable water use (gal)					**539**
	Annual workdays					**260**
	Total annual potable water use (gal)					**140,166**
	Total annual wastewater generation (gal)					**140,166**
	Potable water savings compared to Baseline Model					**49.4%**

TABLE 10.8

Water Model for a Combination of Alternative Water and Low-Flow Fixture Strategy

Occupant Type	Flush Fixture	Daily Uses	Potable Water (gpf)	No. of Occupants		Water Use (gal)
FTE	HET, single-flush gravity (male)	1.0	0.0	50		0
FTE	HET, single-flush gravity (female)	3.0	0.0	30		0
FTE	Waterless urinal	2.0	0.0	50		0
Transient	HET, single-flush gravity (male)	0.1	0.0	300		0
Transient	HET, single-flush gravity (female)	0.5	0.0	200		0
Transient	Waterless urinal	0.4	0.0	300		0
	Total flush fixture potable water use (gal)					**0**
Occupant Type	**Flow Fixture**	**Daily Uses**	**Potable Water (gpm)**	**Duration (sec)**	**No. of Occupants**	**Water Use (gal)**
FTE	High-efficiency lavatory faucet	3.0	1.8	15	50	68
FTE	High-efficiency kitchen sink faucet	1.0	1.8	15	30	14
FTE	High-efficiency showerhead	0.1	1.8	300	50	45
Transient	High-efficiency lavatory faucet	0.5	1.8	15	300	68
Transient	High-efficiency kitchen sink faucet	0.0	1.8	15	200	0
Transient	High-efficiency showerhead	0.0	1.8	300	300	0
	Total flow fixture potable water use (gal)					**194**
	Total daily potable water use (gal)					**194**
	Annual workdays					**260**
	Total annual potable water use (gal)					**50,310**
	Total annual wastewater generation (gal)					**50,310**
	Potable water savings compared to Baseline Model					**81.8%**

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Water Budget Rules of Thumb (Heuristics)

Based on the three models shown in the previous sections, it is now possible to develop some rules of thumb, sometimes called *heuristics*, to set targets for potable water consumption. For the low-flow fixture strategy, high-efficiency fixtures are used aggressively, and the result is about a 50 percent, or Factor 2, reduction in potable water consumption compared to code requirements. For a combination of low-flow fixtures and alternative water strategies, an 80 percent reduction in potable water consumption was achieved. Consequently, it is possible to develop water reduction strategies that are in excess of Factor 4 for an aggressive strategy that includes alternative water sources and low-flow fixtures and at least Factor 2 for a less aggressive strategy that uses a simple low-flow fixture strategy.

As mentioned earlier in this chapter, the concept of net zero water is receiving serious consideration, and it actually provides a sensible approach based on one of the core ideas of sustainability; that is, resource use should be constrained to what nature provides. If we assume the building in the three water models in the preceding sections were located in a climate zone with 24 inches (0.61 m) of annual rainfall and that the facility had a roof area of 15,000 ft^2 (1,394 m^2), then 30,000 ft^3 (840 m^3), or 224,000 gallons (850,000 L), of water would be available for all uses. The baseline model shows that 277,030 gallons (1.5 million L) are required, and the result is that a net zero water strategy would require about a 20 percent reduction in water consumption, which matches up to using high-efficiency WaterSense fixtures throughout the facility.

Sustainable Stormwater Management

Stormwater management has long been a challenging issue for built environment development. Replacing plants and trees that naturally uptake large quantities of water with buildings and covering porous soils with impermeable surfaces result in large quantities of water flowing horizontally across parking and paving and picking up particles and chemicals along the way. The result has been an enormous headache for municipalities that then have to build large stormwater management facilities at high cost to taxpayers and with additional costs to the environment. Water supplies are threatened by polluted stormwater, and the health of ecosystems into which the stormwater is discharged often is compromised.

One of the results of adopting sustainable construction approaches has been the emergence of innovative, effective schemes that attempt to maintain the natural hydrology of the area. Sometimes referred to as *sustainable stormwater management*, this strategy, according to the Portland Bureau of Environmental Services, "mimics nature by integrating stormwater into building and site development to reduce the damaging effects of urbanization on rivers and streams. Disconnecting the flow from storm sewers and directing runoff to natural systems like landscaped planters, swales and rain gardens or implementing an ecoroof reduces and filters stormwater runoff."[8]

Sustainable stormwater management recognizes that there is a relationship between the natural and built environments and treats them as integrated components of the watershed. Instead of the traditional approach of using piping and extensive and expensive collection systems, it focuses on on-site collection and conveyance of stormwater from roofs, parking lots, streets, and other services, to promote the infiltration of water into the ground. Vegetated natural systems slow and filter the water and enhance the intersection and evaporation of rainfall through their leaves and roots. Vegetation also reduces stormwater runoff and removes pollutants in the process. Studies have shown that this approach can reduce stormwater runoff volume

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by as much as 65 percent. It also can remove 80 percent of suspended solids and heavy metals and as much as 70 percent of nutrients, such as phosphate and nitrogen.

Sustainable stormwater management integrates natural components, such as landscape swales and infiltration basins, with structural devices, such as cisterns, planters, pervious pavers, and pervious concrete and asphalt surfaces. Figure 10.16A–N illustrates some of the components that may be part of a sustainable stormwater management system.



Figure 10.16 (A) Disconnecting downspouts from storm sewer systems prevents roof runoff from overloading these systems by dispersing it to vegetated areas. (*Source:* City of Gresham, Oregon)



Figure 10.16 (B) Rain barrels collect roof runoff and store it for later nonpotable use. (Maxine Thomas, Florida Master Gardener/ University of Florida—IFAS Extension Realtors)



Figure 10.16 (C) Cisterns are similar to rain barrels except they are more permanent and constructed with more durable material. They can be installed above or beneath the ground, with sizes ranging from 100 to 10,000 gallons. (*Source:* City of Portland, Oregon)

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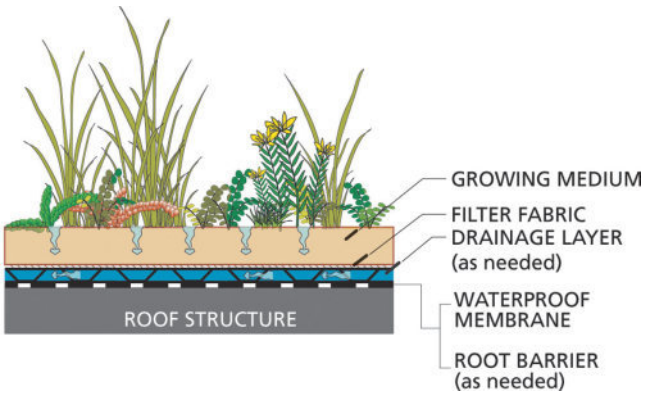


Figure 10.16 (D) Eco-roofs are an extensive green roof system. These roofs typically are constructed with layers of waterproof membrane, drainage material, and a lightweight soil and planted with shallow-root plant material. This application is appropriate for conventional roofs that are flat or low-sloped. (*Source:* City of Portland, Oregon)

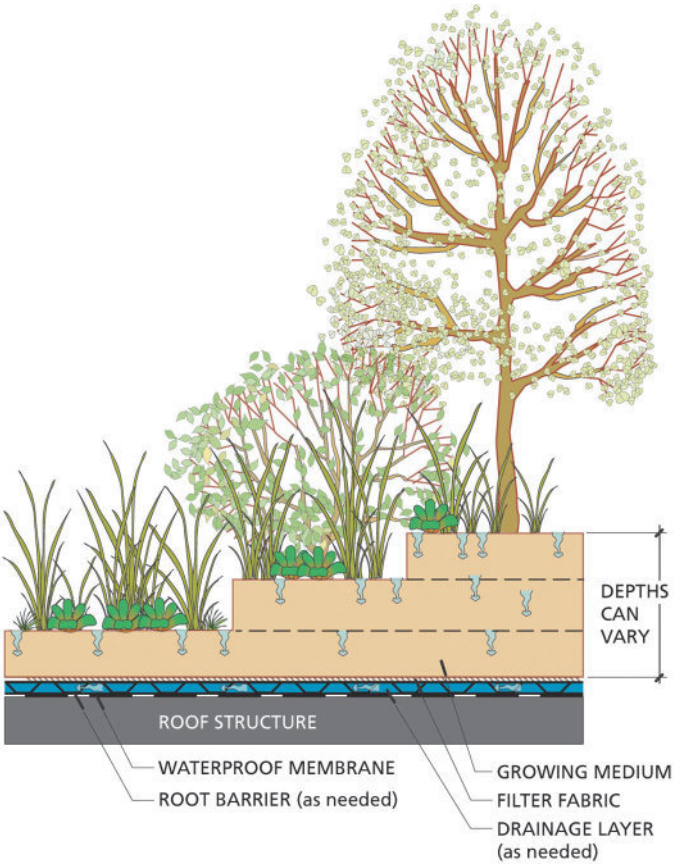


Figure 10.16 (E) Roof gardens are intensive green roof systems, with a deeper soil layer that allows for deeper-rooted and thus larger plant material than extensive systems. Some green roofs will have access points and walkways for occupants to enjoy. (*Source:* City of Portland, Oregon)

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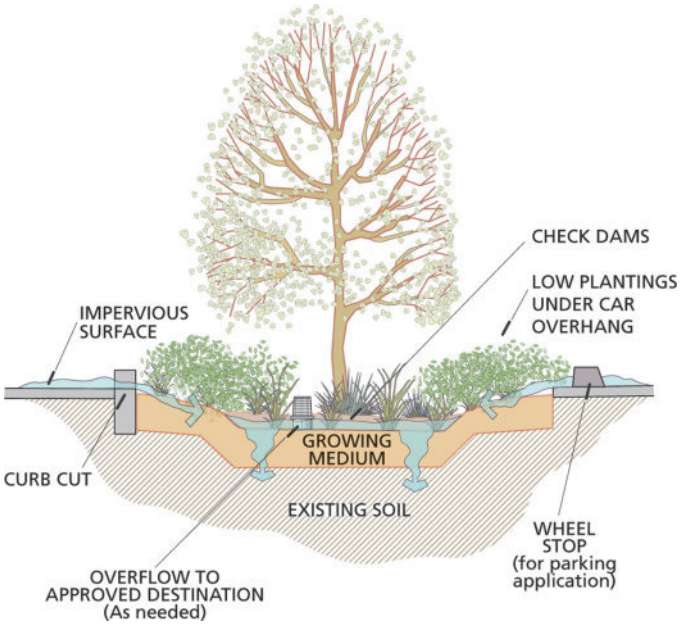


Figure 10.16 (F) Vegetated swales, or bioswales, are gently sloping depressions planted with dense vegetation or grass to divert and treat stormwater runoff. The plant material slows and filters the water as it seeps into the ground. (*Source:* City of Portland, Oregon)

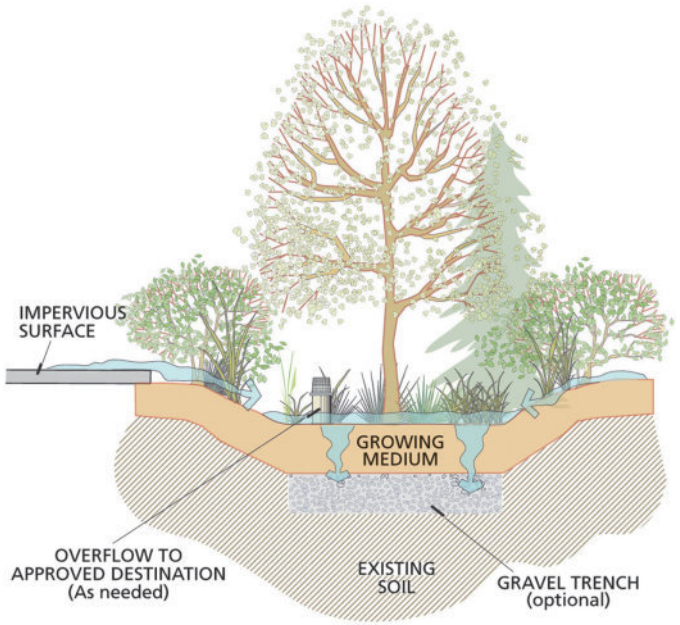


Figure 10.16 (G) Vegetated infiltration basins are also known as *rain gardens or detention ponds*. The basin is either excavated or created with berms, then landscaped to temporarily store runoff until it infiltrates into the ground. These designs temporarily detain water during a large storm and usually incorporate an overflow system for safety purposes. (*Source:* City of Portland, Oregon)

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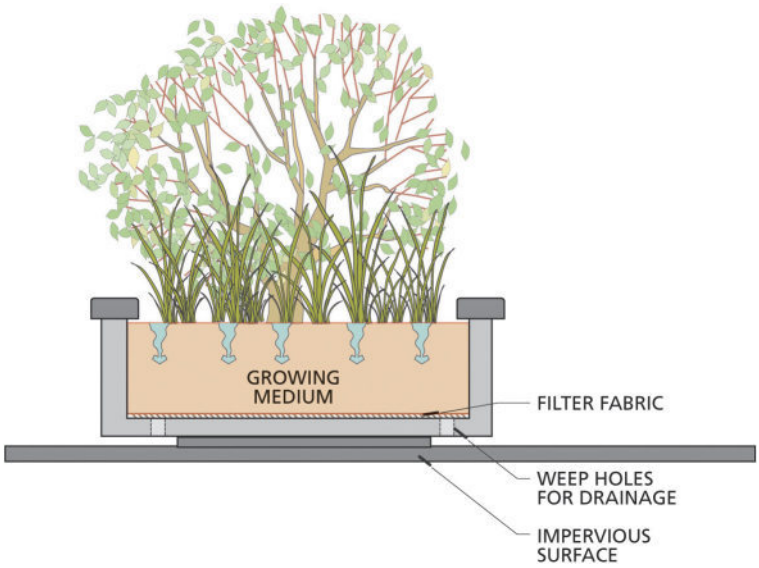


Figure 10.16 (H) Contained planters are filled with soil and plants that absorb fallen rainwater. Excess water infiltrates to the bottom of the planter and drains through weep holes. (*Source:* City of Portland, Oregon)

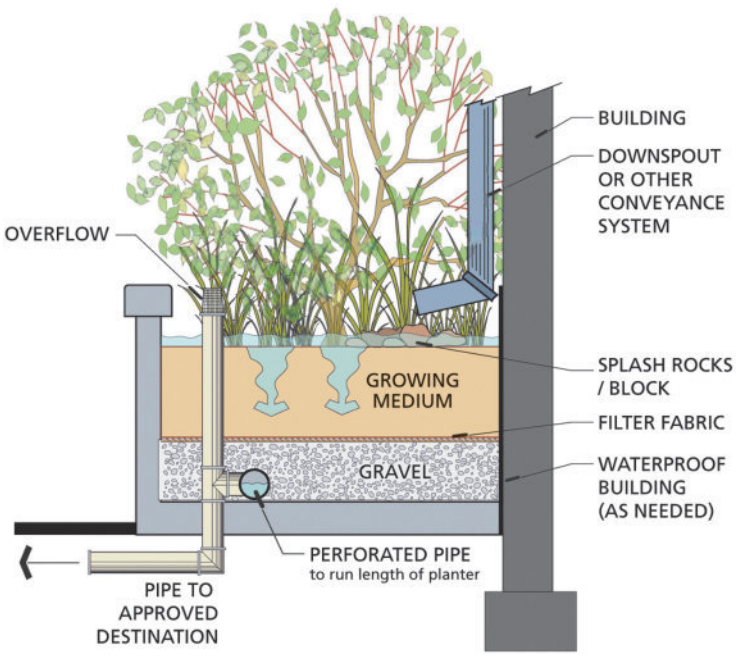


Figure 10.16 (I) Flow-through planters are used in areas where the water cannot infiltrate into the ground. They are sealed and filled with gravel, soil, and vegetation to absorb and filter the rainwater. Excess water escapes through a perforated pipe located at the bottom of the planter or to an overflow system. (*Source:* City of Portland, Oregon)

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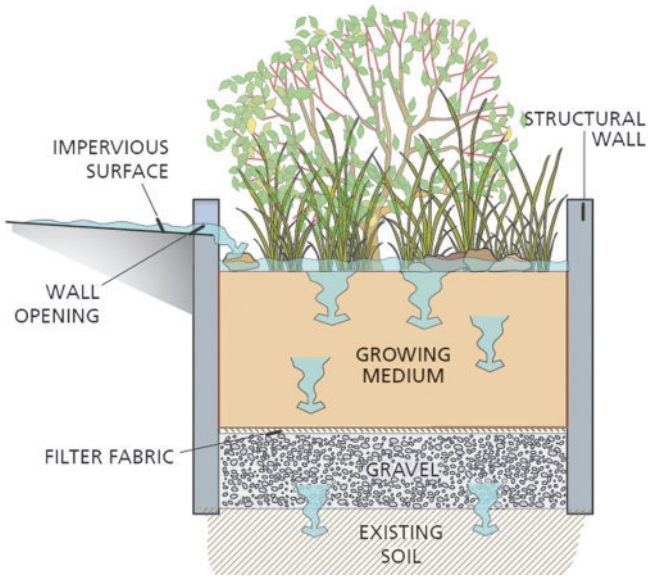


Figure 10.16 (J) Infiltration planters have open bottoms to allow stormwater to collect in the topsoil and slowly infiltrate into the ground. Materials and sizes range depending on the application. (*Source:* City of Portland, Oregon)



Figure 10.16 (K) Pervious pavers or unit pavers replace impervious surfaces and allow stormwater to soak into the ground. They typically are made out of precast concrete, brick, stone, or cobbles and form interlocking patterns with the gaps filled with either sand or gravel. (Photograph courtesy of Holly Piza)

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Figure 10.16 (L) Pervious pavement is made from concrete or asphalt, with coarse aggregates that create air voids, allowing water to pass through the system. (*Source:* City of Fairway, Kansas)

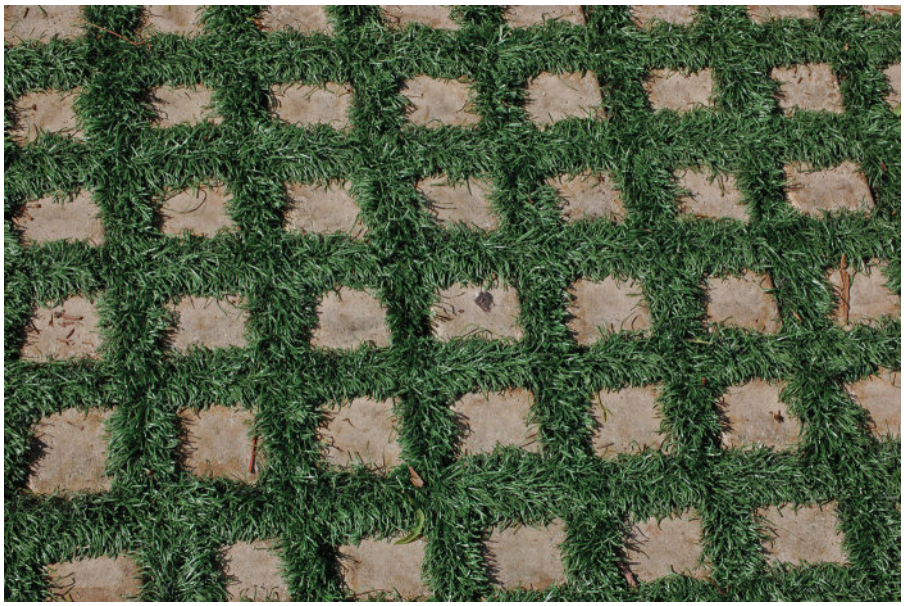


Figure 10.16 (M) Turf block, also known as *grass grid* or *open-cell unit pavers*, has gaps filled with soil and grasses allowing water to pass through. This option accepts only precipitate and not stormwater runoff; thus, suited for low traffic and infrequent car parking. Applications include patios, walkways, emergency access roads, street shoulders, and residential driveways. (Photograph courtesy of Western Interlock, Inc.)

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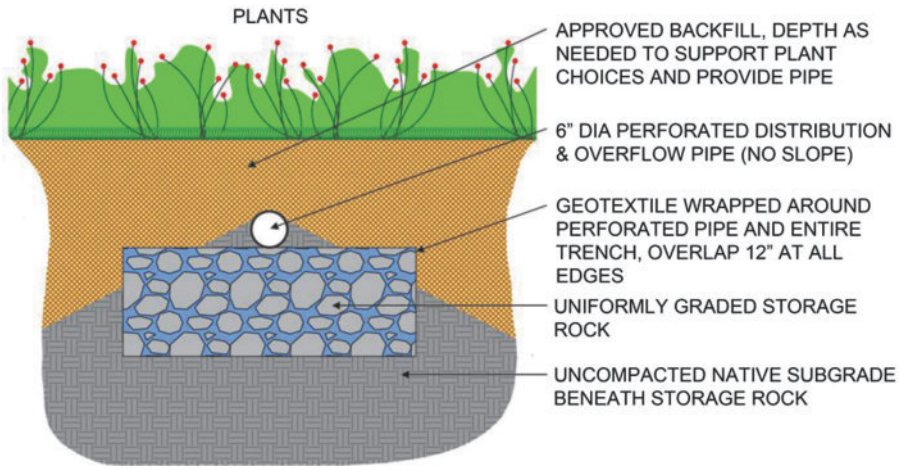


Figure 10.16 (N) Soakage trenches, or infiltration trenches, are shallow trenches lined with perforated pipe. The pipe collects rainwater from roofs or other impervious surfaces and disperses it underground to the backfill material in which it can infiltrate to the ground. (D. Stephany)

Pervious asphalt and pervious concrete are particularly interesting materials because they allow stormwater to infiltrate rapidly through the hard exterior surface and then into the ground. Pervious asphalt consists of coarse stone aggregate and asphalt binder, with very little fine aggregate. Water percolates through the voids caused by the absence of fine aggregates. A thick layer of gravel underneath allows water to drain quickly through the surface. Pervious asphalt is similar to conventional asphalt, although with a rougher service, which accounts for its name, popcorn mix. Pervious concrete consists of specially formulated mixtures of Portland cement, coarse aggregate, and water. Owing to the absence of fine aggregate, it has enough void space to allow the rapid percolation of water. Due to the lack of fine aggregates, the pervious concrete has a rough surface and resembles exposed aggregate concrete.

Applying stormwater management strategies (see Figure 10.17) from a tool chest of available technologies provides the best solution to minimize stress on water treatment plants and maximize groundwater and aquifer recharge.



Figure 10.17 Several components are integrated into this sustainable stormwater management system in Portland, Oregon. All constraints and benefits are considered when selecting which components to use for any given site. (*Source:* City of Portland, Oregon)

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Landscaping Water Efficiency

Approximately 30 percent of residential water use, or about 32 gallons (121 L) per person per day, is used for exterior uses; and the bulk of this, as much as 29 gallons (110 L) per person per day, is used for maintaining landscaping, with wide variations depending on the climatic region. Most of the water used for this purpose is wasted due to overwatering. Water-intensive turfgrass creates the major demand for irrigation. In the United States, more than 16,000 golf courses consume 2.7 billion gallons (10.2 billion L) of water per day (Vickers 2001, chapter 3).[9]

Several forms of sustainable landscaping are emerging after several decades of evolution. The best known is *xeriscaping*, which emphasizes the use of drought-tolerant native and adapted species of plants and turfgrass. (Note that the terms *enviroscaping* and *water-wise landscaping* sometimes are used interchangeably with *xeriscaping*.) Seven principles can be used to ensure a well-designed, water-efficient landscape:

1. Proper planning and design
2. Soil analysis
3. Appropriate plant selection
4. Practical turfgrass areas
5. Efficient irrigation
6. Use of mulches
7. Appropriate maintenance

Perhaps an even more sustainable form of landscaping than xeriscaping is *natural* or *native landscaping*.[10] Using restorative landscaping principles, natural landscaping supports the use of indigenous plants that, once established, virtually eliminate the need for watering. Even turfgrass, the most ubiquitous consumer of water, can be replaced with indigenous species because there are thousands of native species in the United States. The restoration of native landscapes has other benefits as well. Animal species that live in native landscapes are reestablished, natural landscapes filter stormwater effectively, and the natural beauty of the landscape is restored. In 1981, Darrel Morrison, a professor at the University of Georgia and a member of the American Society of Landscape Architects, defined three characteristics necessary for natural landscape design:

1. Regional identity (sense of place)
2. Intricacy and detail (biodiversity)
3. Elements of change

Opposition to natural landscaping was initially strong because many people, after having grown accustomed to manicured turfgrass lawns, had difficulty accepting landscaping that appeared wild and unconventional. In fact, numerous people were prosecuted for attempting to implement natural landscaping; they were accused of violating weed laws. Fortunately, natural landscaping is now far more widely accepted, and the beauty and aesthetics of this approach are winning over most skeptics. Natural landscaping can include butterfly gardens, native trees and shrubs that attract birds, small ponds, native groundcovers in lieu of turfgrass, and gardens composed of native plants. Native plants have several environmental advantages that fit in with the concept of a high-performance green building: they survive without fertilizers or synthetic pesticides and rarely need watering, they provide food and habitat for wildlife, and they contribute to biodiversity (see Figure 10.18).

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Figure 10.18 The Environmental Nature Center in Newport Beach, California, is landscaped with a water-saving design and a diverse selection of native species. Native plant material use in the landscape requires little or no irrigation and helps to maintain not only the ecosystem but also the indigenous character of the site. (LPA, Inc./Costea Photography, Inc.)

Case Study: LOTT Clean Water Alliance, Olympia, Washington

The new Regional Services Center for Olympia's wastewater treatment facility fosters active engagement of the public in the wastewater treatment process. This multiuse facility contains water quality laboratories and offices as well as an educational and technology center (see Figure 10.19A–D). One of the goals of the facility is to create a strong community outreach program emphasizing water conservation while providing the highest-quality reclaimed water to four counties with a population totaling approximately 85,000. Visitors to the facility are quickly surrounded by water being processed as they approach the building—a design that promotes community education at many levels, from the reclaimed water in the front plaza to the hands-on children's museum. Once inside, the technology center continues to communicate the importance of water and the process by which the facility meets the demands of the region.

The success of this project can be attributed to the early collaborative effort among the owner, design team, construction manager, facilities and management staff, and other stakeholders. The project goals were clearly identified and communicated to everyone involved with the project. Some of the green features of this project include polished concrete floors, a former brownfield site, the use of reclaimed timber, daylighting of offices, and louver shading to reduce solar gain.

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Figure 10.19 (A) The new Regional Services Center for Olympia's LOTT Clean Water Alliance stands as an icon in the neighborhood and welcomes the public for hands-on water treatment education. A reclaimed water pond edges two sides of the building, enticing visitors to become engaged in the process. (©Nic Lehoux)



Figure 10.19 (B) Visitors enter the building by way of a bridge, which puts them in close contact with the center's reclaimed water pond. (© Nic Lehoux)

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Figure 10.19 (C) The administrative offices of the LOTT Clean Water Alliance are situated in the center of the region's wastewater treatment facility. The public is welcomed and frequents the offices, technology center, and adjacent children's museum to gain a hands-on understanding of water issues. (Susan Kelly)



Figure 10.19 (D) Daylighting of the offices and the use of reclaimed timber are just two examples of the many sustainable features of the building's design. (© Nic Lehoux)

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Summary and Conclusions

Much of the attention to high-performance green building design has focused on superior energy performance because there are demonstrable, easy-to-document savings that can be used to justify investments in energy conservation. But for the building hydrologic system, the savings for water conservation and innovative handling of wastewater are not so easy to document because, in the United States, water has been a heavily subsidized resource, as has been the treatment of wastewater effluent and stormwater. However, it is water, not energy, that can be the limiting resource for development, as demonstrated by several growth moratoriums that have been imposed to limit or stop development and construction activity until the shortage of water or lack of an adequate wastewater treatment system can be resolved.

Water is, in fact, such a critical issue that project teams in many areas of the United States should consider making extraordinary efforts to reduce potable water consumption to exceptionally low levels. Extensive recent experience has shown that the use of rainwater harvesting, reclaimed water, graywater systems, and new waterless fixture technologies are eliminating the need for water use in urinals. HETs are also available, requiring only about one-half of the water needed by toilets meeting current plumbing codes. One area where progress still needs to be made is landscape irrigation where about 50 percent of the total potable water for the built environment is consumed.

If the construction industry does not make significant reductions in the consumptive water profile of the built environment, growth moratoriums, often instituted because of water or wastewater limitations, will reduce the volume of its business. It is now apparent that finding more appropriate ways of using potable water and treating wastewater will result in a win–win situation for both the public and the construction industry.

Notes

1. The text of the resolution can be found at www.un.org/en/ga/search/view_doc.asp?symbol=A/RES/64/292.
2. Originally from the Letters to the Editor section of the online version (www.elytimes.com) of the *Ely Times*, April 7, 2004, no longer available.
3. From the January 31, 2004, online edition of Emmitsburg.net (http://emmitsburg.net), a nonprofit Internet source for information about the Emmitsburg area.
4. The US Geological Survey publishes a detailed report on US water consumption at five-year intervals for a time frame five years earlier. The title of the 2010 report is *Estimated Water Use in the United States in 2005* and can be found at: http://pubs.usgs.gov/circ/1405/.
5. In chapter 11, Hawken, Lovins, and Lovins describe the faulty logic of contemporary building water and wastewater systems and suggest remedies that can ensure the sustainability of the world's potable water supply.
6. Sisolak and Spataro also provide information on net zero water approaches in the United States.
7. In the early 1970s, the EPA began investigating alternatives to centralized, technically complex WWTPs; part of this effort was the creation of an alternative technology program to encourage the development of systems that employ ecological systems to break down their own waste.
8. The definition of sustainable stormwater management is from "A Sustainable Guide to Stormwater Management" and can be found on the Portland Bureau of Environmental Services website at www.portlandonline.com/bes/index.cfm?c=34598. Portland, Oregon, has many award-winning sustainable stormwater projects, and its website contains a wide range of resources for supporting sustainable stormwater management.

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9. Figure 10.17 adapted from the *Stormwater Solutions Handbook* developed by the Bureau of Environmental Services of the city of Portland, Oregon.
10. Vickers also provides extensive information about water conservation in general and technical and policy information on the subject of reducing potable water use.
11. An excellent source of information about natural landscaping is the nonprofit organization Wild Ones: Native Plants, Natural Landscapes. Information and free downloads are available at its website: www.for-wild.org

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Chapter 11

Closing Materials Loops

The selection of materials and products for high-performance green building projects is a major challenge for project teams. The attributes that make materials and products acceptable for application in high-performance buildings include high recycled content, reused building materials, locally and regionally available materials, certified wood products, and wood products made from rapidly renewable resources. However, coming to a common understanding of how to prioritize and combine these attributes into a decision system for product selection has been lacking. The good news is that significant progress is being made in crafting a widely accepted approach for determining the environmental efficacy of materials and products used in construction. The advent of *environmental product declarations* (EPDs) and *environmental building declarations* (EBDs) promises to ease past problems of determining the impacts of both products and whole buildings based on a commonly accepted approach. In short, an EPD is the equivalent of a nutrition label for products and materials and is issued by independent third-party organizations that ensure uniformity and transparency in the process. An EBD can be considered to be the sum total of EPDs for all the products and materials in a building and represents its total impact. Some building rating systems, notably the Deutsche Gesellschaft für Nachhaltiges Bauen certification, include whole-building impact assessment as part of the scoring system for the certification. Historically the process of determining the life cycle impacts of the totality of a building's materials and energy consumption has been very difficult to develop because it is dependent on information supplied by independent third-party organizations and because it is very data intensive. Additionally, for what they perceive as competitive reasons, manufacturers have been resistant to participating in a transparent scheme of product declarations. However, the old days of manufacturers being unwilling to provide information to third-party certification organizations is drawing to a close as a competitive atmosphere created by early adopters is forcing others to share their information as part of the overall green building process. Noteworthy among the early adopters is InterfaceFLOR Corporation, a manufacturer of carpet tiles, which has pledged to obtain third-party-validated EPDs on all InterfaceFLOR products. Ultimately, when EPDs are available for all products that comprise a building, including complex items, such as air handlers and lighting systems, then EBDs, or whole-building declarations, will be possible. At present, EPDs simply allow a comparison between products being used for the same purpose—for example, steel versus concrete structural systems. Whole-building declarations will allow trade-offs between systems in order to minimize total impact. For example, the impacts of significant additional insulation and triple-pane, gas-filled windows can be compared to the effects of reducing the size and mass of heating, ventilation, and air-conditioning (HVAC) components, thus supporting a holistic approach to decision making about products and materials.

In addition to the advent of EPDs and EBDs, another significant trend is the emergence of independent, or third-party, organizations that produce standards, conduct testing, and provide important input to building assessment systems. These third-party organizations include Green Seal, GreenGuard, and the Forest Stewardship Council (FSC; www.fscus.org). They provide the equivalent of environmental

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Figure 11.1 Partial demolition of the Levin College of Law library at the University of Florida in Gainesville for a building expansion project. Truly green buildings of the future should be designed for deconstruction to maximize the reuse and recovery of building components and materials. (Photograph courtesy of M. R. Moretti)

labels, or ecolabels, for products that meet the requirements of green building rating systems. Meeting their standards is often a requirement for gaining points toward building certification for the US building assessment systems. A second tier of organizations that are industry-related, or second party, are contributing to the atmosphere of openness and to easing the selection process for a wide variety of materials used in construction. These organizations include the Carpet and Rug Institute (CRI) and the Sustainable Forestry Initiative (SFI). Although not without their critics due to their industry ties, many of these groups provide a useful service while at the same time setting high standards.

Another issue that is highly important when discussing the closing of materials loops is the fate of building materials at the end of their service life in a facility. Building assessment systems address the recycling and reuse of materials from building demolition (see Figure 11.1) and the reduction of waste in the construction process. Deconstruction, or the ability to disassemble a building for the purpose of reusing its components, also is finding its way into the mix of high-priority materials-related requirements.

This chapter addresses the issues of green building materials and products, the criteria for defining environmentally friendly products, the application of life-cycle assessment (LCA) in decision making for materials selection, and the subject of EPDs and their role in high-performance green building design and construction. The role of third-party standards organizations in high-performance building assessment and certification is addressed. Finally, this chapter provides information about specific materials and product groups where new technologies and approaches are beginning to take hold in support of the green building movement.

The Challenge of Materials and Product Selection

Historically, the selection of building materials and products for a high-performance green building project has been the most difficult and challenging task facing the project team. In the third edition of *Green Building Materials: A Guide to Product*

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Selection and Specification, one of the first books about the subject of green building materials, Ross Spiegel and Dru Meadows defined green building materials as "those that use the Earth's resources in an environmentally responsible way" (p. 27). At present, however, there is no clear consensus about the criteria for materials and products that would characterize them as *environmentally preferable, environmentally responsible*, or *green.* As a matter of fact, alternative terminologies are infiltrating the language of high-performance building green materials and products. For example, the label *environmentally preferable products* (EPPs) is commonly used and can be found in US government specifications for building materials and products. As a result, the question of what is or is not environmentally preferable still is being settled and is open to controversy. For example, some organizations promote green products based on a narrow range of attributes they specify as being important for this purpose. The FSC, represented in the United States by the SmartWood Program and Scientific Certification Systems, defines green products as wood products derived from a sustainably managed forest. The Greenguard Environmental Institute instead relies on levels of chemical emissions that affect indoor environmental quality to describe what constitutes a green product ("Navigating the Maze" 2003). As noted, the advent of EPDs is changing this situation somewhat by providing third-party-verified information on the impacts of products using a transparent process.

Clearly, it would be advantageous for green products to carry a certification, or ecolabel, to designate them as being preferable on the basis of consensus standards that address each type of building product. EPDs, while providing detailed information about products, are not certifications attesting to the environmental friendliness or "greenness" of a product. Ecolabels, in contrast, designate the superior performers in a given class of products. In Europe, several ecolabels cover at least some building materials. The Blue Angel ecolabel in Germany (www.blauer-engel.de), the Nordic Swan ecolabel (www.nordic-ecolabel.org) of the Nordic countries, and the European Union ecolabel (ec.europa.eu/environment/ecolabel) all have programs for labeling some types of building products. For example, the Blue Angel Standard RAL-UZ-38 addresses the requirements for certification of wood panels. Unfortunately, the range of products covered by these labeling programs is very limited; consequently, they provide minimal assistance in identifying those products that might be considered green. Thus, project teams must rely on their own best judgment in deciding which materials fit the criteria for environmental friendliness.

On the positive side, several tools are available to assist this process, the most familiar being LCA. LCA provides information about the resources, emissions, and other impacts resulting from the life cycle of materials use, from extraction through disposal, and incorporates a high degree of rigor and science in the evaluation process. LCAs are also important because they are the tool used in crafting EPDs, which will likely become the commonly accepted approach for comparing products in the decision-making process. Two readily available LCA programs, Athena[1] and Building for Environmental and Economic Sustainability (BEES),[2] apply to North American projects and can provide the project team with a science-based decision system for materials selection. These are covered later in this chapter.

ISSUES IN SELECTING GREEN BUILDING MATERIALS AND PRODUCTS

As discussed, determining how building materials and products will affect the environment is the central unresolved problem of the green building movement. Even evaluating the relative worth of using recycled versus virgin materials—which should be a relatively simple matter—can result in controversy. One school of thought, here referred to as the *ecological school*, maintains that keeping materials in productive use, as in an ecological system, is of primary importance and that the energy and other resources needed to feed the recycling system are of secondary importance.

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Nature, after all, does not use energy *efficiently*, but it does employ it *effectively*; that is, it matches the energy needed to the available energy sources. Another school of thought, here referred to as the *LCA school*, suggests that if the energy and the emissions due to energy production are higher for recycling than for the use of virgin materials, then virgin materials should be used. The LCA school also contends that too much attention is given to solid waste and that greater emphasis should be put on climate change (Trusty and Horst 2003).

Nothing, in fact, is obvious when it comes to using renewable resources in construction. Consider wood from old-growth forests. Although these forests are certainly a renewable resource, extracting resources from them is generally frowned on by environmental groups, and the green building movement is in favor of protecting the biodiversity of these beautiful and increasingly rare natural assets. Rather, it is generally agreed that wood should come from plantation forests and, even better, from rapidly renewable species. The US Green Building Council (USGBC) Leadership in Energy and Environmental Design (LEED) standard defines a class of materials known as *rapidly renewable resources*, which are species with a growth and harvest cycle of 10 years or less. However, in spite of this strategy to shift extraction from old-growth forests to other resources, plantation forestry, which produces rapidly renewable resources, must be questioned, because it can require large quantities of water, fertilizer, pesticides, and herbicides to support the rapid growth cycle and protect the company's financial investment, not to mention that monoculture forestry runs counter to the notion of biodiversity. The definition of *rapidly renewable* as 10 years or less is itself arbitrary, and any number of other definitions are equally applicable.

Besides determining which materials are environmentally preferable or green, one must decide which products or materials will have low environmental impact. Many building products are selected to help reduce the overall environmental impact of the building, not for their own low environmental impacts. Using an energy recovery ventilator (ERV), for example—a relatively complex device containing desiccants, insulation, wiring, an electric motor, controls, and other materials—contributes to an exceptionally low energy profile for the building, but it cannot be considered inherently green because its constituent materials cannot be readily recycled. Today, one of the greatest challenges in designing a high-performance green building is selecting materials and products that lower the overall impact of the building, including the impact on its site. As time progresses, a hoped-for outcome is the development of more products that both have a low environmental impact and are inherently green—that is, can be disassembled into their recyclable constituent materials.

Distinguishing between Green Building Products and Green Building Materials

The terms used to refer to the materials and products used in high-performance building can be contradictory and confusing. The term *green building products* generally refers to building components that have any of a wide range of attributes that make them preferable to the alternatives. For example, low-emissivity (low-E) glass is a spectrally selective type of glass that allows visible light to pass through but rejects a substantial part of the heat-producing infrared portion of the light spectrum. As a product, it is preferable to ordinary float glass in windows because of its energy performance. The term *green building materials* refers to basic materials that may be the components of products or used in a stand-alone manner in a building. Green building materials have low environmental impacts compared to the alternatives. As noted earlier, an example of a classic green building material is wood products certified by

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the FSC as having been grown using sustainable forestry practices. Wood is a renewable resource, the forest is managed to produce wood at a replenishable rate, and the biodiversity of the local ecosystems is protected. In short, wood meets all the criteria for a green building material as a raw input to the production process. However, the processing of the sustainably harvested wood may produce significant waste, requires large quantities of energy and water, and may contribute to the degradation of the environment. Consequently, although the raw material may be ideal from an environmental point of view, the entire life cycle must be considered to assess the entire environmental performance of a product.

The point is, depending on how they are defined, green building products may not even be made of green building materials. For example, the glass in the low-E window may be difficult or impossible to recycle because of the films utilized to provide spectral selectivity, which are glued to the glass. In contrast, ordinary float glass can be recycled readily; therefore, with respect to materials, it may be considered greener than the low-E product. This example illustrates the complexity of the product and materials selection process for high-performance buildings.

GREEN BUILDING MATERIALS

The basic materials of construction and construction products have changed over time from relatively simple, locally available, natural, minimally processed resources to a combination of synthetic and largely engineered products, especially for commercial and institutional buildings. Vernacular architecture— design rooted in the building's location—evolved to take advantage of local resources, such as wood, rock, and a few low-technology products made of metals and glass. Today's buildings are made from a far wider variety of materials, including polymers, composite materials, and metal alloys. A side effect of these evolving building practices and materials technology is that neither buildings nor the products that comprise them can be disassembled and recycled readily. There is some controversy over the relative merits of materials from natural resources versus those of synthetic materials made from a wide variety of materials, some of which do not even exist in nature. Most ecologists would, in fact, agree that there is nothing fundamentally wrong with synthetic materials. For example, it could be argued that recyclable plastics can be more environmentally friendly than cotton, whose cultivation requires large quantities of energy, water, pesticides, herbicides, and fertilizer. Nonetheless, debate continues in the contemporary green building movement about the efficacy of synthetic materials versus materials derived from nature.

GREEN BUILDING PRODUCTS

A basic philosophical approach to selecting materials for building design is sorely lacking in today's green building movement. Consequently, there are many different schools of thought, many approaches, and abundant controversy. It is not obvious, for example, that building products made from postcommercial, postindustrial, or postagricultural waste are, in fact, green. Many of the current green building products contain recycled content from these various sources.

To shed light on this topic, this section describes three philosophies or points of view about what constitutes a green building product: the Natural Step, the Cardinal Rules for a Closed-Loop Building Materials Strategy, and a pragmatic approach suggested by *Environmental Building News (EBN).*

The Natural Step and Construction Materials

One philosophical approach to designing the built environment is to use the well-known Natural Step, a tool developed to assess sustainability, as guidance for materials, product, and building design. The Natural Step (www.naturalstep.org),

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which is based on four scientifically based "system conditions," was developed in the 1980s by Dr. Karl-Henrik Robèrt, a Swedish oncologist. These four conditions are listed next:[3]

1. *In order for a society to be sustainable, nature's functions and diversity will not be systematically subjected to increasing concentrations of substances extracted from the Earth's crust.*

   In a sustainable society, human activities such as the burning of fossil fuels and the mining of metals and minerals must not occur at a rate that causes them to systematically increase in the ecosphere. There are thresholds beyond which living organisms and ecosystems are adversely affected by increases in substances from the Earth's crust. Problems may include an increase in greenhouse gases leading to global climate change, contamination of surface water and ground water, and metal toxicity which can cause functional disturbances in animals.

   In practical terms, this condition requires society to implement comprehensive metal and mineral recycling programs and decrease economic dependence on fossil fuels.

2. *In order for a society to be sustainable, nature's functions and diversity will not be systematically subject to increasing concentrations of substances produced by society.*

   In a sustainable society, humans will avoid generating systematic increases in persistent substances such as DDT [dichlorodiphenyltrichloroethane], PCBs [polychlorinated biphenyls], and chloroflurocarbons (CFCs), such as Freon. Synthetic organic compounds such as DDT and PCBs can remain in the environment for many years, accumulating in the tissue of plants and animals, causing profound deleterious effects on predators in the upper levels of the food chain.

   Freon and other ozone-depleting compounds may increase the risk of cancer due to added UV radiation in the troposphere. Society needs to find ways to reduce economic dependence on persistent human-made substances.

3. *In order for a society to be sustainable, nature's functions and diversity must not be systematically impoverished by physical displacement, over-harvesting, or other forms of ecosystem manipulation.*

   In a sustainable society, humans will avoid taking more from the biosphere than can be replenished by natural systems. In addition, people will avoid systematically encroaching upon nature by destroying the habitat of other species. Biodiversity, which includes the great variety of animals and plants found in nature, provides the foundation for ecosystem services, which are necessary to sustain life on this planet. Society's health and prosperity depend on the enduring capacity of nature to renew itself and rebuild waste into resources.

4. *In a sustainable society, resources are used fairly and efficiently in order to meet basic human needs globally.*

   Meeting the fourth system condition is a way to avoid violating the first three system conditions for sustainability. Considering the human enterprise as a whole, we need to be efficient with regard to resource use and waste generation in order to be sustainable. If 1 billion people lack adequate nutrition while another 1 billion have more than they need, there is a lack of fairness with regard to meeting basic human needs. Achieving greater fairness is essential for social stability and the cooperation needed for making large-scale changes within the framework laid out by the first three conditions. To achieve this fourth condition, humanity must strive to improve technical and organisational efficiency around the world, and to live using fewer resources, especially in affluent areas.

   This condition implies an improved means of addressing human population growth. If the total resource throughput of the global human population continues to increase, it will be increasingly difficult to meet basic human needs, as human-driven processes intended to fulfill human needs and wants are systematically degrading the collective capacity of the Earth's ecosystems to meet these demands.

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TABLE 11.1

Violation of Natural Step Conditions in the Application of Construction Materials

Item	Violation Examples	1	2	3	4
Item	Use of less abundant mined metals and minerals (copper, chromium, titanium)		X		X
	Use of heavy metals (mercury, lead, cadmium)				
Durables	Use of persistent synthetic materials—polyvinyl chloride (PVC), hydrochlorofluorocarbons (HCFC), formaldehyde	X	X	X	X
	Use of wood from rainforests and old-growth timber that is harvested unsustainably				
	Use of petroleum-based products—solvents, oils, plastic film				
Consumables	Excessive packaging and other disposables		X	X	X
Solid Waste	Landfill disposal of construction and demolition waste, including toxic components, such as lead and asbestos	X	X	X	X

Source: Adapted from the Oregon Natural Step Construction Industry Group (2004).

Applying the system conditions to new building construction, with a particular focus on building materials, produces a matrix, as shown in Table 11.1. The matrix indicates the relationship between the conditions and the various major types of materials used or generated in construction: durables, consumables, and solid waste. It also shows which conditions are violated when contemporary practices are used.

In practical terms, applying the Natural Step to the employment of building materials would result in these materials practices, adapted from the Oregon Natural Step Construction Industry Group (2004):

1. All materials are nonpersistent and nontoxic and procured either from reused, recycled, renewable, or abundant (in nature) sources:
   - **a.** *Reused* means reused or remanufactured in the same form, such as remilled lumber, in a sustainable way.
   - **b.** *Recycled* means that the product is 100 percent recycled and can be recycled again in a closed loop in a sustainable way.
   - **c.** *Renewable* means able to regenerate in the same form at a rate greater than the rate of consumption.
   - **d.** *Abundant* means that human flows are small compared to natural flows—for example, aluminum, silica, and iron.
   - **e.** In addition, the extraction of renewable or abundant materials has been accomplished in a sustainable way, efficiently using renewable energy and protecting the productivity of nature and the diversity of species.
2. Design and use of materials in the building will meet the next criteria in order of priority:
   - **a.** Material selection and design favor deconstruction, reuse, and durability appropriate to the service life of the structure.
   - **b.** Solid waste is eliminated by being as efficient as possible.
   - **c.** Where waste does occur, reuses are found for it on-site.
   - **d.** For what is left, reuses are found off-site.
   - **e.** Any solid waste that cannot be reused is recycled or composted.

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On a systemwide—in this case, planetary—scale, the Natural Step contends that, unless we are willing to severely compromise human health, we ultimately need to eliminate the extraction of ores and fossil fuels mined and extracted to produce energy and materials. Additionally, the Natural Step calls for the ultimate elimination of synthetic materials whose concentration in the biosphere is compromising not only human health but also the very health of the biosphere in which we reside. The Natural Step also cautions against the degradation of the biosphere by human activities because it is the very source of the resources needed to sustain life. And, finally, it addresses the social aspects of sustainability by noting that human needs in all parts of the world must be met. In sum, the message of the Natural Step is to reduce resource extraction, increase reuse and recycling, and minimize emissions that affect both ecosystems and human systems.

Cardinal Rules for a Closed-Loop Building Materials Strategy

A truly green building product ideally should be composed of several different materials that are also green. As pointed out earlier in this chapter, many green building products are not themselves inherently green: for example, low-E windows, T-8 lighting fixtures, and ERVs. Although there are many arguments about what constitutes a green building product, perhaps the primary question relates to the ultimate fate of the product and its constituent materials. Presuming that ecology is the ideal model for human systems and that in nature there is said to be no waste, it follows that the building materials cycle should be closed and as waste-free as the laws of thermodynamics permit. A *closed-loop* building product and materials strategy must address several levels of materials use in its implementation: the building, the building products, and the materials used in the building products and in construction. Ideally, the building materials system should follow the cardinal rules for a closed-loop building materials strategy listed in Table 11.2.

TABLE 11.2

Cardinal Rules for a Closed-Loop Building Materials Strategy

1. Buildings must be deconstructable.
2. Products must be disassemblable.
3. Materials must be recyclable.
4. Products/materials must be harmless in production and in use.
5. Materials dissipated from recycling must be harmless.

According to the cardinal rules, complete dismantling of the building and all of its components is required so that materials input at the time of the building's construction can be recovered and returned to productive use at the end of the building's useful life. These rules also establish the ideal conditions for materials and products used in building. It is, however, important to point out that very few materials and products today adhere to these five rules, meaning that the behavior of materials is far from its ideal state. Devising a system of materials, products, and buildings to support closed-loop behavior is in the distant future. Nonetheless, this thought process can be used as a touchstone for making decisions about the development of new products, materials, and technologies that support the high-performance green building movement.

Pragmatic View of Green Building Materials

In order to take a pragmatic view of green building materials, it is useful to examine contemporary efforts to wrestle more directly with these issues based on our current understanding, capabilities, and technologies. As noted several times in previous chapters, *Environmental Building News* (*EBN*) is an excellent source of well-reasoned approaches to most matters concerning high-performance buildings, and the subject of building materials and products is no exception. According to *EBN*, green building products can be broken down into five major categories:

1. Products made from environmentally attractive materials
   - **a.** Salvaged products
   - **b.** Products with postconsumer recycled content
   - **c.** Products with postindustrial recycled content
   - **d.** Certified wood products
   - **e.** Rapidly renewable products

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   f. Products made from agricultural waste material
   g. Minimally processed products
2. Products that are green because of what is not there
   a. Products that reduce material use
   b. Alternatives to ozone-depleting substances
   c. Alternatives to products made from PVC and polycarbonate
   d. Alternatives to conventional preservative-treated wood
   e. Alternatives to other components considered hazardous
3. Products that reduce environmental impacts during construction, renovation, or demolition
   a. Products that reduce the impacts of new construction
   b. Products that reduce the impacts of renovation
   c. Products that reduce the impacts of demolition
4. Products that reduce the environmental impacts of building operation
   a. Building products that reduce heating and cooling loads
   b. Equipment that conserves energy
   c. Renewable energy and fuel cell equipment
   d. Fixtures and equipment that conserve water
   e. Products with exceptional durability or low maintenance requirements
   f. Products that prevent pollution or reduce waste
   g. Products that reduce or eliminate pesticide treatments
5. Products that contribute to a safe, healthy indoor environment
   a. Products that do not release significant pollutants into the building
   b. Products that block the introduction, development, or spread of indoor contaminants
   c. Products that remove indoor pollutants
   d. Products that warn occupants of health hazards in the building
   e. Products that improve light quality

—"Building Materials: What Make a Product Green" (2012)

This pragmatic view of building materials and products is a useful starting point because it deals with the contemporary supply chain and with today's technologies and practices. The question, then, is: How do we evolve closer to the ideal of green building materials and products espoused by the Natural Step and the cardinal rules for a closed-loop building materials strategy?

PRIORITIES FOR SELECTING BUILDING MATERIALS AND PRODUCTS

There are three priorities in selecting building materials for a project:

1. Reduce the quantity of materials needed for construction, as is done with energy and water resources.
2. Reuse materials and products from existing buildings; this is a relatively new strategy called *deconstruction*. Deconstruction is the whole or partial dismantling of existing buildings for the purpose of recovering components for reuse.
3. Use products and materials that contain recycled content and that are themselves recyclable or use products and materials made from renewable resources.

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TECHNICAL AND ORGANIC RECYCLING ROUTES

There are two general routes for recycling: technical and organic. The *technical recycling route* is associated with synthetic materials (i.e., materials that do not exist in pure form in nature or are invented by humans). These include metals, plastics, concrete, and nonwood composites, to name a few. As noted earlier, only metals and plastics are fully recyclable; hence, they potentially can retain their engineering properties through numerous cycles of reprocessing. Materials in the technical or synthetic category require major investments of energy, materials, and chemicals for their recycling. Materials recyclable through the *organic recycling route* are described in the previous section under renewable resources. Composting is the best-known organic recycling route. This route is designed to allow nature to recycle building materials and turn them back into nutrients for ecosystems. Although feasible in theory, organic recycling has not been attempted on a large scale in the United States. For the organic route to work, it would have to incorporate products from a wide range of applications, including agricultural waste and landscape clearing debris as well as organic waste from construction.

GENERAL MATERIALS STRATEGY

Assuming that a building is, in fact, needed for a given function, minimizing the environmental impacts of building materials suggests the following strategy, in general order of priority:

1. *Reuse existing structures.* By modifying an existing building and reusing as much of its structure and systems as possible, one can minimize: the use of new materials, with their accompanying impacts of resource extraction; transportation; and processing energy, waste, and other effects. Clearly, trade-offs must be made when considering a building for reuse. For example, a building that, historically, has been inefficient and would need significant changes to its envelope and mechanical/electrical systems might incur significant waste, and require enormous quantities of new materials, in order for the original structure to be retrofit for its new use.
2. *Reduce materials use.* Using the minimal amount of materials required for a building project also lowers the environmental impact of introducing products manufactured from virgin resources. In a typical building, however, the opportunities for *dematerialization* are few, and center on the possible elimination of systems that are not absolutely necessary. Rejecting floor finishes in favor of finished concrete is an example of reducing materials use, but probably at the cost of aesthetic appeal. Materials waste caused by handling and conventional construction processes also contributes to unnecessary materials use. In general, dematerializing a building is difficult because of building code provisions, the desires of the users, and, sometimes, the need for new systems that are becoming standard in high-performance green buildings. An example of a relatively new system frequently used in green buildings is a rainwater harvesting system that requires cisterns, piping, pumps, power, and controls, which are not present in a conventional building. Fortunately, building performance often can be enhanced by the introduction of more systems and materials that may offset the impacts caused by increasing the mass of materials in the building project. The building materials cycle also can be enhanced by modifying existing building designs so that they incorporate design for deconstruction (DfD) as a component of the overall building design strategy and by using materials that will have future value for recycling. DfD is addressed in more detail later in this chapter.
3. *Use materials created from renewable resources.* Materials created from renewable resources offer the opportunity to close materials loops via an

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organic recycling process. The organic route involves recycling by biodegradation—that is, by composting or aerobic/anaerobic digestion, either by nature itself or by processes that mimic the decomposing action of nature. This approach applies to all products made of wood or other organic materials, such as jute, hemp, sisal, wool, cotton, and paper. Recycling of renewable resources or organic products via the organic recycling route can be accomplished with low to zero energy, additional materials, and chemicals. Note, however, that some materials are composites of organic and technical materials and hence would fall into the technical class for purposes of recycling. Other emerging materials, such as polylactic acid (PLA) polymers, are hybrid synthetics. PLA is a polymer made from the lactic acid that results from cornstarch fermentation; it is used in plastics that are competitive with and often superior to hydrocarbon-based polymers and is completely renewable. PLA can be engineered to be biodegradable in controlled compost situations, so although it is a synthetic material, it can be recycled through the organic route.

4. *Reuse building components.* Reusing intact building components from deconstructed buildings reduces the environmental impacts of building materials because these components require minimal resources for reprocessing. Progress in the techniques for deconstructing existing buildings, instead of demolishing them, means that used building components are becoming more widely available; likewise, businesses that specialize in the sale of components salvaged from deconstructed buildings are becoming more commonplace. One problem that remains to be solved, however, is how to recertify most used building products. That said, good progress has been made in developing visual regrading standards for some types of dimensional lumber—for example, western cedar and southern yellow pine.
5. *Use recyclable and recycled-content materials.* To close the materials loop in construction, all materials must have the capacity for recycling. Currently, this remains a very ambitious objective simply because few building materials are recyclable and many others can be recycled only into a lower-value application. For example, recycled concrete aggregate can be used as a subbase material but not—at least not readily, in the United States—as an aggregate in new concrete. Metals and plastics are perhaps the only materials that are fully recyclable without loss of their basic strength and durability properties. A wide range of recycled-content materials is available for the green building market. These generally contain either postindustrial or postconsumer waste. *Postindustrial waste* refers to materials recycled within the manufacturing plant. For example, during the extrusion of plastic lumber made from high-density polyethylene (HDPE), sprools of the HDPE, which peel off during the process, can be recycled back into the plastic being input to the process. *Postconsumer waste* refers to materials that are recycled from home or business use into new products. Plastic lumber made entirely of HDPE from recycled milk bottles would be considered to have 100 percent postconsumer content. Postconsumer waste recycling is far more difficult than postindustrial waste recycling. This fact is reflected in the LEED-New Construction (NC) building assessment system, which weights postconsumer content as double postindustrial content for the purpose of awarding points.
6. *Use locally produced materials.* Examining the resources and emissions associated with transporting materials between the various sites of extraction, materials production, product manufacture, and installation is one of the steps in an LCA evaluation. There is no doubt that minimizing transportation distances by using locally produced materials and locally manufactured products can greatly reduce the overall environmental impacts of materials.

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Figure 11.2 Typical of new materials emerging to serve the green building market is compressed wheatboard, made from wheat straw, which can be used in millwork or for cabinetry, as shown here in a laboratory at Rinker Hall at the University of Florida at Gainesville. (T. Wyman)

Defining what is meant by *local* can, however, be a challenge. The LEED-NC building assessment standard sets 500 miles (806 kilometers) as the radius within which a product is considered local for the purpose of obtaining points. Another difficulty with assigning weight to locally produced products is that improved technologies may be passed over. A classic example is the introduction of Japanese automobiles to the US marketplace in the late 1970s, when the quality and workmanship of these cars compelled a rapid shift away from American products. The subsequent bailout by the US government of the Chrysler Corporation in 1979–1980, coupled with higher energy prices, forced US companies to rethink their products. Ultimately, fundamental changes took place in the design and production of American cars. Today, American cars are almost on a par with Japanese automobiles and exceed many European cars in terms of quality. In short, products not considered local may be far superior, result in lower life-cycle environmental impacts, and encourage improvements in local products (see Figure 11.2).

The materials selection process may be summarized as follows: Rely on the three Rs—reduce, reuse, and recycle (with the meaning of *recycle* being extended to address products and materials with recycled content or from renewable resources).

LCA of Building Materials and Products

As stated previously, the most important tool currently being used to determine the impacts of building materials is LCA. LCA can be defined as a methodology for assessing the environmental performance of a service, process, or product, including a building, over its entire life cycle (Trusty and Horst 2003). LCA comprises several steps, which are defined in the International Organization for Standardization (ISO) 14000 series of standards that address environmental management systems.[4] These steps include inventory analysis, impact assessment, and interpretation of the impacts.

Put simply, LCA is a methodology for assessing the environmental performance of a product over its full life cycle, often referred to as *cradle-to-grave or cradle-to-cradle* analysis. Environmental performance generally is measured in terms of a wide range of potential effects, for example:

- Fossil fuel depletion
- Other nonrenewable resource use
- Water use
- Global warming potential
- Stratospheric ozone depletion
- Ground-level ozone (smog) creation
- Nutrification/eutrophication of water bodies
- Acidification and acid deposition (dry and wet)
- Toxic releases to air, water, and land

Comparing these effects for a building takes careful analysis. For example, the total energy for a building's life cycle is composed of the embodied energy invested in the extraction, manufacture, transport, and installation of its products and materials, plus the operational energy needed to run the building over its lifetime. For the average building, the operating energy is far greater than the embodied energy,

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perhaps 5 to 10 times higher. Consequently, the operational stage has far more energy impacts than stages up through the construction stage. For other effects, however, the impacts of the stages up through construction can be far greater. Toxic releases during resource extraction and the manufacturing process can be far greater than those occurring during building operation. The net result is that the designer using LCA tools must keep in mind the entire life cycle of the building, not just the stages leading to construction.

ATHENA ENVIRONMENTAL IMPACT ESTIMATOR

The Athena Environmental Impact Estimator (EIE) is an LCA tool that focuses on the assessment of whole buildings or building assemblies such as walls, roofs, or floors. It was created and is maintained by the nonprofit Athena Institute and is intended to assist project team members making decisions about product selection early in the design stage. The EIE has a regional character, meaning that the user can select the project site from among 12 different North American locations. It accounts for materials maintenance and replacement over an assumed building life and distinguishes between owner-occupied and rental facilities, if relevant. If an energy simulation for a design has been completed, it can be entered into the EIE to take account of operating energy impacts and the impacts of generating that energy. The EIE has a database of generic products covering 90 structural and envelope materials. It can simulate more than 1,000 different assembly combinations and can model the structure and envelope systems for over 95 percent of the building stock in North America. The output of the EIE provides cradle-to-grave and region-specific results of a design in terms of detailed flows from and to nature. It also provides summary measures for embodied energy use, global warming potential, solid waste emissions, pollutants to air, pollutants to water, and natural resources use. Graphs and summary tables show energy use by type or form of energy, and emissions by assembly group and life-cycle stage. A comparison dialogue feature allows the side-by-side comparisons of up to five alternative designs. Similar projects with different floor areas can be compared on a unit floor area basis (Trusty 2003).

A typical array of information produced by EIE, version 3.0, is shown in Table 11.3. The information in this table is not meaningful unless it is compared to alternative strategies. For example, the building depicted is an 18-story office building with five levels of underground parking; it has a concrete structure and an exterior curtain wall. An alternative would be a steel structure with masonry walls. The purpose of making these comparisons is to determine the building systems that have the lowest life-cycle impact—within the construction budget. An LCA program such as the EIE has a very complex array of outputs, as shown in Figure 11.3.

TABLE 11.3

Example of an LCA Output

Building Components	Embodied Energy (GJ)	Solid Waste (metric tons)	Air Pollution* (index)	Water Pollution* (index)	GWP† (equivalent carbon dioxide metric tons)	Weighted Resource Use (metric tons)
Structure	52,432	3,273	859.0	147.0	13,701	34,098
Cladding	17,187	281	649.8	24.7	5,727	2,195
Roofing	3,435	145	64.8	5.8	701	1,408
Total	73,054	3,554	1,573.6	177.5	20,129	37,701
Per square meter	2.36	0.11	0.05	0.006	0.65	1.21

*The air and water pollution indices are based on the critical volume measure (method).
†GWP is global warming potential. Energy and emission estimates do not include operating energy.

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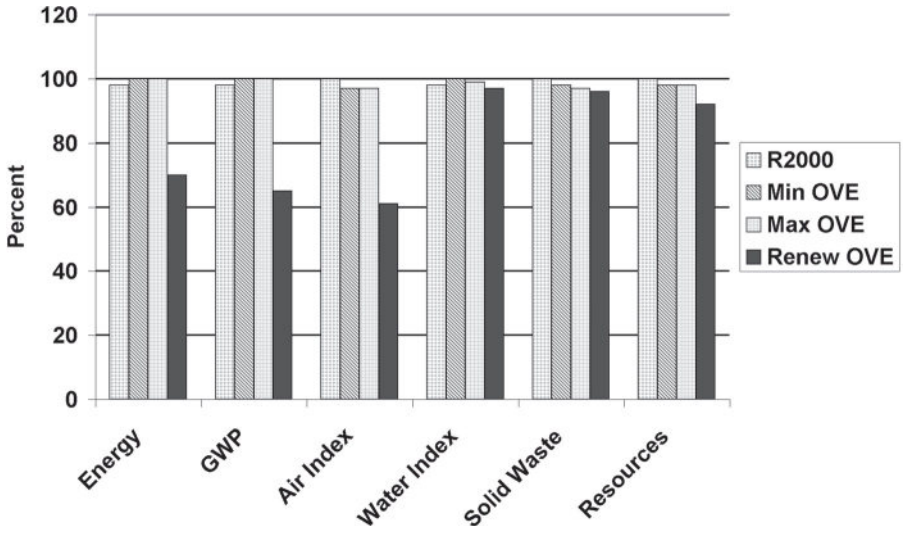


Figure 11.3 Sample output screen from the Athena EIE, version 3.0, program showing energy use, various impacts, and other resource use for a comparison of four products (Courtesy of the Athena Sustainable Materials Institute)

BUILDING FOR ENVIRONMENTAL AND ECONOMIC SUSTAINABILITY

As noted earlier, BEES is the other prominent North American tool for LCA of building materials and products; it is specific to the United States. It was developed by the National Institute of Standards and Technology with support from the US Environmental Protection Agency Environmentally Friendly Purchasing Program. BEES allows side-by-side comparison of building products for the purpose of selecting cost-effective EPPs, and includes both LCA and life-cycle costing data (see Figure 11.4). The result is that the user obtains both environmental performance and economic comparisons.

In addition to the typical measures of performance, BEES provides data about air pollutants, indoor air quality, ecological toxicity, and human health for each material or product. BEES can compare building elements to determine where the greatest impacts are occurring and which building elements need the most improvement. The user assigns weights to categories, then combines the environmental and economic

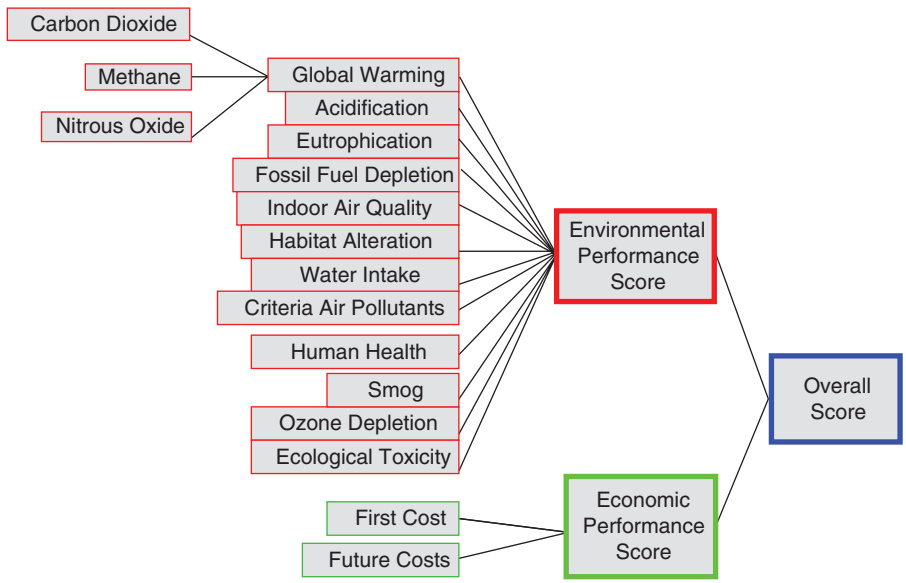
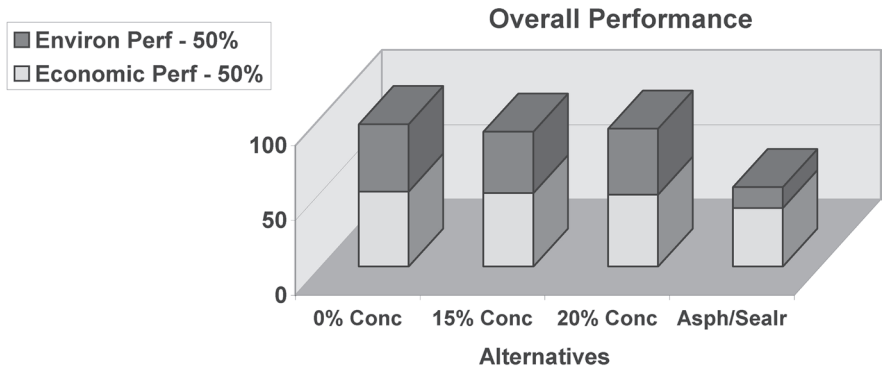


Figure 11.4 The BEES model combines environmental and economic performance into a single score for use in comparing product selection options. (*Source:* National Institute of Standards and Technology)

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Note: Lower values are better

Category	0% Conc	15% Conc	20% Conc	Asph/Sealr
Economic Perf - 50%	50	49	48	39
Environ Perf - 50%	45	41	44	14
Sum	95	90	92	53

Figure 11.5 Sample output from BEES 3.0 showing comparative environmental performance for concrete with various levels of fly ash and for sealed asphalt. BEES is a free LCA program available from the National Institute of Standards and Technology. (*Source:* National Institute of Standards and Technology)

performance into a single performance score. For example, the user first decides how to weigh environmental versus economic performance, say, 50–50 or 40–60. The user then selects from among four different weighting schemes for the environmental performance measures. The latest version of BEES is available online (www.nist.gov/el/economics/BEESSoftware.cfm) and has a database of over 200 building products, including 80 brand-name products. As an example, for floor coverings, there are 18 brand-name products and 17 distinct generic products. A sample output screen for a BEES LCA analysis is shown in Figure 11.5.

