Buildings for extreme environments

Arid

CIBSE

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Cover illustration: Construction work in Dubai, UAE (© nodiff, sourced through Shutterstock.com)

Note from the publisher

This publication is primarily intended to provide guidance to those responsible for the design, installation, commissioning, operation and maintenance of building services. It is not intended to be exhaustive or definitive and it will be necessary for users of the guidance given to exercise their own professional judgement when deciding whether to abide by or depart from it.

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Foreword

CIBSE's TM04: *Design notes for the Middle East* was published in 1990. With the effects of climate change becoming better understood and the need to embrace relevant engineering solutions more necessary, the review became long overdue.

In examining what would be appropriate to our members, a publication that embraced the world and environments beyond the confines of the Middle East became an obvious step forward. Instead of generating a document that had a geographical base as before, it seemed more relevant to create one that was climate zone driven, which could be applied to different parts of the world as appropriate.

This document on arid zones is the first of a three-part series that will reflect different climate zones; the others representing polar and tropical climates.

With an ever-increasing number of our members working on international projects, or being based in locations unfamiliar to them, these documents have been designed to provide an introduction to topics that might be unfamiliar and to provide information upon which reasoned judgements may be made or lead to further research to be undertaken in support of their professional duties.

We were fortunate in assembling an international steering group whose members were all experts in their respective fields.

Contents

1 Introduction (arid climate)

This section outlines the basic weather, solar and design notes required to provide designers of engineering services with the basic information to engineer building services to satisfactory standards in an arid extreme climate condition. It cannot replace sound engineering judgement, which is the basis of all good design. It directs the designer to the appropriate sections of CIBSE and other equivalent guides and sources of information. Three extreme climates will be covered in the *Buildings for extreme environments* series (see Table 1). This publication looks at buildings for arid climates.

Institutions around the world recognise that professional building services design engineers engage with considerable amounts of work outside their native country. This document has been developed in recognition of this. The sources for the geographical descriptions are based on the Köppen-Geiger climate classification system, which is considered to be the most widely used.

CIBSE will update and re-issue this document as further information becomes available. CIBSE will accumulate this information and welcomes advice from users and any constructive criticism.

1.1 General

There are different systems for classifying climate; Köppen-Geiger is recognised as the most widely used.

The type of climate affects whether the area is desert, grassland or rainforest. It determines the plants that grow and what animals inhabit it. The climate of a region also controls or determines the biome. World biomas is controlled by climate.

Climate can be described as follows:

'Climate is the characteristic condition of the atmosphere near the earth's surface at a certain place on earth. Climate is the long-term weather of that area (over at least 30 years). This includes the region's general pattern of weather conditions, seasons and weather extremes such as hurricanes, droughts or rainy periods/floods. Two of the most important factors determining an area's climate are air temperature and precipitation. Solar radiation and humidity also play an important role. World biomes are controlled by climate. The climate of a region will determine what plants will grow there and what animals will inhabit it. All three components—climate, plants and animals—are interwoven to create the fabric of a biome.' (Strahler and Strahler, 1984)

Figure 1 shows the world map of Köppen-Geiger climate classification.

The rapid development of countries around the world has required building services engineers from all over the globe to apply their specialist knowledge to areas with extreme climatic conditions and changing social patterns and technologies.

It is difficult to define the countries that make up the climate zones and there is no political implication attached to the choice of countries covered by this document. The locations covered are those for which information has been readily available and covered by the climate zone system used.

There are limitations to the data, which must be appreciated by those who use it. The reliability of the meteorological data is limited by the relatively

Table 1: Extreme climates
Source: Arup

Climate zone	Descriptor	Typical latitude	Geographic descriptor
1: Cold climates	Ice cap, tundra, sub-Arctic	50°N and above 50°S and above	▪ Arctic, Greenland, North Canada, North Asia ▪ Antarctica
2: Arid	Steppe, desert	15°N–25°N 15°N–25°S	▪ Africa (part), Middle East ▪ Central Australia, America (part)
3: Tropical	Savannah, rainforest	15°N–15°S	▪ Africa, India (part), South Asia, Indonesia, South America

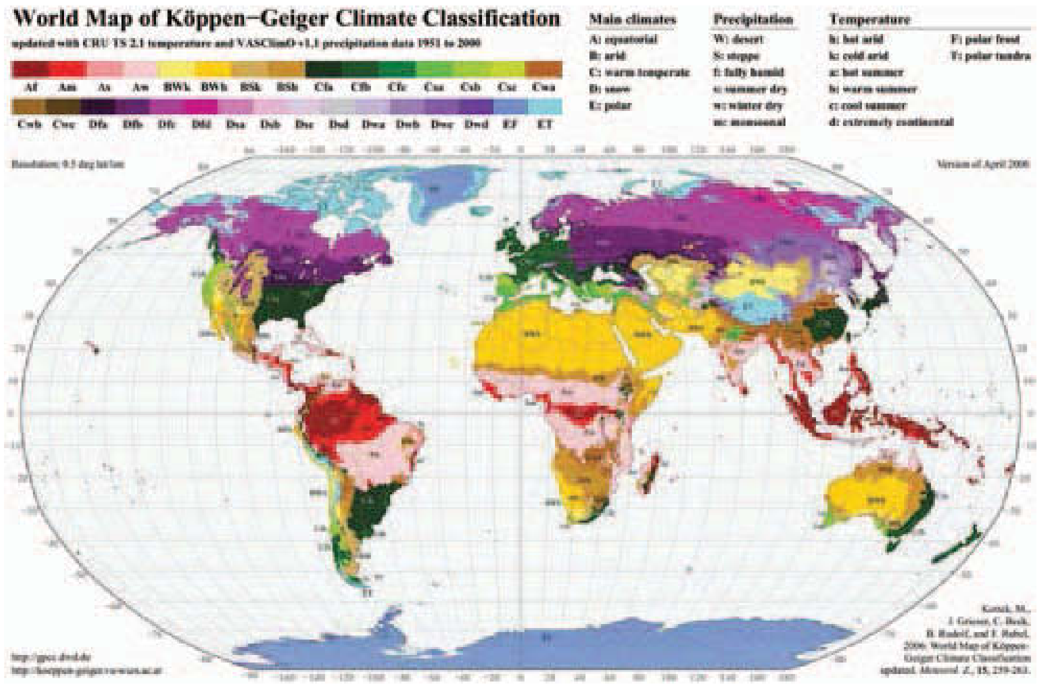


Figure 1: World map of Köppen-Geiger climate classification
(See section 1.3 for an explanation of these abbreviations)
Source: koeppen-geiger.vu-wien.ac.at (Kottek *et al.*, 2006)

short period over which the data have been accumulated. This varies from location to location. If meteorological data is of critical importance to a design, the designer should carry out his or her own detailed research; however the data provided in this publication should be adequate for most preliminary design work. CIBSE and ASHRAE both provide meteorological data for various countries for design purposes.

It is not possible to cover all the countries listed with example data and calculations. Therefore, as arid climates are hot, humid, desert-type terrain, the Middle East (Dubai) will be used as an example (see section 1.6).

1.2 Scope of data

1.2.1 Climate facts

The hotter spots around the earth are at a direct angle of between 23°N and 23°S latitude to the sun, where the most intense rays/radiation reach the earth's atmosphere and strike its surface.

The sun's rays hit other parts of the earth at a more obtuse angle and are therefore less intense. The climate is colder towards the earth's poles because the angle to the sun is smaller and the radiation is less intense, reducing its effect on the earth and atmosphere.

This affects the atmosphere and air mass (climate) and causes hot and cold air mass regions, which circulate around the earth.

Trade winds in the northern hemisphere blow from the northeast; in the southern hemisphere they tend to blow from the southwest. These winds then meet at the equator where the air rises and cools, developing into clouds and rain. As this is near to the equator, tropical conditions are generated.

The so-called westerlies coming from the southwest in the northern hemisphere, and from the northwest in the southern hemisphere, create storms from west to east across the middle latitudes. These blow away from the 30° latitude zone; they cover large areas and at this latitude the surface winds tend to be light. As this air blows away, it is replaced by slowly descending air, and any moisture contained within the air evaporates. These conditions can be seen in the tropical deserts of the African Sahara and Mexico's Sonoran.

1.2.2 Seasons

The earth rotates around the sun with its axis at a slight tilt (23.5°). When its tilt is towards the sun, it is summer in the northern hemisphere and winter in the southern hemisphere; thus when the earth moves around the sun and its tilt is away from the sun, it is winter in the northern hemisphere and summer in the southern hemisphere.

This affects the sun's radiation on the earth, which causes the earth's seasons. The rays emitted from the sun hit the earth at different angles. Rays hitting the earth's surface at 90° have the highest levels of energy, and these places have the highest temperatures. Areas where the Sun's rays hit the earth at different angles tend to be cooler.

1.3 Climate classification

1.3.1 Köppen climate classification system

Wladimir Köppen was a climatologist of Russian-German descent, who introduced his climate classification system in approximately 1900. He divided the earth's surface into climate zones/regions, which coincided with the earth's patterns of soils and vegetation.

The system was originally divided into five main groups; another was added later. Each climate type is depicted with a two- to four-letter reference and is colour coded (Figure 1). Native vegetation is used as the best expression of climate; climate boundaries are selected according to its distribution. It combines the average monthly and annual temperatures, precipitation and seasonality of precipitation.

1.3.1.1 Main climates

The main groups referenced in the Köppen system are as follows.

- Group A: Moist, tropical/mega-thermal climates: These are very warm climates, found in the tropics and experience high amounts of precipitation. They experience average temperatures of 18 °C and above for all 12 months of the year.
- Group B: Dry (arid and semiarid) climates: These are climates that have little precipitation for most of the year. Due to the large daily temperature swing, potential losses of water due to evaporation and transpiration vastly exceed atmospheric input.

  Two subgroups, S (semiarid or steppe) and W (arid desert), are used with B climates, which are outlined in section 1.4.
- Group C: Temperate (moist, mid-latitude, mild winters): These climates have warm to hot summer temperatures and mild to cool winters. The coldest months having an average temperature ranging between −3 °C and 18 °C.
- Group D: Continental (moist mid-latitude, cold winters): These climates tend to have warm summers but cold winters. The average summer temperature of the warmest month will exceed 10 °C, the coldest will be below −3 °C
- Group E: Polar climates (cold): 'Cold climates' describes this climate type perfectly. These climates are cold in winter with no real summer season. The average temperature of the warmest month is below 10 °C.
- Group H: Highland climates: These climates are different to areas at lower elevations at similar latitudes, as they are influenced strongly by the effects of altitude.

1.3.1.2 Secondary categories

These are depicted by lowercase letters and identify precipitation patterns, degree of aridity and ice.

(*a*) Precipitation

Letters f, w and s are used, which are applicable to A, C and D. Examples are indicated below:

- Af: tropical wet
- Aw: tropical wet and dry
- Am: tropical monsoon.

The uppercase letter W identifies desert (arid) and S represents steppe (semiarid); both are applicable to B major category:

- BW: desert (arid)
- BS: steppe (semiarid).

For polar climate (E), letters F and T identify whether the area is permanent ice field/glaciers or free of snow/ice during the summer months:

- ET: tundra (polar)
- EF: ice cap (polar).

(*b*) Temperature

To further denote variations in climate, a third letter is added to the code.

Major climates B, C and D use this letter to distinguish temperature characteristics, where h associated with the B climate depicts subtropical location and annual average temperature above 18 °C. The cooler mid-latitude (dry climates) are depicted with the letter k:

- BWh: dry arid (low latitude)
- BWk: dry arid (mid latitude).

C and D climates use the letters a, b, c, and d; these indicate different monthly temperature characteristics:

- Cfa: humid (subtropical)
- Cfb: marine (mild winter)
- Cfc: marine (cool winter)
- k: cold arid
- a: hot summer
- b: warm summer
- c: cool summer
- d: extremely continental.

1.4 Climate information and data

1.4.1 Climate group B: dry (arid and semiarid) climates

Dry, arid climate (desert) is found in low latitude deserts and covers at least 12% of the earth's surface. If precipitation is less than 50% of the potential 'evapotranspiration', this is defined as the process of transferring moisture from the earth to the atmosphere by evaporation of water and transpiration from plants. The threshold value (in mm) is determined as follows.

$$\text{Precipitation threshold} = \text{average annual temperature } ^{o}\text{C} \times 20 + N$$

where:

- $N = 280$ (if 70% or more of total precipitation is in the high-sun half of the year April to September in the northern hemisphere or October to March in the southern hemisphere)
- $N = 140$ (if 30–70% of the total precipitation is received during the applicable period)
- $N = 0$ (if less than 30% of the total precipitation is so received.

Where precipitation is less than half the threshold for group B, the classification used is BW 'desert climate' and if it less than the threshold but more than half the threshold, BS 'steppe climate is used. Where it is more than the threshold, it is not classified as a group B climate).

The third letters h and k indicate temperature.

- h is used to represent low latitude climate, where the average annual temperature is above 18 °C
- k is used to represent middle latitude climate, where the average annual temperature is below 18 °C.

The common practice today, mainly in the US, is to use h to represent the coolest month where the average temperature is above 0 °C and k is used where one month average is below 0 °C.

Köppen-Geiger climate classification examples are given below.

BWh examples:

- Alice Springs, Australia
- Kufra, Libya
- Bilma, Niger
- Yuma, Arizona, US
- Luxor, Egypt
- Dubai, UAE
- Timbuktu, Mali
- Riyadh, Saudi Arabia.

BWk examples:

- Ashgabat, Turkmenistan
- Isfahan, Iran
- Turpan, China
- Samarkand, Uzbekistan
- Ruoqiang, China.

BSh examples:

- Aleppo, Syria
- Argos, Greece
- Mossoro, Rio Grande do Norte, Brazil
- Nicosia, Cyprus
- Porto Santo, Portugal
- Murcia, Spain
- Tympaki, Greece.

BSk examples:

- Ogallala, Nebraska, US
- Denver, Colorado, US

- Boise, Idaho, US
- Medicine Hat, Alberta, Canada
- Kelowna, British Columbia, Canada
- Bejs, Portugal
- Albacete, Spain
- Konya, Turkey
- Kabul, Afghanistan.

Further B classifications (BWn, BSn) are used to depict desert areas that are located along coastal continents (west coasts) that are at tropical or near tropical locations. They are generally cooler due to the effect of cold ocean currents nearby and are prone to fog and low clouds. However, they are still among the driest areas in terms of the amount of precipitation they receive.

BWn examples:

- Lima, Peru
- Walvis Bay, Nambia.

BSn examples: Foggy, coastal steppes.

A fourth letter is sometimes added to demonstrate that the winter or summer is wetter than the other half of the year.

1.5 Climate analyses

1.5.1 Climate data (arid environment)

The following list shows various countries with their Köppen climate classification.

- Afghanistan: arid to semiarid; cold winters and hot summers.
- Algeria: arid to semiarid; mild, wet winters with hot summers along coast; drier with cold winters and hot summers on high plateau and experience sirocco, a hot, dust/sand-laden wind especially common in summer.
- Angola: semiarid in south and along coast to Luanda; north has cool, dry season (May to October) and hot, rainy season (November to April).
- Australia: generally arid and semiarid; temperate in south and east; tropical in north.
- Azerbaijan: semiarid steppe.
- Bahrain: arid; mild, pleasant winters; very hot, humid summers.
- Bolivia: varies with altitude; humid and tropical to cold and semiarid.
- Botswana: semiarid; warm winters and hot summers.
- Cameroon: varies with terrain; from tropical along coast to semiarid and hot in north.
- Djibouti: desert; torrid, dry.
- Egypt: desert; hot, dry summers with moderate winters.
- Eritrea: dry desert strip along red sea coast; cooler and wetter in the central highlands (up to 61 cm of rainfall annually, heaviest June to September; semiarid in western hills and lowlands.
- Haiti: tropical; semiarid where mountains in east cut-off trade winds.
- Iran: mostly arid or semiarid, subtropical along Caspian coast.
- Jordan: mostly arid desert; rainy season in west (November to April).
- Kazakhstan: cold winters and hot summers; arid and semiarid.
- Kuwait: dry desert; intensely hot summers; short, cool winters.
- Mali: subtropical to arid; hot and dry (February to June); rainy, humid, and mild (June to November); cool and dry (November to February).
- Mauritania: desert; constantly hot, dry, dusty.
- Mexico: varies from tropical to desert.
- Mongolia: desert; continental (large daily and seasonal temperature ranges).
- Namibia: desert; hot, dry; rainfall sparse and erratic.
- Niger: desert; mostly hot, dry, dusty; tropical in extreme south.
- Oman: dry desert; hot, humid along coast; hot, dry interior, strong southwest summer monsoon (May to September) in far south.
- Pakistan: mostly hot, dry desert; temperate in northwest; arctic in north.
- Peru: varies from tropical in the east to dry desert in west; temperate in Andes.
- Qatar: arid; mild, pleasant winters; very hot, humid summers.

- Saint Barthelme: practically no variation in temperature; has two seasons—dry and humid.
- Saudi Arabia: dry desert with great temperature extremes.
- Somalia: principally desert; northwest monsoon (December to February), moderate temperatures in north and hot in south; southwest monsoon (May to October), torrid in the north and hot in the south, irregular rainfall, hot and humid periods (Tangambili) between monsoons.
- South Africa: mostly semiarid; subtropical along east coast; sunny days, cool nights.
- Sudan: tropical in south; arid desert in north; rainy season varies by region (April to November).
- Syria: mostly desert; hot, dry, sunny summers (June to August) and mild rainy winters (December to February) along coast; cold weather with snow or sleet periodically in December.
- Tunisia: temperate in north with mild, rainy winters and hot, dry summers, desert in south.
- United Arab Emirates (UAE): arid subtropical climate due to location within the northern desert belt; cooler in eastern mountains
- Western Sahara: hot, dry desert; rain is rare; cold offshore air currents produce fog and heavy dew.
- Yemen: mostly desert; hot and humid along west coast; temperate in western mountains affected by seasonal monsoon; extraordinarily hot, dry, harsh desert in east.

Figure 3: Dubai desert
Source: Mariia Savoskula, Shutterstock

Figure 2: Geographical location (Dubai)
Map data courtesy © Google; imagery courtesy © 2014 TerraMetrics
Geographical coordinates: 25° 15' 8" N, 55° 16' 48" E

1.6 Climate analysis (example: Dubai)

1.6.1 General information

This section provides an overview of Dubai in general and the climate around the UAE (Dubai).

An understanding of the climate is required to guide the proposed design and to assess the potential energy savings that can be achieved even in adverse climates and conditions.

The key climatic variables presented in this section are air temperature, solar radiation, humidity and wind.

The United Arab Emirates is located on the Arabian/Persian Gulf; it is made up of seven states of which Dubai is one. Dubai is the second largest state and is bordered by Abu Dhabi (UAE capital), Sharjah and Oman.

Figure 4: Dubai
Source: Marat Dupri, Shutterstock

Dubai has a multicultural society and the highest population in the UAE. Dubai developed as trade grew along the banks of its creek, a natural inlet from the gulf that extends some 15 km inland. Deira was the first area to develop on the north side of the creek, followed by Bur Dubai on the south side of the creek. Bur Dubai links to the tourist and residential areas of Jumeirah, which runs along the coast. Due to its strategic location Dubai has easy access to its neighbouring Gulf States, Africa and Asia, allowing easy connections for travel and commerce.

1.6.2 Climate

The UAE geographically lays on the line of the Tropic of Cancer, causing warm and sunny weather in Dubai. Average daytime temperatures inland are 25 ºC, and nights are slightly cooler in winter months. Coastal temperatures average 12–15 ºC; desert and mountainous regions have an average of 5 ºC. Due to its coastal location, humidity levels can average 50% to 60%.

The summer weather in Dubai is very hot and humid—temperatures reach on average mid 40 ºC and have been known to peak at over 50 ºC, with humidity's averaging 90% plus. The seawater temperatures along the coast can reach 37 ºC, with cooler temperatures at deeper depths.

Rainfall in the UAE (Dubai) occurs within the winter months; it is infrequent and generally does not last for long periods, with either short showers or downpours, although it can last for several hours and be accompanied by the occasional thunderstorm. On average, rain falls only for about five days of the year.

1.6.3 Sources of data

Weather data can be acquired from a number of sources. Figure 5 shows the location of local weather recording stations around the UAE.

For a statistically representative assessment of the climate in a particular location, at least 30 years of weather data are required, ideally from multiple sites close to the project site. This is particularly important when considering the wind climate. The climate data presented here is from Dubai International Airport and Sharjah International Airport—both have over 30 years of recorded data. Local weather data should be used if available; if not it may be possible to source from CIBSE or ASHRAE data.

Figure 5: Sources of available weather data

CQCM: Minhad Military Airport
D1117: Jumeriah (inactive station)
OMDB: Dubai International Airport
OMSJ: Sharjah International Airport
OMRK: Ras Al Khaimah International Airport
OIBA: Abu Musa Islands
WMO40890: Abu Musa Islands
OMAL: Ain International Airport
OMAA: Abu Dhabi International Airport

Map data courtesy © 2011 Google, LeadDog Consulting

When assessing the expected energy performances of a building, a single year of hourly data is normally used. These weather files are widely used for energy analysis in the UAE and represent the likely temperatures, humidity and solar radiation values throughout the year. The climate represented in this file was compared with recorded data from Dubai International Airport and Sharjah International Airport and was considered suitable for use in this example.

If weather files do not exist, the designer needs to seek guidance from an authoritative body about suitable alternative data.

1.6.4 Temperatures

The temperature in Dubai is characterised by high air temperatures throughout the summer months. The highest temperature recorded in the data from Dubai airport is 48 °C and the air temperature often stays above 30 °C at night in summer.

During the winter months, the air temperatures are much more comfortable and lows of 8 °C have been recorded.

Dubai has a reasonable diurnal range, which is present throughout the year.

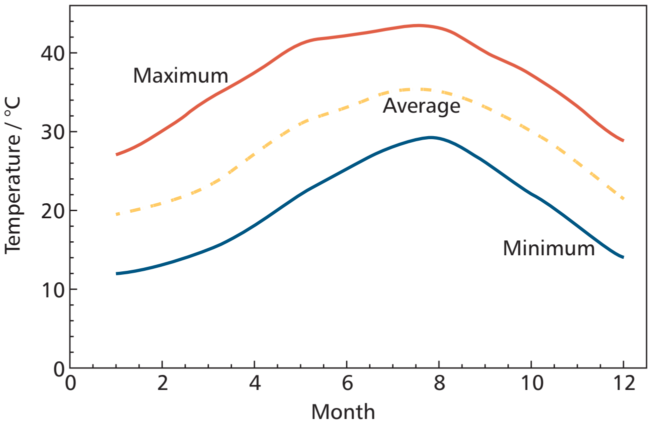


Figure 6: Dubai air temperature ranges

The average temperatures at different times of the day and different seasons are shown in Figure 6. The following conclusions can be made from this data.

The air temperatures during the day in the summer months are very high, and it is extremely unlikely that buildings can be used passively during these times.

The air temperatures during the night in summer are still high, and it is extremely unlikely that benefit can be gained in the form of night-time purge cooling during these months.

The average air temperatures during the day in winter are comfortable, so there is the potential for useable external spaces.

The air temperatures at night are cooler in winter months, and could be used to provide free cooling to the building (subject to air quality).

In order to provide comfortable internal spaces throughout the rest of the year, some treatment of the air will be required during the day to cool the space down.

The mid seasons between summer and winter have air temperatures that will suit comfortable external spaces at some times.

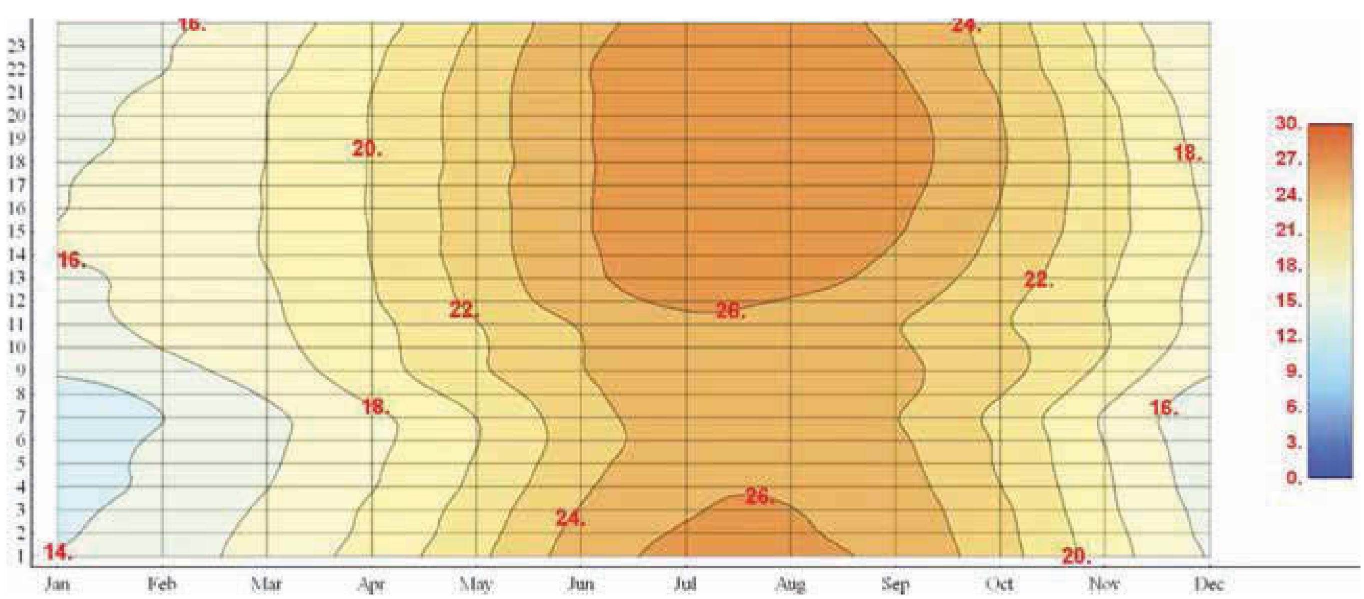
A good design would increase the apparent effect of the cool period and reduce the apparent effect of the hot period; optimum passive design should harness these climatic conditions to minimise the reliance on air conditioning.

1.6.5 Solar radiation

The climate across the Middle East is dominated by high solar intensity throughout the day. A key design feature is to achieve low-energy buildings and comfortable internal and external spaces with shading to block solar radiation. The orientation of the building and location and size of windows can be used to provide a degree of self-shading.

It should be noted that in the summer mornings and evenings the sun is in the northern part of the sky (illustrated in Figure 8). This means that the quantity of glazing will need to be limited and shading will be required on all facade orientations. This will affect both the thermal performance and visual comfort.

Figure 7: Dubai mean wet-bulb temperature, °C



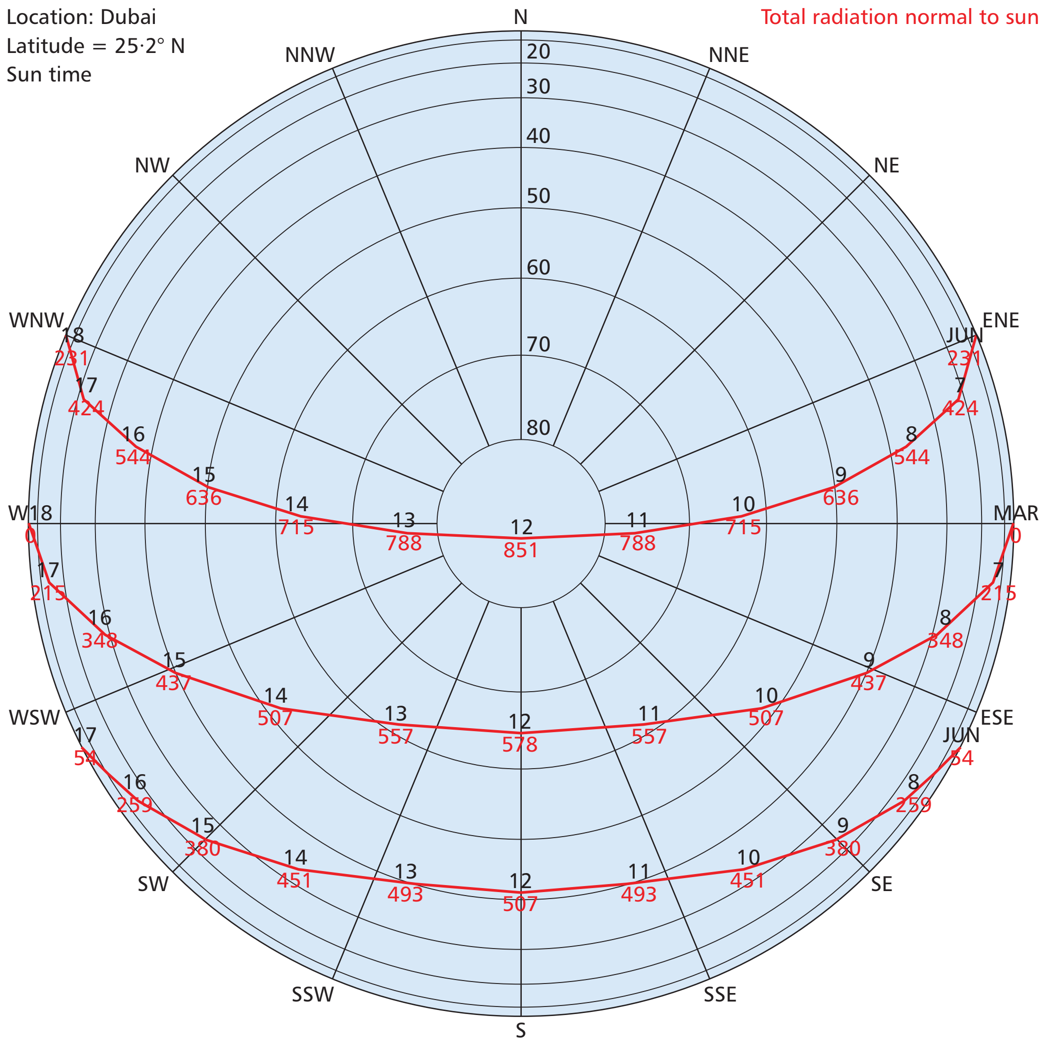


Figure 8: Solar location

1.6.6 Wind

The wind climate around a building should have an important effect on the form and orientation of a building because the wind can be used to ventilate internal and external spaces. Figures nine to twelve show the average wind direction and strength for different seasons and at different times of the day.

The benefits afforded by wind are strongly dependent on the temperature of the air. It may be desirable at some times of the year to prevent wind from entering the building if the air temperature is high.

The following conclusions can be made from the data available.

During the normal day hours, the strongest winds are in the winter and spring and tend to come from a westerly direction. These winds are cool to warm and can be used for passive cooling of the external spaces. To exploit the benefits of these winds, the openings in buildings should be orientated in this direction.

During the summer, the wind tends to come from the northwest. These winds are hot and should be prevented from entering the building by the orientation of the building or by shutting the building openings.

The wind speeds during the night and mornings are low in strength and are expected to come from a range of directions from east around to southwest.

During the night, it is possible to use purge ventilation cooling for a portion of the year. Due to the low wind strength, if night purge cooling is supplied using natural ventilation, ventilation rates will be dominated by buoyancy forces rather than driven by the wind.

It should be noted that wind is inherently a transient phenomenon and will be constantly changing with time. Therefore, although the wind roses show the likely average wind directions, in reality the wind direction and strength will continually change.

Figure 9: Spring wind roses m/s

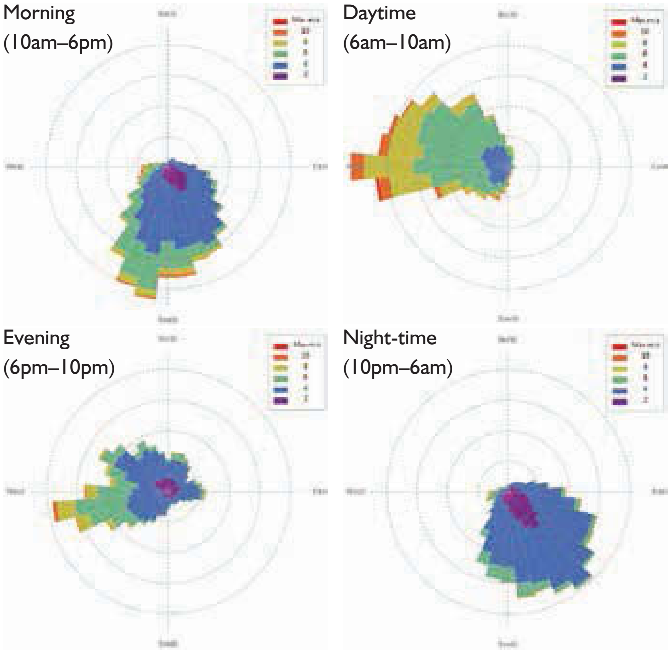


Figure 10: Summer wind roses m/s

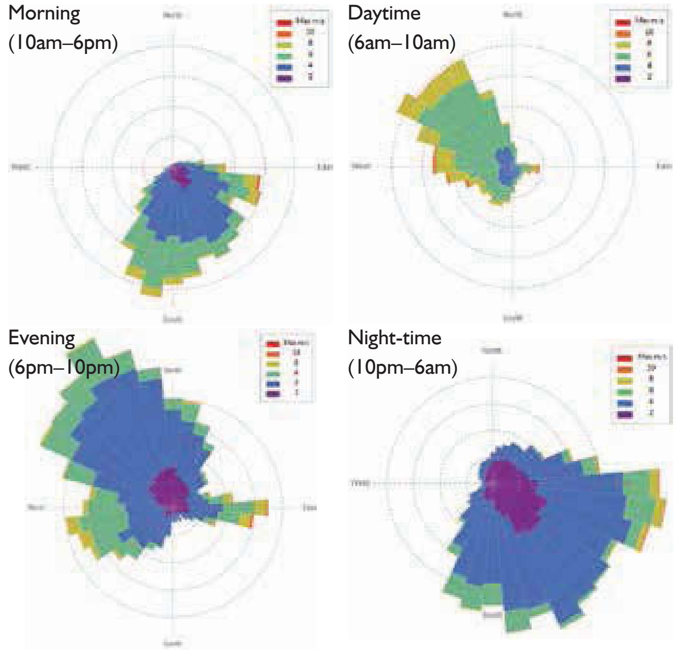


Figure 11: Autumn wind roses m/s

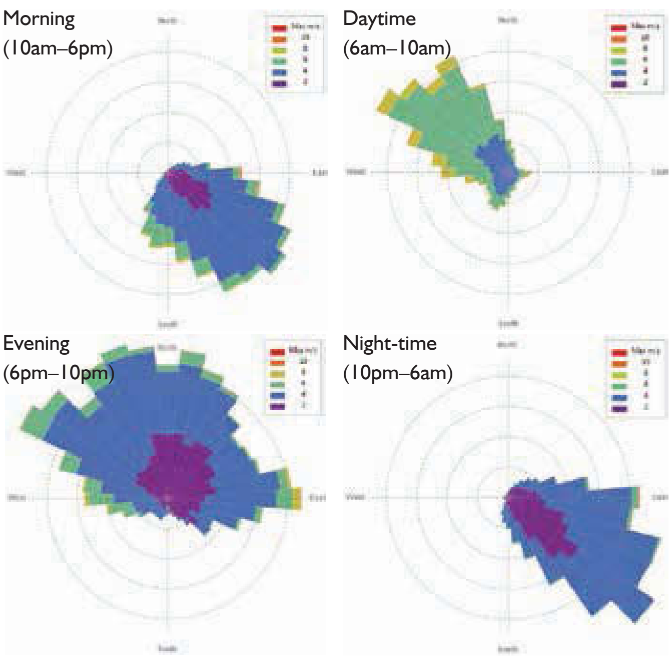
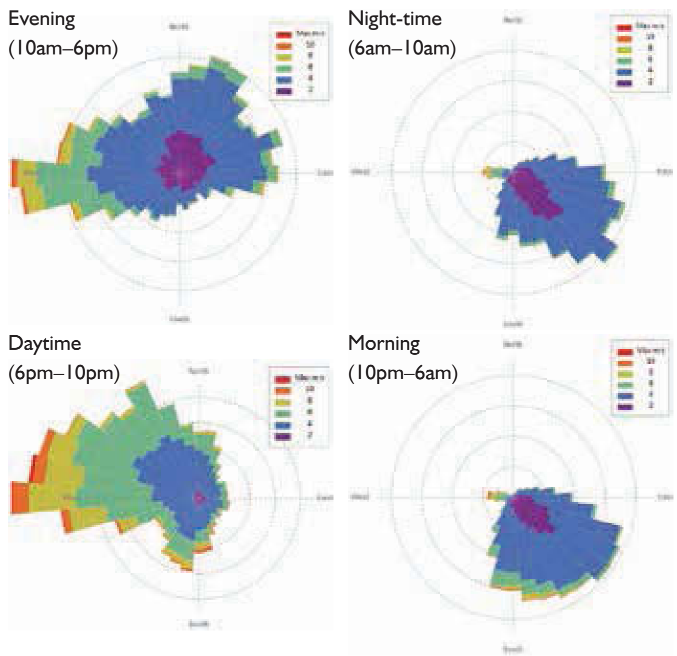


Figure 12: Winter wind roses m/s



Finally, the wind climate local to buildings is strongly dependent on the surrounding terrain and surrounding buildings. Where the design is dependent upon the wind patterns and profiles, site-specific surveys are recommended. In such cases, consideration must be given to the impact of future neighbouring developments.

1.6.7 Humidity

The humidity of the air is important when considering human comfort and the efficiency of cooling systems

Figure 13 shows the humidity and external air temperature for three months. The following information can be concluded from this.

In summer, the air temperatures are high, but also the humidity levels are often high, although not coincident. During these times, evaporative cooling will work well during the day but not at night when the humidity level increases and mechanical systems will be required to achieve satisfactory internal conditions.

In the mid seasons there are a range of humidity values, but generally when the air temperature is high, the relative humidity is low, which means that evaporative cooling could be beneficial.

In winter the air temperature is lower and, similar to the mid seasons, a range of relative humidity values occur.

Due to its proximity to the sea, Dubai has a relatively humid climate when compared with more inland locations. This will be a limiting factor in the implementation of evaporative cooling and means that the diurnal range is reduced when compared with a more inland location.