Environmental Product Declarations

An EPD presents quantified environmental data for products or systems based on information from an LCA that was conducted using a standard approach defined by the ISO. Specifically, the LCA approach is defined by ISO 14040, *Environmental Management—LCA—Principles and Framework*. An EPD is based on the output of an LCA, and its format is governed by ISO 14025, *Environmental Labels and Declarations— Type III Environmental Declarations—Principles and Procedures*. The LCA includes information about the environmental impacts associated with a product or service, such as raw material acquisition; energy use and efficiency; content of materials and chemical substances; emissions to air, soil, and water; and waste generation. It also includes product and company information. An EPD is a voluntarily developed set of data that provides third-party, quality-assured, and comparable information regarding the environmental performance of products based on an LCA. It is a statement of product ingredients and environmental impacts that occur during the life cycle of a product, from resource extraction to disposal. An EPD is similar to a nutrition label on a box of cereal, but instead of nutrients and calories, it indicates raw material consumption; energy use; air, soil, and water emissions; water use and waste generation; and other impacts. An EPD is not a certification, a green claim, or a promise; it simply shows product information in a consistent way, certified to a public standard and verified by a credible third party.

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Although they are now important in the arena of selecting high-performance building materials and products, EPDs are not especially helpful in isolation. A significant number of EPDs must be available in each product class—for example, ceiling tiles—to allow comparison among like products. And, as noted earlier, the ultimate goal is whole-building comparisons that combine EPDs into an EBD to allow trade-offs between systems. InterfaceFLOR is the North American leader in issuing EPDs and extracts from its EPD for GlasBac nylon carpet tiles are shown in Figures 11.6 to 11.8.

Layer	Component	Material	Availability	Mass %	Origin
Wear Layer	Face Cloth/Yarn	Nylon 6 Post Industrial & Post Consumer Recycled	Recycled material, abundant	17%	IT
Carrier	Tufting Primary	Polyester	Fossil resource, limited	3%	US
Backing	Latex	Ethylene vinyl acetate	Fossil resource, limited	5%	US
	Filler	CaCO3	Mineral resource, non-renewable, abundant	15%	US
Stabilization	Fiberglass	Silica	Mineral resource, non renewable, abundant	1%	US
Structural Backing	GlasBac® Backing	Polyvinyl chloride copolymer	Ethylene – Fossil resource, limited and Salt – Mineral resource, non-renewable, abundant	10%	US
		di-isononyl phthalate	Fossil resource, limited	10%	US
		Calcium alumina glass spheres, post industrial	Recycled material, abundant	39%	US

Figure 11.6 Extract from the EPD for InterfaceFLOR's GlasBac type 6 nylon carpet tiles showing materials selection. (InterfaceFLOR Commercial, Inc., environmental product declaration for GlasBac, January 2011)

Yarn Weight	Unit	Total Life Cycle	Production			Installation	Use*	End of Life
Low (441 grams/square meter)	MJ	132.04	120.67			2.68	6.56	2.13
			Primary Material	Secondary Material	Internal Processing			
			101.65	6.58	12.44			
Medium (712 grams/square meter)	MJ	144.64	132.95			2.85	6.56	2.28
			Primary Material	Secondary Material	Internal Processing			
			109.39	11.12	12.44			
High (949 grams/square meter)	MJ	155.68	143.72			2.99	6.56	2.41
			Primary Material	Secondary Material	Internal Processing			
			128.23	3.05	12.44			

Figure 11.7 Extract from the EPD for InterfaceFLOR's GlasBac type 6 nylon carpet tiles showing primary energy use. (InterfaceFLOR Commercial, Inc., EPD for GlasBac, January 2011)

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	Yarn Weight			Units
	441	712	949	grams/square meter
	13	21	28	ounces/square yard
PCR Impact Category	**Impact**			**Units**
US TRACI				
TRACI, Acidification Air	1.7	1.9	2.1	mol H+ Equiv.
TRACI, Eutrophication Water & Air	0.003	0.003	0.003	kg N-Equiv.
TRACI, Global Warming Air	9.28	10.28	11.34	kg CO2-Equiv.
TRACI, Ozone Depletion Air	1.2×10^{-6}	1.3×10^{-6}	1.4×10^{-6}	kg CFC 11-Equiv.
TRACI, Smog Air	1.6×10^{-5}	1.8×10^{-5}	1.9×10^{-5}	kg NOx-Equiv.
CML				
CML, Abiotic Depletion (ADP elements)	1.1×10^{-5}	1.1×10^{-5}	1.1×10^{-5}	kg Sb-Equiv.
CML, Acidification Potential (AP)	0.034	0.040	0.044	kg SO2-Equiv.
CML, Eutrophication Potential (EP)	0.007	0.008	0.008	kg Phosphate-Equiv.
CML, Global Warming Potential (GWP 100 Years)	9.46	10.57	11.54	kg CO2-Equiv.
CML, Ozone Layer Depletion Potential (ODP, steady state)	1.2×10^{-6}	1.3×10^{-6}	1.3×10^{-6}	kg R11-Equiv.
CML, Photochem, Ozone Creation Potential (POCP)	0.005	0.006	0.006	kg Ethene-Equiv.

Figure 11.8 Extract from the EPD for InterfaceFLOR's GlasBac type 6 nylon carpet tiles showing environmental impacts generated by the product LCA. (InterfaceFLOR Commercial, Inc., environmental product declaration for GlasBac, January 2011)

Materials and Product Certification Systems

One of the means of selecting green building materials and products for high-performance buildings is to rely on certification programs that are well recognized, especially by building assessment systems, such as LEED. For example, the FSC, which certifies wood products, Green Seal, which certifies low-emission paints, and the CRI, which certifies low-emission carpets, provide assurance that the products comply with their standards and are referenced in building assessment systems. Like ecolabels, product certification by programs established by reputable organizations greatly simplifies the search for environmentally friendly products. Figure 11.9 is a list of the major materials certification programs generally applicable in the United States. It is useful to distinguish between certification organizations and the standards they develop. For example, Green Seal is a certification organization while Green Seal Standard 13 for Paints and Coatings is a standard produced by Green Seal that specifies maximum volatile organic compound content for specific classes of paints and coatings. Green Seal is a third-party certifier; that is, it is an independent entity. The CRI, because it was set up by the carpet industry, is considered a second-party certifier. Although not totally independent, it is considered to be fair and reliable with respect to its testing and certification. First-party certification is provided directly by the manufacturer, and the data provided have not been verified by an outside organization. An example is a material safety data sheet provided by the manufacturer for the purposes of complying with Occupational Safety and Health Administration safety requirements on the construction site.

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Key Aspects of Major Green Product Certification Programs

	Program	Managing Organization	Product Range	Levels	Used in LEED*	Type of Standard or Certification	Comments (see article text for details)
Sustainable Forestry	Forest Stewardship Council	Forest Stewardship Council (FSC)	Forest products	Variety of labels for pure and percentage content	Y	Third-party certification to regionally specific standards	Only forestry program in LEED; roots in the environmental movement. More prescriptive than SFI.
	Sustainable Forestry Initiative	Sustainable Forestry Initiative (SFI)	Forest products	Variety of labels for pure and percentage content	N	Third-party certification	Thorough system but less prescriptive than FSC. Historically close to the forest industry.
	American Tree Farm System	American Forest Foundation	Forest products	Single standard for small U.S. landowners	N	Third-party certification	Very non-prescriptive standard. Does not label products itself, but the SFI label applies.
	CSA Sustainable Forest Management System	Canadian Standards Association (CSA)	Forest products	Single standard applied to specific forest areas	N	Third-party certification	Industry- and government-backed standard used in Canada.
Emissions Certifications	California Section 01350	California Department of Health Services	Wide range of interiors products	n/a	Y	Specification guidance on which other certifications are based	Designed to reduce pollutant concentrations in classrooms and offices.
	Greenguard	Greenguard Environmental Institute	Wide range of interiors products	Greenguard Indoor Air Quality, Greenguard for Children & Schools	Y	Third-party certification	Uses ASTM test methods.
	FloorScore	Scientific Certification Systems, Resilient Floor Coverings Institute	Non-textile flooring	FloorScore	Y	Third-party certification	Based on California Section 01350 specification. Equivalent to Indoor Advantage Gold.
	Indoor Advantage	Scientific Certification Systems (SCS)	Wide range of interiors products	Indoor Advantage, Indoor Advantage Gold	Y	Third-party certification based on a variety of standards	Indoor Advantage meets LEED requirements; Indoor Advantage Gold also meets stricter California Section 01350 limits.
	Green Label	Carpet & Rug Institute (CRI)	Carpet, pad, adhesive	Green Label, GreenLabel Plus	Y	Second-party certification	Green Label Plus meets California Section 01350 limits.
Energy	Energy Star	U.S. EPA and U.S. Department of Energy	Range of products	n/a	Y	Government label based on manufacturer data	Popular program with wide impact. Moderate standards capture wide market share.
Multi-Attribute Standards and Certifications	Sustainable Choice	Scientific Certification Systems (SCS)	Carpet; others expected	Silver, Gold, Platinum	ID	Third-party certification, based on both consensus and proprietary standards	Similar to SCS's EPP standard but with social considerations. Respected as a leader in the field.
	Cradle to Cradle (C2C)	McDonough Braungart Design Chemistry (MBDC)	Wide range of products	Biological, Technical Nutrients; Silver, Gold, Platinum	ID	Second-party certification, based on a proprietary standard	Developed by respected industry leaders, but key pieces are not transparent.
	SMaRT Consensus Sustainable Product Standards	Institute for Market Transformation to Sustainability (MTS)	Wide range of products	Sustainable, Silver, Gold, Platinum	ID	Third-party certification	Works with outside auditors to verify performance.
	NSF-140 Sustainable Carpet Assessment	NSF International	Carpet	Bronze, Silver, Gold, Platinum	ID	Standard, requiring third-party certification	California Gold Sustainable Carpet Standard has merged with NSF-140 Platinum.
	Sustainable Furniture Standard	Business and Institutional Furniture Manufacturer's Association (BIFMA)	Furniture	Silver, Gold, Platinum	N	Standard, to which first-, second-, or third-party certification is possible	Draft standard being developed; no certification program available yet.
	Green Seal	Green Seal	Wide range	n/a	Y	Third-party certification	Uses various ASTM standards depending on product type.
	EcoLogo/ Environmental Choice	TerraChoice Environmental Marketing	Wide range of products	n/a	Y	Third-party certification	Backed by the Canadian government.

*Y = referenced in LEED credit language N = not referenced ID = referenced in Innovation in Design options

Figure 11.9 Certification programs available for materials selection for US high-performance buildings. Many of these certification programs are referenced by US building assessment systems, such as LEED. (Adapted from "Behind the Logos: Understanding Green Product Certification" (2008).)

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Key and Emerging Construction Materials and Products

For many conventional building materials, admirable progress is being made in rethinking their extraction and application in construction. Perhaps the most notable and successful effort has been the inclusion of sustainable forestry as the key criterion for wood products used in construction. LEED-NC, for example, provides a point if a minimum of 50 percent of the building's wood-based materials and products are certified in accordance with the FSC's Principles and Criteria. Green Globes provides points for wood products certified by the FSC, the SFI, under the Canadian Standards Association Standard for Sustainable Forest Management (CAN/CSA Z809), and the American Tree Farm System. For metal products, the emphasis is on their recycled content, and organizations such as the Steel Recycling Institute ensure that the benefits of their member companies' products are well known.

New technologies are being developed to improve performance or to provide new capabilities of building products. But in part because there is no commonly accepted vision of what constitutes a green building material or product, there are many different approaches to product development. Therefore, one of the most effective ways to track progress is to examine the products emerging to serve the green building marketplace.

The next sections address the current issues and status of major classes of construction materials. A comprehensive discussion of the wide range of green building materials and products, both existing and emerging, is beyond the scope of this book. Therefore, the materials discussed here are those considered most important because of the scale of their application in construction: wood and wood products, concrete and concrete products, metals, and plastics.

WOOD AND WOOD PRODUCTS

Wood and products made of wood are very important construction materials, made all the more important because of their renewability. Enormous areas of the United States are considered to be covered with trees, some 747 million acres (302 million hectares [ha]), or about one-third of the US landmass. Of this, 504 million acres (204 million ha) are classified as timberland—that is, productive forest capable of growing at least 20 cubic feet (0.6 m^3) of commercial wood per acre per year. Approximately 67 million acres (27 million ha) are owned by the forest products industry, 291 million (118 million ha) are held by 10 million individual private landowners, and another 49 million acres (20 million ha) contained within the National Forest System are available for forest management.[5]

A wide variety of wood products are used in construction, including dimensional lumber, engineered wood products, plywood, oriented strand board, and composite materials with wood fiber content. Wood products used in high-performance green buildings should originate in sustainably managed forests and should bear labels certifying this fact. The major organization governing sustainable forestry internationally is the FSC, whose US-based certifiers are the SmartWood Program (www.rainforest-alliance.org/forestry/certification) and Scientific Certification Systems (www.scsglobalservices.com. The FSC program is based on a set of 10 principles used as the basis for the criteria to qualify forests for certification (see Table 11.4). The USGBC LEED building assessment standard provides a point related to certified wood products and for rapidly renewable resources (i.e., wood products grown in plantation forests). FSC Principle 10 addresses the forestry practices required to earn certification for these types of forests.

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The SFI program is a comprehensive system of principles, objectives, and performance measures developed by professional foresters, conservationists, and scientists that combines the perpetual growing and harvesting of trees with the long-term protection of wildlife, plants, soil, and water quality. On January 1, 2007, the SFI program became a fully independent forest certification program. The multistakeholder board of directors of the SFI is now the sole governing body over the SFI Standard (SFIS) and all aspects of the program. The diversity of the board members reflects the variety of interests in the forestry community.

The SFIS spells out the requirements of compliance with the program. The standard is based on nine principles that address economic, environmental, cultural, and legal issues, and a commitment to continuously improve sustainable forest management (see Table 11.5).

Only companies and organizations that have successfully completed an audit by an independent and accredited certification body can claim certification to the SFIS. SFI certification audits are rigorous, on-the-ground assessments, conducted by highly qualified and objective individuals.

Of the leading certification schemes in operation in the United States, only the SFI program has a strict separation between standard setting and accreditation of certifying bodies. Recognized international protocols (ISO) for auditing explicitly require that these functions be separate. To date, over 127 million acres have been independently certified to the SFIS.[6]

It should be noted that there are several other third-party certification systems for sustainably harvested wood, including the American Tree Farm System and CSA Sustainable Forest Management. The Green Globes building assessment system takes all of these into account in awarding points, while the USGBC relies solely on the FSC certification system.

TABLE 11.4

FSC Principles for Management of Forests

Principle 1: Compliance with Laws and FSC Principles. Forest management shall respect all applicable laws of the country in which they occur, and international treaties and agreements to which the country is a signatory, and comply with all FSC Principles and Criteria.

Principle 2: Tenure and Use Rights and Responsibilities. Long-term tenure and use rights to the land and forest resources shall be clearly defined, documented, and legally established.

Principle 3: Indigenous Peoples' Rights. The legal and customary rights of indigenous peoples to own, use, and manage their lands, territories, and resources shall be recognized and respected.

Principle 4: Community Relations and Workers' Rights. Forest management operations shall maintain or enhance the long-term social and economic well-being of forest workers and local communities.

Principle 5: Benefits from the Forest. Forest management operations shall encourage the efficient use of the forest's multiple products and services to ensure economic viability and a wide range of environmental and social benefits.

Principle 6: Environmental Impact. Forest management shall conserve biological diversity and its associated values, water resources, soils, and unique and fragile ecosystems and landscapes, and, by so doing, maintain the ecological functions and the integrity of the forest.

Principle 7: Management Plan. A management plan—appropriate to the scale and intensity of the operations—shall be written, implemented, and kept up to date. The long-term objectives of management, and the means of achieving them, shall be clearly stated.

Principle 8: Monitoring and Assessment. Monitoring shall be conducted—appropriate to the scale and intensity of forest management— to assess the condition of the forest, yields of forest products, chain of custody, management activities, and their social and environmental impacts.

Principle 9: Maintenance of High Conservation Value Forests. Management activities in high conservation value forests shall maintain or enhance the attributes that define such forests. Decisions regarding high conservation value forests shall always be considered in the context of a precautionary approach.

Principle 10: Plantations. Plantations shall be planned and managed in accordance with Principles and Criteria 1 through 9, and Principle 10 and its criteria. While plantations can provide an array of social and economic benefits, and can contribute to satisfying the world's needs for forest products, they should complement the management of, reduce pressures on, and promote the restoration and conservation of natural forests.

Source: Forestry Stewardship Council at https://ic.fsc.org/the-10-principles.103.htm.

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TABLE 11.5

SFIS Principles

1. **Sustainable Forestry**
   To practice sustainable forestry to meet the needs of the present without compromising the ability of future generations to meet their own needs by practicing a land stewardship ethic that integrates reforestation and the managing, growing, nurturing and harvesting of trees for useful products and ecosystem services such as the conservation of soil, air and water quality, carbon, biological diversity, wildlife and aquatic habitats, recreation and aesthetics.
2. **Forest Productivity and Health**
   To provide for regeneration after harvest and maintain the productive capacity of the forestland base, and to protect and maintain long-term forest and soil productivity. In addition, to protect forests from economically or environmentally undesirable levels of wild re, pests, diseases, invasive exotic plants and animals, and other damaging agents and thus maintain and improve long-term forest health and productivity.
3. **Protection of Water Resources**
   To protect water bodies and riparian areas, and to conform with forestry best management practices to protect water quality.
4. **Protection of Biological Diversity**
   To manage forests in ways that protect and promote biological diversity, including animal and plant species, wildlife habitats, and ecological or natural community types.
5. **Aesthetics and Recreation**
   To manage the visual impacts of forest operations, and to provide recreational opportunities for the public.
6. **Protection of Special Sites**
   To manage lands that are ecologically, geologically or culturally important in a manner that takes into account their unique qualities.
7. **Responsible Fiber Sourcing Practices in North America**
   To use and promote among other forest landowners sustainable forestry practices that are both scientifically credible and economically, environmentally, and socially responsible.
8. **Legal Compliance**
   To comply with applicable federal, provincial, state and local forestry and related environmental laws, statutes and regulations.
9. **Research**
   To support advances in sustainable forest management through forestry research, science and technology.
10. **Training and Education**
    To improve the practice of sustainable forestry through training and education programs.
11. **Community Involvement and Social Responsibility**
    To broaden the practice of sustainable forestry on all lands through community involvement, socially responsible practices, and through recognition and respect of Indigenous Peoples' rights and traditional forest-related knowledge.
12. **Transparency**
    To broaden the understanding of forest certification to the SFI 2015-2019 Forest Management Standard by documenting certification audits and making the findings publicly available.
13. **Continual Improvement**
    To continually improve the practice of forest management, and to monitor, measure, and report performance in achieving the commitment to sustainable forestry.

Source: SFI (2015)

CONCRETE AND CONCRETE PRODUCTS

As one of the mainstays of construction and one of its oldest and best-known materials, concrete has an enormous and increasing number of roles in construction. Concrete normally is composed of coarse aggregate (rock), fine aggregate (sand), cement, water, and various additives. With respect to high- performance buildings, concrete has many positive qualities: high strength, thermal mass, durability, and high reflectance; is generally locally available; can be used without interior and/or exterior finishes; does not off-gas and affect indoor air quality; is readily cleanable; and is impervious to insect damage and fire. Concrete can be designed to be pervious

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or cast into open-web pavers, thus allowing water to infiltrate directly into the ground to reduce the need for stormwater systems.

The key issue with concrete is the carbon dioxide (CO_2) emitted in the cement manufacturing process. Cement, which comprises 9 to 14 percent of most concrete mixes, is second only to coal-fired utilities in CO_2 emissions. For each ton of powder cement produced, up to an equal mass of CO_2 is generated. However, during the life cycle of a concrete element, the cement reabsorbs about 20 percent of the CO_2 generated in the manufacturing process, at least partially mitigating the CO_2 emitted during manufacturing.. Minimizing the quantity of cement in a concrete mix is a strategy that has a number of potential benefits. Fly ash and ground blast furnace slag, both of which have cementitious properties, can be substituted at least partially for cement and result in increased concrete performance. Fly ash can be readily substituted for over 30 percent of the cement volume; blast furnace slag, for more than 35 percent. These substitutions have the advantage of making beneficial use of otherwise industrial waste while simultaneously reducing the quantity of CO_2 associated with concrete production. Fly ash and blast furnace slag also can be blended with cement in the cement manufacturing process, resulting in reduced CO_2 emissions, reduced energy consumption, and expanded production capacity.

The recycling properties of concrete are generally satisfactory. Crushed concrete can be used as subbase for roads, sidewalks, and parking lots. In the Netherlands, recycled concrete aggregate may substitute for one-third of the virgin aggregate in concrete mixes. In general, recycled concrete aggregate is in high demand and has relatively high value.

METALS: STEEL AND ALUMINUM

Metals in general have high potential for recycling, and most metal products used in typical building applications have significant recycled content. The performance of metal products in building applications can be outstanding, providing high strength and durability with relatively light weight. Additionally, metals are readily recycled, and their dissipation into the environment during the recycling process is benign. Although the LCA and embodied energy impacts associated with metals may appear to be higher than those of alternatives, the inherent recyclability of metals, their durability, and their low maintenance make them competitive for high-performance building applications.

Steel production today incorporates used steel products in the two production processes still being used. The basic oxygen furnace (BOF) uses 25 to 35 percent scrap steel for products that require drawability—for example, automobile fenders and cans—while the electric arc furnace (EAF) uses almost 100 percent scrap steel for products whose main requirement is strength—for example, structural steel and concrete reinforcement. Steel made from the BOF process generally has a total recycled content of 32 percent, which is composed of 22.6 percent postconsumer content and 8.4 percent postindustrial content. EAF-produced steel generally has a recycled content of about 96 percent, with a postconsumer content of 59 percent and postindustrial content of 37 percent.[7] Recycled steel consumes a fraction of the resources and energy of steel produced from iron ore. Each ton of recycled steel saves 2,500 pounds (1,134 kg) of iron ore, 1,400 pounds (635 kg) of coal, and 120 pounds (54 kg) of limestone. Only one-fifth of the energy needed to produce steel from iron ore is required to recycle scrap steel. Steel recycling systems in the United States are well established, so much so that recycling is dictated less by environmental concerns than by economics.

Aluminum recycling also has marked environmental benefits. Recycled aluminum requires only 5 percent of the energy needed to produce aluminum from bauxite ore, thus eliminating 95 percent of the greenhouse gases that would be generated by manufacturing aluminum from bauxite. Approximately 55 percent of the world's

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aluminum production is powered by hydropower, which, although controversial because of its environmental impacts, is a renewable resource. Recycling 1 pound (0.45 kg) of aluminum saves 8 pounds (3.6 kg) of bauxite and 6.4 kilowatt-hour of electricity. Aluminum recycling in the United States is highly successful and well established, with about 65 percent of aluminum being recycled. The recycled content of the average aluminum can is about 40 percent, and improved engineering means that, today, 1 pound (0.45 kg) of aluminum produces 29 cans versus 22 cans in 1972. Although there has been controversy over the value of recycling aluminum cans, the industry claims that they can be recycled profitably by individuals and groups. Recycling rates for building applications range from 60 to 90 percent in most countries.[8] Aluminum panels used in buildings are corrosion-resistant, lightweight, and virtually maintenance-free; aluminum also has high reflectivity, making it extremely useful as a roofing material. Aluminum also is used extensively in electrical wiring applications, as a casing for appliances, and in moldings and extrusions for windows.

PLASTICS

Along with wood and metals, plastics, which are composed of chains of molecules known as *polymers*, are a major constituent of building products, both as virgin materials and as recycled content. Plastics have a high potential for recycling, and the industry has developed a systematic method for designating and labeling the seven major classes of plastics. The Society of the Plastics Industry, Inc., introduced this system in 1988 to facilitate recycling of the growing quantity of plastics entering the marketplace and the waste stream. Large quantities of postconsumer plastics, particularly HDPE and polyethylene terephthalate (PET), are being recycled into a range of building products, such as plastic lumber. Construction products are the second highest user of plastics in the United States, exceeded only by packaging.

At present, however, there is little, if any, recycling of plastic building products into other end uses, which is a serious problem. Closed-loop behavior is, of course, desirable. But there are some success stories in plastic recycling. One is the development of processes that recycle HDPE into high-quality plastic lumber, a product with very high durability that is impervious to rot, insects, and saltwater damage and with a lifetime measured in hundreds of years. The holy grail of any recycling effort is to develop technologies that can recycle products back into their original use. The United Resource Recovery Corporation technology developed in Germany, can recycle PET plastics back into very high quality flakes, which can then be used to produce the ubiquitous clear plastic of soft-drink bottles. Recycling rates for HDPE and PET in the United States are in the 20 percent range, the highest for the common classes of plastics used in consumer products.

Manufacturers of plastics derived from chlorine or that employ chlorine in their production are under severe pressure from environmental groups such as Greenpeace because of the various impacts associated with their manufacture and disposal. PVC, a ubiquitous product in construction (it appears in piping, siding, flooring, and wiring, to name a few), is the main focus of these struggles. To date, recycling rates for PVC are among the lowest for the seven major classes of plastics covered by the Society of the Plastics Industry—less than 1 percent. And in the United States, PVC is being defended by its industry based on its technical and economic merits, meaning that fundamental changes to the product or its manufacture are not anticipated in the near future. In contrast, the European PVC industry is exploring how to make fundamental changes in the production and disposal of its products, positioning PVC to be regarded as an environmentally responsible product. According to a green paper on PVC released by the Commission of the European Communities in 2000, the major problems with PVC are the use of certain additives (lead, cadmium, and phthalates) and the disposal of PVC waste.[9] According to the green paper, only 3 percent of PVC waste is recycled; 17 percent is incinerated and the remaining 80 percent is landfilled,

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with the total waste stream amounting to 3.6 million tons per year. The risks associated with landfilling PVC, especially the loss of phthalate from soft PVC, were highlighted, along with the problems caused by incineration—namely, the generation of dioxins, which are very hazardous chemicals. Unquestionably, PVC recycling must be improved, and reformulation of the basic product must be considered in order to remove the barriers to its recycling. PVC product recycling faces many of the same problems associated with other plastics—the use of additives such as plasticizers, stabilizers, fillers, flame retardants, lubricants, and colorants, which are used to provide specific properties.

A relatively new development in the plastics industry is the production of biobased polymers, such as PLA. In 2002, Cargill Dow Polymers (CDP) opened a large facility in Blair, Nebraska, to manufacture a plastic product from PLA, the first of its kind, thus marking the introduction of a polymer technology based on a renewable resource, rather than oil, a nonrenewable resource. The product is known as NatureWorks PLA, which CDP says can be produced from agricultural products such as sugar beets and cassava. Not to be outdone, Dow Chemical introduced a product called BIOBALANCE polymers, which are advanced polyurethane polymers designed to be used as commercial carpet backing. One of the polyurethane components, polyol, is derived from renewable resources. Another Dow Chemical product, WOODSTALK, is manufactured from formaldehyde-free polyurethane resin and harvested wheat straw fiber, a renewable resource. It is a boardlike material that can be used as an alternative to medium-density fiberboard for millwork, cabinetry, and shelving. BioBase 501 is a relatively new, low-density, open-cell polyurethane foam insulation partially made from soybeans. The polyol component of BioBase 501 is made of SoyOl, the soy-based component that is also used in carpet backing. And in Stockholm, Sweden, a process developed by the Royal Institute of Technology uses wood to create polymers known as *hemicellulose-based hydrogels*. In addition to being produced from renewable resources such as agricultural products and wood, biobased polymers hold the promise of being recyclable via natural processes.

Design for Deconstruction and Disassembly

It is undeniable that the current state of construction is wasteful and will be difficult to change. As noted at the start of this chapter, closing materials loops in construction remains the most challenging of all green building efforts. More specifically, choosing building materials and products is by far the most daunting challenge.

Criteria for materials and products for the built environment should be similar to those for industrial products in general. Many materials used in buildings, most notably metals, are the same as those used in other industries. But buildings have a distinct character compared to other industrial products. The major factors that make closing materials loops in this segment of the economy particularly difficult are delineated in Table 11.6. The vision of a closed-loop system for the construction industry is, by necessity, one that is integrated with other industries to the maximum extent possible. Many materials—again, metals—can flow back and forth for various uses, whereas others, such as aggregates and gypsum drywall, are unique to construction, so their reuse or recycling would stay within construction. Closing materials loops for the built environment will be much more difficult due to the factors that make its materials cycles differ significantly from those of other industries.

Deconstruction is the whole or partial disassembly of buildings to facilitate component reuse and materials recycling; DfDs is the deliberate effort during design to maximize the potential for disassembly, as opposed to demolishing the building totally or partially, to allow the recovery of components for reuse and materials for

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TABLE 11.6

Factors that Increase the Difficulty of Closing Materials Loops for the Built Environment

1. Buildings are custom-designed and custom-built by a large group of participants.
2. No single "manufacturer" is associated with the end product.
3. Aggregate, for use in subbase and concrete, brick, clay block, fill, and other products derived from rock and earth, are commonly used in building projects.
4. The connections of building components are defined by building codes to meet specific objectives (e.g., wind load, seismic requirements), not for ease of disassembly.
5. Historically, building products have not been designed for disassembly and recycling.
6. Buildings can have very long lifetimes exceeding those of other industrial products; consequently, materials have a long "residence" period.
7. Building systems are updated or replaced at intervals during the building's lifetime (e.g., finishes at 5-year intervals; lighting at 10-year intervals; HVAC systems at 20-year intervals).

recycling and to reduce long-term waste generation. To be effective, DfDs (a notion that emerged in the early 1990s) must be considered at the design stage.

Experiments in DfDs conducted at Robert Gordon University in Aberdeen, Scotland, included a wide range of approaches that can facilitate a greatly improved materials cycle: handling, materials identification, simplicity of construction techniques, exposure of mechanical connections, independence of structure and partitioning, and making short-life-cycle components readily accessible. Research indicates that DfD must be implemented at three levels of the entire materials system in buildings in order to produce sound product design and construction strategies: the systems or building level, product level, and materials level. A number of examples exist to test various DfD ideas. One, a multistory residential housing project in Osaka, Japan, employs a reinforced concrete frame to support independently constructed dwellings that can be replaced on 15-year cycles without removing the supporting frame. Ultimately, closing construction materials loops will necessitate the inclusion of product design and deconstruction together in a process that might be labeled *design for deconstruction and disassembly*.

Philip Crowther (2002) of Queensland Technical University in Brisbane, Australia, suggested 27 principles for building DfDs that are enumerated in Table 11.7. This comprehensive list covers a wide range of thinking about materials selection, product design, and deconstruction.

Crowther's work serves as an excellent starting point in the discussion of a comprehensive approach to developing a seamless framework for closing construction materials loops. Importantly, these principles perhaps generate as many questions as they answer. An example is Principle 4, which calls for avoiding composite materials. In the context of materials, "composite" can have many meanings—for example, mixed materials (concrete, steel) or homogeneous layered materials (PVC pipe, laminated wood products). Composites may be very acceptable under certain conditions, where recycling the composite mixture is feasible or where the ability to disassemble the layers has been designed into the product. The question is how to develop a systematic approach for determining the acceptability of composites as building materials within the context of attempting to increase reuse and recycling.

Deconstruction offers an alternative to demolition that has two positive outcomes: (1) it is an improved environmental choice, and (2) it can serve to create new businesses, to dismantle buildings, transport recovered components and materials, remanufacture or reprocess components, and resell used components and materials. Existing buildings, although not designed to be taken apart, are, in fact, being disassembled to recover materials. There are distinct benefits to be gained from increasing the recycling rates of materials from buildings from the 20 percent

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TABLE 11.7

Principles of DfDs as Applied to Buildings

1. Use recycled and recyclable materials.
2. Minimize the number of types of materials.
3. Avoid toxic and hazardous materials.
4. Avoid composite materials and make inseparable products from the same material.
5. Avoid secondary finishes to materials.
6. Provide standard and permanent identification of material types.
7. Minimize the number of different types of components.
8. Use mechanical rather than chemical connections.
9. Use an open building system with interchangeable parts.
10. Use modular design.
11. Use assembly technologies compatible with standard building practice.
12. Separate the structure from the cladding.
13. Provide access to all building components.
14. Design components sized to suit handling at all stages.
15. Provide for handling components during assembly and disassembly.
16. Provide adequate tolerance to allow for disassembly.
17. Minimize the number of fasteners and connectors.
18. Minimize the types of connectors.
19. Design joints and connectors to withstand repeated assembly and disassembly.
20. Allow for parallel disassembly.
21. Provide permanent identification for each component.
22. Use a standard structural grid.
23. Use prefabricated subassemblies.
24. Use lightweight materials and components.
25. Identify the point of disassembly permanently.
26. Provide spare parts and storage for them.
27. Retain information on the building and its assembly process.

Source: Crowther (2002).



Figure 11.10 One of the innovations in the design of Rinker Hall at the University of Florida in Gainesville was to include DfD as a design criterion. One of the design features is the use of bolted, exposed steel connections to permit their ready removal. (Photograph courtesy of M. R. Moretti)

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range to in excess of 70 percent, because waste from demolition and renovation activities can comprise up to 50 percent of national waste streams. Economic and noneconomic policy instruments can assist in the shift from demolition to deconstruction by providing financial incentives and aiding in allotting the time needed for deconstruction. In developing countries, building deconstruction practices offer a source of high-quality materials to assist in improving the quality of life and the potential for new businesses, which may provide economic opportunity for their citizens.

In spite of its many benefits, designing buildings for deconstruction has rarely occurred in the United States. Rinker Hall at the University of Florida in Gainesville is likely the only LEED-certified building, out of thousands that have been certified, that was designed to be disassembled, receiving an innovation credit from the USGBC for its deconstructability (see Figure 11.10).

Case Study: Project XX Office Building, Delft, Netherlands

According to the architect Jouke Post, office buildings typically have a life span of just 20 years due to inevitable changes in technology and corporate management. Demolition produces an enormous amount of waste from materials that have not reached their useful life expectancy. The XX Office Building in Delft, Netherlands, explored a solution to this waste problem by planning for a shorter building life and by planning for deconstruction and materials reuse in the initial design (see Figure 11.11A–F). The semipermanent design concept challenges designers to think in terms of reality: a 20-year building life rather than the ideal 100-year life of a typical framed structure. Once its practical use has ended, the XX Office Building can be deconstructed and the materials can be reused or recycled.



Figure 11.11 (A) The XX Office Building located in Delftech Park in Delft, Netherlands, has a ceiling-to-floor rectangular glass façade. Standard-sized glazing will be reused after the building is deconstructed. (J. M. Post, XX Architecten)

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Figure 11.11 (B) The columns and beams, shown during construction. (J. M. Post, XX Architecten)



Figure 11.11 (C) The columns and beams in a completed office are exposed and connected by stand-off steel rod lower chords and bolts to promote ease of construction and deconstruction. (J. M. Post, XX Architecten)

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Figure 11.11 (D) Ceiling-to-floor window screens control the amount of daylight entering the building. (J. M. Post, XX Architecten)



Figure 11.11 (E) Cardboard ductwork is inexpensive, resourceful, and recyclable and will be close to the end of its life expectancy by the time the XX Office Building is ready for deconstruction. (D. Stephany)

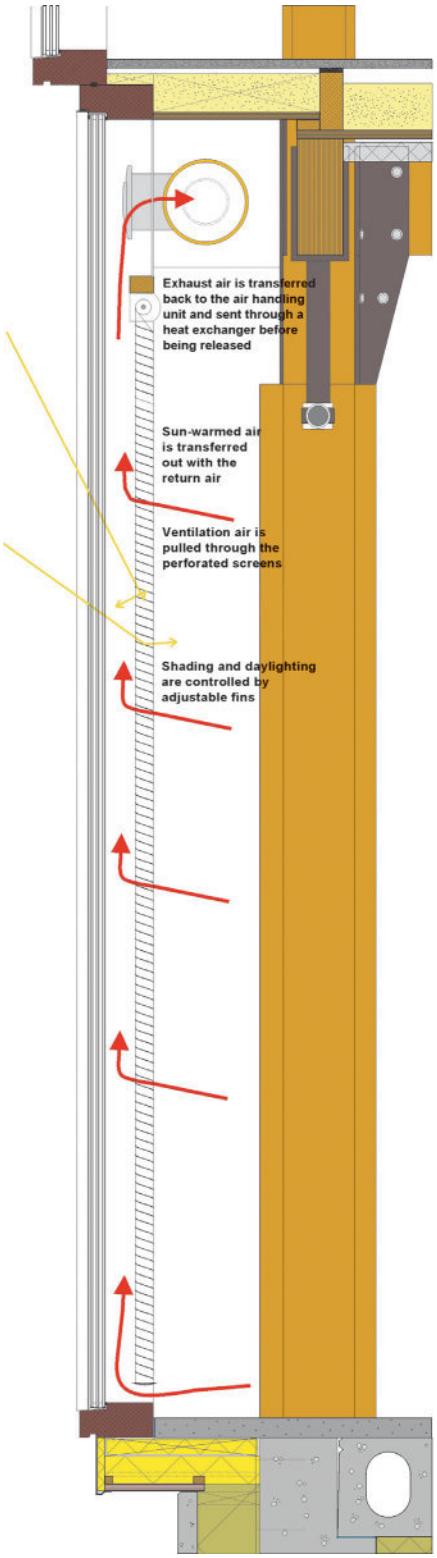


Figure 11.11 (F) An air inlet between the screen and window creates a thermal buffer zone, resulting in energy savings and improved climate control (J. M. Post, XX Architecten)

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The 19,200-square-foot (2000-square-meter), two-story building was constructed in 1998 and is a simple, open, and unified rectangular plan. The structure is primarily laminated wood, which was chosen after an analysis of steel, aluminum, concrete, stone, synthetic material, and cardboard for their durability, strength, cost, and future recyclability. The exposed columns and beams are connected by steel rod chords and bolts to provide ease of construction and deconstruction.

The ground floor consists of a concrete slab with 20 percent recycled aggregate. Between levels, sandwiched panels (600 centimeters × 3,500 centimeters) filled with sand are used to improve the acoustical separation. The roof is made of fibrous concrete and recyclable bitumen roof covering. Originally, the roof was held down by weights in the pattern of two Xs representing Roman numerals, hence the building's name. The façade consists of wooden frames attached to the main structure by brackets for ease of deconstruction. These frames have standardized triple-paned windows (approximately 2 m × 5 m) fastened to them. Each frame segment has its own ceiling-to-floor window screen controlling the amount of daylight entering the building. The screens are perforated and help keep heat from entering the building by creating a double-façade system, or Mercator climate façade. The return air ductwork is composed of cardboard tubes that run along the perimeter of the building. The design uses the energy generated by its 80 occupants and their electric office equipment in place of a heating system.

THOUGHT PIECE: CLOSING MATERIALS LOOPS

The notion of closing materials loops is central to sustainable construction, but it is likely the most difficult and challenging of all the concepts emerging in the shift to a much more environmentally responsible built environment. Buildings are simply not generally made of materials that are recyclable or reusable; instead, the materials are optimized, at lowest cost, for their function. As a result, future high-performance buildings are likely to be composed of materials and systems that have a much greater closed-loop potential than those being utilized today. In this thought piece, Brad Guy, an international expert on the subject of deconstruction, discusses the practicality of more sustainable materials practices in the near term.

Closing Materials Loops

Bradley Guy, School of Architecture and Planning, Catholic University of America, Washington, DC



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Closing materials loops is a necessary paradigm for any attempts to minimize the impacts of the built environment on the human and ecological environment now and for the survival prospects of future generations. The resource flows in the United States and globally that are dedicated to the built environment materials have consequences across the entire spec trum of resources and in every environmental impact category. The single activity of cement production alone is responsible for between 5 and 7 percent of global greenhouse gases (European Commission, 2011). While harvesting of lumber is a relatively low-energy activity, the effects of deforestation and changes in land use because of building impacts have a globally significant impact on the use of land and timber resources for building activities. The list goes on for the upstream impacts of the provision of materials resources into the built environment. This ecological rucksack can be very high in relative mass and environmental impacts in proportion to the final material. Alan Durning (1992) proposed that the average consumer product requires 16 times more resources than will end up in the final product. This suggests that, for every kilogram of building material avoided, reduced, reused, remanufactured, or recycled, another 16 times its mass of materials have been conserved.

It is not remotely sufficient to strive for more benign new building materials or high-performance new buildings when the even higher-than-expected levels of CO_2 reported by the Intergovernmental Panel on Climate Change, resulting from current greenhouse gas emissions pose the long-term threats for which operationally efficient buildings will come too late when providing their full benefits over 10 or 20 years of building life. While predictions of operational energy efficiencies typically are based on models and subject to the whims of users and often underappreciated maintenance, the one certainty in the life of a building is the materials of which it is made and the systems used to construct them. The other certainty is that the materials-use impacts are in real time and the environmental degradation and emissions caused by their extraction, manufacture, transport, and construction can be reduced at the moment of a building project's conception through the choices that are made by the owner, designer, engineer, and builder who have the expertise and stake in the outcome at building sign-off. In the cause of consideration for future generations, I would like to also posit that it is a professional and ethical responsibility for any architect or builder to consider the end-of-life consequences of his or her design and materials choices. To not do so would be the equivalent of standing in a crowded city and shooting a bullet into the air. It will come down somewhere.

For every kilogram of material avoided through effective design, and reuse of buildings and building parts, a kilogram of raw resources will be preserved. Some suggest that this will not occur because of the Jevons paradox, whereby efficiencies of use of a resource will tend to increase its consumption. Even if this were true in areas of personal finance, at least for the built environment, the relatively static and long-lived nature of buildings ensures that materials investments will remain for some period. The consequences of the reuse of a building, the reuse of materials, and designing for the adaptation of buildings to extend their invested structure and designing for disassembly at end of life of nonstructural and structural building assemblies are physical manifestations in a physical realm.

Design for recovery, reuse, and recycling is a fundamental precept of cradle to cradle, zero waste, extended producer responsibility, and so forth. All matter degrades, and there is no perpetual-motion machine of materials flow. In order to design for recycling, there must be a recycler, and for the recycler to function, there must be a materials flow allowed by the materials producer and the architect and builder. The constant refrain of the catch-22 that without waste there will be no reuse and recycling infrastructure and without infrastructure we cannot propose design for recovery of materials does not aid the way forward. Many green building systems, for example, have developed design for adaptation and/or disassembly within their systems, as a means to use green building standards as an aid to the market of these design practices. One is the Australia Green Star, which has a credit for use of design for disassembly and for "dematerialization," to use less steel for a structure of equivalent performance. The current version of LEED for Health care awards points for "design with flexibility," and the proposed next version of LEED for Commercial Interiors has proposed adding design for flexibility. The state of California has recently, as of 2011, put into effect legislation requiring all carpet sold in that state to have an extended producer responsibility system by the manufacturer. This legislative policy and the voluntary market transformation that LEED has proven to be possible are essential ingredients in extending the life of materials and their maintenance in the social and economic system of materials flow. Once extracted, no building material should leave the economic loop until it has reached the true end of its utilitarian or energetic value, and materials of high order should never be substituted for materials of lower order.

The design paradigm for closing materials loop is slowly changing and will continue to progress as the realization of resource constraints become more severe. In some cases this will be political. Local resources, the reuse of blighted vacant land, reusing existing buildings, and specifying salvaged materials represent the basic elements of resource conservation.

Summary and Conclusions

Many new materials and products are being developed to serve the high-performance green building movement. But in the face of the rapid changes taking place in this area, no clear philosophy precisely articulates the criteria for this new class of products and materials. One proposal is that LCA should determine what constitutes

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greenness in the context of building materials and products. But LCA has limitations in that it does not adequately address closed-loop materials behavior, which is how nature behaves. Nor does LCA address whether a product or building can be disassembled and recycled, or the recyclability of products and materials. A material or product conceivably could appear to be very beneficial according to the LCA data but may not be recyclable and subject to disposal after use. LCA does, however, provide an excellent account of the resources and environmental impacts of a given decision and allows side-by-side comparisons of various approaches—for example, a steel versus a concrete structural system. Combined with other criteria, LCA offers a good way of evaluating the appropriateness of labeling a product or material green. At this point in the evolution of high-performance green buildings, considering both the production and the fate of materials and products should be a high priority. And as pointed out in the cardinal rules for a closed-loop building materials strategy, the products and materials must be harmless in use and in recycling before they can be considered truly green.

Notes

1. The Athena Environmental Impact Estimator is available for purchase from the Athena Sustainable Materials Institute online at www.athenasmi.org. Athena uses a location-specific database of materials to provide LCA information about whole-building systems—for example, wall or roof sections. A demonstration version of Athena is available for download from the website.
2. BEES is a product of the Building and Fire Research Laboratory of the National Institute of Standards and Technology. BEES measures the environmental performance of building products using the LCA approach specified in the ISO 14000 standards. It is available from www.bfrl.nist.gov/oae/software/bees.html.
3. The information on page 372 is originally from the Natural Step website. The 4 basic principles remain (www.thenaturalstep.org/our-approach/), but the detailed discussion is no longer on the site.
4. An overview of the ISO can be found at its website, www.iso.ch/iso/en/ISOOnline.frontpage. ISO 14000 is one of many standards promulgated by this organization. The ISO 14040 series is the member of the ISO 14000 family of standards that addresses LCA.
5. Forestry statistics are from the American Forest and Paper Association website, www.afandpa.org.
6. The SFI Standard can be found at www.sfiprogram.org/files/pdf/2015-2019-standardsandrules-section-2-pdf/.
7. Statistics from "2002: The Inherent Recycled Content of Today's Steel," available on the Steel Recycling Institute's website, www.recycle-steel.org.
8. Data on aluminum are from the International Aluminum Institute at www.world-aluminium.org.
9. The European Community's "Green Paper: Environmental Issues of PVC" (2000) can be found at http://ec.europa.eu/environment/waste/pvc/pdf/en.pdf.

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Chapter 12

Built Environment Carbon Footprint

The major environmental challenge facing humanity today is *climate change*, a manifestation of an imbalance in the global biogeochemical carbon cycle caused by human activities. The main cause of climate change is the dramatically increasing emissions of carbon gases, mainly carbon dioxide (CO_2), into the atmosphere from fossil fuel combustion by power plants, transportation, building energy systems, cement production, and agriculture. At the same time, Earth is losing its ability to stabilize CO_2 concentrations because biomass, such as forests, which absorb CO_2, are being lost to land development, deforestation, and mining. The combination of rapidly increasing emissions and decreasing absorption capacity is accelerating the atmospheric concentrations of CO_2. CO_2 and other climate change gases trap solar energy, and as their atmospheric concentrations rise, average global atmospheric temperatures also increase. Prior to the start of the Industrial Age (about 1780), the natural balance of CO_2 emissions and absorption resulted in a relatively stable global temperature regime, and the effect of human activities on climate was small. Increasing population and energy consumption have upset this balance and consequently Earth's climate is not as stable and is noticeably changing.

CO_2 released from combustion processes in both fossil fuel electric power plants and automobiles is the main source of increasing CO_2 emissions. Although CO_2 is the main contributor to climate change because of the magnitude of its emissions, there are also significant climate change effects associated with methane (CH_4) and several other gases. Indeed, CH_4 is a far more potent per mass in this respect than CO_2, but it is being released at a far smaller rate than CO_2. As Earth warms and the ice cover in the northern Arctic boreal forests melts, enormous quantities of biomass that were frozen for millions of years are being exposed to the air. The biomass then decomposes and releases CH_4 and CO_2, thus further contributing to climate change. The process of biomass decay in the Arctic is also accelerating because, as the ice cover disappears, its reflective properties are lost. The darker biomass revealed in the process absorbs the sun's energy, increasing the rate of decay. An additional climate change contributor that is also accelerating climate change is the loss of snow and ice over the North Pole, Greenland, and other regions. Similar to the biomass being exposed under the tundra, the solar energy is being absorbed by the much darker ocean instead of being reflected, further increasing energy inputs to the atmosphere. Fracking for natural gas production is also having an effect because significant quantities of natural gas, which is largely CH_4, are being released to the atmosphere during the process. Additional sources of CH_4 releases to the atmosphere include livestock and rice farming. The result of the confluence of all these human impacts is that changes to Earth's climate are occurring at an alarming rate. Nine of the 10 hottest years on record have occurred since 2000 with the warmest year being 2014.

This chapter is devoted to the issue of climate change and the built environment's contributions to worsening the situation. Climate change poses an unprecedented threat to both human and other life on the planet, and the major contributor to the conditions causing it are connected to buildings and infrastructure and the resources needed to construct and operate them. About 40 percent of anthropogenic, or human, carbon emissions are associated with the construction and operation of

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the built environment. This is expected to increase to at least 50 percent by 2035. An additional 20 percent of carbon emissions result from fossil fuel consumption by cars, trucks, trains, and aircraft. Because transportation energy and carbon are largely the result of how buildings and infrastructure are planned, it will be included in the discussion of climate change and the built environment.

The goals of this chapter are to: (1) describe the global carbon biogeochemical cycle and how it has been disrupted from its stable state during pre-industrial times, (2) understand the connection between human-caused, rapidly increasing atmospheric carbon concentrations and climate change, (3) learn to calculate the carbon footprint of the built environment, and (4) apply the knowledge gained from the built environment carbon footprint to help rapidly slow and reverse climate change.

Human Impacts on the Biogeochemical Carbon Cycle

On Earth, there are several large-scale, cyclic movements of certain chemicals that have profound effects on living organisms. The pathways and rate of movement of these chemicals through both living (biotic) and nonliving (abiotic) compartments of the planet have enormous effects on life on Earth. These large-scale movements of key chemicals through the biosphere are referred to as *biogeochemical cycles*. The seven important biogeochemical cycles that have been identified are the cycling of carbon, water, oxygen, nitrogen, phosphorous, sulfur, and rock. The *carbon cycle* is important because all known life-forms are comprised of carbon and carbon compounds. CO_2, an important component of the carbon cycle, regulates planetary temperature, making life on Earth possible. Although CO_2 is a tiny portion of Earth's atmosphere—just 0.4 percent—it causes 63 percent of the energy trapping that occurs in the atmosphere. The powerful ability of CO_2 to trap energy contributes to a climate regime that supports life. Changes to atmospheric CO_2 levels affect average global temperatures. Although CO_2 concentrations in the atmosphere have varied naturally for thousands of years, current levels exceed those measured in ice cores from 420,000 years ago and are in fact reaching concentrations not experienced on Earth for several million years. These concentrations are continuing to increase at an accelerated pace and are upsetting the relative stability of Earth's climate. This upset is referred to as *climate change*, and its root cause has been traced to human activities and technologies that are dumping enormous quantities of climate change gases, primarily CO_2, into the atmosphere.

The carbon biogeochemical cycle exhibits two major behaviors: *active*, or more rapid-cycling, systems and *slow-cycling* systems. The naturally active carbon cycle, comprising carbon movements among the atmosphere, oceans, and the terrestrial and aquatic biospheres, contains about 41 billion tons (41 gigatons) of carbon. As noted, it is the impact of human activities on the active carbon cycle that is disrupting the otherwise relatively stable atmospheric. The imbalance resulting for human activities is illustrated in Table 12.1. Fossil fuel consumption, land use changes in which biomass is removed, and cement production increase CO_2 emissions to the atmosphere by about 7.0 gigatons per year. Natural oceanic and terrestrial systems absorb about 3.8 gigatons of this increase, leaving 3.2 gigatons of excess CO_2 per year to accumulate in the atmosphere. The 3.2 gigatons per year of additions to the 730-gigaton active carbon cycle, about 0.5 percent per year, are important because there are no natural mechanisms capable of absorbing this excess at a rate that would prevent its accumulation (Intergovernmental Panel on Climate Change [IPCC], 2001).[1] Indeed, the only systems capable of absorbing this excess are the natural mechanisms of erosion and sedimentation associated with Earth's lithosphere[2] (see Figure 12.1 and Table 12.1). However, these mechanisms are associated with the slow-cycling portion of the

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TABLE 12.1

Human Activities Contributing to Imbalances in the Global Carbon Cycle

Human Activity	Gigatons (billion tons) of Carbon/Year
Fossil fuel burning	6.2
Cement production	0.1
Land-use change	1.7
Subtotal human caused carbon increase	***7.0***
Land removal	1.9
Ocean removal	1.9
Subtotal human caused carbon removal from atmosphere	***3.8***
Net annual carbon accumulating in the atmosphere	**3.2**

Source: Intergovernmental Panel on Climate Change, 2013

carbon cycle, and they function not on short time scales, such as years or decades, but on geological time scales of thousands of years. The quickest path to slowing and reversing climate change is the reduction of human carbon emissions and the restoration of the biosphere. Because the built environment is the dominant cause of excess CO_2 emissions, the solution lies in dramatically reducing energy consumption along with shifting to energy sources that have the lowest CO_2 emissions. Shifting from coal to natural gas is an example of the latter because it would cut CO_2 emissions in half for the same amount of energy (see Table 12.2). Due to the extensive combustion of fossil fuels to support the built environment, transportation, and industry, atmospheric CO_2 concentrations have risen from preindustrial levels of about 280 parts per million (ppm) to over 400 ppm today, an increase of 43 percent (see Table 12.3). Because average atmospheric temperatures have been found to track the changes in CO_2 concentrations, it is reasonable to expect that dramatic upward changes in temperature will result from significant increases in these concentrations.

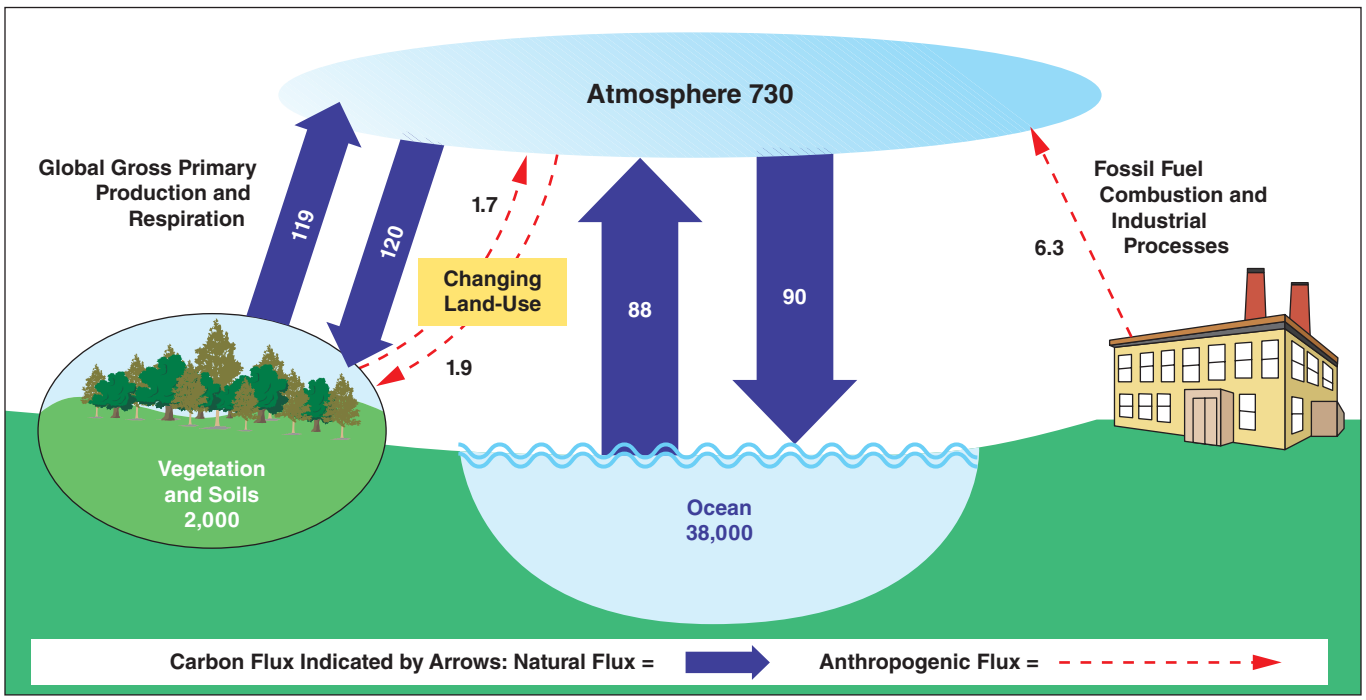


Figure 12.1 The global carbon cycle showing stocks and flows of carbon (*Source:* IPCC, 2001)

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TABLE 12.2

CO_2 Emissions for Common Fossil Fuels

Fuel	Pounds CO_2/million BTUs	Kilograms CO_2/kWh
Coal (anthracite)	228.6	0.354
Coal (bituminous)	205.7	0.318
Coal (lignite)	215.4	0.333
Diesel fuel & heating oil	161.3	0.250
Gasoline	157.2	0.243
Propane	139.0	0.215
Natural gas (methane)	117.0	0.181

Source: US Energy Information Agency, 2013

TABLE 12.3

Current and Preindustrial Concentrations of Greenhouse Gases

Gas	Chemical Formula	Preindustrial Level	Current Level*	Increase since 1750
Carbon dioxide	CO_2	280 ppm	400 ppm	120 ppm
Methane	CH_4	700 ppb	1745 ppb	1045 ppb
Nitrous oxide	N_2O	270 ppb	314 ppb	44 ppb
CFC-12 refrigerant	CCl_2F_2	0	533 ppt	533 ppt
HCFC-22 refrigerant	$CHClF_2$	0	206 ppt	206 ppt

*Concentrations are given in ppm (parts per million), ppb (parts per billion), and ppt (parts per trillion).
Source: IPCC 2007, 2013

Climate Change and the Carbon Cycle

According to the US National Oceanic and Atmospheric Administration www.coris.noaa.gov/glossary/#/search/main, the term *climate change* describes the long-term fluctuations in temperature, precipitation, wind, and all other aspects of Earth's climate. The United Nations (UN) Framework Convention on Climate Change describes the phenomenon as a change of climate attributable directly or indirectly to human activity that alters the composition of the global atmosphere and that is, in addition to natural climate variability, observable over comparable time periods.

The vast majority of Nobel Prize–winning scientists believe there is very strong evidence that the average temperature of the planet's surface will increase 9° to 13.5°F (4° to 6°C) in the twenty-first century. The likely result will be rapidly rising sea levels, substantially reduced crop yields, drought, and more energetic hurricanes and cyclones, all threatening the very survival of the human species. Increasing concentrations of climate change gases produced by human activities, particularly CO_2, are the primary force pushing up global average temperatures. CO_2 concentrations are now over 400 parts per million (ppm) compared to 280 ppm at the start of the Industrial Revolution 225 years ago in the late eighteenth century. The geological record indicates that an average CO_2 level of 450 ppm defines the boundary between an ice-free planet, when water levels were 220 feet (67 m) higher than today, and a planet with ice sheets. Climate scientists originally suggested that 350 ppm was the safe upper limit for CO_2, one we have already surpassed. The continuation of business as usual will likely cause CO_2 levels to increase from the current concentration of 400 ppm to over 450 ppm between 2030 and 2050. The UN is actively discussing trying to limit CO_2 increases to 550 ppm, a potentially catastrophic level, but representative of the as-yet-futile efforts to

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TABLE 12.4

Atmospheric Lifetime and Global Warming Potential of Greenhouse Gases

Gas	Chemical Formula	Lifetime (years)*	GWP†
Carbon dioxide	CO_2	Variable	1
Methane	CH_4	12	25
Nitrous oxide	N_2O	114	298
CFC-12 refrigrant	CCl_2F_2	100	11,000
HCFC-22 refrigerant	$CHClF_2$	12	5,160

*The lifetime of carbon dioxide is variable because about 50 percent is removed in a century while about 20 percent is resident in the atmosphere for thousands of years.
†The GWP of carbon dioxide is defined as 1. The GWP of 72 for methane means that each molecule is 72 times more potent than a carbon molecule at trapping energy. Although methane is far more potent, its atmospheric concentration is relatively small.
Source: IPCC 2007, 2013

rein in these emissions. Clearly, strong and drastic action is needed to stop and reverse atmospheric CO_2 concentrations to avoid the worst outcomes of climate change. It should be noted that CO_2 is the most common greenhouse gas by far, but more potent greenhouse gases, such as CH_4 that have a much higher impact per molecule.

The term *global warming potential* (GWP) in Table 12.4 warrants additional explanation. The GWP of a greenhouse gas indicates the amount of warming a gas causes over a given period of time (normally 100 years). GWP is an index. CO_2 has the index value of 1, and the GWP for all other greenhouse gas is the number of times more warming they cause compared to CO_2. Related to GWP is the *greenhouse multiplier*, which should be used to determine the impact of other gases in terms of CO_2 (see Table 12.5). It is derived by combining GWP and other factors to calculate the climate change impact of climate change gases relative to CO_2. CO_2 is by far the significant greenhouse gas because of the vast quantities of CO_2 present in the various compartments of the biosphere and lithosphere. With respect to calculating the greenhouse gas multiplier, 1 kilogram (kg) CH_4 causes 21 times more energy trapping compared than 1 kg CO_2; thus CH_4 has a greenhouse multiplier of 21. A compact way of describing this is to state that, in terms of climate change, 1 kg CH_4 is the *carbon dioxide equivalent* (CO_2e) of 21 kg CO_2e. Using this methodology, the effects of all climate change gases can be expressed in terms of the CO_2e. t $CO_2$2e often is used to refer to the *tons of carbon equivalents*; Mt Co_2e indicates megatons (millions of tons of CO_2 equivalent); Gt CO_2e is gigatons (billions of tons) of CO_2 equivalent.

TABLE 12.5

Greenhouse Multiplier for Various Atmospheric Gases

Atmospheric Gas	Greenhouse Multiplier
CO_2 (carbon dioxide)	1
CH_4 (methane)	21
NO_2 (nitrous oxide)	310
CFC-11 (CCl_3F) refrigerant	1320
CFC-12 (CF_2Cl_2) refrigerant	6650
HCFC-22 ($CHClF_2$) refrigerant	1350
Surface ozone	100

Note: The multiplier indicates how many grams of CO_2 equivalent impact each gram of gas causes. Although some gases have large multipliers, the vast mass of CO_2 is being emitted dwarfs the mass of other gases and causes over 99 percent of the climate change impact.

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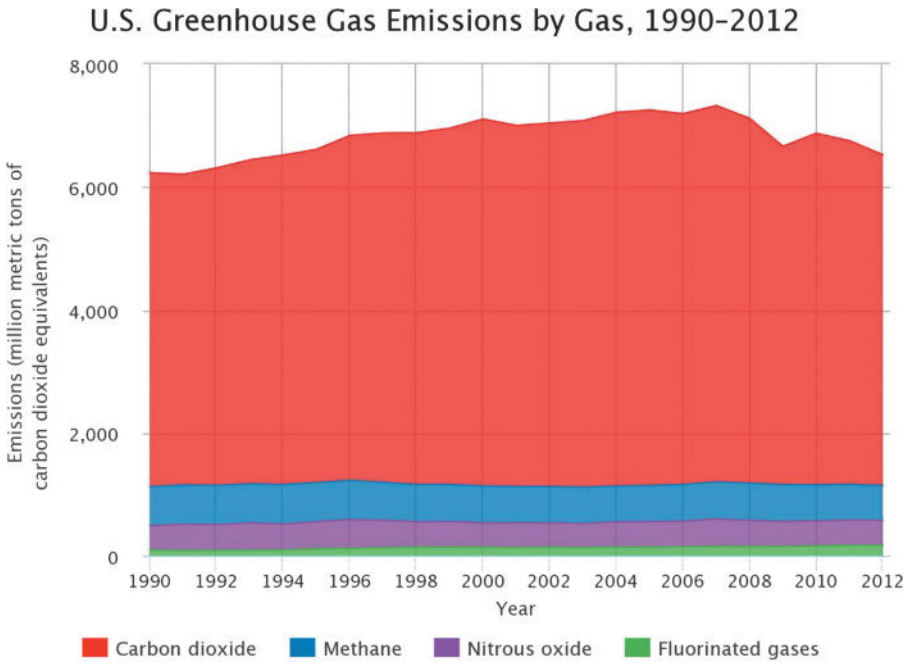


Figure 12.2 Annual US emissions of climate change gases, 1990 to 2012. The quantity of CO_2 releases has been about 10 times greater than CH_4 emissions. (*Source:* US Environmental Protection Agency, 2015)

With respect to the scale of greenhouse gas emissions, CO_2 discharges are generally 10 times greater than the next most emitted greenhouse gas, CH_4 (see Figure 12.2). While U.S. CH_4 emissions were relatively flat in the period 1990–2012, CO_2 emissions climbed by almost 6 percent.

The IPCC was established by the World Meteorological Organization and the UN in 1988 to assess, on a comprehensive, objective, open, and transparent basis, the scientific, technical, and socioeconomic information relevant to understanding the scientific basis of the risk of human-induced climate change, its potential impacts, and options for adaptation and mitigation. The Fifth Assessment Report (AR5) of the IPCC, finalized in 2013 and released in four parts, is the latest report to the global community. According to AR5, the best estimate range of projected temperature increase is 3.1° to 7.2°F (1.8°–4.0°C) by the end of the century. As noted, tropical cyclones (hurricanes and typhoons) are likely to become more intense, with higher peak wind speeds and heavier precipitation associated with warmer tropical seas. Extreme heat, heat waves, and heavy precipitation are very likely to continue becoming more frequent. Sea ice is projected to shrink in both the Arctic and the Antarctic under all model simulations. Some projections show that, by the latter part of the century, late-summer Arctic sea ice will disappear almost entirely. According to AR 5, it is very likely that circulation in the Atlantic Ocean will be 25 percent slower on average by 2100 (with a range from 0 to 50 percent). Nevertheless, Atlantic regional temperatures are projected to rise overall due to more significant warming from increases in heat-trapping emissions. Increasing atmospheric CO_2 concentrations will lead to increasing acidification of the ocean, with negative repercussions for all shell-forming species and their ecosystems.

The models used by the IPCC in AR5 project that, by the end of this century, the global average sea level will rise between 7 and 23 inches (0.18–0.59 meters [m]) above the 1980 to 1999 average. Also, the IPCC stated that if the observed contributions from the Greenland and Antarctic ice sheets between 1992 and 2003 "were to grow linearly with global average temperature change," the upper ranges of sea-level rise would increase by 3.9 to 7.9 inches (0.1–0.2 m). In other words, in this example, the upper range for sea-level rise would be 31 inches (0.79 m). Global air and water

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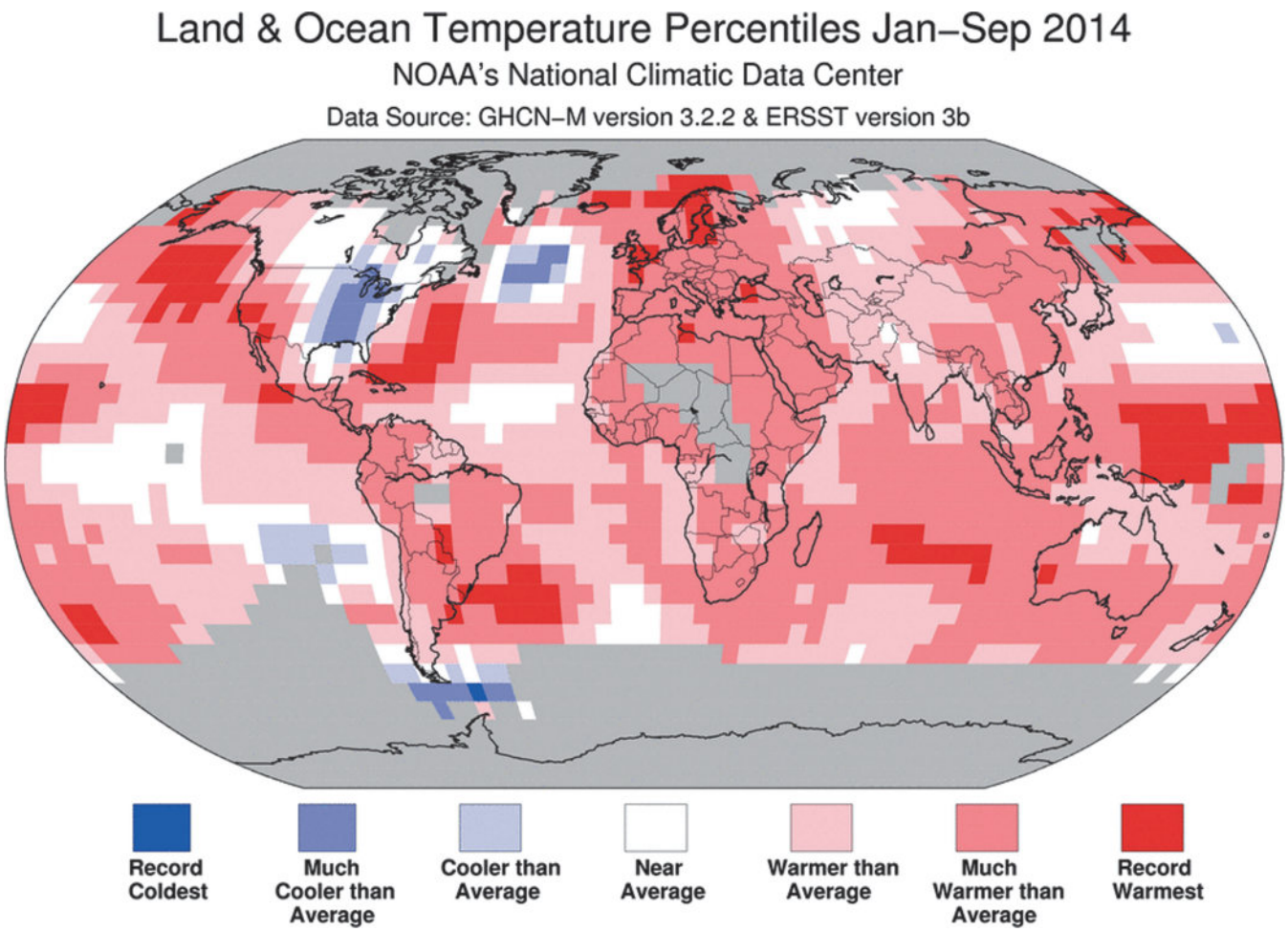


Figure 12.3 Global air and water temperatures for the period January 2014 to December 2014 were the hottest ever. (*Source:* National Oceanic and Atmospheric Administration, 2015)

temperatures have been rising steadily and appear to be accelerating, perhaps foreshadowing even more dramatic changes over the next century (see Figure 12.3).

Moreover, there could be changes in climate variability as well as in the frequency and intensity of some extreme climate phenomena. It is important to note that systems theory shows that the behavior of global systems such as climate is nonlinear. Each increase in CO_2will not necessarily produce a proportional change in global temperature. However, the dynamic, chaotic character of Earth's climate is such that climate can "flip" from one temperature regime to another in a relatively short time. Indeed, fossil records indicate that previous flips have occurred, with temperatures increasing or decreasing almost 10°F (5.6°C) in about a decade. The potential for climate change has profound implications for every aspect of human activity on the planet. Shifting temperatures, more violent storms, rising sea levels, melting glaciers, and other effects will displace people, affect food supplies, reduce biodiversity, and greatly reduce the average quality of life. Creators of the built environment, a major energy consumer, must dramatically reduce energy consumption, particularly reliance on fossil fuels.

In addition to causing climate change, certain chemicals used in building construction and facility operations have been thinning the ozone layer, the protective sheath of the atmosphere consisting of three-molecule oxygen (O_3), which is located 10 to 25 miles (16–40 kilometers [km]) above Earth and serves to attenuate

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TABLE 12.6

Climate Change Gases Typically Used in Typical Building

Halogen Gas*	Lifetime (years)†	Global Emissions (1,000s of metric tons/year)	Ozone Depletion Potential (ODP)‡
Chlorine			
CFC-12	100	130–160	1
CFC-113	85	10–25	1
CFC-11	45	70–110	1
HCFCs	1–26	340–370	0.02–0.12
Halon 1301	65	~3	12
Halon 1211	16	~10	6

*The chlorine gases are used in refrigerants and the bromine gases in fire suppression systems.
†"Lifetime" refers to their duration in the atmosphere, and ODP is their ozone depletion impact.
‡The ODP of CFC-11 is defined as 1. With an ODP of 12, Halon 1301 depletes ozone at a rate 12 times greater than that of CFC-11.
Source: As defined on the UN Environmental Program climate mitigation website at www.unep.org/climatechange/mitigation/

harmful ultraviolet radiation. In 1985, scientists discovered a vast hole the size of the continental United States in the ozone layer over Antarctica. By 1999, the size of the hole had doubled. Ozone depletion is caused by the interaction of halogens—chlorine- and bromine-containing gases such as chlorofluorocarbons (CFCs) used in refrigeration and foam blowing, and halons used for fire suppression. Table 12.6 provides a summary of the main contributors to the destruction of the ozone layer. In one of the few successful examples of international environmental cooperation, the UN Montreal Protocol of 1987 produced an international agreement to eventually halt the production of ozone-depleting chemicals. Assuming that the Montreal Protocol is faithfully adhered to by the international community, the ozone layer is projected to be fully restored by the year 2050.

Mitigating Climate Change

The term *climate change mitigation* refers to strategies or actions that attempt to limit the scale and rate of long-time climate change (Houghton 2002). A wide variety of measures are being attempted, including shifting to low-carbon energy systems represented by wind, solar, and nuclear technologies; designing compact urban areas with high-efficiency mass transit systems; improvements to the efficiencies of motors, appliances, and air-conditioning systems; and investments in bikeways and bicycling infrastructure, to name but a few. The problem, as noted, is that the trajectory of increasing atmospheric CO_2 concentrations is such that it will take a vast coordinated international effort to maintain climate change gas concentrations at levels that will not cause certain catastrophe. We do know that CO_2 has increased by over 60 percent since the start of the Industrial Age 230 years ago, from 280 to 400 ppm. In just 25 years since 1990, CO_2 levels have increased from 350 to 400 ppm, about 42 percent of the total. This acceleration in CO_2 levels shows no sign of slowing down, and by 2040, we are likely to reach the critical 450 ppm level, the dividing line between a planet with glaciers, ice-covered poles, and snow-covered mountaintops and one that is ice-free world.

A wide variety of possible remedies are associated with climate change mitigation, ranging from nontechnical, behavioral options to highly technical solutions that remove carbon from the atmosphere and store it in rock formations or caverns.

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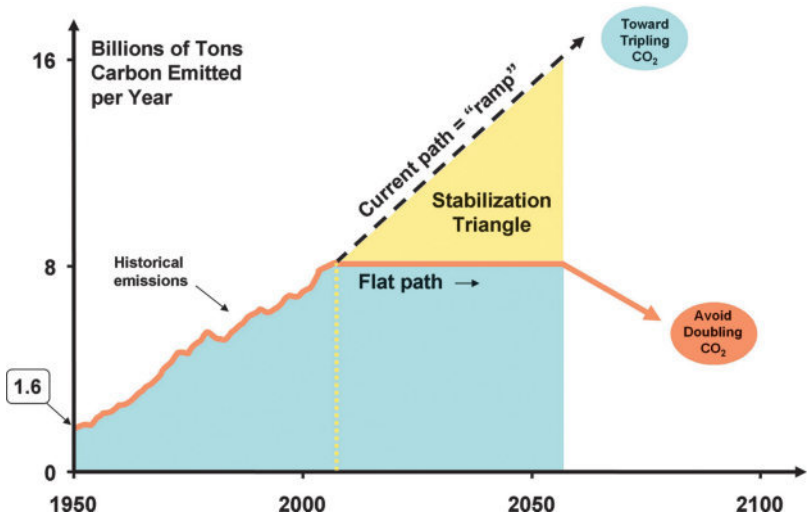


Figure 12.4 The climate stabilization wedge or triangle represents the amount of carbon (about 8 gigatons) that must be prevented from entering the atmosphere to prevent the worst effects of climate change. (*Source:* Carbon Mitigation Institute, 2011)

This latter approach to handling climate change gases is often referred to as *climate engineering.* The storage of CO_2, either by natural or climate engineering means, is known as *carbon sequestration*. The natural sequestration possibilities for the excess carbon being created by human actions include two major planetary environments: terrestrial and ocean.

The Carbon Mitigation Institute (2011) described eight major carbon mitigation strategies, or stabilization wedges, that, applied together in a comprehensive fashion, do have the potential to reduce CO_2 to 2000 levels by 2060. Each Stabilization Wedge can reduce human carbon emissions by 1 gigaton annually. Taken together, they constitute the triangular area in Figures 12.4 and 12.5, which represents the additional carbon that will be emitted if nothing is done to mitigate it, about 200 gigatons. By 2060, if nothing is done and carbon emissions continue to increase, we can expect triple the atmospheric carbon of the pre-industrial era and an increase from 280 ppm to almost 900 ppm. If, in contrast, carbon emissions could be flattened and emissions would remain constant, the result would the possibility of adapting to climate change without its worst effects. The Stabilization Triangle in these figures represents the quantity of carbon that can possibly minimize planetary scale disruptions,

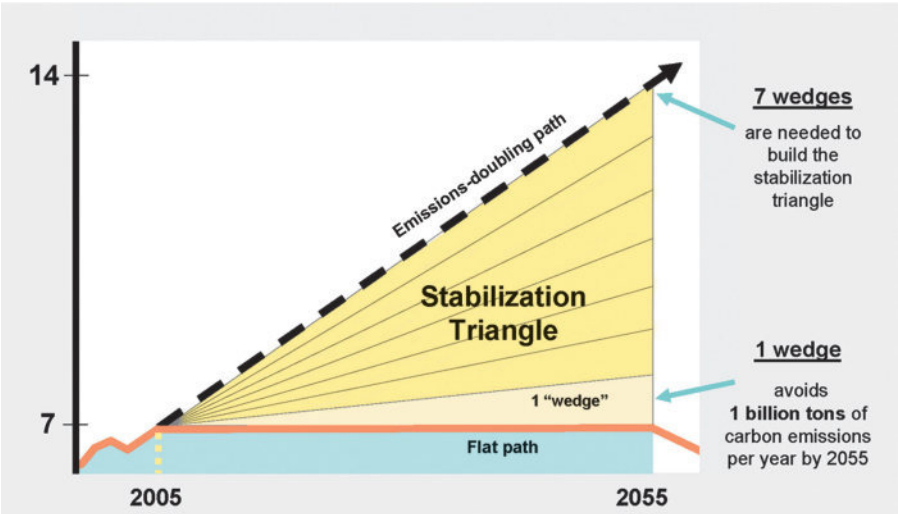


Figure 12.5 The stabilization triangle has 8 wedges, each of which represents the prevention of 1 gigaton of carbon from entering the atmosphere. (*Source:* Carbon Mitigation Institute, 2011)

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TABLE 12.7

Climate Stabilization Strategy Proposed by the Carbon Mitigation Institute

Stabilization Wedge	Strategies in the Stabilization Wedge
Efficiency	**1.** Double the efficiency of 1 billion cars from 30 to 60 miles per gallon. (12.8 to 25.6 km/liter)(give kilometer measure too?
	2. Decrease the number of car miles traveled by half.
	3. Use best efficiency practices in all residential and commercial buildings.
	4. Produce current coal-based electricity with twice today's effiency.
Fuel Switching	**5.** Replace 1,400 coal-fired power plants with gas-powered facilities.
Carbon Capture and Storage	**6.** Capture and store emissions from 800 coal electric plants.
	7. Produce hydrogen from coals at six times today's rate and store the resulting CO_2.
	8. Capture carbon from 180 coal-to-synfuels plants and store the CO_2.
Nuclear	**9.** Double the current global nuclear capacity to replace coal-based electricity.
Wind	**10.** Increase wind electricity by 10 times relative to today for a total of 2 million large windmills.
Solar	**11.** Install 100 times the current capacity of solar electricity.
	12. Use 15,400 square miles (40,000 km^2) of solar panels (or 4 million windmills) to produce hydrogen for fuel cell cars.
Biomass Fuels	**13.** Increase ethanol production 12 times by creating biomass plantations with an area equal to 1/6th the world's cropland.
Natural Sinks	**14.** Eliminate tropical deforestation.
	15. Adopt conservation tillage in all agricultural soils worldwide.

Climate Mitigation Institute, 2011

about 1 gigaton per wedge in the triangle, or 8 billion tons total. Table 12.7 describes the eight wedges in the triangle and the strategies that would have to be implemented to reduce carbon emissions as suggested. It is worth noting that the world is already experiencing significant impacts from the 400 ppm of atmospheric carbon. The effect of allowing a doubling of preindustrial carbon to about 560 ppm could prove to be catastrophic.

The next sections describe the major climate mitigation strategies.

TERRESTRIAL SYSTEM CARBON SEQUESTRATION

Terrestrial carbon sequestration systems include vegetation, soils, and sediments that uptake and store CO_2. Terrestrial systems are able to store substantial portions of natural CO_2 emissions, but disturbances to these systems, such as logging and land cultivation, have reduced the ability of vegetation and soil to store carbon. Some clear trade-offs will have to be made if CO_2 absorption by vegetation and soil were to become a dominant climate change mitigation strategy. For example, restoring old-growth forests on agricultural land would significantly increase carbon sequestration capacity and provide other benefits, such as increasing wildlife habitat and recreational areas, but it would displace agricultural production, resulting in crop loss. Additionally, terrestrial carbon sequestration is not reliable because fires, disease, increasing temperatures, and other disturbances can reduce vegetation and impact carbon storage. Rising global temperatures are melting the permafrost in northern

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boreal forests and peatlands. In North America, these areas store about half of the terrestrial carbon. Large-scale thawing will release enormous quantities of CO_2 and CH_4. Alaska has at least 10 gigatons of carbon stored in its soil that would be susceptible to release due to fire and decomposition under warming conditions. In short, because terrestrial carbon storage is uncertain and not well understood, it cannot realistically be the centerpiece of climate change mitigation strategies. However, it can be combined with other strategies to create an overall effective solution (US Geologic Survey 2013).

GEOLOGIC CARBON SEQUESTRATION

The geologic storage of CO_2 captured from the combustion gases of fossil fuel energy power plants involves piping it underground to depths of up to 2.5 miles (4 km), where it would be injected into porous rock formations or other types of underground systems, such as depleted mines and oil reservoirs. This strategy is also known as carbon capture and storage. Once in the rock formation, the CO_2 is trapped by impermeable barriers, such as saline water, located in or above the porous rock. The US Department of Energy (2015) estimates that in the United States, storage for between 900 and 3,400 gigatons of CO_2 is available in deep rock formations that contain saline groundwater. Unmineable coal beds and oil and gas reservoirs provide other potential storage site for CO_2 extracted from power plants. Although the scale of these potential sequestration sites is enormous, there are significant uncertainties about the permanence, effectiveness, and cost of these strategies. Significant additional research will be required to gain a better understanding of the feasibility of geologic carbon sequestration.

Defining the Carbon Footprint of the Built Environment

The *carbon footprint* is generally defined as the total amount of greenhouse gases produced to directly and indirectly support human activities, usually expressed in pounds, kilograms, or tons of CO_2equivalents (CO_2e). Climate change, the long-term fluctuations in temperature, precipitation, wind, and all other aspects of the earth's climate is the result of the *total global carbon footprint*. The carbon footprint of the built environment is by far the dominant fraction of the total carbon footprint. It results from carbon emissions connected to the construction, operation, and disposal of the built environment, plus the carbon emissions from transportation servicing buildings.

For the purpose of calculating the built environment carbon footprint, carbon emissions can be classified as operational carbon, embodied carbon, and transportation carbon.

Operational carbon (OC) is the carbon resulting from energy produced to operate the built environment for heating, cooling, lighting, elevators, electronics loads, and other functions requiring electricity or thermal energy. This category of carbon emission is the most obvious and has received the most scrutiny over time. Another source of operational carbon that is not as well known or analyzed is the energy required to pump water and wastewater to and from buildings.

Embodied carbon (EC) results from the front-end energy investment in the materials and products that comprise the built environment. It includes the extraction of resources, the manufacture of products, the installation of products and materials, building maintenance, and facility disposal.

Transportation carbon, (TC) which accounts for 20 percent of total US carbon emissions, is greatly affected by the distribution of buildings on the landscape and by the

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availability of mass transit systems with low carbon emissions per passenger mile. It makes sense to include the emissions from transportation systems in accounting for the quantities of CO_2 attributable to buildings.

In summary, the carbon footprint of a building is the combination of these three components normalized to the building area.

$$\text{Carbon Footprint (kg } CO_2e/m^2) = [OC + EC + TC]/\text{Building Area}$$

The next section provides a method for calculating the carbon footprint for buildings. The approach described will provide a good estimate of each of the three sources of carbon associated with the built environment. The outcome of this effort will be to allow project teams to find the best combination of factors for minimizing a project's carbon footprint. This approach also can be used in urban planning efforts to support minimizing the transportation portion of the carbon footprint.

EMBODIED CARBON FOOTPRINT

The investment of energy in the extraction of material resources and product manufacturing creates a carbon footprint that depends on the type of energy sources used in fabricating the product. The amount of energy and carbon associated with the materials and products that comprise the built environment is quite large and can be equivalent to from 5 to 20 years of operational energy, depending on the type of building and its energy profile. For high-performance green buildings with a low Energy Use Index, the years of operational energy that are equivalent to the embodied energy of the building may be much longer due to the lower annual energy consumption. In Germany, the Deutsche Gesellschaft für Nachhaltiges Bauen (DGNB) and Bewertungssystem Nachhaltiges Bauen für Bundesgebäude (BNB) building assessment systems have provisions for rating buildings based on their total embodied carbon footprint per square meter (m^2). DGNB/BNB has a life-cycle assessment (LCA) tool. The total mass of all building materials are input into the tool to determine the embodied carbon per square meter as well as other impacts. The team designing the building can try various trade-offs—for example, more insulation and shading devices to reduce the size of the mechanical plant and reduce the annual operational energy requirements to determine if the total carbon footprint can be reduced. The tool contains historic data on German buildings, and any new designs can be compared to the database to determine how the proposed design rates with respect to its carbon footprint. Although this level of detailed information is not yet available in the United States, both the Leadership in Energy and Environmental Design and Green Globes have provisions for comparing the impacts of alternative building assemblies, such as wall sections. In any event, the life-cycle emissions of carbon are being determined for a wide range of materials, including carpet (see Figure 12.6). These data are being compiled into detailed databases, such as the Inventory of Carbon and Energy (ICE) developed by researchers at the University of Bath in the United Kingdom. The information displayed in Table 12.8 was extracted from ICE. Note that both the embodied energy and the EC of recycled metals are about one-third to one-seventh the levels for virgin metals. This is true of all materials, whether they are concrete, plastics, glass, paper, or wood products.

The EC footprint of buildings can be greatly reduced by creating facilities that are durable, low maintenance, and adaptable. Doubling the lifetime of a building from 50 to 100 years in effect cuts the EC footprint in half, a major effect. Clearly, good planning with a long time horizon will ensure that frequent redesign of urban areas that requires removal of large numbers of buildings is unnecessary.

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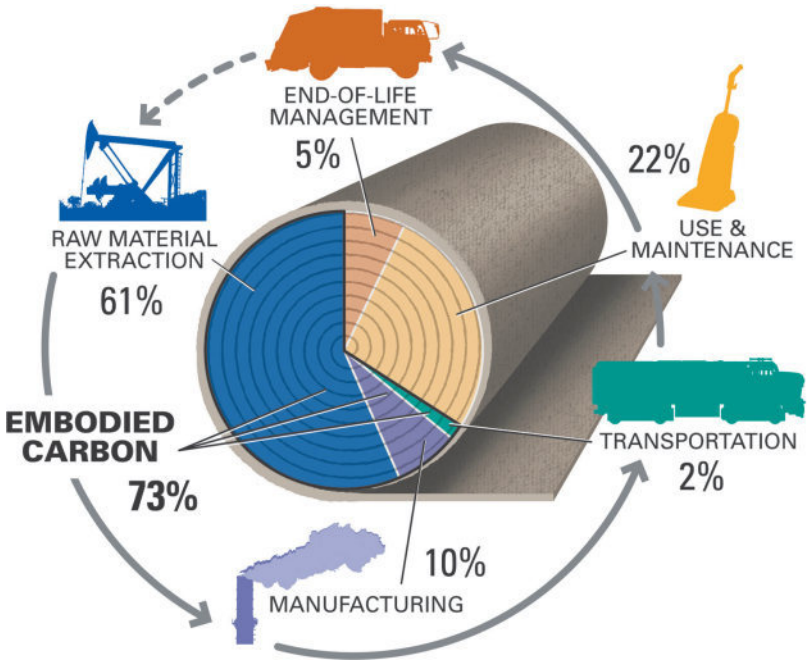


Figure 12.6 The embodied carbon of carpet is determined by examining the entire life cycle of the materials from extraction through removal. (Peter Harris/ BuildingGreen, Inc.)

OPERATIONAL CARBON FOOTPRINT

Operational energy is the energy required to power the built environment. All industrial systems and the electrical power systems that support them have carbon footprints. CO_2 and other greenhouse gases are emitted over the life cycle of power plants, and their climate change impact is expressed as kilograms of CO_2 equivalent per kilowatt-hour (kWh) of generation. For electrical energy generation, there are both direct and indirect emissions of CO_2 and other greenhouse gases. Direct emissions are those arising from the operation of the power plant; indirect emissions

TABLE 12.8

Embodied Energy and Embodied Carbon of Common Materials Used in Construction as Indicated in the Inventory of Carbon and Energy Developed by the University of Bath

Material	Embodied Energy (MJ/kg)	Embodied Carbon (kg CO_2e/kg)
Aluminum—virgin	218	12.79
Aluminum—recycled	29	1.81
Asphalt 6% binder	3.93	0.076
Brick	3.00	0.24
Concrete 0% fly ash	0.55	0.076
Concrete 15% fly ash	0.52	0.069
Concrete 30% fly ash	0.47	0.061
Copper tube—virgin	57.0	3.81
Copper tube—recycled	16.5	0.84
Glass	15	0.91
Paint	70	2.91
Plastics (general)	80.5	3.3
Steel—virgin	35.4	2.89
Steel—recycled	9.4	0.47
Timber	10	0.72

Source: Hammond and Jones 2011

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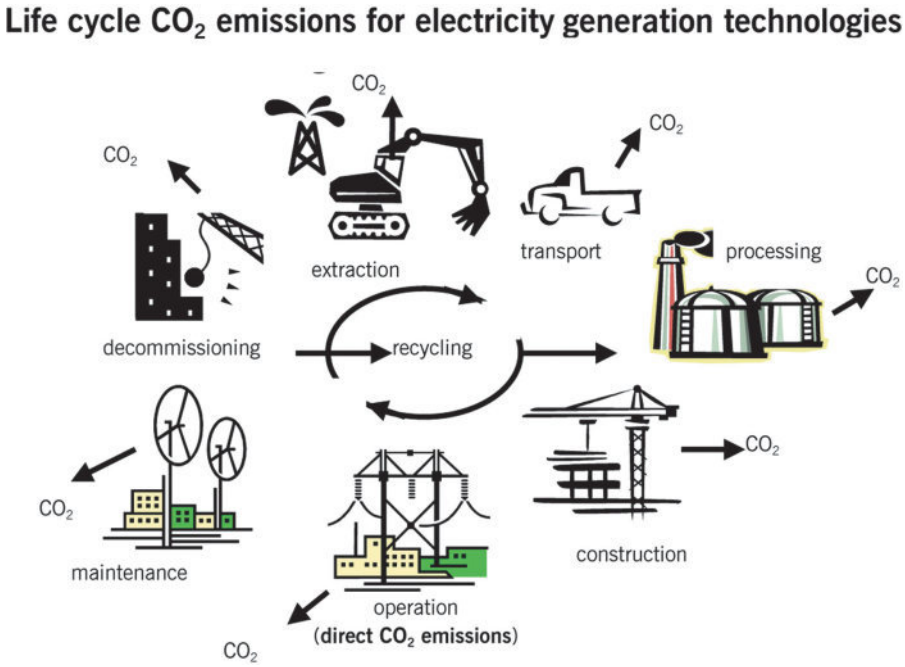


Figure 12.7 The carbon footprint of an electrical power generating station includes the emissions from all phases of the life cycle in extracting and transporting the fuel required for the plant, the materials and products from which the plant is constructed, plus all emissions associated with the extraction and transportation of these resources. The carbon footprint also includes the maintenance and decommissioning of the power plant at the end of its useful life. (*Source:* Parliamentary Office of Science and Technology, 2006)

arise from other phases of the life cycle, such as fuel extraction, transportation of fuel, processing of the fuel, construction of the power plant, maintenance, and power plant decommissioning. An LCA of a power plant to determine its carbon footprint is carried out in exactly the same way as an LCA for products of any kind, and it is based on the International Organization for Standardization 14000 series of standards. For any type of electrical generation plant, whether it is a fossil fuel plant, hydropower installation, nuclear power plant, or solar photovoltaic array, the exact same analysis is used to determine the carbon footprint (see Figure 12.7).

Power plants that burn fossil fuel have by far the largest carbon footprint of all forms of power generation. This is due to the long-chain, carbon-containing molecules from which fossil fuels are derived. A typical coal-fired plant, for instance, will have emissions on the order of 1 kilogram of CO_2e/per kilowatt-hour of electricity generated (1 kg CO_2e/kWh). Oil-fired power plants also contribute a significant amount of carbon for each kilowatt-hour of electricity generated, on the order of 0.60 kg CO_2e/kWh. Gas-fired power generation, which is becoming an increasing fraction of power generation, contributes on the order of 0.40 kg CO2e/kWh. Renewable forms of energy have significantly lower carbon footprints, as shown in Figures 12.8 and 12.9.

Biomass has a carbon footprint ranging from 25 to about 80 g CO_2/kWh, while hydropower has a fairly low carbon footprint of 10 g CO_2e/kWh or lower. Nuclear power has the lowest carbon footprint of all forms of energy generation at 5 g CO_2 e/kWh and lower. Photovoltaic power production has a lower but still surprisingly high carbon footprint compared to wind energy and hydropower, ranging from about 30 to 60 grams (g) CO_2e/kWh (Parliamentary Office of Science and Technology 2006).

TRANSPORTATION CARBON FOOTPRINT

The location of buildings on the landscape is a function of decisions made by owners and government. It is now well recognized that the distribution of buildings causes some of the carbon and energy associated with transportation. Table 12.9 shows data from a case study conducted by *Environmental Building News* that determined the

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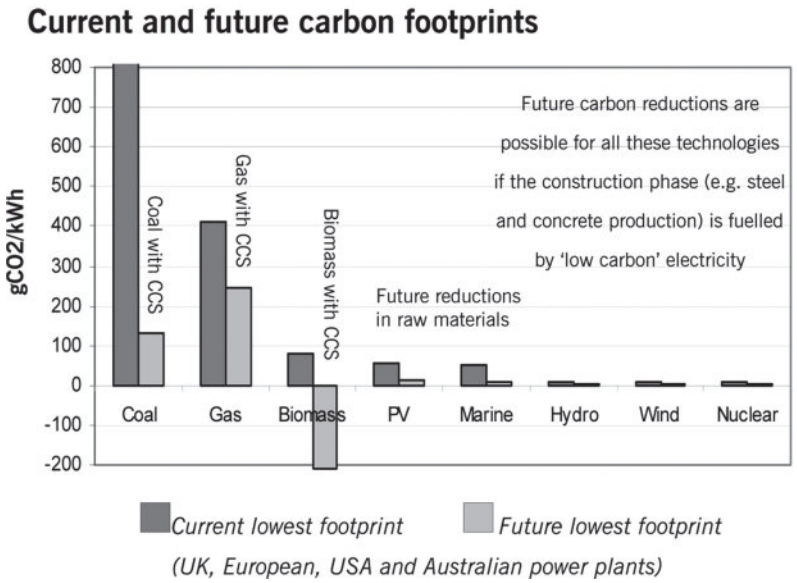


Figure 12.8 The carbon footprint of various electrical power generation technologies. Carbon capture and storage technologies that remove carbon dioxide from combustion gases are being developed but have not been proven and tested at large scale. Coal-fired power plants not only dominate the electrical power generation industry but also produce the greatest amount of carbon dioxide at about 1 kg CO_2e/kWh. Renewable energy systems range from about 50 grams (g) of CO_2e/kWh for photovoltaics to about 5 g CO_2e/kWh for hydropower and wind power. Nuclear power plants also have a relatively small carbon footprint, at about 5 g CO_2e/kWh. (*Source:* Parliamentary Office of Science and Technology 2006)

quantity of energy associated with just the daily commute of the workforce to and from commercial office buildings in the United States. This study discovered that, in fact, transportation energy for commuting to the building is significantly larger than the operational energy of the facility. Average building energy was found to be about 92.9 kBTU/ft^2-yr (293 kWh/m^2-yr), while transportation energy was 121 kBTU/ft^2-yr (381 kWh/m^2-yr). The gap widens even further for newer, code-compliant buildings, where the operational energy might be 51 kBTU/ft^2-yr (161 kWh/m^2-yr), with transportation energy two times greater than operational energy. An even larger gap occurs for high-performance green buildings where the building energy may be 32 kBTU/ft^2-yr (100 kWh/m^2-yr); the transportation energy would almost four times greater than operational energy.

Each type of transportation has a different energy and carbon intensity, as shown in Tables 12.10 and 12.11. This information can be used to forecast the impacts of changes to the transportation system and the distances between various services on the carbon footprint. Figure 12.10 provides a snapshot of the relationship of average miles traveled to population density.

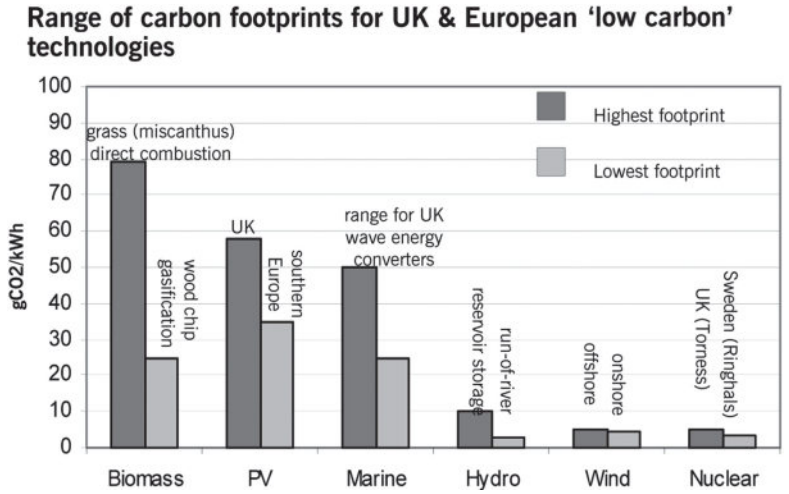


Figure 12.9 Contributions of renewable and nuclear power systems to climate change. Biomass, at about 80 g CO_2e/kWh, has just one-tenth the climate change contribution of coal-fired power plants. At the lower end of the spectrum, wind energy and nuclear have just 5 g CO_2e/kWh. (*Source:* Parliamentary Office of Science and Technology 2006)

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TABLE 12.9

Transportation Energy Associated with Office Building Commutes, United States

	US Units	Metric Units	Source
Average U.S. commute distance—one way	12.2 mi	19.6 km	US Department of Transportation, *Transportation Energy Data Book*, 26th edition, (2007), Table 8.6
U.S. average vehicle fuel economy—2006	21.0 mi/gal	8.9 km/liter	US EPA Light-Duty Automotive Technology and Fuel Economy Trends: 1975 Through 2006
Work days	235 days/yr		
Annual fuel consumption	273 gal/year	1,030 liters/yr	
Annual fuel consumption per automobile commuter	33,900 kBtu/yr	9,890 kWh/yr	Assumes 124,000 Btu/gallon of gasoline, DOE Energy Information Administration data
Transportation energy use per employee	27,700 kBtu/yr	8,100 kWh/yr	Assumes 76.3% commute in single-occupancy vehicle, 11.2% carpool (2 per car) and no other energy use (commuting transportation modes from US Department of Transportation, *Transportation Energy Data Book*, 26th edition (2007), Table 8.14
Average office building occupancy	230 ft^2/person	21.3 m^2/person	US General Services Administration
Transportation energy use for average office building	121 kBTU/ ft^2	381 kWh/ m^2	
Operating energy use for average office building	92.9 kBTU/f ft^2-yr	293 kWh/ m^2-yr	This includes site energy only, not source energy. US DOE Energy Information Administration Commercial Building Energy Consumption Survey data for 2003, published June 2006
Operating energy use for code-compliant office building	51.0 kBTU/f ft^2-yr	161 kWh/ m^2-yr	Bruce Hunn, ASHRAE, personal communication
Percentage transportation energy use exceeds operation energy use for an average office building			30.20%
Percentage transportation energy use exceeds operation energy use for an office building built to ASHRAE 90.1-2004 code			137.00%

Source: "Driving to Green Buildings: The Transportation Energy Intensity of Buildings" 2007

TABLE 12.10

Energy Intensity of Different Forms of Travel in the United States

Vehicle Type	Load Factor (persons/vehicle)	Energy Use (BTU/ vehicle-mile)	Energy Intensity (Btu/passenger-mile)
Cars	1.6	5,489	3,496
Personal trucks	1.7	7,447	4,329
Taxi and van (demand response)	1	14,952	14,301
Vanpool	6.4	8,226	1,294
Bus—Transit	8.7	38,275	4,318
Airline	90.4	358,000	3,959
Rail—Intercity (Amtrak)	17.9	51,948	2,760
Rail—light and heavy	22.4	70,170	2,750
Rail—commuter	32.9	91,525	2,569

Source: US Department of Transportation 2007; "Driving to Green: The Transportation Energy Intensity of Buildings" 2007

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TABLE 12.11

Carbon Emissions for Various Modes of Transportation

Mode of Travel	CO_2 Generation
Vehicle	8.91 kg (19.6 lb) per gallon of gasoline 0.44 kg (0.88 lb) per passenger-mile*
Air travel	0.40–0.60 kg (0.88–1.32 lb) per passenger-mile
Rail travel (commuter and subway)	0.16 kg (0.35 lb) per passenger-mile
Rail travel (long distance)	0.19 kg (0.42 lb) per passenger-mile
Bus travel (inner city)	0.30 kg (0.66 lb) per passenger-mile
Bus travel (long distance)	0.18 kg (0.40 lb) per passenger-mile

*Assumes an automobile fuel performance of 20 miles/gallon (8.5 km/L)
Source: US Department of Transportation 2007; "Driving to Green: The Transportation Energy Intensity of Buildings," 2007

A National Academy of Science, Engineering, and Medicine report calls for a shift to compact development to reduce carbon emissions (NAS 2009). The report states that if 75 percent of new development were built at twice the current density norms, vehicle miles traveled would drop 25 percent and greenhouse gas emissions by 8 percent by 2050. A report by the Brookings Institution backed up these findings with an analysis of the carbon footprint of metropolitan America compared to the nation as a whole (Brown, Southworth, and Sarzynski 2008). The study reported these conclusions:

1. *Large metropolitan areas offer greater energy and carbon efficiency than nonmetropolitan areas.* Despite housing two-thirds percent of the nation's population and three-quartersof its economic activity, the country's 100 largest metropolitan areas emitted just 56 percent of U.S. carbon emissions from highway transportation and residential buildings in 2005.
2. *Carbon emissions increased more slowly in metropolitan America than the rest of the country between 2000 and 2005*….The average per capita carbon footprint of the 100 metro areas grew by only 1.1 percent during the five-year time period, while the U.S. partial carbon footprint increased twice as rapidly (by 2.2 percent) during the same timeframe.

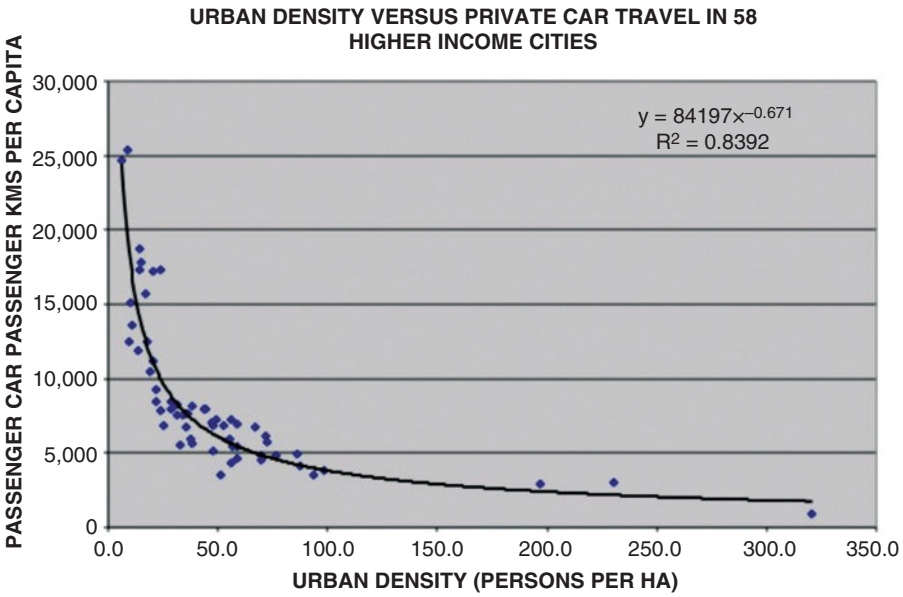


Figure 12.10 Relationship between population density and average daily miles traveled by automobile. Per capita vehicle travel tends to decrease with increases in density (*Source:* Todd Litman, Victoria Transport Policy Institute; "Driving to Green: The Transportation Energy Intensity of Buildings.")

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3. *Per capita carbon emissions vary substantially by metro area*.... In 2005, per capita carbon emissions were highest in Lexington, KY, and lowest in Honolulu. The average resident in Lexington emitted 2.5 times more carbon from transport and residences in 2005 than the average resident in Honolulu, at 3.46 metric tons compared with 1.36 metric tons. This variation is even more striking when adjusting for a metro area's economic output, orgross metropolitan product (GMP)—an indicator of carbon intensity.... The carbon footprints range from a high of 97.6 million metric tons per dollar GMP in Youngstown, OH, to a low of 22.5 million metric tons per dollar GMP in San Jose, CA—more than a four-fold difference.

   Looking just at carbon footprints from highway transportation highlights a cluster of low emitters located along the Washington to Boston corridor (see Appendix A). In addition to benefiting from rail transit, these cities also tend to have high population densities characteristics of older cities of the Northeast.

4. *Development patterns and rail transit play important roles in determining carbon emissions.*... Many of the older, denser cities in the Northeast, Midwest, and California (e.g., Boston, New York, Chicago, and San Francisco) are all low emitters.... Many metro areas with small per capita footprints also have sizable rail transit ridership. New York, San Francisco, Boston, and Chicago have some of the highest annual rail ridership in the nation, ranging from 296 to 757 miles per capita, and carbon footprints ranging from 1.5 to 2.0 tons of carbon per capita—much lower than the average of 2.2 tons for all 100 metro areas.

5. *Other factors, such as weather, the fuels used to generate electricity, and electricity prices are also important*.... Many areas in the Northeast,...have large residential footprints because of their stronger reliance on carbon-intensive home heating fuels such as fuel oil. Warm areas in the South often have large residential footprints because of their heavy reliance on carbon intensive air-conditioning.... The fuel mix used to generate electricity matters in residential carbon footprints. For example, the Washington, DC, metro area's residential electricity footprint was 10 times larger than Seattle's footprint in 2005. The mix of fuels used to generate electricity in Washington includes high-carbon sources like coal, while Seattle draws its energy primarily from essentially carbon-free hydropower.

In general, the carbon footprint of transportation varies greatly with development density and the availability of modes of transportation other than the automobile. Rail travel is particularly important due to its low carbon footprint for both commuter and long-distance trave.

Reducing the Carbon Footprint of the Built Environment

Significantly reducing built environment energy consumption and its corresponding carbon footprint is a very important goal of sustainable construction. As noted in Chapter 9, the total energy associated with the built environment is probably on the order of 65 percent of total US energy consumption, or about 65 quads. Although there are some differences in energy sources for building, transportation, and industry, the carbon footprint of the built environment is likely about the same percentage of the total human carbon footprint. Of the 100 quads of energy being consumed annually in the United States, 40 quads are consumed by building operations, and another 25 quads are consumed by transportation energy, the embodied energy of the materials and products of construction, and water pumping and processing. Consuming 100 quads of energy annually produces 6,600 million metric tons (MMT) of CO_2 equivalent (MMT CO_2e), with the built environment contributing about 4,300 MMT CO_2 CO_2e.

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Climate change is the most serious issue of the twenty-first century. To reverse course with respect to climate change, we must focus our activities on the built environment. Several strategies can be used to reduce the built environment carbon footprint; among them are:

1. Dramatically reducing energy consumption
2. Shifting to renewable energy sources
3. Emphasizing compact forms of development
4. Shifting to mass transportation
5. Designing buildings for durability and adaptability
6. Restoring natural systems
7. Designing low-energy built environment hydrologic systems
8. Designing buildings for deconstruction and material reuse
9. Selecting materials for their recycling properties
10. Including the carbon footprint of buildings in building assessment systems

Reducing atmospheric carbon will require a concerted effort on the part of all stakeholders to the built environment. Building design must focus on long-term strategies that rebalance carbon emissions into the atmosphere by greatly reducing the carbon associated with building construction and operation and with the distribution of buildings in communities. This latter point addresses the problem of how buildings and their location drive energy consumption and carbon emissions and transportation systems. Additionally, enormous efforts must be made to restore the quantity of biomass on the planet to help in the reabsorption of carbon. Although many technical fixes have been proposed to reduce and absorb carbon in the atmosphere, thus far nothing has proved to remove the enormous quantities of carbon that would be required to stabilize the atmosphere.

Notes

1. The IPCC assessment reports are published every six years. The Fourth Assessment Report (AR4) was published in 2007 and the Fifth Assessment Report (AR5) was issued in 2013. See also IPCC (2013).
2. The Earth System Research Laboratory of the National Oceanic and Atmospheric Administration describes the carbon cycle imbalance caused by human activities on the Carbon Cycle Science page at: www.esrl.noaa.gov/research/themes/carbon/.

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Chapter 13

Indoor Environmental Quality

Providing excellent indoor environmental quality (IEQ) has emerged as one of the key goals in the design of high-performance green buildings, on a par with energy efficiency and ecological system restoration. The US Centers for Disease Control and Prevention defines IEQ as the quality of the air in an office or other building environment. Although the quality of indoor air is indeed very important, the high-performance green building movement considers a much wider range of health, safety, and comfort factors. In addition to indoor air quality (IAQ), other aspects of IEQ that are routinely considered include lighting quality, daylighting and exterior views, acoustics, noise and vibration control, thermal comfort and control, odors, electromagnetic radiation, potable water monitoring, and ergonomics. In this chapter, we first discuss the problems that have stimulated such enormous interest in IEQ in general and IAQ in particular. These include sick building syndrome (SBS), building-related illness (BRI), and evidence that poor lighting quality, noise and vibration, and other factors are impacting the health and quality of life of the people using or living in buildings. Then we cover the best practices being used to address these issues and the integration of these solutions into the design of high-performance buildings. The specific issues of ventilation and emissions from materials are addressed, followed by a discussion of the potential financial benefits of providing excellent IEQ in buildings.

Indoor Environmental Quality: The Issues

Most prominent of all the issues addressed by IEQ is air quality. According to the National Safety Council and the US Environmental Protection Agency (EPA), air quality in buildings can be up to 100 times worse than the quality of outside air. This is especially important because Americans spend a large fraction of their day indoors—about 90 percent of the total time with 65 percent of our time spent in our homes. Chemical contaminants, such as volatile organic compounds (VOCs) and radon, plus biological pollutants, such as mold, pet dander, and plant pollen, produce toxic environments in homes and buildings. However, as noted, air quality is not the only factor affecting the health and performance of workers in office buildings; students and teachers in schools; the workforce in factories; and people using fitness centers, theaters, and retail outlets. A wide range of other factors that affect people's health are being considered and becoming part of the integrated design process. In the next section, we discuss some of these contributions to poor IEQ and the dangers they pose.

INDOOR ENVIRONMENTAL FACTORS

The indoor environment of a building has a complex makeup. Table 13.1 lists building elements that are thought to affect the indoor environment. The factors that comprise IEQ can be classified as chemical, physical, and biological. The sensory systems of the

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TABLE 13.1

Building Elements Affecting Indoor Environmental Quality

Operation and Maintenance of the Building	Ventilation and performance standards
	Ventilation system operational routines and schedules
	Housekeeping and cleaning
	Equipment maintenance, operator training
Occupants of the Building and Their Activities	Occupant activities: occupational, educational, recreational, domestic
	Metabolism: activity and body characteristic dependent
	Personal hygiene: bathing, dental care, toilet use
	Occupant health status
Building Contents	Equipment: heating, ventilation, and air conditioning (HVAC), elevators
	Materials: emissions from building products and the materials used to clean, maintain, and resurface them
	Furnishings
	Appliances
Outdoor Environment	Climate, moisture
	Ambient air quality: particles and gases from combustion, industrial processes, plant metabolism (pollen, fungal spores, bacteria), human activities
	Soil: dust particles, pesticides, bacteria, radon
	Water: organic chemicals including solvents, pesticides, by-products of treatment process chemical reactions
Building Fabric	Envelope: material emissions, infiltration, water intrusion Structure Floors and partitions

Source: From Levin 1999

inhabitants interact directly with some factors, such as sound level, light, odor, temperature, humidity, touch, electrostatic charges, and irritants (SMACNA 2009). Hundreds of other substances also can be harmful to inhabitants yet go undetected by the sensory systems. Some of these actually can be more dangerous than those that are detected, as their presence can be determined only through testing. Inhabitants may be exposed to high concentrations of these substances—such as radioactive substances, many toxic substances, carcinogens, and pathogenic microorganisms—for long periods of time without even knowing it.

Physical indoor environmental problems are traceable primarily to the electrical and mechanical infrastructure of a building. They include sound/noise transmission, lighting quality, thermal conditions, and odors. Physical factors are generally nontoxic but are at least a nuisance to building occupants and can lead to health problems after exposure for extended periods.

A wide variety of chemicals can contaminate the indoor environment. Chemicals may be introduced into the indoor environment by painting, installation of carpets, or cleaning products. Chemical factors are classified according to the form they take at room temperature: vapor, gas, liquid, or particulate. Particulates include inorganic fibers; respirable particulates, such as dust and dirt; metals; and a variety of organic materials. Because small particulates can penetrate deep into the lungs, they are a serious concern. The size and density of particulates determine how deeply they can penetrate the respiratory system. Radon, a naturally occurring radioactive gas that has been connected to health problems, is a problem in many regions of the United States; thus, taking measures to mitigate it is important for ensuring a good indoor environment.

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Biological contaminants include bacteria, fungi, viruses, algae, insect parts, and dust, which may result in allergenic or pathogenic reactions. There are many sources for these pollutants: pollens from outdoors, viruses and bacteria from humans, and hair and skin flakes from household pets, to name but a few.

Sound/Noise Transmission

Control of sound and noise transmission in buildings is a major problem. Noise from air-handling systems, lights, transformers, and other sources can cause discomfort and even health problems for building occupants. Building designers and engineers often are intimidated by the challenge of dealing with sound and noise transmission because it is a somewhat intangible concept in a world of mostly tangibles: metal, size, color, and so on.

The basic premise in creating an acoustically acceptable indoor environment is to ensure that sound levels in particular areas of a building are at or below an acceptable range for the specific application. For instance, it would be a mistake to locate a helicopter pad just outside of a library. Clearly, sections of a building where low noise levels are required must be separated and insulated from noise-generating areas. When it comes to acoustics, designers can easily prevent obvious problems—for example, taking care not to locate a conference room next to a chiller plant. But more subtle problems may be overlooked, such as neglecting to insulate a wall that separates a restroom from a private office.

A less obvious requirement for ensuring good indoor sound quality is to eliminate as much as possible the subtle background noises that, although not necessarily apparent to building occupants, can be irritating and may, over time, lower morale and decrease productivity. Building systems can generate a wide variety of annoying sounds. Fluorescent light ballasts often buzz when they are not in perfect order, and ventilation systems produce a host of grating yet seemingly untraceable noises. Fan vibrations, too, are a nuisance inherent in ventilating systems; when they are isolated, they can be dealt with effectively and cheaply. Duct air noises are more problematic and much more difficult to fix. High-speed air in a duct can create whistling sounds and vibrations that are difficult to eliminate. The solution is to reduce the air velocity. To maintain the same quantity of air at a lower velocity, a duct with a larger cross-sectional area must be used. But this solution itself can pose problems when the ductwork is installed in a tight ceiling space or a heating, ventilation, and air conditioning (HVAC) chase. The best answer is to address this problem before it happens by including an acoustic specialist on the team designing the HVAC system.

As noted, high noise levels in commercial buildings can lead to morale problems and loss of productivity when occupants become irritated and annoyed and thus distracted from work. The other major noise-related problem for building occupants is caused by exposure to unhealthy noise levels generated by air handlers, transformers, lighting, elevators, machinery, and motors.

Lighting Quality

Problems associated with lighting quality are similar to those associated with noise in that the cause is a poorly understood building support system. As a requirement for a high-quality indoor environment, lighting is probably better understood than sound, but nevertheless it often is overlooked in building design.

It is widely acknowledged that natural sunlight is the best light source for the eye. Unfortunately, these days most people spend an inordinate amount of time indoors and away from natural sunlight. Thus, the ideal healthy indoor light environment is one that allows natural light indoors or whose lighting system replicates natural light as closely as possible. Natural sunlight has an equal spectral distribution of the visible light frequencies combined to appear as white light. In contrast, artificial light sources are bound by the laws of physics; hence they are limited in the

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TABLE 13.2

General Color Characteristics of Typical Building Lighting Systems

Type of Light	Color Characteristics
Incandescent (argon-surrounded filament)	White with yellow tint
Incandescent (halogen-surrounded filament)	White
Fluorescent	White with blue tint
Light-emitting diode	White or white with blue tint
Mercury vapor	White with blue tint
Metal halide	White with blue-green tint
Sodium vapor (high pressure)	Amber white
Sodium vapor (low pressure)	Yellow

frequencies of visible light that they emit. A list of common artificial light sources and their general color characteristics is shown in Table 13.2.

Incandescent lights, particularly the halogen type, give the best color rendition of natural light. Fluorescent and mercury vapor lights emit white light with a distinct preponderance of blue frequencies. Fluorescents can be made to offer warm color ranges, but the color of fluorescent lighting is not natural and typically tends to produce a too-bright, sterile atmosphere. Sodium-based lights produce a yellowish light and are often used for outdoor applications.

In commercial buildings, the primary sources of artificial light are incandescent, fluorescent, and LED lighting fixtures. Mercury vapor and metal halide sources are also used in large rooms or high-bay areas. In a typical building, general lighting in office areas is either LED or fluorescent. LED lights are used for more direct applications where a fluorescent tube is not applicable—for example, accent lighting. Both LED and fluorescent lights are used in dimming applications, such as recessed lighting in lecture halls and meeting rooms. The glow of fluorescent lighting in office settings can often be irritating to occupants. The obvious complaints caused by too much fluorescent light are sore eyes and headaches, lowered morale, and decreased productivity. Poor lighting also has more subtle effects on mood. The eye, it is now known, is most comfortable with natural sunlight, which changes in intensity and color throughout the day. Because indoor artificial light is basically unchanging in color and intensity, there may be adverse effects on the health and well-being of those subjected to it. This is an important new field of study in the area of IEQ, and it is not entirely understood.

Flickering lights can also cause irritation and health problems. Ballasted lights—for example, fluorescent, mercury vapor, metal halide, and sodium lights—are subject to flickering when the ballast malfunctions. This can easily lead to sore eyes and headaches and, ultimately, lower productivity. Glare is also a problem; however, unlike the other problems described here, it is not a consequence of artificial light but rather involves the light source and reflector positioning. Windows, desktops, and computer screens, even shiny paper, are all reflectors that can cause uncomfortable glare. Depending on the intensity of the light, glare can quickly lead to discomfort and headaches, especially when reading, typing, or looking at a computer screen.

Thermal Conditions

The climatic setting in which people are working has a profound impact on how they behave and how well they work. But because everyone is different, what is perfectly comfortable to one person in an office may be profoundly uncomfortable to his or her neighbor. In general, the indoor comfort range is considered to be located in the center of the psychometric chart. Generally accepted ranges for comfort are as follows: in winter, temperatures between 68°F and 75°F (20°C–24°C) and relative

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humidity between 30 and 60 percent; in summer, temperatures between 72°F and 80°F (22°C–27°C) and relative humidity between 30 and 60 percent. *Relative humidity* is the amount of moisture in the air relative to the amount of moisture the air can hold when it is completely saturated. Relative humidity below 30 percent in any season is considered too dry and will lead to discomfort. Typically, lower humidity levels can be tolerated in the winter and higher humidity levels can be tolerated in the summer, but relative humidity levels outside the 30 to 60 percent range are generally uncomfortable in all seasons.

Air velocity, mentioned briefly earlier, is another variable in the indoor climate that is not a fundamental property of the air. Air velocity varies greatly, depending on where a person is in relation to vents, doors, windows, and fans. It is an integral aspect of air conditioning (heating and cooling) that indoor air be circulated; hence, it must have a certain velocity. The goal of HVAC designers is to introduce the highest-velocity air where it has little or no effect on the building occupants, usually along ceilings or walls, so that by the time it comes in contact with people, it has slowed to an undetectable rate. High-velocity air is more likely to cause discomfort in cool indoor climates and, conversely, to be welcome in warm indoor climates.

Odors

Odors are one of the most common and annoying indoor environmental problems. Solving these problems is not easy, because the human olfactory system is highly complex and not well understood; moreover, the chemical sources that create many of these odors also are poorly understood. Even simple odors in office settings are complex, consisting of many substances. Typical sources of odors in the indoor environment include tobacco smoke, human body odor, and cleaning and personal grooming products. Off-gassing of building materials is another common source of smells. Complicating this issue is the pronounced difference in individual sensitivity to odors. Visitors to an office are generally far more sensitive to odors than its longtime occupants for example. Because human reactions to odors are so varied, it is nearly impossible to predict how any one person or group of people will react.

Volatile Organic Compounds

VOCs are carbon-containing compounds that evaporate readily at room temperature and are found in many housekeeping, maintenance, and building products made with organic (carbon-based) chemicals. Paints, glues, paint strippers, solvents, wood preservatives, aerosol sprays, cleansers and disinfectants, air fresheners, stored fuels, automotive products, and even dry-cleaned clothing and perfume are all sources of VOCs. In any indoor environment, there can be up to 100 different VOCs in varying concentrations. Carbon filters can be used to adsorb VOCs, but they must be replaced regularly, as the odors deplete the carbon.

There are six major classes of VOCs:

1. Aldehydes (formaldehyde)
2. Alcohols (ethanol, methanol)
3. Aliphatic hydrocarbons (propane, butane, hexane)
4. Aromatic hydrocarbons (benzene, toluene, xylene)
5. Ketones (acetone)
6. Halogenated hydrocarbons (methyl chloroform, methylene chloride).

Formaldehyde is highly reactive and may be found in all three states of matter. It is highly soluble in water and can irritate body surfaces that normally contain moisture—for example, the eyes and the upper respiratory tract. Formaldehyde gas is pungent and easily detectable by its odor at concentrations well below 1 part per million. It is perhaps the most commonly occurring VOC in construction, found in

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many common products, such as paints, wood products, and floor finishes. When combined with other chemicals, it can be used as glues and binders in numerous products. Urea formaldehyde (UF) foam insulation, particleboard, interior-grade plywood, wallboard, some paper products, fertilizers, chemicals, glass, and packaging materials contain significant amounts of formaldehyde.

Radon

Radon, a colorless and odorless gas, is the product of the decay of the radium isotope that results from the disintegration of uranium-238. An inert gas, radon itself is fairly harmless, but as it decays, the resulting materials, known as *radon daughters*, are not. Radon daughters are not chemically inert, and they form compounds that bind to dust particulates in the atmosphere. When inhaled, these particles can lodge in the respiratory system and cause damage due to the alpha particle radiation they emit. The half-life of the daughters is relatively short: They disintegrate in 1 hour or less. Despite this rapid disintegration, radon is a major concern because it may take 10 to 20 years for the first signs of exposure to develop, and it has serious consequences. The inhalation of radon is the second leading cause of lung cancer in America, is suspected in the deaths of 2,000 to 20,000 individuals a year, and is considered one of the most deadly indoor air pollution problems.

Anthony Nero (1988) of the Indoor Environment Radon Group at Lawrence Berkeley National Laboratory noted that the average indoor level of radon represents a radiation dose about three times larger than the dose most people get from X rays and other medical procedures in the course of their lifetime (Meckler 1991). Hundreds of thousands of Americans living in houses with high radon levels are exposed yearly to as much radiation as people who were living in the vicinity of the Chernobyl nuclear power plant in 1986, when one of its reactors exploded. According to the EPA, an acceptable maximum level of radon is 4 picocuries per liter (pCi/L) of air. In Canada, the Atomic Energy Control Board also set a level of 4 pCi/L for the general public in homes and other nonoccupational settings. If this level is exceeded, action must be taken to reduce it.

In buildings, radon occurs primarily through diffusion from the underlying subsoil into the building structure. Radon gas can enter a building through cracks or openings, such as sewer pipe openings, cracks in concrete, wall–floor joints, hollow masonry walls, and other similar pathways. If the foundation of the building is tight, very little or no radon will enter. Because of the ground-up infiltration process of radon, a multistory building will have lower radon concentrations than a single-story building with an identical foundation. Indoor radon concentrations also relate directly to ventilation and fresh air intake of buildings. Due to energy conservation techniques and the resultant tighter buildings, new buildings actually may encourage the infiltration of radon gas by negative pressurization.

Asbestos

Asbestos is another potentially deadly IAQ problem. Unlike radon, however, the health implications of asbestos have been documented in detail, for it has been a major environmental problem for many years. When it was discovered that the thread-like particles in asbestos could lodge in human lungs, its use began to be phased out. Exposure to asbestos has been definitively linked to stomach and lung cancers.

The term *asbestos* refers to a group of silica-based minerals in fibrous bundles. Introduced in the 1930s and widely used in the United States from 1940 to 1973, asbestos comprises a large number of naturally occurring materials that are processed to produce a manageable form for use in construction, insulation, and fire retardation materials. Indoor building materials containing asbestos include thermal insulation on ceilings and walls; insulating materials used on pipes, ducts, boilers, and tanks; and finishing materials, such as ceiling and floor tiles and wall boards. The materials that pose the greatest threat are those that can be easily crumbled or powdered by hand pressure.

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High-quantity release of asbestos into the airstream usually occurs during maintenance, renovation, and other construction activities, and this is when the asbestos becomes dangerous. There is very little danger to human health if the material is left undisturbed; asbestos becomes a health hazard only when its fibers are released into the air. Most experts agree that if asbestos surfaces are not deteriorating or being abraded, thus releasing asbestos fibers, they are best left alone. Removal of asbestos is very costly and can be done safely only by professionals. An unsafe removal process can do more harm than good by releasing more particles into the air, where they can continue to contaminate a building for years.

Combustion By-products

Combustion by-products are created under conditions of incomplete combustion. The primary sources of combustion by-products that contribute to the contamination of indoor air are gas, wood, and coal stoves; unvented kerosene space heaters; fireplaces under downdraft conditions; and tobacco smoke. The major by-products include carbon dioxide (CO_2), carbon monoxide (CO), nitrogen dioxide (NO_2), sulfur dioxide (SO_2), and particulates. Their health effects can vary, depending on the type of by-product produced (Bas 1993). Each of these by-products is described more fully next.

Carbon dioxide. CO_2 is a colorless, odorless, and tasteless gas. Although it is a by-product of combustion, it is relatively harmless; it is, after all, also a natural product of respiration. That said, and despite the fact that it is nontoxic, if the concentration of CO_2 is too high, the result can be unpleasant and perhaps unhealthy for a building's inhabitants. And since it is a natural product of respiration, it can also be an indicator of the quality of ventilation and IAQ.

Carbon monoxide. CO is another colorless, odorless, and tasteless gas, but it must not be confused with CO_2. The effects of high-level CO exposure can range from nausea and vomiting to headaches and dizziness to coma and death. The health effects of low-level CO exposure are not clearly defined, but its toxicity is unquestionable. The symptoms of CO poisoning, which include nausea, dizziness, confusion, and weakness, may be confused with those of the flu. People with anemia or a history of heart disease can be especially sensitive to CO exposure.

Nitrogen dioxide. Concentrated NO_2 is a dark-brown gas with a strong odor. Exposure can cause irritation of the skin and eyes and other mucous membranes. Controlled human exposure studies and epidemiological studies in homes with gas stoves illustrate that, depending on the level of exposure, NO_2 can alter lung function and cause acute respiratory symptoms. Because of its ability to oxidize, NO_2 has been shown to damage the lungs directly. Symptoms of exposure may include shortness of breath, chest pains, and a burning sensation or irritation in the chest. People with chronic respiratory illnesses, such as asthma and emphysema, may be especially sensitive to NO_2.

Sulfur dioxide. $SO_2$is a colorless gas with a suffocating odor. It is highly soluble in water and thus is readily absorbed by the mucous membranes. Once it is inhaled, SO_2 is dissolved and forms sulfuric acid, sulfurous acid, and bisulfate ions. During normal nasal respiration, SO_2 is absorbed primarily by the nasal tissues; only 1 to 5 percent reaches the lower respiratory tract. However, when a person breathes through the mouth—for example, during heavy exercise—significant quantities of SO_2 can penetrate the lower respiratory tract even at low concentrations. The primary physical effect of SO_2 exposure is bronchoconstriction, which begins at considerably lower levels for persons with asthma than for healthy individuals. The constriction develops almost immediately upon exposure, but it also subsides just as quickly when exposure ends. The intensity of the constriction is directly related to the amount of SO_2 per unit

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of time that reaches the lower respiratory tract, not necessarily the level of the exposure. Also, the effect of SO_2 does not increase with time.

Combustion particulates. Particulates produced by combustion can affect lung function directly. The smaller the particulates, the more deeply they penetrate the lungs and thus the more dangerous they become. The particles can serve as carriers for other contaminants or as mechanical irritants that interact with chemical contaminants.

Mold and Mildew

Humidity and airflow rates significantly affect the concentrations of biological contaminants. Moisture can act as a breeding ground for molds, bacteria, and mites. Mites are the most prominent cause of house dust allergies. They are found in beds and pillows, especially when humidity levels are high. An indoor moisture level of 30 to 50 percent relative humidity is recommended to maintain good health as well as comfort. Biological contaminants also may multiply in standing water, in cooling towers, in water-damaged ceilings, and on surfaces where moisture in the air condenses on cold walls. Additionally, damp organic materials, such as leather, cotton, furniture stuffing, and carpets, can be contaminated with fungi. Airflow rates also have an important effect on the concentrations of airborne biological pollutants. Reduced flow rates tend to provide a favorable medium for molds, dust, and fungi. The HVAC equipment in a building plays a very important role in maintaining proper airflow rates.

Sick Building Syndrome and Building-Related Illness

Of the wide variety of issues associated with IEQ, in the recent past two in particular stand out: SBS and BRI. Although both terms refer to health problems associated with IAQ, there is a very important difference between them. SBS describes an assortment of symptoms experienced by a majority of building occupants for which no specific cause can be identified. Typically, SBS is diagnosed when the affected employees' symptoms disappear almost immediately on leaving the building. In contrast, BRI refers to symptoms of a diagnosable illness that can be attributed directly to a defined IAQ problem.

SBS, also known as *tight building syndrome*, is the "condition in which at least 20 percent of the building occupants display symptoms of illness for more than two weeks, and the source of these illnesses cannot be positively identified" (Bas 1993). Most of the structures that fall victim to SBS are modern office buildings, the majority of which have been constructed over the past two decades and are tightly sealed, mechanically ventilated, and have few or no operable windows. Symptoms of SBS may include headache; fatigue and drowsiness; irritation of the eyes, nose, and throat; sinus congestion; and dry, itchy skin. These symptoms can occur alone or in combination. The most common complaints include flulike symptoms or respiratory tract infections. Some occupants relate SBS to stresslike headaches, coughs, and the inability to concentrate, while others experience dry skin or rashes (Bass 1993).

The economic impact of SBS can be tremendous, making it a building owner's worst nightmare. The EPA has estimated that the United States spends over $140 billion in direct medical costs attributable to IAQ problems (Zabarsky 2002).[2] SBS is also believed to be responsible for marked decreases in productivity coupled with increases in absenteeism. Vacant buildings and nonrenewed building leases may be a direct result of SBS. An example of the high costs associated with SBS is the Polk County Court House in Florida. Located in Lakeland, a community in central Florida, the court house was constructed for $37 million and opened in the summer of 1987. Due to a severe case of SBS, it was closed in 1992; its occupants, including prison inmates, had to be evacuated and temporarily relocated. It took three years and $26 million to literally rebuild the facility to correct the original toxic mold problems that were attributed to design and construction problems.

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The wide range of conditions associated with both SBS and BRI, some chemical and some biological—including multiple chemical sensitivity, legionellosis, and allergic reactions—are described in the next sections.

Multiple Chemical Sensitivity

Multiple chemical sensitivity (MCS), a relatively recently identified condition related to IAQ, is marked by sensitivity to a number of chemicals, all at very low concentrations (EPA 1991). MCS is characterized by severe reactions to a variety of VOCs and other organic compounds that are released by building materials and many consumer products. These reactions may occur after one sensitizing exposure or a sequence of exposures. It should be noted, however, that currently there is a great deal of debate over the legitimacy of the condition. Some contend that it is a physical illness, while many others believe the cause to be psychosomatic.

Legionellosis

The term *legionellosis* refers to two important bacterial diseases: Legionnaire's disease and Pontiac fever, caused by the bacterium *Legionella pneumophila*. The diseases are not spread via person-to-person contact but rather through the soil-air and water-air links both indoors and outdoors. The bacteria can survive in water for up to a year under certain conditions. *Legionella* prefers stagnant water, which is found in the drain pans of HVAC units and cooling towers. Fans then can transfer the bacteria, to be inhaled by unsuspecting victims. Sources of *Legionella* in residences and other buildings also may include hot tubs, vaporizers, humidifiers, and contaminated forced-air heating systems. Algae and other aquatic life-forms can promote the growth of *Legionella* by providing the bacteria with food.

Pontiac Fever

In July 1968, 95 out of 100 people employed in—ironically—a public health building in Pontiac, Michigan, became ill with a flulike ailment. In fact, if the number of cases had not comprised such a high proportion of the employees, the disease probably would have been diagnosed as the flu. The employees all claimed to suffer from headaches, fevers, and muscle aches and pains. Called Pontiac fever, the disease was eventually traced back to a faulty HVAC system. However, it was not until the discovery of Legionnaire's disease, nearly 10 years later, that the bacterium that caused Pontiac fever was finally identified.

Pontiac fever is a mild form of legionellosis. It is characterized by a high attack rate (90 percent) and a short incubation period of two to three days. The disease lasts for only three to five days and requires no hospitalization. Symptoms include those exhibited by the employees in 1968, as well as chills, sore throat, coughing, nausea, diarrhea, and chest pain. Many people may never suspect that they have Pontiac fever, as only an estimated 5 to 10 percent of those seeking medical care have lab tests done.

Legionnaire's Disease

Legionnaire's disease is a type of pneumonia caused by *Legionella*. Both the disease and the bacterium were discovered following an outbreak traced to a 1976 American Legion convention in Philadelphia, Pennsylvania. This disease develops within 2 to 10 days after exposure to *Legionella*, and early symptoms may include loss of energy, headache, nausea, aching muscles, high fever [often exceeding 104°F (40°C)], and chest pains. Later, many bodily systems, as well as the mind, may be affected. The disease eventually causes death if high fever and antibodies cannot defeat it. Victims who survive may suffer permanent physical or mental impairment. The Centers for Disease Control has estimated that the disease infects 10,000 to 15,000 persons annually in the United States; others have estimated as many as 100,000 annual US cases.

Legionnaire's disease is a severe multisystem illness that can affect the lungs, gastrointestinal tract, central nervous system, and kidneys. It is characterized by a

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low attack rate (2–3 percent), a long incubation period (2–10 days), and severe pneumonia. Unlike Pontiac fever, hospitalization is required. Most victims are men in their 50s and 60s who are smokers and/or have underlying respiratory problems. Alcohol consumption, diabetes, and recent surgery can also be contributing factors.

Allergic Reactions

Allergies are reactions to a form of indoor air pollution that occur when the body responds to nontoxic substances, such as pollen, as threats. The body will mimic the effects of a real illness by stimulating the production of white blood cells to combat the allergen. An individual usually does not experience an allergic reaction until after the second exposure to a specific allergen. The first exposure results in the manifestation of the allergy. Allergens that cause an allergic response include viable and nonviable agents. Viable agents include bacteria, fungi, and algae. Common nonviable agents include house dust, insect and arachnid body parts, animal dander, mite fecal pellets, remains of molds and their spores, pollens, and dried animal excretions.

Preventing encounters with offending allergens is easier said than done. These allergens constitute a new variation on the IAQ problem in that the reactions of a building's inhabitants to an allergen can vary more than with other environmental factors. What may send one person gasping to the emergency room may have absolutely no effect on another. Regular cleaning to remove dust, the use of high-efficiency filters, and regular filter changing can help to reduce or eliminate biological contaminants (Bas 1993; Hays, Gobbell, and Ganick 1995).

Integrated IEQ Design

Clearly, the complex range of IEQ issues warrants an integrated approach to the design of buildings to maximize the quality of human occupied spaces. The *Whole Building Design Guide* (www.wbdg.org) provides a good overview of integrated IEQ design and suggests that these measures for attaining good IEQ in buildings be undertaken:

- Facilitate quality IEQ through good design, construction, and operating and maintenance practices.
- Value aesthetic decisions, such as the importance of views and the integration of natural and man-made elements.
- Provide thermal comfort with a maximum degree of personal control over temperature and airflow.
- Supply adequate levels of ventilation and outside air for acceptable IAQ.
- Prevent airborne bacteria, mold, and other fungi through building envelope design that properly manages moisture sources from outside and inside the building and with HVAC system designs that are effective at controlling indoor humidity.
- Use materials that do not emit pollutants or are low emitting.
- Ensure acoustic privacy and comfort through the use of sound absorbing material and equipment isolation.
- Control disturbing odors through contaminant isolation and removal and by careful selection of cleaning products.
- Create a high-performance luminous environment through the careful integration of natural and artificial light sources.
- Provide quality water.

These important recommendations are covered in more detail in the next sections.

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FACILITATE QUALITY IEQ THROUGH GOOD DESIGN, CONSTRUCTION, AND OPERATING AND MAINTENANCE PRACTICES

The project design team can make major contributions to the quality of the project's IEQ through the specification of products and materials as well as the design of lighting, daylighting, air-conditioning, ventilating, and other systems that have a direct bearing on the environmental quality of the building. Specifying materials that contain zero or low VOCs and entryway systems that remove chemicals and dust particles from people entering the building are examples of materials and product specifications that can contribute to good IEQ. Designing an integrated daylighting/lighting system often involves computer simulation and the selection of appropriate types of windows that can both facilitate good daylighting and minimize solar thermal heat gains in the building. The construction phase of the project is also very important in ensuring a high-quality indoor environment because best practices can eliminate possible future causes of indoor environmental problems. An example is the potential contamination of air handlers, ductwork, diffusers, and grilles that carry air throughout the building by dust and debris generated during the construction process. Good construction practices can eliminate this possible threat to air quality. Clearly, the operations and maintenance phase is key to good long-term IEQ, and facilities managers must be aware of best practices in retaining the environmental quality provided by the project team.

VALUE AESTHETIC DECISIONS

Designers have a responsibility to ensure a high degree of aesthetic quality in buildings, which not only contributes to the cultural value of the facility over the long term but also promotes IEQ. For example, operable windows, which have long been considered problematic for buildings due to the issue of coordinating their use with the operation of the mechanical systems, are making a comeback, because of their ability to provide natural ventilation. Buildings are also now being designed to connect people to nature, and the provision of good views for building occupants is often a goal of the project team.