The wet-bulb temperature can be used as a measure of comfort because it relates to the ability of a person to sweat in order to keep cool. The wet-bulb temperatures are shown in Figure 14, from which the following conclusions can be made.

In the summer, the wet-bulb temperature is very high at all times of day. A wet-bulb temperature of 26 °C will be very unpleasant for a person who is outside. It is not possible to passively achieve comfortable external conditions during these times.

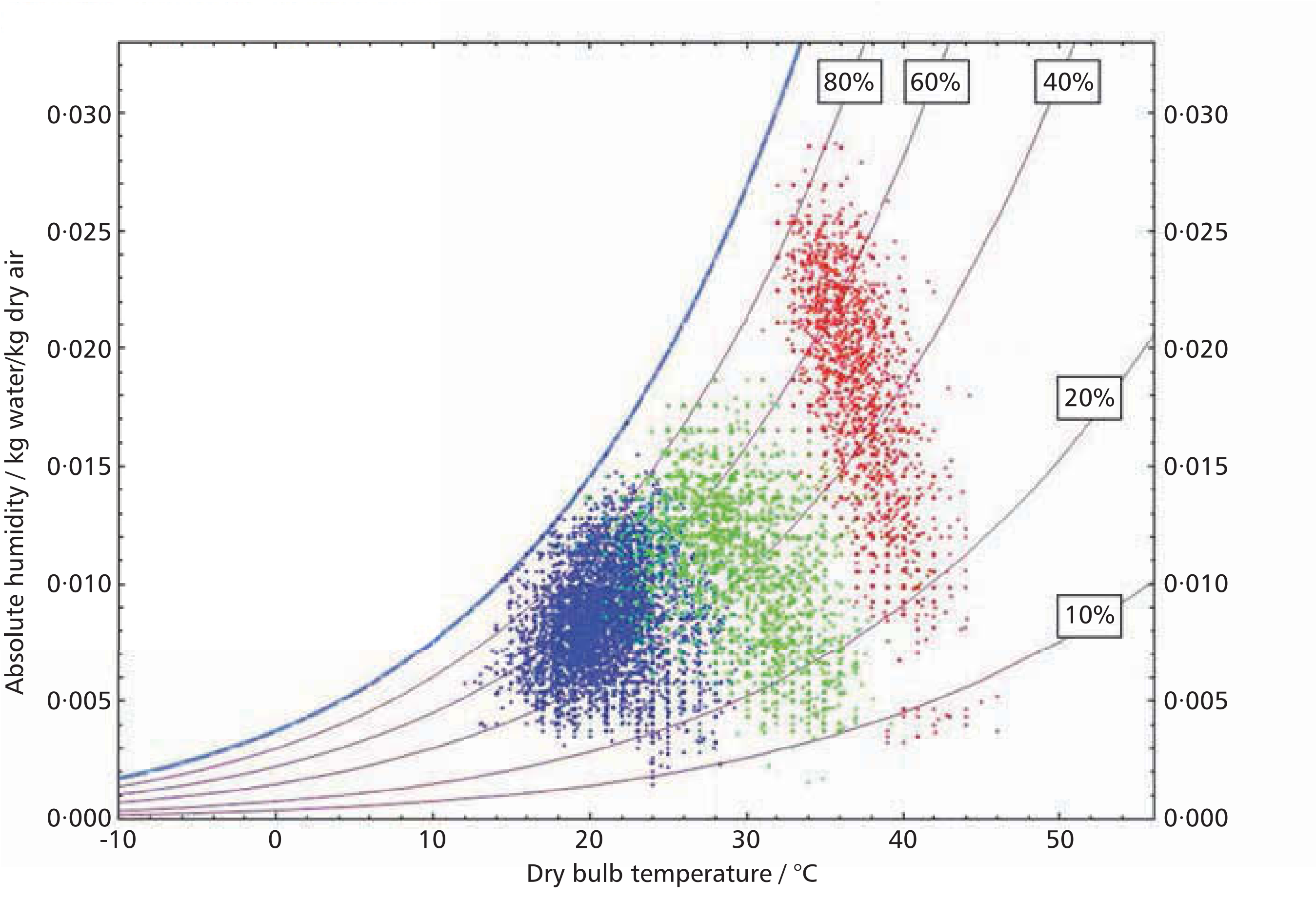
In the mid seasons the wet-bulb temperature is still high. It is generally recommended by both CIBSE and ASHRAE that evaporative cooling is not undertaken for wet-bulb temperatures above 21 °C. During these times, external spaces are likely to be suitable for people moving between internal spaces but not for people to spend considerable time in during the day.

In winter the wet-bulb temperature is generally low, indicating pleasant external spaces and the potential for natural or evaporation assisted ventilation.

1.6.8 Precipitation (rainfall)

The rainfall intensity for this region is sparse. Dubai has short and irregular rainfall as is typical for the Middle East. Most of the rainfall in Dubai occurs between December and March, as can be seen from Figure 15. Design intensity typically is 75 mm per hour.

Figure 13: Dubai psychrometric chart



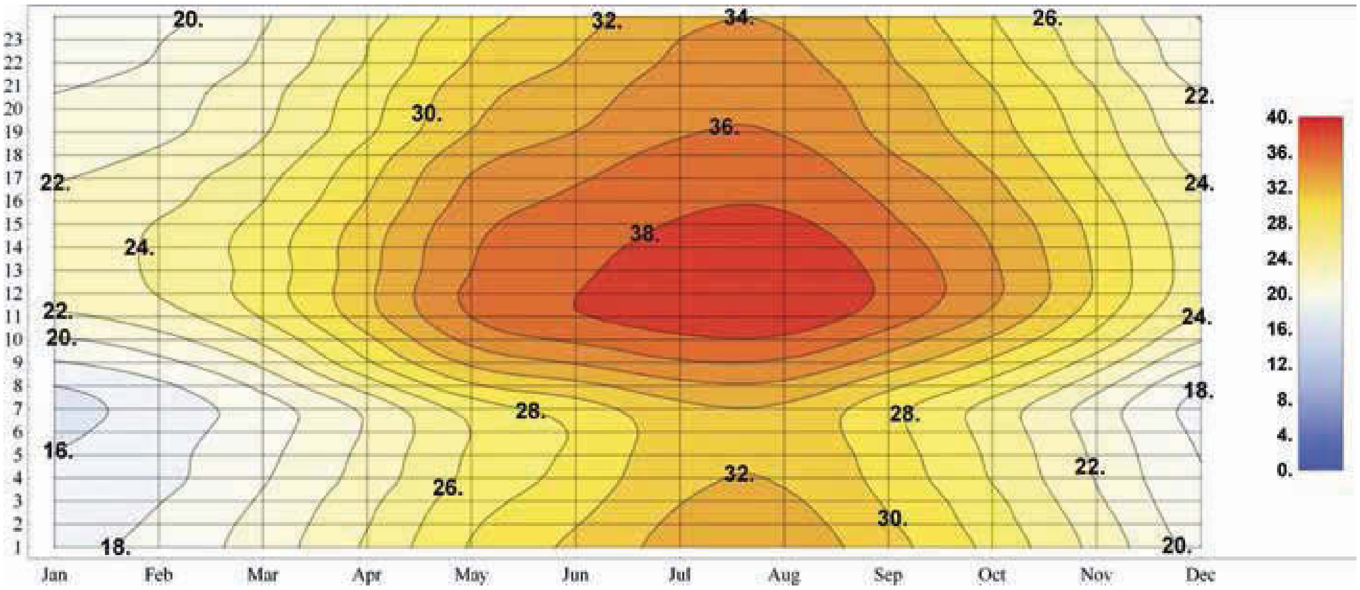
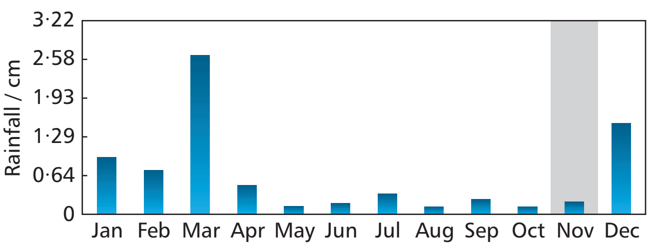


Figure 14: Dubai annual mean wet-bulb temperatures °C

Figure 15: Monthly rainfall (cm)



1.6.9 Climate considerations

In conclusion, the climate in Dubai is relatively pleasant in winter in terms of external comfort and offers good potential for passive environmental control. However, in summer the climate conditions are extremely hot and humid; mechanical systems are required to deliver the comfort expectations of the building. Mid-season presents opportunities to use hybrid approaches, and to reduce the energy consumption of the building.

Whilst climate considerations need to be taken into account, it is also important to recognise that there may be microclimate issues to consider.

1.7 Microclimate consideration

The opportunity to develop a project where the microclimate is considered from the beginning will have the potential to produce a development that is environmentally, socially and economically sustainable. Improving comfort in external spaces will considerably improve the public realm, and encourage walking, cycling and the use of public transport, thereby reducing car use.

In addition, the microclimate strategies will reduce the heat island effect and lead to reduced energy consumption for cooling.

The microclimate of outdoor spaces is defined by the air and radiant temperatures, wind conditions and humidity. Modifying these factors according to the intended use of the space allows improvements in external comfort to be made by 'microclimate design'. The building design should be influenced by a need to produce an urban form applicable to the climate—wind, sun and climate data need to be analysed to inform solutions. The layout of the site should be designed in order to maximise shade and channel breezes and/or sea breezes if coastal, using properly orientated streets and air movement where possible. Some architects aspire to creating shaded courtyards that capture spill from the building to form cold wells and provide a more hospitable external environment. These need to be sheltered from the winds.

1.7.1 Shading

Shade is the most important aspect to improve comfort at all times of day and night, all year round.

The exposed architecture of temperate climates is not appropriate for the gulf. Spaces between buildings need to be protected from direct sun in order to facilitate comfortable circulation of people on foot. This will lead to an under croft area that is well shaded. Occupants of these areas by day will be shielded from the direct sun. The surfaces will also be protected from direct sun, which will prevent

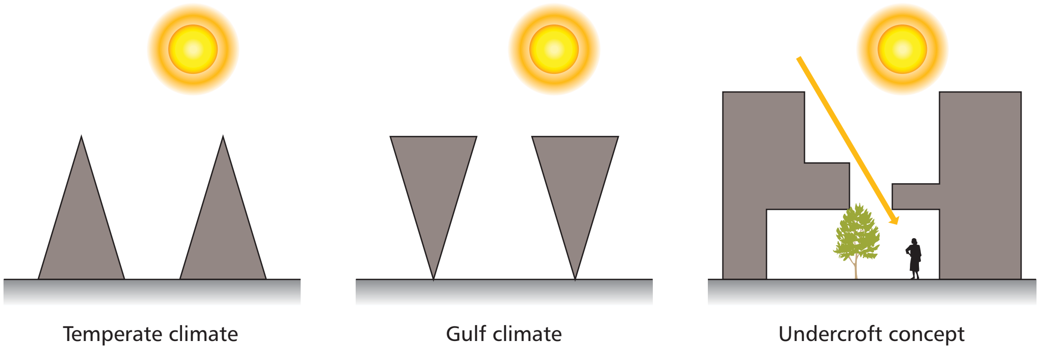


Figure 16: Example of shading concepts

them heating up. On summer evenings, comfort will be improved, as the surfaces will not radiate heat. Figure 16 illustrates the different building configurations to protect spaces between buildings, depending on climate.

The orientation of the streets can be configured to improve the amount of shading the streets receive due to buildings. Because the sun tracks relatively high in the sky from east to west, the east and west flanks of buildings offer the most shading. This leads to an ideal street orientation running from north to south, thus maximising shading.

When considering shading at the scale of buildings, exposed horizontal faces must be taken into account. Direct sunlight can penetrate underneath shading structures in the morning and afternoon when the sun is at a low angle in the sky—the extent of shade required will be defined by the surrounding massing and the requirements of each space. It should be noted that solar intensity tends to increase from low sun angles to higher ones.

The facades of buildings should be configured to reduce solar heat gain and cooling energy consumption. This is particularly crucial for the windows, which should be small and can be shaded well by deep reveals and external structures. This needs to be balanced with daylight and view requirements.

A variety of methods can be used in the public realm to provide shade, including:

- building overhangs and bridges
- colonnades
- passages through and between buildings
- shade structures and screens
- vegetation canopies.

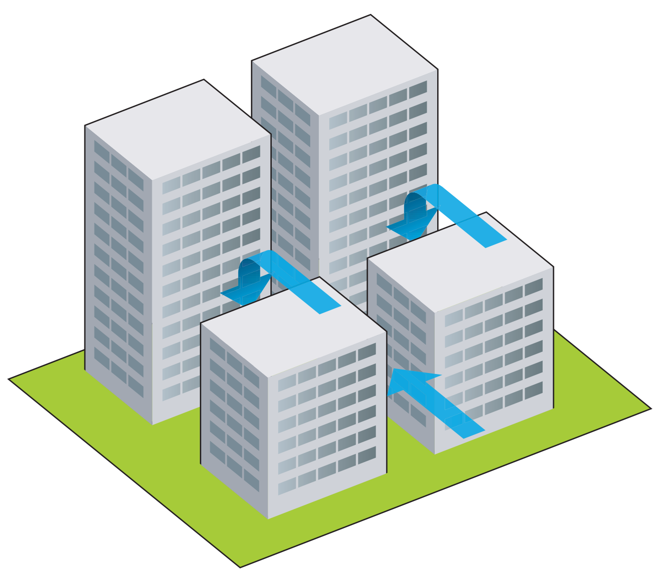
Additionally, internal spaces can be improved by setting back glazing behind shaded balconies.

1.7.2 Air movement

Air movement is an important factor in improving comfort in external areas during the cooler months of the year. While the air temperature is lower than skin temperature (33–34 °C), air movement will improve the loss of heat from the skin and enhance comfort. Additionally, air movement over the skin will increase the rate of evaporation and improve cooling of the body due to sweat, thus increasing comfort.

The wind can be used to increase air movement passively (so there is no need to input any energy). The majority of the wind comes from the north/northwest and can be channelled along orientated streets. Planning the site with building height rising from these wind directions will allow the buildings to bring wind down onto the site, as illustrated in Figure 17.

Figure 17: Wind channelling by using building height to increase air movement at low level



Traditionally, localised devices are used to improve conditions in their vicinity. Wind catching towers (see Figures 18 and 19) have been used in the Middle East to provide natural ventilation to buildings. They work by presenting a bluff body to the wind. The wind causes a positive pressure on the windward side and a negative pressure on the leeward side. Fresh air will enter any windward opening and be drawn up through from any leeward opening.

1.8 Illumination

1.8.1 Illuminance

The luminous flux per unit area at any point on a surface exposed to incident light is measured in luxes—also called illumination.

1.8.2 Illuminance data

Quantitative daylight illuminance data are needed for daylighting design calculations including the sizing of windows, choice of glazing materials and the design of window shading systems. Daylighting and electric lighting systems must be designed to operate interactively. The quantitative estimation of the energy consumption of artificial lighting with different control systems needs knowledge of the statistical availability of the horizontal components of daylight, the global horizontal illuminance and the diffuse horizontal illuminance from the sky vault. A means of assessing the effect of orientation on vertical surface daylight availability is also required. These issues are considered in detail in SLL Lighting Guide LG10: *Daylighting and window design* (SLL, 1999). The required climatic data are discussed in detail in CIBSE Guide J: *Weather, solar and illuminance data* (CIBSE, 2002).

In photometry, illuminance is the total luminous flux incident on a surface, per unit area. It is a measure of how much the incident light illuminates the surface. Similarly, luminous emittance is the luminous flux per unit area emitted from a surface. Luminous emittance is also known as luminous exitance.

In SI units, illuminance is measured in lux (lx) and luminous emittance (excitance) in lumens per m^2 (lm/m^2).

Illuminance was often called brightness, but this lead to confusion between the uses of the word. 'Brightness' should never be used for quantitative description, but only for non-quantitative references to physiological sensations and perceptions of light.

The human eye is capable of seeing more than a two-trillion-fold range. The presence of white objects can only just be seen under starlight, at 5×10^{-5} lux, while at the bright end it is possible to read large text at 10^8 lux, or about 1000 times that of direct sunlight, although this can be very uncomfortable and cause long-lasting after-images.

Figure 18 (far left): Operation of a traditional wind catching tower

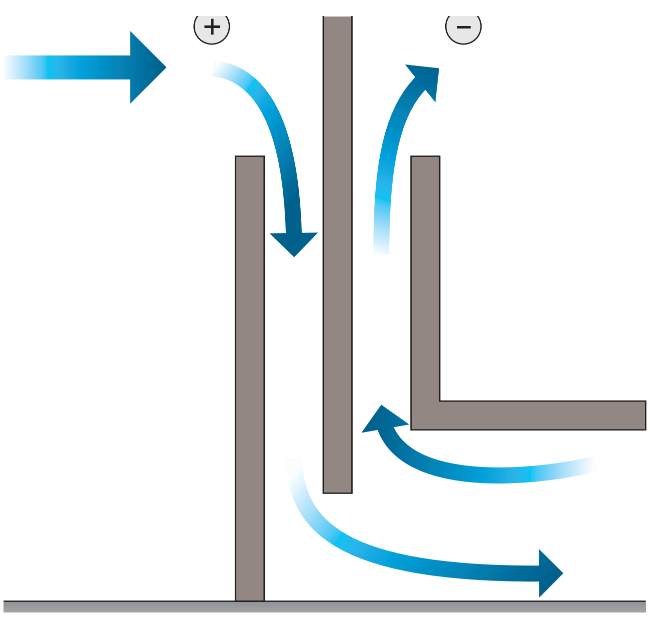


Figure 19: Historical photograph of wind catching towers
Source: © M Khebra, Shutterstock

1.8.3 Sunlight

Sunlight is the total frequency spectrum of electromagnetic radiation given off by the sun, particularly infrared, visible and ultraviolet light. On earth, sunlight is filtered through the earth's atmosphere, and is obvious as daylight when the sun rises above the horizon. When the direct solar radiation is not blocked by clouds, it is experienced as sunshine, a combination of bright light and radiant heat. When it is blocked by the clouds or reflects off other objects, it is experienced as diffused light, an example of this is known as crepuscular rays, which are parallel beams of light, see Figure 20 for an example.

The World Metrological Organisation uses the term 'sunshine duration' to mean the cumulative time during which an area receives direct irradiance from the sun of at least 120 watts per m^2. Sunlight may be recorded using a pyranometer or pyrheliometer, basically a sunshine recorder. Sunlight takes about 8.3 minutes to reach the earth. On average, it takes energy between 10 000 and 170 000 years to leave the sun's interior and then be emitted from the surface as light.

Direct sunlight has a luminous efficacy of about 93 lumens per watt of radiant flux. Bright sunlight provides illuminance of approximately 100 000 lux or lumens per m^2 at the earth's surface. Sunlight's composition at ground level, per m^2, with the sun at the zenith, is about 527 W of infrared radiation, 445 W of visible light, and 32 W of ultraviolet radiation. At the top of the atmosphere, sunlight is about 30% more intense with more than three times the fraction of ultraviolet (UV), with most of the extra UV consisting of biologically damaging shortwave ultraviolet. Figure 21 shows the solar radiation spectrum above the atmosphere and at the earth surface. Sunlight is a key factor in photosynthesis, a process vital for many living things on earth.

Extreme UV and X-rays are produced (at left of wavelength range shown in Figure 21) but comprise very small amounts of the sun's total output power.

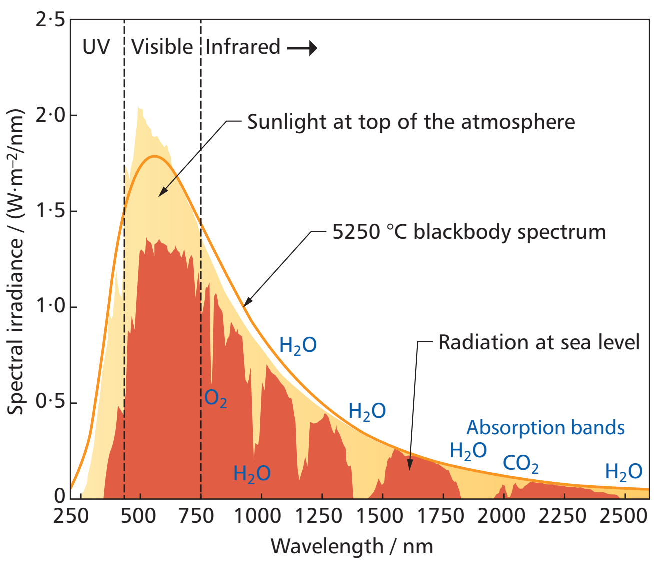
The spectrum of the sun's solar radiation is close to that of a black body with a temperature of about 5800 K (a black body is any object that is a perfect emitter and a perfect absorber of radiation—the surfaces of the sun and the earth behave approximately as black bodies). The sun emits electromagnetic radiation across most of the spectrum. Although the sun produces gamma rays as a result of the nuclear fusion process, these high energy photons are converted to lower energy photons before they reach the sun's surface and are emitted out into space. As a result, the sun does not emit gamma rays. The sun does, however, emit X-rays, UV and visible light also infrared and radio waves.

Figure 20 (right): Sunlight shining through clouds
Source: © Nazzu, Shutterstock

Although the solar corona is a source of extreme UV and X-ray radiation, these rays make up only a very small amount of the power output of the sun (see Figure 21) and will not be discussed further. The spectrum of nearly all solar electromagnetic radiation striking the earth's atmosphere spans a range of 100 nm to about 1 mm. This band of significant radiation power can be divided into five regions in increasing order of wavelengths.

1. Ultraviolet C (UVC) range, which spans a range of 100–280 nm. The term 'ultraviolet' refers to the fact that the radiation is at higher frequency than violet light (and, hence also invisible to the human eye). Atmospheric absorption means very little reaches the earth's surface (lithosphere). This spectrum of radiation has germicidal properties, and is used in germicidal lamps.
2. Ultraviolet B (UVB) range spans 280–315 nm. It is also absorbed by the atmosphere and, along with UVC, is responsible for the photochemical reaction leading to the production of the ozone layer. It directly damages DNA and causes sunburn.
3. Ultraviolet A (UVA) spans 315–400 nm. This band was once thought to be less damaging to DNA, and is used in cosmetic artificial sun tanning (tanning booths/beds). However, UVA is now known to cause significant damage to DNA via indirect routes (formation of free radicals and reactive oxygen species), and is able to cause cancer.

Figure 21: Irradiance spectrum above atmosphere and at surface



4. Visible range of light spans 380–780 nm. As the name suggests, this range is visible to the naked eye.
5. Infrared range spans 700–10^6 nm (1 mm). It is responsible for an important part of the electromagnetic radiation that reaches the earth. It is divided into three types on the basis of wavelength:
   a. Infrared-A: 700–1400 nm
   b. Infrared-B: 1400–3000 nm
   c. Infrared-C: 3000–1 mm.

Sunlight in space at the top of earth's atmosphere at a power of 1366 W/m^2 is composed (by total energy) of about 50% infrared light, 40% visible light and 10% UV light. At ground level this decreases to about 1120–1000 W/m^2, and by energy fractions to 44% visible light, 3% UV (with the sun at the zenith, but less at other angles), and the remainder infrared. Thus, sunlight's composition at ground level, per m^2, with the sun at the zenith, is about 527 W of infrared radiation, 445 W of visible light and 32 W of UV radiation.

1.8.3.1 Calculation

To calculate the amount of sunlight reaching the ground, both the elliptical orbit of the earth and the attenuation by the earth's atmosphere have to be taken into account. The extra-terrestrial solar illuminance (E_{ext}), corrected for the elliptical orbit by using the day number of the year (n), is given by:

$$E_{ext} = E_{sc}\left(1 + 0.033412\cos\left(2\pi\frac{n-3}{365}\right)\right) \quad (1.1)$$

where n = 1 on 1 January; n = 2 on 2 January; n=32 on 1 February, etc. In this formula $n - 3$ is used, because in modern times earth's perihelion—the closest approach to the sun and therefore the maximum E_{ext}—occur around 3 January each year. The value of 0.033412 is determined knowing that the ratio between the perihelion (0.98328989 astronomical unit (AU)) squared and the aphelion (1.01671033 AU) squared should be approximately 0.935338.

The solar illuminance constant (E_{sc}), is equal to 128 × 10^3 lx. The direct normal illuminance (E_{dn}), corrected for the attenuating effects of the atmosphere is given by:

$$E_{dn} = E_{ext}\, e^{(-cm)} \tag{1.2}$$

where c is the atmospheric extinction coefficient and m is the relative optical air-mass.

1.8.4 Solar constant

The solar constant, a measure of flux density, is the amount of incoming solar electromagnetic radiation per unit area that would be incident on a plane perpendicular to the rays, at a distance of one astronomical unit (AU), roughly the mean distance from the sun to the earth. The 'solar constant' includes all types of solar radiation, not just the visible light. Its average value was thought to be approximately, 1.366 kW/m² varying slightly with solar activity, but recent recalibrations of the relevant satellite observations indicate that a value closer to 1.361 kW/m² is more realistic. This radiation is about 50% infrared, 40% visible and 10% UV at the top of the atmosphere.

1.8.5 Total solar irradiance (TSI) and spectral solar irradiance (SSI) on Earth

Total solar irradiance (TSI)—the amount of solar radiation received at the top of the earth's atmosphere—was measured by satellite to be roughly 1.366 kW per m², but NASA describes TSI as '1361 W/m² as compared to ~1366 W/m² from earlier observations', based on regular readings from NASA's Solar Radiation and Climate Experiments (SORCE) satellite, active since 2003. This is a NASA-sponsored satellite mission that provides measurements of incoming X-ray, UV, visible, near-infrared and total solar radiation. These measurements specifically address long-term climate change, natural variability and enhanced climate prediction, and atmospheric ozone and UVB radiation. These measurements are critical to studies of the sun, its effect on the earth system and its influence on humankind. The Laboratory for Atmospheric and Space Physics (LASP) has further information on this topic.

1.8.6 Surface illumination

The spectrum of surface illumination depends on solar elevation due to atmospheric effects, with the blue spectral component from atmospheric scatter dominating during twilight before and after sunrise respectively, and red dominating during sunrise and sunset. These effects are apparent in natural light photography where the principal source of illumination is sunlight as mediated by the atmospheric conditions.

1.8.7 Climate effects

On earth, solar radiation is obvious as daylight when the sun is above the horizon. This is during daytime and at night in summer near the poles, but not in winter near the poles. When the direct radiation is not blocked by clouds, it is experienced as sunshine, combining the perception of bright white light (sunlight in the strict sense) and warming. The warming on the body, the ground and other objects depends on the absorption of the electromagnetic radiation in the form of heat.

The amount of radiation intercepted by a planetary body varies inversely with the square of the distance between the star and the planet. The earth's orbit and obliquity change with time (over thousands of years), sometimes forming a nearly perfect circle and at other times stretching out to an orbital eccentricity of 5% (currently 1.67%). The total insolation remains almost constant due to Kepler's second law:

$$\frac{2A}{r^2}\, dt = d\theta \tag{1.3}$$

where A is the 'areal velocity' invariant, i.e. the integration over the orbital period (also invariant) is a constant.

$$\int_0^T \frac{2A}{r^2} = \int_0^{2\pi} = \text{constant} \tag{1.4}$$

If we assume the solar radiation power as a constant over time and the solar irradiation given by the inverse-square law, we also obtain the average insolation as a constant.

The seasonal and latitudinal distribution and intensity of solar radiation received at the earth's surface also varies. For example, at latitudes of 65° the change in solar energy in summer and winter can vary by more than 25% as a result of the earth's orbital variation. Because changes in winter and summer tend to offset each other, the change in the annual average insolation at any given location is near zero, but the redistribution of energy between summer and winter does strongly affect the intensity of seasonal cycles. Such changes associated with the redistribution of solar energy are considered a likely cause for the coming and going of recent ice ages.

1.9 Climatic design information

Climate design information is generally sourced from recognised weather data files and used for design, sizing, distribution, installation and marketing of heating, ventilating, air conditioning and dehumidification equipment, as well as for other energy-related processes in residential, agricultural, commercial and industrial applications. These summaries include values of dry-bulb, wet-bulb and dew-point temperatures, and wind speed with direction at various frequencies of occurrence. Note that when using any software packages the designer should confirm what and where any climate data is from and how it is used.

Climate design information in this chapter was developed largely through Thevenard's final report (2009) for ASHRAE research project, RP-1453.

The information includes design values of:

- dry-bulb temperature with mean coincident wet-bulb
- design wet-bulb temperature with mean coincident dry-bulb
- design dry-bulb temperature with mean coincident dry-bulb and corresponding humidity ratio.

These data allow the designer to consider various operational peak conditions. Design values of wind speed facilitate the design of smoke management systems in buildings (Lamming and Salmon, 1996; 1998).

Warm-season temperature and humidity conditions are based on annual percentiles of 0.4, 2, 5 and 10%. Cold-season conditions are based on annual percentiles of 99.6 and 99.0. The use of annual percentiles to define design conditions ensures that they represent the same probability of occurrence in any climate, regardless of the seasonal distribution of extreme temperature and humidity. Monthly information including percentiles is compiled in addition to annual percentiles, to provide seasonally representative combinations of temperature, humidity and solar conditions.

Changes in the 2009 edition of ASHRAE Handbook: *Fundamentals* (ASHRAE, 2009) from the 2005 edition include the use of different percentiles for monthly design dry-bulb and mean coincident wet-bulb temperatures and monthly design wet-bulb and mean coincident dry-bulb temperatures.

Additions to the 2009 edition (ASHRAE, 2009) were monthly average temperature and standard deviation of daily average temperature, which can be combined to estimate heating and cooling degree-days to any base, as explained later in this chapter.

The tables in ASHRAE (2009) also list heating and cooling degree-days for bases 18.3 °C and 10 °C, as well as cooling degree-hours for bases 23.3 °C and 26.7 °C.

The calculation of daily dry-bulb and wet-bulb temperature profiles are useful for generating 24-hour weather data sequences. This data is suitable for inputting to many HVAC analysis methods. This weather data is found in ASHRAE (2009), including mean dry-bulb and wet-bulb temperature ranges, coincident with the 5% monthly dry bulb and wet-bulb design temperatures.

Two new parameters were included in the tables for that purpose: clear-sky optical depths for beam and diffuse irradiances. From these two parameters, clear-sky radiation for any time of any day of the year can be calculated, using a relatively simple method described later in the chapter. For convenience, the tables include noon-hour beam and diffuse irradiance values on the 21st day of each month. For more information, see the tables in ASHRAE (2009).

1.9.1 Climatic design conditions

Table 2 shows climatic design conditions for Dubai (UAE), to illustrate the format of the data available refer to ASHRAE (2009).

A limited subset of these data for 1450 of the 5564 locations for 21 annual data elements can be sourced from ASHRAE (2009).

The top part of the table contains the following station information.

- Name of the observing station, state (Dubai International, UAE).

- World Meteorological Organization (WMO) station identifier (411940).
- Weather Bureau Army Navy (WBAN) number (–99999 denotes missing).
- Latitude of station, °N/S.
- Longitude of station, °E/W.
- Elevation of station, m.
- Standard pressure at elevation, in kPa .
- Time zone, 4.00 (ARN).
- Period analysed (e.g., 82–06 = data from 1982 to 2006 were used).

1.9.1.1 Annual design conditions

Annual climatic design conditions are contained in the first three sections following the top part of the table. They contain the following information.

- Annual heating and humidification design conditions: Coldest month (i.e. month with lowest average dry-bulb temperature; 1 = January, 12 = December).

1.9.1.2 Climatic design information

- Dry-bulb temperature corresponding to 99.6% and 99.0% annual cumulative frequency of occurrence (cold conditions), °C.
- Dew-point temperature corresponding to 99.6% and 99.0% annual cumulative frequency of occurrence, °C; corresponding humidity ratio, calculated at standard atmospheric pressure at elevation of station, g of moisture per kg of dry air; mean coincident dry-bulb temperature, °C.
- Wind speed corresponding to 0.4% and 1.0% cumulative frequency of occurrence for coldest month, m/s; mean coincident dry-bulb temperature, °C.
- Mean wind speed coincident with 99.6% dry-bulb temperature, m/s; corresponding most frequent wind direction, degrees from north (east = 90°).
- Clear sky solar irradiance, sky beam normal and diffuse horizontal irradiances at solar noon W/m^2.

1.9.1.3 Annual cooling, dehumidification and enthalpy design conditions

- Hottest month (i.e. month with highest average dry-bulb temperature; 1 = January, 12 = December).
- Daily temperature range for hottest month, °C (defined as mean of the difference between daily maximum and daily minimum dry-bulb temperatures for hottest month).
- Dry-bulb temperature corresponding to 0.4%, 1.0% and 2.0% annual cumulative frequency of occurrence (warm conditions), °C; mean coincident wet-bulb temperature, °C.
- Wet-bulb temperature corresponding to 0.4%, 1.0% and 2.0% annual cumulative frequency of occurrence, °C; mean coincident dry-bulb temperature, °C.
- Mean wind speed coincident with 0.4% dry-bulb temperature, m/s; corresponding most frequent wind direction, degrees true from north (east = 90°).
- Dew-point temperature corresponding to 0.4%, 1.0% and 2.0% annual cumulative frequency of occurrence, °C; corresponding humidity ratio, calculated at the standard atmospheric pressure at elevation of station, g of moisture per kg of dry air; mean coincident dry-bulb temperature, °C.
- Enthalpy corresponding to 0.4%, 1.0% and 2.0% annual cumulative frequency of occurrence, kJ/kg; mean coincident dry-bulb temperature, °C. Number of hours between 8am and 4pm (inclusive) with dry-bulb temperature between 12.8 °C and 20.6 °C.

1.9.1.4 Extreme annual design conditions

- Wind speed corresponding to 1.0%, 2.5% and 5.0% annual cumulative frequency of occurrence, m/s.
- Extreme maximum wet-bulb temperature, °C. Mean and standard deviation of extreme annual minimum and maximum dry-bulb temperature, °C.
- 5-, 10-, 20-, and 50-year return period values for minimum and maximum extreme dry-bulb temperature, °C.

1.9.1.5 Monthly design conditions

Monthly design conditions are divided into subsections as follows.

Table 2: Design conditions for Dubai

2013 ASHRAE Handbook - Fundamentals (SI)

DUBAI INTERNATIONAL, United Arab Emirates

WMO#: **411940**

Lat: **25.25N** Long: **55.33E** Elev: **10** StdP: **101.2** Time Zone: **4.00 (ARN)** Period: **86-10** WBAN: **99999**

Annual Heating and Humidification Design Conditions

	Coldest Month	Heating DB		Humidification DP/MCDB and HR						Coldest month WS/MCDB				MCWS/PCWD to 99.6% DB		
				99.6%			99%			0.4%		1%				
		99.6%	99%	DP	HR	MCDB	DP	HR	MCDB	WS	MCDB	WS	MCDB	MCWS	PCWD	
	(a)	(b)	(c)	(d)	(e)	(f)	(g)	(h)	(i)	(j)	(k)	(l)	(m)	(n)	(o)	
(1)	1	12.9	13.9	0.0	3.8	29.0	2.2	4.4	27.7	10.5	20.0	9.4	20.1	2.2	170	(1)

Annual Cooling, Dehumidification, and Enthalpy Design Conditions

	Hottest Month	Hottest Month DB Range	Cooling DB/MCWB						Evaporation WB/MCDB						MCWS/PCWD to 0.4% DB		
			0.4%		1%		2%		0.4%		1%		2%				
			DB	MCWB	DB	MCWB	DB	MCWB	WB	MCDB	WB	MCDB	WB	MCDB	MCWS	PCWD	
	(a)	(b)	(c)	(d)	(e)	(f)	(g)	(h)	(i)	(j)	(k)	(l)	(m)	(n)	(o)	(p)	
(2)	8	9.6	42.9	23.6	41.4	24.0	40.2	24.3	30.3	35.0	29.8	34.6	29.3	34.4	4.9	200	(2)

	Dehumidification DP/MCDB and HR									Enthalpy/MCDB						Hours 8 to 4 & 12.8/20.6	
	0.4%			1%			2%			0.4%		1%		2%			
	DP	HR	MCDB	DP	HR	MCDB	DP	HR	MCDB	Enth	MCDB	Enth	MCDB	Enth	MCDB		
	(a)	(b)	(c)	(d)	(e)	(f)	(g)	(h)	(i)	(j)	(k)	(l)	(m)	(n)	(o)	(p)	
(3)	29.2	25.9	33.3	28.8	25.3	33.3	28.1	24.2	33.2	102.3	35.1	99.6	34.5	97.1	34.6	292	(3)

Extreme Annual Design Conditions

	Extreme Annual WS			Extreme Max WB	Extreme Annual DB				n-Year Return Period Values of Extreme DB								
					Mean		Standard deviation		n=5 years		n=10 years		n=20 years		n=50 years		
	1%	2.5%	5%		Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	
	(a)	(b)	(c)	(d)	(e)	(f)	(g)	(h)	(i)	(j)	(k)	(l)	(m)	(n)	(o)	(p)	
(4)	9.1	8.1	7.3	32.5	10.7	45.7	1.4	0.9	9.7	46.3	8.9	46.9	8.1	47.4	7.1	48.1	(4)

Monthly Climatic Design Conditions

				Annual	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
				(d)	(e)	(f)	(g)	(h)	(i)	(j)	(k)	(l)	(m)	(n)	(o)	(p)	
(5)	Temperatures, Degree-Days and Degree-Hours	Tavg		28.0	19.2	20.7	23.2	27.1	31.3	33.5	35.4	35.8	33.3	29.9	25.5	21.3	(5)
(6)		Sd			2.02	2.73	3.16	3.25	2.67	2.12	2.12	1.74	1.60	1.77	2.01	2.11	(6)
(7)		HDD10.0		0	0	0	0	0	0	0	0	0	0	0	0	0	(7)
(8)		HDD18.3		21	13	6	1	0	0	0	0	0	0	0	0	2	(8)
(9)		CDD10.0		6588	284	299	408	513	661	704	788	800	698	616	464	352	(9)
(10)		CDD18.3		3568	39	72	151	263	403	454	529	542	448	358	214	95	(10)
(11)		CDH23.3		49383	131	356	1106	2972	5851	7132	8696	8905	6888	4807	2055	487	(11)
(12)		CDH26.7		30779	12	87	384	1425	3591	4759	6216	6425	4506	2602	708	63	(12)
(13)	Precipitation	PrecAvg		94	11	36	22	8	1	0	0	0	0	0	2	14	(13)
(14)		PrecMax		N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	(14)
(15)		PrecMin		N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	(15)
(16)		PrecSD		N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	(16)
(17)	Monthly Design Dry Bulb and Mean Coincident Wet Bulb Temperatures	0.4%	DB		28.2	32.1	35.9	39.2	42.5	43.8	44.6	44.2	41.8	38.8	34.1	30.0	(17)
(18)			MCWB		17.3	17.8	18.2	19.8	20.9	21.8	24.0	23.8	23.0	20.7	19.2	18.5	(18)
(19)		2%	DB		26.2	29.1	32.9	36.9	40.2	41.3	42.8	42.8	40.0	36.9	32.4	28.2	(19)
(20)			MCWB		17.5	17.6	18.3	19.6	21.2	22.8	24.5	24.3	23.2	21.5	20.7	19.3	(20)
(21)		5%	DB		24.8	27.1	30.7	35.0	38.8	39.9	41.1	41.1	38.8	35.5	31.2	27.1	(21)
(22)			MCWB		17.5	17.5	18.3	19.7	21.6	23.3	25.2	24.9	23.9	22.5	21.3	19.4	(22)
(23)		10%	DB		23.2	25.2	28.7	33.1	37.1	38.4	39.8	39.9	37.2	34.2	30.1	26.0	(23)
(24)			MCWB		17.0	17.8	18.2	19.8	22.0	24.4	25.5	25.5	24.8	23.3	21.6	19.1	(24)
(25)	Monthly Design Wet Bulb and Mean Coincident Dry Bulb Temperatures	0.4%	WB		20.6	21.3	22.5	24.6	27.9	30.1	31.1	31.0	30.2	28.7	25.6	22.5	(25)
(26)			MCDB		24.2	25.1	27.4	30.9	33.1	34.7	35.8	35.5	34.3	33.0	30.0	26.2	(26)
(27)		2%	WB		19.6	20.5	21.6	23.5	26.8	29.2	30.4	30.3	29.6	27.7	24.4	21.5	(27)
(28)			MCDB		23.6	24.4	26.4	29.9	32.4	34.0	35.2	35.0	33.9	31.9	29.2	25.8	(28)
(29)		5%	WB		18.8	19.7	20.9	22.7	26.0	28.7	29.8	29.8	29.1	26.9	23.6	20.7	(29)
(30)			MCDB		23.0	23.9	25.8	29.1	32.2	33.7	34.8	34.7	33.5	31.5	28.5	25.2	(30)
(31)		10%	WB		18.0	19.0	20.3	22.0	25.1	28.0	29.3	29.2	28.5	26.3	22.8	19.9	(31)
(32)			MCDB		22.3	23.5	25.1	28.3	32.0	33.5	34.7	34.7	33.2	31.1	28.0	24.6	(32)
(33)	Mean Daily Temperature Range		MDBR		8.5	8.7	9.2	10.5	11.6	10.9	9.5	9.6	9.9	10.1	9.5	8.8	(33)
(34)		5% DB	MCDBR		10.2	11.1	12.1	13.0	13.3	12.6	11.1	11.0	11.2	11.2	10.4	10.1	(34)
(35)			MCWBR		4.9	5.1	5.8	6.3	6.5	6.9	6.4	6.3	6.7	6.5	5.1	4.9	(35)
(36)		5% WB	MCDBR		8.7	8.7	9.4	10.8	11.7	10.6	9.1	9.4	9.5	9.7	9.7	9.1	(36)
(37)			MCWBR		4.8	4.8	5.2	5.8	6.3	5.9	5.6	5.7	5.5	5.5	5.0	5.0	(37)
(38)	Clear Sky Solar Irradiance	taub			0.463	0.508	0.547	0.558	0.596	0.675	0.792	0.684	0.585	0.499	0.463	0.451	(38)
(39)		taud			2.185	2.029	1.902	1.828	1.708	1.551	1.427	1.611	1.820	2.046	2.186	2.232	(39)
(40)		Ebn,noon			779	771	763	765	734	673	598	664	722	767	772	773	(40)
(41)		Edh,noon			131	164	195	214	241	280	317	263	209	158	130	121	(41)

Nomenclature: See separate page

(*a*) Temperatures, degree-days and degree-hours

- Average temperature, °C. This parameter is a prime indicator of climate and is also useful to calculate heating and cooling degree-days to any base.
- Standard deviation of average daily temperature, °C. This is useful to calculate heating and cooling degree-days to any base. Its use is explained in the section on estimation of degree-days, or see ASHRAE (2009).
- Heating and cooling degree-days (bases 10 and 18.3 °C). These parameters are useful in energy estimating methods. They are also used to classify locations into climate zones in ASHRAE Standard 169-2006: *Weather Data for Building Design Standards*.
- Cooling degree-hours (bases 23.3 °C and 26.7 °C). These are used in various standards, such as ANSI/ASHRAE Standard 90.2-2007: *Energy-Efficient Design of Low-Rise Residential Buildings*.

(*b*) Monthly design dry-bulb, wet-bulb and mean coincident temperatures

These values are derived from the same analysis that results in the annual design conditions. The monthly summaries are useful when seasonal variations in solar geometry and intensity, building or facility occupancy, or building use patterns require consideration. In particular, these values can be used when determining air conditioning loads during periods of maximum solar radiation. The values listed in the tables include:

- dry-bulb temperature corresponding to 0.4%, 2.0%, 5.0% and 10.0% cumulative frequency of occurrence for indicated month, °C; mean coincident wet-bulb temperature, °C
- wet-bulb temperature corresponding to 0.4%, 2.0%, 5.0% and 10.0% cumulative frequency of occurrence for indicated month, °C; mean coincident dry-bulb temperature, °C.

For a 30-day month, the 0.4%, 2.0%, 5.0% and 10.0% values of occurrence represent the value that occurs or is exceeded for a total of 3, 14, 36 or 72 hours, respectively, per month on average over the period of record. Monthly percentile values of dry- or wet-bulb temperature may be higher or lower than the annual design conditions corresponding to the same nominal percentile, depending on the month and the seasonal distribution of the parameter at that location. Generally, for the hottest or most humid months of the year, the monthly percentile value exceeds the design condition for the same element corresponding to the same nominal percentile. For example, Table 2 shows that the annual 0.4% design dry-bulb temperature at Dubai, is 34.9 °C; the 0.4% monthly dry-bulb temperature exceeds 34.4 °C from March to October, with values ranging from 35.9 °C, 42.2 °C and 38.2 °C, respectively. Two new percentiles were added to the data sheets 5.0 and 10.0% values to give a greater range in the frequency of occurrence, in particular providing less extreme options to select for design calculations.

A general, very approximate rule of thumb is that the n% annual cooling design condition is roughly equivalent to the 5n% monthly cooling condition for the hottest month; i.e. the 0.4% annual design dry-bulb temperature is roughly equivalent to the 2% monthly design dry-bulb temperature for the hottest month; the 1% annual value is roughly equivalent to the 5% monthly value for the hottest month, and the 2% annual value is roughly equivalent to the 10% monthly value for the hottest month.

1.9.1.6 Mean daily temperature range

These values are useful in calculating daily dry- and wet-bulb temperature profiles, as mentioned in the section on generating design-day data. Three kinds of profile are defined, as follows.

- Mean daily temperature range for month indicated, °C (defined as mean of difference between daily maximum and minimum dry-bulb temperatures).
- Mean daily dry- and wet-bulb temperature ranges coincident with the 5% monthly design dry-bulb temperature. This is the difference between daily maximum and minimum dry- or wet-bulb temperatures, respectively, averaged over all days where the maximum daily dry-bulb temperature exceeds the 5% monthly design dry-bulb temperature.
- Mean daily dry- and wet-bulb temperature ranges coincident with the 5% monthly design wet-bulb temperature. This is the difference between daily maximum and minimum dry- or wet-bulb temperatures, respectively, averaged

over all days where the maximum daily wet-bulb temperature exceeds the 5% monthly design wet-bulb temperature.

1.9.1.7 Clear-sky solar irradiance

Clear-sky irradiance parameters are useful in calculating solar-related air conditioning loads for any time of any day of the year. Parameters are provided for the 21st day of each month. The 21st of the month is usually a convenient day for solar calculations because 21 June and 21 December represent the solstices (longest and shortest days) and 21 March and 21 September, are close to the equinox, (days and nights have the same length). Parameters listed in the tables are:

- clear-sky optical depths for beam and diffuse irradiances, which are used to calculate beam and diffuse irradiance as explained in the section on calculating clear-sky solar radiation
- clear-sky beam normal and diffuse horizontal irradiances at solar noon.

These two values can be calculated from the clear-sky optical depths but are listed here for convenience.

1.9.1.8 Data sources

Two primary sources of observational data sets were used in calculating design values.

- Integrated Surface Dataset (ISD) data for stations from around the world provided by NCDC for the period 1982 to 2006 (Lott, Baldwin and Jones 2001; NCDC 2003) (see Figure 22).
- Hourly weather records for the period (provided by ASHRAE as required).

In most cases, the period of record used in the calculations spanned 25 years—a compromise between trying to derive design conditions from the longest possible period of record and using the most recent data to capture climatic or land use trends from the past two decades. The actual number of years used in the calculations for a given station depends on the amount of missing data, and, as discussed in the next section, may be as few as eight years. The first and last years of the period of record used to calculate design conditions are listed in the top section of the tables of climatic design conditions, as shown in Table 2 for Dubai.

Clear-sky solar irradiance parameters listed in the tables constitute a simple parameterisation of a sophisticated broadband clear-sky radiation model called REST2 (Gueymard, 2008; Thevenard, 2009). The REST2 model requires detailed knowledge of various atmospheric constituents such as aerosols, water vapour, ozone, etc. To extend applicability

Figure 22: Location of worldwide weather stations

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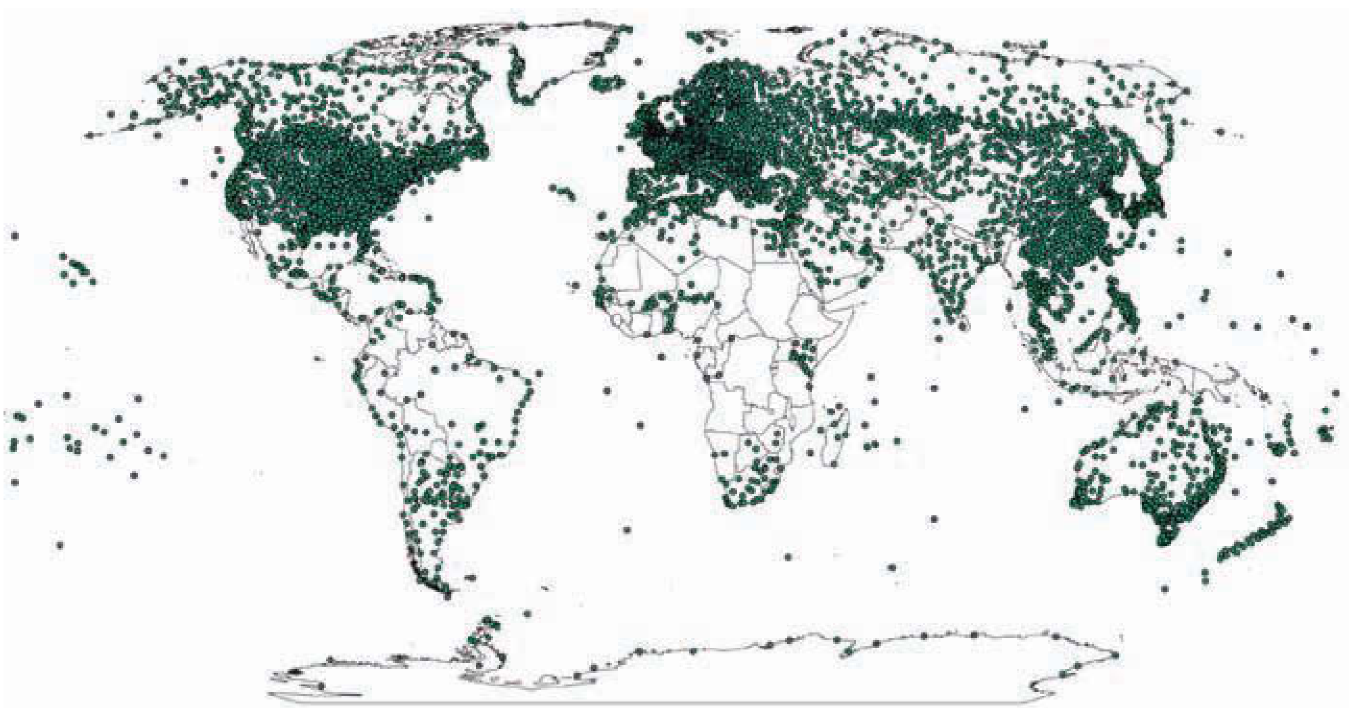


of the model to the whole world, multiple data sets, mainly derived from space observations, were used to obtain these inputs. Water vapour data were derived from the NVAP satellite/radiosonde assimilated dataset for 1988–1999 (Randel *et al.*, 1996), corrected for elevation (Thevenard, 2009). Total ozone amount was derived from observations of the Total Ozone Mapping Spectrometer (TOMS) instrument aboard the Nimbus 7 satellite. More information is available from the Goddard Earth Sciences Distribution Information and Service Center (GES DISC), NASA. A fixed NO_2 amount of 0.4 matm·cm was used throughout the world. Far-field ground albedo was obtained from the Surface and Atmospheric Radiation Budget (SARB) based on Clouds and the Earths Radiant Energy System (CERES) data for 2000–2005 by NASA's Langley Research Centre. Aerosol turbidity data received special attention because they are the primary inputs that condition the accuracy of the direct and diffuse irradiance predictions under clear skies. Space-borne data sets were used and were calibrated against a large number of ground-based sites. Six years (2000–2005) of simulated monthly-average aerosol optical depth at 550 nm were prepared with the MATCH model (Rasch, Mahowald and Eaton, 1997) by the Science Directorate/Climate Science Branch at NASA Langley Research Center, which also supplied aerosol single-scattering albedo estimates. Aerosol optical depth data from MATCH were combined with retrievals from two MODIS instruments (http://modis-atmos.gsfc.nasa.gov), and compared for ground-truthing with a large number of ground-based sites, mostly from the AERONET network (http://aeronet.gsfc.nasa.gov). Other details can be found in Thevenard (2009).

1.9.1.9 Calculation of design conditions

Values of ambient dry-bulb, dew-point and wet-bulb temperature and wind speed corresponding to the various annual percentiles represent the value that is exceeded on average by the indicated percentage of the total number of hours in a year (8760). The 0.4%, 1.0%, 2.0% and 5.0% values are exceeded on average 35, 88 hours, 175 hours and 438 hours per year, respectively, for the period of record. The design values occur more frequently than the corresponding nominal percentile in some years and less frequently in others. The 99.0% and 99.6% (cold-season) values are defined in the same way but are usually viewed as the values for which the corresponding weather element is less than the design condition for 88 hours and 35 hours, respectively. Simple design conditions were obtained by binning hourly data into frequency vectors, then deriving from the binned data the design condition having the probability of being exceeded a certain percentage of the time. Mean coincident values were obtained by double-binning the hourly data into joint frequency matrices, then calculating the mean coincident value corresponding to the simple design condition. Coincident temperature ranges were also obtained by double-binning daily temperature ranges (daily maximum minus minimum) versus maximum daily temperature. The mean coincident daily range was then calculated by averaging all bins above the simple design condition of interest. The weather data sets used for the calculations often contain missing values (either isolated records or because some stations report data only every third hour). Gaps up to 6 h were filled by linear interpolation to provide as complete a time series as possible. Dry-bulb temperature, dew-point temperature, station pressure and humidity ratio were interpolated. However, wind speed and direction were not interpolated because of their more stochastic and unpredictable nature. Some stations in the ISD data set also provided data that were not recorded at the beginning of the hour. When data at the exact hour were missing, they were replaced by data up to 0.5 h before or after, when available. Finally, psychrometric quantities, such as wet-bulb temperature or enthalpy, are not contained in the weather data sets. They were calculated from dry-bulb temperature; dew-point temperature and station pressure using the psychrometric equations (ASHRAE, 2009).

Measures were taken to ensure that the number and distribution of missing data, both by month and by hour of the day, did not introduce significant biases into the analysis. Annual cumulative frequency distributions were constructed from the relative frequency distributions compiled for each month. Each individual month's data were included if they met the following screening criteria for completeness and unbiased distribution of missing data after data filling.

- The number of hourly dry-bulb temperature values for the month, after filling by

interpolation, had to be at least 85% of the total hours for the month.
- The difference between the number of day and night-time dry-bulb temperature observations had to be less than 60.

Although the nominal period of record selected for this analysis was 25 years (1982 to 2006 for most stations), some variation and gaps in observed data meant that some months' data were unusable because of incompleteness. Some months were also eliminated during additional quality control checks. A station's dry-bulb temperature design conditions were calculated only if there were data from at least eight months that met the quality control and screening criteria from the period of record for each month of the year. For example, there had to be eight months each of January, February, March, etc. for which data met the completeness screening criteria. These criteria were ascertained from results of RP-1171 (Hubbard *et al.*, 2004) and were the same as used in calculating the design conditions in ASHRAE (2001, 2005).

Dew-point temperature, wet-bulb temperature and enthalpy design conditions were calculated for a given month only if the number of dew-point, wet-bulb or enthalpy values was greater than 85% of the minimum number of dry-bulb temperature values defined previously; wind speed and direction conditions were calculated for a given month only if the number of values was greater than 28.3% (i.e. one-third of 85%) of the minimum number of dry-bulb temperature values. For example, the month of January was included in calculations if the number of dry-bulb temperature values exceeded 85% of 744 h or 633 h. The month was included in calculation of dew-point temperature design conditions only if dew-point temperature was present for at least 85% of 633 h, or 538 h. The month was included in calculation of wind speed design conditions only if wind speed was present for at least 28.3% of 633 h, or 179 h. Annual dry-bulb temperature extremes were calculated only for years that were 85% complete. At least eight annual extremes were required to calculate the mean and standard deviation of extreme annual dry-bulb temperatures. Daily minimum and maximum temperatures were calculated only for complete days, and so were daily temperature ranges and mean coincident temperature ranges. A final quality check was made of the calculated design values to identify potential errors. These checks included contour plots, consistency checks among the various parameters and comparison to the 2005 edition of the ASHRAE handbook (ASHRAE, 2005); about 32 stations from the 2005 edition have no equivalent within a 12-mile distance in the 2009 edition, these stations may have been dropped because of quality problems, or simply because they did not have enough data within the 1982–2006 period of record used for the present edition (ASHRAE, 2009). Further details of the analysis procedures are available in Thevenard (2009).

1.9.1.10 Applicability and characteristics of design conditions

Climatic design values in this chapter represent different psychrometric conditions. Design data based on dry-bulb temperature represent peak occurrences of the sensible component of ambient outdoor conditions. Design values based on wet-bulb temperature are related to the enthalpy of the outdoor air. Conditions based on dew-point relate to the peaks of the humidity ratio. The designer, engineer or other user must decide which set(s) of conditions and probability of occurrence apply to the design situation under consideration. Additional sources of information on frequency and duration of extremes of temperature and humidity are provided in the section on other sources of climatic information. Further information is available from Harriman, Colliver and Quinn (1999). This section discusses the intended use of design conditions in the order they appear in Table 2.

1.9.1.11 Annual heating and humidification design conditions

The month with the lowest mean dry-bulb temperature is used, for example, to determine the time of year where the maximum heating load occurs. The 99.6% and 99.0% design conditions are often used in sizing heating equipment. The humidification dew point and mean coincident dry-bulb temperatures and humidity ratio provide information for cold season humidification applications. Wind design data provide information for estimating peak loads accounting for infiltration: extreme wind speeds for the coldest month, with the mean coincident dry-bulb temperature; and mean wind speed and direction coincident to the 99.6% design dry-bulb temperature.

1.9.1.12 Annual cooling, dehumidification and enthalpy design conditions

The month with the highest mean dry-bulb temperature is used, for example, to determine the time of year where the maximum sensible cooling load occurs, not taking into account solar loads. The mean daily dry-bulb temperature range for the hottest month is the mean difference between the daily maximum and minimum temperatures during the hottest month and is calculated from the extremes of the hourly temperature observations. The true maximum and minimum temperatures for any day generally occur between hourly readings. Thus, the mean maximum and minimum temperatures calculated in this way are about 0.5 °C less extreme than the mean daily extreme temperatures observed with maximum and minimum thermometers. This results in the true daily temperature range generally being about 1°C greater than that calculated from hourly data. The mean daily dry-bulb temperature range is used in cooling load calculations. The 0.4%, 1.0% and 2.0% dry-bulb temperatures and mean coincident wet-bulb temperatures often represent conditions on hot, mostly sunny days. These are often used in sizing cooling equipment such as chillers or air conditioning units. Design conditions based on wet-bulb temperature represent extremes of the total sensible plus latent heat of outdoor air. This information is useful for design of cooling towers, evaporative coolers and fresh-air ventilation systems. The mean wind speed and direction coincident with the 0.4% design dry-bulb temperature is used for estimating peak loads accounting for infiltration. Design conditions based on dew-point temperatures are directly related to extremes of humidity ratio, which represent peak moisture loads from the weather. Extreme dew-point conditions may occur on days with moderate dry-bulb temperatures, resulting in high relative humidity. These values are especially useful for humidity control applications such as desiccant cooling and dehumidification, cooling-based dehumidification and fresh-air ventilation systems. The values are also used as a checkpoint when analysing the behaviour of cooling systems at part load conditions, particularly when such systems are used for humidity control as a secondary function. Humidity ratio values are calculated from the corresponding dew-point temperature and the standard pressure at the location's elevation. Annual enthalpy design conditions give the annual enthalpy for the cooling season; this is used for calculating cooling loads caused by infiltration and/or ventilation into buildings. Enthalpy represents the total heat content of air (the sum of its sensible and latent energies). Cooling loads can be calculated knowing the conditions of both the outdoor ambient and the building's interior air.

1.9.1.13 Extreme annual design conditions

Extreme annual design wind speeds are used in designing smoke management systems. The extreme maximum wet-bulb temperature provides the highest wet-bulb temperature observed over the entire period of record and is the most extreme condition observed during the data record for evaporative processes such as cooling towers. For most locations, the extreme maximum wet-bulb value is significantly higher than the 0.4% wet-bulb (see above) and should be used only for design of critical applications where an occasional short-duration capacity shortfall is not acceptable. The mean and standard deviation of the extreme annual maximum and minimum dry-bulb temperatures are used to calculate the probability of occurrence of very extreme conditions. These can be required for design of equipment to ensure continuous operation and serviceability, regardless of whether the heating or cooling loads are being met. These values were calculated from extremes of hourly temperature observations. The true maximum and minimum temperatures for any day generally occur between hourly readings. Thus, the mean maximum and minimum temperatures calculated in this way are about 0.5 °C less extreme than the mean daily extreme temperatures observed with maximum and minimum thermometers. The 5-, 10-, 20- and 50-year return periods for maximum and minimum extreme dry-bulb temperature are also listed. Return period (or recurrence interval) is defined as the reciprocal of the annual probability of occurrence. For example, the 50-year return period maximum dry-bulb temperature has a probability of occurring or being exceeded of 2.0% (i.e., 1/50) each year. This statistic does not indicate how often the condition will occur in terms of the number of hours each year (as in the design conditions based on percentiles) but describes the probability of the condition occurring at all in any year. The following method can be used to estimate the return period (recurrence interval) of extreme temperatures:

$$T_n = M + I\,F\,s \qquad (1.5)$$

where:

- T_n = n-year return period value of extreme dry-bulb temperature to be estimated, years
- M = mean of annual extreme maximum or minimum dry-bulb temperatures, °C
- s = standard deviation of annual extreme maximum or minimum dry-bulb temperatures, °C
- I = 1 if maximum dry-bulb temperatures are being considered
- $F = -\sqrt{6} \div \pi \{0.5772 + \ln (n \div (n - 1))\}$.

For example, the 50-year return period extreme maximum dry-bulb temperature estimated for Dubai, is 47.9 °C (according to Table 2, M = 45.6 °C, s = 0.9 and n = 50; I = 1). Similarly, the 50-year return period extreme minimum dry-bulb temperature for Dubai, is 7.1 °C (M = 10.6 °C, s = 1.3, and n = 50; I = –1). The n-year return periods can be obtained for most stations using ASHRAE's Weather Data Viewer 4.0 (ASHRAE, 2009), which is discussed in the section on other sources of climatic information. Calculation of the n-year return period is based on assumptions that annual maxima and minima are distributed according to the Gumbel (Type 1 Extreme Value—this method is one of the probability distributions used to model extreme events) distribution and are fitted with the method of moments (a method of estimating the parameters of a frequency distribution). The uncertainty or standard error using this method increases with standard deviation, value of return period and decreasing length of the period of record. It can be significant. For example, the standard error in the 50-year return period maximum dry-bulb temperature estimated at a location with a 12-year period of record can be 3 °C or more. Thus, the uncertainty of return period values estimated in this way are greater for stations with fewer years of data than for stations with the complete period of record from 1982–2006.

1.9.1.14 Temperatures, degree-days and degree-hours

Monthly average temperatures and standard deviation of daily average temperatures are calculated using the averages of the minimum and maximum temperatures for each complete day within the period analysed. They are used to estimate heating and cooling degree-days to any base, as explained in AHSRAE (2009), in the section on calculating degree-days. Heating and cooling degree-days (base 10 or 18.3 °C) are calculated as the sum of the differences between daily average temperatures and the base temperature. For example, the number of heating degree-days (HDD) in the month is calculated as:

$$\mathrm{HDD} = \sum_{i=1}^{N} (T_{\mathrm{base}} - \overline{T}_{\mathrm{i}})^{+} \qquad (1.6)$$

where N is the number of days in the month, T_{base} is the reference temperature to which the degree-days are calculated, and $\overline{T}_{\mathrm{i}}$ is the mean daily temperature calculated by adding the maximum and minimum temperatures for the day, then dividing by two. The + superscript indicates that only positive values of the bracketed quantity are taken into account in the sum. Similarly, monthly cooling degree-days (CDD) are calculated as:

$$\mathrm{CDD} = \sum_{i=1}^{N} (\overline{T}_{\mathrm{i}} - T_{\mathrm{base}})^{+} \qquad (1.7)$$

Degree-days are used in energy estimating methods, and to classify stations into climate zones for ASHRAE Standard 169-2006.

1.9.1.15 Monthly design dry-bulb and mean coincident wet-bulb temperatures

These values provide design conditions for processes driven by dry-bulb air temperature. In particular, air conditioning cooling loads are generally based on dry-bulb design conditions (plus clear-day solar radiation).

1.9.1.16 *Monthly design wet-bulb and mean coincident dry-bulb temperatures*

Wet-bulb design conditions are of use in analysis of evaporative coolers, cooling towers and other equipment involving evaporative transfer. Note also that air wet-bulb temperature and enthalpy are closely related, so applications with large ventilation flow rates may have maximum cooling requirements under high wet-bulb conditions.

1.9.1.17 *Mean daily temperature range*

Mean daily range values are computed using all days of the month, as opposed to coincident values that derive from design days. Mean daily range values have been published in previous handbook editions and are included for completeness in new editions. Coincident daily range values should be used for generating design-day profiles.

1.9.1.18 *Clear-sky solar irradiance*

Clear-sky solar irradiance data are used in load calculation methods.

1.9.1.19 *Beam normal irradiance*

This refers to solar radiation emanating directly from the solar disk and measured perpendicularly to the rays of the sun.

1.9.1.20 *Diffuse horizontal irradiance*

This refers to solar radiation emanating from the sky dome, sun excepted, and measured on a horizontal surface. Because beam and diffuse irradiance vary during the course of the day, new load calculation methods require their estimation at various times, a method for which is explained in the section on calculating clear-sky solar radiation below. The method uses the clear-sky optical depths, τ_b and τ_d, listed in Table 2 as 'taub' and 'taud', respectively, as inputs. Clear-sky beam normal and diffuse horizontal irradiances at solar noon are also listed in Table 2 for convenience.

1.9.2 Calculating clear-sky, solar radiation

Knowledge of clear-sky solar radiation at various times of year and day is required by several calculation methods for heat gains in HVAC loads and solar energy applications. The tables of climatic design conditions now include the parameters required to calculate clear-sky beam and diffuse solar irradiance using the equations in the following section. The section on transposition to receiving surfaces of various orientations (explains how to use these values to calculate clear-sky solar radiation incident on arbitrary surfaces.

Note: in all equations in this section, angles are expressed in degrees. This includes the arguments appearing in trigonometric functions.

1.9.3 Solar constant and extraterrestrial solar radiation

The solar constant E_{sc} is defined as the intensity of solar radiation on a surface normal to the sun's rays, just beyond the earth's atmosphere, at the average earth-sun distance. One frequently used value is that proposed by the World Meteorological Organization in 1981, E_{sc} = 1367 W/m^2 (Iqbal, 1983).

Because the earth's orbit is slightly elliptical, the extraterrestrial radiant flux E_o varies throughout the year, reaching a maximum of 1412 W/m^2 near the beginning of January, when the earth is closest to the sun (aphelion) and a minimum of 1322 W/m^2 near the beginning of July, when the earth is farthest from the sun (perihelion). Extraterrestrial solar irradiance incident on a surface normal to the sun's ray can be approximated with the following equation:

$$E_o = E_{sc}\left\{1+0.033\cos\left[360°\frac{(n-3)}{365}\right]\right\} \quad (1.8)$$

where n is the day of year (1 for 1 January, 32 for 1 February, etc) and the argument inside the cosine is in degrees. Table 3 tabulates values of E_o for the 21st day of each month.

1.9.3.1 *Equation of time and solar time*

The earth's orbital velocity also varies throughout the year, so apparent solar time (AST), as determined by a solar time sundial, varies somewhat from the mean time kept by a clock running at a uniform rate. This variation is called the equation of time (ET) and is approximated by the following formula (Iqbal, 1983):

$$\begin{aligned} ET = 2.2918\,(0.00075 + 0.1868\cos(\Gamma) \\ - 3.2077\sin(\Gamma) - 1.4615\cos(2\Gamma) \\ - 4.089\sin(2\Gamma) \end{aligned} \quad (1.9)$$

Table 3: Approximate astronomical data for the 21st day of each month

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Day of year	21	52	80	111	141	172	202	233	264	294	325	355
E_δ W/m²	1410	1397	1378	1354	1334	1323	1324	1336	1357	1380	1400	1411
Equation of time (ET), min	−10.6	−14.10	−7.9	1.2	3.7	−1.3	−6.4	−3.6	6.9	15.5	13.8	2.2
Declination δ, degrees	−20.1	−11.2	−0.4	11.6	20.1	23.4	20.4	11.8	−0.2	−11.8	−20.4	−23.4

Source: ASHRAE. **LST** = local standard time, decimal hours; **ET** = equation of time in minutes, from Table 3 or equation 1.9;
LSM = longitude of local standard time meridian, °E of Greenwich (negative in western hemisphere); **LON** = longitude of site, °E of Greenwich

with ET expressed in minutes and:

$$\Gamma = 360° \frac{n-1}{365} \quad (1.10)$$

Table 3 tabulates the values of ET for the 21st day of each month.

The conversion between local standard time and solar time involves two steps: the equation of time is added to the local standard time, and then a longitude correction is added. This longitude correction is four minutes of time per degree difference between the local (site) longitude and the longitude of the local standard meridian (LSM) for that time zone; hence, AST is related to the local standard time (LST) as follows:

$$\text{AST} = \text{LST} + \text{ET}/60 + (\text{LON} - \text{LSM})/15 \quad (1.11)$$

where AST = apparent solar time, decimal hours.

Most standard meridians are found every 15° from 0° at Greenwich, UK, with a few exceptions such as the province of Newfoundland in Canada. Standard meridian longitude is related to time zone as follows:

$$\text{LSM} = 15\ \text{TZ} \quad (1.12)$$

where TZ is the time zone, expressed in hours ahead or behind coordinated universal time (UTC). If daylight saving time (DST) is to be used, rather than local standard time, an additional correction has to be performed. In most locales, local standard time can be obtained from daylight savings time by subtracting one hour:

$$\text{LST} = \text{DST} - 1 \quad (1.13)$$

where DST is in decimal hours.

1.9.4 Declination

Because the earth's equatorial plane is tilted at an angle of 23.45° to the orbital plane, the solar declination δ (the angle between the earth-sun line and the equatorial plane) varies throughout the year, as shown in Figure 23. This variation causes the changing seasons, with their unequal periods of daylight and darkness. Declination can be obtained from astronomical or nautical almanacs; however, for most engineering applications, the following equation provides sufficient accuracy.

$$\delta = 23.45 \sin\left(360° \frac{n+284}{365}\right) \quad (1.14)$$

where δ is in degrees and the argument inside the sine is also in degrees. Table 3 provides δ (for the 21st day of each month.

1.9.5 Sun position

The sun's position in the sky is conveniently expressed in terms of the solar altitude above the horizontal and the solar azimuth measured from the south (see Figure 24).

The solar altitude angle β is defined as the angle between the horizontal plane and a line emanating from the sun. Its value ranges from 0° when the sun is on the horizon, to 90° if the sun is directly overhead. Negative values correspond to night-times.

The solar azimuth angle φ is defined as angular displacement from south of the projection, on the horizontal plane, of the earth-sun line. By

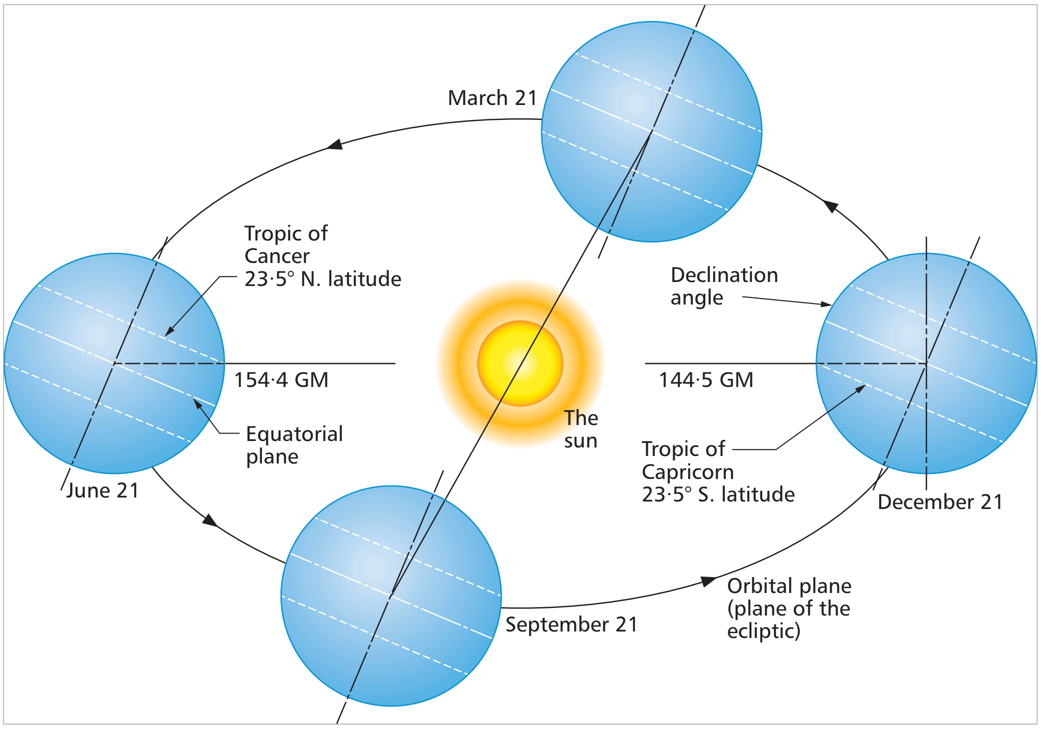


Figure 23: Motion of earth around the sun

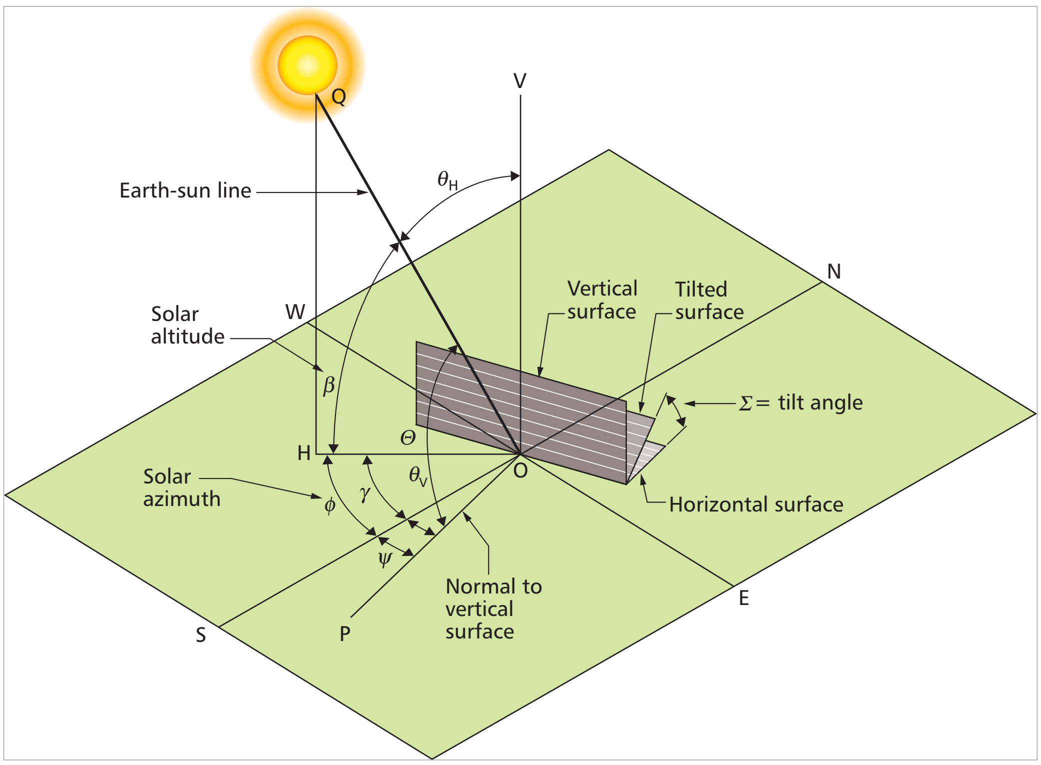


Figure 24: Solar angles for vertical and horizontal surfaces

convention, it is counted positive for afternoon hours and negative for morning hours.