PROVIDE THERMAL COMFORT

Thermal comfort for building occupants is a major objective of most high-performance building projects and involves the interplay of several parameters: air speed, temperature, humidity, and radiant temperature. The first three parameters—air speed, temperature, and humidity—are provided by the designers of the building's HVAC system, while radiant temperature, which is the result of direct solar radiation on the skin, is controlled by the selection of windows, shading devices, and other approaches that can affect solar radiation through windows. The American Society of Heating, Refrigerating and Air-Conditioning Engineers' (ASHRAE) 55-2010, *Thermal Environmental Conditions for Human Occupancy*, is the basis for thermal comfort in high-performance buildings in the United States. Provision of control over thermal comfort by building occupants is also an important consideration for high-performance buildings because the health and productivity of the occupants is, at least in part, a function of their ability to adjust their surroundings to make them comfortable and, hence, more productive.

SUPPLY ADEQUATE LEVELS OF VENTILATION AND OUTSIDE AIR

Contamination levels inside buildings deteriorate over time depending on the number of occupants, the activities in the building, the materials and products of construction,

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and, most important, the ventilation in the building. ASHRAE 62.1-2010, *Ventilation for Acceptable Indoor Air Quality*, provides the framework for designing effective insulation systems for buildings. CO_2 levels in buildings are an important surrogate for the overall air pollution levels in them; that is, as CO_2 levels rise, so too do the levels of other contaminants, such as VOC fine particulates and a wide range of other chemicals. Recently, designers have learned how to optimize building ventilation systems by monitoring CO_2 levels and then using this as feedback for the control of the ventilation system, such that, as CO_2 levels rise and fall, ventilation rates are adjusted accordingly by the automatic control system. This strategy has the benefit of both providing precise ventilation and minimizing the energy required to condition outside air being brought into the building for conditioning purposes. System designers also have learned how to separate the ventilation air system from the recirculating air system in order to provide even more precise control over ventilation rates.

PREVENT AIRBORNE BACTERIA, MOLD, AND OTHER FUNGI

Mold has become a major issue of IEQ systems design. It is important that the building envelope be designed to prevent intrusion of water through careful detailing and the incorporation of moisture barriers into the exterior wall system of the building. Controlling humidity with the HVAC system is also essential to preventing the growth of mold in the building, especially at extreme load conditions, when outside humidity is either very high or very low. Mold is measured by the number of spores per cubic meter of air, and it is important to ensure that the level of mold in the indoor air is less than that of the outside air and in no case more than 700 spores per cubic meter of air.

USE MATERIALS THAT DO NOT EMIT POLLUTANTS OR ARE LOW EMITTING

VOCs are complex chemicals that are both synthetic and naturally occurring. Many, like formaldehyde, are incorporated into building materials to enhance their properties (e.g., making paint more durable and more rapidly drying). Toluene, xylene, and benzene are other examples of synthetic VOCs that are toxic and harmful to human and ecosystem health. In spite of the benefits they may provide, VOCs pose a threat to the health of building occupants and are being eliminated in high-performance green buildings. Chemicals that are used in the building—for example, in cleaning supplies and copy machines—should be specially stored in spaces that prevent their migration into the surrounding building environment. Radon control also should be considered in areas where it has been identified as present in the local soils. For renovation projects, the removal of asbestos and lead-based paint should be accomplished in a manner that prevents exposure to workers and future exposure to building occupants.

ENSURE ACOUSTIC PRIVACY AND COMFORT

Transmission of noise and sounds through buildings can affect both the health and the comfort of building occupants, and significant effort should be made to minimize noise generation and transmission by the use of sound-absorbing materials; sound and noise attenuating walls, floors, and ceilings; by isolating air handlers and other rotating machinery from the building; and by designing HVAC systems that are quiet and do not transmit conversations between spaces.

CONTROL DISTURBING ODORS THROUGH CONTAMINANT ISOLATION AND PRODUCT SELECTION

Some building spaces, such as copying rooms, janitors' closets, storage rooms, and designated smoking areas, should be negatively pressurized and isolated from the

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other spaces in the building, and they should be exhausted directly to the building's exterior. This strategy prevents the migration of chemicals and odors typical of these spaces to the occupied areas of the building.

CREATE A HIGH-PERFORMANCE LUMINOUS ENVIRONMENT

Daylighting has enormous benefits because it contributes directly to human health and also can provide significant energy savings when part of a well- designed, integrated lighting system. A wide range of high-performance lighting systems are available that can provide high-quality, high-efficiency light.

PROVIDE QUALITY WATER

The building water system should be designed to provide the appropriate quality of water for all purposes. Potable water is needed for drinking, kitchen sinks, water fountains, lavatories, and dishwashers, and its quality should be monitored to ensure that it does not contain inappropriate levels of various metals and bacteria. Good-quality water that does not meet potable water standards can be incorporated into the building for uses such as flushing toilets and urinals and for landscape irrigation. As is the case with all aspects of high-performance building, periodic maintenance helps ensure that the building's water systems provide the quality of water required for the activities in the building.

Addressing the Main Components of Integrated IEQ Design

In the next sections, we address the design of the major subsystems that affect IEQ, including integrated lighting, daylighting, and views; thermal comfort and comfort control; acoustic comfort; electromagnetic radiation; and the design of building HVAC systems.

INTEGRATED LIGHTING, DAYLIGHTING, AND VIEWS

Building lighting systems are complex, and their design should consider optimizing a balance between contributing to human health and reducing energy consumption. Lighting systems in buildings consume about 30 percent of total US energy, a significant cost and a significant contribution to climate change. Yet good lighting design is important to human health, and providing an inadequate lighting system would be counterproductive because it would result in increased illness and absenteeism and decreased productivity. Daylighting has the dual benefit of both contributing to human health and significantly reducing building lighting energy. An important consideration in the design of an integrated lighting system for buildings is the provision of views to the outside for building occupants. The health and productivity of building users is directly affected by their ability to see the outside world, especially nature, during their normal workdays or school days. This concept was first articulated Edward O. Wilson (1988) in his book *Biophilia*, when he suggested that humans crave connection with nature and that improving the ability of people inside buildings to connect with the outside world provides positive benefit for their psyche and health. The idea is that humans evolved deeply enmeshed with the intricacies of nature and that we still have an affinity with nature ingrained in our genes. Not all daylighting systems provide views. Buildings that rely on rooftop clerestory windows and skylights

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Figure 13.1 The outside is brought in at Hillside Middle School in Salt Lake City, Utah. Floor-to-ceiling windows throughout the design provide not only transparency and daylighting but also excellent views from common areas (A) as well as from the library (B), classrooms, and office clusters. (GSBS Architects and Benjamin Lowry Photographer)

for daylighting provide views of the sky but not of nature at the ground level. Vision windows that extend from near the floor to the ceiling provide this type of visual access to nature (see Figure 13.1).

The degree of visual comfort in a building is a function of both daylight and artificial lighting levels. Generally, these two forms of lighting can be evaluated separately, since artificial lighting must be provided for those situations where there is no or insufficient daylight available—for example, in the evenings or on cloudy days. However, there is a transition point in modern green buildings where artificial lighting and daylighting are traded off, depending on the availability of daylighting. Modern lighting control systems have the capability of throttling artificial light levels in response to the availability of daylighting, thus optimizing the use of electrical energy in the building for lighting purposes. Note that the energy benefits of daylighting are covered in Chapter 9.

Daylighting, of course, has long been important to architecture for obvious reasons. In the era prior to electricity, building illumination was provided largely by

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TABLE 13.3

Design Features Available to Architects to Maximize Daylighting in Buildings

Atrium	Open area that interconnects a number of floor spaces within a building
Sawtooth roof	Comprised of a number of triangular-shape parallel sections
Roof monitor	A raised section of roof that includes a vertically (or near vertically) glazed aperture for the purpose of illumination
Skylight	A relatively horizontal glazed roof aperture for the admission of daylight
Light court	A large shaft sometimes using the walls of its surroundings to reflect light
Clerestory windows	Vertical glazing high on a wall
Light shelf	A reflective horizontal surface that can be installed on both the exterior and interior of a building
Heliostat	Mirror that tracks the sun to reflect light
Synthetic wall window	Wall glazing located at ground level to provide natural light to below-grade areas
Deadlight	Fixed glass segment embedded into cast iron stair or sidewalk frames to facilitate natural light to subsurface areas

openings, windows, and glazing, and significant design effort was invested in using natural light to the maximum extent possible. A wide variety of design features are available to architects for the purposes of enhancing the daylighting system (see Table 13.3 and Figure 13.2A–D).

According to the *Whole Building Design Guide*, a daylighting design consists of systems, technologies, and architecture. The next list indicates some of the components of a typical daylighting system design, although all of them may not be present at the same time:

- Daylight-optimized building footprint
- Climate-responsive window-to-wall-area ratio
- High-performance glazing
- Daylight-optimized fenestration design
- Skylights (passive or active)
- Tubular daylight devices
- Daylight redirection devices
- Solar shading devices
- Daylight-responsive electric lighting controls
- Daylight-optimized interior design (such as furniture design, space planning, and room service finishes)

As is the case with most aspects of passive design, the design of the daylighting system begins with the building footprint. In general, for good daylighting, buildings should be oriented on an east–west axis that maximizes north and south exposures. It is important that the width of the building footprint in the north–south direction be minimized and in no case be less than 60 feet wide. German regulations stipulate that, in an office building, the occupants must be within 15 meters of an outside window to support both daylighting and views.

Lighting controls integrated with daylighting are important in the design of lighting systems because they help provide a constant level of illumination by using

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Figure 13.2 (A) A clerestory conducts diffuse light into a lobby below at St. Johns River State College in St. Augustine, Florida. (D. Stephany)



Figure 13.2 (B) A sawtooth roof design at Manassas Park Elementary School in Manassas Park, Virginia, a suburb of Washington, DC, is oriented to allow diffuse light to enter the building. This building also uses solar tubes that illuminate separate interior spaces on sunny days. (© Prakash Patel for VMDO Architects)

artificial lighting to compensate for changing levels of daylight. These types of lighting controls consist of photocells that control either continuous dimming or stepped ballasts in the light fixtures. Nowadays, occupancy sensors, which turn the lights on and off in response to the presence of people in the space, also are integrated with the daylight-responsive lighting controls.

Design of the daylighting system must consider glare control, which deals with direct sunlight entering a space. Clearly, maximizing daylighting is important, but not at the expense of creating unpleasant working conditions in space. This is particularly important in daylighting design because the south side of the building generally will provide the bulk of its natural light, and care must be taken to ensure that direct-beam sunlight is controlled by internal and external shading devices, horizontal and vertical louvers, and light shelves.

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Figure 13.2 (C) A light shelf allows sunlight in while protecting users from glare that is often associated with tall windows. (Decorating with Fabric)



Figure 13.2 (D) An atrium at EDS corporate headquarters in Plano, Texas, connects several floors through the use of daylighting. (*Source:* National Institute of Building Sciences)

Some of the design considerations in designing daylighting systems are listed next:

- Increase the number of perimeter daylight zones.
- Promote daylight penetration high in the space by locating windows high on the wall or by providing roof monitors and clerestories.
- Reflect daylight by using light colors to increase room brightness.

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- Slope ceilings to direct more light into space. Avoid direct-beam sunlight on critical visual tasks.
- Filter daylight with vegetation, curtains, and louvers to help distribute the light.
- Be aware that different building orientations require different daylighting strategies. For example, light shelves, while effective on the south side of a building, would not be effective on the east and west sides.

In general, it is a good idea to use either a computer model or a physical model to assist in the design of an integrated lighting and daylighting system. Computer software, such as Radiance and Ecotect, is available to perform a detailed design of the lighting system. Similarly, a physical model of the building can be constructed and used to test different daylight strategies, such as glazing, orientation, and trade-offs between daylighting and energy savings.

THERMAL COMFORT AND COMFORT CONTROL

ASHRAE 55-2010, *Thermal Environmental Conditions for Human Occupancy*, defines thermal comfort as the state of mind in humans that expresses satisfaction with the surrounding environment. It describes a person's psychological state of mind and usually is referred to in terms of whether someone is feeling too hot or too cold. More accurately, it describes the combination of environmental factors that can provide good thermal comfort. For example, according to the ASHRAE standard, office spaces have a suggested summer temperature between 74.3°F and 77.9°F (23.5°C–25.5°C) and an airflow velocity of 0.59 feet per second (ft/s) (0.18 meters per second [m/s]). In the winter, the recommended temperature is between 70°F and 73°F (21.0°C– 23.0°C) with an airflow velocity of 0.49 ft/s (0.15 m/s).

In the United States, maintaining constant thermal conditions in offices is important, and even a minor deviation from comfort may be stressful and affect performance and safety. Workers already under stress are less tolerant of uncomfortable conditions. In other countries, such as Germany, where there is enormous emphasis on low-energy buildings, the comfort zone is not as rigid and there is more acceptance of a wider range of comfort conditions.

Providing thermal comfort in building spaces is a complex undertaking because it is a function of four environmental and two personal factors. The environmental factors are temperature, thermal radiation, humidity, and air speed, and the personal factors are clothing and metabolism. Three of the four environmental factors—temperature, humidity, and air speed—are familiar. Thermal radiation is the affect of direct solar or other radiation on the skin, and it can affect people in building spaces where there is direct sunlight, without shading or glare protection, into the space. Thermal comfort can be achieved through a wide variety of combinations of these factors. For example, it is well known that air speed can compensate for higher temperatures. Thus, ceiling fans used in rooms provide airflow that makes the higher temperatures more tolerable. Similarly, lower humidity can make higher temperatures more acceptable. In addition to the four environmental factors noted, other factors, such as clothing, activity levels, and personal factors such as individual health, affect thermal comfort. Thermal comfort control is the ability of occupants to adjust at least one of the four environmental factors to their liking. Giving building users at least some degree of control over thermal comfort is recognized as contributing to the health and productivity of the occupants and is considered a significant measure in the design of high-performance green buildings.

Thermal comfort is based on research conducted on the four environmental factors by Ole Fanger and others at Kansas State University in the 1970s. Perceived comfort was found to be a complex interaction of the four factors. It was found that the majority of individuals would be satisfied by an ideal set of values. As the range of values deviated progressively from the ideal, fewer and fewer people were

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satisfied. This observation could be expressed statistically as the percentage of individuals who expressed satisfaction by comfort conditions and the predicted mean vote (PMV). The PMV index predicts the mean response of a larger group of people who vote according to the ASHRAE thermal sensation scale where:

In general, the rule is that if 80 percent of a population agrees that the thermal conditions are comfortable, then the combination of environmental factors is providing comfortable conditions. This is the basis for the recommendations in ASHRAE 55-2010, *Thermal Environment Conditions for Human Occupancy*, for acceptable combinations of environmental factors.

Inclusion of clothing levels and metabolic rates in the determination of thermal comfort is also included in ASHRAE 55. The clothing level (CLO) is a numerical value describing thermal insulation provided by clothing and ranges from 0.5 to 1.5. The CLO valuation assumes that a person is standing. If an individual spends most of the day sitting, the CLO value may need to be increased, depending on the type of chair. CLO values are determined for the average occupant for each season on a space-by-space basis.

The metabolic rate (MET) estimates the typical level of activity of the occupants within a given space. MET is expressed on a decimal scale and ranges from 0.7 to 8.7. The 0.7 level represents sleeping or resting, while above 1.0 is light activity; greater than 2.0 represents moderate activity and perspiration. When values rise above 1.0, evaporation of perspiration becomes a factor in an individual's level of comfort. An estimate of the average metabolic rate of the occupants in a given space is determined as an input to assessing thermal comfort.

The latest version of ASHRAE 55-2010 addresses the use of various new technologies to deliver thermal comfort using lower-energy approaches (see Figure 13.3). Air movement, in general, is becoming a more popular strategy for cooling occupants as opposed to lower operational temperature because the energy requirements are lower. ASHRAE 55-2010 includes a new method for determining the cooling effect of air movement above 30 feet per minute (fpm) (1.64 meters/second). This method allows ceiling fans or other means of elevating air speed to provide comfort at higher summer temperatures than were previously permissible. New provisions based on field-study research allow elevated air speed to broadly offset the need to cool air in warm conditions. ASHRAE 55-2010 allows modest increases in operative temperature beyond the predicted PMV limits as a function of air speed and air turbulence, both of which increase the cooling sensation by using convection to remove heat from the skin.

ACOUSTIC COMFORT

Consideration of acoustic comfort in buildings generally falls far down the list of priorities, both in sustainable construction and in conventional building design. Acoustics are, in fact, very important to the health, well-being, and productivity of people in offices, schools, and virtually every other type of facility. Providing a good acoustical environment for building occupants helps increase their performance and reduces the incidence of illness and lost workdays. Acoustic comfort is part of a bigger picture of overall space comfort and includes not only acoustics but also other issues, such as thermal comfort, lighting quality, the availability of daylight, and other similar factors. Noise is prevalent in buildings and can come from outside traffic noise, voices within the building, mechanical equipment in adjacent spaces, copiers, phones, and numerous other sources. In order to produce a good acoustical environment, several problems must be addressed: (1) noise outside the building, (2) noise from adjacent spaces, and (3) lack of self-control in the spaces of the building. Although the noise in the spaces may not be harmful to hearing, the presence of distracting noise reduces concentration on work or study and decreases the productivity of individuals. The Center for the Built Environment at the University

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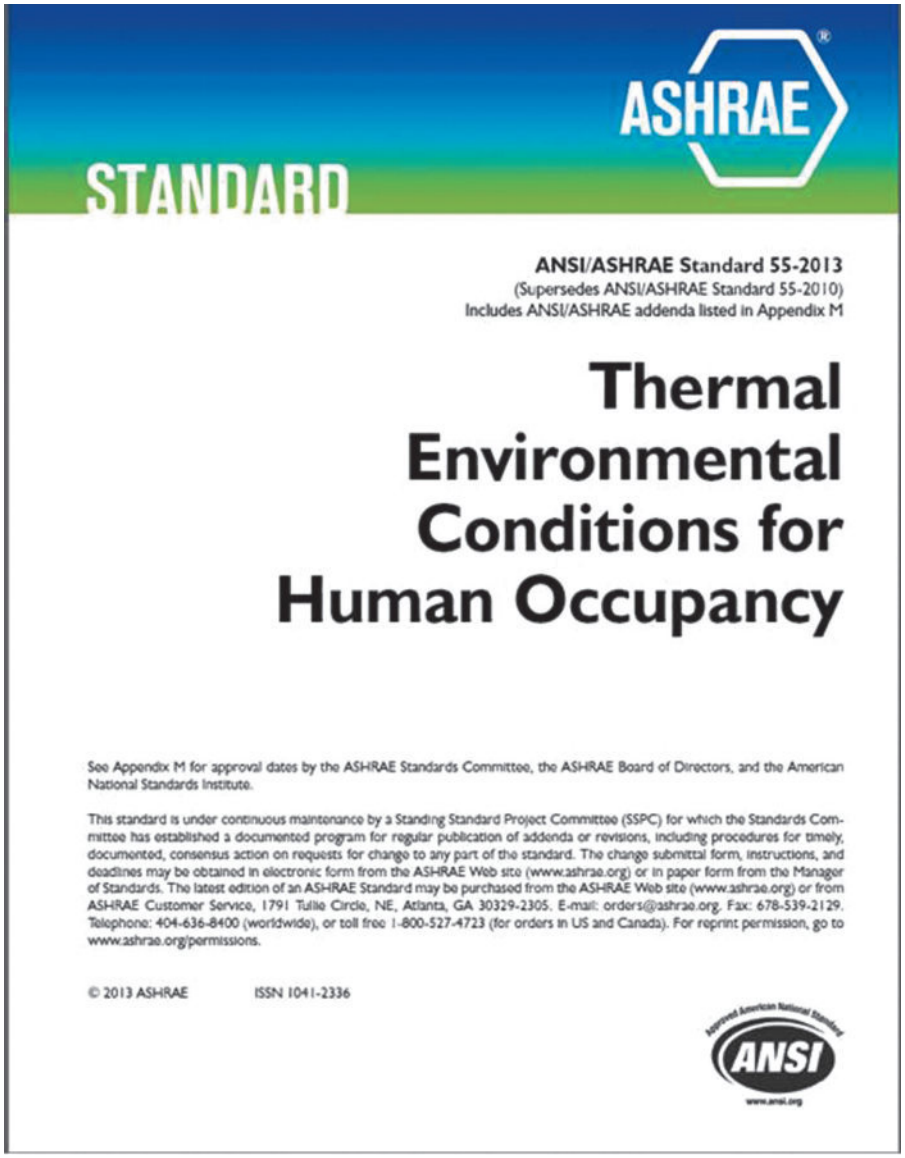


Figure 13.3 The 2013 version of ASHRAE 55 allows several approaches to achieving thermal comfort, among them the use of increased air speeds.

of California at Berkeley conducted postoccupancy evaluations of 15 buildings through a survey of 4,096 respondents and found that over 60 percent of the occupants of office cubicles think that acoustics interfere with their productivity (Jensen and Arens 2005) (see Figure 13.4). Clearly, acoustics are a major concern of people and the workforce, and poor acoustics design can result in the building performing in a manner that compromises, rather than contributes, to human health.

Starting Point: Sound and Noise Control Terminology

In the United States, noise reduction is measured by the *Sound Transmission Class* (STC), which is a number that represents the noise reduction, in decibels (dBA), of a building element such as a wall or window. Note that the decibel scale is logarithmic; thus, a 10-dBA reduction in sound between two spaces corresponds to about a 50 percent reduction in the sound volume. For example, a 40-dBA sound is about half as loud as a 50-dBA sound. With respect to STC ratings, a wall with an STC rating of 20 provides a 20-dBA sound reduction. A wall with an STC rating of 20 and with a 60-dB sound level on one side would reduce the noise level to 40 dB on the other side. A typical home interior wall constructed of one

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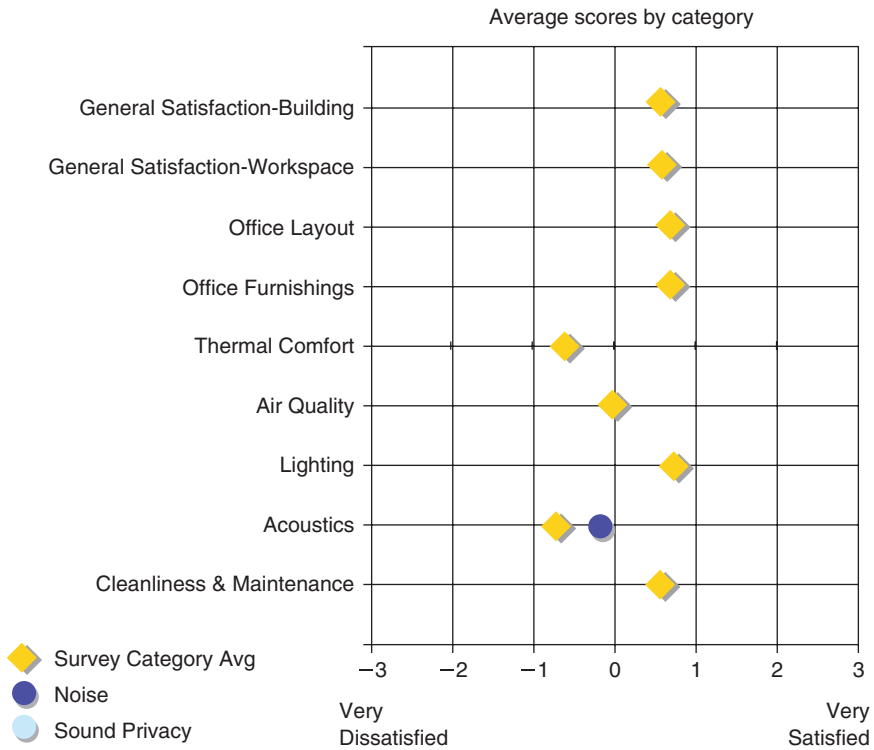


Figure 13.4 A survey conducted by the Center for the Built Environment at the University of California at Berkeley indicated that of the various factors that constitute work space comfort, occupants were most dissatisfied with the acoustics of the spaces. (*Source:* National Institute of Building Sciences)

sheet of ½-inch drywall on either side of a wood frame has an STC of about 33. The scale most commonly used to measure decibels in a space is referred to as the dBA scale. Typical STC values and their effects on sound levels are indicated in Table 13.4. Outside the United States, the *Sound Reduction Index* is used instead of STC ratings.

The *noise criterion* (NC) is a rating for interior noise and noise from a variety of sources, including air-conditioning equipment. The lower the required NC rating for a space, the quieter the space will be. Table 13.5 shows the recommended range of NC and dBA values for various typical building spaces.

TABLE 13.4

Effects of STC Rating on Sound Transmission through a Building Element

STC	Sound Level
25	Normal speech can be understood quite easily and distinctly through the wall.
30	Loud speech can be understood fairly well, normal speech heard but not understood.
35	Loud speech audible but not intelligible.
40	Onset of "privacy."
42	Loud speech audible as a murmur.
45	Loud speech not audible; 90% of statistical population not annoyed.
50	Very loud sounds such as musical instruments or stereo can be faintly heard; 99% of population not annoyed.
601	Superior soundproofing; most sounds inaudible.

Source: North American Insulation Manufacturer's Association, "Sound Control for Commercial and Residential Buildings." Available at www.icsinsulation.com/specifications/general/Sound%20Control.pdf.

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TABLE 13.5

Recommended NC and Equivalent Sound Levels for Various Typical Building Spaces

Type of Space	Recommended NC Level	Equivalent Sound Level (dBA)
Assembly halls	25–30	35–40
Churches	30–35	40–45
Factories	40–65	50–75
Private offices	30–35	40–45
Conference rooms	25–30	35–40
Classrooms	25–30	35–40
Libraries	35–40	40–50
Homes	25–35	35–45
Restaurants	40–45	50–55
Concert halls	15–20	25–30
Motel rooms	25–35	35–45

Source: Adapted from "Comparing Noise Criteria," at The Engineering Toolbox website, www.engineeringtoolbox.com/noise-criteria-d_726.html.

Reverberation time is an important description of the acoustic environment of a space. It is the time, in seconds, that it takes a sound to decay 60 dB below its original level. Spaces with longer reverberation times—above 2 seconds—are characterized by hard surfaces. In such spaces, the ability to hear conversations or lectures is impaired because of the presence of past sounds. Such areas do make sense as spaces for concerts. A space with a long reverberation time is referred to as a "live" environment. When sound dies out quickly within a space, the environment is referred to as being an acoustically "dead."An optimum reverberation time depends highly on the use of the space. For example, speech is best understood within a "dead" environment. Music can be enhanced within a "live" environment as the notes blend together. Different styles of music also will require different reverberation times (see Table 13.6).

Reverberation time is affected by the size of the space and the amount of reflective or absorptive surfaces within the space. A space with highly absorptive surfaces will absorb the sound and stop it from reflecting back into the space.

This would yield a space with a short reverberation time. Reflective surfaces reflect sound and increase the reverberation time within a space. In general, larger spaces have longer reverberation times than smaller spaces. Therefore, a large

TABLE 13.6

Recommended Maximum Reverberation Times for Speech and Music

	Reverberation Time Range (seconds) and Acceptability			
Type of Sound	0.8–1.3	1.4–2.0	2.1–3.0	Optimum Reverberation Time† (sec)
Speech	Good	Fair–Poor	Unacceptable*	0.8–1.1
Contemporary music	Fair–Good	Fair	Poor	1.2–1.4
Choral music	Poor–Fair	Fair–Good	Good–Fair	1.8–2.01

*With an adequately designed and installed sound system, speech intelligibility concerns can be mitigated.
†The optimum reverberation time can be somewhat subjective and can shift based on numerous variables.
Source: Adapted from the former ReverberationTime.com website which was at www.reverberationtime.com.

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space requires more absorption to achieve the same reverberation time as a smaller space. Notre Dame Cathedral in Paris, France, has a reverberation time of over 8 seconds and is a good space to hear pipe organ music, but a speech would be virtually unintelligible.

Reverberation time also can be adjusted within an existing space. Tests can be performed in a space to determine the existing reverberation time. Absorptive materials then can be added to or removed from a space to achieve the desired reverberation time. Whenever possible, it is highly advisable to consider reverberation time and other aspects of acoustics at the design stage. Making revisions to a space after the fact can be more costly and compromise aesthetics.

The *noise reduction coefficient* (NRC) is a single-number index determined in a lab test and used for rating how absorptive a particular material is. This industry standard ranges from 0 (perfectly reflective) to 1 (perfectly absorptive). Acoustical ceiling tiles typically are specified to have an NRC of at least 0.75. Although they sound similar, the terms *NRC* and *STC* have very different meanings. STC is the sound attenuation, in dBA, of a building element such as a wall, while NRC is the fraction of the sound that is absorbed by a material.

Exterior Noise Issues and Control

Producing a good indoor acoustical environment requires good planning and site selection to handle potential problems with high external noise levels. In general, sites that are in high noise areas, such as near industrial areas and highways, should be avoided, and site selection should include locations that are suitable for the given purpose. For example, it is a good idea to site a school in a relatively quiet area so that the ambient external noise levels are relatively low and extreme measures are not required to reduce the noise transmission into the building. If there is noise from a nearby highway, for example, the building can be designed such that storage areas, restrooms, janitors' closets, and mechanical rooms are on the side facing the source of the noise. More sensitive areas, such as classrooms, can be located on the quiet side of the building. Earth berms or other structural solutions, such as concrete barriers, may be required if there is more than one direction from which significant noise is generated. Selection of building components is important in providing good acoustical protection from exterior noise sources. Windows, for example, are an important consideration because although they allow daylight and control heat and glare, they are vulnerable to noise transmission and must be selected with special consideration under acoustical characteristics. Double- and triple-pane glass with inert gas infill may be the best solution for situations where there is significant exterior noise yet maximum daylighting is desirable for health and energy reasons.

Interior Space Acoustic Requirements

Each type of interior space has different considerations and requirements, depending on the types of activities occurring in the space. Private offices, for example, require a space where private conversations can occur without being heard in adjacent spaces and where the acoustic conditions support worker health and productivity. These types of spaces generally have problems of noise transmission through partitions, excessive noise levels in the room, and noises from the building's air-handling system. Some of the solutions recommended by the *Whole Building Design Guide* are to extend walls from floor to structural deck above, insulate partitions to achieve the required STC value to reduce noise transmission from adjoining spaces, and locate offices and conference rooms so that they are not adjacent to mechanical equipment rooms.

Classrooms are spaces designed for learning, and modern classrooms generally have multimedia communications environments. Good acoustics are needed for effective verbal communication, which means that there must be relatively low noise levels and vertical reverberation. Some types of noises that interfere with the learning

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process are noises from outside the school, such as the nearby traffic and aircraft flying over, hallway noise, and noise from other adjacent classrooms, mechanical equipment and ductwork, and noises within the classroom itself. The recognition of the need to have a high-quality acoustical learning environment in classrooms resulted in the publication of American National Standards Institute, Inc. (ANSI)/Acoustical Society of America (ASA) S 12.60, *American National Standard Acoustical Performance Criteria, Design Requirements, and Guidelines for Schools*. ANSI/ASA S 12.60 provides acoustical performance criteria, design requirements, and design guidelines for new school classrooms and other learning spaces. It requires both maximum background noise levels and maximum reverberation times for core learning spaces, such as classrooms:

- ANSI/ASA S 12.60 requirements for background noise set the tone for acoustic comfort in core learning spaces in schools. Background noise is composed of noise from building systems, exterior sound transmission, and sound transmission from adjacent spaces. Excessive background noise can seriously degrade the ability to communicate.
- For core learning spaces with internal volumes of 20,000 cubic feet (ft^3)or less, 1-hour steady-state background noise levels should not exceed 35 dBA.
- For core learning spaces with internal volumes of 20,000 ft^3 or more, 1-hour steady-state background noise levels should not exceed 40 dBA.
- If the noisiest 1-hour period during which learning activities take place is dominated by transportation noise, the maximum noise limits are increased by 5 dB.

Controlling the background noise levels within a space involves careful consideration of several building systems. Noise from the HVAC system, electrical fixtures, light fixtures, and plumbing system should all be considered in the noise control design. According to this standard, it is the architect's or designer's responsibility to specify systems and installation methods in order to meet the background noise levels required in the standard. The implementation of the noise control design is the responsibility of the contractor.

The key reverberation time requirements for core learning spaces are listed next:

- The maximum reverberation time for core learning spaces with internal volumes greater than 10,000 ft^3 should not exceed 0.6 seconds.
- For core learning spaces with internal volumes of more than 10,000 but less than 20,000 ft^3, the maximum reverberation time is 0.7 seconds.
- Reverberation time for spaces with more than 20,000 ft^3 of internal volume is not specified; however, guidelines are given in Annex C of the standard.

Sound Masking

Sound masking is the introduction of unobtrusive background sounds in the office environment to reduce interference from distracting office sounds and render speech from nearby workers virtually unintelligible. Sound masking means that the stable background noise of the office is raised controllably to minimize the intelligibility of nearby speech without creating a new source of distraction. A sound-masking level of 40 to 45 dBA typically would be recommended for office use. Sound masking often is used in open and closed offices where the ambient sound level is too low and, as a result, privacy is compromised. Sound masking works by electronically producing sounds similar to softly blowing air and projecting it through speakers installed above tiles in the ceiling. The sound is evenly distributed throughout the area being masked and can be adjusted to the individual privacy requirements in any given area. In an open-plan office without a suspended ceiling, speakers can be set

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Figure 13.5 A networked sound-masking system manufactured by Lencore Acoustics Corporation includes digital signal processors, electronic noise generators, amplifiers, wiring, loudspeakers, controls, and other components to generate, amplify, distribute, and reproduce digitally synthesized and stabilized background sound masking to create speech privacy. (Photograph courtesy of Lencore Acoustics Corp. www.lencore.com)

on the systems furniture or even under the raised floor. Appropriate sound masking can be used to achieve acceptable speech privacy between two neighboring workstations. Optimum sound masking is smooth and unnoticeable and similar to ventilation system noise. The sound pressure level and spectrum need to be considered to obtain a balance between acoustic comfort and efficient masking performance. In many cases, ventilation creates appropriate masking. In large and high open offices, constant occupant activities and babble can create an appropriate masking. But, in many cases, an electronic audio system is required to create optimum masking requires (see Figure 13.5).

The use of electronic masking has not become common practice although the importance of masking is emphasized in acoustic design guidelines worldwide. One reason may be that very few research reports have been published in this area and the human health impacts of electronic masking have not been established. However, in general, due to the relatively low noise levels of these systems, they tend to be within the range of normal office noise and are not considered harmful to the building occupants.

ELECTROMAGNETIC RADIATION

Exposure to electromagnetic radiation is fairly commonplace. Natural electromagnetic radiation occurs in the form of light and heat and, aside from direct sunlight power, naturally occurring radiation levels are rather low. However, through advances in technology, additional radio radiation sources are having an impact on humans. Figure 13.6 shows frequently occurring radiation sources, arranged according to their frequency ranges and their effect on humans (Bauer, Mösle, and Schwarz 2010). Electromagnetic radiation from technology is often referred to as *electrosmog*, which can further be defined as the invisible electromagnetic radiation resulting from the use of both wireless technology and electricity in the power system of buildings. The most common sources of wireless electrosmog are cordless phones, cordless baby alarms, mobile/cellular phone masts/towers/transmitters, mobile/cellular phones, and wireless networks. Table 13.7 shows the contribution of various common communications devices on human performance. High-frequency radiation, like ultraviolet light and X rays, has an ionizing effect

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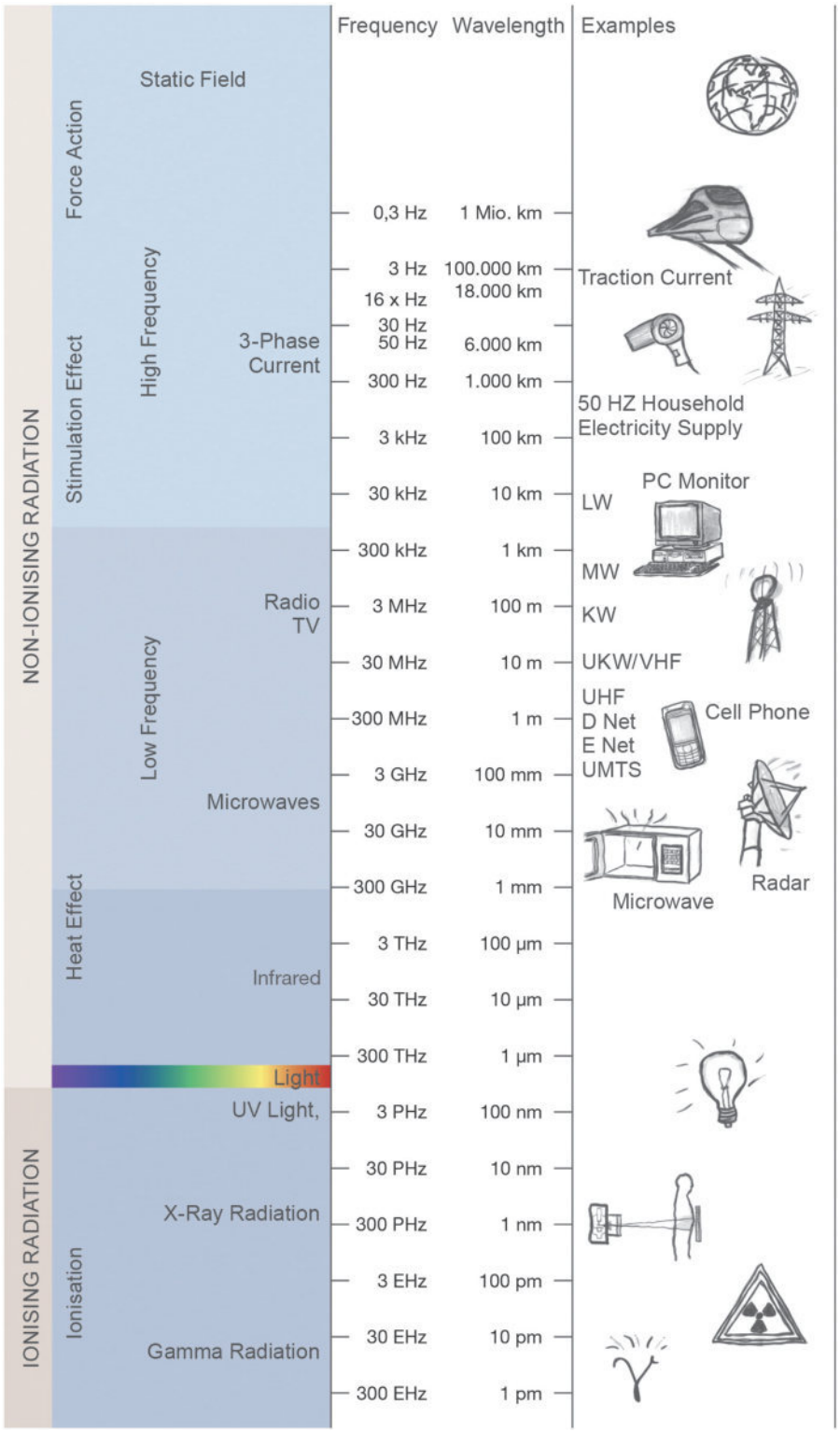


Figure 13.6 Overview of different radiation sources with their corresponding frequency ranges. (*Source:* Bauer, Mösle, and Schwarz 2010. Illustration courtesy of Drees & Sommer)

that has been proven to harm body cells. Other frequency ranges have proven heat and irritation impacts on humans. These include electromagnetic fields caused by, for example, communications systems such as telephones and computer systems. Exposure to these types of radiation leads to tissue warming and, depending on intensity and duration, high blood pressure. At present, the short- and long-term

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TABLE 13.7

Relative Effects of Electromagnetic Radiation from Common Office Communications and Computer Equipment

Office Equipment	Low	Medium	High	Extreme
Computer monitor		X		
Flat screen	X			
Normal keyboard and mouse		X		
Radio/infrared keyboard and mouse			X	
Bluetooth and wireless local area network (WLAN)				X
Printer	X			
Fax	X			
Copier	X			
Lights		X		
Laptop		X		
Normal telephone			X	
Portable telephone				X
Personal computer		X		
Desk lighting			X	
Ceiling lighting		X		
Beamers			X	
Office Furnishings				
Chairs	X			
Tables with metal frames		X		
Shelving	X			

Source: Bauer et al. 2010; Gustavs 2008

impacts are unknown. However, it is well known that high levels of electromagnetic radiation in the frequency range of communications can have a negative impact on sleeping patterns, brain performance, the immune system, and nervous and cellular systems. With the rapid rise in touch communications, electromagnetic loads on humans also have increased. Until current long-range and short-term studies have been interpreted scientifically, buildings should be designed with the precautionary principle in mind; that is, recommendations of international expert panels ought to be adhered to, and there should be a detailed analysis of particular critical areas with high radiation loads.

The aspects of electromagnetic radiation that should be considered are frequency range, field intensity, distance to the emitter, and the length of exposure. Radiation intensity is measured in watts per square meter, and the intensity of the radiation decreases with the square of the distance from the emitter. This means that a high-capacity emitter that is farther away, such as a cell phone tower, may be less harmful than a small emitter in the vicinity of a body, such as a cell phone. The radiation load from a cell phone at the ear is 100 times more than when it is 3.1 feet (1 m) from the body. For high-performance green buildings, reducing electromagnetic radiation loads should be considered, and work tools, such as telephone systems and cell phones, need to be taken into account as well as computers and other electronic devices. Table 13.8 shows the critical values for electromagnetic radiation in different countries. Note that the countries and regions listed have allowable electromagnetic radiation levels that are up to 1,000 times lower than international recommendations. In each case, these are significantly lower than the 10–50 watts per square meter w/m^2) recommended by the International Commission on Non-Ionizing Radiation Protection (ICNIRP). Russia, which is rarely thought of as having high human or environmental standards, has one of the most stringent electromagnetic limits in the world at 0.02 w/m^2. Equally important is that the problem of electromagnetic radiation is

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TABLE 13.8

Critical Values for Electromagnetic Radiation in Different Countries

Country/Region	Critical Value for Electromagnetic Radiation (watts per square meter)
Germany	2–9
Australia/New Zealand	2
Italy	0.1
Poland	0.1
Czech Republic	0.24
Russia	0.02
Salzburg, Austria	0.001
Switzerland	1/10 of ICNIRP critical values*

*Critical values set by the ICNIRP are 10 W/m^2 for general public exposure and 50 W/m^2 for occupational exposure for the range between 10 and 300 gigahertz.
Source: Bauer et al. 2010

not yet recognized as being important by the green building community in the United States. In contrast, in Germany, the problem of electrosmog is taken far more seriously. Figure 13.7 shows a German office worker with instrumentation to determine the effects of electromagnetic radiation from office equipment on brain activity and the effects of efforts to neutralize this radiation. German research indicates that frequency modulators can be effective in neutralizing extraneous electromagnetic radiation.



Figure 13.7 An office worker in Germany equipped with a portable electroencephalogram device to determine the effects of neutralizing electromagnetic radiation from office equipment. (Photograph courtesy of Drees & Sommer)

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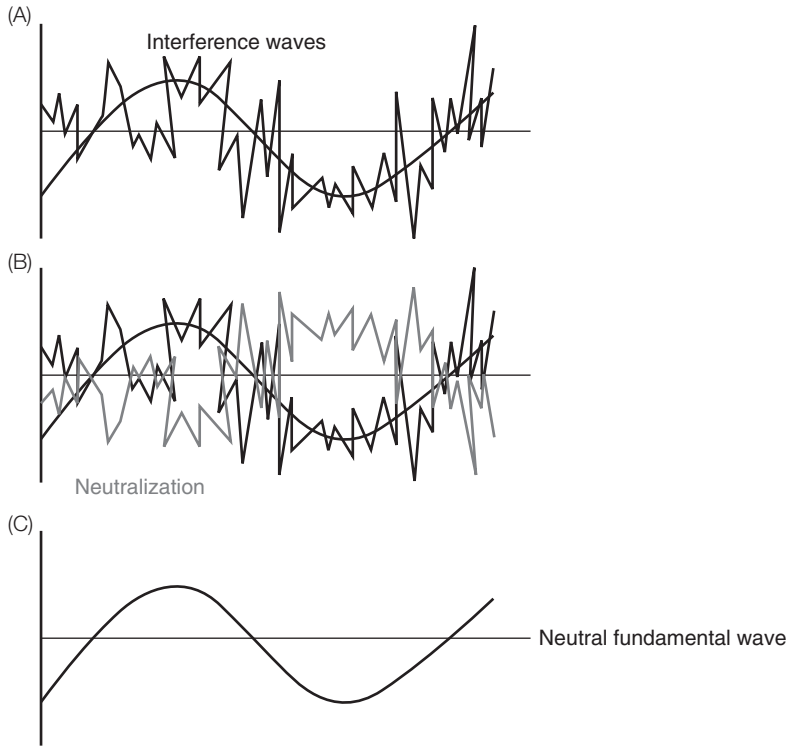


Figure 13.8 (A) Extraneous electromagnetic radiation is superimposed on an alternating current electrical wave. (B) A neutralizing wave that is the opposite of the extraneous electromagnetic radiation in magnitude and polarity is introduced. (C) The result is a clean wave from which the extraneous electromagnetic radiation has been removed. (Illustration courtesy of Institut für Physikalische Raumentstörung, Berlin, Germany)

Figure 13.8 indicates how frequency modulators can neutralize electromagnetic radiation superimposed on a power line. Figure 13.9 shows how this approach was adapted by the Institut für Physikalische Raumenstörung in Berlin, Germany, to neutralize similar radiation affecting brain wave activity.

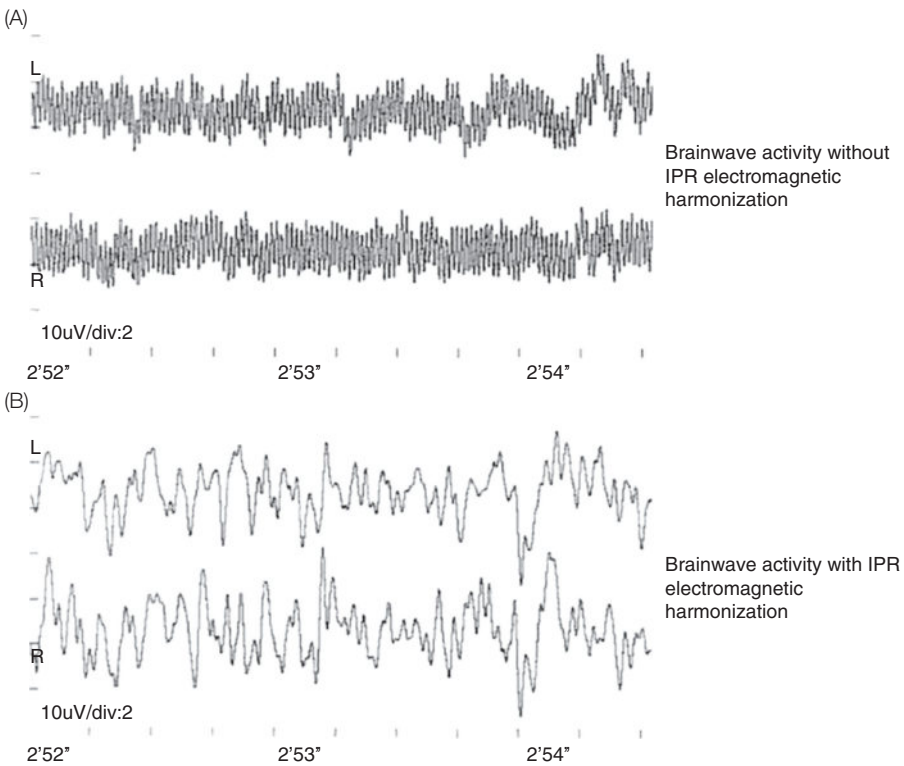


Figure 13.9 (A) The effects of electromagnetic radiation on brain wave activity, and (B) normal brain wave activity after neutralization of electromagnetic radiation by frequency modulators. (Illustration courtesy of Institut für Physikalische Raumentstörung, Berlin, Germany)

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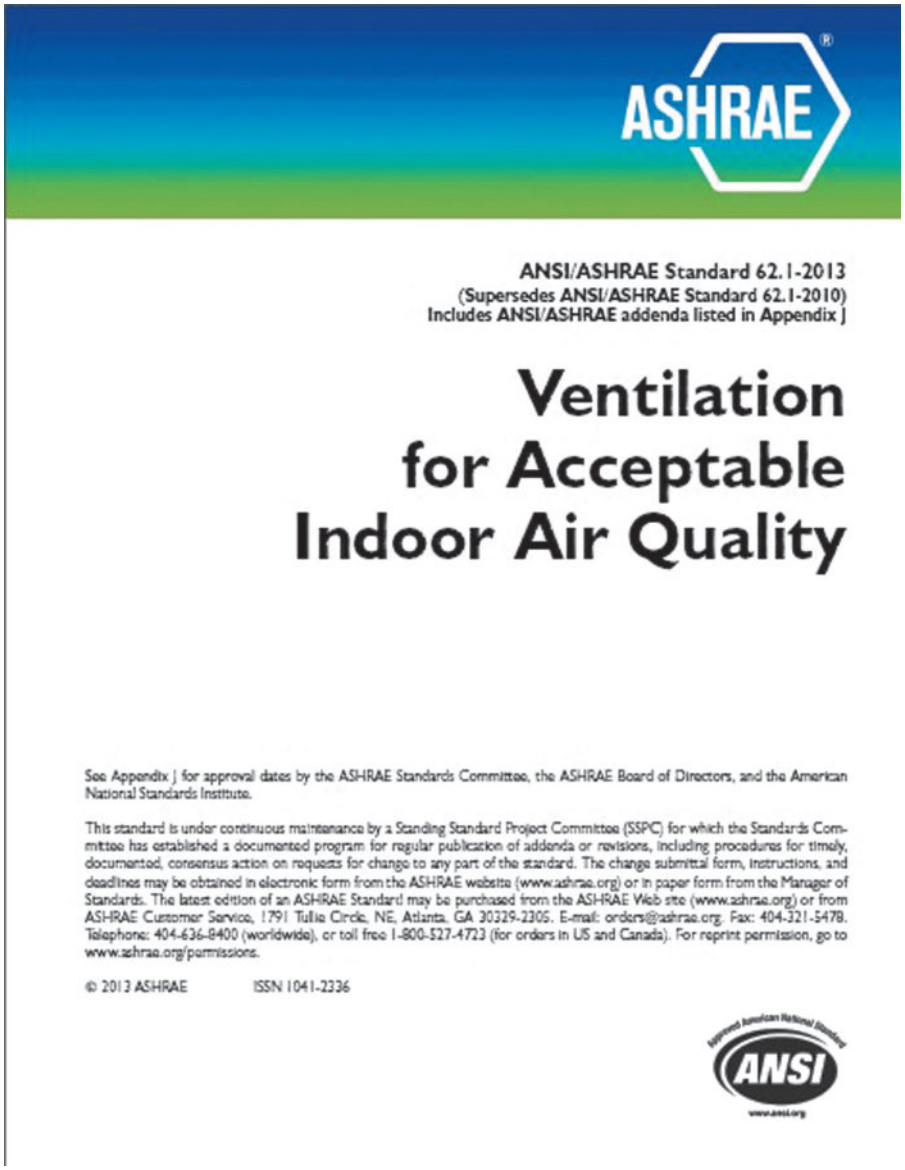


Figure 13.10 ASHRAE 62.1-2013 is the current version of the US standard that governs the design of building ventilation systems and ventilation rates.

HVAC SYSTEMS AND IEQ

Proper design of a building's HVAC system is perhaps the most important approach for providing a healthy indoor environment. Conversely, a poorly designed HVAC system can be a harbinger of trouble. The HVAC system provides a means for moving, exchanging, filtering, and conditioning all of the air in a building. Because the HVAC system plays such an important role in IEQ, it is imperative that it be understood and maintained properly. The next section describes the advantages offered by an effective HVAC system and the problems caused by a poorly designed system.

HVAC System Design

HVAC systems differ greatly from building to building, from simple facilities with a simple forced-air furnace to hospitals with state-of-the-art, computer-controlled, automated systems. In all cases, however, the HVAC system affects IEQ because

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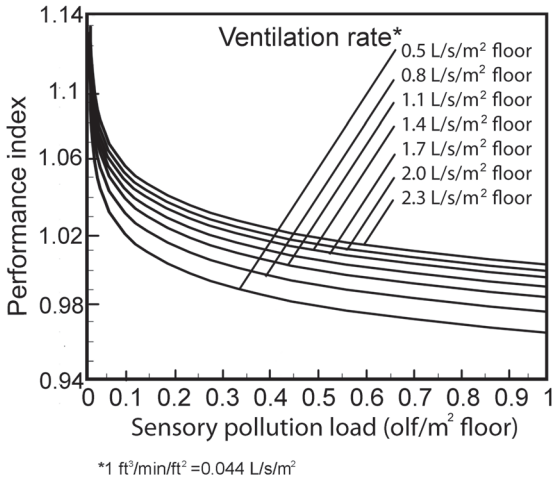


Figure 13.11 The performance of office workers increases (*y*-axis) as ventilation rates increase (series of curves) for specific pollution levels (*x*-axis). The ventilation rate is given in liters per second per square meter ($L/s/m^2$) of floor area. (Courtesy SenseAir)

it moves and conditions air. A typical office building HVAC system is a complex arrangement of equipment, with sources of chilled water and hot water coupled to air handlers. The chilled and hot water can be either generated in the building via chillers and boilers or obtained from a central plant serving a group of buildings. The air handlers are composed of fans, cooling coils, heating coils, filters, and other components arranged in a large container that condition and circulate air through the building. *Conditioning* means that the air is heated or cooled, cleaned, and humidified, if needed, to ensure that the desired temperature and humidity conditions in the various building spaces and zones are provided. The total HVAC system consists of one or more air handlers (depending on building size), each of which is responsible for conditioning a specific zone of the building. The HVAC system is responsible for ensuring that the proper quantity of outside ventilation air is provided for the building occupants. The outside ventilation air is probably the most important contribution of the HVAC system to a quality indoor environment. In terms of IAQ, the higher the ventilation rate, the better is the air quality in the building. In the United States, ASHRAE 62.1-2010 governs the design of building ventilation systems (see Figure 13.10). A 2000 study by Wargocki, Wyon, and Fanger showed that a so-called productivity index based on tasks performed by office workers increased as ventilation rates were increased, resulting in a decrease in pollution loads (see Figure 13.11).

Climate Control

Climate control is the general objective of the HVAC system; most likely, it is the reason the system was installed in the first place. Surprisingly, though, keeping in mind that the system is designed primarily for climate control, there is often a tremendous amount of dissatisfaction in this area. Before the advent of air conditioning, when opening windows was the only way to help cool a space, building occupants accepted any discomfort as unavoidable.

The state of the air in a space is defined by its psychrometric properties: temperature, relative humidity, enthalpy, and moisture content. Any two properties uniquely define the state of the air. The two most common properties that are controlled by an HVAC system are the temperature and the relative humidity (or moisture content, as the two are different manifestations of the same property). The HVAC system must maintain the proper balance of temperature and humidity in order to maintain a comfortable indoor environment. Temperatures in the range of 65°F to 78°F (18°C–26°C) and relative humidity levels between 30 and 60 percent are considered the comfort range for the majority of the population.

The HVAC system must be capable of controlling the supply air in spite of changing conditions . For example, if a summer thunderstorm saturates the outside air and suddenly increases the humidity level of the air flowing into the HVAC

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system, the system must be able to adapt and maintain the proper humidity level for the outgoing supply air. Moisture control is a critical yet difficult-to-achieve purpose of the HVAC system. When air is too dry, discomfort is a problem; when air is too moist, discomfort and contaminant generation become problems.

Contaminant Generation and Circulation

The HVAC system often can be the source of several types of airborne contaminants. It is a potential breeding ground for many types of biological contaminants, including molds, spores, and fungi. Certain components of the HVAC system can be contaminated more easily than others, particularly porous ductwork linings that are used for insulation and sound control. The HVAC system, because it is responsible for humidification and dehumidification, also can be the cause of uncomfortable humidity levels in the air. High humidity levels help to accelerate the production of biological contaminants. Excess water buildup in the HVAC system, particularly in locations near the evaporator coils or humidifiers, is a major breeding ground for biological contaminants. Water buildup inside components of the HVAC system is sometimes difficult to detect and often expensive to fix. If a well-designed HVAC system is running properly, there should be no excess water buildup.

When it becomes a circulator of airborne contaminants generated both inside and outside the building, the HVAC system is negatively affecting IAQ. ASHRAE 62.1-2010 defines the requirements for the quantities of outside air ventilation required to remove excess CO_2 generated by people. Unfortunately, ventilation sometimes has the effect of introducing new pollutants from the outside. The ASHRAE standard is based on the National Ambient Air Quality Standards and provides guidelines to follow if the supply of outside air does not meet the standard.

Care must be taken to ensure that the outside air source for a building is not unnecessarily or inadvertently contaminated by an isolated pollutant source. IAQ problems frequently arise when air intakes are positioned near loading docks or other possible sources of pollutants. Air intakes should be located away from exhaust sources, both from automobiles and from other buildings, and they should be high enough above the ground to avoid bringing in ground source contaminants, such as radon and pesticides.

Interior source contaminant circulation is another major problem in buildings. The most probable cause of unnecessary circulation of internal contaminants is improper zoning. Most buildings have areas designated for specific purposes, and the HVAC system must meet the needs of each area. Some areas, such as laboratories and machine shops, have a greater need for ventilation than others—for example, office space. If the HVAC system is not zoned properly, contaminants from one area may affect the air quality of another area. For example, if an area of a building is turned into a metal shop where welding is performed, but the HVAC system continues to function as if it were an office space, contaminants will be spread to other parts of the building.

TABLE 13.9

Building Materials of Particular Concern Because of Their IAQ Impacts

Site Preparation and Foundation
Soil treatment pesticides
Foundation waterproofing
Mechanical Systems
Duct sealants
External duct insulation
Internal duct lining
Building Envelope
Wood preservatives
Curing agents
Glazing compounds
Thermal insulation
Fireproofing materials
Interior Finishes
Subfloor or underlayment
Carpet backing or pad
Wall coverings
Paints, stains
Partitions
Ceiling tiles

Source: Adapted from Hansen 1991

Emissions from Building Materials

All materials have emissions, some more than others, and they all may contribute to deterioration of the air quality. Many health complaints have been linked to new materials installed during the construction or renovation of buildings. Engineering out materials known to have an adverse effect on IEQ is perhaps the easiest means of ensuring excellent IAQ. Proper materials selection offers a type of quality control that can save millions of dollars in remediation and lessen legal liability. Table 13.9 lists materials of particular concern that warrant careful selection because of their potential adverse effects on IAQ.

The primary concern with respect to building materials is the types of contaminants they emit. But of additional concern is that some materials act as "sinks" for

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emissions for other materials or for contaminants that enter the building from other sources. For example, many building materials readily absorb VOCs and rerelease them into the air. In fact, the majority of harmful building material constituents are VOCs, which typically are components of the manufacturing and installation processes. Usually, however, the emission rate will be reduced in proportion to the time the contaminant is exposed to the air.

Due to the increasing awareness of issues related to IAQ, both public agencies and private industry are promoting the use of low-emission building materials. Communicating IEQ requirements to subcontractors and suppliers is an important step in the process of creating a healthy building, but there is still debate about how to include materials emissions requirements in specifications. The MasterFormat form of specifications developed by the Construction Specifications Institute (CSI) is generally employed to describe the methods and materials of construction. MasterFormat had 16 divisions until 2005, when it was expanded to 50 divisions. Each division covers major aspects or systems of the building; further, each division is divided into sections that cover subsystems. Each section has three parts: Part 1—General, Part 2—Products, and Part 3—Execution. One suggestion for addressing the issue of how to include the required environmental attributes is to expand this three-part format to four parts for each section and to include information on materials emissions requirements and other environmental attributes in the new Part 4—Environmental Attributes.

Another option is to simply introduce an entire section into the general division (Division 1) of the CSI MasterFormat that addresses all the environmental requirements of the project, including materials emissions. This approach is being implemented in California with the creation of Section 01350—Special Environmental Requirements, which includes emissions requirements for materials.[3] Section 01350 covers product selection guidelines, emissions testing protocols, and nontoxic performance standards for cleaning materials. It requires that material safety data sheets be submitted for each material and that these materials be tested by an acceptable testing laboratory in accordance with American Society for Testing and Materials D5116-97, *Standard Guide for Small-Scale Environmental Chamber Determinations of Organic Emissions from Indoor Materials/Products*. Section 01350 also provides information about so-called chemicals of concern, which are carcinogens, reproductive toxicants, and chemicals with an established Chronic Reference Exposure Level (REL). A Chronic REL is an airborne concentration level that would pose no significant health risk for individuals indefinitely exposed to that level. Chronic RELs have been developed for 80 hazardous substances; another 60 chemicals are under review. The modeling of total concentrations of airborne emissions must show that the maximum indoor air concentration of any of the chemicals of concern must not exceed half of the REL. Table 13.10 lists some of the RELs for common VOCs present in building materials.

ADHESIVES, SEALANTS, AND FINISHES

Adhesives, sealants, caulks, coatings, and finishes are placed in the building when wet and are expected to dry, or cure, on the premises. The release of VOCs is an inherent part of this process. The solvents used in formulating these materials are the source of most VOCs emitted during drying and later during building occupation.

Adhesives and Sealants

Adhesives are materials or substances that bind one surface to another. They affect a wide range of construction materials; adhesives can be applied with floorings and wall coverings, or they may be a component of a material, such as plywood, particleboard, movable wall panels, and office workstations. Adhesives are applied in a liquid or viscous state, then cure to a solid or more solid state to achieve bonding. The majority of adhesives release VOCs and pose the greatest threat during their application and curing. When applied, adhesives should be used in areas with

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TABLE 13.10

Chronic RELs for Selected Organic Chemicals Associated with IAQ

Chemical Name	Chemical Abstracts Service Number	REL (ppb)	REL (mg/m^3)
Benzene	71-43-2	20	60
Chloroform	67-66-3	50	300
Ethylene glycol	75-00-3	200	400
Formaldehyde	50-00-0	2	3
Naphthalene	91-20-3	2	9
Phenol	108-95-2	50	200
Styrene	100-42-5	200	900
Toluene	100-88-3	70	300
Trichloroethylene	79-01-6	100	600
Xylenes	Several	200	700

Note: ppb = parts per billion; mg/m^3 = micrograms per cubic meter.

increased ventilation (at normal room temperature) for 48 to 72 hours to avoid accumulation of VOCs. The packaging label or other installation information for adhesives should always be consulted for additional product-specific precautions.

One method of characterizing adhesives in terms of their influence on IAQ is to identify the resin used in the base. Resins can be natural or synthetic. Natural resins usually have low emission potential, but in synthetic resins, emission potential can vary dramatically. Currently, advances are being made in the development of adhesives with no or low emissions.

Sealants are applied to joints, gaps, or cavities to eliminate penetration of liquids, air, and gases. (Note: Although the construction industry differentiates between indoor and outdoor sealants, the former being referred to as *caulks* and the latter as *sealants*, this discussion does not make this distinction.) Sealants usually are selected on the basis of their flexibility and resin base. Like adhesives, sealants can be hazardous during installation and curing. Their emission potential is directly related to the percentage of base resins and solids. Fortunately, sealants, which definitely raise a concern with regard to their VOC emission potential, are used indoors in small quantities. Alternate water-based sealants manufactured using nontoxic components are available. One such product for interior use is a vinyl adhesive sealant. An acrylic latex exterior sealant for building joints is also on the market.

The USGBC, LEED, and Green Globes building assessment systems provide credit for the use of low-emission adhesives and sealants. To earn this credit, adhesives, sealants, and sealant primers must meet the VOC content limits of the South Coast Air Quality Management District Rule 1168 (see Table 13.11).[4] Aerosol adhesives must meet the requirements of Green Seal GS-36, *Standard for Commercial Adhesives*.

TABLE 13.11

Hazardous Chemicals in Pigments

Antimony oxide	Titanium dioxide	Rutile titanium oxide
Cadmium lithopone	Chrome yellow	Molybdate orange
Strontium chromate	Zinc chromate	Phthalocyanine blue
Chrome green	Chromium oxide	Phthalocyanine green
Hydrated chromium oxide	Copper powders	Cuprous oxide

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Finishes

Finishes encompass a wide range of products, including paints, varnishes, stains, and sealers. Finishes are a major component of building materials and furnishings whose primary purpose is to provide protection against corrosion, weathering, and damage. Secondarily, they may also add aesthetic value to building materials. All finishes have similar characteristics. They require resins and oils to form a film and to aid adhesion by promoting penetration into the substrate. All coatings require carriers (water or organic solvents) that provide viscosity for application. Carriers also improve adhesion through evaporation.

Paints and stains require solids, including pigments, to provide various colors. The amount of solids is a good indicator of the VOC emission potential of the finish. Table 13.12 lists the hazardous chemicals associated with particular pigments used in paints. The sanding or burning of finishes generates potential IEQ hazards such as dust from talc, silica, mica, and especially lead.

Water-based finishes typically are low emitting; however, organic solvent-based finishes are more likely to be high emitting. The current trend is to replace conventional finishes with water-based alternatives, although paints have been targeted primarily in this effort. Very few stains, sealers, and varnishes have been successfully adapted for low VOC emissions, because, to date, alternative finishes generally do not perform as well as their traditional counterparts. The new products often require more applications to achieve results similar to those of traditional products. The

TABLE 13.12

Sample VOC Limits on Adhesives Established by South Coast Air Quality Management District Rule 1168*

Architectural Applications	**VOC Limit (grams per liter less water)**
Indoor carpet adhesives	50
Carpet pad adhesives	50
Wood flooring adhesives	100
Rubber floor adhesives	60
Subfloor adhesives	50
Specialty Applications	**VOC Limit (grams per liter less water)**
PVC (polyvinyl chloride) welding	510
CPVC (chlorinated polyvinyl chloride) welding	490
ABS (acrylonitrile-butadiene-styrene) welding	325
Plastic cement welding	250
Adhesive primer for plastic	550
Substrate-Specific Applications	**VOC Limit (grams per liter less water)**
Metal-to-metal	30
Plastic foams	50
Porous material (except wood)	50
Wood	30
Fiberglass	80
Sealants	**VOC Limit (grams per liter less water)**
Architectural	250
Nonmembrane roof	300
Roadway	250
Single-ply roof membrane	450

*Through January 7, 2005, amendments
Source: Hays et al. 1995

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color selection of alternative paints is limited as well. And although hypoallergenic, preservative-free paints are available, their shelf life and color selection are limited.

It is also important to point out that water-based products may have low VOCs but contain other hazardous materials. Unlike organic solvent-based paints, water-based paints require preservatives and fungicides, such as arsenic disulfide, phenol, copper, and formaldehyde. These additives are considered chemical hazards by the National Institute for Occupational Safety and Health.

The USGBC LEED and Green Globes building assessment standards provide credit for the use of low-emission paints and coatings if their VOC emissions do not exceed the VOC and chemical component limits of Green Seal's GS-11 requirements. This standard specifies VOC limits of 150 grams per liter for nonflat interior paints and 50 grams per liter for flat interior paints.[5] There is growing interest in the use of paints with recycled content, and Green Seal issued GS-43, *Environmental Standard for Recycled Content Latex Paint*, in 2006, setting VOC limits of 250 grams per liter. Although having the environmental attribute of recycled content, paints just meeting this standard would not qualify as low-emission paints under GS-11.[6]

Particleboard and Plywood

Adhesives containing UF are an integral part of the composition of particleboard and plywood. These materials emit the UF after they have been manufactured and installed in construction. The rate of emission of UF is affected by the temperature and humidity of the installation location.

PARTICLEBOARD

Particleboard is a composite material made from wood chips or residues, bonded together with adhesives under heat and pressure. Particleboard is relatively inexpensive and is available in sheets that measure 4 by 8 feet (1.2 × 2 m). The major IAQ concern with particleboard is the off-gassing of formaldehyde. Most particleboard (about 98 percent) contains UF. The remaining 2 percent contains phenol formaldehyde (PF). Particleboard containing PF emits far less formaldehyde than board made with UF. PF is used in particleboard where a high-moisture environment is anticipated, specifically restrooms and kitchens.

The most common construction application of particleboard is as a core material for doors, cabinets, and a wide variety of furnishings, such as tables and prefabricated wall systems. Particleboard also is used in wood-framed housing, primarily for nonstructural floor underlayment. Usually, a finished floor is installed over particleboard. Particleboard also is used as a backing for paneling. Once the board is covered, the VOC content is inconsequential because the formaldehyde emissions are delayed for as long as the board remains covered.

Although particleboard can be manufactured with lower formaldehyde emissions, it is still of great concern because of the possibility of large exposed surface areas in relation to the volume of a given space. Emissions of trace amounts of formaldehyde can continue for several months or even years. These emissions do decrease over time, but rates increase as temperature and/or humidity rises. It is estimated that emission rates double with every increase of 12°F (7°C).

Plywood

Plywood is composed of several thin wood layers oriented at alternating 90° angles that are permanently bonded by an adhesive. The exterior plies are referred to as *faces*, and the interior plies are known as the *core*. Plywood generally is classified as hardwood or softwood. Approximately 80 percent of all softwood plywood is

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used as wall and roof sheathing, siding, concrete framework, roof decking, and subflooring. Hardwood plywood is used for building furniture, cabinets, shelving, and interior paneling.

The type of adhesive used to bond the plies plays a major role in assessing the effects of the plywood on IAQ. The surface area of the plywood in relation to the volume of the space is another determining factor for proper IAQ. Interior- grade plywood is generally bonded with UF resins. The off-gassing of UF in plywood can be compounded by finishes or sealants used in conjunction with the plywood. Size, temperature, humidity of the space, surface area, and finish of the plywood all can affect the concentration of formaldehyde emissions.

FLOOR AND WALL COVERINGS

Carpet, resilient flooring, and wall coverings may have VOC-emitting components and may use adhesives that emit VOCs as part of their installation process. New products with zero or low emissions are entering the marketplace to serve the green building industry. As competition and demand increase, the quality of the products also will improve; at the same time, prices will decrease, making these new products very competitive with conventional products.

Carpet

Of all building materials, carpet has generated the most debate, which is ironic considering that emissions from carpet systems are relatively low compared with emissions from other building materials. The majority of the emissions associated with carpeting actually are due to the adhesives used to secure it. Thus, when selecting a carpet, the entire system and the emissions of each constituent must be evaluated. The components of a carpet system are the carpet fiber, carpet backing, adhesive, and carpet pad (generally used in residential applications only).

Carpet backing is used to hold the fibers in place. Often two backings are used: one keeps the fibers in place, and the other adds strength and stability. The secondary backing is made from fabric, jute, or polypropylene bonded with either styrene-butadiene rubber (SBR) latex or a polymer coating, such as synthetic latex. SBR latex contains the chemicals styrene and butadiene, which are known irritants to mucous membranes and skin. SBR latex adhesives are found in primary and secondary backings and emit low but steady amounts of the by-product 4-phenylcyclohexene, the chemical that is responsible for the "new carpet" smell and is suspected of being a possible source of building occupant illness complaints.

Adhesives may be used twice in common carpet systems: to glue the backing to the fiber and/or to glue the carpet system to the substrate.

Carpet pads are an optional part of the carpet system. They generally do not contribute to IAQ problems. There are five basic types of pads: bonded urethane, prime polyurethane, sponge rubber, synthetic fiber, and rubberized jute.

There are five basic carpet fiber materials. Wool is the only natural fiber, and it accounts for less than 1 percent of the carpet market. The remaining four—nylon, olefin, polyester, and polyethylene terephthalate—are synthetic fibers. Derived from petrochemicals, synthetic fibers are stronger, more durable, and usually less expensive than wool; they are also less likely than wool to release small fibers into the air.

Both the USGBC LEED-NC and Green Globes building assessment standards provide credit for using low-emission carpeting systems if the system meets or exceeds the requirements of the Carpet and Rug Institute's Green Label Plus program.[7]

Resilient Flooring

Resilient flooring is a pliable or flexible flooring. Tile and sheet are the two basic forms, both of which are attached to a substrate using adhesives. Resilient flooring

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can be composed of vinyl, rubber, or linoleum. Vinyl flooring is made primarily of PVC resins, with plasticizers, to provide flexibility; fillers; and pigments for color. Rubber flooring comes in two basic forms—smooth-surface or molded—and is made from a combination of synthetic rubber (styrene butadiene), nonfading organic pigments, extenders, oil plasticizers, and mineral fillers. Linoleum is a natural, organic, and biodegradable product. Its main components are linseed oil, pine rosin, wood flour, cork powder, pigments, driers, and natural mildew inhibitors. Linoleum tiles are durable, greaseproof, and water- and fire-resistant. They also are easily maintained and long-lasting.

Typically, no individual compound in resilient flooring has high VOC emissions. The plasticizers are the main source of emissions. Using a more rigid, less plastic tile is recommended to avoid potential hazards. Note, however, that low-emitting tiles may be glued with high-emitting adhesives.

Wall Coverings

Wall coverings are a popular alternative to paints. The majority of available coverings pose little or no threat to IAQ. The three basic types of wall coverings are paper, fabric, and vinyl. Paper itself has no impact on IAQ, but the adhesives used to apply it may contain formaldehyde. However, the majority of paper adhesives are purchased as a powder and mixed with water; thus, they emit little or no VOCs.

Fabric wall coverings may contain formaldehyde, which sometimes is used to keep the material from fading and to improve resistance to water. Fabric coverings also can act as a sink by absorbing extraneous VOCs in a building and reemitting them into a space. Two major concerns with vinyl wall coverings are the environmental conditions of the project location and the construction of the walls receiving the finish. In temperate climates, when moisture may not be readily evaporated, vinyl-covered walls can become moldy.

INSULATION AND CEILING TILES

Insulation and acoustical ceiling tiles can contribute VOC and particulate contaminants from a variety of sources. Depending on their composition, these materials may incorporate a variety of adhesives and fibrous materials that can combine to complicate the IAQ issue.

Insulation

Most insulation is made of fiberglass, mineral wool, and cellulose (made from recycled wood). Asbestos was also used frequently until the late 1970s. Fiberglass and mineral wool have raised IAQ concerns because of the small fibers that are produced when the material is disturbed. Fiberglass is listed by the International Agency for Research on Cancer as a possible carcinogen. Cellulose insulation is generally spray-applied and is considered a nontoxic material. In this materials category, foam insulation has received most of the attention because of its impacts on the environment rather than on IAQ. That said, VOCs are emitted from synthetic foam during manufacturing or while spray foam is used.

Acoustical Ceiling Tile

The suspended acoustical ceiling is one of the most common structures found in commercial buildings today. Most acoustical ceiling tile is made from mineral or wood fibers, which are wetted and compressed to the desired thickness, size, and pattern. The tiles usually are coated with a latex paint at the factory. The primary concern regarding the effects of acoustical ceiling tile on IAQ is the occurrence of microbial growth on either mineral fiber or fiberglass tile exposed to moisture. Another concern is that porous tiles can absorb VOCs and then reemit them.

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Economic Benefits of Good IEQ

The key emerging economic benefits of high-performance green buildings appear to be their health and productivity benefits, with paybacks that may be as much as 10 times higher than their energy savings. More and more hard evidence of the effects of good IAQ is emerging, supporting design and construction efforts that provide excellent building air quality. More recently, the range of health problems connected to buildings has shifted from air quality alone to include a far wider range of human health effects associated with lighting quality, noise, temperature, humidity, odors, and vibration. This broader range of impacts is referred to as IEQ and includes the subject of IAQ.

The impact of buildings on human health is substantial and results from a combination of building design, construction practices, and the activities of the occupants. A study by Fisk and Rosenfeld in 1998, updated in 2002, placed the annual cost of IAQ problems at $100 billion. Table 13.13, which is adapted from the 2002 study, shows estimated productivity gains from improvements made to indoor environments. In the United States, people spend about 90 percent of their time indoors—in their homes, workplaces, schools, shopping malls, fitness centers, or numerous other types of structures. Air quality in some of these buildings often is cited as being far worse than that of the outside air. This poor air quality can be attributed to a number of factors: tight buildings, materials that off-gas pollutants into the indoor environment, poor ventilation, and poor moisture control, to name a few. In addition, poor construction practices can contribute to significant IEQ problems. For example, ductwork that has been stored and handled without being covered and sealed can be contaminated with particulates that are blown into occupied spaces during building operation, potentially affecting the health of the people in the building.

The high-performance green building movement has been highly successful in integrating indoor environmental issues into the criteria for green buildings, in essence taking ownership of IEQ when it comes to new buildings, so it is now expected that a high-performance green building will have excellent IEQ. In particular, the USGBC's LEED suite of standards addresses IEQ and provides points for incorporating at least some of the major IEQ components, generally those concerned with air quality and individual control of temperature and humidity. Green Globes, an emerging competitor to LEED, addresses the same issues as LEED but also includes other important IEQ matters, such as acoustic comfort for building occupants and neighbors. Green Globes addresses noise from air-conditioning systems, plumbing, preventing noise generated in the building from affecting neighbors, protecting building occupants from outside noise, and noise attenuation for the structural system.

The actual savings attributed to a high-quality interior building environment are substantial and are thought to be greater than even the energy savings. A study by

TABLE 13.13

Estimated Potential Productivity Gains from Improvements Made to Indoor Environments

Source of Productivity Gain	Strength of Evidence	US Annual Savings or Productivity Gain
Respiratory disease	Strong	$6–$14 billion
Allergies and asthma	Moderate to strong	$1–$4 billion
Sick building syndrome	Moderate to strong	$10–$100 billion
Worker performance	Moderate to strong	$20–$200 billion
Total range		$37–$318 billion

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Greg Kats (2003) of Capital E indicated 20-year life health and productivity savings of $36.89 per square foot for LEED-certified silver buildings and $55.33 per square foot for LEED-certified gold and platinum buildings. The productivity and health benefits of high-performance green buildings, a result of designing a high-quality indoor environment, dominate the discussion of benefits. For gold and platinum buildings, the claim is that the health and productivity benefits are almost 10 times greater than the energy savings, which amount to $5.79 per square foot. These results are not only impressive but startling. However, the basis for these claims is rarely scientific; these results should be used in life-cycle costing or in economic analyses only with extreme caution to avoid compromising the justification of an otherwise sound approach.

Health, Well-Being, and Productivity

One of the major attributes of high-performance, green buildings is that they directly address the negative effects of the built environment on human health. Prior to the onset of the green building movement, there was frequent negative press regarding SBS, BRIs, and a range of other health problems associated with building design and construction. Although health is an important issue for all types of buildings, it is particularly true for office buildings, where the well-being and productivity of the workforce affect the fortunes of the organization that owns or leases the space. For a typical business, energy expenses represent about 1 percent of total operating costs, rent costs 9 percent, and the remaining 90 percent are staff costs in salaries and benefits (see Figure 13.12). As a result, a modest increase in the productivity of an organization's workforce can benefit the bottom line significantly. Green building can contribute to reducing both absenteeism and ill health. Studies consistently show that well-being and productivity are strongly affected by the design of office spaces. The health factors that must be included in the design of workplaces include: IAQ, comfort, lighting and daylighting, biophilia, noise, and interior space layout. Additional factors include the availability of amenities and services, active design (the provision of opportunities to exercise within the workday, either on the building

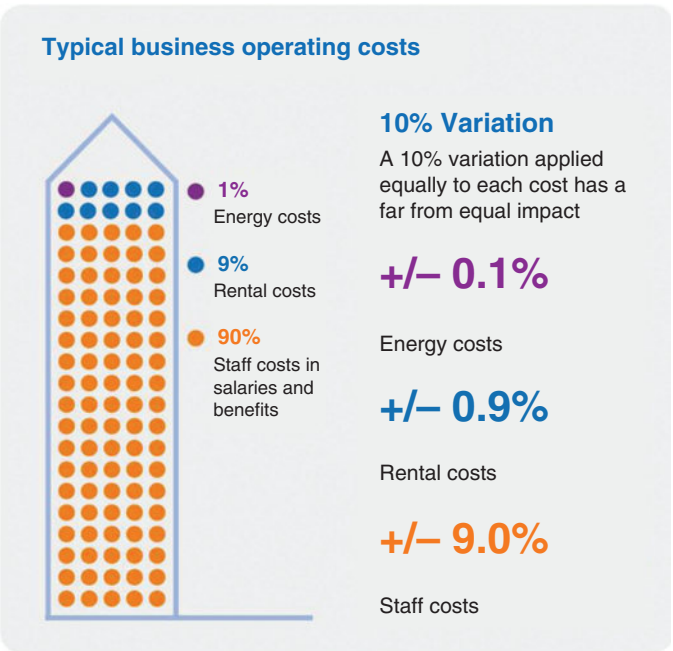


Figure 13.12 Health and productivity are especially important in commercial and institutional office settings because a modest improvement in these factors can have an enormous impact on the bottom line of the organization. In this graphic, a 10 percent improvement in energy performance produces a 0.1 percent impact on costs while the same improvement in human performance produces a 9 percent improvement in personnel costs, which remarkably is about the same as the rental cost of the space. (*Source:* World Green Building Council (2015))

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grounds or in the vicinity), and the look and feel of the space. Several productivity factors are also important to consider in high-performance building design. These include putting users in control of their indoor environments, maximizing daylighting, and passive design, which provides fresh air and good thermal comfort. Table 13.14 lists the wide range of factors that should be considered in designing office spaces with a focus on health, wellness, and productivity. The evidence of how well this approach works can be measured. The indicators of how well the design has performed are shown in Table 13.15. Also shown are the outcomes that affect the financial fortune of the organization and how impacts on productivity and be determined

TABLE 13.14

The Physical Environment and its Factors

Indoor Air Quality
- Pollutants including VOCs
- CO_2
- Aroma
- Ventilation rate or fresh air
- Moisture content

Thermal Comfort
- Indoor air temperature
- Mean radiant temperature
- Air velocity
- Relative humidity
- Clothing
- Activity

Lighting and Daylighting
- Quantity
- Quality
- Glare
- Daylight
- Task type

Noise and Acoustics
- Background noise
- Privacy and interference
- Vibration

Interior Layout and Active Design
- Workstation density
- Task-based spaces and ergonomics
- Breakout spaces and social features
- Active design

Biophilia and Views
- Connections to nature
- Views outside

Look and Feel
- Design character and brand ethos, including color, shape, texture, and art
- Cultural-, gender-, and age-sensitive design

Location and Access to Amenities
- Access to amenities
- Transport
- Quality of public realm

Source: World Green Building Council

TABLE 13.15

Occupant Outcomes Resulting from Designing with a Focus on Health, Well-Being, and Productivity

Occupant Health Outcomes

The positive benefits of a high-quality indoor environment can be measured by reductions in:
- headaches
- eyestrain/damage
- skin irritations
- infections
- fatigue
- Seasonal Affective Disorder
- asthma & breeding disorders
- stress & depression
- other physical complaints
- other serious disorders

Occupant Well-Being and Perception Outcomes

Health is an important element of well-being, but an occupant's sense of well-being is also affected by their perceptions:
- Perceived physical health
- Perceived psychological health
- Perceived productivity
- Perceived office environment
- Perceived organizational culture

Organizational or Financial Outcomes

The office environment can have a direct impact on optimum productivity, which is affected by employee health and well-being. Productivity can be measured by reductions in:
- Absenteeism
- Presenteeism
- Staff turnover/retention
- Revenue
- Medical costs
- Medical complaints
- Physical complaints
- Task efficiency and deadlines met

Source: World Green Building Council

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Figure 13.13 The WELL Scorecard for a gold-level certification showing the scores for each of the seven Concepts in the left column. (*Source:* Well Building Standard)

THE WELL BUILDING STANDARD

The emphasis of the green building community on human health and well-being resulted in the development of a LEED-like standard that focuses solely on health and wellness. The WELL Building Standard (Figure 13.13) focuses on the people in the building and uses evidence-based medical and scientific research as its foundation. This standard is used to measure, certify, and monitor the many features of the built environment that impact human health and well-being. At present, WELL Building Standard version 1 is being piloted in about 8 million ft² of buildings (Well Building Standard 2015). Appendix D shows the Well Building Standard Features Matrix for the three general classes of projects covered by the standard: New Construction, Core and Shell, and Tenant

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Improvement. It is a comprehensive system covering 71 features that affect health and well-being, grouped into seven Concepts: air, water, nourishment, light, fitness, comfort, and mind. Some of the features in the Concepts are considered to be preconditions (i.e., they are mandatory)—for example, meeting air quality standards, banning smoking, and reducing VOCs. Other features, such as humidity control, operable windows, and displacement ventilation, are referred to as optimizations (i.e., they are not mandatory but contribute to the certification of the project). The various strategies are accumulated into a Wellness Score from 0 to 10 for each Concept, with certification requiring a score of at least 5 for all Concepts. Certification levels are silver, gold, and platinum. The International Well Building Institute administers the WELL Building Standard and collaborates with the Green Building Certification Institute, which is the certification body for the LEED building assessment system. To maintain its certification, a building must be recertified a minimum of every three years.

Summary and Conclusions

IEQ is perhaps the most important human-related issue of green building, as it directly affects the health of the building occupants. Although IEQ covers a wide range of effects, LEED focuses on IAQ, with far less emphasis on noise and lighting quality. Green Globes does address a wider range of IEQ issues, such as acoustic comfort and lighting quality, which is a definite step forward in the evolution of green building rating tools. As a consequence of relatively recent efforts to address building health, a number of new products have emerged, among them paints, carpets, adhesives, furniture, and wood products for millwork and cabinetry, which have zero or low emissions. Furthermore, greater attention is being paid to the proper sizing of HVAC equipment and control of humidity in spaces. The important issue of moisture infiltration and the consequent problems caused by mold and mildew growth also are being addressed by appropriate architectural detailing and the proper design of the building's air distribution system. Daylighting is receiving increased emphasis because of its demonstrated health benefits and its contribution to reductions in energy consumption. Providing exterior views to the building occupants to enhance their well-being is also a component of IEQ, which both the LEED and Green Globes rating systems acknowledge by allocating points for providing exceptional views. Future versions of these building assessment systems should consider increasing the importance of quiet, relatively noise-free building systems as an aspect of an important health issue. And to cover the full array of IEQ issues, lighting quality should receive additional focus and consideration.

Notes

1. These are estimated productivity losses quoted by Mary Beth Smuts, a toxicologist with the US EPA, in Zabarsky (2002).
2. The latest version of Section 01350 can be found on the CalRecycle website: www.calrecycle.ca.gov/greenbuilding/specs/section01350/Block225Spec.pdf.
3. The latest version of Rule 1168 can be found at: www.arb.ca.gov/DRDB/SC/CURHTML/R1168.PDF.
4. The Green Seal GS-11 Standard can be found at the Green Seal website: www.greenseal.org/Portals/0/Documents/Standards/GS-11/GS-11_Paints_and_Coatings_Standard.pdf
5. The Green Seal Environmental Standard for Recycled Content Latex Paint (July 2013) can be found at www.greenseal.org/Portals/0/Documents/Standards/GS-43/GS-43_Ed1-1_Recycled_Content_Latex_Paint.pdf.
6. More information about the Green Label Carpet Testing Program can be found at www.carpet-rug.org/Documents/Factsheets/GLP-Fact-Sheet.pdf.

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Part IV

Green Building Implementation

Part III provided an overview of the major systems of a green high-performance building: land and landscape, energy, water, materials, and indoor environmental quality. Proper design of these systems is the starting point for green building. But without careful execution of the construction phase of the project and thorough commissioning of the finished building, a green building project is incomplete. Part IV of this book addresses these two important aspects of a project and how they fit into the overall green building process. In addition, this part covers the economics of green building and offers an overview of the possible life justifications for green buildings, including energy savings, water and wastewater savings, the benefits of commissioning, operations and maintenance savings, and other approaches to addressing the economics of green buildings. This part concludes with an overview of the future of green building and the variety of directions in which this movement may evolve. It includes these chapters:

Chapter 14: Construction Operations and Commissioning

Chapter 15: Green Building Economics

Chapter 16: The Cutting Edge of Sustainable Construction

Chapter 14 elaborates on major aspects of green building that are not covered separately in Leadership in Energy and Environmental Design (LEED) or Green Globes but that warrant additional consideration. The construction managers or general contractors who actually execute the design must be clearly aware of their responsibilities. Therefore, the importance of developing a site protection plan, a health and safety plan, and a construction and demolition waste management plan is addressed in Chapter 14. Each plan is an extension, or elaboration, of current building assessment system requirements. The site protection plan includes the erosion and sedimentation control plan requirements found in the Sustainable Sites category of LEED and the Site category of Green Globes as well as other measures designed to protect the biological and physical integrity of the site. The health and safety plan elaborates on issues during the construction phase and indoor air quality requirements, and includes additional measures designed to protect the workforce and the building's future occupants. The construction and demolition waste management plan is addressed in the Materials and Resources category of LEED, which was described in Chapter 5. Building commissioning, which has emerged as a key

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step in the third-party certification of high-performance buildings, is also thoroughly explored in Chapter 14. The building commissioning process continues to evolve, from its original role of testing and balancing heating, ventilation, and air conditioning systems to a more complete check of all building systems, including, for example, building finishes, ensuring that the owner receives the exact building called for in the design. Commissioning is becoming a service that occurs throughout the entire project, from the onset of design, rather than only at the completion of construction. Initial economic analyses of high-performance green buildings indicate that the savings due to building commissioning are truly staggering, even outstripping the financial benefits of energy savings. This is a remarkable outcome, and if future analyses were to confirm this result, these findings would transform a number of fundamental assumptions about buildings. For example, if the savings from commissioning were so marked at the onset of building operation, ongoing commissioning would also have notable benefits.

Economic analysis of green buildings is addressed in Chapter 15. Life-cycle costing is the key tool for justifying the decisions to create a high-performance building. Initial studies indicated that the added costs for a LEED for New Construction project new building were about 2 percent for a silver or gold certification and that total 20-year savings, using conservative financial assumptions, are on the order of $50 to almost $70 per square foot ($500–$700 per square meter [$m^2$]) for an initial additional investment of about $4 per square foot ($40/m^2) for a $140-per-square-foot ($1,400/ m^2) base building construction cost. Some studies report a one-year simple payback for a green building when all savings are included—energy, water, emissions, and health/productivity benefits.

The future of green building is covered in Chapter 16, the final chapter of this book. LEED, as might be expected, pushes green building in a given direction because the point system for achieving the various levels of certification, although generally performance based, tends to result in a fairly limited range of outcomes. At present, only a few attempts are being made to define the "ultimate" green buildings—those that will emerge in 20 years or more. The Living Building Challenge described in Chapter 4 is perhaps pushing the envelope the farthest of any of the building assessment systems. This chapter attempts to remedy this oversight. To that end, three potential future strategies are described: one based on technology, a second on vernacular architecture, and a third on biomimetic models. No one of these strategies is likely to provide the long-range solution; instead, most likely, a synthesis of the key ideas in these three strategies will be the outcome. Future versions of LEED, Green Globes, and other building assessment systems ideally will pave the way for green building and raise the bar for everyone engaged in this movement, from owners to materials suppliers, designers, and builders.

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Chapter 14

Construction Operations and Commissioning

The role of the construction team in executing a green building project and making it a reality is extremely important and should not be underestimated. A general contractor or construction management company (GC/CM) that orients its employees and its subcontractors to the purposes of the project can make an enormous difference in the overall outcome. Several types of construction activities are specifically identified in the Leadership in Energy and Environmental Design (LEED) and Green Globes building assessment systems as potentially providing credit for certification, including construction waste management, erosion and sedimentation control, limiting the footprint of construction operations, and construction indoor air quality (IAQ). In addition to these aspects of the high-performance green building project, the construction team may make other contributions that are not specifically covered by building assessment systems. Examples include improving materials handling and storage; reusing site materials, such as topsoil, lime rock, asphalt, and concrete; metering site electrical and water usage; and reducing pollution generation activities. It is important for the GC/CM to administer construction operations in a fashion that clearly communicates the unique aspects and requirements of high-performance green buildings to all the subcontractors and suppliers involved. This chapter focuses on identifying how construction operations for high-performance green buildings may differ from conventional construction practices. Specific areas of focus in this chapter are site protection planning, materials handling and installation, construction and demolition waste management, managing IAQ during construction, and building commissioning.

Site Protection Planning

A *site protection plan* is used to ensure that disturbances to the site ecology and soils are minimized during construction operations. The GC/CM must understand the potential impacts that can result from construction activities in order to establish and implement a site protection plan effectively. Currently, neither LEED nor Green Globes has specific requirements for the components of a site protection plan; however, many construction activities clearly have the potential to impact site ecology and soils negatively. Addressing these activities in the site protection plan will enhance the high-performance green building project by involving contractors and subcontractors in the process. A site protection plan includes erosion and sedimentation control, pollution control, reduced site disturbance, and on-site construction management operations. These topics are discussed in more detail next.

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EROSION AND SEDIMENTATION CONTROL

Erosion and sedimentation control measures are important for reducing soil loss and the pollution of nearby water bodies. Erosion and sedimentation are caused by soil particles from the site being carried by wind or water to other locations. The result may be clogged sewer drains, contaminated adjoining sites and water bodies, and possibly costly site rework and cleaning in order to restore the site and surrounding areas to the required condition. Projects located on a site larger than 1 acre must meet the National Pollutant Discharge Elimination System requirements of the US Environmental Protection Agency (EPA) by implementing a Stormwater Pollution Prevention Plan. Projects seeking LEED certification must establish and implement an erosion and sedimentation control plan. Erosion-prone areas are identified by design professionals and construction managers so that a plan can be designed that controls water flow in the event of precipitation. Silt fences, storm drain inlet protection, and sediment traps are temporary solutions that must be monitored continuously due to the potential damage from construction activity. If these types of control devices are implemented on a project, a log containing daily and weekly walk-through inspections is required, along with photos and corrective actions taken if the control devices have been damaged. Figure 14.1 is an example of a temporary sedimentation control device that prevents soil-carrying water from entering the stormwater system and clogging it. More permanent water control devices may include infiltration trenches, vegetated swales, and bioretention cells. Information on these devices can be found in Chapter 10. Grading can control not only the direction of water flow but also the velocity through strategies such as lengthened flow paths, reduced gradients, and sheet flow (National Center for Construction Education and Research [NCCER] 2011). Sheet flow is a strategy that causes water to flow at a low depth across a wide area to increase surface friction and minimize erosion. Seeding can also be used to help stabilize soil conditions and reduce water flow. Depending on the construction operations, seeding can be either a temporary or permanent means to control water flow.



Figure 14.1 Storm drain inlet protection implementation on a newly constructed site. This type of device must be monitored continuously during construction operations to ensure it is functioning properly. (Don Thieman, CPESC, ASP Enterprises)

POLLUTION PREVENTION

Controlling pollution is a daily responsibility of the GC/CM, and it is an activity that protects both workers and areas adjacent to the site. Pollution can be anything that is harmful, whether it is a substance or an effect introduced into the environment as a by-product of another activity. Noise, dust, air pollution, and light are a few types of pollution that can result from construction activities and that must be mitigated by corrective measures. Neither LEED nor Green Globes requires an overall construction pollution prevention plan; however, it is important to identify the short- and long-term effects of construction activities and the appropriate measures to reduce their impact. These measures can be either reactive, meaning that the construction activity assumes that pollution problems are going to happen, or proactive, whereby pollution problems are prevented entirely. Established approaches for reducing pollution at its source can virtually eliminate the problem for those directly and indirectly involved with the project. Table 14.1 lists generic pollution sources together with reactive and proactive measures for handling construction site pollution (NCCER 2011). These types of activities should be included in the site protection plan.

REDUCED SITE DISTURBANCE

The very act of constructing a building and the supporting infrastructure that supplies power, water, communications, sidewalks, and roads causes tremendous changes to the existing site. It is often said that "the greenest building is the one that has never been constructed." From an ecological system point of view, it is important to

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TABLE 14.1

Examples of Reactive and Proactive Measures for Handling Construction Site Pollution

Pollutant	Source(s)	Reactive (Mitigation) Measures	Proactive (Prevention) Measures
Light	Night operations Welding or cutting operations	Shielding or redirecting light fixtures to focus only on work site	Revising construction schedules to avoid night operations
	Temporary lights left on at night	Turning off temporary lights at end of workday	Using smaller lights focused directly on task areas
Noise and vibration	Equipment operation	Arranging work shifts to allow worker breaks Perimeter fencing for noise barrier	Revising construction schedule to avoid operations during sensitive times
		Personal protective equipment (PPE) for workers	Choosing equipment with lower noise production
Dust and airborne particles	Equipment operation Wind erosion of exposed soils	PPE for workers Surface treatment of exposed soils with water or dust suppression chemicals	Limiting site disturbance Covering exposed soil with temporary or permanent seeding Leaving existing vegetation intact
Airborne chemical emissions	Volatile organic compounds (VOCs) from the off-gassing of new synthetic materials	Increasing ventilation rates during product installation PPE for workers	Using low- or no-VOC products Designing for exposed surfaces Using prefinished materials
Soil and groundwater pollution	Engine drippings Refueling Accidental spills Improper disposal	Spill cleanup plans/equipment Providing contained storage for chemicals and hazardous materials Spill countermeasures such as berms, absorbent mats, and barriers	Centralized refueling Spill prevention training for employees Proper equipment maintenance Using nonhazardous materials where possible
Surface water pollution (heat and contaminants)	Engine drippings Accidental spills Exposed soil without erosion control measures	Spill countermeasures Perimeter silt fences Spill cleanup plans/equipment Providing contained storage stormwater detention basins	Proper equipment maintenance Pervious or high-albedo surfaces Seeding exposed soil Limiting construction disturbance Infiltration basins
Tracked soil on neighboring streets	Vehicle wheels	Vehicle wash stations	Limiting construction disturbance Off-site materials staging Just-in-time delivery

preserve as much of the site's existing biological systems and ecological functions as possible. The GC/CM must manage procedures for reducing the physical footprint of the construction process . One way to approach constructing in an environmentally friendly manner is to first determine whether there are any endangered or threatened species located on or near the project site. By definition, an *endangered species* is an animal or plant listed by regulation as being in danger of extinction. A *threatened species* is any animal or plant that is likely to become endangered within the foreseeable future. Determining if endangered or threatened species exist on or near the site can be accomplished by contacting the local US Fish and Wildlife Service, the

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National Marine Fisheries Service, state agencies, or tribal heritage centers or by researching online for information on locations of endangered or threatened species. If there is a possibility that an endangered or threatened species is located in the area, it is important to conduct visual inspections, formal biological surveys, and an environmental assessment as required by the National Environmental Policy Act. These contacts and research will indicate whether there may be a potential problem and if the Endangered Species Act Requirements for Construction Activities should be implemented. Although this process may seem like a difficult task, addressing this before construction begins will prevent potential delays in the project.

There are many possibilities for reducing site disturbance during construction. Examples include reducing the number of on-site parking spaces, specifying additional areas to be kept traffic-free, staging equipment and materials off-site, allowing only one accessible lane of traffic around the perimeter of the project, and having an active and aggressive pollution control policy. Adequate fencing and signage must be used to communicate construction goals clearly and avoid damage from construction equipment and activities. The establishment of contractual penalties can be used to minimize site disturbance, prevent damage to trees, and protect ecological systems.

Identifying responsibilities and clearly communicating site-specific requirements to the entire team will greatly improve efforts to minimize site disturbance. Preserving habitat biodiversity is important, especially for greenfield sites. Reducing site disturbance also makes it easier to restore the site when the project is complete.

CONDUCTING ENVIRONMENTALLY FRIENDLY CONSTRUCTION OPERATIONS

There are numerous opportunities to enhance the conduct of construction operations from an environmental standpoint. For instance, a recycling facility for paper, commingled plastics, and other types of recyclable waste can be made available to the workforce. Additionally, containers can be made available for the collection of rechargeable batteries, compostable food waste, or other types of waste. The GC/CM can further reduce waste by sourcing reclaimed materials, such as office furniture, cabinets, and tables for the construction trailer. Paper waste can be reduced through the use of a printer that is defaulted to double-sided printing. Strategies that avoid direct material ownership by the GC/CM, such as renting temporary construction barriers and fencing, foster preservation and reuse of the materials used to facilitate the construction process. Identifying sources of material waste and implementing procedures that redirect those materials from entering landfills will reduce tipping fees.

Material efficiency is not the only practice that can be improved. Other opportunities include reducing the consumption of fuel and water and using energy-efficient equipment. Practices that increase efficiency and reduce waste should be included in the site protection plan so that they can be communicated clearly and enforced. Some examples of these types of practices include these:

- Using conference calls and webinars to reduce transportation time and fuel costs for scheduled meetings. In situations where progress meetings are held on a regular basis, it may be advantageous to host the meeting at an appropriate location with strategically placed webcams to indicate the progress of construction operations.
- Incentivizing a carpool system to reduce site disturbance and fuel costs. This is particularly useful for subcontractors to reduce the number of vehicles brought to the site, reduce on-site congestion, and increase construction site flexibility.
- Using alternatively fueled vehicles for errands in order to reduce fuel costs.

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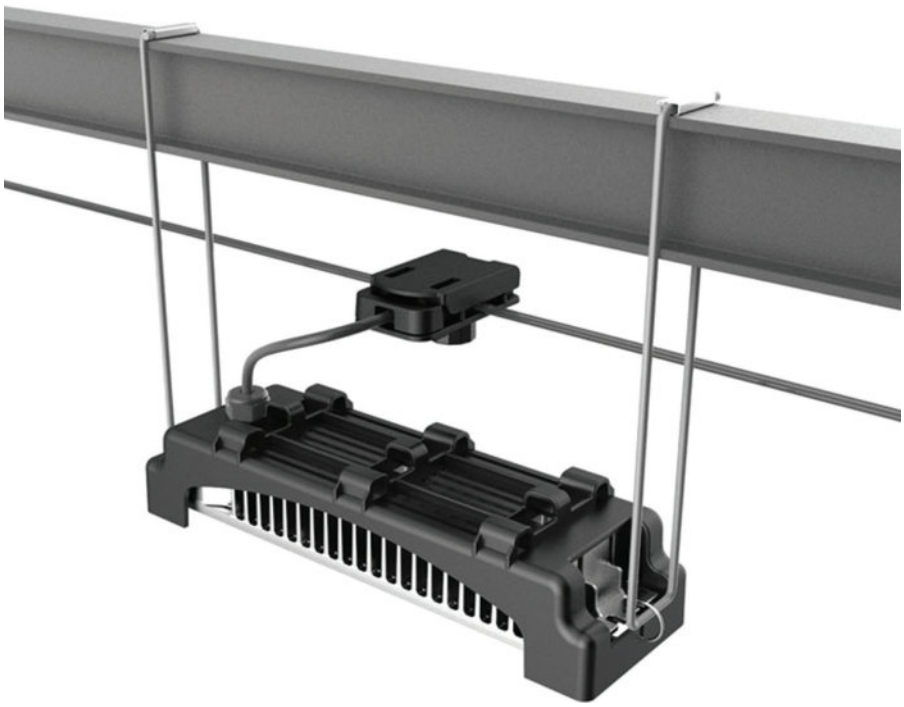


Figure 14.2 These modular, water-resistant LED fixtures from Clear-Vu Lighting mount on low-voltage wires powered by remote LED drivers and provide dramatic energy and labor savings on job sites. (Clear-Vu Lighting LLC)

- Monitoring energy and water consumption to help identify potential areas of excessive consumption. Identifying these problem areas will result in cost savings that will directly benefit the GC/CM by increasing profit margins. An example of improving energy efficiency is the use of light-emitting diode (LED) lighting technology, as shown in Figure 14.2. Depending on the amount of construction lighting used on a site, LEDs may be an option because of their ability to reduce energy consumption by more than 67 percent compared to conventional incandescent and metal halide fixtures.

By implementing and executing a site protection plan, the builder will ensure that the existing ecosystems are protected and that the workforce and neighbors have all been considered in the construction process. Additionally, a site protection plan is a public sign that the construction firms managing the project are fully committed to the concept of high-performance green building.

Managing Indoor Air Quality during Construction

Perhaps the most important actors in a building construction project are the subcontractors. It is generally true in today's construction industry that general contractors themselves are performing less of the work involved in the actual erection of the building. Instead, the general contractor or construction manager organizes and orchestrates a diverse group of subcontractors to erect the building. For a green building project to meet its objectives, the subcontractors must be made aware of how the building project differs from a conventional construction project. Green building projects demand the utmost attention to worker and future occupant safety and health. Chronic exposure to occupational hazards can cause serious long-term health

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TABLE 14.2

Steps for Managing IAQ during Construction

1. *Identify potential threats to IAQ.* This step typically is associated with the type of construction task required to complete the job. Identify the risks associated when installing specific products, materials, and systems, and evaluate the solutions in terms of cost and benefit for the overall project.
2. *Incorporate IAQ goals into the bid and construction documents.* These goals will help reduce risks that would conventionally be present.
3. *Ensure that all members of the project team are knowledgeable about IAQ issues.* Ensure they have defined responsibilities for implementation of good IAQ practices.
4. *Require the development and use of an IAQ management plan.* The purpose of the management plan is to prevent residual problems with IAQ in the completed building and to protect workers on the site from undue health risks during construction. The plan should identify specific measures to address:
   a. Problem substances, including construction dust, chemical fumes, off-gassing materials, and moisture. The plan will make sure that these problems are not introduced during construction or, if they must be, that they will be eliminated or their impact reduced.
   b. Areas of planning, including product substitutions and materials storage, safe installation, proper sequencing, regular monitoring, and safe, thorough cleanup.
5. *Conduct regular inspection and maintenance of IAQ measures.* These include ventilation system protection and ventilation rate.
6. ***Conduct safety meetings, develop signage, and establish subcontractor agreements that communicate the goals of the construction IAQ plan***. The IAQ construction plan is also a good place to proscribe behaviors unacceptable to the owner that represent a potentially negative impact on long-term IAQ, such as smoking, using chewing tobacco, or wearing contaminated work clothes.
7. *Require contractors to provide information on product substitutions.* This information should be sufficient to allow operations and maintenance staff to properly maintain and repair low-emitting or otherwise healthy materials in place.

Source: Adapted from "Maintaining Indoor Environmental Quality (IEQ) during Renovation and Construction" at the Centers for Disease Control website, www.cdc.gov/niosh/topics/indoorenv/ConstructionIEQ.html.

effects for the subcontractor workforce. These hazards include noise, dust, chemicals, and vibrations. Immediate job hazards, such as moving equipment, unstable earthwork, and working at heights, also can result in injury or death.

One significant area where the overall safety of the workforce can be improved is IAQ during construction. It is always good practice for the GC/CM to generate and implement a *construction IAQ management plan* for use both during construction activities and before occupancy. A construction IAQ management plan aids in communicating the specific plan to protect air quality and establishes the process for accomplishing this. Typical steps for developing and executing a good construction IAQ plan are shown in Table 14.2. Proper management of an IAQ plan also aids in earning credit toward green building certification under both LEED and Green Globes. Table 14.3 indicates the measures that builders can take to ensure good IAQ in the occupied building and which should be included in an IAQ plan.

In the development of the IAQ management plan, it is critical to include tangible measures to improve working conditions. The Sheet Metal and Air Conditioning Contractors' National Association (SMACNA) has produced several guidelines that can be used to assist the process of ensuring good air quality during and after construction. The SMACNA publication, *IAQ Guidelines for Occupied Buildings under Construction* (2007), provides a comprehensive approach to be applied during construction, demolition, or renovation of occupied spaces. Chapter 3 of this standard focuses on control measures and guidelines to be used during construction. These areas of concern include (1) heating, ventilation, and air conditioning (HVAC) system protection before and after installation, (2) source control, (3) pathway interruption, (4) housekeeping, and (5) scheduling.

HVAC PROTECTION

Careless installation of the HVAC system components during construction can pose a health hazard to both the construction workforce and the future occupants of the

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TABLE 14.3

Measures for Builders to Implement to Ensure Good IAQ for Building Occupants

- Keep building materials dry. Building materials, especially those like wood, porous insulation, paper, and fabric, should be kept dry to prevent the growth of mold and bacteria.
- Dry water-damaged materials quickly—within 24 hours. Due to the possibility of mold and bacteria growth, materials that are damp or wet for more than 72 hours may need to be discarded.
- Clean spills immediately. If solvents, cleaners, gasoline, or other odorous or potentially toxic liquids are spilled onto the floor, they should be cleaned up immediately.
- Seal unnecessary openings. Seal all unnecessary openings in walls, floors, and ceilings that separate conditioned space (heated or cooled) from unconditioned space.
- Ventilate when needed. Some construction activities can release large amounts of gases into a facility, and if the building is enclosed with walls, windows, and doors, outdoor air can no longer easily flow through the structure and remove the gases. During certain construction activities, temporary ventilation systems should be installed to remove the gases quickly.
- Provide supplemental ventilation. During installation of carpet, paints, furnishings, and other VOC-emitting products, provide supplemental (spot) ventilation for at least 72 hours after work is completed.
- Require VOC-safe masks for workers installing VOC-emitting products (interior and exterior).
- Reduce construction dust. Minimize the amount of dust in the air and on surfaces. Examples include the use of vacuum-assisted drywall sanding equipment and the use of vacuums instead of brooms to clean construction dust from floors.
- Use wet sanding for gypsum wallboard assemblies.
- Avoid use of combustion equipment indoors.

Source: "Construction IAQ Management" (2002).

facility. Dust, volatile organic compounds (VOCs), and emissions from equipment can infiltrate the building and be circulated by the air-handling units. It is therefore important to store and protect all HVAC equipment, including ductwork, air handlers, and other air movement components, from dust, moisture, and odors during construction. This protection is accomplished by requiring that the equipment be wrapped with protection film as it is delivered on-site, as shown in Figure 14.3A. Once installed, the HVAC system must be sealed, as shown in Figure 14.3B, to prevent the introduction of moisture and contaminants. For ventilation purposes, the HVAC system must have installed filters with a Minimum Efficiency Reporting Value (MERV) of 8 on either all return air registers or the negative-pressure side of the system. These filters must be replaced whenever dirty and once again before occupancy with filters with a MERV of 13.

CONTAMINATION SOURCE CONTROL

Improving IAQ can be accomplished by mitigating contamination levels at their source. One way to do this is to establish and monitor an IAQ baseline as described in the *EPA Protocol of Environmental Requirements, Baseline IAQ and Materials, for Research Triangle Park Campus*, Section 01445. Establishing and monitoring an IAQ baseline will help increase awareness of air quality during the project and help reduce airborne pollutant and emission discharges. For example, using low- or zero-emission materials wherever possible helps reduce exposure to toxic chemicals, such as VOCs. In situations where some level of formaldehyde or other VOC may be present, proper control measures such as space isolation and ventilation is essential. At a minimum, supplying workers with personal protective equipment (PPE) is an important consideration when needed. Workers may be tempted to avoid PPE if they believe projects pose no hazards. Proper training and work policies are essential to ensure that construction materials and products are installed safely. Dust collection systems for all equipment used for cutting or sanding should be utilized to protect both workers and building IAQ.

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Figure 14.3 (A) Ductwork should be protected during storage and prior to installation. (B) Openings should be sealed during the installation process to prevent contamination. (Photographs courtesy of DPR Construction, Inc.)

PATHWAY INTERRUPTION

In order to keep dust down, construction activities should be physically isolated from clean or occupied areas. This can be accomplished with temporary barriers, such as plastic sheeting, tape, and entrance control measures such as sticky mats, as shown in Figure 14.4. When used, temporary barriers must be inspected regularly to identify actual or potential leaks or tears that need to be repaired. Clean, completed areas must be positively pressurized, with the construction areas negatively pressurized and exhausted directly to the outside. The use of a high-efficiency vacuum to clean up construction dust frequently will reduce the spread of potential contaminants.

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HOUSEKEEPING

Proper maintenance and cleaning should be undertaken regularly on any construction project. Construction site cleaning consists of more than just picking up scrap materials or sweeping the floor. It also includes cleaning and storing porous materials that tend to absorb liquids and gases that are commonly present on a construction site. Porous materials include drywall, insulation, and ceiling tiles, to name a few. Materials that are porous act as a sink, absorbing contaminants, such as formaldehyde, during construction and slowly releasing them over time. Contaminant gases are absorbed from other materials that off-gas, such as furniture, adhesives, mastics, varnishes, paints, or carpeting, or as combustion by- products, fuel fumes, and particulates from engines, motors, compressors, or welders. If possible, porous materials should be staged in an area isolated from off-gassing materials and be checked routinely for excessive levels of moisture prior to installation. Porous materials can also affect IAQ if they become wet and moldy. In the event that these materials must be cleaned, it is best either to wipe them with a dry cloth or to use a high-efficiency vacuum system.



Figure 14.4 Sticky mats and walk-off mats are entrance control measures to help reduce contaminants entering into a clean area. (Photograph courtesy of D. Stephany)

SCHEDULING

Construction activities can be sequenced to minimize dust, mold, emissions, and debris that can contaminate previously installed materials. For example, "wet" construction procedures, such as painting and sealing, should occur before storing or installing "dry," porous materials. Additionally, increasing the outside air and ventilation exchange rates will decrease indoor air contamination levels. This process is known as a *building flush-out* and is conducted after construction has been completed. For LEED projects, the requirement is a building flush-out with a minimum of 14,000 cubic feet (ft^3) of outdoor air for every square foot of building floor area prior to occupancy. Air supplied to these internal spaces must be at least 60°F with no more than 60 percent relative humidity; otherwise, problems may occur, such as mold or damage to electrical equipment. A typical building flush-out requires about two weeks, depending on the HVAC capacity and indoor air conditions. In the event that occupancy is desired prior to completion of a flush-out, LEED requires a minimum of 3,500 $ft^3$of outdoor air for every square foot before occupancy. Once occupied, a minimum ventilation rate of 0.30 ft^3per minute per square foot is needed at least three hours prior to occupancy and must be continued during occupancy until the required 14,000 ft^3 of outdoor air is provided. The schedule should also include a reminder to replace all filtration media prior to occupancy.

Poor job-site construction practices can undermine even the best building design by allowing moisture and other contaminants to become potential long-term problems. Preventive job-site practices can preclude residual IAQ problems in the completed building and reduce undue health risks for workers.

Construction Materials Management

Effective materials management improves project sustainability, with the potential to reduce project costs. Working with vendors on product procurement and delivery practices can reduce solid waste. Appropriate storage helps prevent damage to products and also saves the cost of replacement and disposal of damaged products. Finding alternative uses for excess materials reduces disposal costs and also may offer benefits such as tax credits.

PRODUCT PROCUREMENT AND DELIVERY

Product procurement involves identifying and selecting a source for products. It also involves communicating product requirements and delivery expectations to

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that source. It is followed up with ensuring that the delivered products meet these requirements. Additionally, it involves working with the vendor or supplier to correct any problems. Procuring green products may require using different vendors and suppliers than is customary for a company. New relationships, accounts, and lines of communication may need to be established. The use of some products may include some risk due to unfamiliar product lead times as well as subcontractor training. Additional effort is needed to address these types of issues. Continual familiarity with the green products selected will reduce risk and improve the sustainability of a building.

An important part of green delivery is the means and methods of the transportation chosen to deliver the product to the site. Typically, construction materials are delivered by either flatbeds or dump trucks. Distance and delivery times and routes must all be analyzed to ensure that the materials arrive on time without excessive fuel consumption. Another consideration is the packaging that is used to transport and protect the product during delivery. Incorporating packaging that is harmless to the environment is desirable. Some manufacturers can supply their product with returnable or reusable packaging, resulting in less packaging materials being landfilled. For instance, delivery of small quantities of sand and aggregate can be arranged using returnable heavy-duty bulk bags that are removed from the delivery truck by crane, as shown in Figure 14.5. These bags allow multiple types of materials to be delivered at once. This approach has lower transportation impacts than bringing loose material in a truck bed. It also keeps these materials from being contaminated on-site or spreading to unwanted areas, thus minimizing cleanup activities. Shipping peanuts and sheet polystyrene can also be reused as long as a local shipping outlet accepts the material. Other types of packaging may be compostable or biodegradable. For instance, many types of plastic are being made from plant products, such as corn and soybean starches, and may be compostable. Other packaging materials, such as wood and corrugated cardboard, can be recycled. Pallets that are no longer usable can be chipped and used as mulch.



Figure 14.5 A crane moving bulk materials in large, reusable heavy-duty bulk bags from a truck for use in construction. (Photograph courtesy of Custom Packaging Products)

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PRODUCT STORAGE AND STAGING

Prior to installation, it is important to have adequate space for product storage and staging to ensure their protection. Several possible issues arise when materials are stored on-site. These can include damage due to environmental conditions, such as moisture or temperature changes, or damages due to material handling, such as crushing or puncturing. Other problems may occur from chemical spills or absorption of contaminants from the surrounding environment.

Protecting products from moisture is clearly important for materials that are water-absorptive. Examples include drywall, carpets, acoustic ceiling tiles, and insulation. Exposure to moisture results in mold growth, swelling, and damage to adhesives. Damage can be prevented by covering materials as well as stacking them loosely to allow for good air circulation (see Figure 14.6). Manufacturers provide materials storage and handling instructions that should be followed.

Another potential source of damage is exposure to ultraviolet (UV) radiation. Products containing plastics must be protected from UV exposure, or they may photodegrade. When exposed to UV radiation, rigid plastics become brittle, softer plastics become chalky and lose their integrity, and color-critical products may start to fade. It is important to shade or cover these materials to prevent damage. Table 14.4 outlines problems that may occur in storing materials and the measures that should be taken to reduce risk.

One way to minimize both the need to store material and the risk of damage to the product is *just-in-time delivery*. Just-in-time delivery is fairly common for projects involving large components for which on-site storage would be difficult (NCCER 2011). For these projects, considerable planning and coordination are required because the components are likely to be custom-fabricated. Just-in-time delivery can also be used when scheduling constraints are looser or for situations where materials are more readily available. Certain commodities, such as drywall, ceiling tiles, carpet, carpet pad, and insulation, are best delivered as close to the time of installation as possible.



Figure 14.6 Construction products and materials such as the gypsum board shown here should be kept dry, covered, and off the ground to prevent future mold and IAQ problems. (Photograph courtesy of DPR Construction, Inc.)

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TABLE 14.4

Potential Risks in Storing Materials and Mitigation Measures

Threats to Material Integrity	Mitigation Measures
Moisture: Exposure to precipitation Excess humidity Absorption from ground contact	Moisture-proof indoor product storage Placement to allow ventilation Preventing ground contact Adequate covering Active ventilation/heating
Photodegradation: Exposure to UV radiation	Indoor product storage Adequate covering Organized laydown yard
Material security	Indoor product storage Protected/locked storage
Temperature fluctuation	Indoor product storage Active ventilation/heating Indoor product storage
Physical damage: By equipment during handling By equipment while stored Improper orientation/support	Adequate support Following manufacturer stacking/protection recommendations
Contamination: Exposure to spills Exposure to dust Absorption of contaminants from surrounding materials	Adequate covering Active ventilation Sealed openings Clean before installation Separate storage of absorptive items from potential contaminants

Sources: Green Professional Skills Training 2011; NCCER 2008

Preventing damage is not the only action necessary for materials storage. Materials themselves may require attention prior to installation. For instance, materials containing synthetic components or adhesives may need to be unwrapped and allowed to off-gas before installation. Doing this prevents potential contamination of indoor air from fabrics, foam, composite wood, adhesives, and finish materials that may need to off-gas.

Construction and Demolition Waste Management

Construction and demolition (C&D) waste management takes advantage of opportunities for source reduction, materials reuse, and waste recycling. Source reduction is most relevant to new construction and large renovation projects, as it involves reduced waste factors in materials ordering, tighter contract language assigning waste management responsibilities to trade contractors, and value engineering of building design and components. During renovation and demolition, building components that still have functional value can be reemployed on the current project, stored for use on a future project, or sold on the ever-growing salvage market (see Figure 14.7). Recycling of building materials can be accomplished whenever sufficient quantities can be collected and markets are readily available. The difference in each opportunity must be understood in order to redirect materials from entering landfills. In doing that, the first step is identifying areas in which construction activities generate C&D waste.

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Figure 14.7 Example of proper waste separation to enhance the potential for materials reuse. (WasteCap Resource Solutions, Milwaukee, WI)

WASTE GENERATION AND OPTIONS FOR DIVERSION AND REUSE

According to the last EPA study on the subject, C&D waste totaled more than 135 million tons (122.5 million metric tons) in the United States in 1998, about 77 million tons (70 million metric tons) of which resulted from commercial work alone (Franklin Associates 1998). Based on a typical developed country C&D rate of about 0.5 ton (0.45 metric ton) per capita annually, the current total C&D waste generation in the United States is likely to be about 170 million tons (154 million metric tons). Per unit area waste generation ranges from about 4 pounds (19.5 kilograms per square meter) for new construction and renovation to about 155 pounds (757 kilograms per square meter) for building demolition. On many construction projects, recyclable materials, such as wood, concrete and masonry, metals, and drywall, make up as much as 75 percent of the total waste stream, presenting opportunities for significant waste diversion. As more C&D landfills reach capacity, new ones become increasingly difficult to site, and as more municipal waste landfills exclude C&D waste, tipping fees will continue to rise. Construction waste—and costs—can be managed just like any other part of the construction process, with positive environmental impacts on land and water resources. Many opportunities exist for reducing C&D waste. Construction managers are responsible for managing waste throughout the entire project. Handling such activities in a sustainable manner will further reduce the environmental impact of the building.

On-site fabrication of building components creates a large amount of construction scrap that is wasted. The likelihood of reusing scrap materials is much less on a job site than in either an off-site shop or a centralized facility where similar products are regularly made. The option of sourcing building components or modules from off-site also permits materials to be delivered when they are needed instead of being staged on-site where they pose an obstacle for construction work. Off-site prefabrication of building components or modules may include walls, kitchen equipment, stairways, ductwork assemblies, precast concrete, shelving and cabinetry, entire rooms that can be craned into place, and other specialized assemblies. If possible, materials should be ordered already cut to size to reduce construction time and on-site waste generation.

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Purchasing materials in bulk often avoids significant packaging waste as well as unit costs. Ideally, leftover materials should decrease if proper storage and staging have been executed; however, at times inefficient procurement results in excess products and materials on-site. Sustainable construction projects should prevent pollution by not ordering more material than necessary to complete the job. Careful attention to materials use can result in the ability to order materials for future projects more precisely. In some cases, manufacturers will buy back construction materials from a job site and restock them in their warehouses, as long as those excess materials are not customized for the project and have been protected from damage.

Proper coordination with the various subcontractors is important to identify the scope of work and proper materials handling, staging, and waste separation. Clearly communicating with subcontractors will help in preventing potential rework as well as physical damage to installed systems. Good communications are especially important when finishes are incorporated into the project and either have high exposure to foot traffic or are located in tight-fit areas. Rework not only generates waste but increases project cost and extends the completion schedule.

Renovation projects require the removal of existing materials before new construction can begin. This removal can occur through either demolition or deconstruction. Demolition is the complete destruction of an existing building, structure, or space, leaving a mixture of materials that is difficult to separate. Deconstruction is construction in reverse in which the building and its components are dismantled for the purpose of reusing them or enhancing recycling. Demolition is not necessarily more cost effective than deconstruction if valuable materials and components are recovered that more than offset the additional time needed for deconstruction. Before either deconstruction or demolition occurs, a materials audit should be conducted to create an inventory of materials that may have value and that should be salvaged. Windows, doors, and brick are examples of building components that may have value and that should be removed in a manner that preserves their integrity. The materials audit may benefit from the opinion of a building materials reuse provider. Reuse providers may be found locally around the United States and Canada through the Building Materials Reuse Association. In other cases, usable leftover materials can be donated to charities, such as Habitat for Humanity. Local universities, colleges, or trade schools may also be interested in using leftover materials as part of education and training.

If materials cannot be deconstructed readily, there still may be value in recycling the demolished materials. Recycling requires establishing areas on the construction site for scrap storage, cutting areas, recycling, and disposal. Doing this includes developing procedures for separating hazardous waste by-products of construction (e.g., paints, solvents, oils, and lubricants) and for disposing of these wastes in accordance with federal, state, and local regulations. Establishing this type of area not only improves the potential for diverting C&D materials from the landfill but also establishes a visible first impression of how green the project may be to those watching the construction process.

Another alternative is to process specific demolition debris and use it as on- site fill. A variety of materials can be used, including concrete, brick, concrete masonry units, and biodegradable and compostable materials. Concrete, brick, and concrete masonry units can be crushed and used as a subbase or for a drainage field for water management purposes.

Commissioning

One of the major contributions of the high-performance green building delivery system is to require building commissioning as a standard practice. This has come about because at least a basic level of commissioning is required for certification under

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the US Green Building Council (USGBC) LEED-New Construction building assessment system and is highly recommended by Green Globes. Building commissioning provides the owner with an unprecedented level of assurance that the building will function as designed, with resultant high reliability and reduced operating costs. The success of building commissioning has culminated in the formation of specialist building commissioning companies and in the development of building commissioning departments in engineering firms whose purpose is to service the green building market. Building commissioning services can be executed in two ways: (1) installation inspection and (2) performance testing. Installation inspection identifies how specified components are installed on-site before equipment start-up. The inspection uses a checklist to verify compliance with construction drawings, specifications, and manufacturers' requirements. Areas of nonconformity can be documented with photos and written descriptions to facilitate resolution. Figure 14.8 shows an example of a defect found by a commissioning authority (CxA) during an installation inspection. Performance testing, or functional testing, happens when all components of a system have been installed. The purpose is to verify that the system, as a whole, is operating properly under full- and partial-load conditions. Sequence-of-operation testing is used to imitate all expected modes of building operation, including start-up, shutdown, capacity modulation, and emergency operations. Alarms are checked to ensure they are functioning properly, and piping and electrical connections to other equipment are inspected for proper installation and function.

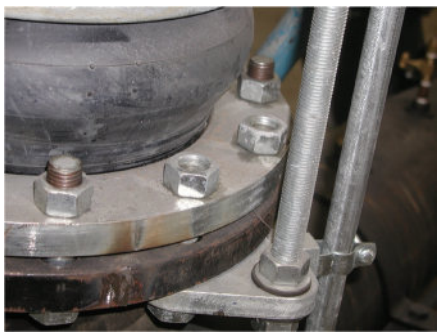


Figure 14.8 Commissioning installation inspection identified improper fastening of a pump flange. This equipment is exposed to significant vibration, which can loosen bolts that are not properly connected and torqued. (Photograph courtesy of John Chyz, Cross Creek Initiative, Inc.)

Studies of the effects of building commissioning indicate that it may reduce building operating costs by a larger margin than energy conservation measures. A report by Greg Kats (2003) of Capital E put the 20-year savings in operations and maintenance (O&M) due to building commissioning at $8.47 per square foot, compared with energy savings of $5.79 per square foot. Unquestionably, then, building commissioning is a powerful tool for ensuring that the design intent—to reduce resource consumption and environmental impacts—is carried out in the construction process. Building commissioning is, however, an additional service, meaning that it adds to the first, or construction, cost of the building project. Furthermore, and unfortunately, during the cost reduction exercises that are now common practice during design, these additional fees are subject to being cut, regardless of their benefits.

Two organizations heavily engaged in and committed to improving building commissioning are the Associated Air Balance Council (AABC) Commissioning Group (ACG) and the Building Commissioning Association (BCA) (see Figure 14.9). According to the BCA, "The basic purpose of building commissioning is to provide documented confirmation that building systems function in compliance with criteria set forth in the Project Documents to satisfy the owner's operational needs. Commissioning of existing systems may require the development of new functional criteria in order to address the owner's current systems performance requirements."[1] The ACG has established a commissioning guideline and a certification program for commissioning agencies. The process defined in the ACG commissioning guideline can apply to any building system, and the same steps of planning, organizing, systems verification, functional performance testing, and documenting the tasks of the commissioning process that apply to building mechanical systems can be applied to building electrical systems, control systems, telecommunications systems, and others.

(A)

(B)

Figure 14.9 Logos of the (A) AABC Commissioning Group and (B) the Building Commissioning Association. ((A) Logo courtesy of the AABC Commissioning Group. Reprinted with permission. (B) Courtesy of BCA)

ESSENTIALS OF BUILDING COMMISSIONING

Federal and state governments are increasingly requiring commissioning of their facilities; in fact, several government organizations also publish building commissioning guidelines. For example, the US General Services Administration's Public Buildings Service published *The Building Commissioning Guide* (2005), and the Federal Energy Management Program published *The Continuous Commissioning Guidebook for Federal Managers* (Liu, Claridge, and Turner, 2002). The first

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provides an overall framework and process for building commissioning from project planning through tenant occupancy, while the latter establishes building commissioning as an ongoing process for use in resolving operating problems in buildings. Another publication, *New Construction Commissioning Handbook for Facility Managers*, was prepared for the Oregon Office of Energy by Portland Energy Conservation, Inc. (2000), as part of a regional program involving four northwestern states. Its aim is to make building commissioning standard practice.

ESSENTIALS OF BUILDING COMMISSIONING

According to the BCA, the building commissioning process is controlled and coordinated by a CxA. The ten essential elements of building commissioning as carried out by the CxA are:

1. The CxA is in charge of commissioning process on behalf of the owner, is an advocate for the owner's interests, and makes recommendations to the owner about the performance of the commissioned systems.
2. The CxA must have adequate experience to perform the commissioning tasks and must have recent hands-on experience in building systems commissioning; building systems performance and interaction; operations and maintenance procedures; and building design and construction processes.
3. The scope of commissioning must be clearly defined in the commissioning contract and commissioning plan.
4. The roles and scope of all building team members in the commissioning process should be clearly defined in the design and engineering consultants' contracts; in the construction contract; in the General Conditions of the Specifications; in the divisions of the specifications covering work to be commissioned; and in the specifications for each system or component for which a supplier's support is required.
5. A commissioning plan must be produced to describe how the commissioning process will be carried out, and should identify the systems to be commissioned; the scope of the commissioning process; the roles and lines of communications for each team member; and the estimated commissioning schedule. The commissioning plan is a single document that reflects specified criteria identified from the contracts and contract documents.
6. For new construction, the CxA should review systems installation for commissioning issues throughout construction.
7. Commissioning activities and findings are documented exactly as they occur, distributed immediately, and included in the final report.
8. A functional testing program, composed of written, repeatable test procedures, is carried out, indicating expected and actual results. [The installation inspection program should be carried out in a similar manner.]
9. The CxA should provide constructive input for the resolution of system deficiencies.
10. A commissioning report is produced that evaluates the operating condition of each system; deficiencies that were discovered and measures taken to correct them; uncorrected operational deficiencies accepted by the owner; functional test procedures and results; documentation of all commissioning activities; and a description and estimated schedule for deferred testing.

MAXIMIZING THE VALUE OF BUILDING COMMISSIONING

As noted, building commissioning has tremendous potential for generating savings for the building owner. To ensure that the maximum value is obtained for building

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commissioning, the BCA recommends that the scope of building commissioning also includes these seven steps:

1. Prior to design, seek assistance in evaluating the owner's requirements, such as energy conservation, indoor environmental quality (IEQ), training, operations, and maintenance.
2. During each design phase, review construction documents for compliance with design criteria, commissioning requirements bidding issues, construction coordination and installation concerns, performance, and facilitation of operations and maintenance.
3. Review equipment submittals for compliance with commissioning issues.
4. Review and verify schedules and procedures for system start-up.
5. Ensure that training of operating staff is conducted in accordance with project documents.
6. Ensure that operations and maintenance manuals comply with contract documents.
7. Assist the owner in assessing system performance prior to expiration of the construction contract warranty.

HVAC SYSTEM COMMISSIONING

Today's process of building commissioning has its roots in the science of testing, adjusting, and balancing (TAB). For more than 40 years, the standards developed by the AABC have been used to verify that a building's HVAC systems are operating as designed. The TAB agency is an independent organization hired to check that air handlers, fans, pumps, dampers, energy recovery systems, hot water heating units, and other components are functioning properly; that the flow rates of hot and chilled water are as designed; and that airflows are properly adjusted so that the quantities of supply air, return air, and ventilation air in each space are also as designed. With the advent of the high-performance green building movement, AABC expanded its activities and nomenclature to cover building commissioning through the development of ACG. Although commissioning of HVAC systems remains the most common commissioning activity (so that the initial evolution from TAB to commissioning was fairly straightforward), commissioning providers today are increasingly called on to perform "total building commissioning" and address a much broader range of building systems. ACG defines the key commissioning activities as those shown in Table 14.5.

TABLE 14.5

Key HVAC System Commissioning Activities as a Function of Project Phase

Phase	Key Commissioning Activities
Predesign	Establish commissioning as an integral part of the project. Owner selects the CxA. Develop the scope of commissioning. CxA reviews the design intent.
Design	Review of design to ensure [that] it accommodates commissioning. Write commissioning specifications defining contractor responsibilities. CxA produces the commissioning plan. The project schedule is established.
Construction	CxA reviews contractor submittals. CxA updates commissioning process. Continued coordination of commissioning process. Carry out and document system verification checks. Carry out and document equipment and system startup. Carry out and document TAB activities.
Acceptance	Carry out functional performance tests for all HVAC systems. Train O&M [operations and maintenance] staff for effective ongoing operations and maintenance of all systems. Provide full documentation of HVAC systems.
Postacceptance	Correct any deficiencies and carry out any required testing. Carry out any required "off season" tests. Update documentation as required.

Source: ACG 2005, p. 18.

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COMMISSIONING OF NONMECHANICAL SYSTEMS

Although the commissioning of mechanical systems is at the heart of building commissioning, the commissioning process should include all building systems: all electrical components; telecommunications and security systems; plumbing fixtures; rainwater harvesting systems; graywater systems; electronic water controls; items such as finishes, doors, door hardware, windows, millwork, and ceiling tiles; and any other component in the building's drawings and specifications. The following tasks are recommended for the process of commissioning nonmechanical systems:

- Ensure appropriate product selection during design and the design intent review.
- Ensure that product specifications are clear by conducting a specification review.
- Ensure [that] the construction manager or subcontractor selects an acceptable product during the submittal review.
- Ensure [that] the construction manager or subcontractor properly installs the product.
- Ensure [that] adequate operations and maintenance (O&M) documentation is provided so that facility staff can properly maintain the item through an O&M documentation review.
- Ensure [that] facility staff receive adequate training to operate and maintain the item through a training verification.
- Ensure [that] the O&M plan addresses all items through an O&M plan review.
- Ensure [that] the building's indoor environmental quality (IEQ) meets the design objectives.

The more involved the commissioning process, the greater is the need for a diverse commissioning team whose members can handle the range of systems included in the building commissioning process. The members involved during the design process may be different from those who test the systems when construction is complete. For example, the commissioning team members engaged during design may be experts in multidisciplinary work and have an overall understanding of the process. This knowledge may include experience in selecting products and ensuring complete documentation to support a clear direction to all design decisions. Figure 14.10 shows an example of how detailed systems knowledge can help detect future operational problems as part of the commissioning process.



Figure 14.10 The CxA identified boiler exhaust condensation and dripping onto an exterior outlet and proposed the relocation of the electrical outlet to prevent future corrosion as well as increase safety. (Photograph courtesy of John Chyz, Cross Creek Initiative, Inc.)

COSTS AND BENEFITS OF BUILDING COMMISSIONING

Building commissioning provides a wide range of benefits—and, it is important to note, the earlier in the building design and construction process that building commissioning is implemented, the greater will be the benefits. The ideal arrangement is for the CxA to be hired at the onset of the project, along with the design team and construction manager. The CxA provides another set of inputs to the building team and ensures that, throughout design and construction, issues related to commissioning are included in the construction documents. Some typical benefits that can be expected as a result of including a full scope of building commissioning services from an independent CxA are listed next:

- Reduced operating costs due to an energy efficiency increase of 5 to 10 percent, attributed to building commissioning
- Increased employee productivity due to improved IEQ resulting from building commissioning

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TABLE 14.6

Energy Savings Attributable to Building Commissioning for Various Building Types

Building Type	Dollar Savings	Energy Savings
110,000 ft^2 office	\$0.11/ft^2/yr (\$12,276/yr)	279,000 kWh/yr
22,000 ft^2 office	\$0.35/ft^2/yr (\$7,630/yr)	130,800 kWh/yr
60,000 ft^2 high-tech manufacturing	\$0.20/ft^2/yr (\$12,000/yr)	336,000 kWh/yr

Source: Oregon Office of Energy 1997

- Improved construction documents resulting from the participation of the CxA in the review process during each design phase and the potential for greatly reducing change orders
- Fewer errors in equipment ordering due to the continual review of equipment requirements by the CxA
- Fewer equipment installation errors because the CxA reviews equipment installation during the construction process
- Fewer equipment failures during building operation due to the testing, calibration, and reporting carried out by the CxA
- Complete documentation of systems provided to the owner
- A fully functioning building from the first day of operation

The Oregon Office of Energy provides information on the benefits of building commissioning for energy savings for several building types. These are listed in Table 14.6.

The cost of commissioning is a function of the size of the project, its complexity, and the level of commissioning selected by the owner (see Table 14.7). Buildings with simple conditioning systems, few zones, and simple control systems would be at the lower end of the commissioning cost range shown for various levels of construction cost, whereas buildings with complex conditioning systems and control systems would be at the higher end of the range. Similarly, the benefits of commissioning for more complex buildings are far greater than those for buildings with relatively simple systems.

It is important to point out that Table 14.7 does not separate the costs of fundamental commissioning, required by the LEED rating system, from those of enhanced

TABLE 14.7

Cost of Commissioning Services by an Independent Third-Party Service

Construction Cost	Total Commissioning Cost*	Note
\$5 million	2%–4%	Costs include moderate travel, but building complexity, number of site visits, and other factors may also affect the cost.
\$10 million	1%–3%	
\$50 million	0.8%–2.0%	
>\$50 million	0.5%–1.0%	
Complex projects (labs)	Add 0.25%–1%	

*As a percentage of the construction cost.
Source: Oregon Office of Energy 1997

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TABLE 14.8

Costs of Commissioning during Design and Construction Phases for Typical Systems

Phase	Commissioned System	Total Commissioning Cost
Design	All	0.1%–0.3%
	HVAC and controls	2.0%–3.0% of total mechanical cost
Construction	Electrical system	1.0%–2.0% of total electrical cost
	HVAC, controls, and electrical system	0.5%–1.5% of total construction cost

Source: Oregon Office of Energy 1997

commissioning, which is optional under LEED. Fundamental commissioning may be carried out by personnel from the design firms on the building team as long as they are not directly involved in the project, and these costs sometimes are rolled into the design fee to minimize costs.

The Oregon Office of Energy provides another viewpoint of commissioning costs, as shown in Table 14.8.

It should be noted that the commissioning costs in the design phase include the costs for the CxA and the architect, with the allocation being approximately 75 percent for the CxA and 25 percent for the architect. Similarly, for the construction phase, additional costs are charged for the engineers to attend meetings, create checklists, and participate in testing. These costs are not listed in Table 14.8 and amount to 10 to 25 percent of the CxA's fee. There may also be additional costs for the architect's involvement in reviewing the commissioning plan and attending meetings, in the range of 5 to 10 percent of the CxA's fee.

THOUGHT PIECE: GREEN BUILDING COMMISSIONING

Due to the nature of construction, virtually every building is a unique, one-off design, including the design of complex mechanical and electrical systems and their control systems. The consequence of this sophistication and complexity is that high-performance buildings need to be carefully tuned and calibrated to ensure their operation is as designed. The commissioning process has been shown to be invaluable in providing a high degree of quality assurance for buildings with sophisticated energy and conditioning systems and is now virtually standard practice for green building certification. As a result of its success, the commissioning process is being extended to other building systems, such as the building envelope and even interior finishes. This thought piece by John Chyz of the Cross Creek Initiative addresses the important and evolving role of commissioning in the production of high-performance facilities.