Solar altitude and azimuth angles, in turn, depend on the local latitude L (°N, negative in the southern hemisphere); the solar declination δ which is a function of the date (see Table 3 or Equation 1.10; and the hour angle H, defined as the angular displacement of the sun east or west of the local meridian due to the rotation of the earth, and expressed in degrees as:

$$H = 15\,(\mathrm{AST} - 12) \qquad (1.15)$$

where AST is the apparent solar time (equation 1.11). H is zero at solar noon, positive in the afternoon, and negative in the morning.

Equation 1.16 relates the solar altitude angle β to L, δ, and H:

$$\sin \beta = \cos L \cos \delta \cos H + \sin L \sin \delta \quad (1.16)$$

Note that at solar noon, $H = 0$ and the sun reaches its maximum:

$$\beta_{max} = 90° - |L - \delta| \quad (1.17)$$

The azimuth angle ϕ is uniquely determined by its sine and cosine, given in equations 1.18 and 1.19:

$$\sin \phi = \sin H \cos \delta / \cos \beta \quad (1.18)$$

$$\cos \phi = (\cos H \cos \delta \sin L - \sin \delta \cos L)/\cos \beta \quad (1.19)$$

For examples refer to ASHRAE (2009) sections 14.8 and 14.9.

1.9.5.1 Air mass

The relative air mass m is the ratio of the mass of atmosphere in the actual earth-sun path to the mass that would exist if the sun were directly overhead. Air mass is solely a function of solar altitude β and is obtained from (Kasten and Young, 1989):

$$m = 1 / [\sin \beta + 0.50572 \, (6.07995 + \beta)^{-1.6364}] \quad (1.20)$$

where β is expressed in degrees.

1.9.5.2 Clear-sky solar radiation

Solar radiation on a clear day is defined by its beam (direct) and diffuse components. The direct component represents the part of solar radiation emanating directly from the solar disc, whereas the diffuse component accounts for radiation emanating from the rest of the sky. These two components are calculated as:

$$E_b = E_o \exp [- \tau_b \, m^b] \quad (1.21)$$

$$E_d = E_o \exp [- \tau_d \, m^d] \quad (1.22)$$

where:

- E_b = beam normal irradiance (measured perpendicularly to rays of the sun)
- E_d = diffuse horizontal irradiance (measured on horizontal surface)
- E_o = extraterrestrial normal irradiance (equation 1.8 or Table 3)
- m = air mass (equation 1.20)
- τ_b and τ_d = beam and diffuse optical depths (τ_b and τ_d are more correctly termed 'pseudo' optical depths, because optical depth is usually employed when the air mass coefficient is unity; 'optical depth' is used here for convenience)
- b and d = air mass exponents for beam and diffuse, respectively.

Values of τ_b and τ_d are location specific, and vary during the year. They embody the dependence of clear-sky solar radiation upon local conditions such as elevation, precipitable water content and aerosols. Their average values were determined through ASHRAE research project RP-1453 (Thevenard, 2009) and are tabulated for the 21st day of each month for all the locations in the tables of climatic design conditions. Values for other days of the year should be found by interpolation.

Air mass exponents b and d are correlated to τ_b and τ_d through the following empirical relationships:

$$b = 1.219 - 0.043\tau_b - 0.151 \, \tau_d - 0.204 \, \tau_b \, \tau_d \quad (1.23)$$

$$d = 0.202 - 0.852 \, \tau_b - 0.007 \, \tau_d - 0.357 \, \tau_b \, \tau_d \quad (1.24)$$

Equations 1.21–1.24 describe a simple parameterisation of a sophisticated broadband radiation model and provide accurate predictions of E_b and E_d, even at sites where the atmosphere is very hazy or humid most of the time.

1.9.6 Transposition to receiving surfaces of various orientations

Calculations developed in the previous section are chiefly concerned with estimating clear-sky solar irradiance either normal to the rays of the sun (direct beam) or on a horizontal surface (diffuse). However, in many circumstances, calculation of clear-sky solar irradiance is required on surfaces of arbitrary orientations. Receiving surfaces can be vertical (e.g. walls and windows) or tilted (e.g. skylights or active solar devices). This section describes transposition models that enable calculating solar irradiance on any surface, knowing beam normal and diffuse horizontal irradiance.

1.9.7 Solar angles related to receiving surfaces

The orientation of a receiving surface is best characterised by its tilt angle and its azimuth, shown in Figure 24. The tilt angle Σ (also called slope) is the angle between the surface and the horizontal plane. Its value lies between 0 and 180°. Most often, slopes are between 0° (horizontal) and 90° (vertical). Values above 90° correspond to surfaces facing the ground. The surface azimuth ψ is defined as the displacement from south of the projection, on the horizontal plane, of the normal to the surface. Surfaces that face west have a positive surface azimuth; those that face east have a negative surface azimuth. Surface azimuths for common orientations are summarized in Table 4. Note that, in this document, surface azimuth is defined as relative to south in both the northern and southern hemispheres. Other presentations and software use relative-to-north or relative-to-equator, so care is required.

The surface-solar azimuth angle γ is defined as the angular difference between the solar azimuth ψ and the surface azimuth ϕ:

$$\gamma = \phi - \psi \tag{1.25}$$

Values of γ greater than 90° or less than –90° indicate that the surface is in the shade.

Finally, the angle between the line normal to the irradiated surface and the earth-sun line is called the angle of incidence θ. It is important in fenestration, load calculations and solar technology because it affects the intensity of the direct component of solar radiation striking the surface and the surface's ability to absorb, transmit or reflect the sun's rays. Its value is given by:

$$\cos\theta = \cos\beta\cos\gamma\sin\Sigma + \sin\beta\cos\Sigma \tag{1.26}$$

Note that for vertical surfaces ($\Sigma = 90°$), equation 1.26 simplifies to:

$$\cos\theta = \cos\beta\cos\gamma \tag{1.27}$$

whereas for horizontal surfaces ($\Sigma = 0°$), it simplifies to:

$$\theta = 90 - \beta \tag{1.28}$$

For examples refer to ASHRAE (2009), section 14.10.

1.9.8 Calculation of clear-sky solar irradiance incident on receiving surface

Total clear-sky irradiance E_t reaching the receiving surface is the sum of three components: the beam component $E_{t,b}$ originating from the solar disc; the diffuse component $E_{t,d,}$ originating from the sky dome; and the ground-reflected component $E_{t,r}$ originating from the ground in front of the receiving surface. Thus:

$$E_{t,} = E_{t,b} + E_{t,d,} + E_{t,r} \tag{1.29}$$

Only a simple method for computing all the factors on the right side of equation 1.29 is presented here. More elaborate methods, particularly with regard to calculating the diffuse component, can be found in Gueymard (1987) and Perez *et al.* (1990).

Table 4: Surface orientations and azimuths, measured from south

Orientation	N	NE	E	SE	S	SW	W	NW
Surface azimuth ψ	180°	−135°	−90°	−45°	0	45°	90°	135°

1.9.8.1 Beam component

The beam component is obtained from a straightforward geometric relationship:

$$E_{t,b} = E_b \cos \theta \qquad (1.30)$$

where θ is the angle of incidence. This relationship is valid when $\cos \theta > 0$; otherwise, $E_{t,b} = 0$.

1.9.8.2 Diffuse component

The diffuse component is more difficult to estimate because of the nonisotropic nature of diffuse radiation: some parts of the sky, such as the circumsolar disc or the horizon, tend to be brighter than the rest of the sky, which makes the development of a simplified model challenging. For vertical surfaces, Stephenson (1965) and Threlkeld (1963) showed that the ratio Y of clear-sky diffuse irradiance on a vertical surface to clear-sky diffuse irradiance on the horizontal is a simple function of the angle of incidence θ:

$$E_{t,d} = E_d\, Y \qquad (1.31)$$

with:

$$Y = \max(0.45, 0.55 + 0.437 \cos \theta + 0.313 \cos^2 \theta) \qquad (1.32)$$

For a nonvertical surface with slope Σ, the following simplified relationships are sufficient for most applications described in this document:

$$E_{t,d} = E_d\,(Y \sin \Sigma + \cos \Sigma) \text{ if } \Sigma \leq 90° \qquad (1.33)$$

$$E_{t,d} = E_d\, Y \sin \Sigma \text{ if } \Sigma > 90° \qquad (1.34)$$

where Y is calculated for a vertical surface having the same azimuth as the receiving surface considered. Note that equations 1.31–1.34 are appropriate for clear-sky conditions, but should not be used for cloudy skies.

1.9.8.3 Ground-reflected component

Ground-reflected irradiance for surfaces of all orientations is given by:

$$E_{t,r} = (E_b \sin \beta + E_d)\ \rho_g \frac{1-\cos \Sigma}{2} \qquad (1.35)$$

where ρ_g is ground reflectance, often taken to be 0.2 for a typical mixture of ground surfaces. Table 5 provides estimates of ρ_g for other surfaces, including in the presence of snow.

For examples refer to ASHRAE (2009), section 14.10.

Table 5: Ground reflectance of foreground surfaces

Foreground surface	Reflectance
Water (large angle of incidences)	0.07
Coniferous forest (winter)	0.07
Bituminous and gravel roof	0.13
Dry bare ground	0.2
Weathered concrete	0.22
Green grass	0.26
Dry grassland	0.2–0.3
Desert sand	0.4
Light building surfaces	0.6
Snow-covered surfaces:	0.2
▪ Typical city centre	0.4
▪ Typical urban site	0.5
▪ Typical rural site	0.7
▪ Isolated rural site	

Source: Adapted from Thevenard and Haddad (2006)

Courtesy 2006 Elsevier

1.9.9 Generating design-day data

This section provides procedures for generating 24-hour temperature data sequences suitable as input to many HVAC analysis methods, including the radiant time series (RTS) cooling load calculation procedure described in Chapter 18 of ASHRAE (2009).

1.9.9.1 Temperatures

Table 6 gives a normalised daily temperature profile in fractions of daily temperature range. Recent research projects RP-1363 (Hedrick, 2009) and RP-1453 (Thevenard, 2009) have shown that this profile is representative of both dry-bulb and wet-

Time, h	Fraction	Time, h	Fraction	Time, h	Fraction
1	0.88	9	0.55	17	0.14
2	0.92	10	0.38	18	0.24
3	0.95	11	0.23	19	0.39
4	0.98	12	0.13	20	0.50
5	1.00	13	0.05	21	0.59
6	0.98	14	0.00	22	0.68
7	0.91	15	0.00	23	0.75
8	0.74	16	0.06	24	0.82

Table 6: Fraction of daily temperature range

Design-day type	Design conditions	Daily ranges	Limits
Dry-bulb Annual Monthly	0.4%, 1% or 2% annual cooling DB/MCWB 0.4%, 2%, 5% or 10% DB/MCWB for month	Hottest month 5% DB CDBR/MCWBR 5% DB MCDBR/MCWBR for month	Hourly wet-bulb temperature = minimum (dry-bulb temperature, wet-bulb temperature)
Dry-bulb Annual Monthly	0.4, 1, or 2% annual cooling WB/MCDB 0.4, 2, 5, or 10% WB/MCDB for month	Hottest month 5% WB MCDBR/MCWBR 5% WB MCDBR/MCWBR for month	Hourly dry-bulb temperature = maximum (dry-bulb temperature, wet-bulb temperature)

Table 7: Input sources for design-day generation

bulb temperature variation on typical design-days. To calculate hourly temperatures, subtract the Table 6 fraction of the dry- or wet-bulb daily range from the dry- or wet-bulb design temperature (limiting by saturation in the case of the wet-bulb). This procedure is applicable to annual or monthly data and is illustrated in Example 9 of ASHRAE (2009), section 14.11. Table 7 specifies the input values to be used for generating several design-day types. Because daily temperature variation is driven by heat from the sun, the profile in Table 6 is, strictly speaking, specified in terms of solar time. Typical HVAC calculations (e.g. hourly cooling loads) are performed in local time, reflecting building operation schedules. The difference between local and solar time can easily be 1 or 2 h, depending on site longitude and whether DST is in effect. This difference can be included by accessing the temperature profile using AST calculated with equation 7, as shown in Example 9 of ASHRAE (2009), section 14.11.

1.9.9.2 Additional moist-air properties

When hourly dry-bulb and wet-bulb temperatures are known, additional moist air properties (e.g. dew-point temperature, humidity ratio, enthalpy) can be derived using the psychrometric chart, equations in Chapter 1 of ASHRAE (2009) or psychrometric software.

$$\mathrm{HDD_b} = N\, s_d\, [Z_b F(Z_b) + f(Z_b)] \qquad (1.36)$$

where (1.34) N is the number of days in the month and Z_b is the difference between monthly average temperature T and base temperature T_b, normalised by the standard deviation of the daily average temperature s_d, and T_i is the mean daily temperature:

$$Z_b = \frac{T_b - \overline{T}}{s_d} \qquad (1.37)$$

Function f is the normal (Gaussian) probability density function with mean 0 and standard deviation 1, and function F is the equivalent cumulative normal probability function:

$$f(Z) = \frac{1}{\sqrt{2\pi}} \exp\frac{(-Z^2)}{2} \qquad (1.38)$$

$$F(Z) = \sum f(z)\, \mathrm{d}z \qquad (1.39)$$

Both f and F are readily available as built-in functions in many scientific calculators or spreadsheet programs, so their manual calculation is rarely warranted.

Cooling degree days $\mathrm{CDD_b}$ to base T_b are calculated by the same equation:

$$\mathrm{CDD_b} = N\, s_\mathrm{d}\, [Z_\mathrm{b} F(Z_\mathrm{b}) + f(Z_\mathrm{b})] \qquad (1.40)$$

except that Z_b is now expressed as

$$Z_b = \frac{\overline{T} - T_b}{s_d} \qquad (1.41)$$

1.9.9.3 Annual degree-days

Annual degree-days are simply the sum of monthly degree-days over the 12 months of the year. For most stations, the monthly degree-days calculated with this method are within 5 °C-day of the observed values.

For examples refer to ASHRAE (2009), section 14.12.

1.9.10 Effects of climate change

The evidence is unequivocal that the climate system is warming globally (IPCC, 2007). The most frequently observed effects relate to increases in average, and to some degree extreme, temperatures. This is partly illustrated by the results of an analysis of design conditions conducted as part of developing the updated values for ASHRAE data (Thevenard, 2009). For 1274 observing sites worldwide with suitably complete data from 1977 to 2006, selected design conditions were compared between the periods of 1977–1986 and 1997–2006. The results, averaged over all locations, are as follows.

- The 99.6% annual dry-bulb temperature increased by 1.52 °C.
- The 0.4% annual dry-bulb increased by 0.79 °C.
- Annual dew-point increased by 0.55 °C.
- Heating degree-days (base 18.3 °C) decreased by 237 °C-days.
- Cooling degree-days (base 10 °C) increased by 136 °C-days.

Although these results are consistent with general warming of the world climate system, there are other effects that undoubtedly contribute such as increased urbanisation around many of the observing sites (airports, typically). There was no attempt in the analysis to determine the reasons for the changes. Regardless of the reasons for increases, the general approach of developing design conditions based on analysis of the recent record (25 years, in this case) was specifically adopted for updating the values (ASHRAE 2009) as a balance between accounting for long-term trends and the sampling variation caused by year-to-year variation.

Although this does not necessarily provide the optimum predictive value for representing conditions over the next one or two decades, it at least has the effect of incorporating changes in climate and local conditions as they occur, as updates are conducted regularly using recent data. Meteorological services worldwide are considering the many aspects of this complex issue in the calculation of climate 'normals' (averages, extremes and other statistical summary information of climate elements typically calculated for a 30-year period at the end of each decade). Livezey *et al.* (2007) and WMO (2007) provide detailed analyses and recommendations in this regard. Extrapolating design conditions to the next few decades based on observed trends should only be done with attention to the particular climate element and the regional and temporal characteristics of observed trends (Livezey *et al.*, 2007).

Table 8: Derived hourly temperatures example—Atlanta for July for 5% design conditions, °C (information would need to be obtained from ASHRAE for each location)

Hour (LDT)	t_{db}	t_{wb}	t_{dp}
1	24.7	20.9	19.2
2	23.9	20.6	19.2
3	23.2	20.4	19.2
4	22.7	20.3	19.2
5	22.4	20.2	19.2
6	22.0	20.1	19.2
7	21.8	20.0	19.2
8	22.0	20.1	19.2
9	22.8	20.3	19.2
10	24.8	20.9	19.2
11	27.0	21.6	19.3
12	28.9	22.2	19.4
13	30.7	22.7	19.4
14	31.8	23.0	19.5
15	32.7	23.3	19.6
16	33.3	23.5	19.6
17	33.3	23.5	19.6
18	32.6	23.3	19.6
19	31.7	23.0	19.5
20	30.5	22.7	19.4
21	28.8	22.1	19.4
22	27.5	21.8	19.3
23	26.5	21.4	19.3
24	25.5	21.1	19.2

LDT = Local daylight saving time
Source: ASHRAE

2 Basic design data

2.1 Comfort

The factors affecting comfort, which include temperature, noise level, intensity of illumination, clothing and the quality of air are discussed in chapter 1 of CIBSE Guide A (CIBSE, 2006) and these factors generally apply to arid climates such as in the Middle East. However, there are certain aspects of thermal comfort that should be highlighted.

A person is capable of maintaining constant body temperature in a wide range of environmental conditions by involuntary mechanisms, such as shivering and sweating, and by adjusting clothing and changing the level of activity. Individuals may differ in their comfort requirements according to the degree of acclimatisation, activity level and clothing.

It has been shown that as a consequence of acclimatisation to 'high' temperatures fewer people can be comfortable in optimum conditions. However, it may be argued that in very warm climates, cooling to any degree is welcome.

Higher temperatures can be acceptable, and may be beneficial, in spaces where occupancy is transient. This is often useful in providing a buffer zone between 'warm' outside conditions and general 'cool' inside conditions allowing gradual acclimatisation by reducing temperature differences and thereby avoiding physiological effects such as 'thermal shock'. In this case the temperature differential between outside and inside should be limited to approximately 15 °C where a buffer zone is provided and to 10 °C in other situations. When temperatures in working environments exceed 30 °C there is likely to be a reduction in mental skills.

In terms of thermal comfort, there are three mechanisms that engineers need to consider when designing. These are summarised here and discussed in more detail later.

1. *Conduction*: this is due to air temperature and accounts for around 30% of perceived comfort. Traditionally, HVAC engineers focus on this.
2. *Convection*: this is due to air movement and humidity and the cooling effect from evaporation of perspiration from the body. This accounts for around 25% of perceived comfort and is provided by moving air through a room, either by mechanical means, or through natural ventilation. Generally, mechanical engineers try to avoid air movement above around 0.5 m/s as cold supply air will be felt as an uncomfortable draught rather than a pleasant breeze.
3. *Radiation*: at 45% of perceived comfort, radiation is the primary driver, yet it is generally overlooked in air conditioned buildings as air conditioning conditions the air, whereas radiative comfort needs the structure to be conditioned.

Design techniques for natural ventilation are detailed in CIBSE AM10: *Natural ventilation in non-domestic buildings* (CIBSE, 2005a) and are not discussed here.

Whether or not natural ventilation can even be used depends on location, as not all hot, arid climates are the same. Natural ventilation techniques, such as night purging, will generally work when there is a large diurnal swing with cool nights, even if the days get hot, provided thermal mass is used wisely and internal loads are not too high.

While natural ventilation might be an acceptable solution in villages, dense cities may not allow it, as heat is trapped in the city. Even ideal thermal conditions are no match for sandstorms or noise, however. Table 9 summarises when natural ventilation could be considered.

Table 9: Natural ventilation options for different conditions

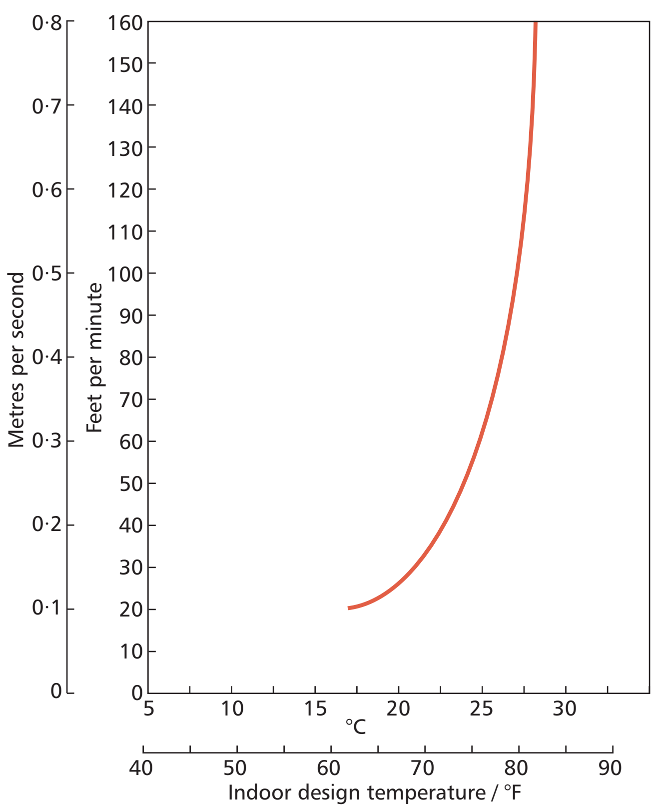
	Natural ventilation?	Other considerations	Examples
Cool night/mild day	Yes	Dust and noise	Winter in Gulf
Cool night/hot day	Yes	Night purge Thermal mass Fans Low internal loads Dust and noise	Iran, Mediterranean cities, American deserts
Warm night/hot day	No		Dense cities, e.g. Damascus

2.1.2 Radiant effects

Human comfort is affected more by radiant effects than by air temperature, so radiant cooling systems should be considered where humidity is either not a problem or can be adequately controlled. Examples of systems that work in some arid climates include the following.

- *Thermal mass*: works particularly well in conjunction with natural ventilation and night purging. Thermal mass should be sized with enough thermal lag to last through the hottest parts of the day.
- *Cooled structure*: supplying cooled fresh air through the building structure cools the structure (which must be exposed), which in turn provides radiant cooling. This reduces cooling air requirements and both peak and annual cooling loads. This has been shown to be effective in environments, such as Riyadh and Dubai, although exposed structure may not be to everyone's taste.
- *Chilled panels*: these work best in areas of low humidity and also reduce supply air requirements. As humidity increases, the temperature of the panel also needs to increase to above the dew-point of the air, reducing its efficiency. They can be made to work in humid environments but infiltration has to be very tightly controlled to avoid condensation.

Figure 25: Maximum recommended air movement for draught-free comfort



2.1.3 Evaporative cooling

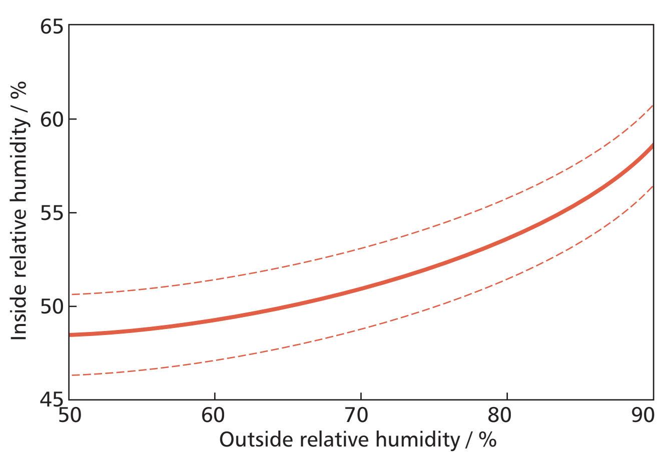
Evaporative cooling is most effective when the dry-bulb temperature is much higher than the wet-bulb. Cooling air by passing it over water so it loses energy to the latent heat of evaporation is an ancient technique of providing comfort and can reduce indoor conditions by several degrees compared with outside. It thus takes the edge off the heat, although may not be sufficient for office environments. In addition, it is less effective in humid environments as water evaporates less readily, while arid environments, by definition, are not likely to have a lot of water to spare for cooling.

2.1.4 Comfort cooling

Refrigerating air to cool a space is the most common form of comfort provision and provides a high degree of control over air temperature. However, comfort cooling does not provide a radiant component of comfort and, to avoid cold draughts, it is typically designed so that air movement is imperceptible. Tolerance levels for comfort in air conditioned spaces are therefore very tight.

When moving from hot outside conditions to inside a steady-state environment with no noticeable air movement, conditions of 24 °C may not be enough to cool people down rapidly (due to lack of evaporate

Figure 26: Indoor relative humidity conditions to be maintained for comfort



Relative humidity (%)	Temperature (°C)			
	Summer		Winter	
	Range	Optimum	Range	Optimum
40	23.0–26.5	25.0	20.5–24.0	22.5
50	22.5–26.0	24.5	20.0–23.5	22.0
70	22.0–25.5	24.0	20.0–23.0	21.5

Table 10: Internal design conditions

and radiant cooling) and as a result many buildings, in practice, are maintained at close to 21 °C or lower, resulting in thermal shock.

2.1.5 Air movement

To achieve higher design temperatures without complaints, additional air movement in the occupied zone is required. At warmer temperatures, a perceptible air movement will add freshness to the comfort response, but a similar rate of movement at the lower temperatures will become a draught.

Figure 25 is an empirical chart that may be used to select recommended rates of air movement. It should be noted that the rates of air movement referred to are terminal air velocities from the sources of air input and not velocities through the cross-sections of treated spaces. Since air is typically supplied at 14 °C, simply increasing terminal velocity without due consideration of room layout is a risky strategy. Options such as supplying air through workstations, which offers total occupant control, or use of recirculating fans within the space, should be considered.

2.1.6 Design conditions

Table 10 gives a range of internal design conditions for hot arid climates such as the Middle East.

Internal relative humidity can also vary with outside conditions. Table 10 indicates suggested values. Relative humidity affects the body sweat rate, which is an important mechanism for body heat loss, particularly in warm humid environments, and in a reduced space relative humidity can lead, under these circumstances, to improved comfort. Note that in central desert areas, low humidity can also cause problems.

2.1.7 Outside air rates

In chapter 1 of CIBSE Guide A (CIBSE, 2006), fresh-air ventilation rates are classified according to the extent that smoking is likely to occur, i.e. 'no smoking', 'some smoking' and 'heavy smoking'. In some regions of the Middle East, there is a drive to have 'non-smoking' policy in government and public buildings.

Based on the these classifications, Table 11 gives recommended rates of fresh-air ventilation for air conditioned buildings in litres per second per m^2 of floor area and in litres per second per person. These rates are provided for information and the designer should confirm them with the Authority Having Jurisdiction (AHJ).

As part of an energy conservation strategy, the designer may consider the use of demand control ventilation (DCV). DCV is a strategy by which the ventilation air quantity is adjusted in response to fluctuations in population. There are three ways to determine dynamic ventilation demand:

1. Carbon dioxide (CO_2) sensors located in either the space or within the return air system.
2. Occupancy sensors to detect presence or the population in a space.
3. Occupancy schedules to reflect changes in population according to time of day.

The control system that responds to varying conditions must be capable of providing at least the minimum ventilation requirement when the space is occupied.

2.1.8 Outdoor comfort

While building services engineers normally focus on the inside of a building, the environment outside the building is also experienced by most building users. The mechanical engineers (or building physicists) are best placed to advise on the treatment of these spaces in terms of comfort, so limited information is included here.

Table 11: Fresh air ventilation rates for air conditioned buildings

Application	Floor area/person (m^2)		Ventilation rate (l/s per m^2)			Ventilation rate (l/s per person)		
	Range	Nominal	No smoking	Some smoking	Heavy smoking	No smoking	Some smoking	Heavy smoking
Offices								
General	5.5–8.5	7	0.9	1.6	2.1	6.3	11.2	14.7
Private	7.5–11.0	9.3	0.75	1.3	1.55	7	12.1	14.4
Directors	9.5–14.0	11.75	0.75	1.05	1.3	8.8	12.3	15.3
Executives	14.0–23.0	18.5	0.75	1	1.25	13.9	18.5	23.1
Meeting rooms								
Staff	2.0–3.0	2.5	2.25	3.3	5.2	5.6	8.3	13
Management	3.7–5.5	4.5	1.3	2.25	3.3	5.8	10.1	14.8
Directors	5.5–8.5	7	0.9	1.6	2.1	6.3	11.2	14.7
Eating rooms								
Staff	1.5–2.5	2	2.65	3.8	5.95	5.3	7.6	11.9
Management	2.0–4.0	3	1.95	2.95	4.55	5.9	8.9	13.6
Directors	3.0–5.5	4.25	1.45	2.3	3.5	6.2	9.8	14.9
Hotels, etc								
Bedrooms	4.5–9.25	7	0.9	1.6	2.1	6.3	11.2	14.7
Public rooms	1.5–2.5	2	2.65	3.8	5.95	5.3	7.6	11.9
Restaurants	1.5–3.25	2.5	2.25	3.3	5.2	5.6	8.3	13
Bars	1.5–2.5	2	2.65	3.8	5.95	5.3	7.6	11.9
Lounges	2.0–5.5	3.75	1.55	2.55	3.85	5.8	9.6	14.4
Auditoria, etc								
Theatres	0.5–1.0	0.75	5.25	6.75	9.75	3.9	5.1	7.3
Cinemas	0.5–1.0	0.75	5.25	6.75	9.75	3.9	5.1	7.3
Concert halls	0.5–1.1	0.8	5.2			4.2		
Religious buildings	1.0–2.0	1.5	3.25			4.9		
Art galleries	2.0–11.0	6.5	1			6.5		
Museums	4.0–14.0	9	0.75			6.8		
Sales areas								
Shops	1.0–5.5	3.25	1.8	2.8	4.3	5.9	9.1	14
Supermarkets	2.0–4.5	3.25	1.8			5.9		
Department stores								
Basements	1.5–5.0	3.25	1.8			5.9		
Ground floors	2.0–6.0	4	1.5			6		
Upper floors	2.0–9.0	5.5	1.15			6.3		
Banks	7.5–11.0	9.25	0.75	1.3	1.55	6.9	12	14.3
Apartments	9.5–14.0	11.75	0.75	1.05	1.3	8.8	12.3	15.3

While hot, arid environments can reach very high temperatures outdoors, this does not mean they necessarily have to be uncomfortable. The following factors should be considered when designing outdoor spaces to be comfortable.

- *Radiation*: protection of direct sun is crucial, but less obvious is radiation from surrounding surfaces that have heated up in the sun.
- *Air movement and evaporation*: wind should be directed, or mechanically augmented, as required. Misting systems may also be appropriate depending on water availability and humidity.
- *Air temperature*: in some applications, mechanical cooling of outdoor spaces may be appropriate, in which case efforts need to be made to contain cooled air and to provide cooling through zero-carbon means.

2.2 Basic design information

2.2.1 Energy considerations

Environmental concerns and the rising cost of fuel mean there is an increased focus on minimising energy usage during the natural occupational life of a building. In many of the world's hot, arid areas, the number of large developments in recent years has grown exponentially. New construction has resulted in millions of refrigeration kWs of new air conditioning equipment being installed or planned. In some of these countries, more than 50% of the electric demand in the summer months comes from air conditioning loads. When air conditioning design considerations are being made for a large new facility, the availability of power is often taken for granted. More than just the local availability of power, the decisions made for air conditioning have an impact on the main power generation plant.

The thermal performance of the building envelope is one of the main drivers in determining what the cooling load and resultant energy use will be. Hence it is important to consider the building envelope design with primary significance. (Insulation, for example, plays an important part in reducing the heat exchange between the inside and outside environment as well as the formation of condensation.)

When calculating summer loads, it should be remembered that the time at which the peak cooling load occurs in an individual space will vary with orientation. Consequently, the maximum simultaneous demand imposed upon the central plant is not generally the sum of the peak loads occurring in the individual spaces or zones of a building but almost certainly a lower figure.

Even on the design-day, it is found in practice that systems do not work at their maximum, because the internal load is always lower than the theoretical peak—the simultaneous sum of the heat gains in the various treated areas in a building will be less than the sum of their maximum individual gains: some of the people will be absent, for varies reasons; a proportion of the lights will be switched off or need replacing; and business machines do not generally operate simultaneously. A diversity factor therefore needs applying to these elements to enable this inevitable load variation to be taken into account at the design stage so the system is not unduly oversized. (Clearly, the diversity applied should be adjusted to suit the design and usage of the building.)

Although in hot climates full load conditions tend to occur more often than in temperate zones, the majority of cooling coils still operate at part load for most of their life. If systems are designed to meet the most extreme circumstances, they and their associated controls will be greatly oversized for 'normal' conditions. Oversized air conditioning systems do not do a good job of reducing humidity, so the result can be a cool but humid environment. Also, predictably, oversized systems waste energy.

Multiple chiller configurations are a common method of effectively meeting both peak and part load conditions in large installations. They allow facilities engineers to stage their operation to match the cooling load while keeping the chillers operating efficiently. They also provide redundancy for routine maintenance and equipment failure.

Multiple chiller installations can be symmetrical (all chillers sized equally) or asymmetrical (one or more chillers sized at a different capacity). The key to deciding the best arrangement is dependent on the minimum anticipated cooling load. For many typical applications, sizing one chiller at one-third peak load and the other at two-thirds peak load enables the system to meet most cooling conditions at relatively high chiller part load efficiencies. Even if the load falls below the capacity of a single chiller, it is still likely to be operating above 30%, which is within a chiller's acceptable region of efficiency.

Because there is a large temperature difference between the incoming and outgoing ventilation airstreams in hot climates, abundant waste energy can be recovered through exhaust energy recovery systems. This can play a significant role in decreasing the cooling load.

In sunny climates, excessive brightness contrast between externally lit surfaces and building interiors causes visual discomfort. This is altered by switching on internal lights permanently, leading to unnecessary energy consumption. A well-considered daylighting approach in buildings will not only reduce the incidence of glare and discomfort but also reduce the need for electric lighting if it is part of an integrated daylight strategy with lighting controls and external shading devices.

2.2.2 Solar energy

Onsite renewable energy is gaining popularity worldwide. However, there are difficulties associated with implementing it in developing countries because the technology is not sufficiently advanced for it to be more cost effective than conventional energy sources, making it difficult to convince private underwriters to make the initial capital investment. The atmospheric conditions in arid areas are quite different from other regions: the air is generally much dustier. This means that many of the lessons learnt from, and technologies fine-tuned for operation in Europe, are not wholly transferable.

At present, solar hot water systems are the most efficient means of using the power of the sun—most buildings have a consistent need for hot water and incorporating a solar water system will significantly reduce electricity usage.

Maintenance is a major consideration when contemplating solar energy. The places with the highest concentration of sunlight (the most ideal locations for solar panels) are desert regions, but these are very dusty and sand needs to be removed from the panels frequently to prevent a decrease in efficiency. Self-cleaning systems are available, but some of these rely on water—not always a practical solution in areas where clean water is not in abundance. A preferred option is perhaps self-dusting solar panels, cleaned by an electric charge provided by the panels themselves; these are based on technology specifically developed for dry and dusty environments. There have also been some recent developments in dust-resistant coatings that are applied to the surface of the panels to actively repel dust.

Another form of solar energy that has vast potential in sunny regions is concentrated solar power (CSP). This system uses a series of parabolic mirrors to capture and focus the sun's energy to create steam to drive a turbine that powers an electric generator (or perhaps an absorption chiller). CSP is a proven and reliable technology but, as opposed to solar panel installations, is only presently used for large, centralised sources of power for utilities. In terms of cost competitiveness, it cannot yet match the low production cost of fossil-fuel power plants. However, as solar energy technology improves, CSP plants will become more economically advantageous.

2.2.3 Mosques

Mosques are places of great importance and function. They constitute the heart of any Islamic community, where people perform their daily and weekly prayers. They are an important sector of buildings in the Muslim world.

In hot climate zones, mosques need to be air conditioned: worshippers need to feel comfortable and relaxed in order to attain a feeling of tranquillity and peace. A design temperature of 24 °C is suggested for prayer areas, but other rooms within the mosque, at the discretion of the designer, may justify a slightly lower design temperature.

Mosques are characterised by their intermittent operating schedule, determined by prayer time, which varies continuously according to the local solar time. Therefore, analysis based on a specific time is not possible. Occupancy is usually five times intermittently throughout the day all year round, each averaging a fraction of an hour to an hour. Exceptions to this are weekly Friday prayers, when worshippers tend to stay longer, and Taraweeh prayers during the nights of the holy month of Ramadan. The occupancy rate in prayer rooms should be determined at 0.75 m^2/person. Maximum worshipper numbers should be used in the air conditioning design calculations.

Infiltration is difficult to measure due to the frequency of doors opening during prayer time, but as long as there has been careful treatment of cracks and leaks around windows and doors, a minimum rate should suffice for design purposes.

The orientation of a mosque is determined by the Qiblah (direction with respect to the Holy Kaabah in the city of Makkah, Saudi Arabia). The orientation is thereby fixed rather than being a design variable. They are usually formed elongated with the long axis facing Qiblah. The orientation will, clearly, be different from one area to another, depending on its location with respect to Makkah.

The subject of thermal comfort is inextricably linked to the issue of energy conservation. Adopting a higher set-point temperature could produce a significant reduction in air conditioning energy usage without a corresponding loss of thermal comfort.

Because a mosque's operation is unlike any other inhabited building, zoning is important for comfort control and energy conservation, especially for mosques with Friday, daily and women's prayer areas. Each should be designed to operate independently for use when needed.

Smaller demand, and hence smaller plant, can be achieved by pre-cooling the building mass below comfort level at least one hour before occupancy to absorb a portion of the peak load. However, a 5% occupancy rate should be assumed to cover for the person who calls for prayer and a few early arrivals.

Mosques generally have high ceilings, causing stratification of heat above the occupied zone. This phenomenon can be used to bring about an energy reduction by placing the supply and return air outlets at a level that limits mixing with the warmer upper air.