The Role of Commissioning in High-Performance Green Buildings

John Chyz, Managing Director, Cross Creek Initiative, Inc., Gainesville, Florida



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Peter J. Wilson argues in The *Domestication of the Human Species* (1991) that settling down into a built environment was the most radical and far-reaching innovation in human development, having a pivotal effect on human psychology and social relations. It is no wonder, then, that the Moore's law–like trajectory in the evolution of human intelligence has given rise to notions of sustainability, reduced carbon footprints, and the defining of a healthy relationship between human beings and their natural world. This trend in thought is coincidentally paralleled by recent strides to enhance the health of the human body—organic diets, alternative medicine, and exercise. Built environments, in addition to being fabricated essentially out of the very building blocks of nature, create visual barriers, define boundaries between outside and inside and between various socioeconomic groups, house user-defined activities, and overwhelmingly serve as physical representations for human interactivity.

Sustainable built environments specifically are realized through the successful implementation of the growing array of strategies that have evolved out of this environmentally conscious movement toward a greener planet. Typically, these efforts focus on energy and water conservation, fastidious materials selection, minimization of site disruption, and attention on healthy indoor environments, to name a few. Of growing importance for the successful delivery of high-performance green buildings is some measure of quality assurance and control during design and construction of new facilities in addition to the ongoing optimization of existing buildings. A green building may be carefully designed and engineered to deliver superior energy performance, but little of this sustainable feature will come to fruition if the mechanical systems have not been installed, programmed, and balanced correctly. One of the biggest challenges facing the construction industry today is the coordination of trades. The growing complexity and sophistication of building systems has driven a market response by way of highly specialized products and the trained professionals to design, install, troubleshoot, and maintain them. Despite the long-standing notion that the most current and widely implemented delivery protocols, including communication structures, for new construction and renovation projects are effective at translating the owner's vision and goals into a fully functional, optimized, and sustainable building, evidence from the field has demonstrated otherwise. The truth of the matter is that new buildings are erected by individual contractors installing their respective systems. At project turnover, rarely are these systems and subsystems tested as a whole living, breathing unit. This approach is analogous to car manufacturers designing, prototyping, and producing a new vehicle, then delivering it to you or me (the driver) without test driving it first. Using the same analogy, we all know that used vehicles require tune-ups and oil changes periodically, and existing buildings are no different. In fact, it may surprise some to learn that in the absence of a retro-commissioning process, there are no other industry standard protocols for "tuning up" an existing building other than the execution of an energy audit. Energy auditing is essentially used to identify where a "vehicle may save on fuel costs" and how much it will cost to implement those measures that will achieve the desired mpg improvement.

We at the Cross Creek Initiative have commissioned well over 1 million square feet (929,000 m^2) of commercial building space ranging from new university academic buildings to existing health care facilities. A brief study of those projects has demonstrated an astonishingly wide range of deficiency issues encountered and subsequently rectified. The following list identifies those problems that have occurred with the greatest frequency:

- Envelope leaks/building pressurization
- Visual observations (incorrect installation, damage, drainage, missing equipment)
- Accessibility issues/housekeeping
- Engineering issues (over/undersized)
- Inadequate outdoor air delivery and CO_2 monitoring
- Sequence optimization/tuning/programming
- Variable-frequency drive control/status/fault
- Runtime/overridden in hand position
- Incorrect labeling/documentation conflict
- Field/building management system issue (incorrect wiring)

It becomes evident rather quickly that these kinds of issues collectively not only cost owners money in wasted energy each year but also can compromise occupant comfort, health, and overall safety.

The world's largest database of commissioning cost/benefit case studies was assembled by Evan Mills and his team at the Lawrence Berkeley National Laboratory in 2004 and updated in 2009. The results of the ensuing meta-analysis were eye-opening. Of data gathered for 643 buildings across 26 states, the median normalized cost to deliver commissioning was \$0.30/ft^2 for existing buildings and \$1.16/ft^2 for new construction projects. All told, according to Mills, this represented an average of 0.4 percent of the overall construction cost. Through the rectification of the 10,000 deficiencies discovered, a median energy savings of 13 percent was realized for the new construction projects and 16 percent for the existing buildings, with payback times of 4.2 and 1.1 years, respectively. Furthermore, project teams that elected to implement a comprehensive commissioning process enjoyed nearly twice the overall median energy savings. With regard to greenhouse gas emissions and using the same study, Mills maintains that the median cost of conserved carbon equaled \$25/metric ton for new construction projects and \$110/metric ton for existing buildings—figures that compare favorably with the current market prices of carbon offsets (\$10–\$30/metric ton).

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Perhaps the most compelling figures derived from the study fall out of a simple extrapolation from the stock of commercial buildings in the United States. Applying the median energy savings derived from the control group nationally results in a projected energy savings of $30 billion by 2030, the equivalent of approximately 340 megatons of CO_2 each year. Believe it or not, the current size of the commissioning industry serving existing buildings has only reached approximately $200 million per year. According to Mills, if each existing building in the United States were retro-commissioned every five years, the commissioning industry would quickly swell to $4 billion per year, requiring an additional 1,500 to 25,000 full-time-equivalent employees.

Rather than simply acting as tool for the realization of energy savings, a well-executed building commissioning process may be more accurately described as a risk management strategy. It ensures that building owners have been delivered with a building that meets their expectations within the specified budget and provides insurance for policy managers that their initiatives accurately meet targeted goals. Furthermore, the building commissioning process serves to detect and rectify issues that would eventually prove far more costly to the owner in the future from the standpoint of operation, maintenance, safety, and unwanted litigation.

In response to the programmatic deficit that plagues the building design, construction, and maintenance industries and in light of the crucial importance of getting it right when it comes to the delivery of a high-performance green building, the building commissioning process has not only become an essential component of business as usual but also presents owners with the unique opportunity to save energy and reduce carbon emissions while simultaneously improving occupant health and comfort. If a quality commissioning process were to be embraced by the design, construction, and maintenance industries nationwide, the potential for job creation, environmental leadership, cost savings, and improvements in occupant health would be significant, to say the least.

Summary and Conclusions

The success of a high-performance green building project is at least in part dependent on the conduct of the construction phase. The construction manager must fulfill several specific responsibilities to ensure that the process embodies the intent of green building, namely, to be environmentally friendly and resource-efficient and to result in a healthy building. By protecting plants and other ecosystem components, keeping the footprint of construction operations as small as possible, and minimizing sedimentation and erosion, the builder can meet the first of these objectives—protecting the environment. The resource efficiency goal can be met by reducing C&D waste and by planning and executing a well-thought-out construction waste management plan. The quality of indoor air can be protected for future building occupants by protecting ductwork from fabrication through installation; by properly storing materials to avoid moisture penetration, mold, and mildew; and by appropriately ventilating and flushing out the building prior to occupancy. A thorough training program for subcontractors should be instituted, and requirements specific to the construction of a green building should be integrated with other standard training programs, such as construction safety. Finally, building commissioning is an important component of the delivery process for high-performance green buildings and has been shown to reap enormous benefits in the form of reduced O&M costs. A diverse range of firms provide building commissioning services in support of the high-performance green building movement. The economic returns for building commissioning are very high—greater, according to some accounts, than for energy savings.

For building commissioning to be truly effective, it must occur periodically throughout the building's life cycle because complex systems tend to drift out of specification and even fail. The high-performance green building system has brought the relatively new discipline of building commissioning to the forefront in terms of its value to the building project. The return on investment for building commissioning warrants consideration of an extensive building commissioning program for green building projects.

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Notes

1. As described on the BCA website at www.bcxa.org/membership/essential-attributes/.
2. Ibid.

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Chapter 15

Green Building Economics

The market for green buildings in the United States continues to increase both in size and in market share. In *Green Outlook 2011*, McGraw-Hill Construction (MHC; 2010) reported that the market size of green construction, including both residential and nonresidential buildings, had jumped fourfold in just three years, from $10 billion in 2005 to $42 billion in 2008, and was expected to range between $55 billion and $71 billion in 2011. In 2010, it was estimated that new nonresidential green construction represented 28 to 35 percent of total construction volume, 50 percent higher than just two years earlier. MHC forecasted that by 2015 the scale of new nonresidential green construction could be in the $120 billion to $150 billion range, representing 40 to 48 percent of total nonresidential construction volume. Similar growth is occurring in building retrofits with MHC forecasting a market of $14 billion to $18 billion in 2015. What is clearly very remarkable, even startling, about this growth is that it is occurring in spite of the major downturn in construction resulting from the so-called great recession of 2008 to 2010. The three sectors with the greatest rate of market growth and penetration are education, health care, and office buildings. Green building data from MHC indicate that there are several major trends in the ongoing shift to green buildings.

First, the bigger the building project, the more likely it is to be a high-performance building. Because health care projects tend to be larger, the number of green health care projects is growing very rapidly. Over 70 percent of projects at least $50 million in size are including the US Green Building Council (USGBC) Leadership in Energy and Environmental Design (LEED) building rating system in their specifications. Second, throughout the United States, schools at all levels from K-12 to university are high-performance green buildings, and green building activity in the educational sector was between $13 billion and $16 billion in 2010. This rapid growth rate is likely being propelled by a combination of state and local mandates that require schools to be certified as green buildings. Third, a significant number of federal, state, and local governments are requiring that publicly owned buildings be high-performance green buildings. At least 12 federal agencies, 33 states, and 384 local government programs have been enacted as of 2010.

In this chapter, we cover the business case for high-performance green buildings; the economics of green building, including how to quantify a wide variety of savings and benefits; and the management of the additional first, or capital, costs that may accompany a green building project. Finally, we discuss the topic of tunneling through the cost barrier, which suggests that the synergies created in greening a building can be so significant that significant capital cost reductions can be achieved.

General Approach

Understanding building economics is important for any construction project, but it is especially important for high-performance green buildings because justifying this approach can involve somewhat more complex analysis than for conventional

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TABLE 15.1

Cost Premiums Derived from 33 Buildings with a LEED-NC Rating

LEED-NC Rating	Sample Size	Cost Premium
Platinum	1	6.50%
Gold	6	1.82%
Silver	18	2.11%
Certified	8	0.66%
Average	—	1.84%

Source: Kats 2003a

construction. High-performance buildings can produce benefits for their owners in a diverse range of categories: energy, water, wastewater, health and productivity, operations and maintenance (O&M), maintainability, and emissions, to name a few. To address the scope of benefits, the building team must be able either to quantify the effects of their decisions by using simulation tools or to rely on the best available research and evidence gathered from other projects.

This chapter addresses the economic and business arguments for high-performance buildings and approaches for quantifying the various benefits achievable by investing in environmentally beneficial buildings.

A report to the California Sustainable Building Task Force states that a 2 percent additional investment to produce a high-performance building would produce life-cycle savings that are 10 times greater than the incremental investment (Kats 2003b). For example, an additional $100,000 investment in a $5 million building should produce at least $1 million in savings for a building with an assumed 20-year life cycle. This is a truly remarkable claim and, if verifiable, makes a virtually unshakable case for high-performance building.

High-performance green buildings are thought to have a higher capital or construction cost than conventional buildings—on the order of 2 percent, or $2 to $5 per square foot ($ft^2$) (Kats 2003a). The additional required capital is proportional, at least generally, to the level of the building's LEED-New Construction (NC) rating (see Table 15.1).

An analysis of the financial benefits of high-performance green buildings concluded that significant benefits could be attributed to this type of delivery system and that there was a correlation between the LEED-NC rating and the financial return. Table 15.2 indicates that for a typical high-performance building, the total net present value (TNPV) of the energy savings over a 20-year life cycle is $5.79 per square foot, with other notable per square foot savings from reduced emissions ($1.18), water ($0.51), and O&M savings resulting from building commissioning ($8.47). Table 15.2 also shows productivity and health savings per square foot of $36.89 for LEED certified and silver buildings and $55.33 for LEED gold and platinum buildings. The 20-year TNPV per square foot in the table represents the sum of the annual net present values for comparison with the investment in green attributes. Clearly, the productivity and health benefits of high-performance green buildings dominate this discussion, and for gold and platinum buildings, the claim is that the savings are almost 10 times greater than the energy savings. It is important to point out, however, that although these claims are generally accepted by high-performance building practitioners, most of those made for productivity and health improvements are based on anecdotal information, not scientific research. The 20-year TNPV is $48.87 for certified and silver buildings and $67.31 for gold and silver buildings. The magnitude of these benefits is very impressive when considering that, on average, the incremental construction cost ranges from about $1.50 per square foot for LEED-certified buildings to about $9.50 per square foot for LEED platinum buildings.

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TABLE 15.2

Value of Various Categories of Savings for Buildings Certified by the USGBC

Category	20-Year TNPV/ft^2*
Energy value	$5.79
Emissions value	$1.18
Water value	$0.51
Waste value—construction only, 1 year	$0.03
Commissioning O&M* value	$8.47
Productivity and health value (certified and silver)	$36.89
Productivity and health value (gold and platinum)	$55.33
Less green cost premium	($4.00)
Total 20-year NPV (certified and silver)	$48.87
Total 20-year NPV (gold and platinum)	$67.31

*Net present value (NPV) is the net savings for each year, taking into account the discount rate (time value of money). The 20-year TNPV is the sum of the NPVs for all 20 years and represents the total life-cycle savings
**O&M commissioning ensures that the building is built and operated according to the design and results in substantially lower O&M costs.
Source: Kats 2003a

A side-by-side analysis of two prototype buildings by the US Department of Energy's Pacific Northwest National Laboratory and the National Renewable Energy Laboratory (NREL) compared the costs and benefits of investing in high-performance buildings. A base two-story, 20,000-square-foot (1858-square-meter [m^2]) building with a cost of $2.4 million meeting the requirements of the American Society of Heating, Refrigerating, and Air-Conditioning Engineers' (ASHRAE) Standard 90.1-1999 was modeled using two energy simulation programs, DOE-2.1e and Energy-10, and compared to a high-performance building that added $47,210 in construction costs, or about 2 percent, for its energy-saving features. Table 15.3 summarizes the results of this study. The features listed in the table are those for which an additional investment was made to produce the high-performance version of the NREL prototype building:

- Building commissioning, as noted previously, can produce significant savings by ensuring that the mechanical systems are functioning as designed.
- Natural landscaping and stormwater management produce savings due to the elimination of infrastructure and the use of easily maintainable native plants.
- Raised floors and movable walls produce savings by improving the flexibility of a building, reducing renovation costs.

TABLE 15.3

Comparison of Costs and Savings for NREL Prototype Buildings

Feature	Added Cost	Annual Savings
Energy efficiency measures	$38,000	$4,300
Commissioning	$4,200	$1,300
Natural landscaping, stormwater management	$5,600	$3,600
Raised floors, movable walls	0	$35,000
Waterless urinals	($590)	$330
Total	$47,210	$44,530

Source: US Department of Energy (2003).

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The results of this comparison are remarkable: They indicate that the annual savings produced by the high-performance version are about equal to the added construction cost, producing a simple payback in just over one year.

The additional capital costs often associated with high-performance buildings are a function of several factors. First, these buildings often incorporate systems that are not typically present in conventional buildings, such as rainwater harvesting infrastructure, daylight-integrated lighting controls, and energy recovery ventilators. Second, green building certification (fees, compilation of information, preparation of documents, cost of consultants) can add markedly to the costs of a project. And, finally, many green building products cost more than their counterparts, often because they are new to the marketplace and demand is only in the process of developing. In this last category are many nontoxic materials, such as paints, adhesives, floor coverings, linoleum, and pressed strawboard used in millwork, to name but a few of the many new green building products emerging to serve the high-performance building market. Conversely, cost reductions for some building systems are achievable in green buildings—for example, in heating, ventilation, and air conditioning (HVAC) systems—that can be downsized as a consequence of improved building envelope design. However, additional energy-saving components such as energy recovery ventilators, premium high-efficiency motors, variable-frequency drives for variable air volume systems, carbon dioxide sensors, and many others all add to the front-end capital cost.

As for every other type of project, understanding the economics of the situation and including them in the decision-making process is of crucial importance. As described earlier, the classical approach used in assessing high-performance building economics is life-cycle costing (LCC), which includes a consideration of both first cost (sometimes referred to as *construction cost* or *capital cost*) and operating costs (utilities and maintenance). These two major cost factors are combined in a cost model that takes into account the time value of money, the cost of borrowed money, inflation, and other financial factors. They are then combined into a single value, the TNPV of the annual costs, and the selection of alternatives is based on an evaluation of this quantity. In some cases, due to legislated requirements, only the capital cost is considered. For example, the state of Florida allows decisions on building procurement to be made solely on the basis of capital costs, whereas the US government requires that an LCC approach be used. Producing a high-performance public sector building in Florida can be very challenging; therefore, finding creative mechanisms for investing in higher-quality construction is imperative. One potential mechanism is the creation of a revolving fund from which building owners or users can borrow and that can be repaid through savings over time.

The Business Case for High-Performance Green Buildings

Making the case for high-performance buildings in the private sector must include a justification of why they make good business sense. In an attempt to address this issue, in 2003 the USGBC produced a brochure, "Making the Business Case for High Performance Green Buildings" (USGBC 2003), which addresses the advantages to a business of selecting green buildings over conventional facilities.[1] The business case described in this publication is still relevant today.

According to the USGBC, high-performance green buildings:

1. *Recover higher first costs, if there are any.* Using integrated design can reduce first costs, and higher costs for technology and controls reap rapid benefits.
2. *Are designed for cost effectiveness.* Owners are experiencing significant savings in energy costs, generally in the range of 20 to 50 percent, as well as

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savings in building maintenance, landscaping, water, and wastewater costs. The integrated design process, which is the hallmark of developing high-performance green buildings, contributes to these lower operational costs.

3. *Boost employee productivity.* Increased daylight, pleasant views, better sound control, and other soft features that improve the workplace can reduce absenteeism, improve health, and boost worker productivity.
4. *Enhance health and well-being.* Improved indoor environments can translate into better results in hiring and retaining employees.
5. *Reduce liability.* Focusing on the elimination of sick buildings and specific problems, such as mold, can reduce the incidence of claims and litigation.
6. *Create value for tenants.* Improved building performance can reduce employee turnover and maintenance and energy costs, thus contributing to better bottom-line performance. Additionally, the operating costs for building tenants will be substantially lower.
7. *Increase property value.* A key strategy of the LEED-NC building rating system is to differentiate green buildings in the marketplace, with the implicit assumption that lower operating costs and better indoor environmental quality (IEQ) will translate to higher value in the building marketplace. A building carrying a LEED-NC plaque will imply superior operational and health performance; hence, buyers will be willing to pay a premium for these features. This investment in green attributes or features would, in turn, spur demand for more high-performance green buildings.
8. *Take advantage of incentive programs.* Many states—for example, Oregon, New York, Pennsylvania, and Massachusetts—have programs in place that provide financial and regulatory incentives for the development of green buildings. The number of these programs is likely to grow and may include, among other possibilities, shorter project approval times, lower permit fees, and lower property taxes.
9. *Benefit the community.* Green buildings emphasize infill development, recycling, bicycle use, brownfield rehabilitation, and other measures that reduce environmental impacts, improve the local economy, and foster stronger neighborhoods. Businesses opting for high-performance green buildings will be contributing to the overall quality of life in the community and earn a better reputation as a consequence of their efforts.
10. *Achieve more predictable results.* The green building delivery system includes improved decision-making processes, integrated design, computer modeling of energy and lighting, and LCC, and ensures that the owner will receive a final product that is of a predictable high quality. The best practices beginning to emerge in this era of high-performance buildings will also enable more accurate results forecasting.

In addition to these 10 factors, a number of other benefits can be claimed for high-performance buildings, many of them societal. For example, as Kats (2003a) discussed, high-performance buildings can help address other problematic issues, among them:

- High electric power costs
- Worsening power grid problems such as power quality and availability
- Possible water shortages and waste disposal issues
- Federal pressure to reduce criteria pollutants
- Global warming
- Rising incidence of allergies and asthma, especially in children

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TABLE 15.4

Some of the Business Benefits of Green Building

Business Benefits	Green Retrofit and Renovation	New Green Buildings
Operating cost savings	—	13.6%
Over 1 year	8.5% for owners (10.5% for tenants)	—
Over 10 years	16% for owners (15% tenants)	—
Building value increase	6.8%	10.9%
Return on investment improvement	19.2%	9.9%
Occupancy increase	2.5%	6.4%
Higher rent	1%	6.1%

Source: The information in the table is as cited in MHC, *Green Outlook 2011*, and attributed to two earlier MHC studies, *Green Building Retrofit and Renovation*, SmartMarket Report (2009); and *Commercial and Institutional Green Building*, SmartMarket Report (2008).

- The health and productivity of workers
- The effect of school environments on children's ability to learn
- Increasing O&M costs for state facilities

There is also a range of benefits specifically for owners of commercial properties. MHC surveyed commercial building office tenants in 2006 and found that, on average, they would be willing to pay a 16 percent premium for green office space. Some additional business benefits were cited by McGraw-Hill in surveys conducted in 2008 and 2009, and these are shown in Table 15.4.

Economics of Green Building

There are two schools of thought with respect to the economics of green buildings. One school maintains that the construction cost of these buildings should be the same as or lower than that of conventional buildings. The argument for this line of thinking is that through integrated design and reducing the size of mechanical systems needed to heat and cool an energy-efficient building, the costs of high-performance building construction can be kept in line with those of conventional buildings. The ING Bank building, south of Amsterdam in the Netherlands, completed in 1987, is an example of a high-performance facility that costs about $1500 per square meter ($150/ft^2), including the land, the building, and its furnishings. At that time, this cost was comparable to or less than that of other bank buildings in the Netherlands.[2] This impressive feat was accomplished for an architecturally complex 50,000-square-meter (500,000-ft^2) building, featuring slanting brick walls and an irregular S-shape footprint, with gardens and courtyards and a 30,000-square-meter (300,000-ft^2) underground parking lot. It is set in a high-density, mixed-use area, with retail, office, and residential buildings surrounding it. If all high-performance buildings could be produced at this high level of architectural quality and at the same or lower cost as conventional buildings, the case for these advanced buildings would be made.

In contrast, the second school of thought is that high-performance green buildings will inevitably have higher capital costs and that by assessing total building costs on a life-cycle basis, the advantages of high-performance building will be achieved. The additional capital costs occur because high-performance buildings incorporate

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technologies and systems that are simply not present in conventional buildings, some of them complex and expensive. When attempting to assess the LCC of the many alternatives that can produce a high-performance green building, two distinctly different cost categories can be identified—hard costs and soft costs—defined as follows:

- *Hard costs* are those that are easily documented because the owner receives periodic billing for them—for example, electricity, natural gas, water, wastewater, and solid waste.
- *Soft costs* are those that are less easy to document and for which assumptions must be made for their quantification. Examples of soft costs are maintenance, employee comfort/health/productivity attributable to a building, improved IEQ, and reduced emissions.

An LCC analysis using only hard costs generally is acceptable as justification for alternative strategies that include a tradeoff of operational costs versus capital costs. It is far more difficult to justify including soft costs in an LCC analysis because soft-cost data cannot be verified with the same degree of rigor as hard-cost data. If the results of an analysis of alternatives for a high-performance building are to be subjected to a strict review by financial decision makers, then verifiable hard costs should dominate the analysis. If there is greater latitude in the decision-making process, justifiable soft costs can be employed in the analysis.

Four key points need to be considered when attempting to develop a case for high-performance buildings based on economic issues:

1. *The primary life-cycle savings for a high-performance building will be a result of superior energy performance.* For some types of buildings, HVAC or mechanical plants may indeed be downsized mechanically as a result of reducing external loads through the employment of superior passive design strategies and the design of a highly thermal-resistant building envelope. A significant reduction in HVAC plant size may also translate to a reduction in the size and cost of the electrical plant. However, for buildings that are dominated by interior loads (people and equipment), the HVAC plant may be unchanged in size compared to a conventional building. A daylit building will certainly require far lower levels of electrically derived light during the day but still will require a full lighting system during the evening. As a result, although it will produce significant operational savings, the daylighting system will not lower the requirements for artificial lighting and, in some cases, actually may complicate the design of the conventional lighting system.
2. *Life-cycle savings can be easily demonstrated for water and wastewater conservation measures* because these utilities, such as energy, are well known. As water and wastewater costs rise, especially in water-short areas, their life-cycle savings may, in some cases, approach the scale of energy savings.
3. *Savings due to good IEQ potentially can exceed all other savings.* For example, for a typical office building, maximum energy savings may be $1 per square foot ($10/m^2) annually, whereas the worth of a 1 percent improvement in employee productivity translates to $1.40 to $3.00 per square foot ($14–$30/m^2). Although these savings are far greater than those of any other category, it is difficult to justify their inclusion in an LCC unless the building owner is especially motivated to include this information in the analysis.
4. *Savings due to materials factors are very difficult to demonstrate.* In many cases, green or environmentally friendly materials may, in fact, cost more—sometimes far more—than the alternatives. For example, compressed wheatboard used for cabinetry currently costs as much as 10 times more than the alternative, plywood.

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Quantifying Green Building Benefits

An LCC for a green building project can address both hard and soft cost issues, either individually or in a comprehensive LCC that includes all cost factors. The general benefits that can be included in the LCC and the range of benefits that can be expected (hard costs) or justified (soft costs) are described next.

QUANTIFYING ENERGY SAVINGS

Green buildings use substantially less energy than conventional buildings and generate some of their power on-site from renewable or alternative energy sources. In a Capital E survey of 60 LEED-rated buildings conducted by Greg Kats in 2003, these buildings consumed an average of 28 percent less energy than their conventional counterparts and generated an average of 2 percent of their energy on-site from photovoltaics, thus reducing total fossil fuel–based energy consumption by about 30 percent. Reducing energy consumption provides a second benefit: a reduction in the emissions of global warming gases, which can also be assigned a cost benefit.

Analyzing the energy advantages of a high-performance green building requires the use of an energy simulation tool, such as the DOE-2.2 or Energy-10. A series of alternatives can be tried out and tested to determine the best combination of measures for the particular building and its location. An LCC analysis is also generated at the same time to provide cost and payback information, which is used in tandem with the energy-savings data to optimize energy performance. Using this approach, first costs and operational costs are combined to provide a comprehensive picture of the building's energy performance over an assumed lifetime.

Estimating the energy savings for a particular project relies on using a base case that meets a minimum standard. The case of the two-story NREL prototype buildings was used as an illustration at the beginning of the chapter to discuss the costs and benefits of high-performance green buildings. The two-story, 20,000-square-foot (1,858-m^2) building with a base cost that meets the requirements of ASHRAE Standard 90.1-1999 was modeled using DOE-2.1e and Energy-10 to simulate various measures that would improve its performance substantially. The results of this comparison are shown in Tables 15.5 and 15.6.

QUANTIFYING WATER AND WASTEWATER SAVINGS

Reductions in water consumption produce significant benefits with respect to water and wastewater. A sample, from Falcon Waterfree Technologies, LLC, of the financial impacts of reducing water consumption through the use of waterless fixtures is shown in Table 15.7. This example indicates that the per-fixture savings for a

TABLE 15.5

Comparison of Energy Performance for a Building Meeting ASHRAE Standard 90.1-1999 with a High-Performance Green Building

	Base Case Building Annual Energy Cost	High-Performance Building Annual Energy Cost	Percentage Reduction
Lighting	$6,100	$3,190	47.7
Cooling	$1,800	$1,310	27.1
Heating	$1,800	$1,280	28.9
Other	$2,130	$1,700	20.1
Total	$11,800	$7,490	36.7

Source: Adapted from US Department of Energy (2003).

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TABLE 15.6

Costs, Economic Metrics, and Energy Use: Base Case Compared to High-Performance Green Buildings

Metrics	Base Case	High-Performance Case
First cost of building	$2,400,000	$2,440,000
Annual energy cost	$11,800	$7,490
Energy reduction from base case	NA	36.7%
Economic Metrics		
Simple payback (years)	NA	8.65
Life-cycle cost	$2,590,000	$2,570,000
Reduction in life-cycle cost from base case	NA	0.85%
Savings-to-investment ratio	NA	1.47
Energy Consumption, Annual		
Million BTU	730	477
Reduction from base case	NA	34.6%

Source: Adapted from US Department of Energy (2003).

TABLE 15.7

Annual Savings Using Waterless Urinals Instead of Flush Urinals

Assumptions	75 Units	100 Units	200 Units
Total facility population	1,500	3,000	5,000
Percent of males	55%	50%	60%
Number of males	825	1,500	3,000
Number of urinals	75	100	200
Uses/day/person	3	3	3
Gallons/flush old urinals	3	3	3
Water cost/1,000 gallons	$2.50	$2.50	$2.50
Sewer cost/1,000 gallons	$2.50	$2.50	$2.50
Operating days/year	260	260	260
Annual Water Savings			
Savings in gallons	1,930,500 gal	3,510,000 gal	7,020,000 gal
Savings in dollars	$4,826	$8,775	$17,550
Annual Sewer Savings			
Savings in gallons	1,930,500 gal	3,510,000 gal	7,020,000 gal
Savings in dollars	$4,826	$8,775	$17,550
Total Water and Sewer Savings	**$9,652**	**$17,550**	**$35,100**
Annual Operating Cost Comparison			
Flush urinal*	$5,625	$7,500	$15,000
Waterless urinal**	$3,217	$5,580	$11,700
Total Operating Cost Savings	**$2,408**	**$1,650**	**$3,300**
Total Annual Savings* **	**$12,060**	**$19,200**	**$38,400**
Annual Savings/Urinal	**$161**	**$192**	**$192**

*Total water savings (3 uses/day x 260 days/year x number of users x water cost)
**Total sewer savings (3 uses/day x 260 days/year x number of users x sewer rate)
***Water/sewer savings plus operating cost savings.

Source: Falcon Waterfree Technologies, LLC.

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TABLE 15.8

Projected Savings from Using Waterless Urinals Instead of Flush Urinals in Various Occupancies: Existing versus New Buildings

Building Type	No. of Males	No. of Urinals	Uses/Day	Gallons/Flush	Days/Year	Water Savings/Gallon	Water Savings/Liter
Small office	25	1	3	3.0	260	58,500	220,000
New office	25	1	3	1.0	260	19,500	73,800
Restaurant	150	3	1	3.0	360	54,000	204,000
New restaurant	150	3	1	1.0	360	18,000	68,100
School	300	10	2	3.0	185	33,300	126,000
New school	300	10	2	1.0	185	11,100	42,000

Source: "Big Savings from Waterless Urinal" (2008)

waterless urinal are on the order of $161 to $192 per year. Although the cost of a waterless urinal, about $300, is much higher than that of a flush urinal, the installation costs are much lower because connection to a source of water for flushing is unnecessary. Consequently, the savings noted in this table are for systems with very similar installation costs.

In fact, some studies report that the installation costs for waterless urinals are lower than those for flush urinals.

Another set of examples of waterless urinal savings is shown in Table 15.8 for various occupancies, such as an office building, a restaurant, and a school, both existing buildings and new buildings. The basic approach indicated in these examples can be extended to a range of other water alternatives, to include rainwater harvesting, graywater systems, ultra low-flow fixtures, and composting toilets. That is, reductions in water and potentially wastewater costs can be used to develop an LCC analysis for assessing the financial performance of the alternatives versus conventional practice.

QUANTIFYING HEALTH AND PRODUCTIVITY BENEFITS

Factoring human benefits into LCC analyses must be done cautiously and conservatively. Although there is ample information about the health and productivity benefits of high-performance buildings, rarely has it been compiled scientifically; therefore, it cannot be said to have the same reliability as that for hard costs. Nevertheless, some of the major benefits that have been cited are impressive. For example:

- A paper by William J. Fisk (2000) of the Indoor Environment Department at Lawrence Berkeley National Laboratory suggests that enormous savings and productivity gains can be achieved through improved indoor air quality in the United States. He estimated $6 to $14 billion in savings from reduced respiratory disease; $1 to $4 billion from reduced allergies and asthma; $10 to $30 billion from reduced sick building syndrome–related illnesses; and $20 to $160 billion from direct, non health-related improvements in worker performance.
- Daylighting benefits to human health and performance potentially can provide marked financial returns—if they can be quantified. A study of student performance in daylit schools indicates dramatic improvements in test scores and learning progress. *The Daylighting in Schools* study study of schools in Orange County, California, by the Heschong Mahone Group (1999a) found that students in classrooms with daylighting improved their test scores 20 percent faster in math and 26 percent faster in reading than students in schools with the lowest levels of daylighting. The study also looked at students in Seattle, Washington, and Fort Collins, Colorado, where improvements in test scores were 7 to 18 percent.[3]

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TABLE 15.9

Human Performance Improvements Associated with Green Building Attributes

Green Building Attribute	Productivity Benefits
Increased tenant control over ventilation	0.5%–34%
Increased tenant control over temperature and lighting	0.5%–34%
Control over lighting	7.1%
Ventilation control	1.8%
Thermal control	1.2%

Source: Compiled by the author from Kats (2003a).

- In *Skylighting and Retail Sales*, the Heschong Mahone Group (1999b) compared sales in stores with skylights versus nonskylit stores and found that the skylit stores had 40 percent higher sales.

A reasonable approach to determining how to include productivity and health savings in green buildings was suggested in a report to California's Sustainable Building Task Force (Kats 2003a). In this report, the authors recommended assigning a 1 percent productivity and health gain to buildings attaining a USGBC LEED-NC certified or silver level and a 1.5 percent gain for buildings achieving a gold or platinum level. These gains are derived in a conservative fashion from information about improvements in human performance (see Table 15.9). Savings are the equivalent of $600 to $700 per employee per year, or about $3 per square foot ($30/m^2) for a 1 percent gain and $1000 per employee per year or $4 to $5 per square foot ($40 to $50/m^2) for a 1.5 percent gain.

QUANTIFYING THE BENEFITS OF REDUCING EMISSIONS AND SOLID WASTE

Emissions attributed to the operation of buildings are staggering in scope. High-performance buildings have the potential to lower these impacts dramatically. As a result of energy requirements, according to the *2011 Buildings Energy Databook*, buildings in the United States are responsible for the creation of 48 percent of the nation's sulfur dioxide emissions, 20 percent of nitrous oxide, and 36 percent of carbon dioxide. Additionally, buildings produce 25 percent of solid waste, consume 24 percent of potable water, create 20 percent of all wastewater, and cover 15 percent of land area (US Department of Energy 2011). Construction and demolition waste in the United States amounts to about 160 million tons per year, or about 0.5 ton per capita annually. Converting avoided emissions to benefits attributable to high-performance buildings can be accomplished by calculating the societal costs of emissions. The societal impacts of these emissions can be quantified as shown:

- Sulfur dioxide: $91 to $6,800 per ton ($100 to $7,500 per metric ton [mt])
- Nitrous oxide: $2090 to $10,000 per ton ($2,300–$11,000/mt)
- Carbon dioxide: $5.50 to $10 per ton ($6–$11/mt)

For the NREL prototype building, Tables 15.10 and 15.11 provide a summary of benefits that can be claimed as a result of energy reductions and avoided emissions.

Including the maximum emissions reductions benefits has a significant impact on the payback time. The payback time due to energy savings is reduced from 8.7 to 6.0 years when the societal costs of avoided emissions are included.

Savings from reduced solid waste generation can also be included in the life-cycle picture. For high-performance buildings, solid waste reductions are a result

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TABLE 15.10

Summary of Energy and Cost Savings for the NREL Prototype Building

	Base Case	High-Performance Case
Area (square feet)	20,000	20,000
Total cost	$2,400,000	$2,440,000
Incremental cost	NA	$40,000
Annual energy use (BTU)	730 million	477 million
Annual energy cost	$11,800	$7,490
Reduction in energy use	NA	34.6%
Reduction in energy cost	NA	36.7%
Simple payback, energy	NA	8.7 years
Simple payback, energy and emissions	NA	6.0 years

Source: US Department of Energy (2003).

TABLE 15.11

Avoided Emissions and Annual Benefit for the NREL Prototype Building: High-Performance Case Compared to Base Case

Emission Type	Tons of Emissions Avoided per Year	Annual Benefit
Sulfur dioxide	0.16	$1090
Nitrous oxide	0.08	$800
Carbon dioxide	10.7	$107
Total	**10.94**	**$1997**

Source: US Department of Energy (2003).

of three factors. First is construction and demolition waste reduction, which is addressed in high-performance building assessment systems, such as the USGBC LEED-NC building rating system. For example, LEED-NC awards one point for diverting at least 50 percent of construction and demolition waste from landfilling and two points for diverting 75 percent or more of this waste stream. Second, high-performance buildings address the generation of solid waste by building occupants by calling for the allocation of building space for the collection and storage of recyclables. In fact, LEED-NC makes this allocation of space a prerequisite for achieving a rating, thereby making it a mandatory requirement. Third, high-performance buildings address the use of recycled content and reuse of building materials, thus creating incentives and demand for closing materials loops and reducing the landfilling of solid waste. LEED-NC provides one point for 5 percent resource reuse and two points for 10 percent resource reuse. For recycled content, one point is provided if 5 percent of materials have postconsumer recycled content or two points for 10 percent postconsumer recycled content. Alternatively, LEED-NC provides one point for a 10 percent total of postconsumer plus one-half of postindustrial content and two points for a 20 percent total of postconsumer plus one-half of postindustrial content.

The financial benefits of diverting construction and demolition waste from landfilling can be calculated readily. For a nominal US construction project, waste is generated at the rate of about 7 pounds per square foot (32 kilograms per square meter). The actual savings are a function of the diversion rate. Table 15.12 itemizes the savings from construction waste diversion as a function of diversion rate and tipping fees—that is, the cost of disposal.

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TABLE 15.12

Savings for Diverting Construction Waste from Landfill for the NREL Prototype Building*

Diversion Rate	$50/Ton Tipping Fee	$75/Ton Tipping Fee	$100/Ton Tipping Fee
0%	$0	$0	$0
50%	$1,750	$2,625	$3,500
75%	$2,625	$3,938	$5,250

*Assuming 7 pounds per square foot (32 kg/m^2) waste generation for various diversion rates and tipping fees.
Source: US Department of Energy (2003).

QUANTIFYING THE BENEFITS/COSTS OF BUILDING COMMISSIONING

One of the hallmarks of high-performance buildings is that upon completion of the building, all systems are carefully checked and validated through testing. As a consequence of the high-performance building movement, building commissioning has become a new profession. Commissioning professionals are engaged in the project from the start, along with members of the design and construction professions. And although commissioning does add extra cost to a building, the value of this service is substantial, because it provides assurance that the building will perform as designed. Costs of commissioning for typical buildings are shown in Table 15.13. The benefits of building commissioning are difficult to quantify, but current general practice is to attribute a 10 percent energy savings to commissioning. In the case of the NREL prototype building used as an example in this chapter to quantify energy savings, the payback period for building commissioning is less than four years.

QUANTIFYING MAINTENANCE, REPAIR, AND MISCELLANEOUS BENEFITS/COSTS

In attempting to minimize LCC, high-performance buildings are designed specifically to lower maintenance costs, but they can also produce lower costs in other areas. Examples of design features that can provide these additional economic benefits for high-performance buildings, adapted from the US Department of Energy, are, are listed next.

Durable Materials

- Fluorescent lighting systems with long-life, 10,000-hour lights in place of short-life, 1,000-hour incandescent lights. Light-emitting diode lights have huge potential with 50,000-hour lifetimes and rapidly decreasing manufacturing costs.
- Fly ash and blast furnace slag concrete with higher durability compared to conventional concrete mix design.

TABLE 15.13

Commissioning Costs for Typical New Construction

Scope of Commissioning	Cost
Whole building	0.5%–1.5% of construction cost
HVAC and control systems	1.5%–2.5% of mechanical system cost
Electrical systems	1.0%–1.5% of electrical system cost
Recommissioning existing buildings	$0.17/ft^2 ($1.83 per m^2)

Source: Adapted from Portland Energy Conservation, Inc. (1997).1997. Portland, OR: Portland Energy Conservation, Inc.

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TABLE 15.14

Economic Comparison of Sustainable Stormwater Management and Landscape Practices for the NREL Prototype Buildings

	Incremental First Cost	Incremental First Cost/1,000 Square Feet (100 m^2)	Total Incremental Cost	Annual Cost Savings/1,000 Square Feet (100 m^2)	Total Cost Savings	Simple Payback (years)
Sustainable stormwater management	$3140	$157 ($169)	$3140	$28.30 ($30.45)	$566	5.6
Sustainable landscape design	$2449	$122 ($131)	$2440	$152.00 ($163.55)	$3040	0.8

Source: Adapted from US Department of Energy (2003)

- Low-emission paints with higher durability compared to conventional paints.
- Light-colored roofing materials that have longer life than conventional roofing materials.
- Polished concrete floors with very long lifetimes and low maintenance costs compared to carpeting and other floor finishes.

Repairability

- Recycled-content carpet tiles that can be replaced in worn areas.
- Mechanical and electrical systems designed for ease of repair and replacement by virtue of space allocation and physical arrangement of equipment, piping, conduit, power and control panels, and other components.

Miscellaneous Costs

- Designing buildings with areas for recycling that reduce waste disposal costs.
- Sustainable landscape design that reduces the need for irrigation, fertilizer, herbicides, and pesticides.
- Stormwater management using constructed wetlands instead of sewers.

The financial benefits of improved maintenance and repair must, of course, be quantified on a case-by-case basis and can be difficult to accomplish because a database containing this type of information is not readily available. Table 15.14 provides an example of how to present the savings for the sustainable landscape design and stormwater management entries listed under "Miscellaneous Costs" above for the NREL prototype buildings used to illustrate energy savings in this chapter. The two site-related strategies for the NREL prototype buildings are sustainable landscape design and sustainable stormwater management.

Sustainable landscape design. A mixture of native warm-weather turf and wildflowers is used to create a natural "meadow" area. This strategy is compared with traditional turf landscaping of Kentucky bluegrass, which requires substantially more irrigation, maintenance, and chemical application.

Sustainable stormwater management. An integrated stormwater management system combines a porous gravel parking area with a rainwater collection system, where rainwater is stored for supplemental irrigation of native landscaping. This porous, gravel-paved parking area is a heavy load-bearing structure filled with porous gravel, allowing stormwater to infiltrate the porous pavement (reducing runoff) and to be moved into an underground rainwater collection system. The water can be used to supplant freshwater from the public supply for uses that do not require potable water. This sustainable system is compared to a conventional asphalt parking area and a standard corrugated pipe stormwater management system without rainwater harvesting.

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Although the particular sustainable stormwater system used for the prototype increases the total construction cost by a little over $3,000 (about 0.1 percent of the total building construction cost), it saves over $500 annually in maintenance costs because less labor is required for patching potholes and performing other maintenance on an asphalt lot. The resulting payback period is less than six years. The sustainable landscaping approach shows even more favorable economics: The incremental first cost is nearly $2,500, but this is repaid in less than one year with an annual O&M cost savings of $3,040 in avoided maintenance, chemical, and irrigation costs.

Managing First Costs

For many organizations, especially state and local governments, the first, or capital, cost is the primary factor in making decisions about a project because legislation often dictates the maximum investment in a specific type of building. For example, in Florida, the new school construction cost per student station is limited to approximately $21,194 for elementary schools, $22,886 for middle schools, and $29,728 for high schools as of 2015. For many other potential green building clients, a similar situation exists, with decision makers heavily constrained by construction cost limitations. Coping with these circumstances requires careful consideration of strategies for producing a high-performance building when LCC may be difficult to bring into the process. The following list, adapted from Syphers Sowell, Ludwig, and Eichel (2003), provides recommendations for managing first costs for high-performance building projects:

1. Make sure that senior decision makers support the concept.
2. Set a clear goal early in the process. Ideally, the decision to go green should be made before soliciting design proposals so that contract language reflects the green goal, thus permitting more flexibility in decision making. Certain green measures that can save money (such as site planning) have to be done early.
3. Write contracts and requests for proposal that clearly describe your sustainability requirements. For example, specify whether the goal is a LEED silver rating or the equivalent.
4. Select a team that has experience with sustainable development. Hiring a mechanical, electrical, and plumbing (MEP) firm with green experience alone can save 10 percent of the MEP construction costs. Look for team members with a history of creative problem solving.
5. Encourage team members to get further training and develop sources of information on green materials, products, and components and technical/pricing information on advanced systems.
6. Use an integrated design process. Do not make the green components add-ons to the rest of the project. Integrate all the candidate green measures into the base budget. Establishing an integrated design can lead to capital savings. Investing 3 percent of total project costs during design can yield at least 10 percent savings in construction through design simplifications and fewer change orders.
7. Understand commissioning and energy modeling. To minimize up-front costs, use a sampling approach for building commissioning.
8. Look for rebates and incentives from states, counties, cities, and utilities.

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9. Educate the decision makers without inundating them with technical information. Stay focused on their objectives. Respect their sense of risk aversion.
10. Manage your time carefully. Select one or two team members to oversee research on green products and systems. Set a specific deadline for research results and give the discovery manager the power to cut off research.

Some design and construction strategies that a team can use to reduce first costs are listed next (US Department of Energy 2011).

- *Optimize site and orientation.* One obvious strategy to reduce first costs is to apply appropriate siting and building orientation techniques to capture solar radiation for lighting and heating in winter, and shade the building using vegetation or other site features to reduce the summer cooling load. Fully exploiting natural heating and cooling techniques can lead to smaller HVAC systems and lower first costs.
- *Reuse/renovate older buildings and use recycled materials.* Reusing buildings, as well as using recycled materials and furnishings, saves virgin materials and reduces the energy required to produce new materials. Reusing buildings may also reduce the time (and therefore money) associated with site planning and permitting.
- *Reduce project size.* A design that is space-efficient yet adequate to meet the building objectives and requirements generally reduces the total costs, although the cost per unit area may be higher. Fully using indoor floor space and even moving certain required spaces to the exterior of the building can reduce first costs considerably.
- *Eliminate unnecessary finishes and features.* One example of eliminating unnecessary items is choosing to eliminate ornamental paneling, doors (when privacy is not critical), and dropped ceilings. In some cases, removing unnecessary items can create new opportunities for designers. For example, eliminating dropped ceilings might allow deeper daylight penetration and reduce floor-to-floor height (which can reduce overall building dimensions).
- *Avoid structural overdesign and construction waste.* Optimal value engineering and advanced framing techniques reduce material use without adversely affecting structural performance. Designing to minimize construction debris (e.g., using standard-size or modular materials to avoid cutting pieces and thereby generating less construction waste) also minimizes labor costs for cutting materials and disposing of waste.
- *Fully explore integrated design, including energy system optimization.* As discussed previously, integrated design often allows HVAC equipment to be downsized. Models such as DOE-2 allow the energy performance of a prospective building to be studied and the sizing of mechanical systems to be optimized. Using daylighting and operable windows for natural ventilation can reduce the need for artificial lighting fixtures and mechanical cooling, thereby lowering first costs. Beyond energy-related systems, integrated design can also reduce construction costs and shorten the schedule. For example, by involving the general contractor in early planning sessions, the design team may identify multiple ways to streamline the construction process.
- *Use construction waste management approaches.* In some locations, waste disposal costs are very high because of declining availability of landfill capacity. For instance, in New York City, waste disposal costs exceed $75 per ton ($82/mt). In such situations, using a firm to recycle construction waste can decrease construction costs because waste is recycled at no cost to the general contractor, thereby saving disposal costs.

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- *Decrease site infrastructure.* Costs can be reduced if less ground needs to be disturbed and less infrastructure needs to be built. Site infrastructure can be decreased by carefully planning the site, using natural drainage rather than storm sewers, minimizing impervious concrete sidewalks, reducing the size of roads and parking lots (e.g., by locating near public transportation), using natural landscaping instead of traditional lawns, and reducing other man-made infrastructure on the site, when possible. For example, land development and infrastructure costs for the environmentally sensitive development on Dewees Island, off the coast of Charleston, South Carolina, were 60 percent below the local average because impervious roadway surfaces and conventional landscaping were not used.

An excellent study of construction costs for green buildings was conducted by Lisa Fay Matthiessen and Peter Morris of Davis Langdon, a cost consulting company (2004). Their report suggests that there is no statistical difference between high-performance green buildings that used LEED-NC for guidance and conventional buildings; that is, the cost per square foot falls into the same range of costs for both green and conventional buildings of a similar program type. The majority of LEED-NC certified buildings examined by the authors did not require additional funding, and where additional costs were incurred, they were due to certain extraordinary specific features such as photovoltaics. The factors that influence the cost of a green building are:

- *Demographic location.* The location of a project, rural versus urban, creates opportunities and problems in obtaining LEED-NC points. For example, points for transportation and urban development are readily available in urban settings, while stormwater management innovations are more likely in rural areas.
- *Bidding climate and culture.* In some states, such as California, contractors and subcontractors are far more familiar with LEED-NC and are less likely to perceive a project as risky, thus lowering costs.
- *Local and regional design standards, codes, and initiatives.* In Oregon and Pennsylvania, where there has been significant government support of green building efforts, the costs are generally lower because green buildings are more likely to be considered the norm.
- *Intent and values of the project.* A clear statement that the owner is serious about the green building concept will motivate the project team members and ensure that green building features are incorporated from the onset of the project, thus lowering overall costs.
- *Climate.* The paybacks for energy-conserving features vary by location because the costs of energy also vary by geographic region. Additionally, some aspects of passive design may be difficult to achieve in very hot, humid, or very cold climates. As a result, more complex and costly active systems are needed to meet the operational requirements of the owner.
- *Timing and implementation.* Fully incorporating green features from the start of design and ensuring their detailed integration into the project will result in lower costs.
- *Size of the building.* Larger, more complex buildings will typically have higher costs for larger, more complex systems simply due to the scale of the project.
- *Synergies.* Selecting systems that have multiple benefits will produce lower costs. For example, a well-designed landscape can integrate stormwater management and building shading and can be designed to require no irrigation, saving infrastructure and lowering operational costs.

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Matthiessen and Morris (2004) also noted that a well-developed budget methodology can go a long way toward reducing construction cost impacts. The authors recommended that these measures be followed at every step of design and construction to keep a green building construction within budget:

- Establish team goals, expectations, and expertise.
- Include specific goals in the program.
- Align the budget with the program.
- Stay on track during design and construction.

Integrating green building goals into the project, having appropriate expertise and commitment in the project team, and detailed planning are perhaps the key elements in keeping costs aligned with the budget. In this respect, green building projects are no different from any other well-organized and well-run building projects except for the inclusion of team knowledge of the green building concept and requirements. Experience to date is that the learning curve for obtaining the requisite knowledge is not very steep and that training in and exposure to one green building project provide the foundation for successfully tackling other similar projects.

Tunneling through the Cost Barrier

The preferred design approach used to create a high-performance green building is sometimes referred to as *integrated design*, which is covered in detail in Chapter 7. The fundamental assumption of integrated design is that by bringing the various disciplines together and forcing them out of their silos, a wide variety of synergies is possible. One of the most commonly cited synergies is in the design of the building energy systems, where architects and mechanical engineers collaborate on the details of the building envelope, resulting in a smaller HVAC plant. The current approach to building design does not promote sustainability because the designers, architects, and engineers each optimize the systems they design, generally resulting in a suboptimal building. Additionally, the fee structures for design professionals are such that maximizing cost and complexity can result in higher fees, clearly the wrong motivation when it comes to creating superior buildings. Consequently, finding the synergies that will produce truly high-performance buildings is a struggle, requiring changes in both attitudes and design contracts.

Amory Lovins (1997) of the Rocky Mountain Institute described the effects of producing integrated design synergies as "tunneling through the cost barrier" because the result can be a dramatic reduction in first, or capital, costs. One example cited by Lovins was the design of an industrial process for the carpet maker Interface for a plant in Shanghai, China. The initial design for this process called for 95 horsepower of pumping power. When Jan Schilhan of Interface examined the design, he threw out the assumptions engineers normally use for sizing pipes and made the pipes larger in diameter, thus greatly reducing pipe friction because fluid velocity was greatly reduced. Because friction is proportional to the fifth power of the pipe diameter, doubling the pipe diameter results in a friction reduction of 86 percent, so that pumping power falls by the same amount. Also, contrary to common design practices, Schilhan laid out the pipes with minimal bends and with the pipe lengths as short as possible, because each bend and each foot of pipe causes additional friction losses. This redesign reduced pumping power from the original 92 horsepower to 7 horsepower, a 92 percent, or Factor 12, improvement. The result of these changes was not only a significant reduction in energy consumption but also a significant reduction in capital cost due to the far smaller pumps, reduced piping

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complexity, and a smaller electrical service, far offsetting the slightly higher cost of larger-diameter piping (Hawken, Lovins, and Lovins 1999).

Many of the tradition-rooted assumptions used by engineers and architects often result in poor design practices that persist for decades, even generations. Challenging these assumptions is important if superior buildings with lower capital costs are the desired outcome. The key, according to Lovins, is whole-system engineering, in which all the benefits of a technology are counted, not just, for example, the energy-savings benefits. High-efficiency electric motors have as many as 18 benefits, and superwindows have as many as 10 benefits, including better daylighting, radiant comfort, no condensation, and noise blocking. Buildings have ample opportunity for synergies and cost reductions, many of which have not been unexplored yet. One area ripe for exploration is the integration of buildings into local ecosystems and geological formations. Trees have enormous capacity for stormwater uptake and can selectively allow sunlight to fall on buildings, depending on the time of year. Their leaves can block and absorb solar radiation during the summer and, when they drop off trees in the fall, allow penetration of the sun during winter days. Living roofs on buildings provide insulation, reduce the heat island effect, store stormwater, and replace the ecological footprint removed by the building. Greenery integrated into buildings contributes to a healthy experience for occupants, as suggested by the biophilia hypothesis (see Chapter 2). Coupling the building with the ground and groundwater can help provide heating and cooling while lowering energy consumption. Wetlands and constructed wetlands could also benefit the built environment via wastewater treatment and stormwater storage, leading to reduced capital costs.

Lovins (1997) suggested four principles as aiding the attempt to tunnel through the cost barrier:

1. *Capture multiple benefits from single expenditures.* By dematerializing buildings, for example, it may be possible to provide more space at lower cost while proportionately reducing environmental impacts. High-efficiency lighting reduces electrical energy requirements and reduces the heat load to the space and can be coupled with occupancy and daylight sensors.
2. *Start downstream to turn compounding losses into savings.* Rather than focusing on the fan power required to push air through ductwork, paying more attention on reducing friction losses in ductwork through better layout, reducing the length of duct runs, eliminating unnecessary bends, and increasing the duct cross section results in far lower fan horsepower, smaller and less costly equipment, and quieter operations. Going one step further downstream, designing systems that heat and cool only the bottom 6 feet (1.8 m) or so of vertical zones, where the occupants actually are, further reduces energy consumption. This is the strategy known as *displacement ventilation* (described in Chapter 9), and by delivering air from an underfloor plenum, it can help reduce floor-to-floor heights. Reducing this dimension results in lower overall building heights and lower material costs.
3. *Get the sequence right.* If the issue is health and productivity, thinking through how people will use the space and how they will have access to daylight, views, and, preferably, greenery, and maximizing the amount of natural light falling on their work spaces should be the first and foremost matter for consideration. The lighting systems should be designed only after the primary human factors are considered. The result: a better indoor environment and lower energy costs.
4. *Optimize the whole system, not just the parts.* This is the crux of whole-system engineering, a collaborative effort among architects and engineers to jointly and creatively design the building and its systems. In Germany, for example, the design disciplines have collaborated to create buildings that

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have superb passive design, totally eliminating the need for cooling systems, resulting in buildings using one-seventh of the primary energy of conventional US buildings. This collaboration represents the essence of integrated design and cost barrier tunneling.

Summary and Conclusions

High-performance buildings have enormous potential benefits: for their owners, for the environment, and for society in general. The ability to express and clearly justify these benefits in an economic analysis is an important factor in determining whether or not the project will be conventional or high-performance in its design and construction. Information continues to develop that the building team can use in develop an economic model that addresses both hard and soft costs. Hard-cost savings on energy, water, and wastewater are fairly straightforward to quantify and include in an economic analysis. Soft costs, such as human health and productivity savings as well as savings due to building commissioning, are not so straightforward to justify; hence, care must be exercised when including them in a cost analysis.

Notes

1. Available in the Members section of the USGBC website, www.usgbc.org/Docs/Member_Resource_Docs/makingthebusinesscase.pdf.
2. An excellent description of the ING Bank building can be found in von Weizsäcker, Lovins, and Lovins (1997). This book had great influence on high-performance buildings because it suggested that reducing resource consumption by 75 percent was necessary to achieve sustainability and that, furthermore, the technologies needed to support this reduction already existed. A follow-on concept, Factor 10, suggests that long-term sustainability would require a 90 percent reduction in resource consumption.
3. The Heschong Mahone Group, which specialized in building energy efficiency, published several landmark reports on the correlation between daylighting and student performance. The have merged with TRC and their reports are available from the company website, www.trc.com.

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Chapter 16

The Cutting Edge of Sustainable Construction

The contemporary high-performance green building movement continues to gain momentum in the United States and other countries and is transforming the entire process of creating the built environment, from design through construction and operation. In the United States, green building is beginning to dominate the market for commercial and institutional buildings; almost 50 percent of new buildings in this sector were forecasted to be green by 2015. This movement is affecting not only new construction but also renovations to existing buildings, building products, design tools, and the education of built environment professionals.

In the United States, for all practical purposes, the US Green Building Council (USGBC) Leadership in Energy and Environmental Design (LEED) building assessment system defines what constitutes a high-performance green building. Although LEED has been an enormous success in the marketplace, two questions remain: What is the ultimate goal of building assessment standards such as LEED and Green Globes, and how will they evolve over time to improve the buildings currently being produced that are using them as guidance? Because of the success of the LEED building assessment system, the USGBC is focused almost exclusively on the implementation of the existing suite of LEED rating products for new construction and for existing buildings and is working to generate and implement other LEED rating tools to cover areas of importance, such as health care and retail. Consequently, a long-term vision of what constitutes the high-performance building of the next generation is lacking. The absence of a long-term vision is hampering progress toward a truly sustainable built environment.

In this final chapter, the cutting-edge and future high-performance green buildings are addressed for the purpose of stimulating thinking about the long-range goals of this movement. The first section addresses the emerging issue of passive survivability, a new building theme embraced by the green building community in the wake of Hurricane Katrina in 2005. Although not yet being incorporated into new buildings, it is on the cusp of consideration and fits nicely into the general philosophical approach underpinning high-performance green buildings. The second section contains several case studies of newer green buildings to illustrate the best practices being employed today. These buildings, of course, point the way to the future and what may possibly be the norm for the green buildings of the future. The future is uncertain, however, and many different outcomes can be hypothesized. Certainly not all can be covered in detail here. In the fourth section of this chapter titled "The Challenges," three main approaches to designing future green buildings are proposed, one based on history, another on technology, and a third on ecology. These approaches represent the main attractors for strategies in this arena, although the likely outcome will be a hybrid of these widely differing but potentially equally successful approaches.

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Resilience

Recent severe weather events are causing a shift in thinking that will result in buildings having the capability of assisting human survival in the wake of natural or human-induced disasters. During the Chicago heat wave of 1995, the deaths of more than 700 people in their homes or apartments were attributed to high temperatures. In many apartments, temperatures remained in excess of 90°F (32°C), even at night. The death toll could have been far higher had Chicago lost power during the heat wave. Ten years after the Chicago heat wave, in August 2005, New Orleans was struck by Hurricane Katrina, resulting in thousands of deaths, incredible suffering, enormous dislocation of residents, and severe economic impacts. Temperatures in the Louisiana Superdome rose to 105°F (42°C), creating dangerous conditions inside the very structure to which people were sent to survive the immediate aftermath of the hurricane.

Passive survivability was a term used to describe how buildings should be designed and built to assist the survival of their human occupants in the wake of disasters. In an editorial in *Environmental Building News* in November 2005, Alex Wilson defined passive survivability by as "the ability of a building to maintain critical life-support conditions if services such as power, heating fuel, or water are lost for an extended period."[1] The term *passive survivability* was first used by the military to describe measures taken to ensure that military vehicles are able to withstand attacks. It was included in a set of proposals called the *New Orleans Principles*, resulting from a reconstruction conference held in Atlanta in November 2005.[2] One of these proposals states: "Provide for passive survivability: Homes, schools, public buildings, and neighborhoods should be designed and built or rebuilt to serve as livable refuges in the event of crisis or breakdown of energy, water, and sewer systems." The term *resilience* has generally displaced passive survivability in the green building vocabulary, an adaptation of a concept from ecology for use in the design of the built environment. The Resilient Design Institute (www.resilientdesign.org) defines resilience as "the capacity to adapt to changing conditions and to maintain or regain functionality and vitality in the face of stress or disturbance. It is the capacity to bounce back after a disturbance or interruption." The Institute defines resilient design as "the intentional design of buildings, landscapes, communities, and regions in response to these vulnerabilities.

The fact of climate change, and the probability of higher temperatures and more frequent and more violent hurricanes, should be sufficient to cause a shift to using passive survivability as a design criterion. Backup generators are unlikely to be able to provide the power needed for ventilation and air conditioning for extended periods of time; consequently, buildings need to have several key design features that help ensure passive survivability. Among these key green design features are cooling load avoidance, capability for natural ventilation, a high-efficiency thermal envelope, passive solar gain, and daylighting.

Most of the preliminary efforts at resilience addressed the very real problem faced by regions prone to hurricane activity, which is thought to be on the increase due to climate change. The same basic principles apply to areas that may be subject to severe winter conditions, such as blizzards and ice storms, where the emphasis shifts to providing the capability for heating, either through passive solar design or the use of local energy resources, such as wood. A 1998 ice storm in eastern Canada left 4 million people without power and forced 600,000 people from their homes, with 28 fatalities; thus, persons living in colder climates also should consider passive survivability strategies for their built environment. Earthquakes have not yet been addressed in the preliminary literature on passive survivability, although, in principle, buildings designed to survive earthquakes still may have downed utilities and should have the added capability of passive

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survivability. It is clear, then, that different regions will have different approaches to passive survivability that will depend on the weather and the typical natural hazards in that region.

Resilience should also be extended to infrastructure. Cisterns can be located throughout a community and under streets for an emergency water supply and for fire protection. Key control and communications systems, such as traffic signals and streetlights, could have solar-charged power backups. Sewage infrastructure also could be planned to have normal and passive survivability functions.

Exactly how resilient design can help mitigate the effects of terrorist attacks remains an open question. Clearly, any area of the country can be subject to the effects of terrorism. Attacks directed at utility infrastructure could be mitigated by a shift to passive survivability as a criterion for building. The impacts of biological or nuclear attacks could also be mitigated, at least for some period of time, by passive survivability, although systems that would seal the building and protect the occupants from airborne biological agents or radioactivity likely would not be incorporated into typical construction. The wide variety of potential attacks makes designing buildings for all eventualities impossible. However, for attacks directed against infrastructure, buildings certainly can be provided with key features that assist the occupants in having a safe place, reasonable temperatures, ventilation, and potable water, the key elements of survival.

The list of measures that can be included in a strategy for passive survivability or resilient design is remarkably similar to a list of typical green building measures (see Table 16.1). Indeed, an argument in support of incorporating these measures into buildings could be considered an argument in favor of green building.

TABLE 16.1

Checklist for Designing Passive Survivability into Buildings

1. *Create storm-resilient buildings.* Design and construct buildings to withstand reasonably expected storm events and flooding.
2. *Limit building height.* Most tall buildings cannot be used during power outages due to their reliance on elevators and air conditioning, and a maximum height of six to eight stories is recommended.
3. *Create a high-performance envelope.* A well-insulated thermal envelope with high-performance glazings will assist in maintaining a reasonable interior temperature.
4. *Minimize cooling loads.* Proper building orientation, overhangs, shading, and high-performance glazing can minimize building heat loads.
5. *Provide for natural ventilation.* Provisions for natural ventilation, such as chimney effect air movement, even for buildings that would be normally air-conditioned, would provide fresh air for the occupants.
6. *Incorporate passive solar heating.* In climates where heating may be the survivability issue, thermal mass and thermal storage walls can be used to help provide thermal energy for heating.
7. *Provide natural daylighting.* The same daylighting strategies used for green buildings also provide light in a passive survivability mode.
8. *Configure heating equipment to operate on photovoltaic (PV) power.* Gas- and oil-fired heating equipment is often dependent on electrical power for operation, and equipment may have to be configured to accept DC power from PV panels or have an inverter to provide AC power.
9. *Provide photovoltaic power.* PV can provide electrical energy during outages and, with battery storage, can also provide electricity at night. Note that PV panels need to be mounted and protected from high winds and flying debris.
10. *Provide solar water heating.* Solar thermal systems coupled with PV-powered pumps can provide hot water during power outages.
11. *Where appropriate, consider wood heat.* Especially in rural areas, low-pollution wood-burning stoves, masonry heaters, or pellet stoves can provide heating.
12. *Store water on site; consider using rainwater to maintain a cistern.* Water storage for extended outages can be provided by a cistern. Storing water high in the building—for example, on the roof—can provide pressure with no need for pumps.
13. *Install composting toilets and waterless urinals.* Fixtures that do not rely on water for flushing have a distinct advantage in the aftermath of disasters.
14. *Provide for food production in the site plan.* Land can be set aside for fruit-bearing trees and shrubs as a source of food in passive survival mode.

Source: Wilson 2006.

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Cutting Edge: Case Studies

Of all the high-performance buildings either registered or certified in the United States, several can be considered at the cutting edge of practice, among them the Federal Building in San Francisco, California. These projects, and the aspects that make them cutting-edge, high-performance buildings, are described next.

Case Study: The Federal Building, San Francisco, California

The 18-story San Francisco Federal Building is referred to by its owner, the General Services Administration (GSA), as "a model of excellence" and rightfully so. Located on a three-acre (1.2 hectare) site in the South of Market Street neighborhood at the intersection of Seventh and Mission Streets, just a 10-minute walk from downtown, it is a long, slender, translucent tower, 60 feet (18 meters [m]) wide and 234 feet (71 m) high, providing 600,000 gross square feet (55,742 m^2) of usable space. It is a federal government complex serving the Social Security Administration, the Department of Labor, the Department of Health and Human Services, and the Department of Agriculture. The design was led by Thom Mayne of Morphosis Architects in a major collaboration with the Los Angeles office of Ove Arup for the integrated structural and mechanical design; with Horton Lees Brogden of Culver City, California, for lighting and daylighting design; and with the Building Technologies Department of the Lawrence Berkeley National Laboratory for modeling the natural ventilation system. The Smith Group of San Francisco served as executive architect and executed all interior space planning for the tenant agencies. The goal of the project was to provide a high-quality government work space within the project budget of $144 million. *High quality* in this context meant that the work space had to be efficient, secure, and flexible to allow change.

The San Francisco Federal Building actually consists of several components, the 18-story tower being the dominant feature (see Figure 16.1). A four-story, broader structure at the southwest base of the tower houses the Social Security Administration, an agency that generates substantial pedestrian traffic and is served by a separate entry for the public. In close collaboration with the ethnically diverse local community—a rich mix of Filipinos, Mexicans, Vietnamese, and other minority groups—the project team developed the building to provide a landscaped plaza that acts as a bridge to the local community, serving as a local asset and accommodating the substantial pedestrian activity in the area. The skin of the building unfolds to cover a day-care facility, and a freestanding cafeteria rounds out the facilities on the site (see Figure 16.2). The publicly accessible day-care center and cafeteria are used by both the employees of the building and the local community, providing an architectural solution with a socially responsible dimension. The design of the building responded to the local residents' desire not to have a massive building that would overshadow the two- and three-story light industrial, commercial, and residential structures (including artists' studios, senior housing, and single-room-occupancy units) that provide the eclectic character of the neighborhood.



Figure 16.1 The Federal Building in San Francisco, California, designed by Morphosis Architects, is a breakthrough structure, with an outstanding passive design strategy coupled with active control systems. All building components are optimized in connecting the building to its surrounding environment for cooling, ventilation, and lighting. (Petros Raptis)

EXCELLENCE IN DAYLIGHTING

Lighting for office buildings in the United States is the single largest energy consumer for this building type, accounting for up to 40 percent of the total energy. Consequently, minimizing artificial lighting can have significant economic and environmental benefits. The narrow floor slab—just 65 feet (20 m) wide—the use of floor-to-ceiling glazing, and a floor-to-floor height of 13 feet (4 m) provide perfect conditions for substantial, deep-penetrating daylight. In contrast to normal practice,

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Figure 16.2 The folded, perforated metal skin covering portions of the San Francisco Federal Building assists in the flow of air through the structure and provides an interesting and appealing appearance for the structure, both at the ground level and at the upper façade. (Photograph courtesy of Jenna Hildebrand)

the perimeter of the building has open-plan offices, with 52-inch-high (132 centimeter) partitions that minimize the amount of light being blocked. The interior core contains meeting rooms and enclosed offices, all with clear glass panels to allow natural light to penetrate throughout the space. Fritted glass has been provided for these interior spaces for privacy when needed. The southeast face of the 18-story tower is covered with perforated panels that rotate to control light and provide unobstructed views across the city. The lighting system contains sensors that provide feedback to reduce artificial lighting as daylighting increases during the day and turn off lights when there are no occupants in a space. Task lights at workstations are on only when people are present in the spaces. The net result of the lighting strategies employed in the San Francisco Federal Building is a 26 percent reduction in lighting energy.

NATURAL VENTILATION STRATEGY

As was noted in Chapter 9, it is becoming standard practice in Germany to use natural ventilation as the strategy for cooling office buildings even during peak summer days. The result is that state-of-the-art German office buildings use less than 100 kilowatt-hours per square meter (kWh/m^2) (9.3 kWh/ft^2) of annual primary energy, about 20 percent the consumption of code-compliant US buildings. Buildings employing passive cooling strategies based on natural ventilation are rare in the United States, especially large buildings. The San Francisco Federal Building embraces passive cooling and ventilation, taking advantage of the 49°F to 65°F (9°C–18°C) air currents around the building and exploiting them via the design of building elements that allow and facilitate the deep penetration and circulation of outside air. A combination of computer-controlled air vents at floor level and occupant interaction with windows permits the use of these breezes to provide a comfortable and healthy interior environment. The air currents are admitted through openings on the northwest façade and vented through the southeast wall (see Figure 16.3). The open office spaces are designed so as not to impede airflow across the floor, and even enclosed offices and meeting rooms have walls that stop short of the floor above, providing a pathway for air to cross the building (see Figure 16.4). In the evening, the air currents cool the concrete structure, providing a cool sink for the following day.