2.2.4 Labour camp accommodation

This section deals specifically with residences for migrant labourers in developing countries, particularly the Middle East.

Many of these residences are closely associated with our industry—they provide the necessary accommodation for workers of contracting and construction companies. The design lifetime for these temporary buildings is usually only 10 years. If the accommodation is for a different application, requiring a more permanent camp, this figure rises to 60 years.

Local regulations generally exist that dictate the provision for such housing, but standards vary from country to country, some stipulating as little as 3 m^2/person minimum requirement. For design occupancy rate, the number of people permissible per m^2 should therefore be reviewed in compliance with local laws.

Notwithstanding the above, there is a loose set of guidelines to which the more enlightened authorities adhere—and this is the basis of the criteria outlined in this section.

These facilities should be air conditioned and ventilated, either naturally or mechanically, to a reasonable level of comfort. Buildings that house fewer than 100 occupants are usually cooled with wall or split units, the advantages being low capital cost and the ability to give room-by-room control without the need to cool the rest of the building (corridors, for example). When there are over 100 occupants, using a centralised cooling system can be justified. If central plant is employed, room control could be as basic as a fan-speed controller.

Bedroom occupancy should be based on a minimum of 3.7 m^2 for each labourer, with a maximum of eight labourers accommodated per room.

Where communal kitchens and catering facilities are provided, the dining area design population density should be taken at 0.33 m^2/person.

In larger accommodation units, entrance lobbies are provided for workers to gather whilst awaiting transport. The occupancy rate for this area should be taken at 50 people per 15 m^2.

2.2.5 Internal refuse disposal areas

These rooms are usually called trash or garbage rooms—a room assigned to the temporary collection and storage of garbage in medium- to high-rise buildings. They are generally on the lowest floor level of the building and accumulate the garbage in preparation for removal and disposal. Through an internal garbage chute system, the garbage is fed into a removable 'bulk-bin' located in the garbage room.

In temperate climates the control of offensive odours can be dealt with by either natural ventilation through the chute or by installing a foul air exhaust fan at the top of the chute, above roof level. Air make-up would be through louvres in the garbage room door. However, in hot climates this method alone is insufficient.

Odour-causing bacteria from rotting food grow inside the garbage. As they accumulate, they become putrid and hot weather intensifies the decomposition process. Not only does this create offensive odours, but at higher temperatures this material also finds it easier to transfer to a gaseous state or break down into small enough particles to be carried by air movement and higher energy warm air. These particles are held in the air and can be inhaled. Consequently, in climatic zones where the outside ambient frequently exceeds 21 °C, garbage storage areas could become a health hazard. In arid regions, enclosed garbage rooms should be mechanically cooled to at least 20 °C.

2.2.6 Chilled water temperatures

The flow temperature of chilled water is a function of the system design; serious consideration should be given to determining the right condition for use in any particular arid environment, bearing in mind that chillers are only able to control the temperature at which chilled water is sent out, while the cooling load determines the temperature at which it is returned and, ultimately, the ΔT.

Typical 'wet coil' chilled water design flow and return temperatures in temperate climates are 7 °C and 12 °C respectively (standard Eurovent conditions), but this should vary depending on the dew-point to be maintained. In high-humidity arid areas (e.g. close to the coast), design temperatures of 6 °C flow and 12 °C return might be more appropriate, to increase latent dropout.

Design water temperatures as low as 5 °C flow and 11 °C return may be encountered (or even lower for district cooling primary water), but keeping the chilled water temperature as high as practicable provides major energy savings: approximately 4% of energy input per °C that the chilled water temperature is raised. The amount the chilled water temperature can be increased is limited only by the need to satisfy the cooling load.

Cooling systems in hot climates very often work all year, but infrequently at peak capacity; variable flow systems (Figure 27) should therefore be favoured because they supply only the required cooling capacity to each load, promoting the efficient use of refrigeration plant. Conversely, constant flow systems (Figure 28) when operating at part load conditions generate a low ΔT, effectively robbing the chiller of its useful capacity, consuming a higher energy rate per kW of cooling. Constant primary with variable secondary systems (Figure 29) are a compromise. These are more energy efficient than constant flow systems, but only because of the electrical power saving brought about by the secondary variable speed pumps.

2.2.7 Plant and equipment selection

The air conditioning load is estimated to provide the basis for selecting the cooling equipment. The equipment selection, however, must be based on design working conditions, which, particularly for outdoor units, can be extreme in arid regions.

Most European selection data is based on Eurovent criteria. Eurovent certification confirms the performance ratings of air conditioning and refrigeration products according to European standards. For manufacturers, the Eurovent certification programmes offer the ground for fair competition on equal terms and based on comparable data. However, this does not necessarily reflect actual design conditions, especially where these are outside the normally accepted parameters for relatively temperate climates.

Consequently, using tabulated data given in manufacturers' catalogues could result in inappropriate plant and equipment selection. For example, Eurovent standard rating conditions are:

- *fan coil units*: entering air 27 °C db, 19 °C wb, entering water temperature 7 °C with a 5 °C temperature rise
- *air/water liquid chilling packages*: evaporator 12 °C on, 7 °C off, condenser temperature 35 °C
- *air-cooled rooftops*: indoor air 27 °C db, 19 °C wb, outdoor air 35 °C wb, 24 °C db.

Figure 27: Variable flow system

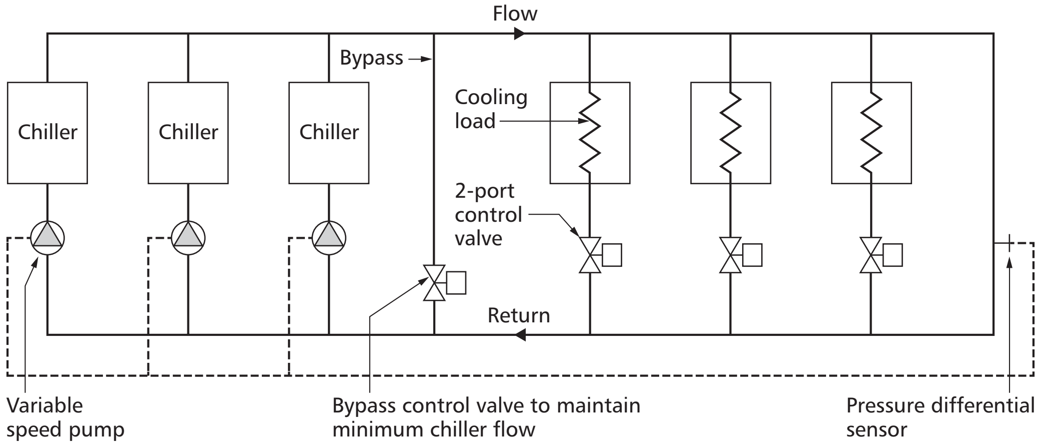


Figure 28: System with constant flow primary and constant flow secondary

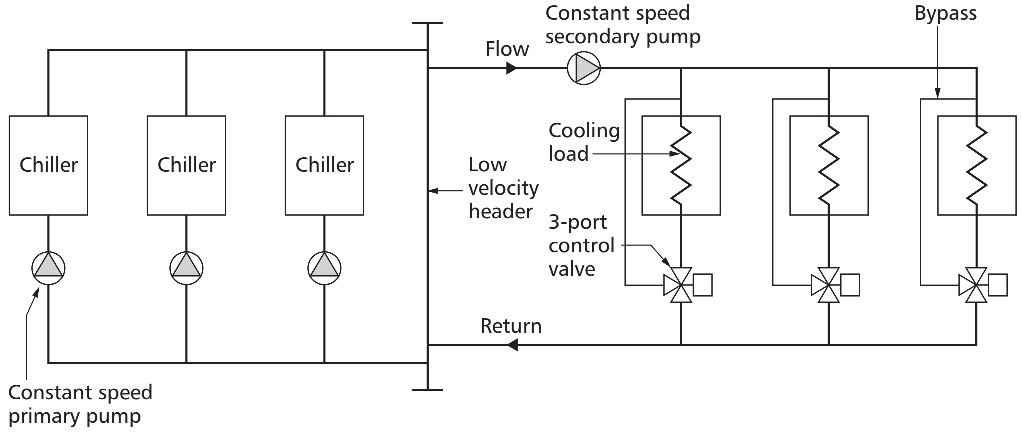
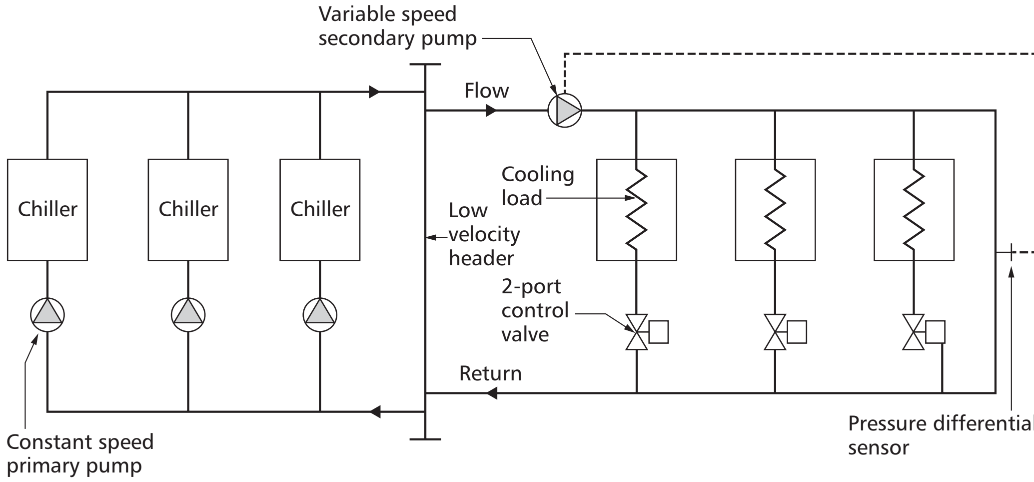


Figure 29: System with constant flow primary and variable flow secondary



Capacity ratings based on these criteria are unlikely to meet the needs of the project.

Most established cooling equipment manufacturers provide tables that give correction factors to adjust the catalogues' tabulated data in line with differing design values. Nevertheless, these factors should only be used for initial equipment selection. Computer-generated actual capacities should be requested from the manufacturer, supplier or agent at an appropriate stage in the design process.

Locally sourced plant and equipment sometimes have their tabulated performance data based on regional conditions. For example, capacity ratings for outdoor machines may be based on an external ambient of 46 °C, being more appropriate for some arid areas. They may also offer outputs based on 60 Hz electrical supply, which is the norm for some countries. In locations where district cooling systems are common, capacity ratings for cooling water temperatures of, say, 5.5 °C entering and 14.5 °C leaving may be contained in the equipment provider's standard brochure.

Most equipment ratings are based on sea-level altitude. However, for any specific place an increase in altitude is accompanied by a drop in both pressure and temperature, and a fall in barometric pressure has a principal influence on psychrometric properties, air mass flow rate, heat transfer coefficients for air and evaporation rates, etc. Air mass flow rate is, however, probably the most important effect of barometric pressure changes on system performance. Quantifying this change due to elevation is not a simple matter, but a crude indication of its effect on a fan coil unit at 600 m would be to reduce its sensible cooling capacity by some 8%. It is therefore imperative that altitude correction be applied to unit selections if they are to be installed at an altitude significantly above sea level.

For the altitude of any particular place, reference should always be made to local meteorological data. Or where this is unavailable, CIBSE Guide A (CIBSE, 2006), or its accompanying CD-ROM, should be consulted (these tabulate the elevation of particular locations throughout the world).

2.2.8 Natural air infiltration

Air infiltration is the unintentional leakage of air through a building due to imperfections in its fabric. The forces that drive natural infiltration are wind and temperature, but these forces create different rates of infiltration in a hot climate compared with a temperate one.

Wind forces outdoor air through gaps and openings on the windward side of a building where the surface pressure is high and out through apertures on the leeward side where the surface pressure is low. Consequently, in hot, still air, found in most arid countries, infiltration will be less than in a more temperate climate. To address this deviation, the empirical air infiltration allowances shown in CIBSE Guide B (CIBSE, 2005b) Table 1.5, should, given a good standard of envelope construction, be modified downwards for arid climatic conditions.

Infiltration also varies with the difference between indoor and outdoor temperatures, and hence air densities, which create a vertical pressure gradient known as 'stack effect'. This stack pressure (or chimney effect) is caused by the different atmospheric pressures at the top and bottom of the building as a result of differing temperatures creating a disparity in the weight of the indoor and outdoor air columns. In cold climates, this causes air infiltration at the bottom of the building and exfiltration at the top. However, for air conditioned buildings in hot environments, this flow is in the opposite direction, effectively creating negative, or reverse, stack effect. This opposite direction flow balances at some neutral point near the mid-height of the building (see Figure 30).

Because reverse stack effect causes infiltration air to flow in a downward direction in tall buildings, part of it will flow out of the external doors, offsetting some the infiltration through those doors.

Clearly, air infiltration from stack effect is greatly influenced by the height of the building and the presence of open stairways and vertical transport. (The door infiltration rate in low buildings would be relatively unaffected by reverse stack effect.)

Air infiltration through external door openings is an important factor when the doors are used frequently. Commercial buildings, for example, are likely to have a high door-opening frequency, either at certain times of the day or, in some cases, throughout the hours of occupation. Air takes the path of least resistance, which means a considerable area for infiltration (or exfiltration in the right circumstances) with a traditional swinging door. One measure that can be employed to decrease this infiltration, and hence reduce the building energy usage, is to use revolving doors.

Internally cooled air is denser than the warm outside ambient air, resulting in a pressure differential that moves conditioned air through open doors and cracks in seals. Revolving doors stop conditioned air from moving freely: they are never truly 'open' because seals remain in contact with the walls of the door at all times; the only air that is displaced is in the chamber of the person going through the door.

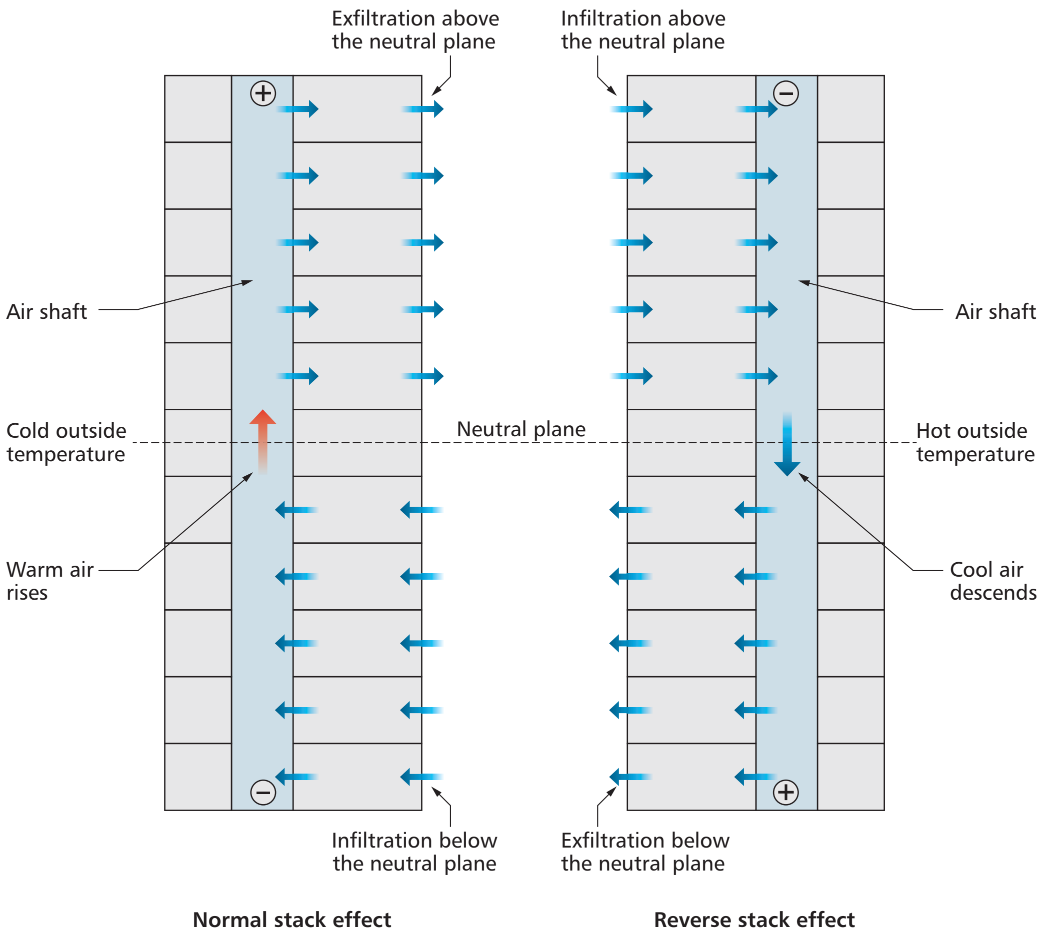


Figure 30: Movement due to normal and reverse stack effect

2.3 Lighting

2.3.1 Daylight

2.3.1.1 Atmospheric conditions

Daylight design in temperate climates is typically based around providing a minimum daylight factor for the majority of the year, based on overcast conditions (i.e. worst case). Arid climates, however, are typically sunny, and often hazy. Additionally, surrounding landscape can be very reflective, affecting daylight on the shaded side of a building. This greatly affects daylight distribution in a building and therefore designing to an overcast condition will often result in too much light entering a space. This causes visual discomfort, and people will shut the blinds and turn on the lights.

To determine the appropriate conditions to consider for daylight design, the designer should consult local illumination data and undertake a frequency analysis of direct and diffuse illumination levels and design accordingly.

2.3.1.2 Daylight thresholds (maximum and minimum)

Given the above, daylight design should aim to maximise the amount of time lux levels are within suitable limits. These limits change depending on building function. For offices they should be 500–5000 lux.

Daylight penetration is directly proportional to the amount of sky that can be seen through the window. Therefore tall windows get light further into a room than low, wide windows of the same area. As a rule of thumb, suitable levels of daylight penetrate into the room a distance equivalent to around twice the height of the window.

2.3.1.3 Window shapes and areas

Daylight penetration is directly proportional to the amount of sky that can be seen through the window. Therefore, tall windows get light further into a room than low, wide windows of the same area.

In hot and sunny climates, where envelope heat gains are a major consideration, thought needs to be given to the balance between daylight, and its associated energy savings, and heat gain. It should not be assumed that reducing envelope heat loads takes priority. Depending on the building, the glass and the climate, turning off lights can save more energy than reducing heat gains through windows. The designer should calculate window size to achieve the optimum balance between daylight and thermal performance in terms of total energy consumption.

2.3.1.4 Window shading

Shading reduces glare and, in the case of externally mounted systems, reduces heat gain.

In terms of glare, shading needs to keep the sun out of people's eyes and off their computer screens. This is generally best achieved with operable shading devices, which can either be external or internal. While external devices also block solar gain, they can get expensive, depending on the complexity and wind loads they need to withstand. Motorised devices in sandy climates are also problematic due to high maintenance requirements.

Several internal shading options exist that are the same regardless of climate, so they are not covered here.

In terms of reducing solar gain, external shading is best, although its effectiveness is reduced in hazy environments due to the high proportion of diffuse solar radiation. Shading also reduces the amount of sky that can be seen from the window, so daylight penetration is also reduced. Again, energy savings from using daylight need to be balanced against solar gains. The cost of installing external shading also needs careful consideration.

Finally, it should not be forgotten that building in low latitudes, such as those in or near the tropics, get sun on all sides, so a northern hemisphere building may need shading on the north. Summer midday sun is less of a concern in terms of solar gain, as the high sun angles mean that most radiation will be reflected by the glass due to Fresnel's equations of reflection.

2.3.1.5 Visual light transmission

The visual light transmission of glass has an inverse relationship to its thermal performance, so the higher the thermal performance, the lower the light transmission. This is not a linear relationship, however, and glasses with the same *U*-value and *g*-value can have very different light transmissions.

If daylight is a consideration in a building, the energy savings available from that need to be balanced against energy savings from using darker glass.

The climate also has an impact on glass selection, as maintaining lux levels within the above thresholds is a function of diffuse illumination. If too much light is allowed in, glare can result. In hazy conditions, this can occur even on the shaded side of a building. Locations with clearer skies can get away with clearer glass, with glare from direct sun controlled by shading.

The suggest maximum visual light transmission (VLT) values are as follows, although simulation should be carried out based on local conditions to make the best decision:

- low diffuse light levels (e.g. clear sky): 80% VLT
- high diffuse light (e.g. hazy sky, reflective open ground): 50% VLT.

2.3.1.6 Roof lights

Roof lights are very effective at bringing light deep into buildings, but in arid climates, which are typically hot and sunny, their heat gains tend to outweigh the benefits because their thermal performance is generally not as good as windows, and solar radiation is higher due to the angle of the sun. It may also be the case that the building operators will leave the lights on anyway, thus making the roof lights obsolete. Therefore, they are not recommended.

Roof lights are also not recommended for providing connectivity to outside in hot and sunny climates as there is rarely anything to see other than clear blue (or hazy white) sky.

2.3.2 Artificial lighting

2.3.2.1 Interior lighting

If the interior environment is being designed to ambient temperatures, similar to those in temperate climates, there are no specific design issues to consider and the general recommendations of the *SLL Code for Lighting* (SLL, 2012) will apply.

2.3.2.2 *Exterior lighting*

External luminaires manufactured and tested according to BS EN 60598-1 (BSI, 2009) will have been designed for an average ambient temperature of 25 °C and luminaires for outdoor applications for an average ambient temperature of 15 °C. The following design criteria need to be considered:

- operating temperature of lamps and control gear
- impact of higher humidity levels
- impact of air-borne dust and sand.

2.3.3 Emergency lighting

If the interior environment is being designed to ambient temperatures, similar to those in temperate climates, there are no specific design issues to consider.

2.3.4 Lighting controls

There are no special requirements for lighting controls in arid environments. Standard control strategies, such as daylight sensing, presence and movement sensing and clearly labelled manual control, all work as well in arid climates as elsewhere.

2.4 Noise and vibration

Building services plant, whether located inside or outside the building, generates noise and vibration that generally needs controlling to prevent disturbance to the building occupants or those of adjacent buildings. This is particularly the case in hot climates with the prolific use of air-cooled chillers, air handling units, fan coil units (FCUs) and other types of mechanical cooling/ventilation systems.

Local regulations and standards should be established and assessed. In some less developed areas the standards may not be strict, or indeed suitable, so the designer must consider this.

Noise control measures could be as simple as making careful selections of type and model of plant to enable noise emission requirements to be achieved. For example, low noise fan and chiller selection can negate unnecessary attenuation, whilst FCUs should be sized to operate at suitably low fan speeds.

2.4.1 Environmental noise survey

An environmental noise survey should be carried out at the early stage of the project to establish the local environmental daytime and night-time noise levels with and/or without the local plant running, as appropriate.

Reasonable efforts should be made to establish any likely increases or decreases in the environmental noise levels.

2.4.2 Building services noise to external areas

It is important to consider noise emissions from external plant that could break back into the building or affect occupants of neighbouring buildings. Guidance should be sought from the relevant local authority or municipality on their specific noise emission requirements. These requirements will relate to all noise-generating items of plant such as heat rejection equipment, air handling units and ventilation intakes/discharges.

The location of plant relative to noise-sensitive receptors (e.g. windows) should be considered, as should the potential for intervening acoustic screening. Designers should be aware that screens close to plant may need to incorporate openings or louvres to allow air movement around the equipment, so should assess the effects of these apertures on the acoustic attenuation effect of the screening. Chiller compounds will need to be kept well away from noise-sensitive openable windows

For residential receptors, building services noise should be at least 5 dB lower (10 dB if tonal) than the otherwise prevailing background noise L_{A90} levels, when measured at a distance of 1 m outside the nearest noise-sensitive openable window. For non-residential receptors 10 dB below the normal internal criteria for building services noise is generally acceptable internally. For external amenity areas, building services noise should not exceed 50–55 $dBL_{Aeq,T}$.

Planning conditions, building control requirements and statutory legislation may be more onerous and should be complied with in addition to the above.

Atmospheric noise emissions from the building services plant should be measured by the acoustic consultant to demonstrate compliance with the daytime and night-time acoustic criteria.

2.4.3 Building services noise to internal areas

To be acceptable, sound in occupied rooms should be free of discernible tonal characteristics and of a level that is unobtrusive. However, in sunny climates, for very practical reasons, occupied spaces tend to have mainly hard surfaces—floors are predominantly marble or granite because of their cooling properties. This cooling effect helps lower energy usage because it assists the air conditioning system's ability to keep areas cool. However, a consequence of hard surface finishes is the reverberant build-up of sound.

The designer must be aware of the locally accepted standards of noise levels, which are often less stringent than in the UK. Accordingly, it may be appropriate to relax the guidance given below (by, say, up to 5 dB), in line with local practice.

The following internal noise criteria are based on building services noise being constant (e.g. FCUs with constant fan speed). For variable air volume systems some relaxation may be appropriate for worst-case conditions (e.g. +5 dB relaxation at maximum design duty).

2.4.3.1 Rooms for residential purposes

Building services noise in rooms for residential purposes should be controlled to meet the criteria in Table 12 when measured in accordance with 'Part 1: Noise from Building Services' of ANC-9701 *ANC Guidelines – Noise Measurement in Buildings* (ANC, 1997). The criteria could potentially be relaxed by 5 dB for labour camps.

2.4.3.2 Offices

Building services noise in office areas should be controlled to meet the criteria in Table 13 when measured under Cat A standards in accordance with 'Part 1: Noise from Building Services' of ANC-9701 *ANC Guidelines – Noise Measurement in Buildings* (ANC, 1997).

Acoustic privacy in offices requires a reasonable level of background noise to mask unwanted noise. Therefore, the levels in Table 13 should be regarded as targets (which could be exceeded by 1–2 dB), rather than maxima, and significantly quieter noise levels should be avoided.

Where noise from building services is significantly quieter than the above noise levels, provision should exist to install electronic sound masking (possibly as part of the fit-out) to maintain acoustic privacy.

2.4.3.3 Other internal areas

Building services noise should be controlled to meet the criteria in Table 14 when measured in accordance with 'Part 1: Noise from Building Services' of ANC-9701 *ANC Guidelines – Noise Measurement in Buildings* (ANC, 1997).

Plant room noise levels should be designed to suit adjacent occupied areas and to comply with noise at work regulations. Noise levels above NR40 may be appropriate for back of house circulation spaces.

Table 12: Criteria for mechanical and electrical (M&E) plant noise transfer to rooms for residential purposes

Tenant area	Noise criterion (NC) or noise rating (NR)		
	FCUs, terminal units or ventilation systems serving actual area	All other M&E systems (within demise)	All other M&E systems (outside the demise)
Bedrooms	▪ Set back night duty NC/NR25 ▪ Normal day duty NC/NR30 ▪ Boost duty NC/NR35	NC/NR20	NC/NR15
En-suite bathrooms	▪ NC/NR35 (central ventilation systems) ▪ NC/NR45 (local extract fan)	NC/NR35	NC/NR30
Non en-suite bathrooms	▪ NC/NR35 (central ventilation systems) ▪ NC/NR45 (local extract fan)	NC/NR35	NC/NR30
Living rooms	▪ Normal duty NC/NR30 ▪ Boost duty NC/NR40	NC/NR25	NC/NR20

Table 13: Criteria for plant noise transfer to offices

Area	Noise criterion (NC) or noise rating (NR)
Circulation areas	NC/NR40
Open plan offices	NC/NR40
Speculative offices (see note)	NC/NR38
Cellular offices	NC/NR35
Small meeting rooms	NC/NR35
Large meeting rooms	NC/NR30

Note: The speculative office criterion is a compromise between the ideals for open plan and cellular offices.

2.4.4 Emergency plant

Relaxations of the aforementioned internal and external criteria are normally acceptable for emergency or standby plant, but should comply with the building control requirements and occupational requirements and not interfere with audible emergency alarms.

2.4.5 Acoustic separation between areas

The sound insulation between areas is dependent on the composite acoustic performance of the constituent parts and may often be negated by ill-considered service penetrations and/or crosstalk via common ductwork. The routing of services and requirement for crosstalk attenuators thus requires careful consideration, taking into account the acoustically critical partitions.

Table 14: Criteria for plant noise transfer to internal areas

Area	Noise criterion (NC) or noise rating (NR)
Place of worship	NC/NR30
Multi purpose hall	NC/NR30
Meeting rooms	NC/NR35
Retail units	NC/NR40
Leisure club/spa	NC/NR40
Restaurant/pre-function	NC/NR40
Reception desks	NC/NR40
Circulation areas	NC/NR40
Toilets	NC/NR45
Car park	NC/NR55
Service yards/loading bays	NC/NR55
Kitchen	NC/NR55

2.4.6 Vibration to internal areas

Vibration transfer from M&E services to internal occupied areas should not exceed 0.01 m/s^2 peak based on the W_b weighting as defined within clause 3.3 of BS 6472-1: 2008 *Guide to evaluation of human exposure to vibration in buildings* (BSI, 2008).

All items of building services plant should be fitted with effective vibration isolation to control the transmission of vibration in line with the above noise and vibration criteria.

The use of flexible connectors as an interface between plant and associated pipework cannot be considered

Table 15: Maximum velocity (m/s) guidelines for various internal criteria

Node	NC/NR40 and above	NC/NR37	NC/NR35	NC/NR30	NC/NR25
Risers	10	9	7.5	6	5
Main branches (see note)	6	5.5	5	4	3
Ductwork to grilles (see note)	3	2.5	2.5	2	1.5
Ductwork to diffusers (see note)	2.5	2	2	1.5	1
Extract stub ducts (above ceiling)	4	3.5	3	2	1.5

Table 16: Maximum velocity (m/s) guidelines for external louvres

Node	Face velocity (m/s)
Intake louvres (non-acoustic)	2.5
Discharge louvres	2.0
Acoustic louvres	1.5
Ductwork to louvres (see note)	5.0

Note: Velocities in ductwork prior to grilles/diffusers/louvres must be reduced gradually down to the values shown. Where main branches are located close to terminal, the velocities in these branches may need to be reduced to a value closer to the guidelines for ductwork to grilles/diffusers.

as adequate vibration isolation. It is therefore recommended that all active pipework should be isolated on resilient mountings/hangers up to the structural penetration adjacent to the service shaft, the first 100 pipe diameters or the first 10 m of pipe run, whichever is the greatest. Thereafter, oversized brackets with neoprene inserts would be advisable.

2.4.7 Lift installations

Lift ride quality and performance characteristics should be set and measured in accordance with BS ISO 18738: 2003 *Lifts (elevators): Measurement of lift ride quality* (BSI, 2003).

2.4.8 Ductwork

The general parameters for ductwork or pipework design, fabrication and installation are laid down in the relevant codes of practice (HVCA and CIBSE). The following good acoustic practices should alleviate the most commonly occurring problems with duct services.

- Bends and bifurcations – 90° bends should either be radiused type, or be fitted with equally short-cord turning vanes.
- All branches should be fitted with boots or coned as a standard practice.
- Transitions should be as gradual as possible within the physical limitations, preferably with one pair of sides remaining parallel.
- The aspect ratio in all main and branch duct runs for rectangular and flat oval ductwork should ideally not exceed 3:1.
- Volume control devices near duct terminations should only be used to provide fine trimming of the airflow. If dampers are likely to be used beyond fine trimming purposes, ‘damper silencers’ may be required.
- Duct velocities should be limited to those stated in Tables 15 and 16.

3 Building design construction and materials

3.1 General

In arid climates, particular environmental conditions need to be considered, such as heat (including diurnal temperature differences), humidity, low precipitation, winds, sand etc. in order to choose the most suitable materials and assemblies. The design and specification of equipment needs to ensure there will be an uninterrupted flow of plant to site that will, once *in situ*, perform as required and can be managed and maintained. They should also be durable and not require frequent replacement: they should be able to withstand the forces of nature. Even if the final location of the equipment is in a controlled internal environment, it should be recognised that the installation may take place in uncontrolled conditions; also, the journey to the final location could have been arduous.

The architectural form of a building can itself pre-eliminate some of the local climatic challenges. For example, if well designed, courtyards can give a degree of protection from sand and wind-borne dust. Fully exposed spaces, however, require barriers to provide protection from overhead dust and side-swirls. In this instance, protection is a function of length and height of the barrier and distance from face of building (generally determined from local empirical data).

Orientating the building towards the prevailing wind, using wind catchers and appropriately designed openings, shade and shadow, fountain and water surfaces, cross-ventilation, heat-resistant and thick walls and other passive and natural techniques are all free and accessible.

Social and environmental issues, in addition to materials, manufacturing and transportation costs, need to be considered. The logistics of importing equipment into a country also requires consideration of non-technical factors such as shipping regulations, transportation concerns, the role of governments and intermediaries and the application of local trade laws. These factors are subject to risks such as programming issues and opportunities for fraud. Consequently, the designer should consider using locally sourced materials that may, on balance, be a preferable option.

Although climate is an important element, other factors—such as government directives, mandates and decrees, local regulations and codes of practice, commercial tradition and available resources—can also affect design decisions, as can historical, cultural, local customs, religious and political factors. All these need to be taken in to account at the outset.

3.2 Architectural and structural issues

3.2.1 Location of capital plant

Because most buildings in arid climates are air conditioned, at an early stage the designer must inform the architect and structural engineer of any specific requirements in relation to major plant items and their particular needs (refrigeration and heat rejection, for example). This will include spatial needs and sufficiency of structural integrity to support heavy machines such as chillers and large mass flow air handling units. For example, floor slabs, other than the ground floor, are not generally designed to support weights imposed by such plant.

Building layout constraints may impose restrictions on where apparatus can be sited. Sizeable cooling plant can, however, be situated in a number of different locations: they can go on, in or remote from the building to which they serve. A convenient place to put chillers and large primary air plant is on the roof of the building, keeping it out of site but readily accommodating its air input and heat rejection needs. If this is to be the case, the architect/structural engineer will need to confirm the roof is capable of bearing the dynamic loads imposed during operation. Fortuitously, in hot climates roofs are generally constructed of high thermal mass dense material, in order to increase the unsteady-state heat gain response factors (time lag and decrement), giving them good load-bearing characteristics. Of course, open roof space shown on architectural concept plans is not necessarily all available to the building services engineers—there may be competing space requirements from other equipment such as satellite dishes, building maintenance tracks and jibs.

If it is unfeasible to place the chilling machines on or in the building, standard practice is to create a chiller compound, which generally incorporates the pump house within its boundary. This method, of course, suffers from the inherent disadvantage of having to pipe the chilled water to the building(s), and in hot climates there could, depending upon the distance involved, be a considerable heat gain to the chilled water system, which would need to be considered when sizing the main plant and pipework. Subterranean pipework has the benefit of not suffering solar gains, but in an arid climate the earth temperature will be relatively high, so the problem is not totally negated by this method of pipework distribution.

To avoid undue static pressure on plant, valves and fittings in high-rise buildings (50 m or more, say), plant rooms at intermediate floor levels should be considered (due regard being paid to noise and vibration). This arrangement is also convenient for large air handling plant, lessening the air quantity conveyed in any one duct and thereby reducing the spatial needs of vertical services shafts, which can be substantial in arid climates because of the habitual use of primary air systems.

3.2.2 Spatial and structural needs

As with any project, at a fairly early stage in the design process (RIBA 'Stage 2' in the RIBA Plan of Work (2013)), an estimate of probable space allowances for services will need to be factored in to the building design layout. This requirement can be exacerbated in hot climates because of the propensity to use large primary air and all-air systems with their associated sizeable ductwork. Space (and the cost of providing space) for plant and building services distribution is often at a premium, therefore pressure to reduce the spatial requirement for building services installations is an understandable constituent part of the overall design process. However, it is unwise to underestimate or compromise on spatial needs at the conceptual stage. (Giving back area to the general build at a later date is not generally problematic, but requiring the structure to grow to accommodate unaccounted-for services elements can cause considerable architectural and structural challenges.)

Ceiling void height should be given particular attention in hot climates because it commonly contains the cooling system's terminal units and primary air or all-air system ductwork, together with the necessary associated condensate piping network. Chassis fan coil units, for example, mounted in the false ceiling void are particularly popular because of the relatively small amount of time required for design, their availability, low capital cost and comparative ease of installation and maintenance. Coordination with other engineering services to be accommodated in the ceiling void is, of course, paramount (there may be several distribution systems vying for the same restricted space).

Adequate space is also required for plant access, operation and maintenance. Without this provision for effective and safe maintenance and operation of the mechanical and electrical engineering services, the building facilities could be reasonably considered as unfit for purpose. However, many developing regions are notorious for their attitude towards equipment maintenance: 'run it until it breaks' is often the only way operators know how to handle even the most critical equipment. Even when maintenance is undertaken, it commonly leaves a lot to be desired. This lack of or poor maintenance will eventually result in the loss of a valuable asset. On a more positive note, the focus on maintenance is slowly increasing.

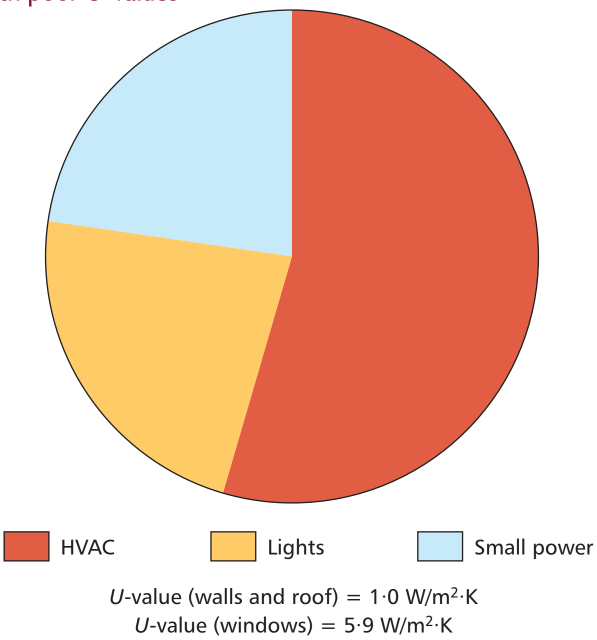
In addition to the usual need for structural openings in walls for equipment such as external louvres, there may be a requirement to provide penetrations for unitary room air conditioners, a rudimentary type of air conditioning unit seldom used in temperate climates such as the UK. Their application is generally relegated to low-cost accommodation and remote guardhouses. Notwithstanding, if the building to which they are being proffered is of any size, there will be numerous apertures, and the architectural (because of their unsightly interference with the building facade) and structural implications could be profound.