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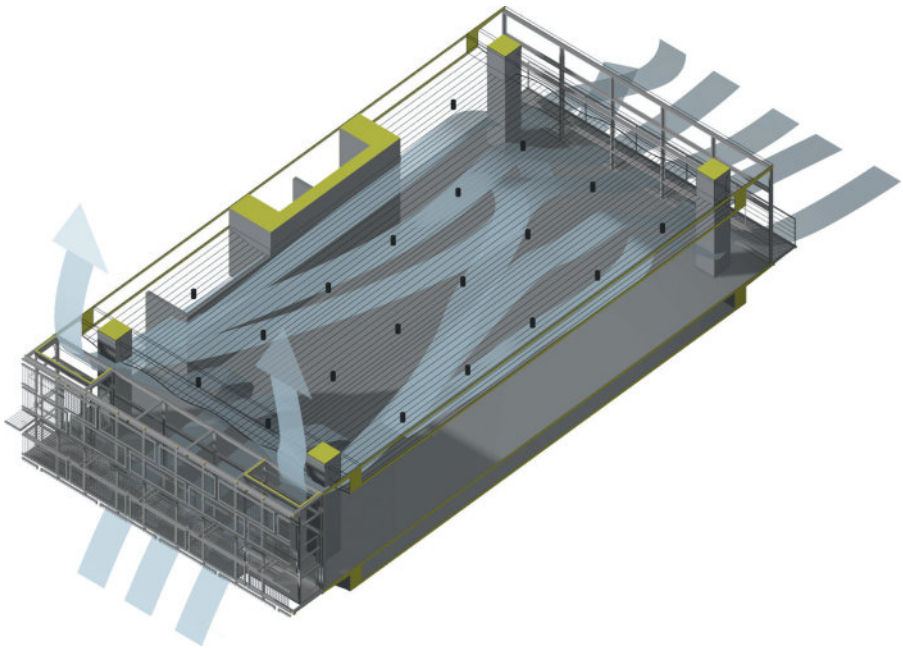


Figure 16.3 The San Francisco Federal Building is cooled and ventilated by using openings on either side of the building to direct outside air through the building. (Illustration courtesy of Morphosis Architects)

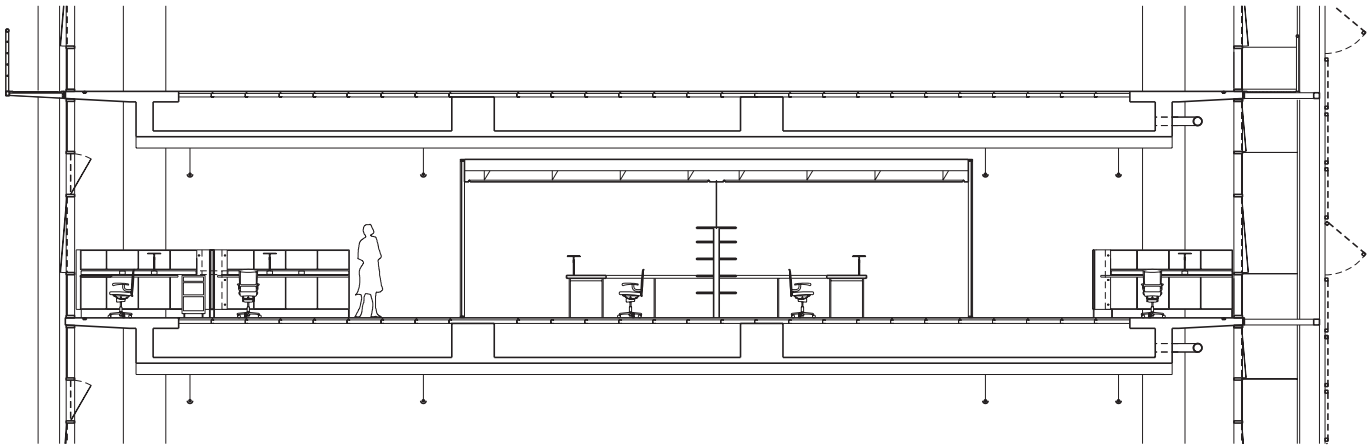


Figure 16.4 This section shows an interior conference room in the San Francisco Federal Building. Air flows from one side to the other via a pathway through and over the interior spaces. (Drawing courtesy of Morphosis Architects)

The southeast façade is covered with a perforated metal sunscreen that also helps induce airflow across the face of the building between the sunscreen and the façade, creating a pressure drop that induces warm airflow out of the building (see Figure 16.5). Solid narrow walls on the northeast and southwest sides contain the fire stairs and thus minimize heat gain on those sides of the building. Lower levels of the building require some mechanical cooling, and an innovative underfloor air distribution (UFAD) system combined with conventional heat pumps is used to meet the requirements of these zones.

The natural ventilation strategy provides cooling for the building from mid-April through mid-October. November and March are swing months during which the building operates optimally with windows closed and no active heating. During the colder months of December through February, a hydronic heating system meets any heating demands; the heat is delivered through a finned-tube convector integrated into the exterior glazing along the entire length of the building. This scheme is estimated to save the federal government a substantial

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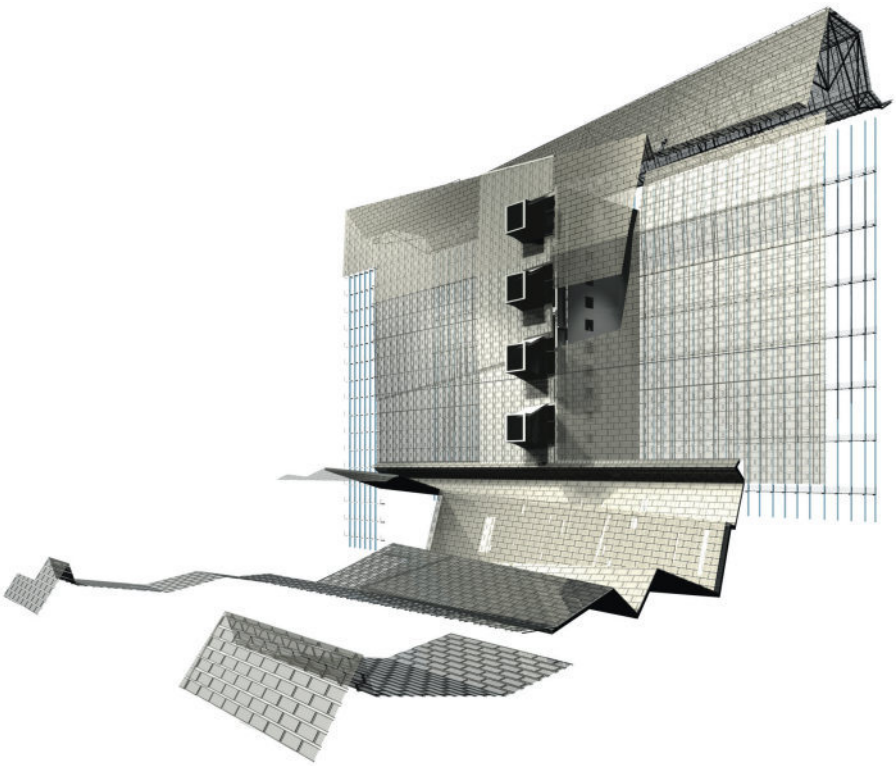


Figure 16.5 The perforated skin of the San Francisco Federal Building controls light and airflow through the building. As a result, as noted by architect Thom Mayne, the building "wears" the HVAC system. (Illustration courtesy of Morphosis Architects)

amount of money in annual energy costs, mostly through the reduction in size of mechanical systems. In the true spirit of sustainable construction, the savings realized from downsizing active, energy-consuming mechanical systems were shifted to an investment in intelligent façade design, allowing the employment of passive ventilation as a cooling strategy. As Thom Mayne of Morphosis described it, "The exterior envelope of the new building is a sophisticated metabolic skin, developed in direct response to light and climate conditions. In lieu of a conventional mechanical plant, the building actually 'wears' the air conditioning like a jacket."

The Federal Building is expected to require only 27,000 BTU/ft^2/yr (85 kWh/m^2/ yr) in comparison to the GSA's national target of 55,000 BTU/ft^2/yr (173 kWh/m^2/yr) and in contrast to a typical consumption of 69,000 BTU/ft^2/yr (218 kWh/m^2/yr) for GSA buildings.

A FLEXIBLE AND INNOVATIVE INTERIOR STRATEGY

The San Francisco Federal Building also provides highly flexible spaces that can be changed as conditions and tenants change. A raised floor and an easily reconfigurable furniture system allow workstations to be arranged in grids or as single units. Each floor is modular, subdivided by circulation and support areas. The design of the building also promotes collaboration and teamwork through an innovative layout of the vertical transportation system. Starting at the third floor, the elevator stops only at every third floor, where there is a multistory lobby with stairs leading to the floor above and the floor below. A dedicated elevator bank serves users of the building who have disabilities as well. The resulting circulation areas and waiting spaces bring people together in unexpected ways, facilitating the exchange of new ideas and information. A three-story interior sky garden, starting at the 11th floor, which is landscaped and has a variety of seating, provides a space for reflection and retreat, an inviting place with beautiful vistas (see Figure 16.6). It is a dramatic addition to a dramatic building.

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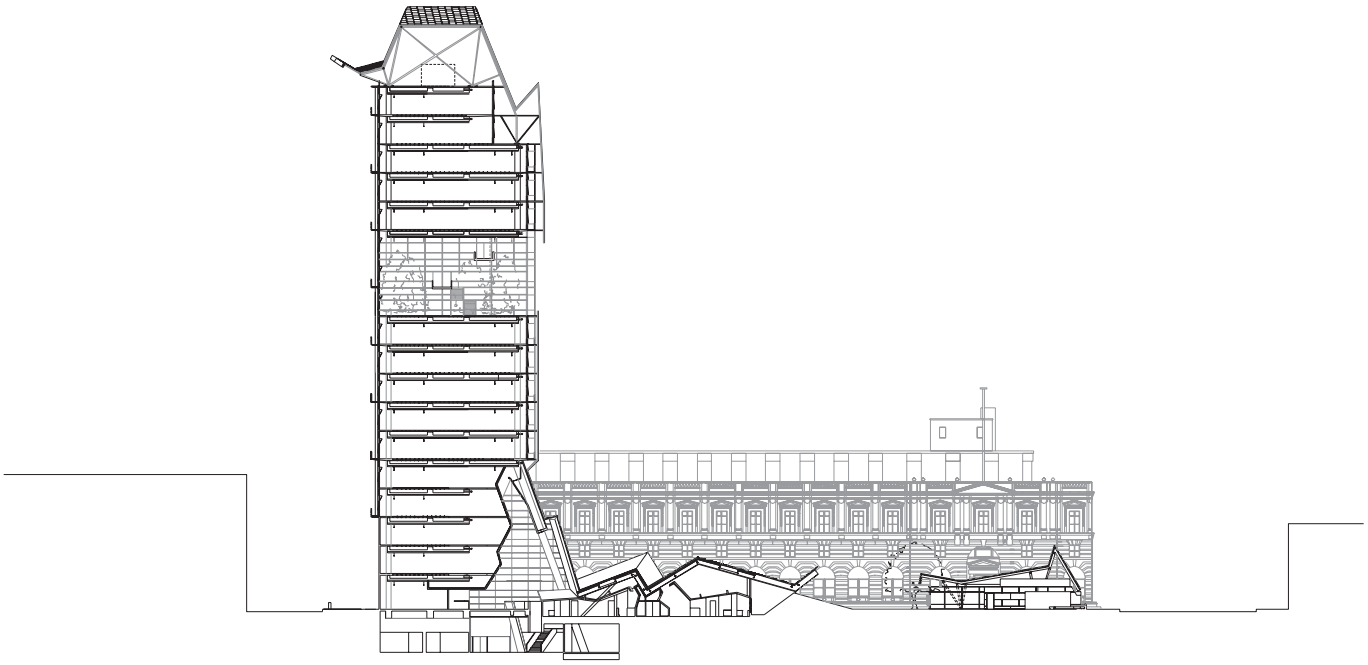


Figure 16.6 Section through the center of the San Francisco Federal Building showing the sky garden, which starts at the 11th floor. (Drawing courtesy of Morphosis Architects)

Articulating Performance Goals for Future Green Buildings

One of the major green building issues is to clarify the specific goals of high-performance green buildings. These goals can be expressed in a variety of suitable ways; this section describes four of them. One option is to apply the Factor 10 approach to buildings and focus on efforts that reduce the consumption of resources in the creation and operation of buildings to one-tenth of their current level, thereby aligning this movement with other sectors and institutions that are striving to behave sustainably.[3] A second option is to express the impact of a building in terms of its *ecological footprint.*[4] The unit of measurement for an ecological footprint is land area, which indicates the impacts by the peoples of different countries based on their lifestyles. The same concept could be applied to buildings, with impacts being stated in acres or hectares per unit area of building. Materials used in building could be measured in part by their *ecological rucksack.*[5] The ecological rucksack, a third approach, is the total mass of materials that must be processed to produce a unit mass of a specific metal or mineral. It is essentially a way to measure impact in terms of transformation of the surface of the planet—a serious matter because humans are now moving twice the amount of materials in natural systems. A fourth way to express the goals is through the routine use of life-cycle assessment, which describes the total inputs and outputs in the production of a given material. Comparisons could be made for different building solutions—for example, wall sections, to determine which approach consumes the least resources and has the fewest emissions.

For the high-performance building movement to make sense, establishing specific and reasonable goals is ultimately necessary to give the various players a direction for their activities. For the most part, the targets set in LEED are based on comparisons to a base building (i.e., a building that just meets the requirements of the building code).

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To project from an ideal future state to the current situation for the purpose of determining the steps that have to be accomplished to create the necessary change, a technique known as *backcasting* is used in the sustainable development arena. This strategy immediately raises questions: What is the ideal future for high-performance green buildings? What do they look like? How do they differ from today's green buildings? Answering these challenging, even daunting, questions is critical if we are to make progress toward a future in which the buildings we construct come far closer to meeting the ultimate standard of high-performance building.

The Challenges

Chrisna du Plessis (2003), a noted research architect and project leader on sustainable development at the Council for Scientific and Industrial Research, the national building research institute of South Africa, located in Pretoria, has identified three major challenges we face in defining the future built environment:

1. Taking the next technology leap
2. Reinventing the construction industry
3. Rethinking the products of construction

TAKING THE NEXT TECHNOLOGY LEAP

In the future, technology undoubtedly will play a powerful role in assisting and even accelerating change. In its simplest form, technology is nothing more than applied science—that is, using discoveries of basic science and mathematics for practical purposes, ideally for the benefit of people and natural systems. Technology is clearly a two-edged sword: Along with its many benefits typically come a wide variety of impacts. Thus, the challenge is to foster technologies whose benefits are great and whose impacts are low. For the built environment, three general approaches are emerging:

1. Vernacular vision
2. High-technology approach
3. Biomimetic model

Each of these is accompanied by technological approaches. Even the vernacular vision, which focuses on relearning the lessons of history, also is about developing technologies that support today's implementation of those hard- learned lessons.

Vernacular Vision: Relearning the Past

Vernacular architecture embeds cultural wisdom and an intimate knowledge of place in the built environment. It comprises technology, or applied science, that has evolved by trial and error over many generations all over the planet as people designed and built the best possible habitat with the resources available to them. With respect to designing high-performance buildings, vernacular design comes closest to the ecological design capabilities available today.

Two contrasting examples of vernacular architecture are the traditional styles of the state of Florida and the Southwest. US cracker architecture in Florida raises houses and buildings off the ground and creates flow paths for air around and through the structures, opening them to ventilation and conditioning by the prevailing winds. Originating in the early 1800s, the cracker house is well designed for the region's hot, humid climate. It emulates the chickee of the Seminole Indians, a covered structure with open sides, in which the floor, an elevated platform 3 feet (0.9 m) above the

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often-wet ground, was used for both eating and sleeping. The galvanized metal roof of cracker buildings is durable and reflects Florida's daily intense solar radiation away from the structure. The structure is lightweight and sheds energy; rather than absorbing energy, it reflects it, thereby helping to maintain moderate interior temperatures.

Modern cracker architecture buildings, although they retain the appearance of their traditional predecessors, with metal roofs, cupolas, and porches, employ modern technology to meet the needs of contemporary businesses and homes. As is the case with much of today's vernacular architecture, some of the original features, such as the capability for passive ventilation, are, for all practical purposes, not useful due to year-round reliance on modern heating, ventilation, and air conditioning (HVAC) systems. Cracker architecture generally is limited to smaller buildings, as it is difficult to apply to large buildings, because the roof tends to become inordinately large, and for urban office buildings, the porches lose their appeal (see Figure 16.7).

Adobe architecture, prevalent in the Southwest and Mexico, relies on local soils and a relatively massive structure made of adobe clay and straw brick. The large thermal mass of the structure enables the building to take advantage of the great diurnal temperature swings prevalent in high-desert areas for heating and cooling. During the day, the thermal mass absorbs solar radiation, storing it for later use, but it also provides just enough thermal resistance to keep the interior temperature at a moderate level. As temperatures in the deserts and mountains plunge in the evening, the energy stored in the massive adobe structure is emitted by radiation and convection into the interior spaces (see Figure 16.8).

These two historical forms of vernacular architecture, in addition to taking advantage of experience with daily and seasonal weather patterns and the assets of the sites, made use of local materials—long-leaf pinewood in Florida and earth and straw in the Southwest. Incorporating local and regional materials is now a criterion in modern building assessment standards such as LEED. In this way, taking a vernacular approach promises an excellent start to incorporating passive energy design features into a building, because it implies using the site and structural design to assist heating and cooling. Fortunately, there are hundreds of examples of vernacular architecture worldwide that can be used as the basis for designing today's high-performance buildings. The challenge, of course, is to use the wisdom of the past to meet the requirements of modern buildings and current building codes while retaining the positive cultural, environmental, and resource aspects of vernacular design.

High-Technology Approach

In contrast to the vernacular vision, which uses historical wisdom and cultural knowledge to design buildings, the high-technology approach generally follows the path of current trends in society. Contemporary society, especially in the developed world, has a love affair with technology. The prevalent attitude is that all our problems, including resource shortages and environmental dilemmas, can be solved simply by developing new technologies. For buildings, the high-technology approach centers on devising new energy technologies, such as photovoltaics (PVs) and fuel cells, and on finding technical solutions to the question of how to utilize renewable energy sources more effectively. Typical examples of this approach include windows with spectrally selective coatings and gas-filled panes, control systems and computer systems that respond to optimize energy use based on weather and interior conditions, energy recovery systems that incorporate desiccants to shift both heat and humidity, and materials incorporating postindustrial and postconsumer waste. Contemporary commercial and industrial buildings are equipped with a wide range of telecommunications and computer technologies that would challenge even the most advanced vernacular design approaches simply because of the need to remove the high levels of energy generated by today's workplace tools. Indeed, it could be argued that the technology of the building itself must be matched carefully to the technologies employed by the building occupants.

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Figure 16.7 Vernacular architecture in northern Florida. Early cracker-style houses were lightweight, wood-framed structures with wooden siding and metal roofs. The passive aspects of these structures help them reflect solar radiation and facilitate cross-ventilation; they are raised off the ground for protection from flooding. Modern versions adapt the materials and energy strategies of early cracker architecture to produce hybrid structures that include high-technology windows, composited siding, and energy- efficient air conditioning. (A) The Geiger Residence, Micanopy, Florida (1906). (B) A small cracker vernacular office building in Gainesville, Florida (1996). (C) Interior of Summer House at Kanapaha Botanical Gardens, a larger, 10,000-square-foot (929-square-meter) cracker-style building near Gainesville, Florida (1998). (Photographs courtesy of (A) Ron Haase; (B) Jay Reeves; and (C) M. R. Moretti)

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Figure 16.8 Examples of New Mexico adobe architecture. (A) As early as AD 350, the Anasazi, the oldest-known inhabitants of New Mexico, began to build aboveground masonry structures, the foundations of which are visible here at the base of their cliff dwellings in Bandelier National Park. (B) Communities called *pueblos* flourished around AD 1250 to 1300 and contained intricate arrays of connected flat-roofed, multilevel adobe buildings. (C) A modern office building in Santa Fe, New Mexico, retains the appeal and function of traditional adobe architecture.

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The high-technology approach to high-performance green building is, in short, an evolution of current practices. Over time, built environment professionals, backed up by experience, research, and the development of better systems and products, will be able to design buildings that are much more resource-efficient than today's green buildings and that will have far lower impacts in their construction and operation. Thus, the key characteristics of the ideal high-performance green building are based on making incremental—as opposed to radical—improvements in existing technology in these areas:

- *Energy.* The ultimate high-performance building consumes just one-tenth of the energy of current buildings and either uses only off-site-generated renewable energy or generates energy from renewable sources on-site for its entire needs. Passive design, assisted by extensive computer modeling, ensures the optimal use of natural ventilation, structural mass, orientation, building site, building envelope design, landscaping, and daylighting to minimize consumption of electricity and other energy sources so that the building can default to nature if it becomes disconnected from external energy sources.[6] Landscaping is integrated carefully into the project to assist in cooling and heating the structure.
- *Water.* The ideal high-performance building uses only 10 percent of the potable water of contemporary buildings and uses graywater, reclaimed water, or rainwater for nonpotable requirements. Wastewater is recycled for nonpotable building uses or is processed by constructed wetlands or Living Machines for discharge back into nature in as clean a state as it entered.
- *Materials.* All materials employed in the ultimate high-performance building are recyclable; building products can be disassembled and their constituent materials easily separated and recycled; buildings are deconstructable, capable of being disassembled and their components either reused or recycled. The cardinal rule for materials used in construction would be to eliminate those that are not recyclable, that are used in a one-off fashion and become waste after one use. An effective Factor 10 reduction in materials consumption would focus on reducing materials extraction by 90 percent, achievable by dramatically increasing the conservation of materials by deconstruction, materials recovery, and recycling and reuse. Increasing the durability and longevity of the built environment also would help achieve Factor 10 performance. However, this presumes that improvements in design would make buildings so much more valuable to society as cultural artifacts that their removal for economic reasons would be far less likely.
- *Natural systems interface.* The ultimate high-performance building is integrated with natural systems in a synergistic manner such that services and nutrients are exchanged in a mutually beneficial manner. Natural systems provide stormwater uptake and storage; assist cooling and heating; provide amenities; supply food; and break down waste from individual building scale to larger scales, up to the bioregional one. The building is designed carefully to take advantage of the natural assets of the site, the prevailing winds, and the microclimate at the building location.
- *Design.* Ideal high-performance buildings are designed using well-developed principles that are rooted in ecology. A robust version of ecological design is employed to ensure the integration of the building with its site and the natural assets. Architecture, landscape architecture, and engineering are carried out in a seamless, integrated process. The building professionals on the team work in a collaborative fashion, with fees based on the quality of design and construction and the building's performance. These same professionals work to minimize building complexity and maximize adaptability and flexibility.

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- *Human health.* All aspects of indoor environmental quality (IEQ) in the ultimate high-performance building are addressed carefully, including air quality, noise, lighting quality, and temperature/humidity control. Ventilation rates are optimized to provide exactly the levels of fresh air that support health. Only zero-emission materials are permitted.

THE BIOMIMETIC MODEL

Popularized by Janine Benyus in her book, *Biomimicry: Innovation Inspired by Nature,* published in 1997, the idea of using nature's designs and processes as the basis for human goods and services is one that has much appeal when it comes to considering high-performance buildings. She refers to biomimicry as ". . . the conscious emulation of life's genius." A biomimetic strategy, one based on biomimicry or imitation of nature, is a relatively recent concept, but one that may provide many of the answers to the questions of to create the ultimate high-performance building. Biomimicry is fundamentally about observing nature, then basing materials and energy systems on these observations. Consider, for example, that ceramic like seashells are produced at ambient water temperatures from materials in the environment, with no waste, with the result being elegant products perfectly designed for their function: to protect their inhabitants. Compare ceramics created by human technology, which are produced at temperatures of several thousand degrees, consuming great quantities energy and producing emissions to air and water, and solid waste. Moreover, the materials and resources necessary for the production of the ceramics must often be transported great distances, thereby adding to the energy investment.

Many other examples of biomimicry can be adapted as safe and sound technological approaches: Nature's ability to convert sunlight into chemical energy via photosynthesis; the phenomenal information storage and transmission capability of nerves and cells; tremendously strong and lightweight materials; powerful adhesives—to name a few. In true, out-of-the-box thinking, Chrisna du Plessis described a fanciful future built environment based on a full-fledged implementation of biomimicry. In it, all components of the building are biologically based and created from proteins, with solar energy collectors embedded in portions of the structure facing the sun. The structure is strong and lightweight and glued together with powerful adhesives based on those used by mussels to attach themselves to rocks in cold, murky water. Temperature and humidity are regulated by membranes that allow energy and moisture to move in and out of the occupied spaces, with embedded nanoprocessors controlling the movement. Like all other components, the membranes are self-repairing, self-regulating, and self-cleaning. Waste from the activities and functions of the building's inhabitants is processed by Living Machines that break down waste into nutrients for use in the food gardens, which are also designed to be self-reproducing and diverse, thereby minimizing pests. At the end of its useful life, the entire building can be "digested," with the organic components cycled for other uses and the mineral and other inorganic materials collected for recycling and reuse.

REINVENTING THE CONSTRUCTION INDUSTRY

The construction industry, referred to in its broadest sense to include design, construction, operation, renovation, and disposal of the built environment, has to change dramatically to meet the future challenges of building. Buildings have become commodities, with little to distinguish one from another in any serious manner, and with little effort to make them—as in the past—cultural artifacts of human existence. Low first cost is the normal order of business, so quality design receives minimal attention; materials and systems are employed that produce minimal performance; the construction process is carried out rapidly and at the lowest possible cost; and the norm is to demolish and landfill buildings at the end of their useful life. Scant

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attention is paid to the implications of this behavior, both for ecological systems and for human society. Owners focus on buildings that have minimal construction cost and that are designed just to accomplish their functions, with little or no attention given to their aesthetic features. Changing the mind-set of this cast of actors is an enormous challenge. To meet that challenge, these changes must take place:

- *Technology.* Technologies that minimize resource consumption and the environmental impact of the built environment need to be developed.
- *Policy.* As a general matter of policy, buildings need to be created based on life-cycle costs as well as first costs.
- *Incentives.* Government needs to develop financial incentives for high-performance construction, such as priority review by building departments, accelerated approval for projects of this type, and reductions in impact fees and/or property taxes for a specified period of time.
- *Education.* All the professionals in the industry need to be educated and trained in the need, process, and approaches for creating high-performance green buildings—owners, architects, engineers, landscape architects, interior designers, construction managers, subcontractors, materials and product manufacturers and suppliers, insurance and bonding companies, real estate agents, building commissioning consultants, and other professionals engaged in the process. This is also necessary for the workforce, crafts workers, journeymen, and apprentices who work for the broad array of subcontractors that make buildings a physical reality.
- *Performance-based design fees.* Contracts for design and construction services need to be revised to offer incentives to the building team to meet and exceed project goals with respect to resource consumption and environmental impacts. These goals include targets for energy and water consumption, building health, construction waste, protection of the site's natural assets, and other objectives that contribute to the building's performance.
- *Construction process.* The physical process of construction needs to be changed to ensure that the activities involved in erecting the building have the lowest possible impact. Among these changes are reduce construction waste and recycle or reuse the residue, understand and implement effective soil and erosion control methods, protect flora and fauna on the site during the construction process, minimize soil compaction during construction, and store materials so that they are protected from wastage and are unlikely to cause IEQ problems.

RETHINKING THE PRODUCTS OF CONSTRUCTION

As this book has pointed out repeatedly, buildings consume enormous quantities of resources and can cause any number of negative impacts on their occupants. In addition to the resources required to build and operate individual buildings, a wide range of additional impacts are the consequence of decisions concerning how to distribute buildings across the landscape. For example, segregating buildings by type (residential, commercial, industrial, government, cultural, etc.) means that people are forced to use their automobiles to get from one type of building to another. The average American makes at least eight automobile trips per day, many of them for no reason other than to socialize. The concepts of new urbanism or traditional neighborhood development are seeking to reverse this trend by mixing building types and uses and by designing streets and neighborhoods for pedestrian movement. A general goal is that all daily needs must be available within a 10-minute walk from where the individual resides.

Other serious impacts result from the building stock itself. In the United States, buildings and houses are generally very large and consume large quantities of energy,

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water, and materials to both build and operate them. The extraction of resources to support the construction industry is profound. Some estimates state that 90 percent of all extracted resources in this country are used to create the built environment. Buildings consume two-thirds of all electricity and 35 to 40 percent of primary energy. Three important questions that need to be asked when a new building is proposed are:

1. Is the building actually needed, or is adequate space already available?
2. Can the building be made smaller?
3. Can an existing building be renovated for the new purpose?

Revamping Ecological Design

As noted in Chapter 3, contemporary ecological design only has very weak links to ecology. Although virtually any definition of high-performance green building makes reference to ecological design, to date there is little or no evidence of the application of ecology to design. To correct this situation, it is crucial that a new, comprehensive concept of ecological design be developed. In addition to considering ecology in far greater depth in building design, it is imperative to consider the potential for applying industrial ecology. Established as a discipline in 1988, industrial ecology seeks to apply ecological theory to industrial production. Many of the issues and problems faced by an industrial system that builds automobiles and airplanes are also faced by those in the building design and construction professions. Consequently, the experience gained by applying industrial ecology to industrial production will be very useful in creating high-performance green buildings.

In a collaboration among architects, ecologists, and industrial ecologists, the possibility of applying current ecological theory to the creation of buildings was explored in great depth to determine which aspects of ecological theory and industrial ecology were applicable to buildings (Kibert, Sendzimir, and Guy 2002). This collaboration offered a number of insights into how ecology and industrial ecology can better inform building design, construction, and operation. The results of this collaboration are summarized in the next lists.

GENERAL

1. Maximize second-law efficiency (effectiveness) and optimize first-law efficiency for energy and materials (Kibert et al. 2002, chap. 3).[7]
2. As with natural systems, industry must obey the maximum power principle (Kibert et al. 2002, chap. 2).[8]
3. Be aware that the ability to predict the effects of human activities on natural systems is limited.
4. Integrate industrial and construction activities with ecosystem functions so as to sustain or increase the resilience of society and nature.
5. Interface buildings with nature.
6. Match the intensity of design and materials with the rhythms of nature. In the built environment, move from the "weeds" stage to the "tree" stage for sites that are not disturbed frequently. "Weedy" structure (minimal built structure that is easily and cheaply replaced) may be much more adaptive to sites frequently disturbed by floods, storms, or fires.
7. Consider the life-cycle impacts of materials and buildings on natural systems.
8. Insist that industry take responsibility for the life-cycle effects of its products, to include take-back responsibility.

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9. Address the consumption end of the built environment by integrating it with production functions.
10. Increase the diversity and adaptability of user functions in buildings through experiment and education.
11. Explore educational processes beyond academia that instruct through "learning by doing," by involving all stakeholders in processes that test different means by which the built environment is produced, sited, deconstructed, and resurrected.
12. Reduce information demands on producers and consumers by testing and improving the means by which materials, designs, and processes are certified as "green." This presupposes the development of a construction ecology based on nature and its laws.
13. Ensure that systems analyses look at system function, processes, and structure from different perspectives and at different scales of analysis.
14. Integrate ecological thinking into all decision-making processes.
15. Follow the precautionary principle to constrain and govern decision making.

MATERIALS

1. Keep materials in productive use, which also implies keeping buildings in productive use.[9]
2. Use only renewable, biodegradable materials or their equivalent, such as recyclable industrial materials.
3. Release materials created by the industrial system only within the assimilative capacity of the natural environment.
4. Eliminate materials that are toxic in use or release toxic components in their extraction, manufacturing, or disposal. Focus first on materials not well addressed by economics—the intermediate consumables (paints, lubricants, detergents, bleaches, acids, solvents) used to create wealth (buildings).
5. Eliminate materials that create "information" pollution—for example, estrogen mimickers.
6. Minimize the use and complexity of composites and the numbers of different materials in a building.
7. Realize that not all synthetic materials are harmful and not all natural materials are harmless. Nature has many pollutants that are harmful; for example, natural fibers, such as cotton, are not necessarily superior to synthetic materials, such as nylon.
8. Recognize that the impacts of natural materials extraction can be high—as is the case with agricultural products; or in forestry, in which pesticide use, transportation distances, processing energy, and chemical use are significant factors.
9. Standardize plastics and other synthetic materials based on recycling infrastructure and the potential for recycling and reuse.
10. Use fossil fuels to produce synthetic materials, rather than to generate power, and use renewable energy resources as the primary power source.
11. Acknowledge that it is not possible to rate or compare materials adequately based on a single parameter.

DESIGN

1. Model buildings based on nature.
2. Make structures part of the geological landscape.

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3. Design buildings to be deconstructable, using components that are reusable and ultimately recyclable.
4. Design buildings and select materials based on intended use and then measure the outcomes of the design.
5. Incorporate adaptability into buildings by making them flexible for multiple uses.
6. Realize real savings by integrating the production, reuse, and disposal functions.
7. Focus on excellence of design and operation, with greenness as a critical component. Focusing exclusively on greenness trivializes it as a marginal movement.
8. Invest in design that improves building function while minimizing energy use and the number of materials. Doing this will reduce the time and effort required to find and optimize new green materials.
9. Revise designs to take into account major global environmental effects such as global warming and ozone depletion. Doing this is critical at this point in time.
10. Allow for experimentation in green building design to produce structures that, like nature, obey the maximum power principle.
11. Make sure that architects have a strong, fundamental education in ecology.
12. Use performance-based design contracts to develop greener buildings and better architects.

INDUSTRIAL ECOLOGY

1. Make changes needed to create an environmentally responsible industrial ecosystem intelligible to the members of the particular industry.
2. Focus on the clients and key stakeholders of the system. This is necessary due to limits on time, knowledge, and resources. Major stakeholders include the educational system and the insurance industry.
3. Make the new paradigm for industry the collaboration of actors versus the possession of technical expertise.
4. Reduce consumption. This is more important than increasing production efficiency as the change agent for industrial ecology.
5. Incorporate ecological engineering into industrial ecology.

CONSTRUCTION ECOLOGY

1. Ensure that construction ecology balances and synchronizes spatial and temporal scales to natural fluxes.
2. Recognize that the corporations leading the way in the production of new, green building materials are a "frontier species" that may be creating a new form of competition, which they are using to their advantage.
3. Be aware that green building probably can be implemented only incrementally because of resistance and potential disruptions from the existing production and regulatory systems.

OTHER ISSUES

1. Better educate government officials and code-writing bodies about ecology.
2. Establish performance standards for buildings and construction to replace existing prescriptive standards. The performance standards need to include provisions for using green building materials.

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3. Regard the insurance industry as a major stakeholder in the built environment, as the threat of severe consequences from global warming will drive it to promote green building.
4. Rely on certification only as a starting point; do not rely on it entirely for information on products.

Today's Cutting Edge

In closing the last chapter of this book, it is useful to reflect on how far the high-performance green building movement has advanced and where the cutting edge of this field is at the present time. The next sections describe the areas in which high-performance green building has made significant progress over the past decade and where the cutting edge of change in high-performance green building can be found. These areas include:

- The development of green building standards
- The net zero built environment concept
- The Living Building Challenge (LBC) building assessment system
- The emergence of environmental product declarations (EPDs)
- Carbon accounting for the built environment

HIGH-PERFORMANCE BUILDING STANDARDS

High-performance green buildings have evolved significantly since the development of the Building Research Establishment Environmental Assessment Method in the United Kingdom in 1990 and the beta test version of LEED in 1998. One of the key challenges has been how to make the green building approach more readily available to all buildings, not just to the growing number of organizations that have been implementing green buildings. According to the USGBC, LEED addresses the top 25 percent of high-performance buildings. By developing a high-performance green building standard using an American National Standards Institute (ANSI) accredited process, the USGBC, in collaboration with the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) and the Illuminating Engineering Society of North America, is making it possible for green building requirements to be incorporated into building codes, thus addressing the other 75 percent of construction. The full name for the LEED-oriented standard is ASHRAE 189.1-2014, *Standard for the Design of High-Performance Green Buildings Except Low-Rise Residential Buildings*. If this standard were to be incorporated into building codes, it would free the USGBC and other green building organizations to set the bar for high-performance buildings even higher. It also would provide a baseline for sustainable design, construction, and building operation in order to drive green building into mainstream construction industry practices. ASHRAE 189.1 applies to new commercial buildings and major renovations. It is modeled after the LEED building assessment system, including prescriptive measures drawn from the five main LEED categories: sites, water efficiency, energy and atmosphere, materials and resources, and IEQ. A second standard, ANSI/GBI 01-2016, *Green Building Assessment Protocol for Commercial Buildings*, also was developed using the ANSI standards development process and is based on the Green Globes building assessment system.

In addition to the two standards just mentioned, a full-fledged building code based on the LEED building assessment system has been developed and is gaining

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support. The *International Green Construction Code* (IgCC) effort was launched in 2009 and the latest version was issued in 2015. The purpose of this effort was to develop a model code focused on new and existing commercial buildings addressing green building design and performance. Jurisdictions that have already adopted the IgCC include Ft. Collins, Colorado; Richland, Washington; Kayenta Township, Arizona; and the state of Rhode Island. The IgCC offers a Zero Energy Performance Index, requiring buildings to use no more than 51 percent of the energy allowable in the 2000 International Energy Conservation Code. Examples of IgCC provisions include:

- A 20 percent water savings beyond US federal standards for water closets in residential settings
- New requirements for identification and removal of materials containing asbestos
- Land use regulations, including new provisions addressing flood risk, development limitations related to "greenfields," use of turfgrass, and minimum landfill diversion requirements
- Clarification of responsibilities from the registered design professional to the owner to prevent potential conflicts with state and local requirements
- Greater consistency with industry standards for air-handling systems

The natural question to be asked when building assessment systems such as LEED are codified into standards is: Is there now a purpose for the organization that originated the assessment system? The building department in each jurisdiction would have the task of evaluating projects for compliance with green building codes and standards. The likely answer is that organizations such as the USGBC will be developing next-generation building assessment systems to push the envelope and maintain the momentum of the green building movement of the past three decades. Additionally, green building standards and codes do not provide an actual certification, which still may have value to a building owner, and only a building assessment system proponent such as the USGBC can provide this outcome.

THE NET ZERO BUILT ENVIRONMENT

A powerful movement centered on the concept of net zero is emerging and setting targets for resource consumption based on one of the core ideas of sustainability that suggests that humans should be surviving using the local resources provided by nature. In the case of energy, the main concept that has emerged is the design and construction of grid-tied buildings that are powered by PV electricity and that have been designed to generate at least the same amount of energy they consume over the course of a year. These buildings are commonly referred to as *net zero energy (NZE)* buildings. The National Renewable Energy Laboratory Research Support Facility described in Chapter 1 is an excellent example of an NZE office building that generates at least as much energy annually as it consumes. A second emerging net zero concept is known as *net zero water*, which requires that the building users depend on recycled water and water falling on the building site for 100 percent of their water needs. The US Army is a major proponent of this concept and defines a net zero water installation as one that "limits the consumption of freshwater resources and returns water back to the same watershed so not to deplete the groundwater and surface water resources of that region in quantity and quality over the course of a year" (Department of the Army 2007, p. 1).[10] The Army is also engaged in a broader net zero initiative that addresses energy and waste as well as water. The 2010 European Union Energy Performance of Buildings directive requires "near" NZE buildings for all new construction by 2020, with the deadline for public-sector compliance

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set for 2018.[11] The California Energy Commission is recommending that the state require NZE for residential construction by 2020 and for commercial buildings by 2030 (Energy Upgrade California 2011). The LBC requires both NZE and net zero water performance for buildings certified by its assessment system. This concept is also being extended to net zero emissions, net zero carbons, net zero land, and even net zero materials.

THE LIVING BUILDING CHALLENGE

The clear leader in building assessment systems in terms of degree of difficulty is the LBC, a product of the Cascadia Green Building Council that joins American green building efforts in the Pacific Northwest with similar efforts in British Columbia, Canada. The LBC requires, among many other stringent measures, NZE, net zero water, and the processing of all sewage on-site. Additionally, unlike other assessment systems that provide several levels of certification, the building either is certified to LBC or is ineligible for certification because it fails to meet at least one of the imperatives spelled out in the requirements. One other outstanding feature of the LBC is that the building actually must demonstrate, via its operation, that it meets all the imperatives. Consequently, certification can be achieved only after one year of operation that demonstrates the building has met its objectives. The ambitious nature of the LBC and its stringent requirements make it the gold standard of building assessment systems and provide a truly remarkable and challenging approach that other assessment systems may want to emulate as they evolve over time. A far more detailed description of the LBC can be found in Chapter 4.

ENVIRONMENTAL PRODUCT DECLARATIONS

The emergence of EPDs in which third-party entities provide an independent, public, and transparent environmental analysis of materials and products intended for construction is a significant step forward in the development of a greener built environment. By providing the equivalent of a nutrition label for building products, the stage is now set for competition among producers to develop the most environmentally friendly products. One of the early adopters of EPDs for its products is InterfaceFLOR Corporation, a manufacturer of carpet tiles. The widespread use of EPDs also creates the potential for whole-building life-cycle assessment in which trade-offs of building materials for reduced energy consumption can be examined to find the optimal relationship. Companies such as InterfaceFLOR are viewing EPDs as an asset, not a liability, because EPDs allow them to more fully communicate their corporate values to their customers, an especially important and useful outlook as the green building certification process moves toward an era where the majority of construction and major renovation projects are green buildings. More about EPDs and their significance can be found in Chapter 11.

CARBON ACCOUNTING FOR THE BUILT ENVIRONMENT

Of the 100 quadrillion BTUs consumed annually in the United States, about 65 percent, or 65 quads (1 quad = 1 quadrillion BTUs), are used by the built environment, and this number, both as a percentage of total energy and in absolute terms, continues to rise. The energy system is powered largely by the combustion of fossil fuels, and as a consequence, any increase in energy consumption also tends to increase the carbon footprint of the activity. The potential consequences of climate change are so catastrophic that accounting for carbon is beginning to occur and project teams soon will be judged for merit based on how well the building minimizes the total carbon invested in its materials of construction and associated with its operational

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energy over its useful life. As the consequences of climate change become more apparent, stringent measures to control greenhouse gas emissions are likely. Due to the scale of emissions of the built environment, it is a likely target for increased and even draconian standards. One interesting outcome of the NZE movement discussed earlier is that a building that uses renewable energy for all of its energy needs has, in effect, a net zero carbon footprint with respect to its operational energy. The reuse of existing buildings and materials extracted from buildings undergoing demolition are other measures that have been identified to reduce the carbon footprint of buildings because reuse has virtually no carbon associated with it. The more durable a building, the lower is its embodied carbon per unit time. Chapter 12 provides a more detailed description of carbon accounting practices for buildings and how it is affecting the design of contemporary high-performance green buildings.

Case Study: Green Skyscrapers

Over the past decade, two keenly waged competitions among the world's great cities have been gaining notoriety: the bragging rights to the world's tallest skyscraper and the world's greenest building. More recently, these two competitions have converged into a battle as to which city has the world's greenest skyscraper. Numerous huge structures labeled as green are emerging in countries as far apart as China, the United States, and Indonesia. The question that begs to be answered is: Can these enormous structures be truly green, or is this simply another blatant case of greenwash? How can these massive, largely glass-clad structures be anything but enormous energy hogs?

Skyscrapers, as a class of building, concentrate business and other activities in dense metropolitan areas, and they are a necessity because property values are staggeringly high in the world's great cities. Recent urban land prices were in the range of $24,000 per square meter in New York, Sydney, Paris and Moscow. Land in Hong Kong is twice as expensive at about $50,000 per square meter, and land in Singapore and London is in between, with costs of about $35,000 per square meter. To be classified as a skyscraper, a building should be at least 492 feet (150 m) high, which translates to 40 to 50 stories. Skyscraper heights have soared over the past decade, doubling and quadrupling in size and various classes of skyscrapers are now recognized. *Supertall* is a classification for skyscrapers that are double the minimum threshold of 150 m and are upward of 984 feet (300 m) in height. Structures that are double the size of supertall buildings, that is, buildings that are 1969 feet (600 m) or more in height are classified as *megatall*. The world's tallest skyscrapers, and the only two in the megatall category are the Burj Khalifa in Dubai with a height of 2717 feet (828 m) and the Tokyo Skytree at 2080 feet (634 m). The Kingdom Tower in Jeddah, Saudi Arabia with a height of 3280 feet (1000 m) will replace the Burj Khalifa as the world's tallest building when it opens in 2017. However, none of these three buildings was designed using green strategies. Green skyscrapers that have earned a degree of fame include the 99-story Pertamina Energy Tower (Jakarta), the 99-story One World Trade Center (New York City), the 128-story Shanghai Tower (Shanghai), and the 71-story Pearl River Tower (Guangzhou, China).

In the next sections we examine the world's great green skyscrapers, first by reviewing several international case studies and then by examining the progress of green skyscraper design in New York City, one of the hotbeds for large, green structures.

INTERNATIONAL GREEN SKYSCRAPERS

Perhaps the most progress in the development of truly green skyscrapers is occurring on the international scene, with a wide variety of new projects that combine daring architecture with cutting edge approaches to green building. Table 16.2 contains statistics on three international examples. The next sections describe the significant green attributes of these buildings.

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TABLE 16.2

Selected International Skyscrapers

Skyscraper Name	Year Built	Stories	Height	Certification
Pertamina Energy Tower	2020	99	1740 ft (530 m)	Under construction
Shanghai Tower	2015	128	2073 ft (632 m)	LEED Gold
Pearl River Tower	2011	71	1016 ft (329 m)	LEED Platinum

The Pertamina Energy Tower

Around the world, green skyscrapers are now emerging at an ever increasing pace. A newly announced green tower for Indonesia's state-owned energy company, Pertamina, is under construction and slated for completion in 2020. It will be a 99-story, 530-meter- (1740 ft) tall NZE building in the supertall category. With a floor area of 540,000 square meters (5.8 million square feet) it will house 20,000 employees. Skidmore, Owings, and Merrill (SOM), the architecture firm designing the Pertamina Energy Tower, stated that this is the first case of a skyscraper where energy is the primary consideration in its design. The tower relies on geothermal, solar, and wind energy, and will have a self-contained central power plant. A wind funnel in the crown of the building, created by rounding and tapering the structure as it reaches skyward, permits the use of wind turbines to convert the kinetic energy of the high winds at this elevation into electricity to power the building. Extensive use of PVs built into the skin of the building provides additional renewable energy. Net zero implies low energy consumption, and the Pertamina Energy Tower will have a sophisticated system of exterior sun shades for blocking direct sunlight and admitting daylighting over the course of the year. The central energy plant in the building uses geothermal energy, a resource Indonesia has in abundance, as the major source of renewable energy. The air-conditioning system relies on radiant cooling to move "cooling" around the facility, a far more efficient approach than using forced air. The building also features zero water run-off and water recycling. As green as the Pertamina Energy Tower is on paper, the critical issue is how well it will perform in operation and how well the actual performance maps onto the computer modeling that predicted its energy consumption. A more detailed case study about the Pertamina Energy Tower is provided in Chapter 1.

The Shanghai Tower

The second tallest structure in the world, after the Burj Khalifa in Dubai, and the tallest building in China is the 128-story, 2073-ft (632-m) Shangahi Tower, completed in 2015 in the Pudong New Area section of Shanghai. Designed by Gensler, the building is essentially a stack of nine cylinders, each rotated slightly on the one below, giving it a twisting spiral appearance. In addition to giving the Shanghai Tower its unique aesthetic, the design reduces wind loads by 24 percent during typhoons, with an additional important benefit being a reduction in structural steel by 25 percent compared to conventional design. Models of the $4.2 billion building were extensively tested in a wind tunnel lab in Toronto, Canada, to determine the effects of swirling winds along the 2000-foot (610-m) length of the building. The twisted stack of cylinders comprising the tower has a facade comprised of a double layer of reinforced, insulated glass that promotes daylighting while also reducing external noise intrusion. Geothermal energy sources provide energy for heating and cooling. The building structure incorporates 270 vertical axis wind turbines (VAWT) in the upper section of the skyscraper, providing about 350,000 kWh of electricity each year. A rainwater collection system helps meet the water needs of the building and reduces potable water consumption. The Shanghai Tower accommodates 16,000 people on a daily basis in its retail stores, office space, cafés, gardens, restaurants, and luxury hotel inside its triangle shaped glass structure.



Figure 16.9 The Pertamina Energy Tower, a 99-story, 530-meter (1740 ft) supertall skyscraper, designed by Skidmore, Owings, and Merrill, under construction in Jakarta, Indonesia and scheduled for completion in 2020. (Photo courtesy of SOM Architects)

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Figure 16.10 The Shanghai Tower, which was designed by Gensler and completed in 2015, is a 128-story, 2073-ft- (632-m-) high green skyscraper. (Photo courtesy of Tony Wasserman)



Figure 16.11 Pearl River Tower, 71 stories, 310 meters (1016 ft), designed by SOM, completed in 2011 (Photo courtesy of Brad Wilkins)

The Pearl River Tower, Guangzhou, China

One of the present day outstanding examples of operating green skyscrapers is the Pearl River Tower in Guangzhou, China designed by Skidmore, Owings, and Merrill (SOM). Completed in 2011, it is 71 stories and 1020 feet (311 m) in height, categorizing it as a supertall skyscraper. Located in Guangzhou's business district, it is situated among a group of other skyscrapers. However it stands out from its neighbors as a ultra-green building that was originally designed to achieve NZE, meaning that the original concept was that the building's built-in renewable energy systems would generate as much energy on an annual basis as it consumes. For several technical reasons the Pearl River Tower did not quite achieve the lofty goal of becoming net zero but it did earn a LEED Platinum rating. One of the signature achievements of the design team is that the building is forecast to consume 40 percent less energy than a tower built to ASHRAE Standard 90.1–2007, which was the basis for assessing energy performance at the time of its design. Key features in the energy design of the Pearl River Tower were two pairs of VAWTs located at floors 25 and 50. The VAWTs had the additional benefit of reducing the differential pressure across the building between the windward and leeward sides, resulting significant structural steel savings. The building was oriented to take advantage of the prevailing southern winds and to capture the available solar and wind energy. PV panels are built into the glazed roof and into shading louvers mounted on the narrow east and west façades, providing maximum

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TABLE 16.3

Selected Green Skyscrapers in New York City

Name	Year Completed	Stories	Architectural Height	EUI kWh/m^2/yr	Certification
Empire State Building	1931 (renovated in 2010)	102	1250 ft (449 m)	74.6	LEED Gold - Existing Buildings
Hearst Tower	2006**	46	597 ft (182 m)	81.3	LEED Gold
New York Times Building	2007	52	1046 ft (319 m)	152.8	Uncertified
Bank of America Tower	2009	55	1200 ft (366 m)	211.2	LEED Platinum – Core & Shell
One World Trade Center	2015	104	1776 ft (541 m)	No data	LEED Gold***

* EUI or Energy Use Index is a metric for comparing energy consumption. The units are kilowatt-hours per square meter per year or kBTU/ft^2/yr. Data is from the 2013 New York City energy consumption survey.
** The Hearst Tower was constructed on top of the old Hearst Building, which was completed in 1926.
*** A LEED rating has not been awarded and the gold-level rating is projected

exposure for generating solar electricity and for protecting the occupants from the sun's glare. The combination of VAWTs and PV panels results in the annual production of two 32 megawatts of electricity, which offsets a portion of the building's energy load.

A wide range of integrated technologies were employed to maximize the building's energy performance. These included a raised floor displacement ventilation system, a double wall façade with a 9-inch-wide (23 cm) cavity, and radiant cooling panels that also contain a daylight-responsive light-emitting diode (LED) system. The office floors are cooled by chilled water circulated in copper tubing in the ceiling panels and the displacement ventilation system. The double wall façade helps increase the energy performance of the building while at the same time mitigating the effects of noise from the exterior. It also provides health benefits by protecting the occupants from the chronic air problems of China's larger cities. The use of radiant cooling allowed the use of minimal ductwork, a reduction in the floor to floor height by about 12 inches (30 cm), thus permitting the addition of five additional floors to the building for the same height, a huge bonus for the building's owner.

NEW YORK CITY'S GREEN SKYSCRAPERS

New York City recently started a block-by-block mapping of energy consumption and in the process created a database that reveals the range of building performance for the prominent green skyscrapers in Manhattan. Table 16.3 summarizes some of the key attributes of what some consider to be the greenest skyscrapers in New York. The extreme variation in Energy Use Index (EUI) among these buildings is remarkable and indicative of the trend in increased energy consumption by newer buildings compared to older skyscrapers. Some of this increased energy consumption, particularly in Bank of America (BOA) Tower, is caused by activities in the building, such as numerous floors of computers and other electronic devices that are commonplace in the newer buildings. Nevertheless, the Empire State Building's EUI of just 74.6 kWh/m^2/yr is quite impressive for any building, and its recent retrofit is a testament to how much energy savings intelligent energy conservation strategies can wring out of urban buildings.

The Empire State Building

The Empire State Building (see Figure 16.12) is an icon of engineering achievement. Completed in 1932, it recently underwent an extensive green retrofit that focused largely on energy efficiency. As a historical building, it faces the same dilemmas as many other older buildings—the space eventually becomes unattractive for first-class

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Figure 16.12 The 80-year old Empire State Building underwent a major green retrofit starting in 2009 and finishing in 2014. The result is a remarkable success story of energy and savings, new first-class tenants, and an energy retrofit model for many other large urban buildings. (Photo courtesy of Jiuguang Wang)

tenants and the owner experiences difficulty competing with newer properties. In 2009, the building was retrofitted under the Clinton Climate Initiative Cities Program and the C40 Cities Climate Leadership Group, the climate initiative among US cities. The retrofit was highly successful and exceeded expectations, with the energy savings about 5 percent higher than the $2.4 million guaranteed by Johnson Controls, the energy retrofit contractor. The $550 million retrofit will be repaid by the energy saved over the life of the contract. The building received a USGBC LEED-Gold for Existing Buildings, and it was also Energy Star certified. The success of the Empire State Building retrofit had a huge impact on similar products across the United States, and the model was replicated for 70 commercial buildings in New York and New Jersey as well as in San Francisco and for Chicago's Union Station. Remarkably, the Empire State Building actually uses significantly less energy than other LEED-certified buildings with an EUI of 74.6 kBTU/ft^2/yr.

The Empire State Building upgrade focused on eight key areas: installing insulation behind all radiators, a chiller plant retrofit, new building management system controls, new revenue-grade meters serving the entire building, and a web-based tenant energy management system. The building's 68 elevators were retrofitted and are now 30 percent more efficient than previously, and the lighting system was upgraded to all LED lights. The overall cut in energy consumption is estimated to be about 38 percent, producing a $4.4 million annual savings. If extrapolated over the entire US building stock, the savings would be astounding, as would be the impacts on US carbon emissions. Buildings contribute to 40 percent of the total US carbon emissions and up to 80 percent in densely populated cities such as New York.

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The Bank of America Tower

The opening move in the global green skyscraper contest likely occurred in New York City with the construction of the Bank of America (BOA) Tower, which was completed in 2009 (see Figure 16.12). Although awarded a LEED Platinum rating by the USGBC for its many documented sustainable features, such as green materials, excellent air quality, and superior water efficiency, the building's energy performance was unremarkable, and it was consuming more energy than the 80-year-old Empire State Building. One critic of the building said that the tower ranked 53rd on the list of New York office buildings in per-square-foot energy consumption and that it was a poor reflection on green buildings. The contrast of being awarded a LEED Platinum rating and having inferior energy performance initially created a credibility problem for the green building movement and also pointed out the need to enforce minimum improvements in energy performance, something that had not been a mandate of LEED prior to 2009. However, as is often the case, there was another side to this story. The BOA Tower was certified using the LEED for Core and Shell rating system, designed for commercial buildings where the completion of office spaces, retail, and financial operations space is left to the clients who will lease the space after construction. For Core and Shell projects, the developer does not have an exact fix on tenants' energy consumption profiles; consequently, the energy modeling focuses on the base systems of the building with educated guesses for tenant consumption. As it turned out, the BOA Tower is occupied by firms with enormous numbers of computers and servers working around the clock on trading floors that occupy about one-third of the building, an operational characteristic not entirely under the control of the project team designing the building. One of the difficulties with assessing the energy performance of buildings in general and skyscrapers in particular is that of normalizing energy performance to allow comparisons. Some buildings operate around the clock while others have 12-hour operations. And others house energy-intensive functions, such as computer-intensive trading floors, which greatly boost energy consumption. It is difficult enough to compare performance for buildings in a specific locale, such as New York City, and even more challenging when comparing building performance in New York to comparable buildings in, for example, Miami. Probably the most accurate assessment of the BOA Tower is that it does have numerous green attributes but that its energy performance may or may not be as good as expected. Newer versions of LEED, such as LEED versions 3 (2009) and 4 (2013), address this problem and require at least a minimum level of improvement in energy performance for all certified green buildings.

The case of the BOA Tower also highlighted deficiencies in the energy modeling process, which is the basis on which energy points are awarded. In LEED, energy points are extremely important for achieving high ratings, such as platinum or gold. For the BOA Tower, the energy modeling had predicted superior energy performance and as a result the project earned 50 points, two more than the minimum 48 point threshold for the top Platinum rating. For most green building rating systems, such as LEED and Green Globes, the award of a rating such as the LEED Platinum rating earned by the BOA Tower is based in part on computer simulation and not the actual performance of the building. Clearly there was a big gap between the actual performance of the tower and the computer simulation used to earn points for the award. One of the main attributes of skyscrapers is that they tend to use more energy per square foot or square meter as the building height increases. The need for elevators to lift people higher and the increased vertical movement of water and materials naturally causes more energy consumption.

One World Trade Center (Freedom Tower)

One World Trade Center (see Figure 16.14) in New York, commonly referred to as the Freedom Tower, is the tallest building in the Western Hemisphere at 1776 feet (541 m) and also the most expensive building in the world, with a price tag of $3.8 billion. It was one of seven towers designed to replace the twin towers of the

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Figure 16.13 The Bank of America Tower, a LEED Platinum—Core and Shell green skyscraper completed in 2009. (Ryan Browne, Cook+Fox Architects)



Figure 16.14 One World Trade Center in New York, 94 stories, 1776 feet (541 meters), 2014. The building was designed by Daniel Libeskind along with David Chiles of Skidmore, Owings, and Merrill. (SOM Architects)

World Trade Center, destroyed in the terrorist attacks of September 11, 2011. When its design was initiated in 2006, One World Trade Center was slated to become the greenest skyscraper in the world. The goal was a LEED Platinum certification from the USGBC. The designers made extensive use of natural light to illuminate the interior, and LED lighting was used as the backbone of the building's artificial lighting system. There was emphasis on responsible use of water, with the selection of very-low-water-consumption plumbing fixtures and the construction of two 25,000-gallon (94,600 liters) storage tanks on the 57th floor to collect rainwater to support building operations. Although the specific details of the building's energy performance were not made public, building designers specified that it would have exceptional energy efficiency. The centerpiece of the building's energy system was to be a bank of nine fuel cells designed to generate electricity from natural gas at high efficiency and also to help heat and cool the building. The fuel cells were to

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Figure 16.15 The New York Times Building is a green building that did not seek green building certification. It was designed by Renzo Piano and completed in 2007. (Figure A: Kevin Prichard. Figure B: Renzo Piano.)

serve One World Trade Center and towers Three and Four, providing 10 percent of the electricity for the One World Trade Center and a combined 30 percent for towers Three and Four. However, in the fall of 2012, Hurricane Sandy struck the New York metropolitan area and dumped about 200 million gallons (757 million liters) of water into the lower floors of the site, destroying the fuel cells. The green building certification process has not been completed due to the issues with the fuel cells. Nevertheless, One World Trade Center remains an exceptionally green skyscraper. At present, the USGBC lists One World Trade Center as projected to earn a LEED Gold rating. It remains a possibility that the fuel cells will be replaced and the building will once again meet all its original design objectives.

The New York Times Building

The 52-story, 1.5-million-square-feet (139,000 square meters) New York Times Building (see Figure 16.15) was designed by Renzo Piano. Although it was not formally certified as a green building, it has many significant green features that certainly make it a high-performance building. Among these features are a double-skin curtain wall system, automated interior louvers, a dimmable lighting system, UFAD, and a cogeneration system. The double-skin curtain wall system is comprised of glass and ceramic silicate rods glazed with a finish that reflects light. The ceramic rods act as a sun screen and contribute to the building's

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aesthetics. The glazing system consists of a floor to ceiling, water-white, low-iron glass envelope, allowing ample natural light into the building. The automated louver shading system is programmed to respond to sun position and to data from sensors in the building providing illumination data. With these inputs, the control systems move the shades, either raising or lowering them to block extreme glare and to permit light to enter when there is no direct sunlight. One of the main goals of the project team was to reduce lighting energy significantly, which can be as much as 44 percent of the total electricity consumption of a skyscraper. This was accomplished through the design of the double-skin curtain wall system, integrated with the interior automated shading system, and a lighting system with controls that maximizes daylight harvesting, using the electric lighting system as a supplement. All three of these systems work together to maximize natural light and to minimize electrical consumption by the lighting system. As part of the lighting system, the building has 18,000 electrical ballasts, each under computer control and programmed to provide exactly the amount of lighting needed in any space at any moment.

The building is provided with an UFAD system to save energy and improve thermal comfort and indoor air quality. The air handling system feeds conditioned air under the floor for distribution to floor diffusers located throughout the spaces. This strategy provides low-velocity air into the spaces, slowly filling them with conditioned air and providing extreme flexibility when relocation of office spaces is required. The combination of a high-performance façade, daylighting, an integrated lighting system, and an UFAD system resulted in a 24 percent reduction in energy consumption compared to the code-compliant base case.

Another important feature of the New York Times Building is its cogeneration plant which provides 40 percent of the power needed for the building's operation. The plant consists of two natural gas–powered generators that can generate up to 1.5 megawatts electrical power. The waste heat from the generators is captured and converted into useful energy to provide heating during the winter and cooling via absorption chillers in the summertime. The system is designed such that the cogeneration system is the primary source of energy and the grid power serves as the backup.

The Hearst Tower

The Hearst Tower (see Figure 16.16) has several unique distinctions as a green building. It was certified as a LEED Gold—New Construction building by the USGBC and became New York City's first green office tower in 2006. In 2012 it was certified again, but this time as a LEED Platinum building under the USGBC's Existing Buildings: Operations and Maintenance program. During the demolition of the original six-story structure on the site, the project team separated and recycled 90 percent of the 1926-era structure for reuse. The Hearst Tower is also distinguished in its design by Sir Norman Foster of Foster and partners. The building structure is a so-called diagrid system, a series of four-story triangles on the façade, that give the building its distinct architectural appearance and that also resulted in a savings of 2000 tons (1814 metric tons) of steel, a 20 percent savings over a conventional design. The building also features extensive use of low-emissivity coated glass that filters out significant amounts of heat or infrared energy from the exterior light while allowing visible light to enter the building. The Hearst Tower has a highly integrated system of daylighting and artificial lighting with sensors installed throughout to detect the amount of natural light at any given time and to provide electrical power lighting only as a supplement. A system of occupancy sensors also is tied into the lighting system to detect human occupancy and to turn lights on and off based on the occupants in the space. The result of these energy saving features is a 26 percent reduction in energy consumption compared to a base building. The tower is also equipped with a rainwater harvesting system that collects water in a 14,000-gallon tank in the basement of the building and is used to support the air-conditioning system and to irrigate interior and exterior landscaping.

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Figure 16.16 The Hearst Tower, designed by Sir Norman Foster, was credited as being New York City's first green skyscraper when it opened in 2006 (Justin Wilcox).

The design minimized the number of interior walls to maximize the transit of natural light across the spaces, and interior walls received light-colored finishes to further enhance daylighting.

The LEED Platinum rating awarded to the building in 2012 was a result of the Hearst Corporation's commitment to maintaining and improving on the green attributes of the facility. Data indicate that energy consumption was actually reduced by 40 percent; waste going to landfills was reduced by 82 percent. It was the first office building in New York City to adopt a composting program that processes 100 percent of its wet food waste. The rainwater system has turned out to be a big success story, and data indicate that potable water usage has been reduced by 30 percent annually.

THOUGHT PIECE: FRACTALS AND ARCHITECTURE

Ecological design is without a doubt the linchpin of sustainable construction and green building. At present, however, it is not well defined, which means that green building design has a shaky foundation. Kim Sorvig, a research professor at the School of Architecture and Planning at the University of New Mexico in Albuquerque and coauthor with Bill Thompson of *Sustainable Landscape Construction* (2000), has created the notion of fractal architecture as a bridge to ecological design. His reflections on the transition between the built and natural environments are excerpted here.

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Processes, Geometries, and Principles: Design in a Sustainable Future

Kim Sorvig, Research Associate Professor, School of Architecture and Planning, University of New Mexico, Albuquerque



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Sustainability is about integrating constructed and living systems. To integrate two different processes or entities, each must be clearly understood in its own right. I am convinced that deepening our understanding, not only of ecology but also of building, is an essential evolution of sustainable design.

Today's understanding of the inherent qualities of constructed systems is detailed and pragmatic, but we often fail to question important principles. Conversely, designers' understanding of ecological systems is generalized, frequently romanticized. In both areas, the relationships between processes (the use of a building, the life cycle of a watershed) and geometries remain unconsidered, with shapes and patterns designed by habit and without insight. There is a pressing need to understand, factually and concisely, the core qualities of constructed and natural systems and to use differences and similarities among these systems creatively.

The core qualities that pertain most to sustainable design can be called processes, geometries, and principles. The future of sustainable design may lie less in technical innovation than in whether designers can work out the conflicts between the core qualities of natural systems and those of human development.

Construction does not create its raw materials, but shapes existing substances into units and assembles those units into structures. This is so obvious that it is often overlooked, but it has a critical effect on the processes and geometry of construction.

The essential processes of construction are cutting and assembling, plus form casting. In natural systems, direct parallels to these form-making processes (especially cutting and assembly) are rare. The processes of making bricks and then building an arch with them is categorically different than the process by which erosion creates a stone arch. Construction is a controlled system, dominated by a selected force (e.g., a saw blade) with extraneous forces excluded (by using jigs and clamps to prevent unplanned movement).

The geometry of construction is based on its processes: cutting and assembling are most efficient when using regular, smooth, Euclidean forms. Such forms also lend themselves to easy measurement and calculation.

Form making in geological and biological systems is markedly different from construction processes. Nature's processes are growth, decay, deposition, and erosion, all radically different from the assembly processes of construction. Natural processes are part of an "open" system, with many forces interacting, no one dominating for long.

Mathematical understanding of the geometry of nature is recent, and designers are just beginning to appreciate it. Resulting from growth/decay processes, the forms characteristic of nature are called fractals. They result when multiple

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forces interact repeatedly over time. No matter what scale they are viewed at, or at what period in time, their forms remain self-similar (like endless variations on a constant theme). Two points are important here:

1. Fractals represent long-term dynamic stability among many forces in a system, with no single dominant force (virtually a definition of biodiversity and health).
2. Fractals are the optimal geometry for doing what natural systems do—collecting, transporting, and diffusing resources; filtering and recycling wastes; and so on.

Construction is ultimately about creating environments from which the forces of climatic and ecological change are excluded (temporarily). Every structure conflicts to some degree with both the processes and the forms of nature. Construction optimizes a few select functions; natural systems appear to optimize for diversity. Construction aims for structural permanence; natural systems self-organize stability through change. Both require resource efficiency, but achieve it differently.

Recognizing the core qualities of built and living systems can help generate new sustainability strategies and evaluate existing ones. One strategy is making built systems more fractal or naturalistic in form: biomimicry (to oversimplify). Cyclical buildings, stability-in-change, and literal integration of landscape with building are other strategies.

Sustainable geometries are, I believe, the next evolution for design. Energy-efficient, materials-efficient structures in the same old shapes and the same old locations are unlikely to be enough. Sustainable design's future is at the edge between buildings and landscapes, where the forms necessary for human structures interface with the forms essential to living systems. Designerly preoccupation with appearance—with buildings that stand out and that privilege machine-look over naturalism—is clearly not helping. We must apply our visual skills to understand how form and function interact, not just in architecture, not just in nature, but at the borders between the two.

Kim Sorvig is at work on a new book on this topic, tentatively titled *Scenery and Survival: Why Humans Evolved a Sense of Environmental Beauty and Why It Matters Today.*

Summary and Conclusions

Describing the qualities of the future high-performance green building is an essential and crucial step toward making real progress in this area. Three possible approaches have been described in this chapter: the vernacular vision, the high-technology approach, and the biomimetic model. Each, or a combination, may be able to answer some of the questions faced today by professionals involved in the high-performance green building movement, which, because it is relatively new, is heavily constrained by a narrow knowledge base, limited availability of appropriate technology, and the absence of a clear vision of the future. A robust theory of ecological design is sorely needed, as, fundamentally, that is what the design of high-performance green buildings is about: developing a human environment that functions in a mutually beneficial relationship with its natural surroundings and that exchanges matter and energy in a symbiotic manner.

Notes

1. Wilson also noted that the requirements for passive survivability and the sustainable design features of many green buildings were remarkably similar.
2. The New Orleans Principles can be found at www.usgbc.org/ShowFile.aspx?DocumentID=4395.
3. Factor 10, which is now part of European Union policy, is influencing change to a sustainable system of production and consumption by providing a target reduction in resource consumption of 90%.
4 An ecological footprint is the land area, in acres or hectares, that a person or activity needs to function on a continuing basis. The term can also be applied to the built environment, for which a measurement such as ecological footprint per 1000 square feet (100 square meters) of building area is a potential metric for comparing building impacts. The term was popularized by Wackernagel and Rees (1996).

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5. The ecological rucksack of a material is the total mass of materials that must be moved to extract a unit mass of the materials, expressed as a ratio. This term was coined by the Wuppertal Institute in Wuppertal, Germany, to draw attention to mass movements of materials that are changing the surface of the planet. Historically, attention has been paid to the impacts of toxic materials, such as DDT and PCBs, which are harmful in the microgram range. The ecological rucksack concept looks at the other end of the materials spectrum—the megaton-range movements of materials to extract resources. The bottom line is that both micrograms of toxic materials and megatons of less harmful materials should be accounted for with respect to their impacts.
6. "Defaulting to nature" is an expression used by Randy Croxton of the Croxton Collaborative in New York City to describe the ability of a well-thought-out, passively designed building to provide heating, cooling, and lighting for its occupants, thus ensuring its operability in spite of being disconnected from external energy sources—for example, the electric power grid.
7. Natural systems match the energy source and its quality to energy use first (effectiveness) and then maximize the system's efficiency. Human-designed systems, in contrast, tend to focus on efficiency alone and neglect energy quality, thus often spending high-quality energy (e.g., electricity) on building needs that could be better served by low-quality energy (e.g., medium-temperature heat). Quality is a measure of the flexibility of applications for a particular energy source. Electricity can be used to drive electric motors and generate power to move vehicles, while moderate-temperature heat (below that of the boiling point of water) has limited application and flexibility. The lower the temperature of the heat source is, the lower the quality of the energy. Using electricity for water heating has a very low level of effectiveness because it uses high-quality energy in an application that could use low-quality energy sources.
8. The maximum power principle was hypothesized by the eminent ecologist H. T. Odum, the founder of a branch of ecology known as *systems ecology*. In its simplest form, the principle states that the dominant natural systems are those that pump the most energy.
9. As is often stated in the green building area, there is no waste in nature; all materials are kept in productive use. Of course, this is very simplified and, strictly speaking, not even true.
10. The Army website for its net zero initiative is www.army.mil/asaiee.
11. See https://ec.europa.eu/energy/en/topics/energy-efficiency/buildings/nearly-zero-energy-buildings.

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Appendix A

Quick Reference for LEED 3.0

Quick Reference for LEED v3.0	Commercial Interiors	Core & Shell	Healthcare	New Construction	Retail: New Construction	Schools
Total possible points	110	110	110	110	110	110
Sustainable sites (SS)	21	28	18	26	26	24
Construction activity pollution prevention		Prereq	Prereq	Prereq	Prereq	Prereq
Environmental site assessment			Prereq			Prereq
Site selection	5	1	1	1	1	1
Development density and community connectivity	6	5	1	5	5	4
Brownfield redevelopment		1	1	1	1	1
Alternative transportation					10	
Alternative transportation—Public transportation access	6	6	3	6		4
Alternative transportation—Bicycle storage and changing rooms	2	2	1	1		1
Alternative transportation—Low-emitting and fuel-efficient vehicles		3	1	3		2
Alternative transportation—Parking capacity	2	2	1	2		2
Site development—Protect or restore habitat		1	1	1	1	1
Site development—Maximize open space		1	1	1	1	1
Stormwater design—Quantity control		1	1	1	1	1
Stormwater design—Quality control		1	1	1	1	1
Heat island effect—Nonroof		1	1	1	2	1
Heat island effect—Roof		1	1	1	1	1
Light pollution reduction		1	1	1	2	1
Site master plan						1
Joint use of facilities						1
Tenant design and construction guidelines		1				
Connection to the natural world—Places of respite			1			
Connection to the natural world—Direct exterior access for patients			1			
Water efficiency (WE)	11	10	9	10	10	11
Water use reduction—20% reduction	Prereq	Prereq	Prereq	Prereq	Prereq	Prereq
Minimize potable water use for medical equipment cooling			Prereq			
Water-efficient landscaping		4	1	4	4	4
Innovative wastewater technologies		2		2	2	2

(continued)

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Quick Reference for LEED v3.0	Commercial Interiors	Core & Shell	Healthcare	New Construction	Retail: New Construction	Schools
Water use reduction	11	4	3	4	4	4
Water use reduction—Measurement and verification			2			
Water use reduction—Building equipment			1			
Water use reduction—Cooling towers			1			
Water use reduction—Food waste systems			1			
Process water use reduction						1
Energy and atmosphere (EA)	37	37	39	35	35	33
Fundamental commissioning of building energy systems	Prereq	Prereq	Prereq	Prereq	Prereq	Prereq
Minimum energy performance	Prereq	Prereq	Prereq	Prereq	Prereq	Prereq
Fundamental refrigerant management	Prereq	Prereq	Prereq	Prereq	Prereq	Prereq
Optimize energy performance		21	24	19	19	19
Optimize energy performance—lighting power	5					
Optimize energy performance—Lighting controls	3					
Optimize energy performance—HVAC	10					
Optimize energy performance—Equipment and appliances	4					
On-site renewable energy		4	8	7	7	7
Enhanced commissioning	5	2	2	2	2	2
Enhanced refrigerant management		2	1	2	2	1
Measurement and verification	5		2	3	3	2
Measurement and verification—Base building		3				
Measurement and verification—Tenant submetering		3				
Green power	5	2	1	2	2	2
Community contaminant prevention—Airborne releases			1			
Materials and resources (MR)	14	13	16	14	14	13
Storage and collection of recyclables	Prereq	Prereq	Prereq	Prereq	Prereq	Prereq
PBT Source reduction—mercury			Prereq			
Building Reuse	2					
Building reuse—Maintain existing walls, floors, and roof		5	3	3	3	2
Building reuse—Maintain 50 percent of interior nonstructural elements			1	1	1	1
Construction waste management	2	2	2	2	2	2
Sustainably sourced materials and products			4			
Materials reuse	2	1		2	2	2
Materials—Furniture and furnishings	1					
Recycled content	2	2		2	2	2
Regional materials	2	2		2	2	2

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Quick Reference for LEED v3.0	Commercial Interiors	Core & Shell	Healthcare	New Construction	Retail: New Construction	Schools
Rapidly renewable materials	1			1	1	1
Certified wood	1	1		1	1	1
PBT source reduction—Mercury in lamps			1			
PBT source reduction—Lead, cadmium, and copper			2			
Furniture and medical furnishings			2			
Resource use—Design for flexibility			1			
Tenant space—Long-term commitment	1					
Indoor environmental quality (EQ)	17	12	18	15	15	19
Minimum indoor air quality performance	Prereq	Prereq	Prereq	Prereq	Prereq	Prereq
Environmental tobacco smoke (ETS) control	Prereq	Prereq	Prereq	Prereq	Prereq	Prereq
Hazardous material removal or encapsulation			Prereq			
Minimum acoustical performance						Prereq
Outdoor air delivery monitoring	1	1	1	1	1	1
Increased ventilation	1	1		1	1	1
Construction IAQ management plan—During construction	1	1	1	1	1	1
Construction IAQ management plan—Before occupancy	1		1	1	1	1
Low-emitting materials			4		5	4
Low-emitting materials—Adhesives and sealants	1	1		1		
Low-emitting materials—Paints and coatings	1	1		1		
Low-emitting materials—Flooring systems	1	1		1		
Low-emitting materials—Composite wood and agrifiber products	1	1		1		
Low-emitting materials—Systems furniture and seating	1					
Indoor chemical and pollutant source control	1	1	1	1	1	1
Controllability of systems—Lighting and thermal comfort		1			1	
Controllability of systems—Lighting	1		1	1		1
Controllability of systems—Thermal comfort	1		1	1		1
Thermal comfort—Design and verification			1			
Thermal comfort—Design	1	1		1	1	1
Thermal comfort—Verification	1			1	1	1
Daylight and views—Daylight	2	1	2	1	1	3
Daylight and views—Views	1	1	3	1	1	1
Enhanced acoustical performance						1
Mold prevention						1
Acoustic equipment			2			

(continued)

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Quick Reference for LEED v3.0	Commercial Interiors	Core & Shell	Healthcare	New Construction	Retail: New Construction	Schools
Innovation and design process (ID)	6	6	6	6	6	6
Integrated project planning and design			Prereq			
Innovation in design	5	5	4	5	5	4
LEED accredited professional	1	1	1	1	1	1
Integrated project planning and design			1			
The school as a teaching tool						1
Regional priority (RP)	4	4	4	4	4	4

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Appendix B

The Sustainable Sites Initiative™ (SITES™) v2 Rating System for Sustainable Land Design and Development

The central message of the SITES program is that "any project—whether the site of a university campus, large subdivision, shopping mall, park, commercial center, or even a home—holds the potential to protect, improve, and regenerate the benefits and services provided by healthy ecosystems."

The latest version of SITES was issued in 2012 in the form of an assessment tool, *SITES v2 Rating System for Sustainable Land Design and Development.* Since 2012, 46 projects have achieved SITES certification, including the Lady Bird Johnson Wildflower Center in Austin, Texas. The SITES guidelines and performance benchmarks offer four certification levels based on a four-star rating system, which works on a 200-point scale allocated among 48 credits. The four levels and the associated minimum points for each are shown next. For certification, a project must achieve all 19 of the prerequisites and at least 100 credit points to become certified with a rating of up to four stars. All prerequisites must be achieved. If just one of the prerequisites is not achievable, the project cannot be certified.

Certification Levels (200 Total Points)	
Certified	70
Silver	85
Gold	100
Platinum	135

The categories and structure of SITES are shown next. The letter "P" in the numbering of, for example, Context P1.1 in the Site Context Category indicates it is a *prerequisite* and must be accomplished for the project to be certified. No points are earned for meeting the requirements of a prerequisite. Similarly, a "C" in the nomenclature—for example, Context C1.5—is a *credit*, and the project can earn points by meeting the requirements of this credit.

Summary of SITES Categories, Prerequisites, Credits, and Points

1. **Site Context (13 points).** Select locations to preserve existing resources and repair damaged systems
   Context P1.1: Limit development on farmland
   Context P1.2: Protect floodplain functions

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Context P1.3: Conserve aquatic ecosystems (e.g., wetlands)
Context P1.4: Conserve threatened or endangered species and their habitats
Context C1.5: Select degraded sites for redevelopment (3–6 points)
Context C1.6: Select sites within developed areas (4 points)
Context C1.7: Select sites that connect multimodal transit networks (2–3 points)

2. **Predesign Assessment and Planning (3 points).** Plan for sustainability from the onset of the project
   Predesign P2.1: Use an integrated site development process
   Predesign P2.2: Conduct a predesign site assessment
   Predesign C2.3: Designate and communicate Vegetation and Soil Protection Zones (VSPZs)
   Predesign C2.4: Engage users and other stakeholders in site design (3 points)
3. **Site Design—Water (23 points).** Protect/restore processes and systems associated with site hydrology
   Water P3.1: Manage on-site precipitation
   Water P3.2: Reduce potable water use for landscape irrigation
   Water C3.3: Manage precipitation beyond baseline (4–6 points)
   Water C3.4: Reduce outdoor water use (4–6 points)
   Water C3.5: Design functional stormwater features as amenities (4–5 points)
   Water C3.6: Restore aquatic ecosystems (4–6 points)
4. **Site Design—Soil and Vegetation (40 points).** Protect and restore processes and systems associated with a site's soil and vegetation
   Soil+Veg P4.1: Create and communicate a soil management plan
   Soil+Veg P4.2: Control and manage known invasive plants
   Soil+Veg P4.3: Use appropriate plants
   Soil+Veg C4.4: Conserve healthy soils and appropriate vegetation (4–6 points)
   Soil+Veg C4.5: Conserve special status vegetation (4–6 points)
   Soil+Veg C4.6: Use and conserve native plants (3–6 points)
   Soil+Veg C4.7: Preserve and restore plant communities native to the ecoregion (4–6 points)
   Soil+Veg C4.8: Optimize biomass (1–6 points)
   Soil+Veg C4.9: Reduce urban heat island effects (4 points)
   Soil+Veg C4.10: Use vegetation to minimize building cooling requirements (2–5 points)
   Soil+Veg C4.11: Reduce the risk of catastrophic wildfire (3 points)
5. **Site Design—Materials Selection (41 points).** Reuse/recycle existing materials and support sustainable production practices
   Materials P5.1: Eliminate the use of wood from threatened tree species
   Materials C5.2: Maintain on-site structures and paving (2–4 points)
   Materials C5.3: Design for adaptability and disassembly (3–4 points)
   Materials C5.4: Reuse salvaged materials and plants (3–4 points)
   Materials C5.5: Use recycled content materials (3–4 points)
   Materials C5.6: Use regional materials (3–5 points)
   Materials C5.7: Support responsible extraction of raw materials (1–5 points)
   Materials C5.8: Support transparency and safer chemistry (1–5 points)
   Materials C5.9: Support sustainable practices in materials manufacturing (1–5 points)
   Materials C5.10: Support sustainable practices in plant production (1–5 points)
6. **Site Design—Human Health and Well-Being (30 points).** Build strong communities and a sense of stewardship
   HHWB C6.1: Protect and maintain unique cultural and historical places (2–3 points)
   HHWB C6.2: Provide optimum site accessibility, safety, and wayfinding (2 points)
   HHWB C6.3: Promote equitable site development and use (2 points)
   HHWB C6.4: Support mental restoration (2 points)

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HHWB C6.5: Provide opportunities for physical activity (2 points)
HHWB C6.6: Support social interaction (2 points)
HHWB C6.7: Provide on-site food production (3–4 points)
HHWB C6.8: Reduce light pollution (4 points)
HHWB C6.9: Encourage fuel efficient and multi-modal transportation (4 points)
HHWB C6.10: Minimize exposure to environmental tobacco smoke (1–2 points)
HHWB C6.11: Support the local economy (3 points)

7. **Construction (17 points).** Minimize effects of construction-related activities
   Construction P7.1: Communicate and verify sustainable construction practices
   Construction P7.2: Control and retain construction pollutants
   Construction P7.3: Restore soils disturbed during construction
   Construction C7.4: Restore soils disturbed by previous development (3–5 points)
   Construction C7.5: Divert construction and demolition materials from disposal (3–4 points)
   Construction C7.6: Reuse or recycle vegetation, rocks, and soil generated during construction (3–4 points)
   Construction C7.7: Minimize generation of greenhouse gas emissions and exposure to localized air pollutants during construction (2–4 points)
8. **Operations and Maintenance (22 points).** Maintain the site for long-term sustainability
   O+M P8.1: Plan for sustainable site maintenance
   O+M P8.2: Provide for storage and collection of recyclables
   O+M C8.3: Recycle organic matter generated (3–5 points)
   O+M C8.4: Minimize pesticide and fertilizer use (4–5 points)
   O+M C8.5: Reduce outdoor energy consumption for all landscape and exterior operations (2–4 points)
   O+M C8.6: Use renewable sources for landscape electricity needs (3–4 points)
   O+M C8.7: Minimize generation of greenhouse gases and exposure to localized air pollutants during landscape maintenance activities (2–4 points)
9. **Education and Performance Monitoring (11 points).** Reward exceptional performance and improve the body of knowledge on long-term sustainability
   Education C9.1: Promote sustainability awareness and education (3–4 points)
   Education C9.2: Develop and communicate a case study (3 points)
   Education C9.3: Plan to monitor and report site performance (4 points)
10. **Innovation or Exemplary Performance (9 points).** Encourage and reward innovation and exemplary performance in site design, construction, and maintenance by going above and beyond the criteria of the current SITES v2 Rating System.
    Innovation C10.1: Innovation or exemplary performance (bonus; 3–9 points)

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Appendix C

Unit Conversions

Multiply	By	To Obtain	Multiply	By	To Obtain
Length					
Inch (in)	0.025	Meter (m)	Meter (m)	39.370	Inch (in)
Meter (m)	100.0	Centimeter (cm)	Centimeter (cm)	0.010	Meter (m)
Kilometer (km)	1000.0	Meter (m)	Meter (m)	0.001	Kilometer (km)
Mile (mi)	1.609	Kilometer (km)	Kilometer (km)	0.622	Mile (mi)
Inches (in)	2.540	Centimeter (cm)	Centimeter (cm)	0.394	Inches (in)
Yard (yd)	0.914	Meter (m)	Meter (m)	1.094	Yard (yd)
Feet (ft)	0.305	Meter (m)	Meter (m)	3.281	Feet (ft)
Centimeter (cm)	0.394	Inches (in)	Inches (in)	2.540	Centimeter (cm)
Feet (ft)	30.480	Centimeter (cm)	Centimeter (cm)	0.033	Feet (ft)
Meter (m)	3.281	Feet (ft)	Feet (ft)	0.305	Meter (m)
Area					
Hectares (ha)	10000.0	Sq. meter (m^2)	Sq. meter (m^2)	0.0001	Hectares (ha)
Acre (ac)	0.405	Hectares (ha)	Hectares (ha)	2.471	Acre (ac)
Acre (ac)	43560.0	Sq. feet (ft^2)	Feet (ft^2)	0.000023	Acre (ac)
Sq. yard (yd^2)	0.836	Sq. meter (m^2)	Sq. meter (m^2)	1.196	Sq. yard (yd^2)
Sq. mile (mi^2)	2.590	Sq. kilometer (km^2)	Sq. kilometer (km^2)	0.386	Sq. mile (mi^2)
Sq. yard (yd^2)	0.836	Sq. meter (m^2)	Sq. meter (m^2)	1.196	Sq. yard (yd^2)
Sq. feet (ft^2)	0.093	Sq. meter (m^2)	Sq. meter (m^2)	10.764	Sq. feet (ft^2)
Sq. inch (in^2)	645.150	Sq. millimeter (mm^2)	Sq. millimeter (mm^2)	0.0016	Sq. inch (in^2)
Sq. feet (ft^2)	929.000	Sq. centimeter (cm^2)	Sq. centimeter (cm^2)	0.0011	Sq. feet (ft^2)
Sq. inch (in^2)	6.452	Sq. centimeter (cm^2)	Sq. centimeter (cm^2)	0.155	Sq. inch (in^2)
Volume					
Acre-feet (ac-ft)	1233.5	Cu. meter (m^3)	Cu. meter (m^3)	0.0008	Acre-feet (ac-ft)
Cu. yard (yd^3)	0.765	Cu. meter (m^3)	Cu. meter (m^3)	1.308	Cu. yard (yd^3)
Cu. feet (ft^3)	0.028	Cu. meter (m^3)	Cu. meter (m^3)	35.315	Cu. feet (ft^3)
Cu. feet (ft^3)	28.317	Liter (L)	Liter (L)	0.035	Cu. feet (ft^3)
Gallon (gal)	3.785	Liter (L)	Liter (L)	0.264	Gallon (gal)
Cu. inch (in^3)	16.387	Cu. millimeters (mm^3)	Cu. millimeters (mm^3)	0.061	Cu. inch (in^3)
Cu. feet (ft^3)	7.481	Gallon (gal)	Gallon (gal)	0.134	Cu. feet (ft^3)
Temperature					
Celsius (C)	$(+17.78) \times 1.8$	Fahrenheit (° F)	Fahrenheit (° F)	$(-32) \times 0.556$	Celsius (°C)
Mass/Weight					
Kilogram (kg)	1000.0	Grams (g)	Grams (g)	0.001	Kilogram (kg)
Kilogram (kg)	2.205	Pounds (lbs)	Pounds (lbs)	0.454	Kilogram (kg)

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Multiply	By	To Obtain	Multiply	By	To Obtain
Short Ton (US)	2000.0	Pounds (lbs)	Pounds (lbs)	0.0005	Short ton (US)
Metric ton (mt)	2240.6	Pounds (lbs)	Pounds (lbs)	0.00045	Metric Ton (mt)
Short ton (US)	0.907	Metric ton (mt)	Metric ton (mt)	1.102	Short Ton (US)
Short ton (US)	0.893	Long ton (UK)	Long ton (UK)	1.120	Short Ton (US)
Metric ton (mt)	0.984	Long ton (UK)	Long ton (UK)	1.016	Metric Ton (mt)
Gram (g)	0.0353	Ounce (oz)	Ounce (oz)	28.350	Gram (g)
Pressure/Force					
lbs/in^2 (psi)	6.895	Kilo Pascal (kPa)	Kilo Pascal (kPa)	0.145	lbs/in^2 (psi)
Pound-force (lbf)	4.448	Newton (N)	Newton (N)	0.225	Pound-force (lbf)
kg/cm^2	14.220	lbs/in^2 (psi)	lbs/in^2 (psi)	0.070	kg/cm^2
kg/m^2	0.205	lbs/ft^2 (psf)	lbs/ft^2 (psf)	4.883	kg/m^2
Energy					
Megawatt-hour (MWh)	1000.0	Kilowatt-hour (kWh)	Kilowatt-hour (kWh)	0.0010	Megawatt-hour (MWh)
Kilowatt-hour (kWh)	3415.0	British thermal unit (BTU)	British thermal unit (BTU)	0.00029	Kilowatt-hour (kWh)
Watt-Hour (Wh)	3.415	British thermal unit (BTU)	British Thermal Unit (BTU)	0.293	Watt-hour (Wh)
Ton-Hour refrigeration	12000.0	British thermal unit (BTU)	British thermal unit (BTU)	0.000083	Ton-hour refrigeration
Power					
Watt (W)	3.412	BTU/hour	BTU/hour	0.293	Watt (W)
Kilowatt (kW)	1000.0	Watt (W)	Watt (W)	0.001	Kilowatt (kW)
Ton of refrigeration	12000.0	BTU/hour	BTU/hour	0.000083	Ton of refrigeration
Horsepower (hp)	33000.0	Foot pound-force/min.	Foot pound-force/min.	0.00003	Horsepower (hp)
Horsepower (hp)	0.746	Kilowatt (kW)	Kilowatt (kW)	1.341	Horsepower (hp)
Speed/Flow Rate					
Cu. feet/minute (cfm)	0.472	Liters/second (L/s)	Liters/second (L/s)	2.119	Cu. Feet/minute (cfm)
Feet/minute (fpm)	0.508	Centimeters/sec. (cm/s)	Centimeters/sec. (cm/s)	1.969	Feet/minute (fpm)
Feet/minute (fpm)	0.305	Meters/minute (mpm)	Meters/minute (mpm)	3.281	Feet/minute (fpm)
Gallon/minute (gpm)	0.063	Liters/second (L/s)	Liters/second (L/s)	15.853	Gallon/minute (gpm)
Feet/second (ft/s)	0.305	Meters/second (m/s)	Meters/second (m/s)	3.281	Feet/second (ft/s)
Miles/hour (mph)	1.610	Kilometer/hour (km/h)	Kilometer/hour (km/h)	0.621	Miles/hour (mph)

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Appendix D

Abbreviations and Acronyms

4-PCH: 4-Phenylcyclohexene
AABC: Associated Air Balance Council
AAMA: American Architectural Manufacturers Association
ACI: American Concrete Institute
ACT: Acoustical ceiling tile
ADA: Americans with Disabilities Act
AGC: Associated General Contractors of America
AGMBC: Application Guide for Multiple Buildings and On-Campus Building Projects
AIA: American Institute of Architects
ANSI: American National Standards Institute
ARI: Air-Conditioning and Refrigeration Institute
ASG: Aluminosilicate glass
ASHRAE: American Society of Heating, Refrigerating and Air-Conditioning Engineers
ASLA: American Society of Landscape Architects
ASTM: American Society for Testing and Materials
ATFS: American Tree Farm System
AWEA: American Wind Energy Association
BAS: Building automation system
BAU: Business as usual
BCA: Building Commissioning Association
BCVTB: Building controls virtual test bed
BD&C: Building design and construction
BEA: Building energy analysis
BEE: Building environmental efficiency
BEES: Building for environmental and economic sustainability
BIM: Building information modeling
BIPV: Building-integrated photovoltaic
BOD: Basis of design
BOMA: Building Owners and Managers Association
BREEAM: Building Research Establishment Environmental Assessment Method (the United Kingdom's building assessment system)
BRI: Building-related illness
BRIC: Brazil, Russia, India, and China
BRMA: Building Materials Reuse Association
BTU: British thermal unit
C&D: Construction and demolition
CARE: Carpet America Recovery Effort
CAS: Chemical Abstracts Service
CASBEE: Comprehensive Assessment System for Building Environmental Efficiency (the Japanese building assessment system)
CBE: Center for the Built Environment

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CBECS: Commercial Buildings Energy Consumption Survey. Developed by the US Department of Energy's Energy Information Administration (EIA)
CCAEJ: Center for Community Action and Environmental Justice
CCS: Carbon capture and storage
CDC: US Centers for Disease Control and Prevention
CDD: Cooling degree day
CFC: Chlorofluorocarbon
CFD: Computational fluid dynamics
CIB: Conseil International du Bâtiment
CIR: Credit interpretation ruling
CLO: Clothing level
CMP: Credential Maintenance Program (for USGBC LEED Green Associates and LEED-APs)
CO_2e: Carbon dioxide equivalent
CO: Carbon monoxide
COMNET: Commercial Energy Services Network
COP: Coefficient of performance
COTE: Committee on the Environment, AIA
CRI: Color Rendering Index
CRS: Center for Resource Solutions
CRT: Cathode ray tube
CSIR: Council for Scientific and Industrial Research
CWPA: Certified Wood and Paper Association
Cx: Commissioning
CxA: Commissioning authority
DCV: Demand-controlled ventilation
DES: Diethylstilbestrol
DfD: Design for disassembly
DfDD: Design for deconstruction and disassembly
DfE: Design for the environment
DGNB: Deutsche Gesellschaft für Nachhaltiges Bauen (the German building assessment system)
DOE: US Department of Energy
EA: Energy and Atmosphere, a LEED category
EBN: *Environmental Building News*
ECM: Energy conservation measures
EDC: Endocrine-disrupting chemicals
EDP: Environmental product declaration
EEA: European Environment Agency
EEM: Energy efficiency measure
EERE: US Office of Energy Efficiency and Renewable Energy
EIA: US Energy Information Administration
EIFS: Exterior insulation and finishing system
EIE: Environmental impact estimator
ELV: End-of-life vehicle
EMS: Environmental management system
EPA: US Environmental Protection Agency
EPD: Environmental product declaration
EPP: Environmentally preferable product
EQ: Environmental Quality, a LEED category
ERV: Energy recovery ventilator
ESA: Endangered Species Act
ESC: Erosion and sedimentation control
ESCO: Energy services company
EU: European Union

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EUI: Energy Use Index
fc: Foot-candle
FEMA: Federal Emergency Management Agency
FEMP: Federal Energy Management Program
FSC: Forest Stewardship Council
FTE: Full-time equivalent
GBCA: Green Building Council of Australia
GBCI: Green Building Certification Institute
GBI: Green Building Initiative
gbXML: Green building XML
GC/CM: General contractor/construction manager
GDDC: Green design and delivery coordination
GDP: Gross domestic product
GGA: Green Globes Assessor
GGGC: Governor's Green Government Council
GGP: Green Globes Professional
GHG: Greenhouse gas
GJ: gigajoule (1 billion joules)
GMO: Genetically modified organism
GMP: Guaranteed maximum price
GNP: Gross national product
GSHP: Ground source heat pump
GWP: Global warming potential
HCFC: Hydrochlorofluorocarbon
HDD: Heating degree day
HDPE: High-density polyethylene
HET: High-efficiency toilet
HEU: High-efficiency urinal
HFC: Hydrofluorocarbon
HVAC&R: Heating, ventilating, air conditioning, and refrigerating
IAI: Alliance for Interoperability
IAMAP: International Arctic Monitoring and Assessment Program
IAQ: Indoor air quality
IARC: International Agency for Research on Cancer
ICC: International Code Council
ICE: Inventory of Carbon and Energy
ID: Innovation and Design, a LEED category
IEEE: Institute of Electrical and Electronics Engineers
IEQ: Indoor environmental quality
IESNA: Illuminating Engineering Society of North America
IEWC: International Electric Wire and Cable
IFC: Industry Foundation Class
IgCC: International Green Construction Code
iiSBE: International Initiative for a Sustainable Built Environment
IPCC: Intergovernmental Panel on Climate Change
IPD: Integrated project delivery
IPMVP: International Performance Measurement and Verification Protocol
IPR: Institut für Physikalische Raumenstörung
ISO: International Organization for Standardization
kW: kilowatt
kWh: kilowatt-hour
LBNL: Lawrence Berkeley National Laboratory
LCA: Life-cycle assessment
LCC: Life-cycle costing
LCD: Liquid crystal display

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LCGWP: Life-cycle global warming potential
LCODP: Life-cycle ozone depletion potential
LED: Light-emitting diode
LEED: Leadership in Energy and Environmental Design (the USGBC building assessment system)
LEED AP: LEED Accredited Professional
LEED-CI: LEED for Commercial Interiors
LEED-CS: LEED for Core and Shell
LEED-EB: O&M: LEED for Existing Building: Operations and Maintenance
LEED GA: LEED Green Associate
LEED-HC: LEED for Healthcare
LEED-ID&C: LEED for Interior Design and Construction
LEED-NC: LEED for New Construction
LEED-ND: LEED for Neighborhood Development
LEED-SCH: LEED for Schools
LID: Low-impact development
LPG: Liquid petroleum gas
LSG: Light-to-solar-gain ratio
M&V: Measurement and verification
MAK: Maximum workplace concentration
MCS: Multiple chemical sensitivity
MEP: Mechanical, electrical, plumbing
MERV: Minimum efficiency reporting value
MET: Metabolic rate
MIPS: Materials intensity per unit service
MOU: Memorandum of understanding
MPC: Model predictive control
MPR: Minimum program requirement
MR: Materials and resources
MSDS: Materials safety data sheet
MW: Megawatt
NAAQS: National Ambient Air Quality Standard
NAVFAC: Naval Facilities Engineering Command
NC: Noise criterion
NCI: National Charrette Institute
NCR: Noise reduction coefficient
NEMA: National Electrical Manufacturers Association
NEPA: National Environmental Policy Act
NFIP: National Flood Insurance Program
NIBS: National Institute of Building Sciences
NIOSH: National Institute for Occupational Safety and Health
NIST: National Institute of Standards and Technology
NOAA: National Oceanic and Atmospheric Administration
NO_x: nitrogen oxide, produced by the burning of fossil fuels
NPDES: National Pollutant Discharge Elimination System
NPV: Net present value
NREL: National Renewable Energy Laboratory
NZE: Net-zero energy
ODP: Ozone depletion potential
OPR: Owner's project requirements
PAFC: Phosphoric acid fuel cell
PCB: Polychlorinated biphenyl
PCR: Carpet Reclamation Program
PET: Polyethylene terephthalate
PF: Phenol formaldehyde

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PHA: Polyhydroxyalkanoate
PLA: Polylactic acid
PNNA: Pacific Northwest National Laboratory
PPA: Power purchase agreement
PPM: Parts per million
PV: Photovoltaic
PVC: Polyvinyl chloride
REL: Reference exposure level
RFP: Request for proposal
RFQ: Request for qualifications
RIBA: Royal Institute of British Architects
RMI: Rocky Mountain Institute
RP: Regional Priority, a LEED category
RSF: Research support facility
SBS: Sick building syndrome
SCAQMD: South Coast Air Quality Management District
SFHA: Special flood hazard area
SFI: Sustainable Forestry Initiative
SHGC: Solar heat gain coefficient
SITES: Sustainable Sites Initiative
SMACNA: Sheet Metal and Air Conditioning Contractors' National Association
SPI: Society of Plastics Industry, Inc.
SS: Sustainable Sites, a LEED category
STC: Sound transmission class
SWPPP: Stormwater pollution prevention plan
TAB: Testing and balancing
TNPV: Total net present value
UF: Urea-formaldehyde
UIA: International Union of Architects
UL: Underwriters Laboratories
UN: United Nations
URRC: United Resource Recovery Corporation
USDA: US Department of Agriculture
USGBC: US Green Building Council
VAV: Variable air volume
VFD: Variable-frequency drive
VOC: Volatile organic compound
VSD: Variable-speed drive
VT: Visible transmittance
WBCSD: World Business Council on Sustainable Development
WBDG: Whole Building Design Guide
WE: Water efficiency
WMO: World Meteorological Organization
WWTP: Wastewater treatment plant

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Appendix E

WELL Building Standard® Features Matrix

Compliance: P = Precondition
Certification: O = Optimization

Air		Core & Shell	Tenant Improvement	New Construction
1	Air quality standards	P	P	P
2	Smoking ban	P	P	P
3	Ventilation effectiveness	P	P	P
4	VOC reduction	P	P	P
5	Air filtration	P	P	P
6	Microbe and mold control	P	P	P
7	Construction pollution management	P	P	P
8	Healthy entrance	P	O	P
9	Cleaning protocol		P	P
10	Pesticide management	P		P
11	Fundamental material safety	P	P	P
12	Moisture management	P	O	P
13	Air flush		O	O
14	Air infiltration management	O	O	O
15	Increased ventilation	O	O	O
16	Humidity control		O	O
17	Direct source ventilation		O	O
18	Air quality monitoring and feedback		O	O
19	Operable windows	O	O	O
20	Outdoor air systems		O	O
21	Displacement ventilation		O	O
22	Pest control		O	O
23	Advanced air purification	O	O	O
24	Combustion minimization	O	O	O
25	Toxic material reduction		O	O
26	Enhanced material safety		O	O
27	Antimicrobial surfaces		O	O
28	Cleanable environment		O	O
29	Cleaning equipment		O	O

(continued)

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Air		Core & Shell	Tenant Improvement	New Construction
Water				
30	Fundamental water quality	P	P	P
31	Inorganic contaminants	P	P	P
32	Organic contaminants	P	P	P
33	Agricultural contaminants	P	P	P
34	Public water additives	P	P	P
35	Periodic water quality testing		O	O
36	Water treatment	O	O	O
37	Drinking water promotion	O	O	O
Nourishment				
38	Fruits and vegetables		P	P
39	Processed foods	P	P	P
40	Food allergies	P	P	P
41	Hand washing		P	P
42	Food contamination		P	P
43	Artificial ingredients	O	P	P
44	Nutritional information	O	P	P
45	Food advertising	O	P	P
46	Safe food preparation materials		O	O
47	Serving sizes		O	O
48	Special diets		O	O
49	Responsible food production		O	O
50	Food storage		O	O
51	Food production	O	O	O
52	Mindful eating		O	O
Light				
53	Visual lighting design		P	P
54	Circadian lighting design		P	P
55	Electric light glare control		P	P
56	Solar glare control	O	P	P
57	Low-glare workstation design		O	O
58	Color quality		O	O
59	Surface design		O	O
60	Automated shading and dimming controls		O	O
61	Right to light	O	O	O
62	Daylight modeling	O	O	O
63	Daylight fenestration	O	O	O
Fitness				
64	Interior fitness circulation	P		P
65	Activity incentive programs		P	P
66	Structured fitness opportunities		O	O
67	Exterior active design	O	O	O
68	Physical activity spaces	O	O	O

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Air		Core & Shell	Tenant Improvement	New Construction
69	Active transportation support	O	O	O
70	Fitness equipment	O	O	O
71	Active furnishings		O	O
Comfort				
72	ADA accessible design standards	P	P	P
73	Ergonomics: visual and physical		P	P
74	Exterior noise intrusion	P	O	P
75	Internally generated noise	O	P	P
76	Thermal comfort	P	P	P
77	Olfactory comfort		O	O
78	Reverberation time		O	O
79	Sound masking		O	O
80	Sound reducing surfaces		O	O
81	Sound barriers		O	O
82	Individual thermal control		O	O
83	Radiant thermal comfort	O	O	O
Mind				
84	Health and wellness awareness	P	P	P
85	Integrative design	P	P	P
86	Post-occupancy surveys		P	P
87	Beauty and design I	P	P	P
88	Biophilia I - qualitative	O	P	P
89	Adaptable spaces		O	O
90	Healthy sleep policy		O	O
91	Business travel		O	O
92	Workplace health policy		O	O
93	Workplace family support		O	O
94	Self-monitoring		O	O
95	Stress and addiction treatment		O	O
96	Altruism		O	O
97	Material transparency	O	O	O
98	JUST organization		O	O
99	Beauty and design II		O	O
100	Biophilia II—quantitative	O	O	O
101	Innovation feature I	O	O	O
102	Innovation feature II	O	O	O

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Glossary

Agrifiber building products are manufactured from agricultural fiber. Examples include particleboard, medium-density fiberboard, plywood, oriented strand board, wheatboard, and strawboard.

Air economizer is a system found in heating, ventilation, and air conditioning air-handling systems that takes advantage of favorable weather conditions to reduce mechanical cooling by introducing cooler outdoor air into the building.

Albedo, or solar reflectance, is a measure of the ability of a surface material to reflect sunlight on a scale of 0 to 1. Solar reflectance is also called *albedo*. Black paint has a solar reflectance of 0; white paint (titanium dioxide) has a solar reflectance of 1.

Baseline building energy performance is the annual energy cost for a building design intended for use as a baseline for rating above standard design, as defined in ANSI/ASHRAE/IESNA 90.1-2007, Appendix G.

Biobased product content is that portion of a material or product derived from plants and other renewable agricultural, marine, and forestry resources.

Biobased product is a commercial or industrial product using at least 50 percent (by weight) biologically generated substances, including but not limited to cellulosic materials (e.g., wood, straw, and natural fibers) and products derived from crops (e.g., soy-based and corn-based).

Biodiversity is the variety of life in all forms, levels, and combinations, including ecosystem diversity, species diversity, and genetic diversity.

Biomass is plant material from trees, grasses, or crops that can be converted to heat energy to produce electricity.

Biomimicry is an emerging design discipline that looks to nature for sustainable design solutions. It sometimes is called *biomimetic design.*

Biomimetic design *See* Biomimicry.

Blackwater is wastewater from toilets and urinals. Wastewater from kitchen sinks (especially when a garbage disposal is installed), showers, or bathtubs is also considered blackwater under some state or local codes.

Building Research Establishment Environmental Assessment Method (BREEAM) is the primary building assessment system in the United Kingdom.

Brownfield is a property whose use may be complicated by the presence or possible presence of a hazardous substance, pollutant, or contaminant.

Building automation system (BAS) is a commonly accepted name for the sensors, controls, and computers that control building energy systems such as lighting, heating, ventilating, and air-conditioning systems with the objective of minimizing energy consumption.

Building information modeling (BIM) is the process of generating and managing building data during its life cycle. It also refers to software that generates a three-dimensional building representation and with the ability to accommodate plug-ins that can potentially perform energy modeling, daylight studies, and life-cycle assessment of building systems.

Building products are building elements and assemblies.

Candela is a measure of luminous intensity.One candela is the luminous intensity, in a given direction, of a source that emits monochromatic radiation of frequency 540×10^{12} Hz and has a radiant intensity in that direction of 1/683 watt per steradian. *See also* **Lumen**.

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Carbon accounting is the process of measuring the amount of carbon dioxide equivalents (CO_2e) an entity, activity, or facility is releasing into the atmosphere.

Carbon dioxide (CO_2) levels are the concentrations of carbon dioxide. They are indicators of ventilation effectiveness inside buildings. CO_2 concentrations greater than 700 parts per million above outdoor CO_2 conditions generally indicate inadequate ventilation.

Carbon dioxide equivalent (CO_2e) is a measure used to compare the impact of various greenhouse gases based on their global warming potential (GWP). CO_2e approximates the time-integrated warming effect of a unit of a given greenhouse gas relative to that of carbon dioxide (CO_2). GWP is an index for estimating the relative global warming contribution of atmospheric emissions of a unit mass of a particular greenhouse gas compared to emission of a unit mass of CO_2. These GWP values are used based on a 100-year time horizon: 1 for CO_2, 23 for methane (CH_4), and 294 for nitrous oxide (N_2O). *See also* **Global warming potential**.

Carbon footprint is the greenhouse gas emissions caused by an organization, event, product, or person.

Comprehensive Assessment System for Building Environmental Efficiency (CASBEE) is the primary building assessment system used in Japan.

Chain of custody (COC) is a tracking procedure for a product from the point of harvest extraction to its end use, including all successive stages of processing, transformation, manufacturing, and distribution.

Charrette is a collaborative session in which a project team creates a solution to a design or project problem. The structure may vary, depending on the complexity of the problem or desired outcome and the individuals working in the group. Charrettes can take place over multiple sessions in which the group divides into subgroups. Each subgroup then presents its work to the full group as material for future dialogue. Charrettes can serve as a way of quickly generating solutions while integrating the aptitudes and interests of a diverse group of people.

Chlorofluorocarbons (CFCs) are hydrocarbons formerly used as refrigerants that cause depletion of the stratospheric ozone layer. CFCs were banned from use by international agreements, including the Montreal Protocol of 1987.

Climate zone, US, is any of the eight principal zones, roughly demarcated by lines of latitude, into which the United States is divided on the basis of climate for the purpose of energy calculations and selecting prescriptive energy conservation measures.

Coefficient of performance (COP) is a measure of the input power to a system compared to the output power of a system; the higher the COP, the more efficient a system is.

Combined heat and power (CHP) or cogeneration, generates both electrical power and thermal energy from a single fuel source.

Comfort criteria are specific design conditions that take into account indoor temperature, humidity, and air speed; and outdoor temperature, outdoor humidity, seasonal clothing, and expected activity.

Commissioning (Cx) is the process of verifying and documenting that a building and all of its systems and assemblies are planned, designed, installed, tested, operated, and maintained to meet the owner's project requirements.

Commissioning authority (CxA) is the individual designated to organize, lead, and review the completion of commissioning process activities. The CxA facilitates communication among the owner, designer, and contractor to ensure that complex systems are installed and function in accordance with the owner's project requirements.

Composite wood consists of wood or plant particles or fibers bonded by a synthetic resin or binder. Examples include particleboard, medium-density fiberboard, plywood, oriented strand board, wheatboard, and strawboard.

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Composting toilets contain and control the composting of excrement, toilet paper, carbon additive, and, optionally, food wastes. (They sometimes are called *biological toilets*, *dry toilets*, and *waterless toilets*.)

Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) is more commonly known as the *Superfund Act.* Enacted in 1980, CERCLA addresses abandoned or historical waste sites and contamination by taxing the chemical and petroleum industries and providing federal authority to respond to releases of hazardous substances.

Constructed wetland is an engineered system designed to simulate natural wetland functions to support ecological systems and water purification.

Construction and demolition debris includes waste and recyclables generated from construction and from the renovation, demolition, or deconstruction of preexisting structures. It does not include land-clearing debris, such as soil, vegetation, and rocks.

Construction indoor air quality (IAQ) management plan outlines measures to minimize indoor air contamination in a building during construction and describes procedures to flush the building to remove contaminants prior to occupancy.

Cradle-to-cradle is a framework for designing manufacturing processes powered by renewable energy, in which materials flow in safe, regenerative, closed-loop cycles.

Cradle-to-gate product life-cycle is a partial product life cycle from resource extraction (cradle) to the factory gate before the product is transported to the consumer. This life cycle includes the product stages of raw material supply, transport, and manufacturing. The construction process, use, and end-of-life stages of the product are omitted in this case.

Cradle-to-grave product life-cycle is the full product life cycle from resource extraction ("cradle") through the disposal stage ("grave"). This life cycle includes the product, construction process, use, and end-of-life stages.

Daylighting is the controlled entry of natural light into a space, used to reduce or eliminate electric lighting.

Daylight-responsive lighting controls are photosensors used in conjunction with other switching and dimming devices to control the amount of artificial lighting relative to the amount and quality of natural daylight.

Deconstruction is the systematic dismantling and removal of a structure or its parts to salvage and harvest the components, for the purpose of reusing and recycling the reclaimed materials for their maximum value; the disassembly of a building with the explicit intent of recovering building materials for reuse in a safe and economical manner.

Demand-controlled ventilation (DCV) is automatic ventilation control based on measured carbon dioxide levels.

Deutsche Gesellschaft für Nachhaltiges Bauen (DGNB), or German Association for Sustainable Building is both the primary building assessment system used in Germany and the name of the organization that is its proponent.

District cooling distributes chilled water to multiple buildings primarily for air conditioning. The chilled water usually is provided by a dedicated cooling plant powered by waste heat.

District heating is the distribution of heat from one or more sources, such as waste heat from a power plant, to multiple buildings.

Drip irrigation delivers landscape irrigation water at low pressure through buried mains and submains. From the submains, water is distributed to the soil through a network of perforated tubes or emitters. Drip irrigation is a high-efficiency type of microirrigation.

Ecological design is an approach to design that transforms matter and energy-using processes that are compatible and synergistic with nature and that are modeled on natural systems.

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Ecological sustainability is a school of sustainability that focuses on the capacity of ecosystems to maintain their essential functions and processes and retain their biodiversity in full measure over the long term.

Ecology is the study of the living conditions of organisms in interaction with each other and with the surroundings, organic as well as inorganic.

Economizer *See* Air economizer.

Ecosystem is a basic unit of nature that includes a community of organisms and their nonliving environment linked by biological, chemical, and physical processes.

Embodied energy is the total energy of all types needed to produce goods or services and is considered to be the energy investment in the product or activity. Relative to buildings, it is the total energy investment in constructing the building and includes the embodied energy of all the materials composing the building plus the energy required to erect the structure and place and install all the products and materials.

Emissivity is the ratio of the radiation emitted by a surface to the radiation emitted by a black body at the same temperature.

Energy conservation measures are installations of, or modifications to, equipment or systems intended to reduce energy use and costs.

Energy simulation model, or energy model, is a computer-generated representation of the anticipated energy consumption of a building. It permits a comparison of energy performance, given proposed energy efficiency measures, with the baseline.

Energy Star Rating is a measure of a building's energy performance compared with that of similar buildings, as determined by the Energy Star Portfolio Manager. It has a scale of 1 to 100, with a score of 50 representing average building performance, while a score of 75 or better represents very good performance.

Enthalpy is the total energy of a thermodynamic system and is the sum of its internal energy and the product of its pressure and volume.

Eutrophication is the increase in chemical nutrients, such as the nitrogen and phosphorus often found in fertilizers, in an ecosystem. The added nutrients stimulate excessive plant growth, promoting algal blooms or weeds. The enhanced plant growth reduces oxygen in the land and water, reducing water quality and fish to other animal populations.

Evapotranspiration (ET) rate is the amount of water lost from a vegetated surface in units of water depth. It is expressed in millimeters per unit of time.

Exhaust air is air that is removed from a space and discharged outside the building by mechanical or natural ventilation systems.

Existing building is a building or portion thereof that was previously occupied or approved for occupancy by the authority having jurisdiction.

Feed-in Tariff (solar) is an incentivizing mechanism for stimulating investment in renewable energy that pays a higher per kilowatt-hour price than charged by the utility company providing energy.

Fly ash is the solid residue derived from incineration processes. Fly ash can be used as a substitute for Portland cement in concrete.

Foot-candle (fc) is the quantity of light falling on a 1-square-foot area from a 1-candela light source at a distance of 1 foot (or 1 lumen per square foot). Foot-candles can be measured both horizontally and vertically by a foot-candle meter or light meter. 1 fc510.764 lux. *See also* **Lumen; Lux**.

Formaldehyde is a naturally occurring volatile organic compound found in small amounts in animals and plants but is carcinogenic and an irritant to most people when present in high concentrations, causing headaches, dizziness, mental impairment, and other symptoms. When present in the air at levels above 0.1 parts per million, it can cause watery eyes; burning sensations in the eyes, nose, and throat; nausea; coughing; chest tightness; wheezing; skin rashes; and asthmatic and allergic reactions.

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Fuel-efficient vehicles have achieve a minimum green score of 40 according to the annual vehicle-rating guide of the American Council for an Energy-Efficient Economy.

Full-time equivalent (FTE) represents a regular building occupant who spends 40 hours per week in the project building. Part-time or overtime occupants have FTE values based on their hours per week divided by 40.

Fully shielded exterior light fixtures have lower edges of their shields at or below the lowest edge of the lamp, such that all the light shines down.

Geothermal energy is hot water or steam from within the Earth that is used to generate electricity.

Geoexchange system is an electrically powered heating and cooling system for interior spaces. It utilizes earth or a body of water, such as a pond or lake, as both a heat source and heat sink. Components of this system include a heat pump, a hydronic pump, a ground heat exchanger, and a distribution subsystem.

Geothermal ground source heat pump (GSHP), or ground heat pump, is a central heating and/or cooling system that pumps heat to or from the ground. It uses earth as a heat source (in the winter) or a heat sink (in the summer). *See also* **Geoexchange system.**

Glare is any excessively bright source of light within the visual field that creates discomfort or loss of visibility.

Global warming potential (GWP) is an index that describes the radiative characteristics of well-mixed greenhouse gases and that represents the combined effect of the differing times these gases remain in the atmosphere and their relative effectiveness in absorbing outgoing infrared radiation. This index approximates the time-integrated warming effect of a unit mass of a given greenhouse gas in today's atmosphere, relative to that of carbon dioxide, which has a GWP of 1.

Graywater is untreated household wastewater that has not come into contact with toilet waste and has low organic content. Graywater includes used water from bathtubs, showers, bathroom wash basins, and water from clothes washers and laundry tubs. It must not include wastewater from kitchen sinks or dishwashers, which often has organic content.

Green Associate is a credential offered by the US Green Building Council that designates a person as being knowledgeable about the fundamentals of green building. Passing the Green Associate examination is a prerequisite for an individual to become a LEED (Leadership in Energy and Environmental Design) Accredited Professional (LEED AP).

Green building is a facility designed using a holistic and collaborative process that addresses life-cycle resource consumption, environmental impacts, and the health of the occupants and local ecosystems.

Green Building Certification Institute (GBCI) is a nonprofit, third-party organization that reviews the application for buildings applying for US Green Building Council Leadership in Energy and Environmental Design (LEED) certification and tests applicants for Green Associate or LEED AP credentials.

Green Building Initiative (GBI) is a nonprofit organization whose mission is to accelerate the adoption of building practices that result in energy-efficient, healthier, and environmentally sustainable buildings by promoting credible and practical green building approaches for residential and commercial construction.

Green Globes is a green building guidance and assessment program that offers an effective, practical, and affordable way to advance the overall environmental performance and sustainability of commercial buildings.

Green Globes Professional (GGP) is a Green Globes certification expert who uses his/her professional and field skills to help clients through the certification process.

Green Globes Associate (GGA) is a project team member who has taken and passed a course on the application of the Green Globes building assessment

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system. GGAs use their expertise to support the team in the Green Globes certification process.

Green roof, or vegetated roof, is a roof system that may include a waterproofing and root-repellant system, a drainage system, filter cloth, a lightweight growing medium, and plants. Vegetated roof systems can be modular, with drainage layers, filter cloth, growing media, and plants already prepared in movable, interlocking grids, or each component can be installed separately.

Green-e is a program established by the Center of Resource Solutions to both promote green electricity products and provide consumers with a rigorous and nationally recognized method to identify those products.

Greenfield is undeveloped land, such as fields, forests, farmland, and rangeland.

Greenhouse gases (GHGs) absorb and emit radiation at specific wavelengths within the spectrum of thermal infrared radiation emitted by earth's surface, clouds, and the atmosphere itself. Increased concentrations of greenhouse gases are a root cause of global climate change.

Halons are substances used in fire suppression systems and fire extinguishers that deplete the stratospheric ozone layer.

Hard costs are the costs of the land, materials, labor, and machinery used to construct a building and are sometimes referred to as *direct construction costs*.

Heat island effect refers to absorption of heat by hardscapes, such as dark, nonreflective pavement and buildings, and its radiation to surrounding areas. Particularly in urban areas, other sources may include vehicle exhaust, air conditioners, and street equipment; reduced airflow from tall buildings and narrow streets exacerbates the effects.

High-performance green building is the term used to more specifically define the intended outcome of a green building design and construction process.

Heating, ventilation, and air conditioning (HVAC) systems are equipment, distribution systems, and terminals that provide heating, ventilating, and air conditioning for a building.

Hydrochlorofluorocarbons (HCFCs) are refrigerants that cause significantly less depletion of the stratospheric ozone layer than chlorofluorocarbons.

Hydrofluorocarbons (HFCs) are refrigerants that do not deplete the stratospheric ozone layer but may have high global warming potential. HFCs are not considered environmentally benign.

Impervious surfaces are surficial structures constructed of materials that do not allow water to absorb or penetrate them. Examples include parking lots, roads, sidewalks, and plazas.

Indoor air quality (IAQ) is the nature of air inside the space that affects the health and well-being of building occupants. It is considered acceptable when there are no known contaminants at harmful concentrations and a substantial majority (80 percent or more) of the occupants do not express dissatisfaction.

Indoor environmental quality (IEQ) is the nature of the overall quality of the environment inside a building resulting from attention to a broad range of effects, which includes air quality, lighting quality, daylighting, acoustics, noise, vibration, odors, thermal comfort, and electromagnetic radiation.

Integrated Design is a design process that includes the active and continuing participation of users and community members, code officials, building technologists, contractors, cost consultants, civil engineers, mechanical and electrical engineers, structural engineers, specifications specialists, and consultants from many specialized fields. It is especially important for solving complex design problems such as optimizing the building envelope for heat transfer, daylighting, and noise control. The best buildings result from continual, organized collaboration among all players throughout the building's life cycle. (Adapted from the *Whole Building Design Guide*, www.wbdg.org.)

LCA *See* **Life-cycle assessment**.

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LCC *See* **Life-cycle costing**.

LEED or Leadership in Energy and Environmental Design, is an internationally recognized green building certification system developed by the US Green Building Council and administered by the Green Building Certification Institute.

LEED Accredited Professional (or LEED AP), is a credential earned by passing an examination administered by the Green Building Certification Institute that designates the holder as having specialized knowledge regarding the LEED building assessment system.

Life-cycle assessment (LCA) is an analysis of the environmental impacts and potential impacts associated with a product, process, or service.

Life-cycle costing (LCC) is an accounting methodology used to evaluate the economic performance of a product or system over its useful life. It considers operating costs, maintenance expenses, and other economic factors.

Light pollution is waste light from buildings and their sites that produces glare, is directed upward to the sky, or is directed off the site, wasting energy and creating navigation problems for some species, such as sea turtles.

Light trespass is obtrusive light that is unwanted because of quantitative, directional, or spectral attributes. Light trespass can cause annoyance, discomfort, distraction, or loss of visibility.

Lumen is a measure of the lighting power perceived by the human eye; the visible light emitted by a source; 1 lumen = 1 candela × steradian (or square radians). *See also* **Candela**.

Lux is the SI unit of illuminance and luminous emittance measuring luminous power per area; intensity of light passing through or hitting a surface, as perceived by the human eye. One lux = 1 lumen per square meter. *See also* **Lumen**.

MEP Mechanical, electrical, and plumbing.

Minimum Efficiency Reporting Value (MERV) is a filter rating defined by ASHRAE Standard 52.2-1999. MERV ratings range from 1 (very low efficiency) to 16 (very high).

Mixed-mode ventilation combines mechanical and natural ventilation modes of ventilation system operation.

Modular building units are factory-produced or shop-fabricated preengineered building units that are delivered to the site and assembled as large volumetric components or as substantial elements of a building.

National Pollutant Discharge Elimination System (NPDES) is a permit program that controls water pollution by regulating point sources that discharge pollutants into the waters of the United States. Industrial, municipal, and other facilities must obtain permits if their discharges go directly to surface waters.

Native (or indigenous) plants are plants that live or grow naturally in a particular region.

Natural, or passive, ventilation is provided by thermal, wind, or diffusion effects openings in the building facade, roof, or other components for the purpose of creating low-energy air movement.

Net metering is a metering arrangement that allows on-site generators to send excess electricity flows to the regional power grid. These electricity flows offset all or a portion of those drawn from the grid.

Noise Reduction Coefficient (NRC) is the arithmetic average of sound absorption coefficients at 250, 500, 1000, and 2000 Hz for a material. Manufacturers often publish the NRC by in product specifications, particularly for acoustical ceiling tiles and acoustical wall panels.

Nonstructural elements are elements attached to or housed in a building or building system that are not part of the main load-resisting structural system of the building. These include (1) architectural elements, such as a parapet wall, partition wall, non-load-carrying windows, suspended ceilings, furnishings, cladding systems, and veneer; (2) mechanical system components; (3) electrical system elements; and (4) miscellaneous components, such as signboards and file cabinets.

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Off-gassing is the emission of volatile organic compounds from synthetic and natural products.

Off-site renewable energy is green power from an electrical utility or other off-site source. There is no physical *renewable energy* system either on-site or directly connected to the building.

On-site renewable energy is energy derived from the sun, wind, water, earth's core, and biomass that is captured and used on the building site, using technologies such as wind turbines, photovoltaic solar panels, transpired solar collectors, solar thermal heaters, small-scale hydroelectric power plants, fuel cells, and ground source heat pumps.

Ozone (O_3) is an oxygen molecule with three oxygen atoms that is both an air pollutant and comprises an atmospheric layer. It is not usually emitted directly into the air, but at ground level. It is the product of a chemical reaction between oxides of nitrogen (NO_x) and volatile organic compounds in the presence of sunlight. The ozone layer is an ultraviolet-absorbing layer in the atmosphere that was being destroyed by synthetic chlorine- and bromine-containing gases. The main objective of the Montreal Protocol of 1987 was protection of the ozone layer.

Ozone depletion potential (ODP) is a number that refers to the amount of ozone depletion caused by a substance. The ODP is the ratio of the impact on ozone of a chemical compared to the impact of a similar mass of CFC-11. Thus, the ODP of CFC-11 is defined to be 1.0. Other chlorofluorocarbons and hydrochlorofluorocarbons have ODPs that range from 0.01 to 1.0. The halons have ODPs ranging up to 10. Carbon tetrachloride has an ODP of 1.2, and methyl chloroform's ODP is 0.11. Hydrofluorocarbons have zero ODP because they do not contain chlorine.

Pervious surfaces are sustainable materials that allow the passage of rainwater while also trapping suspended solids and other potential pollutants.

Perviousness is the percentage of the surface area of a paving system that is open and allows moisture to soak into the ground below.

Phenol formaldehyde resins are used as binding agent in products, including some building products. These resins have the property of tightly bonding the formaldehyde in its matrix to prevent off-gassing during typical building operations.

Photovoltaic (PV) energy is electricity from photovoltaic cells that convert sunlight into electricity.

Plug load is an electrical load due to an appliance or other electrical device that is normally "plugged" into an electrical receptacle, such as a computer, printer, or cell phone charger.

Postconsumer recycled content is product waste material generated by households or by commercial, industrial, and institutional facilities, which is incorporated into new products. This process includes returns of material from the distribution chain.

Potable water *See* **Water, potable**.

Preassembled products are products assembled in a factory or shop prior to delivery or sale.

Preconsumer recycled content is material diverted from the waste stream during a manufacturing process. Excluded is reutilization of materials such as rework, regrind, or scrap generated in a process and capable of being reclaimed within the same process that generated it.

Prefabricated products are products consisting of manufactured subassemblies ready for quick assembly and erection on-site.

Process water is used for industrial processes and building systems, such as cooling towers, boilers, and chillers. It also can refer to water used in operational processes, such as dishwashing, clothes washing, and ice making.

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Product formulation is any combination or blend of two or more constituent chemicals, if the combination does not occur in nature and is not, in whole or in part, the result of a chemical reaction.

R-value indicates the thermal resistance of a material. The R-value of thermal insulation depends on the type of material, its thickness, and its density. The higher the R-value, the greater is the insulating effectiveness. In calculating the R-value of a multilayered installation, the R-values of the individual layers are added.

Rainwater harvesting is capturing rainwater for potable, nonpotable, industrial, or irrigation applications.

Rapidly renewable materials are agricultural products, both fiber and animal, that take 10 years or less to grow or raise and can be harvested in a sustainable fashion.

Reclaimed water is wastewater that has been treated for reuse.

Recovered material is material that otherwise would have been disposed of as waste or used for energy recovery (e.g., incinerated for power generation), but that has instead been collected and recovered as a material input, in lieu of virgin primary material, for a recycling or a manufacturing process.

Recycled content is the proportion, by cost or weight, of recycled material in a product or packaging. Only preconsumer and postconsumer recycled materials are considered to be recycled content.

Recycled material is material that has been reprocessed from *recovered* (reclaimed) *materials* by means of a manufacturing process and made into a final product or into a component for incorporation into a product.

Regenerative design is a system of technologies and strategies, based on an understanding of the inner working of ecosystems, that generates designs to reinforce rather than deplete underlying life-support systems and resources.

Regionally extracted materials are raw materials mined or harvested within a 500-mile (800 km) radius of the project site.

Regionally manufactured materials are assembled as finished products within a 500-mile (800 km) radius of the project site. Assembly does not include on-site assembly, erection, or installation of finished components.

Relative humidity is the ratio of partial density of airborne water vapor to the saturation density of water vapor at the same temperature and total pressure.

Remediation is the process of cleaning up a contaminated site by physical, chemical, or biological means. Remediation processes typically are applied to contaminated soil and groundwater.

Renewable energy is energy from sources that are not depleted by consumption. Examples include energy from the sun, wind, (low-head) hydropower, geothermal energy, and wave and tidal systems.

Renewable Energy Certificates (RECs) are tradable commodities representing proof that a unit of electricity was generated from a renewable energy resource. RECs are sold separately from electricity itself and thus allow the purchase of the attributes of green power for a green building project.

Resource Conservation and Recovery Act (RCRA) addresses active and future facilities and was enacted in 1976 to give the Environmental Protection Agency authority to control hazardous wastes from cradle to grave, including generation, transportation, treatment, storage, and disposal. Some nonhazardous wastes are also covered under RCRA.

Restorative design is a design approach that combines the restoration of polluted, degraded, or damaged sites back to a state of acceptable health through human intervention with biophilic designs that reconnect people to nature.

Reuse is using an object, material, or resource again, either for its original purpose or for a similar purpose, without significantly altering the physical form of the object or material.

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Reverberation is an acoustical phenomenon that occurs when sound persists in an enclosed space because of its repeated reflection or scattering on the enclosing surfaces or objects within the space.

Reverberation time (RT) is a measure of the amount of reverberation in a space and is equal to the time required for the level of a steady sound to decay by 60 decibels after the sound has stopped. The decay rate depends on the amount of sound absorption in a room, the room geometry, and the frequency of the sound. RT is expressed in seconds.

Risk is the probability that a product formulation, article, or constituent chemical will cause an unacceptable hazardous or toxic human health or safety, or ecological, effect under the intended exposure and use conditions.

Risk assessment is a product composition analysis that determines if a product formulation, article, or constituent chemical will produce a risk under the intended use and exposure conditions.

Risk Characterization Ratio (RCR) is the quantitative, probability estimate for adverse effects (i.e., toxicity) to occur under defined exposure conditions. It is calculated as: RCR = exposure dosage/no adverse effects dosage, with RCR values < 1.0 indicating that the risk is adequately controlled.

Salvaged materials (reused materials) are discarded or unused construction materials or products that have value and are removed in whole form from a structure or site and can be substituted directly for new materials or products with minimal reprocessing.

Service life is the expected lifetime of a building.

Set points are the operating targets for building energy systems and for indoor air quality.

Site energy is the amount of heat and electricity consumed by a building as reflected in utility bills.

Soft costs are expense items that are not considered direct construction costs. Examples include architectural, engineering, financing, and legal fees.

Solar reflectance. *See* **Albedo**.

Solar Reflectance Index (SRI) is a measure of a material's ability to reject solar heat, as shown by a small temperature rise. Standard black (reflectance 0.05, emittance 0.90) is 0, and standard white (reflectance 0.80, emittance 0.90) is 100. For example, a standard black surface has a temperature rise of 90°F (50°C) in full sun, and a standard white surface has a temperature rise of 14.6°F (8.1°C). Once the maximum temperature rise of a given material has been computed, the SRI can be calculated by interpolating between the values for white and black. Materials with the highest SRI values are the coolest choices for paving.

Solar thermal systems collect or absorb sunlight via solar collectors to heat water that is then circulated to the building's hot water system. Solar thermal systems can be used to heat water for residential and commercial use or for heating swimming pool water.

Sound absorption is the portion of sound energy striking a surface that is not returned as sound energy.

Sound Absorption Coefficient describes the ability of a material to absorb sound, expressed as a fraction of incident sound. The Sound Absorption Coefficient is frequency-specific and ranges from 0.00 to 1.00. For example, a material may have an absorption coefficient of 0.50 at 250 Hz and 0.80 at 1,000 Hz. These coefficients indicate that the material absorbs 50 percent of incident sound at 250 Hz and 80 percent of incident sound at 1,000 Hz. The arithmetic average of absorption coefficients at midfrequencies is the Noise Reduction Coefficient.

Sound Transmission Class (STC) is a single-number rating for the acoustic attenuation of airborne sound passing through a partition or other building element, such as a wall, roof, or door, as measured in an acoustical testing laboratory

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according to accepted industry practice. A higher STC rating provides more sound attenuation through a building component.

Source energy is the total amount of raw fuel energy required to operate a building. It incorporates all transmission, delivery, and production losses for a complete assessment of a building's energy use.

Structural system is the load-resisting system of a structure that transfers loads to the soil or supporting structure through interconnected structural components or members.

Submetering is the use of meters to determine the proportion of energy use within a building attributable to specific end uses or subsystems (i.e., lighting or HVAC systems).

Supply air is air delivered by mechanical or natural ventilation to a space; it is composed of a combination of outdoor air and recirculated air.

Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs.

Sustainable forestry is the practice of managing forest resources to meet the long-term forest product needs of humans while maintaining the biodiversity of forested landscapes. The primary goal is to restore, enhance, and sustain a full range of forest values, including economic, social, and ecological considerations.

Systems thinking is a framework for understanding interrelationships in a system rather than individual components and for understanding patterns of change rather than static "snapshots." It addresses phenomena in terms of wholeness rather than in terms of parts. In relation to the built environment, systems thinking is an approach to bringing together these relationships in the design of a building.

Tertiary treatment is the highest form of wastewater treatment and includes removal of organics, solids, and nutrients as well as biological or chemical polishing.

Thermal comfort exists when occupants express satisfaction with the thermal environment. It is a psychological state of mind, and no numerical value can be assigned.

Thermal efficiency is a measure of the efficiency of converting a fuel to energy and useful work. Useful work and energy output is divided by the higher heating value of input fuel.

Tipping fees are fees charged by landfills, typically quoted per ton, for disposal of waste.

Total material value (TMV) is the invoiced cost of materials and products as received by the contractor, permanently installed in the building project, not including profit, overhead, or labor. Alternatively, 45 percent of the total construction cost may be used to establish the TMV. TMV is used in calculating the percentage of recycled or reused content of materials in a high-performance building project.

Total suspended solids (TSS) are particles that are too small or light to be removed from stormwater via gravity settling. Suspended solid concentrations typically are removed via filtration.

U-value (thermal transmittance) is the rate of heat transmission per unit time per unit area for an element of construction and its boundary air films.

Urea formaldehyde is a combination of urea and formaldehyde used in some glues that may emit formaldehyde at room temperature.

Variable air volume (VAV) system is a heating, ventilation, and air conditioning system that provides temperature control by varying the supply of conditioned air in different zones of the building according to its heating and cooling needs. The air supply temperature may be constant or varied.

Vegetated roof. *See* **Green roof**.

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Ventilation is the process of supplying air to or removing air from a space for the purpose of controlling air containment levels, humidity, or temperature within the space.

Visible light transmittance (VLT) is the ratio of total transmitted light to total incident light (i.e., the amount of visible spectrum, 380 to 780 nanometers, of light passing through a glazing surface divided by the amount of light striking the glazing surface). The higher the VLT value, the more incident light passes through the glazing. (VLT is also abbreviated as Tvis.)

Vision glazing is the portion of an exterior window between 30 and 90 inches (76 to 229 cm) above the floor that permits a view to the outside.

Volatile organic compounds (VOCs) are any one of several organic compounds that are released to the atmosphere by plants or through vaporization of oil products and that are chemically reactive and involved in the chemistry of tropospheric ozone production.

Waste diversion is a management activity that disposes of waste other than by incineration or the use of landfills. Examples include reuse and recycling.

Wastewater is the spent or used water from a home, community, farm, or industry that contains dissolved or suspended matter.

Water, potable, is water that meets or exceeds the Environmental Protection Agency's drinking water quality standards and is approved for human consumption by the state or local authorities having jurisdiction; it may be supplied from wells or municipal water systems.

Watergy refers to the relationship between water and energy and can have two distinct meanings. The first is the amount of energy required per unit of water to extract, treat, and distribute a given water source (e.g., groundwater, reclaimed water, or rainwater). In this same context, it is the energy required per unit of water to move, treat, and dispose of wastewater. The unit of measurement is in kilowatt-hours/1,000 gallons (or kilowatt-hours/cubic meter) of water or wastewater. For example, for a 150-foot-deep groundwater well, the watergy is typically around 1.5 to 2 kWh/1,000 gal (0.4—0.5 kWh/m^3). For conventional wastewater treatment and disposal, 2 to 4 kWh/1,000 gal (0.5–1.0 kWh/m^3) are required. A second meaning of watergy is the water needed to produce a unit of energy from a specific energy source. One kilowatt-hour of energy would require 56 gallons (212 liters) of water for its production if the source was a high hydroelectric dam. For a coal-fired power plant, each kilowatt-hour would require 0.51 gallons (2 liters) of water for its production.

Waterless urinals are dry plumbing fixtures that use advanced hydraulic design and a buoyant fluid to maintain sanitary conditions.

Weighted decibel (dBA) is a sound pressure level measured with a conventional frequency weighting that roughly approximates how the human ear hears different frequency components of sounds at typical listening levels for speech.

Wetlands are natural or constructed areas that are inundated or saturated by surface water or groundwater at a frequency and duration sufficient to support, and that under normal circumstances do support, a prevalence of vegetation typically adapted for life in saturated soil conditions. Wetlands generally include swamps, marshes, bogs, and similar areas.

Whole building design is viewing a building as a system rather than as a set of components and using integrated design strategies to maximize the potential of the facility for its owners.

Xeriscaping is a landscaping method that makes routine irrigation unnecessary. It uses drought-adaptable and low-water plants as well as soil amendments, such as compost and mulches, to reduce evaporation.

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