3.3 Building thermal performance

The thermal performance of a building has a direct effect on the comfort of people in the building and, as a result, on the energy to heat or cool it. To maintain comfort while keeping energy consumption low, designers need to consider the:

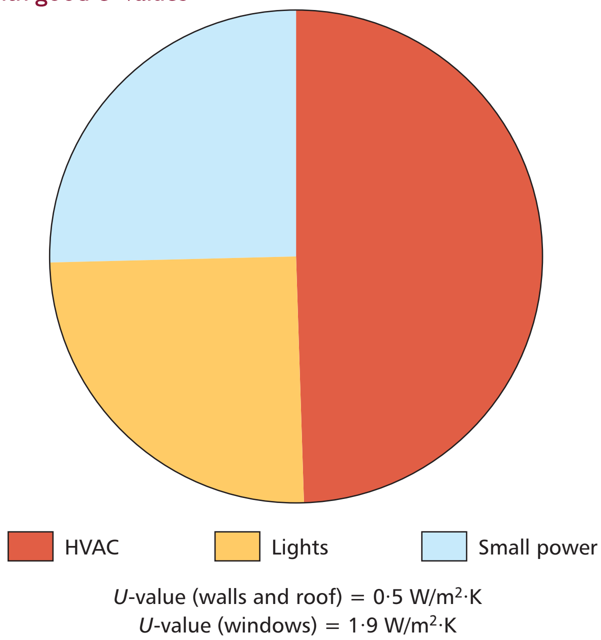
- *U*-value of the envelope
- solar heat gain coefficient of the glass
- thermal lag of the envelope.

Figure 31: Basic energy breakdown for a nominal building with poor *U*-values



U-value (walls and roof) = 1.0 W/m²·K
U-value (windows) = 5.9 W/m²K
Solar heat gain coefficient (SHGC) = 0.87
Glazing ratio = 50%
Internal gains = 10 W/m²
Lighting gains = 10 W/m²
Occupancy density = 15 m² per person
Outside air (OA) = 8.5 litres per person
Total plant coefficient of performance (COP), including fans and pumps

Figure 32: Basic energy breakdown for a nominal building with good *U*-values



U-value (walls and roof) = 0.50 W/m²·K
U-value (windows) = 1.9 W/m²·K
Solar heat gain coefficient (SHGC) = 0.28
Glazing ratio = 50%
Internal gains = 10 W/m²
Lighting gains = 10 W/m²
Occupancy density = 15 m² per person
Outside air (OA) = 8.5 litres per person
Total plant coefficient of performance (COP), including fans and pumps

Figure 33: Breakdown of cooling loads by source for a nominal building with poor *U*-values

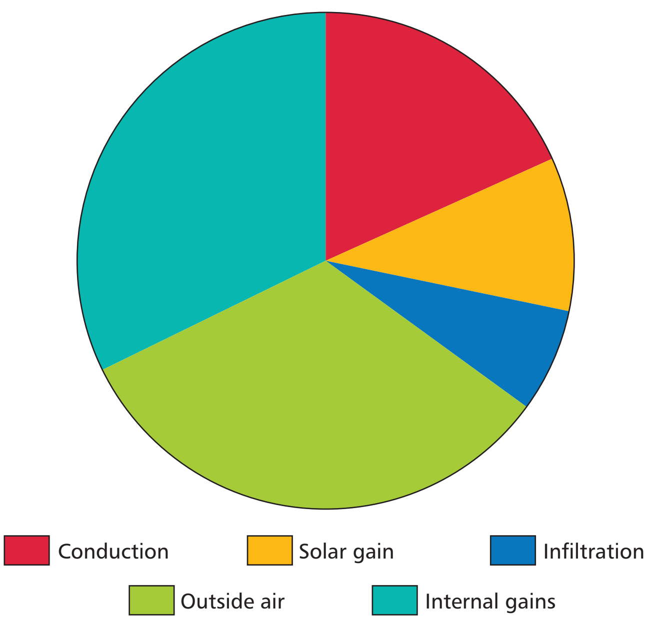
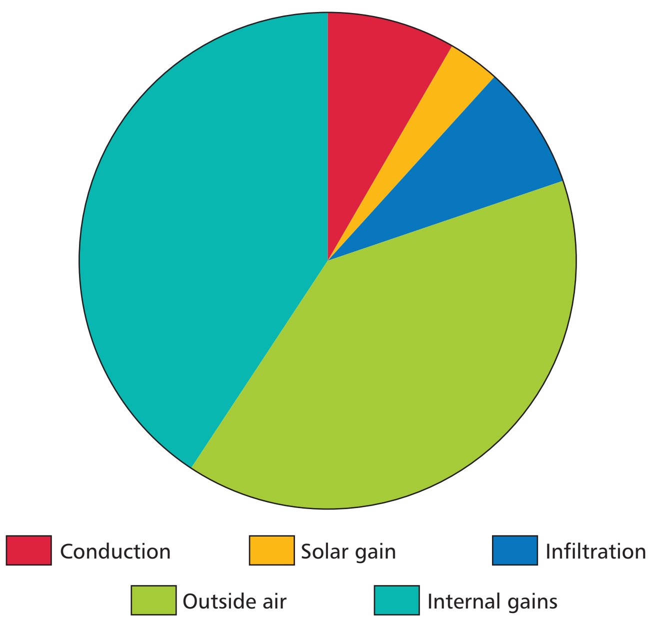


Figure 34: Breakdown of cooling loads by source for a nominal building with good *U*-values



3.3.1 Relative energy breakdowns

In many countries the building codes already specify minimum performance levels that are adequate, and it is worth noting that in this case the biggest energy consumer may not be related to the envelope's thermal performance. Those looking for energy savings in this case should look beyond *U*-values and towards building services. Figures 31 and 32 show an energy breakdown for a nominal 20-storey commercial building with both 'moderate' and 'poor' *U*-values in a hot climate.

HVAC energy is clearly the most significant in this simple example, but looking at the breakdown of this energy in Figures 33 and 34 shows that facade gains (conduction and solar) are not necessarily the most important.

3.3.2 Form and orientation

In smaller buildings especially, and in countries without effective minimum standards for insulation of buildings, building form and orientation is important in optimising heat gains and thus energy consumption. As a rule of thumb, windows should be concentrated on the north and south (with appropriate shading, see Table 17) to avoid high-intensity, low-angle sun.

Where natural ventilation is possible, care should be taken to allow building form to promote effective ventilation, with room depth-to-ceiling height ratios as below proving effective:

- single sided ventilation: 2.5
- cross ventilation: 5.

Refer to AM10: *Natural ventilation in non-domestic buildings* (CIBSE, 2005a).

It is noted that where insulation levels are high, including the glass, and where internal loads are also high, orientation actually makes very little difference to overall energy consumption.

3.3.3 Building fabric

Buildings should be well insulated in hot and dry arid climates. Where there is a good diurnal range, the use of thermal mass is recommended; this can reduce both peak energy loads and annual energy consumption.

3.3.4 Solar shading

Solar shading has two purposes: to reduce solar gains to a building and to improve comfort for building users, both visually (glare) and thermally (radiation, particularly through and from windows).

It should be remembered that in low latitudes the sun will directly strike both the north and south facades, regardless of which hemisphere the building is in.

Depending on the relative importance in energy terms of solar gain (see Figures 33 and 34), designers may find a client's money is best spent somewhere other than solar shading. Nonetheless, Table 17 summarises some key shading options.

3.3.5 Infiltration and exfiltration

The movement of air in and out of a building through gaps in the building envelope is called infiltration and exfiltration, respectively. In arid climates, this increases the sensible cooling load in a building, and the latent load is also increased where humidity is high.

There are three main causes of infiltration in hot climates: wind loads, reverse stack effect and poorly balanced extraction systems.

When there are gaps in the building envelope, such as around and through windows and doors or between cladding panels, the wind simply pushes outside air into the windward side of a building and sucks it out of the leeward side. To counter this, minimum leakage criteria are recommended, for example: 5–10 $m^3 \cdot h^{-1}/m^2$ at 50 Pa.

Infiltration also occurs due to the reverse stack effect in tall buildings. Here, the building can be considered as a tall column of cool, dense air surrounded by hot outside air. Being denser, the cool air drops and leaks out of a building from the below the neutral pressure plane (around two thirds of the way up the building). Hot air is then sucked in from outside to replace it.

Finally, if air extraction systems are not properly balanced during commissioning, infiltration can be forced on a building.

To counter the effects of infiltration, architectural designers (and particularly building contractors) should provide good sealing throughout the

Table 17: Shading options

	Views	Efficacy	Maintenance
Horizontal shades	Generally unobstructed	Best on north/south facade (depending on project location).	May obstruct building maintenance units (BMUs).
Louvres	Obstructed	Allows same shading as horizontal shades with less width.	Easier for BMUs but more surfaces to clean. Operable louvres have higher maintenance costs.
Vertical fins	Obstructed, especially if distributed across the window	Limited efficacy in low latitudes due to high sun angles, even on east/west facades.	Less cleaning. Operable fins have higher maintenance costs.
Lattices/mashrabiya	Highly obstructed	Very high.	May cause difficulties in accessing glass behind. These systems are generally designed with dust accumulation in mind, so cleaning can perhaps be discounted.
Shutters or other operable systems (manual or automatic)	Highly obstructed when closed, otherwise unobstructed	Very high as only used when needed. Costs vary with system complexity.	Depends on the complexity of the systems and the height at which it is installed. Wind loads can cause damage.
Electrochromatic glass	Unobstructed	Not strictly shading, but a variable shading coefficient. Electrochromatic glass is very expensive.	No BMU issues, only power supply.
Internal blinds	Highly obstructed when closed, otherwise unobstructed	Limited to no impact on energy but greatly reduces solar radiation for those beside the window.	Low.

building envelope. For tall buildings, breaking the vertical path of air within the building, with stairwells and elevator shafts, for example, should be considered; this will reduce the size and weight of the column of cool air trying to get out. Doors at the top of tall buildings, such as at roof level, deserve special attention because they can be one of the main sources of infiltration. Revolving doors and airlocks should be considered. Where possible, air leakage tests of buildings are recommended.

3.3.6 Plant location and shading

HVAC plant works more efficiently if located in a relatively cool environment. Plant rooms should therefore be shaded as a minimum, if not conditioned. Landscaping around outdoor air intakes can also be used to slightly cool the air prior to entering the main cooling apparatus.

3.3.7 Factors affecting thermal performance

Table 18 summarises some key issues to consider.

Table 18: Factors affecting thermal performance

Characteristics	Low-rise	Medium/ high-rise
Orientation	North/south	Less important
Site layout	Close together to shade neighbours	Views dominate
Internal plan	Courtyard	Wet services near core
External spaces	Courtyard	Balconies and podiums
External walls	Heavyweight	Insulated panels
Roof	Heavyweight	
External openings/ windows	Small, near ceiling	30% glazing ratio, VLT <50%
Shading	Comfort and energy	Comfort
Infiltration		Prevent at high level
Internal walls	Heavyweight	
External circulation	Shaded	Shaded
Special precautions	Dust, insects	Dust, insects

3.4 Thermal response (thermal weight)

3.4.1 Thermal mass

Thermal mass refers to elements in a building, usually exposed structure, that have a high heat capacity (i.e. can store a lot of heat energy). It works in two related ways to help provide comfort.

First, heat energy goes from a source (e.g. people at 37 °C) to a sink (e.g. concrete at 24 °C). Exposing this mass means that heat loads can be absorbed through radiation, providing a good deal of comfort. It is important, however, not to saturate the thermal mass with heat, or let it get hot from the outside, because the radiative cooling effect is then lost (or worse, replaced with radiative heating).

Thus the second mechanism of thermal mass is time lag, or how long it takes heat to travel from outside to inside through the mass. If this is long enough (say eight hours or more), then heat from outside will not have time to penetrate into the building before night comes and cools it again. Exposed mass on the inside then provides radiative cooling to the occupants. This can be experienced with stone buildings in hot climates that are cool inside, even in the height of summer.

Thermal mass has also been used historically in Mediterranean countries and American deserts. In the northern parts of Australia and the Arabian/ Persian Gulf countries, this is a less effective strategy as high overnight temperatures means the mass eventually heats up and stops cooling. With the ubiquity of air conditioning, this is no longer much of a consideration, however.

3.4.2 Thermal bridging

Significant energy savings related to overall conduction loads can be achieved by considering thermal bridging. This occurs when structural elements in facades (e.g. window frames) have an unbroken line of conduction between outside and inside. Structural ties within insulated panels can also cause bridging, significantly reducing the effect of the insulation.

3.4.3 Surface resistance

The outside surface resistance of building construction is:

$$R_{so} = \frac{1}{E\ h_r + h_c} \qquad (3.1)$$

However, h_r depends on the outside surface temperature of the building and for Middle Eastern countries is taken as 7.0 W/m²K as opposed to 5.7 for the UK. Consequently, the values of outside surface resistance to be used are:

- walls: 0.049 m²·K/W
- roofs (non-metallic): 0.042 m²·K/W
- roofs (aluminium): 0.051 m²·K/W.

Values for inside surface resistance are the same as those given in chapter 3 of Guide A (CIBSE, 2006).

In practice, this change in the value of the outside surface resistance may be neglected and the U-values given in chapter 3 of Guide A (CIBSE, 2006) can be used without modification.

3.5 Thermal properties of building structures

In the selection of materials for buildings in hot, dry climatic regions, the overriding engineering principle is to reduce heat transmission from outside into the building.

The thermal and energy performance of a building depends largely on the thermal properties of the building envelope. This performance is mainly determined by its thermal conductivity, which describes the ability of heat to flow across the material in the presence of differential temperature. The value of the thermal conductivity of a particular material is subject to variation, due to changes in both moisture content and temperature. In reality, structures are exposed to significant and continuous temperature variations, because of varying outdoor air temperatures and, significantly in desert environments, solar radiation. However, when calculating cooling loads or performing energy analysis for buildings, designers generally use published values of thermal conductivity such as those found in Tables 3.36, 3.37, 3.38 and 3.39 of Guide A (CIBSE, 2006).

In hot areas of the world, the thermal properties afforded by high thermal mass structures can be used to slow down the flow of heat into a building, thereby keeping it cooler. It makes use of the fact that the days may be extremely hot but the nights are significantly cooler, which prevents excessive build-up of heat. This storage and release ability of high thermal mass structures does not happen, however, in locations where the night-time temperature varies little from the day, as is typical in more humid climates.

Whereas in England and Wales, for example, the maximum permitted limits for thermal properties of building structures are regulated and contained in Approved Document L of the Building Regulations (2010), many developing countries have no such code. Of those that do, the thermal transmittance requirement of the building envelope is unlikely to be as stringent as those set out in Part L. For example, the maximum permitted value of heat transmission coefficients in some Gulf countries are only: roof, 0.44 $W/m^2{\cdot}K$; wall, 0.57 $W/m^2{\cdot}K$.

The designer should contact the local regulatory body to gain first-hand knowledge of their current statutory requirements.

3.6 Dynamic thermal performance of a structure

One of the simplest methods of assessing the dynamic, or non-steady-state, performance of a structure is the admittance procedure. In addition to the thermal transmittance coefficient (U-value), this takes into account the ability of walls and roofs to reflect solar radiation and the delay of heat flow through the structure.

The performance parameters are:

1. thermal transmittance (U-value)
2. solar heat factor (the proportion of incident solar radiation transmitted through the structure)
3. time lag (response of the structure to temperature change)
4. thermal admittance (rate of heat flow between the structures internal surface and space temperature).

3.7 Moisture control and condensation problems

3.7.1 Forms of moisture

Water vapour is a natural component of air, even in arid climates—air's capacity to carry water increases in straight relation to its dry-bulb temperature. Hot, arid areas therefore have the potential for high air moisture content, creating the known hot and humid climate patterns typically found near the coast and major bodies of water. With imperfect building construction found in many of these regions, buildings are more prone to uncontrolled moisture issues through high rates of air infiltration and liquid water leakage.

3.7.2 Potential moisture-related problems

If uncontrolled, moisture in the air can generate problems within the built environment. One of the main components of people's thermal comfort is the relative humidity of air i.e. moisture content, because it relates to the ability to perspire; hence, unrestrained moisture can create discomfort. However, it can also affect indoor air quality and cause structural damage to buildings.

3.7.3 Indoor air quality

Sustained high humidity levels create an optimum environment for microbial growth. Bacteria and fungi find ideal fields for growth in building components, creating poor indoor air quality (and also deterioration of the building fabric). Bacteria, fungi and dust mites are responsible for odours, allergens and even toxins. Exposure to allergens and toxins can cause health problems such as asthma and lung diseases.

Certain conditions sustained over time are needed for mould, fungi and bacteria to grow and flourish.

- A source of food (majority of construction materials).
- Temperatures between 5 °C and 40 °C.
- A sustained high moisture content (70% relative humidity (RH) or higher).
- Mould and mildew spores.

These conditions are readily found in buildings, and there are few opportunities to design them out: construction materials, an acceptable temperature range and spores are intrinsic in the built environment. Building services designers can, however, influence the internal relative humidity and thus diminish the possibility of microbial growth.

Fortuitously, a well-designed environment for human comfort is too dry for mould and fungi to propagate. Therefore, by maintaining internal spaces below 65% RH, uncontrolled moisture issues are reduced along with the potential for discomfort through poor indoor air quality (and the risk of structural corrosion).

3.7.4 Sources of moisture

Ingress of moisture into buildings takes the form of water vapour or liquid water. Both these states can transform—vapour to liquid through condensation on cold surfaces; liquid to vapour through evaporation—allowing the moisture to migrate around the building. Typical liquid sources of moisture include rain, fog, ground water, water ingress through basements, leakages, internal processes and equipment failures.

In arid areas, storm water drainage systems in buildings often do not undergo a natural-event functional test during the construction phase. And to compound this, there is often no annual planned maintenance regime in place. As a consequence, water leakages are common in the rainy season, even in new builds. Notwithstanding good design details of roof surfaces, windows and walls can help minimise this source of moisture ingress.

In some arid regions, fog is a common phenomenon at certain times of the year, typically forming at sunrise. Because fog droplets are too small to be eliminated by louvres or filtration devices, they can enter buildings through mechanical ventilation systems. Evaporated droplets add moisture to the indoor environment and, although this is generally of no great consequence, it should be taken into consideration in system design and functionality.

3.7.5 Condensation

The most common source of liquid water in buildings in hot and humid climates is in the form of condensation from water vapour coming into contact with internal cold surfaces. High relative humidity in conjunction with a high dew-point increases the probability of condensation formation. Mechanical comfort cooling systems should, therefore, be designed and sized to cater for the total cooling load (latent and sensible) to obviate moisture concerns resulting from a low internal dew-point.

3.7.6 Water vapour barriers

Controlling moisture requires an understanding of its nature. Water vapour moves through solid elements proportionally to the different vapour pressure on each side of the material and the resistance of that material (or composite of materials) to water vapour flow (permeance). To minimise this moisture transfer by vapour pressure diffusion, vapour barriers are recommended for walls, roofs and floor assemblies. The most effective location for a vapour barrier is at the warm side of the structure. To help keep the external high water-vapour content air from the cooler interior surfaces, low permeance materials should be used for the building's outer skin.

3.7.7 Condensation control

Any cool surface is prone to condensation: unconditioned area building fabric adjacent to conditioned area, chilled water pipes, ventilation ductwork and even concrete surfaces under carpeted floors can be cooler than the average internal surface temperature, and this situation is of particular concern where the climatic conditions are both hot and humid. To contain this condition, the dew-point temperature of the space should be depressed. This can be accomplished by supplying air dry enough to, as far as possible, absorb moisture from the different sources.

3.7.8 Air infiltration control

Notwithstanding the use of vapour barriers and low permeance materials, moisture-bound air will inevitably enter the building by natural infiltration through cracks, other building imperfections and, moreover, planned openings such as doors, windows and mechanical services apertures, as a result of buoyancy, stack effect and air pressure differential. This means it is particularly important to try and minimise outdoor air infiltration in environments that have a high wet-bulb temperature.

A positive building pressure in respect to the outdoor static pressure can help limit unwanted infiltration while maximising design exfiltration. Where there is no central treatment and dehumidification plant, such as in a residential building, this process needs to be undertaken by the local cooling system such as FCUs. For large, centrally supplied systems, solid desiccant wheels are recommended to efficiently and passively dehumidify the outdoor air supply, and thus, by recovering energy from the exhaust air, reduce the energy demand on cooling equipment.

4 Equipment design data

4.1 Introduction

This section highlights some of the significant differences in approach required to overcome problems, particularly related to the equipment used, when designing engineering systems for buildings in an arid environment.

4.1.1 General design philosophy

The general design philosophy for building services installation in an arid environment can be summarised as follows.

1. Establish a sound basis of design, taking full and proper account of geographical, local climatic, commercial, legal and social conditions and requirements.
2. Take care, both in system design and equipment/material selection, to anticipate problems that may arise because of high temperature and humidity, exposure to dust, sand and intense solar radiation, salty atmosphere, brackish water supplies and irregularity of supplies.
3. Avoid unnecessary or unwanted design complications or sophistications. Also avoid over-design (unjustifiable safety margins, over-engineering through specifications and detailing). Keep it simple. Do not experiment or use unproven techniques without undertaking a proper due diligence.
4. Take full advantage of local experience, expertise and resources including local fully trained engineers and technicians capable of applying Western technology in building services.
5. If the design includes specialist plant, such as chillers, sewage treatment plant and incinerators, allow for the manufacturer, specialist engineer or representative to supervise, set to work and commission as necessary.
6. The use of packaged equipment that involves a minimum amount of specialised site installation work should be encouraged.

4.1.2 Climate and terrain

Weather data are given in chapter 1 of this document. The following issues have an impact on equipment.

- High intensities of solar radiation will degrade plastic materials and, although these materials may be intended for indoor use, they are likely to be exposed to the elements during transport and storage. Pipelines and tanks will absorb radiation and should be treated with reflective paint. The clear skies may cause temperatures to rise to over 50 °C dry-bulb during the day, with surface temperatures rising to 60–70 °C through solar radiation, but can fall to −10 °C dry-bulb during the night.
- Coastal areas and offshore islands, have a highly saline atmosphere often accompanied by high salt content in the ground. Often the ground water level is only just below the surface and varies with the tide, although the coast may be several kilometres away. The high humidity, saline atmosphere and effects of sandstorms and fine dust will attack exposed surfaces and damage the internal parts of motors, fans and, in particular, control equipment if it is not suitably protected.
- Buried tanks or pipelines should be suitably protected against the corrosive effects of the ground, which may contain high levels of suspended solids and chloride as heavy metals and faecal matter.
- In certain areas, sandstorms can occur at frequent intervals. In these and other areas sudden storms can cause flash flooding. Tall structures, such as chimneys, should be designed for the wind loadings likely to be encountered in practice and consideration given to providing lightning protection.
- If the areas also coincide with earthquake zones, and ground tremors of magnitudes up to very severe are relatively commonplace, the overall resilience necessary for the system should be confirmed during the design phase. Essential services equipment should comply with structural requirements, which may necessitate earthquake provision. This means they may require allowance for excessive movements (e.g. by means of articulated bellows and joints).

The construction techniques for buildings are quite well understood and usually fall into one of two main types.

1. Lightweight structure for minimum collapse damage with easy clearance of site and re-erection.
2. Massive structure to withstand any reasonable or foreseeable shock levels.

Although many of the problems outlined above can be overcome by taking precautions on site, this cannot always be relied upon and the designer may have to preclude the use of certain materials to avoid serious problems of material and component failure prior to installation.

4.1.3 Location and accessibility

If equipment, either complete or for assembly, has to be transported to its final location, each item should be unambiguously labelled before it is shipped. Items requiring assembly on site should have their component parts labelled or numbered so that assembly can be carried out with minimal delay. Explicit drawings, such as exploded views, should be available and should provide positive identification of components. The use of factory acceptance tests for larger items of equipment should be considered at high ambient temperatures.

It should be remembered that during transportation, articles may be left in the sun, roughly handled and generally treated in a casual way. During storage, materials are likely to be exposed to the elements so any precautions that need to be taken should be arranged. Many items of equipment may have to be inspected and turned over by hand at regular intervals. Control devices, electric motors and starters, control panels and instrumentation are likely to require special consideration. It may be necessary to provide air conditioned site storage for certain items of equipment.

Maintenance and the availability of spares must also be considered at an early stage. Some buildings are associated with industrial sites that have engineering resources available to maintain and repair equipment, but others are not. Some areas have local stockists and agents who can be relied upon to provide replacements, while others do not. The designer must consider these points and decide whether or not the design can rely on the ability of local maintenance staff using readily replaceable spare parts carried by the building owner, local stockists or replacements from overseas. An effective system of maintenance procedures must be established. Comprehensive maintenance manuals must be left with responsible personnel and be written in the language used locally as well as in English. Effective testing procedures must be established, involving regular test running of plant and equipment. The results of these tests must be properly recorded.

In every instance, a careful check must be made on the availability, quality, reliability, capacity and supply conditions of utility services before starting a design. This can only be done by direct reference to those concerned with the design, installation and operation of the utilities. It is important to discuss the requirements of projects with those responsible locally. This would include gaining an understanding of normal provisions for resilience and redundancy.

The client may consider the relative advantages and disadvantages of several different options for system performance and characteristics in considerable detail before deciding on the type of system best suited to a particular project.

4.1.4 Protection from extreme external conditions

Outdoor building services equipment must be dust proof to prevent premature failure of switchgear, control gear and machines. ANSI/IEC 60529-2004 *Degrees of Protection Provided by Enclosures* (IP Code) (National Electrical Manufacturers Association, 2004) outlines the sealing effectiveness of enclosures of electrical equipment. Using this classification system, external control panels and switchboards should be rated between IP53 and IP64. Where control panels must be located outside, the designer should consider local shading to provide some protection of the electrical components. Where humidity is an issue, anti-condensation precautions should be undertaken to ensure continuous operation of electrical distribution and control systems.

4.1.4.1 Sunlight

Where building services equipment will be exposed to direct sunlight, the choice of material for constructing the equipment enclosures is paramount.

Enclosures should protect the equipment and the material will determine the quality and durability of the installation. UV radiation is a great concern in arid regions and the equipment degradation may vary on the basis of temperature, exposure and prevailing humidity. As thermoplastics and thermosetting chemical compounds are more susceptible to UV degradation, it is advisable to offer composite material or suitably treated metallic solutions for high exposure applications. Sun screens are also advisable for equipment that will be exposed for a long duration.

4.1.4.2 Protection from sand and dust

In areas where high winds and sandstorms can cause sand drifting, protection walls or screens can be erected around equipment located outdoors, provided such structures do not impede airflows to condensers and other components requiring ventilation. Any surrounding structure must be designed to withstand the high wind speeds (45 m/s) that may be encountered.

Very fine sand and dust causes particular problems and will rapidly foul the coils of air-cooled condensers, reducing the operating efficiency, particularly when there are low fresh air intake velocities and local settlement plenums. Regular use of a high-pressure air hose or pressurised water spray unit will contain this problem. External fin spacing on coils should be selected to prevent sand and dust obstructing the spaces between fins. Adiabatic spray mesh helps to reduce fouling on chillers and saves energy by reducing dry-bulb temperature

Adequate access to ponds and tanks of evaporative condensers and cooling towers must be provided to allow regular cleaning. The free area of water filter on pump suction lines should be selected to avoid premature blocking. Centrifugal sand filters should be considered for the continuous and automatic removal of sand from cooling water systems.

4.1.4.3 Corrosion/oxidation

Corrosion levels increase with dust and moisture content in the atmosphere and at times when humidity levels are high. Dust and moisture are the primary threats in arid climates. Dust particles can form deposits on surfaces with moisture content and give rise to chemical reactions. A thin layer of moisture will form on equipment surfaces, which will constitute an electrolyte. If the arid region is coastal, the atmosphere will be saline saturated, which will lead to oxidation and hence corrosion. In some cases, cathodic protection can be applied, however any metallic equipment exposed should be properly treated to withstand the corrosive nature of the atmosphere. Suitable space heating should be provided to prevent any excessive condensation in electrical switchgear and equipment to prevent flash-over threats.

4.1.5 Factory acceptance tests

Factory acceptance tests (FATs) aim to ensure the requirements for the specification are met, particularly for custom fabricated units. This is particularly important when there are potentially onerous conditions such as an arid environment.

FATs are advisable, as they allow the stakeholders with the highest level of interest in the outcome to witness the tests. By witnessing the verification testing of critical performance parameters, the designer, client and contractor can feel confident that the special performance features that were purchased have been provided. The manufacturer will also have a vested interest in this test approach because it allows them to document that the unit met the project specifications and limits their liability for defects that may show up in the field due to improper shipping, handling or installation. The factory often provides a better test setting than the construction site, since special instrumentation is readily available.

FATs also ensure that design, operation and maintenance features can be verified prior to the unit's shipment and corrections can be made at the factory. Even with a detailed specification and submittal review process, misinterpretations can occur. Occasionally a special feature does not work as anticipated. Detecting these problems in the factory allows them to be corrected in a controlled environment by people intimately familiar with the required fabrication processes. Most equipment manufacturers will have a vested interest in this approach because they avoid the costs associated with sending a skilled technicians and engineers out to the field to correct a deficiency not caught by their own quality control process.

People attending a FAT will vary according to how the responsibilities of the contract are allocated, but they may include a client's representative, a design engineer (or their representative), the commissioning services provider and the sub-contractor.

4.2 Utility services

It should not be presumed that there are public utility services available in the same way as in the UK, in which case either standalone or renewable sources will need to be used. In some developing areas, the conditions of utility services are also changing rapidly; early engagement is recommended. Conditions that apply at the start of a design process can alter dramatically during the design and construction of a project. The designer must, therefore, frequently check and re-check information that has been provided during the whole design and construction period. It is advisable to ensure that the information on which the design is based is unambiguously recorded and agreed by all parties concerned

4.2.1 Public utility services

The design engineer should be cognisant of the public utility services providers' requirements for the design and construction phase of projects. Each utility provider has its own processes and procedures. Successful liaison with utility providers and authorities having jurisdiction (AHJ) is a key attribute for any project. In light of this, the design engineer may consider employing a 'local' consultant to assist in authority liaison. Particular issues to consider are:

- enforcing codes e.g. what codes, standards and specifications are used
- procedures for applying for services including meters and civil engineering works
- availability of services
- reliability of services
- supply parameters e.g. voltage and frequency for electricity, pressure and flow rate for water
- tolerances of local supplies.

4.2.2 Standalone systems

In some areas, it may not be possible or prudent to connect to public utility services, and standalone systems will be used. The main utility services are now considered.

4.2.2.1 Electrical

Refer to CIBSE Guide K (CIBSE, 2005c) for details of designing systems that use generators as the prime power. In particular, the building services engineer should ensure that the set is designed for continuous operations at the particular external conditions.

4.2.2.2 Water supply

With endless deserts, arid climate and salty seas, natural water supply is as rare as rainfall. The thickness of the sand layers in the arid areas inhibits groundwater recharge and can decrease underground water levels to a point that they are only accessible through boreholes or hand-dug wells. These can be at large depths (100 m is not unusual). The water is sometimes saline due to lack of recharge from rainfall. Water is found nearer the surface in areas of calcrete, silcrete and ferricrete formations. Drilling boreholes involves endless problems of striking blanks or saline sources.

Alternatively, desalination could be considered, which could enable the use of saline water resources. Desalination is a water treatment process that separates salts from saline water to produce potable water. The desalination process uses large amounts of energy to produce pure water from a saltwater source. Saltwater is fed into the process, and the result is an output stream of pure water and another stream of water with high salt concentration.

Desalination techniques are mainly classified into two types.

1. Processes based on physical change in the state of the water.
2. Processes using a membrane that employ the concept of filtration.

4.2.3 District systems

A district cooling system distributes thermal energy from a central source to residential, commercial and/or industrial consumers for use in space cooling. The energy is distributed by chilled water lines. Thus, energy comes from a distribution medium rather than being generated on site at each facility. District cooling systems are capitally expensive and are therefore best used in arid climates where the thermal load density is high and the annual load factor is high.

District cooling systems consist of three primary components.

1. Main district cooling plant.
2. Distribution piping network (reticulation).
3. Consumer system.

District cooling is typically provided for large developments, particularly in the Middle East, North America and other arid climates as part of the main infrastructure. District cooling enables cooling plant to be centralised in one or a number of energy centres depending on the cooling capacity required. The advantage of using district cooling is primarily the efficient use of water-cooled chillers with cooling towers in one location providing economic and environmental benefits where the plant is easily and readily maintained. In large mega projects where a number of towers may be part of the overall plan, finding space for the number of air-cooled chillers required to overcome the cooling load is often difficult. Providing on-site, water-cooled chillers uses valuable floor space and maintenance of the associated cooling towers is not always undertaken in accordance with industry best practice requirements.

Locating central chillers in a district cooling energy centre is therefore advantageous and offers added benefits such as the ability to introduce energy storage systems to improve the plant efficiency. They can also take advantage of diversity between differently performing buildings. Site-wide condensate recovery systems should also be considered, as water for cooling tower make-up can be expensive and scarce in the more extreme arid environments. Greywater recovery may also be considered.

The initial capital investment for a district cooling system is usually the major economic driving force. District cooling is typically provided by the district cooling provider, although some medium-scale sites do utilise the district cooling concept by providing their own centralised plant to a number of buildings. District cooling providers tend to be independent private companies that build the plant and infrastructure at their own cost and then recover this outlay by charging each plot on the development a chilled water connection charge, an annual capacity charge and a monthly usage charge.

4.2.3.1 District cooling energy centre and reticulation

This section does not attempt to inform the designer how to design and size district cooling plant as this is normally undertaken by the specialist provider, but to provide an overview of how such plant may be arranged, sized and integrated into a building where district cooling is the primary cooling source. The district cooling energy centre generally comprises the main water-cooled chillers and pump room at ground level and the tank rooms at either ground level or below ground. The cooling towers are located directly above, open to atmosphere. The substation element is often provided as part of the energy centre building or it can be located adjacent. The design life for the plant and equipment should be a minimum of 25 years, which can be difficult to achieve in the more harsh arid climates.

District cooling chiller plant is usually of the water-cooled centrifugal type, located in series. Each chiller should be provided with a minimum of two compressors. For each chiller, there will be an associated cooling tower, condenser water pump and primary pump, piped in an arrangement to ensure the necessary level of resilience. The number of secondary pumps should consider system resilience, turndown, capacity and rating to optimise performance.

The use of constant flow systems should be limited to relatively small central chilled water plants. Variable speed pumping saves energy and should be considered for distribution system pumping.

In arid climates in particular, thermal storage should be considered to reduce chiller requirements and lower operating costs. By moving part of the cooling load, chillers can be sized closer to the average load than the peak load. Both ice and chilled water storage should be considered, although chilled water storage requires four to six times the volume of ice storage for the same capacity.

A typical district cooling energy centre layout is shown in Figures 35 and 36.

Sizing of the district cooling plant typically involves calculating the cooling load for each plot on the development and then calculating the overall diversified load based on the development mix and usage. A rule of thumb diversified cooling load is typically 70% of the total cooling for each plot. The

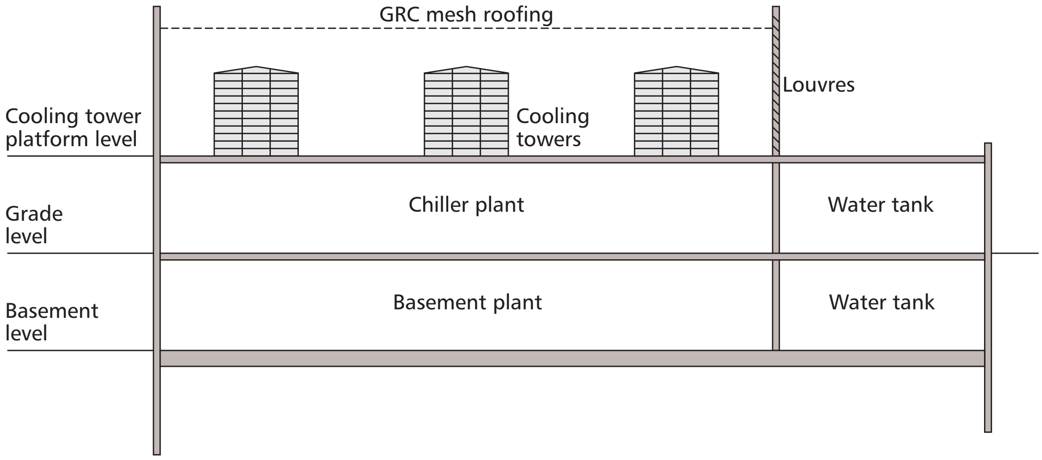


Figure 35: Example plan of central plant building

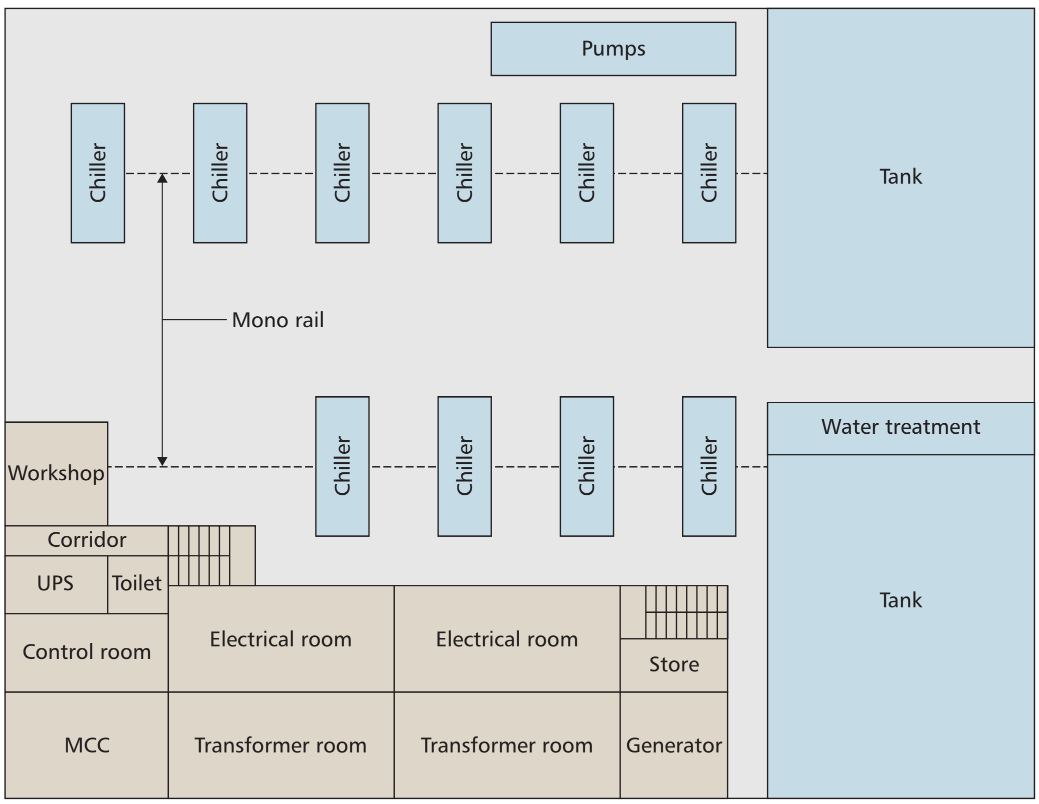


Figure 36: Example section of central plant building

designer of the district cooling plant is responsible for creating, updating and maintaining an up-to-date load schedule similar to that presented for the areas to be served by this plant. A design load analysis should be provided at part load and full load conditions with detailed predicted monthly profiles.

How a district cooling system operates at design conditions is not always a good indicator of its overall annual performance, particularly in a seasonal arid climate. Controls, logic and design conditions can be used to optimise chiller, cooling-tower and condenser-pump system performance throughout the year. Optimising the chiller-tower condenser-pump system can be managed in two steps. First, optimise the design conditions while taking into account the local design weather data and project specific details. Second, optimise the control logic to take full advantage of the capital equipment in the chiller plant. Changing from very basic to advanced controls can make a 5–8% improvement in performance without changing the capital equipment.

From the district cooling energy centre, the reticulation network is typically distributed around the development in a ring main arrangement with sectional isolation valves to prevent downtime in the event of a mains failure. Sectional isolation valves are normally located between each plot. The maximum water velocity in any part of the system (including plant) should be precisely selected ensuring the best and the most efficient parameters. The calculation is typically prepared based on 90% of the diversified peak cooling load at 3 m/s. All piping reticulation sizing should be undertaken using a dynamic software for district distribution. The maximum pressure loss in the system should be selected to suit the chilled water flow performance.

All piping should also be stress analysed for the worse-case scenario for thermal expansion and contraction for every district cooling network. It is recommended that stress analysis is undertaken by an approved independent third party consultant. A thermal degradation study should also be undertaken by an approved specialist for the buried reticulation.

The buried chilled water supply and return piping system can be a number of materials, provided the system assures long life and zero maintenance. Often, pre-insulated steel pipe with polyurethane insulation and High Density Polyethele (HDPE) jacketing is provided. All district cooling pipelines should be installed with a minimum 1 m ground cover. The reticulation network should be coordinated with all other civil and infrastructure work.

Each plot should be provided with a building valve chamber (BVC) at the boundary that is the point of chilled water connection for the consumer. The BVC within the allocated district cooling corridor typically comprises a flushing loop, complete with all valves and fittings inside the chamber.

Large developments should consider a condensate recovery network from each plot back to the energy centre for the energy centre cooling-tower water make-up.

4.2.3.2 Energy transfer stations

The primary side of the district cooling system includes everything up to the plate heat exchangers located within the energy transfer station (ETS) room. The secondary side of the chilled water system includes everything after the plate heat exchangers, and this is the consumer side of the system.

The ETS is a room where the chilled water plate exchangers are located. The plate exchangers provide the hydraulic separation between the primary district cooling plant and reticulation and the consumer's secondary side of the system. It is important that this hydraulic separation is provided for distinct demarcation between primary and secondary and also to prevent leaks from individual buildings impacting on the chilled water network for an entire development.

Typical ETS room requirements are as follows.

- There should only be one ETS room per building and one chilled water connection per building.
- The ETS room should be located on the building perimeter for ease of access and maintenance. For tower projects with basements this is typically at basement level −1 to enable the chilled water pipelines to enter directly into the ETS room.
- The ETS room and the customer side (secondary) pump room should generally be located in separate rooms as the district cooling provider will require access to the heat exchangers and control panel located in the ETS room.
- There should be a minimum of 900 mm clear space on the back side of the plate heat exchanger and 600 mm clear space above. The space at the front should be sufficient for safe withdrawal and removal of each heat exchanger. Each heat exchanger should be commonly delivered in a single package vertically handled.
- The exchanger frame should be oversized to accommodate 15% of the specified demand for future expansion.
- All heat exchangers should be selected for a maximum 1.0 °C approach temperature (temperature difference between the leaving process fluid and the entering service fluid).
- Concrete plinths are required for each heat exchanger, typically 300 mm high.
- The energy meter requires up to 16 times the pipeline diameter as a straight section of pipe with no fittings.
- Drainage provision should be provided.
- Basement ETS rooms will require puddle flanges for pipelines entering/exiting the room.

A typical ETS room schematic layout is shown in Figure 37.

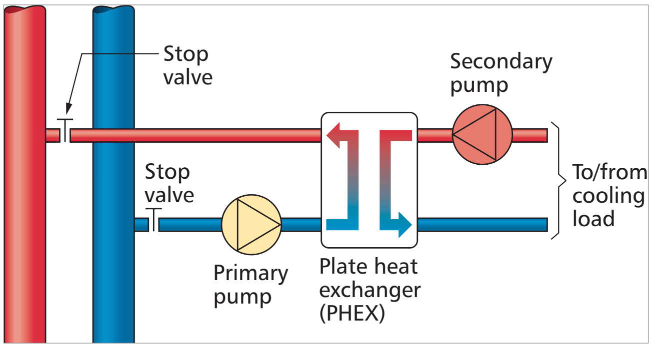


Figure 37: Heat exchanger schematic diagram

4.2.3.3 Demarcation between district cooling provider and consumer

For the building designer, it is important to establish at the outset what works will be undertaken by the district cooling provider and what works will be undertaken by the designer. The district cooling provider often prepares a set of demarcation guidelines that detail the works to be undertaken by both parties. Table 19 is not exhaustive, will differ from region to region and is provided as guidance only

The building chilled water design, including cooling load calculations, should be submitted to the district cooling provider for review and authorisation. Approval is typically required before the chilled water works can be commenced on site. In the Middle East, for example, a NOC (No Objection Certificate) is required before commencement of works.

4.2.3.4 Design considerations

District cooling is unlike standard air-cooled chilled water systems and there are certain differences that the designer must be aware of. The chilled water temperature differential for a conventional system ranges from 5 °C to 7 °C (6–7 °C flow, 12–13 °C return). Due to the cost of distribution system piping, district cooling systems are usually operated at lower supply water temperatures to allow a larger temperature differential to be achieved. This reduces the chilled water flow per kilowatt of delivered capacity. An economic evaluation of piping and pumping costs versus chiller power requirements can establish the most suitable supply water temperature.

Typical district cooling chilled water temperatures are distinctly different to standard chilled water systems and generally operate on a 9 °C temperature differential. Typical supply (flow) and return chilled water temperatures on the primary side are 4.5 °C supply and 13.5 °C return to and from the heat exchangers. The lower practical limit for chilled water supply temperatures is 4 °C. The customer side of the plate heat exchangers shall typically allow for a 1 °C increase in the chilled water flow and return temperatures to 5.5 °C flow and 14.5 °C return. It is important that all consumer (secondary) side pumps, pipelines, coils and fan coil units are designed, sized and selected based on the district cooling flow and return temperatures. The designer must seek confirmation of these temperatures at the outset of the design.

The consumer side secondary chilled water system should be variable flow, with two-port control valves used predominantly throughout the secondary side of the system. All two-port valves should be selected to have proper close-off ratings and a design pressure drop of at least 20% of the maximum design pressure drop for controllability. For high-rise projects, the use of differential pressure control valves should also be considered.

It is important, particularly for high-rise projects, to check the pressure rating of the entirety of the secondary side system, including heat exchangers.

The chilled water connection charge and the monthly charge for cooling are generally expensive in arid climates. It is therefore important that the designer accurately calculates the building cooling load and does not over-design the chilled water system. Safety margins should be removed from the contracted cooling load otherwise the building owner will pay for it. District cooling providers must meet the contracted load. Safety margins can be added to air handling units (AHUs) etc for future degradation but should not be carried over the PHEXs.

Such careful and accurate design, using dynamic thermal modelling for example, can provide the client with significant cost savings. Some district cooling providers also charge individual consumers if they repeatedly return low chilled water return temperatures back to the network.

4.3 HVAC

4.3.1 General

Designing HVAC systems in arid climates poses many challenges for the designer, particularly if there are large differentials between summer and winter conditions.

Table 19: Typical demarcation of works in a district cooling system

Works by district cooling provider	Works by consumer
Installation of the heat exchanger and all valves, fittings etc on the primary side of the heat exchanger, and the temperature transmitter on the secondary side.	Chilled water pipelines and ducts for controls wiring from the building valve chamber (BVC) and into the energy transfer station (ETS) room. Primary side works within the ETS room are generally by the district cooling provider.
Design, supply and installation of the plate type heat exchanger (PHEX) in the ETS room. A minimum of two heat exchangers should be provided although the capacity and redundancy does differ. A minimum of two PHEXs at 50% of the rated cooling load should be provided to ensure a degree of redundancy is ensured.	Design, supply and installation of the complete secondary side chilled water system.
Procurement and laying of control cables and wiring from BVC to ETS.	Provision in the ETS room for monitoring the consumer chilled water secondary side pumps only.
Supply and installation of all necessary controls, control wiring and interfaces within the ETS required for monitoring of the building chilled water system on the secondary side and control of the primary district cooling return water temperature. This will include all sensors, instruments and control panels etc.	Secondary side chilled water distribution control.
Supply and installation of all primary side flow control valves, isolating valves, strainers and all electromechanical items relating to the energy meter including energy meter on the primary side.	

In arid climates where high summertime dry- and wet-bulb temperatures are prevalent, the challenges are further compounded, and the designer should consider:

- treatment of fresh air at source with the use of fresh air, air handling plant. Terminal units, such as fan coil units, may not be able to cool the fresh air load independently if it is not treated at source due to the high latent component
- pressurisation of buildings to offset infiltration
- the use of energy recovery to minimise the amount of cooling required for the building fresh air system (in certain arid climates, such as the Middle East, the fresh air load can add an additional 50% to the building cooling load)
- software to be used for cooling load calculations
- production of system psychrometrics to establish system operation at each key condition
- the use of reheat and/or humidification after dehumidification to provide supply air temperature control for certain applications
- type of terminal cooling or building system to be used to overcome the building cooling loads.

In arid climates with high summertime wet-bulb conditions, and therefore a large portion of latent cooling, the treatment of fresh air at source is an important design consideration. Fresh air, air handling units (FA-AHUs) are recommended to supply the outdoor air to the building cooling systems. Cooling coils can be of the direct expansion (DX) refrigerant type or the chilled water type, although they can have stages and need a reasonably constant airflow and may not be suitable for a demand control application. Control of the off-coil condition should be considered, particularly with the use of DX systems. The number of DX units and stages should therefore form part of the design process discussions. A second cooling coil should be considered when coil sizes exceed 250 kW to improve controllability.

The fresh air rate should be provided on an occupancy basis (litres per second per person) to meet local standards and requirements or to provide a minimum of one air change per hour, whichever is the greater. In arid climates with high summertime dry- and wet-bulb conditions, it is recommended that buildings, wherever possible, be pressurised to offset infiltration. Such a design approach reduces the building cooling load in arid climates, particularly in large volume spaces. Consideration can then be given to discounting the infiltration rate in the building coaling load calculations. Typically, the pressurisation system should provide a minimum of 120% of the extract rate.

Where there is a large latent cooling component, the fresh air cooling load can be high. Recirculation extract systems should therefore be considered where possible to reduce the system cooling load. Energy recovery techniques, such as thermal wheels, heat pipes or plate heat exchangers can then be used and are recommended wherever possible. If cross contamination of air streams is not an issue, thermal wheels are particularly advantageous due to their high efficiencies and are particularly popular in arid regions such as the Middle East. Where cross contamination might be an issue, a thermal wheel with purge facility can be considered. In more critical applications, plate heat exchangers may be more appropriate.

The use of recognised and approved software differs from region to region. In some Middle Eastern countries for example, dynamic thermal modelling software may not be recognised by the local authority with jurisdiction and more steady-state type calculations must be utilised. Notwithstanding, the designer should still consider the use of dynamic software for calculating the building cooling load and steady-state calculations for calculating individual room loads. This helps to ensure the building central plant is not oversized and the correct diversities are applied.

Production of system psychrometrics is an important part of the design process, particularly in arid climates where the external design conditions may differ substantially between summer and winter months. High external ambient conditions can also complicate the psychrometric process e.g. 50 °C dry-bulb, 50% RH, which is not identified on a standard psychrometric chart. Not only will a psychrometric analysis enable accurate sizing of the plant and components, but it will also allow the correct unit selection and configuration to be identified.

Heating in arid areas is generally confined to certain geographical/climatic areas – often in mountainous regions. It may also be required where the project requires close environmental tolerance such as data centres or museums. Depending on the regional infrastructure, utilities and availability of resources, the heating medium will invariably vary from all electric, to liquefied petroleum gas (LPG) boiler plant to natural gas or diesel oil boiler plant. The designer should research the region and select the most efficient and appropriate system.

For specific applications, the utilisation of reheat should be considered at both, or either, the central fresh air plant and the building cooling system. The use of reheat is an important consideration after dehumidification to ensure a controlled supply air condition and therefore room temperature and humidity level. In some arid regions with low wintertime conditions, reheat via the HVAC system may provide sufficient space heating and offset the requirement for a separate building heating system. Reheat is not required for all applications as it is an expensive and energy intensive means of providing control and each region and building must be individually assessed. Reheat may also be provided in process or special applications, e.g. computer rooms or operating theatres.

As with reheat, humidification should also be considered at the central fresh air plant. The use of humidification is particularly important in arid climates where wintertime conditions are particularly dry. Humidification should also be considered in process or special applications, e.g. computer rooms or operating theatres.

The building cooling systems may vary from fan coil units, to variable air volume (VAV) air handling plant to chilled beams or ceilings. DX cooling systems are often used up to 100 kW cooling capacity. Variable refrigerant flow (VRF) systems are becoming popular—they are more efficient than air-cooled chillers and offer the advantage of reverse cycle heating.

Air-cooled central chiller plant is recommended up to loads of 2 MW and water-cooled considered thereafter. Although more efficient, water-cooled chillers can not be considered in some regions due to problems with availability and suitability of the water supply, unless it is for district systems. Closed circuit radiator dry cooled water chillers are also available.

4.3.2 Air distribution

4.3.2.1 Primary air units

One dimension to the location of external air handling plant in hot climates is to try and protect them from solar gains, which would decrease their efficiency. Preferably, units should be placed on the side of the building where it naturally receives less direct sunlight, or adjacent to the shady side of a rooftop structure. If this is not practicable, thought should be given to some form of sun screening such as a canopy. This should allow a suitable combination of light, and reduction in solar gain and solar glare. (Care should be taken to allow enough space for airflow, air intake and exhaust air requirements.)

Air filters are an essential component of every air handling unit. Their primary function is to prevent the clogging of heat exchangers and to minimise staining on walls and ceilings around supply grilles. Different types of filters have evolved, each to suit a particular application. These different applications demand different levels of efficiency, and Eurovent provides a filter grading plan (EU rating) to help classify filters. Arid environments, however, present a unique challenge to the filtration of contaminates.

Because arid countries suffer from high levels of contamination from wind-blown sand, traditional filters alone do not have sufficient dust-holding capacity to be cost effective. Therefore a ‘roughing filter’ in the form of a sand-trap louvre should be used as the first line of defence for all outdoor air inlets, to avoid excessive dust-loading of the conventional filters.

Sand-trap louvres are used in desert-like conditions because they are designed for the removal of sand while allowing airflow into the building; they also perform the function of a traditional weather louvre in preventing the ingress of rain. This type of louvre has a high degree of separation of sand, even at levels of high dust concentration.

This type of louvre consists of vertical channels with no straight path between them; sand is captured from the air and either falls out of the front of the louvre or is dispelled through the self-emptying sand drain holes at its base, making it self-cleaning and maintenance free. The typical efficiency of these units is 80% on 20–200 microns test dust distribution and 50% on 1–70 microns test dust distribution.

The sand-trap louvre is designed to separate particles at low velocity, and is therefore usually sized on a relatively low face velocity of 1 m/s. This has the effect of making them substantially larger than would be the case with a conventional weather louvre, which can sometimes be spatially problematic. Increasing the design face velocity to, say, 1.5 m/s would not decrease the louvre’s efficiency to a level that would make it unviable; however, due consideration of the increased pressure drop needs to be taken into account—at 1 m/s this will be in the order of 30 Pa, but at 1.5 m/s this figure doubles to 60 Pa and may create noise issues.

Intake louvres should be located sufficiently above the roof to minimise the pickup of roof dust and should not be directed towards residential or other quiet areas unless provision is made for baffling or attenuating unit-transmitted noise.

To attain comfort conditions in arid areas that are also humid, such as coastal areas, the primary air unit must lower the humidity in addition to air temperature. If the system fails to reduce the humidity adequately, the air may be cool but will feel uncomfortably damp.

One technology that addresses this humidity problem, and is ideally suited to hot, humid climatic conditions, is the dehumidifying heat pipe, a passive device that enables dehumidification and still efficiently cools the air. Strictly speaking, the heat pipe is an energy transfer device and alters the psychrometrics; it does not generate cooling. It is good for raising the supply air temperature after the cooling coil to avoid a saturated condition.

A heat pipe dehumidification system is a set of two coils, one placed before the cooling coil (pre-cooling) and the other after the cooling coil (reheat); closed tubes filled with refrigerant connect the two. The tubing is tilted so that the liquid refrigerant settles in the pre-cooling coil. As the outside air passes through the heat pipe pre-cooling coil, it is cooled by the liquid refrigerant. The air then passes through the cooling coil and is further cooled past its dew-point, extracting the latent energy through condensation. The air then passes through the heat pipe reheat coil and is heated by the refrigerant to a comfortable supply temperature (see Figure 38).

In the heat pipe, the cold refrigerant in the pre-cooling coil is heated past its boiling point by the outside air and therefore evaporates. The refrigerant vapour rises up to the reheat coil. The cold post-cooling coil air passes through the reheat coil, causing the refrigerant vapour to condense, and the liquid refrigerant flows back to the pre-cooling coil. Heat transfer occurs as a result of the alternating evaporation and condensation of the refrigerant.

Because the heat pipe provides initial air cooling, the cooling coil can drop the post-cooling coil temperature lower than if the pre-cooling were not present. This pre-cooling allows an increased amount of moisture to be removed by condensation because less sensible cooling is required to reach the supply air dew-point, resulting in a lowering of the supply air humidity level. During off-peak conditions, the heat pipe pre-cooling coil decreases the load on the cooling coil necessary to provide a given level of dehumidification, thereby reducing energy consumption.

The effectiveness of a heat pipe increases as the outside air temperature increases.

Since they are activated by temperature difference alone, heat pipes consume no energy. Other benefits of heat pipes include: no moving parts; totally passive; virtually maintenance free; environmentally safe; improve air quality and comfort level.

4.3.2.2 Ductwork

The designer sholud ensure the ductwork manufacturing company selected has sufficient expertise, organisational ability, drawing office production capacity and site erection capability, as this is not always the case in certain arid regions.

In determining ductwork specifications, particularly the types of joints and seams to obtain air tightness, consideration must be given to the experience of the erection operatives. If ductwork has to be manufactured abroad and shipped to site, it is desirable to minimise shipping costs, either by having it designed and manufactured in the sizes suitable for stacking one piece inside another, or by arranging for it to be shipped in a ‘knocked-down’ form. Where the weight of sheet metal to be used for ductwork is around 40 tonnes or more, it may be economic to establish a site fabrication workshop.

Generally, the guidance in Table 20 applies to ductwork in arid regions.

All fresh air and supply ductwork should be thermally insulated, as should return air systems. Supply air grille and diffuser plenum boxes should also be thermally insulated to help minimise the risk of condensation.

Caution should be exercised in the use of plastic materials. Insulating materials must be resistant to surrounding air at high temperatures, often with high moisture content. Where duct surfaces are below the dew-point temperature of the surrounding air, the use of an efficient vapour barrier is essential.

The following checklist identifies some general points concerning the use of air cleaners for applications in an arid region.

Figure 38: Primary air unit with heat pipe for dehumidification

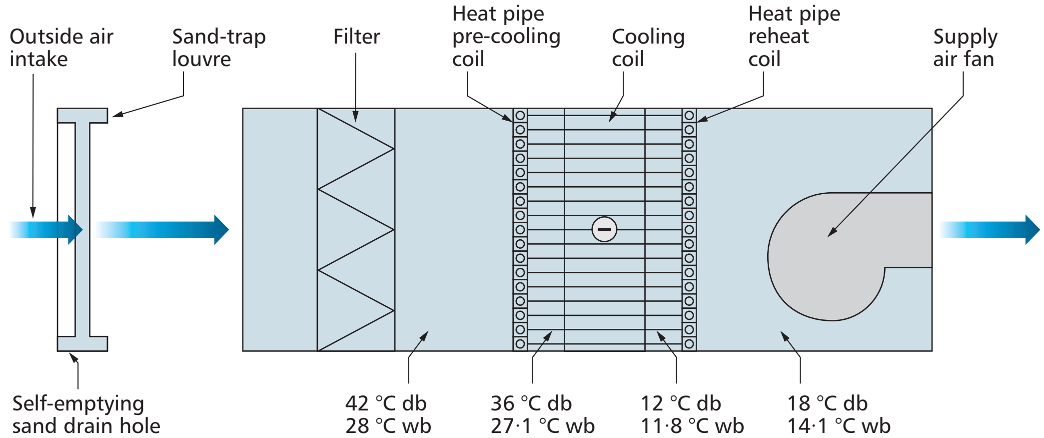


Table 20: Ductwork system pressure classification: over 250 Pa up to 500 Pa

Duct size (mm)	US GA GI sheet/sheet thickness (mm)	Reinforcement (mm)
Up to 700	24/0.50	None required
725 to 900	22/0.70	None required
925 to 1350	22/0.70	32×32×3 centred between flanges
1375 to 1800	20/0.80	38×38×6 at 550 spacing
1825 to 2100	20/0.80	50×50×6 at 550 spacing
2125 and over	18/1.20	38×38×6 centred between flanges with 10 mm diameter tie rods at 1200 maximum spacing along joints and intermediates

1. Ensure that outside air intakes are elevated as high as possible and located away from exhaust air systems.
2. If possible, locate fresh air intakes away from the prevailing wind direction. This is particularly important in arid desert regions to minimise the possibiliy of sand entering the HVAC system.
3. Specify filters with lowest possible requirements for the replacement of consumable media and materials (i.e. use washable filter media if possible).
4. Ensure that fresh air intakes in desert climates are provided with sand-trap louvres. Specify self-cleaning sand-trap louvres to reduce maintenance requirements.
5. Keep face velocity through sand-trap louvres as low as possible.
6. Incorporate dirty filter alarms on all filter media.
7. Select fans capable of operating the plant with filters in a dirty condition.
8. Provide access in ductwork at regular intervals to facilitate cleaning.
9. If possible, close outside fresh air intake dampers when dust storms and sandstorms occur.

4.3.2.3 Mechanical equipment

Equipment selection should account for the conditions under which the equipment will be installed and required to operate. The effects of high temperatures and/or altitude on air density must be taken into account and equipment ratings and duties adjusted accordingly. For example, air-cooled chiller capacities may reduce by as much as 20% in arid regions where the external ambient may reach 50 °C during peak summer months. Adiabatic screens using recycled water can reduce energy by 25%. High ground or roof temperatures may produce a significant increase in dry-bulb temperature at the location of fresh air intakes, while heat gains to ductwork external to the building, or in unconditioned spaces, may be unusually high.

Surface finishes on the inside of air-handling plant, such as heating/cooling coils and fans, should be resistant to salt and any corrosive atmospheric conditions that may prevail. Filter materials should be suitable for the prevailing conditions and consideration should be given to the possible advantages of using cleanable filters in preference to disposable types.

All equipment, such as air-handling units and fan-coil units, particularly if it is to function in humid conditions, should be carefully selected to ensure that construction details are adequate. Particular attention should be paid to the following points.

1. Equipment casings should have an adequate protective coating against corrosion. Note that galvanised sheeting is generally inadequate without an additional protective coating.
2. There should be adequate insulation and rugged vapour sealing to prevent thermal bridging to outside casing.
3. The units should have adequate access panels or doors that can be readily removed without damaging the vapour sealing and insulation when normal maintenance and cleaning is carried out.

4.3.3 Water distribution

4.3.3.1 Piping

Materials used for piping, fittings, valves and pumps often have to be made suitable for handling water that may be contaminated or corrosive. An analysis of the local water should be obtained and specialist advice sought regarding choice of materials and methods of water treatment.

Dezincification problems may be encountered in some areas and copper fittings should be selected accordingly. Flux for soldering and brazing fittings should be carefully selected to eliminate the external corrosion effects in areas with high humidity.

Caution should be exercised in the use of plastic materials. Proper thought must be given to the suitability of plastic pipe jointing solvents, and to other chemical adhesives or bonding materials, in high temperature and/or high moisture content environments.

Insulating materials must be resistant to ambient air at high temperatures and often at high moisture content. Where pipe or water equipment surfaces are below the dew-point temperature of the air, the use of an efficient vapour barrier is essential. Valve bodies, control valve actuators, condensate collection pans, coil return bends, pipe flanges and drain lines generally need to be insulated to avoid condensation problems. External insulation should be able to withstand prolonged periods of solar radiation, and should be insect and vermin proof. The specification for insulation work should take into account the operatives' available to carry out the work.

The specification for pipeline components, such as valves, strainers, piping brackets and expansion bellows, should take into account atmospheric conditions that may lead to external corrosion and operating problems. The recommendations above regarding water treatment also apply.

4.3.3.2 Mechanical equipment

Equipment must be selected with due regard to the conditions under which it will be installed and required to operate; these include the effects of high temperatures and humidity, exposure to dust, sand and intense solar radiation. Heat gain to piping systems located outside the building or in unconditioned spaces may be unusually high and these factors should be taken into account and equipment ratings and duties adjusted accordingly.

4.3.4 Practical tips

4.3.4.1 Ventilation air

Table 11 provides recommendations on minimum ventilation rates, both where the density of occupation is known and for specific types of building and applications.

The cooling load due to introduction of fresh air into the air conditioning system is very closely related to the difference in wet-bulb temperature between the space and outdoor air. In arid environments where the outdoor summer wet-bulb temperature is high, careful selection of space internal design conditions, particularly wet-bulb temperature, and accurate assessment of the minimum acceptable fresh air quantity can significantly affect comfort, system design and refrigerating capacity.

4.3.4.2 Air conditioning load calculations

Design data for determining air conditioning cooling loads and estimating plant capacity are given in CIBSE Guide B (2005b).

In arid locations, care must be taken to calculate solar gains accurately and to assess system gains (i.e. heat from fans and pumps and gains to ductwork and piping systems).

4.3.4.3 Solar radiation

Determination of the air-conditioning cooling load due to solar radiation is essential in arid locations, particularly in desert or semi-desert (arid) areas where the sky is clear and ground reflections may be high.

Since tropical architecture normally makes adequate provision for external structural shading, the solar gain through glazing is often less, in total, than in many metropolitan UK applications. Although glazing may be shaded from direct radiation, the ground reflected component can be very much higher than that found in temperate zones, while the direct solar intensity on a horizontal roof can be 20–25% higher in arid regions, or at altitude, than most standard tabulated values.

Solar gains may be significantly underestimated unless an adequate assessment is made of the necessary corrections for sky clarity, ground reflection or altitude of the building location.

The importance of determining proper values of solar radiation intensities in air conditioning cooling load calculations has been demonstrated. In an arid climate, the total solar intensity can be as much as 36% greater on a sunlit east vertical surface, 57% greater on a sunlit south vertical surface and 18% greater on a horizontal surface than that for a humid climate.

4.3.4.4 *System gains*

These comprise additions to the required cooling capacity of the system necessary to offset heat added to the system by fan and pump power, by gains to distribution ductwork and piping located external to the building or outside the conditioned space, and due to duct air leakage. In arid locations, the cumulative effect of these various system gains can be a major item—sometimes as much as 15–20% of the total load. Therefore, a reasonably accurate assessment of their value should be made.

4.3.4.5 *Heat gain due to fans and pumps*

Fans and pumps contribute to the heat loads in air condition systems and have influence on the cooling equipment dimensions. Various graphical methods of determining heat gains to air distribution ducts are available.

4.3.4.6 *Air duct leakage*

Air duct leakage from supply ducts (or into recirculating ducts) can result in a serious loss of heating or cooling effect, wastage of energy and a system that fails to perform as specified.

The design of air conditioning systems for the arid environment should include an assessment of the probable magnitude of duct leakage and its effects on system capacity and performance. Account should be taken of proposed ductwork specification, system layout, quality of ductwork construction and installation supervision, and difficulties associated with job site location.

Generally, leakage is related to static pressure and joint type, and is roughly proportional to the number of joints in the system. A well-designed and installed low pressure duct system should not leak more than about 3% of the total system airflow, but badly designed and installed systems may leak up to 10–20% of the total airflow. Leak tests may be specified in accordance with Ductwork Specification DW/143: *Practical Guide to Ductwork Leakage Testing* (HVCA, 2000).

It should be recognised that air leakage from (or into) a ductwork system affects the latent heat cooling capacity of the system, and hence space humidity control, as well as altering system sensible cooling capacity.

4.3.4.7 *Abnormal air inlet temperatures*

In arid locations, ground or roof surface temperatures may be many degrees above the general ambient dry-bulb temperature due to prolonged exposure to solar radiation. These hot surfaces may produce a significant increase in the air temperature at air intakes or air-cooled condensers. This must be taken into account in design calculations. HVAC equipment ratings and duties should be adjusted accordingly.

4.4 Refrigeration

4.4.1 General

The majority of refrigeration plants installed in the Middle East operate in a harsh environment where routine maintenance is frequently forgotten, and there are few skilled refrigeration engineers.

High ambient temperature and humidity, and the effects of sand and dust, should all be carefully considered when designing a system and selecting equipment. ASHRAE Handbook: *Refrigeration* (ASHRAE, 2010) also describes the fundamental requirements for the accepted design of refrigeration systems.

Care should be taken when locating air-cooled condensers to ensure adequate clearance around each unit to ensure air will circulate properly.

4.4.2 Safety

There is a renewed interest in using ammonia refrigerants (R-717) as an alternative to traditional refrigerant systems. However, ammonia is considered a high health hazard because it is corrosive to the skin, eyes and respiratory systems. This results in ammonia being subject to a distinct set of health and safety requirements. These requirements may vary depending on the local AHJ.

CO_2 (R-744) is regarded as a 'natural refrigerant'—it is non-flammable and non-toxic. However, as CO_2 refrigeration systems operate at high pressure, there are engineering challenges in both containment and safety. Overall, CO_2 refrigerant systems provide a comparable alternative when considering capital cost, environmental and safety related issues.

4.4.3 Maximum working temperature

The maximum working pressure will depend on the highest temperature expected to occur in the plant. The maximum working pressure permissible is the design pressure, which should not be less than the highest set pressure of any safety valve.

This pressure may be affected by solar radiation, ambient dry-bulb and wet-bulb temperatures, presence of non-condensables or condenser fouling etc. The detrimental effects of regular sandstorms must be thoroughly considered in the location, orientation and protection of plant.

Pressure drops in the refrigerant lines reduce the system's efficiency, so it is important to consider all factors when determining maximum working pressure.

4.4.4 Ambient temperatures

The use of solar shields is recommended for all refrigeration plant located outdoors. Overhead canopies designed to provide shading must not obstruct the airflow through condensers or cause short-circuiting of the airflow.

The high daytime dry-bulb temperatures are frequently accompanied by high humidity, so air-cooled and evaporative condensers must be oversized. Condensers and compressors must be selected for the high ambient temperatures experienced in the region.

Liquid receivers should be located in a well-ventilated internal plant room area. If an outdoor location cannot be avoided, the receiver must be provided with solar shading.

Thermal insulation on vessels, pipework and ducting must be of adequate thickness with special attention paid to maintaining a good vapour seal throughout. The high humidity will quickly cause extensive damage to insulation if moisture penetrates a damaged vapour seal. Mechanical protection of insulation through the use of painted metal sheathing is recommended.

Consideration must be given to the effects of continuous operation of electrical components at high ambient temperatures e.g. motors, switchgear contractors, relays, wiring, motor overload trips and fuses. Control panels should be located indoors in well-ventilated areas where possible (see section 4.7).

4.4.5 Water

In certain areas, two qualities of water are available: potable and 'reclaimed'. Depending on the project location, potable water may be expensive and its use is sometimes restricted. Reclaimed or treated water may be considerably cheaper but brackish.

Before considering the use of brackish water for condensers, cooling towers, jacket cooling etc, a full analysis of samples local to the site should be carried out. It is recommended that designers discuss the intended use of treated water within the project with the AHJ.

'Hard' potable water used in evaporative condensers and cooling towers will require a high 'bleed-off' rate to maintain the solids content within acceptable limits. The practice of reducing bleed rates below those recommended in order to save on water costs should be avoided.

Where used with high condensing temperatures, water that is high in solids content will hasten scale formation on tubes and fins. Rapid blocking of spray header jets will also occur.

A suitable water treatment unit may resolve the problem, provided maintenance of the equipment and topping up with chemicals takes place regularly.

Evaporative condensers and cooling towers must be carefully designed and maintained to minimise the risk of Legionnaires' disease. These will form part of a water system and should be considered in the project's *Legionella pneumophila* management plan. Information on *Legionella pneumophila* mitigation strategies can be obtained from reliable sources including:

- *Legionnaires' disease: The control of legionella bacteria in water systems* (HSE, 2013)
- CIBSE TM13: *Minimising the risk of Legionnaires' disease* (CIBSE, 2013).

4.4.6 Condensation

Ductwork, pipework and any vessel containing refrigerated services must be insulated and carefully vapour sealed. Ambient dew-point temperatures are often very high and condensation readily occurs.

Condensate drainage is required for both indoor and outdoor units to remove moisture created through latent cooling. Outdoor units are comparatively easy to deal with: the condensate can often drain onto the roof or discharge over a floor drain. Condensate disposal from indoor comfort cooling units, however, needs a greater design input, particularly in hot climates where the number and disposition in any significantly sized building can produce challenges to draining the condensate from multiple terminal units.

Simplistically, the apparatus for condensate removal is divided into four main elements: the drain tray, the trap, the network of pipework and the point of final discharge.

The drain tray collects condensate from the cooling coil of the unit. It also has a secondary function of catching water from any small leaks from valves and joints. It should be externally insulated to prevent moisture condensing on the outside surface, known as 'sweating'. Usually, the cooling unit manufacturer will offer a drain tray that incorporates the requirements outlined. However, not all provide an extended drain tray to catch any leaks from contractor-fitted control valves, an option well worth the additional investment.

Condensate traps are necessary wherever there is a fan associated with a cooling coil, be it an air handling unit or a simple fan coil. The purpose of the trap is to allow accumulating condensate to drain off while preventing air entering a draw-through unit or escaping from a blow-through unit. The purpose of the trap is to use a column of condensate to prevent air movement into or out of the equipment casing while still allowing the condensate to drain away.

Each unit on a shared system of condensate removal should have its own trap. If they are not independently trapped and one of the units shuts down, the others will blow air into or draw air from the inactive system (depending on whether the units are of the draw-through or blow-through type).

A potential problem in very arid regions during periods when cooling coils are inactive is evaporation of the water in the traps. If this is likely to occur, a liquid seal should be maintained by either continuous drip or intermittent trap priming.

The simplest means to drain the condensation from multiple units in a false ceiling void is by a network of pipes laid to fall to a suitable discharge point. This is a gravity assisted condensate drainage system. At the point where the system discharges its contents, there should be an air break. Where the condensate discharges to a drainage system, it should discharge indirectly to a trapped and vented receptor, such as a tundish, through an air break or gap. The pipework gradient should be 1:50, but this can be difficult to accommodate in larger runs. In these situations a fall of 1:80 would not be unreasonable. A formula for calculating the rate at which condensate is produced can be found in CIBSE TM43: *Fan coil units* (CIBSE, 2008).

In situations where the condensate cannot be drained by gravity into the main condensate network, it may be necessary to use a condensate lifting pump. These normally operate only when water is available to be pumped. This type of system should be discouraged, however: a condensate pumping set is a mechanical device, and mechanical devices are susceptible to failure. If there is no option but to use this method of condensate disposal, consideration should be given to linking it into the building management system to activate an alert to the facilities manager in the event of a pump failure.

Pipework material for condensate drain lines can be either insulated copper or plastic, but these two different materials should not be mixed.

There is a small risk of *Legionella pneumophila* occurring if condensate is not properly removed, therefore the condensate disposal system should be easily cleaned to minimise that risk. Refer to CIBSE TM13 (CIBSE, 2013) for further guidance on minimising the risk of Legionnaires' disease.

Any electrical control panels, or motors mounted outdoors or indoors where there is a possibility of condensation, must be equipped with heaters to prevent condensation occurring inside at night. Variation of temperature in desert areas is very high and surfaces often fall below dew-point temperatures at night, causing heavy condensation. Heaters in panels should be controlled by a thermostat, and heaters in motors should be automatically switched off when the motor is started.

4.4.7 Ambient conditions

High ambient air temperatures in the Middle East dictate almost continuous use of air water or refrigerant cooled plant. The refrigeration plant should operate at design temperatures with the specified output and at a maximum temperature with a reduced output. This will reduce the risk of the plant tripping out on high pressure at extreme temperatures.

4.4.8 Testing

In industrial applications, the refrigeration plant equipment used will be custom built. Therefore, it is wise to test a unit under design conditions before it leaves the manufacturer's works. Failure to do so can cause considerable problems on site and make the diagnosis of malfunction impossible. The system resilience should be tested as part of a complete commissioning plan.

4.5 Heat generation and fuels

4.5.1 Source, type and consistency of fuel

While most oil and gaseous fuels are similar to those used in the UK (LPG and natural gas), there are some differences. Solid fuel and waste product burning (e.g. Bagasse) pose other problems and it is essential that details of the fuel to be used be obtained to enable the correct combustion equipment to be provided.

Details should include: calorific value, density, viscosity characteristics, carbon, hydrogen and sulphur content, grading and acidity

4.5.2 Ambient temperature effects

Oil storage tanks and mains will absorb radiant heat. Gas oil tanks could reach high temperatures. Vents should be fitted with flame traps and the tanks painted with an aluminium or other reflective finish. Similarly, above-ground oil mains should be insulated and painted in reflective paint.

Low night-time ambient temperatures may dictate tank/line heating even for light grades. Such heating must be controlled accurately and shut off before the high daytime temperatures are reached.

With low night-time temperatures, considerable condensation can form inside oil tanks, particularly when the level of oil is low. Ensure that provision is made for draining and removing sludge.

Fans must be selected bearing in mind the elevation of the installation and the ambient temperature variations.

Natural draught from chimneys is a function of the difference in density between the hot gases in the chimney and the equivalent column of cooler ambient air. This must be worked out for each chimney from the following formula:

$$D = (p_a - p_g)\, g \tag{4.1}$$

where:

- D = draught/m chimney (Pa/m)
- p_a = density of ambient air (kg/m^3)
- p_g = density of flue gasses (mean) (kg/m^3)
- g = gravitational acceleration (m/s^2).

4.5.3 Salinity of soil

The installation of fuel storage tanks below ground should follow one of two options. The selected option will influence the location of the tank in relation to the building.

1. Tank installed within a sealed concrete enclosure.
2. Tank installed within a sealed concrete enclosure and filled with clean sharp sand.

Buried tanks and mains must be protected against corrosion by the careful application of external protective coatings, such as bitumen-based paints or similar materials, before back filling with clean, sharp sand.

4.5.4 Water table

The location of the water table will impact on the design of the tank location. The designer must establish the location of the local water table as part of the design process. Where the tank is to be located in close proximity to the water table, the tank must be anchored to adequate concrete structures to avoid flotation.

4.5.5 Make-up water, quality and quantity

The source of water on a project will contribute to determining the water treatment required. Mains water will be of appropriate quality for typical boiler supply. Boiler feed water should be demineralised to avoid scaling.

Brackish or well water will require treatment (ion exchange treatments), such as full demineralisation, to ensure the water is of an appropriate quality. A full analysis of available water and its seasonal and long-term variation must be made before the treatment is selected.

4.5.6 Fuel storage

The overall fuel storage strategy will require approval from the AHJ. Bulk storage of boiler fuel on a project site may necessitate a more onerous fire compartmentation strategy.

Most fuels are delivered by truck, so the location of the fill point will require careful consideration.

4.5.7 Boiler efficiency

When commissioning boilers, a flue gas analysis will provide information relevant for efficiency and environmental performance. When considering boiler efficiency, the analysis will consider carbon (C) and oxygen (O_2). For determining environmental compliance, nitrous-oxide (NOx) and CO_2 should be measured.

4.5.8 Boilerhouse ventilation

This should follow UK requirements, but in areas with extreme temperatures it may be necessary to:

- heat incoming air during the night
- cool the incoming air during the day in order to maintain a workable environment within the boilerhouse of 30 °C max.
- consider spot cooling of equipment such as control panels and motors
- consider a pressurised plant house with high volumes of filtered air to provide cross ventilation.

4.5.9 Windloads on chimneys and tanks

Ensure that chimneys and vertical tanks are designed to withstand the maximum wind force expected. As wind speeds may reach 45 m/s, this will require a structural engineer to confirm the fixing strategy.

4.5.10 Service ducts in floors

In areas with a high water table or areas that are subject to flooding, it is prudent to avoid having services in floor ducts. It may be necessary, therefore to consider the plant room layout, to accommodate such services as fuel systems to equipment, boiler blow down and feed water systems and electrical services, above ground.

4.6 Water and sanitation

4.6.1 General

Although there has been rapid growth and urbanisation in many countries of the Middle East, there will be instances when there is limited infrastructure to service a project. At the start of the project, the designer must establish the infrastructure availability and also capacity.

The availability of materials should be checked—this may depend on the area of operation and the contractor. Soil report/analysis should be carried out to establish ground conditions.

Materials proposed for the system require careful assessment by the designer at the commencement of the project. HDPE piping is used frequently to address the corrosive environment that occurs both in below- and above-ground applications.

Although not a recommended material, uPVC pipework is still used on projects. If uPVC is to be used, it is important to ensure the materials are stored out of direct sunlight to avoid UV attack and are installed in accordance with the manufacturer's recommendations, making due allowance for thermal movement and extreme conditions in the Middle East.

Regardless of the material selected, the amount of expansion in the pipework can vary depending on the time of installation and the air temperature. Adequate cleaning facilities should be provided in the form of access doors, cleaning eyes etc—these should be located above the flood level of the fittings.

Where squat toilets are installed in suspended slabs, consider suitable waterproofing details, and allow for adequate builder's work requirements in the form of a drop floor slab or adequate structural openings to contain the pan.

In all toilet facilities, ensure that spray taps and floor drains are provided and located according to local custom.

4.6.2 Internal sanitation

As part of establishing the project's basis of design, the designer should consider these points.

1. Sewer system configuration: in some countries the sewage systems are designed so that soil water containing excreta is kept separate from wastewater. In this case a two-pipe system is necessary.
2. An appropriate ratio of 'European' to squat toilets should be established. The orientation and location of all toilets must conform to religious practices particular to the area, which should be established by consulting the local religious authorities.

Adequate floor drainage must be provided within toilet and bathroom areas in the form of lift-flap floor outlets. These outlets prevent the entry of insects and vermin into habitable areas and reduce the entry of foul air into the building. Where bidets are installed they should be treated as soil fittings and connected directly to the soil drain or soil pipe and not to a gulley trap. Gullies in public buildings, commercial building and hospitals should be fitted with a gulley primer to maintain a water seal at all times.

4.6.3 Rainwater

Recent rainfall data for the project site should be obtained. As rainfall occurs in short intense periods, it is also important to understand the topographical layout of the site and the potential impact of stormwater run-off from adjoining sites.

The rainwater system should be designed to:

- discharge all rainwater as it falls and thus avoid any possibility of flooding buildings
- assume all roof outlets could be blocked and provide alternative outlets to ensure that the maximum level of water on the roof is not exceeded in a storm to avoid damage to the inside of the building
- ensure there are no traps or offsets within the system where sand could collect
- ensure that there are at least two rainwater outlets for each flat roof.

4.6.4 Drainage of foul and surface water

Although infrastructure is being installed in most areas to provide a connection for foul water and a separate connection for surface water, there may be projects where an alternative drainage strategy is required. The following methods of waste disposal must be considered in consultation with AHJ:

1. septic tank: foul water only
2. aqua-privy: foul drainage only
3. pit latrine: foul drainage only
4. packaged sewage treatment plant: foul water only
5. settlement tank, filter bed and sewage treatment plant: foul water only
6. soak away (check ground permeability): surface water and treated foul water
7. borehole: surface water and treated foul water
8. wadi: surface water only
9. lake: surface water only (surface water run-off may contain nutrients from landscape areas and result in accelerated algae growth)
10. monsoon channel: surface water only
11. French drain: surface water only
12. aeration and evaporation pumps
13. oxidation ditches
14. extended aeration
15. contact stabilisation.

Septic tanks, aqua-privy and pit latrines, or the discharge from them, must not lead into wells or other sources of water. The last four options are particularly suitable for the Middle Eastern climate.

It is important to avoid the use of conventional surface water drainage gullies, as these remain dry for extended periods and become blocked with sand and grit. In specific applications, provision must be made for sand and grit removal in the form of dirt buckets or purpose-made gullies. Petrol/oil separators and run-off attenuation due to hardscaping need to be considered with respect to surface water disposal.

Manhole construction details and local construction practises must be considered. In certain countries, bricks are not available and therefore concrete block construction is required. In this case, sulphate-resistant cement/concrete should be used. In all cases, reference should be made to the structural engineer's specification to ensure concrete works are compatible. As the protection of manholes by cast iron covers is very difficult, it is worth considering the use of sealed drainage systems.

Care should be taken to ensure the gradient is correct to provide continuous and even flow. Settled sewage in pipework can cause septicity, so it is essential to ensure that pipework materials, manholes and sewage treatment plant are capable of withstanding acid attack. Cement and cast iron pipes are particularly prone to this problem.

In certain areas, the discharge of surface water to boreholes is being considered to replenish ground water aquifers. Subject to the AHJ granting permission to discharge surface water into the ground water system, the borehole should be of adequate depth and diameter to allow the water to permeate. A perforated lining should be provided to stabilise the borehole walls, and the annular gap between the lining and the borehole should be filled with large granular material.

To avoid penetration of silt, a silt trap should be provided before entry to the borehole. Corrosive or contaminated affluent must not be allowed into the groundwater system. An adequate seal at the top of the borehole in the form of removable cover should always be provided.

Boreholes or soakaways for surface water disposal should be sited away from buildings. The water should not be able to percolate beneath load bearing surfaces.

Ground permeability and soil reports should be checked carefully. In certain soil types, such as limestone, the soil can be absorbed into suspension, which can cause collapse. If cast iron pipes and fittings are buried below ground, protective wrapping in the form of adhesive tape or welded PVC sheeting should be provided. Ideally, the internal and external surfaces should also be protected with a coating of ethyl vinyl alcohol copolymer.

4.6.5 Water supplies

The water supply for a building or complex can be provided by:

- water authority main
- shallow or deep well
- water tower
- underground or above ground reservoir
- river or water course
- tanker or bowser delivery.

Comparative costs studies may be required.

In most countries, galvanised tubing is not acceptable because of the corrosive nature of the water supplies. Copper or cement-lined ductile iron pipes are normally specified for mains water distribution, provided the water is not too corrosive.

As part of a water minimisation strategy, the use of water meters is recommended. An overall metering strategy should be determined early in the project. Although meters may be connected to the building management system, the meters themselves must be located in accessible locations either at the point of entry to the building or, in the case of split tenancies, on each individual supply. It must be ascertained whether water meters are to be provided by the water authority or by the landlord/tenant; they can also be used for leak detection i.e. if consumption exceeds historical trends.

Where it is necessary to drill a borehole or well, the following items should be considered.

- The local environmental agency should be approached for permission or approval to sink a new well. When approval is obtained, a wells engineer will be required to advise on groundwater aquifer location and potential and, if available, an isosalinity map giving the concentration of total dissolved solids will be needed. Water from a shallow well may be suitable for irrigation, but the analysis should be checked with an irrigation specialist to ensure that the water is suitable for the plants being considered.
- For potable water supplies, a deep well should be considered to reduce treatment costs. A 'pilot-well' should be constructed and a yield test carried out. After an initial pumping period of 24/48 hours, a water sample should be obtained for analysis.
- The well should be suitably sealed with an appropriate (HDPE/uPVC) lining to avoid penetration by contaminated water from a shallow aquifer. At the base of the lining, a

suitable stainless steel or uPVC well screen should be provided, sized to give sufficient flow capacity into the well. The well must have a sealed cover containing the well assembly, which must be located in a suitable position to avoid the well head being submerged by contaminated surface water.

- Borehole pumps should be either well head or submersible types and be linked to low water cut-out probes in the well. The pumps should be compatible with the system controlling the water treatment plant and should be sized to provide adequate duty and meet pressure requirements.
- The salinity levels in wells should be tested and, if necessary, treated at monthly intervals. In some countries, particularly in the Arabian Gulf area, there is evidence of seawater intrusion into well systems. This intrusion can cause serious problems to the efficiency of water treatment plant and pump/well materials.

4.6.6 Water treatment

Water provided from local authorities is regarded as ‘wholesome’ water and should not require further on-site treatment for general purposes. If there is a requirement for water treatment, this can be provided in one of the following ways.

- Reverse osmosis membrane system (spiral wound cartridge tube filter).
- Electro-dialysis membrane system (flat ‘sandwich’ filter).
- Desalination flash evaporation.
- Sand-bed filteration/chlorine dosing.

When considering any of the above, it is recommended that advice be obtained from specialist manufacturers to find the most efficient and economical solution. Due to the fluctuations in water temperature delivered from the mains (20–42 °C), the designer should determine whether cooling of potable water is required.

When calculating supplies to membrane filtration systems, allowance must be made in the calculations for the quantity of reject water and final product water. The total amount of product water is related to the total dissolved solids (TDS) content of the raw water. A considerable quantity of water with a high TDS concentration can be discharged to waste in the form of brine.

The need for pre-treatment should always be checked before connecting a flow line to a membrane filtration plant.

If the quality of the raw water is uncertain, heavy dosing with chlorine should be used followed by sand and activated carbon filters.

4.6.7 Domestic water supplies

The local water authority should be consulted to establish the exact amount of storage required. As a guide, water storage requirements should be based on a minimum of 48-hour supply. This water storage is in addition to the provisions for on-site storage of firewater.

The water storage system must be designed with features to mitigate any outbreak of Legionella pneumophila. Typically these features include:

- pump to circulate water in the tank
- inlet or ‘fill’ valve and outlet valve located on the opposite sides of the tank
- access hatches to allow regular inspection and cleaning of the tank
- water treatment (UV filtration, chlorination).

The internal water supply system should be designed to meet the requirements of the building, layout of the sanitary fittings, the pattern of use and the water supply network. Materials should be specified to suit the type of water available.

During the summer period, the temperature of water supplied by the AHJ may be 25–40 °C. The designer should consult with the project team on the need to mechanically cool this water when ambient temperatures are at their peak.

Any cool water storage systems should be protected from extreme changes in temperature and direct sunlight to avoid deterioration of the system and to avoid increasing the temperature of stored water. The system should be located within a ventilated plant room, if possible.

As the stored water is used both for ablution and consumption, the system should be sealed and filters fitted to overflows, warning pipes and vent pipes to prevent entry of airborne contamination. Where a bowser fill-point is required, this should be in a form of a screwed cap with retention chain fixed to a pipe entry.

The water storage tank must be sectionalised to allow drainage and cleaning.

Where pipework serves bidets, garden watering points and other possible sources of contamination, anti-syphonage (back flow) preventers must be fitted.

Pressurised water systems are used frequently in the Middle East as they avoid the necessity of roof storage and ensure satisfactory operation of showers, however some AHJs insist on roof tanks, so as to provide water in the event of mains electricity failure

When considering water pressurisation systems, complicated installations should be avoided with a simple pumping arrangement used whenever possible. It is best not to rely solely on a low-level pneumatic pressure installation without elevated storage system unless there is a guaranteed electrical supply or a standby generator. If a local pressurisation unit is used, it may be necessary to use water hammer arresters and pressure reducers on lower floors.

4.6.8 Domestic hot water supplies

The internal hot water supply system should be simple in design, avoiding extensive distribution mains and complicated control systems, but arranged to meet the requirements of the buildings and its relationship to the layout of sanitary fittings. Hot water is often supplied from electrically heated water storage vessels located adjacent to the fittings being served. Materials for all components in hot and cold water systems should be carefully selected to suit the type of water available.

The use of solar hot water generation plants for domestic and commercial applications is a common approach. This is now extending into industrial applications.

4.6.9 Irrigation systems

The water supply source for irrigation systems can be:

- brackish water
- fresh water (particularly in public areas)
- river, lake or canal
- partially treated sewage effluent (but this should not be used in public areas due to health risks and possible odour problems)
- sea water (but expert advice should be obtained before making a final decision)
- fully treated/chlorinated sewage effluent (TSE).

The extent of irrigation requirements should be established and the total water requirements calculated allowing for absorption, evaporation and plant requirements. The irrigation system may be:

- manual operation to a fixed system
- half/fully automatic timed sequence control system
- fixed bed bubblers/drip feed system
- pop-up/surface mounted sprinklers to grassed areas
- spray/rain gun irrigation to agricultural areas
- flexible manual hoses fitted to hose unions and taps.

Materials resistant to corrosion should be specified, particularly for pipework buried below ground, and it is recommended that HDPE pipework compatible with standard irrigation equipment be used for this purpose.

4.6.10 Sewage treatment

Where there is no infrastructure near by or planned for a development, it is important to ensure that the requirements of the development are met by the sewage treatment plant provided. The plant may be one of the following types:

- Packaged diffused air sewage plant.
- Septic tank, which should be sized in accordance with the local AHJ requirements. Septic tanks are not recommended unless further treatment is to be carried out.

As noted earlier, the use of treatment plants is limited and therefore will require extensive discussion and approval from AHJ. The designer should consider recycling wastewater from the sewage plant for irrigation or industrial use. The internal reuse of treated water is unlikely to be permitted.

Where the cost of producing water is high, consideration must be given to the efficient use of water and, if recycling is considered, ensure that the treatment equipment is regularly maintained by trained personnel.

4.6.11 Sewage pumping

Pumping plant may be of the following types.

- Submersible sewage pumps.
- Sewage ejectors incorporating compressed air.
- Dry well pump linked to a wet sump.
- Vertical spindle pumps located in surface plant room linked to a wet well installation.

If pumping stations are to be connected to sewage treatment plant, the two systems must be compatible to ensure efficiency of the sewage plant during the discharge of effluent from the sewage pumping station. The wet sump should be sized to meet the requirement of the building, but not oversized as this will create conditions that cause septicity in the sewage leading to deterioration of the pipework, pumps and pump impellers. Stone and grit should be prevented from penetrating the pumping station.

Pump motors should be suitably rated for the temperatures prevailing in the area of the site. Control panels should be suitable for tropical application and incorporate condensation heaters. They must also be suitably sealed to prevent ingress of sand and dust. Sewage pumps must be connected to the standby electrical supply.

Sewage ejectors move sewage using compressed air and therefore avoid the activity problems experienced with centrifugal pumps. Avoidance of septicity is assisted and the small discharge of fresh sewage makes treatment less complicated.

4.7 Control systems

The operability and function of the building services systems is crucial in providing a controlled environment. Continuous improvement of a building's energy performance and energy reduction demand highlights the importance of a reliable control system. The integration of various control systems, such as air conditioning and ventilation, lighting, communications, security systems and others, provides a holistic approach.

The complexity of the control system should be appropriate for the system's functionality. The underlying approach is that the control systems should be kept as simple as possible; effective and reliable control may be achieved with relatively simple control systems.

Although technological advancements have been incorporated into projects, the designer must be aware that the individual components that make up the system may be subject to the harsh local environment. The external location of ambient temperature sensors will require careful consideration to ensure they are not unduly subject to direct sun.

Electrical and pneumatic equipment is susceptible to changes in temperature and humidity, and ingress of fine sand. Care is needed to ensure that the working conditions are specified and also achievable. Plantroom temperatures can rise to levels much higher than the design ambient conditions, and it is essential to check that the equipment specified is suited to such temperatures. It may be necessary to provide spot cooling to areas where control devices or field panels will be located.

For all systems, the quality of installation and commissioning of systems requires close attention and specific instructions for testing and commissioning must be provided. Post-occupancy training for the building management system (BMS) operators is recommended. Conducting audits of the BMS operation, post occupancy is likely to highlight whether further operator training is required.

For more information, refer to CIBSE Guide H: *Building control systems* (CIBSE, 2009).

4.8 Electrical distribution systems

Electrical supplies can fluctuate in frequency and voltage and are sometimes disconnected. Failure of the supply may be complete or only a single phase may fail. For these reasons, several precautions should be taken, including:

- phase failure protection should be provided for all electric motors
- plant should not be allowed to restart immediately on reestablishment of the supply, particularly if shutdown has been for a long duration, since crank case heaters will not have energised and considerable oil loss may occur on compressor start-up.

Standby generators may be considered to maintain life-safety loads and essential services particularly at remote site locations

All electrical components should be sized for continuous operation and starting at reduced supply voltage. It is common for supply voltages to be reduced by up to 20% during periods of peak loading. Imbalance of phases is also a considerable problem. Cables, fuses and miniature circuit breakers and other items, where appropriate, should be de-rated for maximum ambient temperature.

Power factor correction equipment may be advisable, particularly where a local electrical authority imposes financial penalties for low power factor.

4.8.1 Climatic considerations

Extreme care should be enforced during the design and installation stages of projects in these regions to ensure electrical equipment is adequately protected from direct heat to prevent excessive operating temperatures. Where possible, all electrical switchgear incorporating protective and control devices should be housed in protected environments with adequate cooling or venting provisions.

4.8.2 Operating temperature of equipment (cooling of plant rooms/condensation issues)

Operating temperature of all electrical equipment should be specifically detailed in designs to ensure continuous operation. In general, all electrical equipment should be suitable for operation at 50 °C. Any systems incorporating electronic/digital or control facilities should be housed in protected conditioned environment. High temperature prevailing in the region also acts as a catalyst for corrosion.

4.8.3 Earthing (aggressive soil conditions)

Soil conditions are aggressive in many arid regions, so the choice of earth rods should be carefully considered. Soil investigation and ground testing should be conducted before selecting earthing rods. Stainless steel of suitable grade or copper/steel bonded rods may be more suitable for corrosive soil situations. Similarly, insulated cables for distribution systems are preferable to bare conductors. Earth resistance should be regularly tested to ensure that they are within permissible limits.

4.8.4 Cabling considerations (de-rating parameters)

Standards followed in the region generally base ratings for cables installed directly in the ground on values of soil temperature and soil thermal resistivity, which are generally representative of conditions in the UK. Suitable de-rating factors should be taken into account for variation in ground temperatures. This also applies to cables installed in ducts and air.

4.8.5 De-rating of protective devices

Protective devices or circuit breakers are generally designed and calibrated to carry their rated current and to operate within their designated thermal time/current characteristics at 30–40 °C (varies with manufacturers). All test certifications will be based on tests carried out in controlled environments. Hence if a protective device is required to operate in conditions that differ from the test reference conditions, certain de-rating factors have to be applied to the standard published manufacturer's data. Higher temperatures will require progressively less current to trip within the designated time/current characteristics. Hence the design rating (de-rating) of all protective devices should be to suit a minimum temperature of 50 °C.

4.8.6 Plant room considerations

Due consideration should be made for maintaining operable temperatures in all mechanical and electrical plant rooms, which is vital to continuous operation. All substations and electrical rooms should be naturally ventilated as a minimum. As protective devices are predominantly microprocessor based, air conditioning of electrical plant rooms is recommended to maintain operational characteristics of all protective devices, specifically any control elements. Similarly, anti-condensation space heaters should also be allowed for to cater for humidity control. All mission-critical plant rooms should be provided with high temperature alarms connected to a building management system to avoid any service disruptions. Similarly all mechanical plant rooms should be provided with base cooling to ensure continuous operation.

If the possibility of water ingress from adjacent sources exists, motor control centres should be located in separate enclosures. In such cases, sufficient method of isolation of equipment/lock out should be provided for maintenance and safety reasons. Alternatively, motor control centres should be constructed to suitable IP rating to withstand prevailing external conditions.

4.8.7 Loading parameters

It must be noted during the planning stages that the connected load/maximum demand assessment should consider the cooling loads as the predominant loading for the arid regions and any seasonal variants are less distinct. Air conditioning loads will need to allow for any air-cooled or water-cooled chiller units (if the project is on standalone cooling plant), associated pumping systems and the air handling systems. As all these elements are motor-related loads, the maximum demand parameters will not be applicable as the diversities are low. Any applicable de-rating factors imposed by the AHJ should be accounted for.

4.8.8 Pumping systems electrical reliability

Dependency on mass water storage is a common phenomenon in arid climate regions, so reliability of pumping systems is paramount. Designs for such applications should build in sufficient resilience to cater for any unforeseen circumstances. All motors should be suitably de-rated for the correct insulation class and temperatures selected, and all associated cabling and controls should be to suit the application. All pumping systems should incorporate standby equipment to cater for the loads in the event of any failures. The configuration of pumps could be electric + electric or electric + diesel to suit the application.

4.8.9 Lightning protection

Static charges in structures are induced in dry air, adding the need to carry out proper equipotential bonding for structures in those regions. Lightning is also common in arid climates, so protection systems should be used to protect structures. Tall structures can utilise inherent structural reinforcement components for conducting paths. Continuity should be ensured for all conducting parts to facilitate an easy path for discharge to earth. This is best achieved by welding of down conductors, which will negate the effects of corrosion and bad conductivity. Sufficient grounding points should be provided for the lightning protection system to ensure that the minimum requirements required by BS EN 62305-1 (BSI, 2011a) are met. A strict regime for testing protection systems should be engaged, as the earth resistance can vary considerably with seasonal changes in the region. Any special protection measures required for critical equipment/telecommunication/data processing systems should be accounted for in accordance with BS EN 62305-4 (BSI, 2011b).

4.8.10 Batteries

Batteries perform best at moderate rather than extreme temperatures due to the varying rate of chemical reactions. Where batteries are proposed, they should be housed in proper conditioned/ventilated areas suitably de-rated for the expected temperatures and the application proposed. Spill containment should be provided. Batteries serving any critical systems (e.g. generator cranking application) should be constantly under trickle charge and monitored. Float charging across a small non-critical load will give rise to an alarm. When located in remote areas, suitable redundancy should be built in to the charging systems.

4.9 Lighting

4.9.1 Interior lighting

As discussed in section 2.3.2, if the interior environment is being designed to ambient temperatures similar to temperate climates, there are no specific special design issues to consider and the general recommendations of the *SLL Code for Lighting* (SLL, 2012) will apply. However, there may be situations when interior luminaires are used in areas where the internal environment is not controlled in terms of temperature, filtration and humidity control—for example, external stores, loading bays, mechanical and electrical plant rooms—thus, they will have to withstand the peculiarities of the local climate. In these cases the following points should be addressed.

1. Has the fitting been tested for operation in +50 °C ambient?
2. How is the lamp life and initial lumen output affected over time at this temperature?
3. Are the entire internal components/electronics/devices/wiring etc treated at +85 °C storage temperature (i.e. daytime or non-operating)?
4. The lamps must fall within specific colour temperature band and colour rendering

requirements and actual must be values stated (set limits vary and depend on type of product use).

5. The luminaire must be designed to IP6X for dust ingress
6. Heat sinks/thermal dissipation system should be designed to minimise build up of sand and dirt, and operation/efficiency should not be affected by any natural build-up.
7. Alloys should be corrosion resistant with very low-copper content. Finishes should be corrosion. Fixtures must be CE or UL certified.

The *SLL Code for Lighting* (SLL, 2012) recommended illuminance levels should be provided unless there is evidence that other values would be more appropriate. Where a range of illuminance levels is given, the higher illuminance is recommended to reduce the contrast with the high brightness of the exterior; this could be a function of the effectiveness or otherwise of the screening of the windows. On the basis that a bluish colour of light produces an impression of coolness, it is often accepted that sources with a correlated colour temperature of 4000 K or above (e.g. fluorescent or metal halide mercury discharge, and 'daylight', 'tropical daylight' or 'northlight' tubular fluorescent lamps) are preferred in warmer climates. However, in some locations it may be desirable to take advantage of modern high efficiency sodium vapour lamps.

4.9.2 Exterior lighting

External luminaires manufactured and tested according to BS EN 60598-1 (BSI, 2009) will have been designed for an average ambient temperature of 25 °C and luminaires for outdoor applications for an average ambient temperature of 15 °C and hence cannot cope with the summer temperatures of 50 °C with 100% humidity and night temperatures of 40 °C with no drop in humidity. Dust and sandstorms, thick morning fog, heavy condensation day and night and the salt and corrosive acids in the soil that are transferred to the air in storms all need to be managed.

At the significantly higher temperatures experienced in arid environments, depending on the type of luminaire-lamp-ballast system applied, lighting characteristics will deviate from those under standard conditions. Ignition, amount of light available and start/run-up characteristics of lamps might differ significantly and manufacturers' details should be consulted.

4.9.2.1 Lamp enclosures

Lantern bodies should be corrosion resistant and made from aluminium or reinforced plastic material. Totally enclosed lanterns should be particularly well sealed with an IP rating of at least IP 65. Special attention must be paid to gasket material, especially its resistance to tropical climates and insects.

Lamp compartments should be a separate enclosure from the gear compartment, with sealing to prevent insects getting through the bracket arm into the lamp enclosure. It is particularly important to seal the lamp housing.

4.9.2.2 Lighting columns

In high humidity, ventilation may have to be provided to a lighting column with a cable way by means of a breather hole at the base and top, which permits air movement without allowing rain to enter. Such ventilation can be incorporated into the door rather than the column structural section.

In areas of dust or sand storms, special consideration may need to be given to door openings or breather holes.

4.9.3 Emergency lighting

When determining whether to use a self-contained or central source battery, it should be remembered that batteries may be adversely affected by a relatively high ambient temperatures.

4.10 Vertical transportation

Arid climates are known to affect vertical transportation systems, principally lifts and escalators. The need for more intensive maintenance and correct specification of components and passenger comfort should be considered.

Lifts and escalators have many moving components, which can be affected by hot, dry and/or dusty conditions.

Some lift suspension ropes contain an inner core that contains a lubricant to minimise internal wear caused by steel wires rubbing together; this can require rope dressing to be applied regularly if the core is drying out but will inevitably lead to premature wear. The ingress of dust into lift door systems can also cause premature wear on top tracks and rollers as well as causing the bottom tracks to become blocked, preventing doors from closing.

In escalators, drive chains, step chains and step roller handrails are rotating whilst the machine is running, so the ingress of dust into these components containing lubricant would create a paste that would be ground, causing premature wear.

Whilst these matters can be dealt with by increasing the levels of maintenance, they can also be minimised by an initial specification that ensures vulnerable components are protected.

In some cases, lifts and escalators are used more intensely over a short period of time for cultural reasons, such as the annual hajj pilgrimage, and at these times more directed maintenance is required. It is not unknown for these lifts and escalators to be isolated all year round and under 'caretaker' maintenance, so case-specific and intensive maintenance prior to restarting would be required.

At the point of specification, the number, size and speed of lifts and escalators needs to be considered, as the passenger loading in the case of religious gatherings can range from zero to incredibly high, although overprovision can be costly.

The effects of different materials need also to be considered, for example, lacquered brass-effect fittings, such as push buttons, quickly become blackened by their use as a result of salt created on human hands due to perspiration. The obvious issue of metals becoming hot and expanding, as well as being difficult to touch, also need to be considered. Passenger comfort should be maintained in circumstances such as a lift failure. Glass lift cars act like greenhouses and insufficient air changes and/or cooling combined with passenger panic at being entrapped could cause suffering, especially when the entrapment is prolonged, so the ability to rescue people quickly in these circumstances needs to be considered.

4.11 Fire life safety

Fire life safety (FLS) encompasses all the major disciplines including:

- architecture
- structures
- MEP
- civil and infrastructure.

However, in practice FLS is often associated with MEP, as many of the fire protection systems are designed by MEP engineers.

This section only addresses differences between UK/US practice and extreme environments; it is not intended to be a fire engineering guide. See CIBSE Guide E: *Fire safety engineering* (CIBSE, 2010) for detailed design guidance, which looks at the following subjects in detail:

- legislation, standards and strategy
- building designation
- performance-based design principles
- application of risk assessment to fire engineering designs
- fire dynamics
- means of escape and human factors
- fire detection and alarm
- emergency lighting
- fire and smoke ventilation
- fire suppression
- compartmentation
- fire fighting
- fire safety management
- fire safety on construction sites.

4.11.1 Cultural differences

4.11.1.1 Fire risk

Smoking is a major fire risk, and many Middle Eastern countries still allow smoking in public buildings. The majority of fires in hotels, for example, are started by smoker's materials, so sprinklers are important.

Cooking in areas other than kitchens is common.

Traditional Arabic pipes and incense burners require hot charcoal and so represent another source of ignition. The charcoal is slow burning and can be easily left unattended.

Building owners and operators, especially from developing countries, will often have lower standards of fire safety than required or assumed by UK/US codes that are normally used in the region.

Staircases are often misused and it is common to find egress stairs blocked by stored furniture.

Many of the buildings in the Middle East are not inspected on a regular basis or to the required standards, so the on-going maintenance of fire measures is not to the same standard as the UK/US.

4.11.1.2 Regulatory procedures

In the Middle East, the Civil Defence authorities will place much larger responsibility on the consultant to ensure that the design meets code. Obtaining Civil Defence approved and stamped drawings does not necessarily mean that the design meets the applicable code and standards. It is expected and assumed that the consultant will ensure full design compliance with applicable codes.

The consultant should also ensure that fire systems are installed as per design, therefore third party site inspection of fire system installation is crucial during construction. Experience suggests that consultants should not rely on the civil defence authority to inspect buildings to the same standard as in the UK.

4.11.1.3 House of fire expertise

In some Middle Eastern countries, for example Oman Civil Defence will only accept designs from qualified and known fire consultants. As a result, fire consultants are required to be registered with Civil Defence before being allowed to submit designs. Foreign fire consultants will not be allowed to submit designs for approval unless they are registered locally.

4.11.2 Codes and regulations

Middle Eastern states have based their old local codes on UK building regulations. In recent years the majority of countries in the Middle East now follow US codes, including:

- NFPA 101 *Life Safety Code* (LSC) (NFPA, 2012a) and NFPA 5000 (NFPA, 2012b)
- *International Building Code* (IBC) ICC (2012)

For example, in Saudi Arabia, the Saudi Building Code (SBC) is adapted from the International Building Code (IBC).

National Fire Protection Association (NFPA) standards are widely used in the Middle East for design of fire systems including sprinklers and fire detection and alarm systems.

UK standards are sometimes used for design of fire alarm and detection systems but rarely for automatic sprinklers.

The majority of projects in the Middle East are sprinklered. Underground car parks are required to be fully sprinklered, which is a different approach from the UK codes.

The following are the popular standards used in the Middle East.

- NFPA 1 *Fire Code* (NFPA, 2012c)
- NFPA 10 *Standard for Portable Fire Extinguishers* (NFPA, 2013a)
- NFPA 13 *Standard for the Installation of Sprinkler Systems* (NFPA, 2013b)
- NFPA 14 *Standard for the Installation of Standpipes and Hose Systems* (NFPA, 2013c)
- NFPA 20 *Standard for the Installation of Stationary Pumps for Fire Protection* (NFPA, 2013d)
- NFPA 22 *Standard for Water Tanks for Private Fire Protection* (NFPA, 2013e)
- NFPA 24 *Standards for the Installation of Private Fire Service Mains and their Appurtenance* (NFPA, 2013e)
- NFPA 70 *National Electrical Code* (NFPA, 2014)
- NFPA 72 *National Fire Alarm and Signalling Code* (NFPA, 2013f)
- NFPA 88A *Standard for Parking Structures* (NFPA, 2011)
- NFPA 92 *Standard for Smoke Control Systems* (NFPA, 2012d)

4.11.2.1 Certified products

It is important that quality fire products are used for the design of buildings. Products should be certified to internationally recognised bodies such as:

- Universal Laboratories (UL)
- Factory Mutual (FM)
- Loss Prevention Council Bureau (LPCB).

Care should be taken to ensure that products are approved. In the Middle East, fake or counterfeit products are on the market and have been installed in buildings, including:

- sprinklers
- fire dampers
- ductwork.

Clearly, counterfeit products will jeopardise the safety of the public and the consultant should check that installed fire products are certified and listed as per the design.

4.11.2.2 Fire dampers

US codes allow the provision of fire dampers to be relaxed where buildings are sprinklered and metal ducts are provided.

NFPA 5000: *Building Construction and Safety Code* (NFPA (2012b) only requires fire dampers in the following locations as per clause 8.8.8.2.3 of NFPA 5000.

- Ducts and air-transfer openings penetrating walls or partitions having a fire resistance rating of two or more hours.
- Ducts and air transfer openings penetrating vertical shaft walls having a fire resistance rating of one or more hours.
- Ducts and air transfer opening penetrating floors that are required to have a protected opening where the duct also is not protected by a shaft enclosure.
- Air transfer openings that occur in walls or partitions that are required to have a fire resistive rating of 30 minutes or more.

4.11.2.3 Emergency lighting

Emergency lighting will typically follow US codes. The main requirements are as follows.

- Emergency lighting should be provided for at least 90 minutes in the event of failure of normal lighting throughout the exit access (stairs, aisles, corridors and passageways leading to an exit), exits and exit discharge (stairs, ramps, aisles and walkways leading to a public way) and operate within 10 seconds after power disruptions.
- NFPA 5000 11.9.2 requires a minimum average illumination level of 10.8 lux.
- Green running man signage with arrows is commonly used.

4.11.3 Access and facilities for the fire and rescue services

4.11.3.1 Vehicle access

As streets and hydrants are not often in place in the Middle East, fire access roads will need to be provided to the site. The US codes are generally used for design, however local fire vehicles will be of the smaller European type and so relaxation of the US codes may be sought.

4.11.3.2 Fire hydrants and standpipes

Private fire hydrants are often required to supply fire fighting water, as the local town main may not be in place or be reliable.

4.11.3.3 Fire command centre

Where a building is designated as a high rise, a fire command centre is required. The location of the central control station must be approved by the fire department. Central control stations are typically located on the ground floor near an entrance to the building. It is common practice to share the command centre with security rooms.

4.11.3.4 Hosereels

Many jurisdictions require hosereel cabinets to be provided in addition to the minimum requirements given in the US codes.

4.11.3.5 Automatic sprinkler systems

Sprinklers are provided in most buildings in the Middle East and are required for any building over 23 m in height.

Sprinklers are required to be installed in accordance with the NFPA 13 *Standard for the Installation of Sprinkler Systems* (NFPA, 2013b).

4.11.3.6 Other suppression systems

Some Civil Defence authorities will require gaseous systems to be provided for certain risks, including high voltage plant rooms, and may not accept sprinklers in these areas.

Kitchen extract hoods and duct fire suppression in food production kitchens would be required in lieu of sprinklers in cooking areas.

4.11.3.7 Fire alarm and detection systems

Systems are installed, tested and maintained in accordance to NFPA 72 *National Fire Alarm*

Code (NFPA, 2013f). Strobe lights are commonly provided as per NFPA in public areas.

4.11.3.8 Emergency voice alarm

A high-rise structure is required to have an emergency voice alarm (VA) communication system. VA systems will broadcast alert messages in both English and Arabic with an intermediate alert tone.

4.11.3.9 Smoke control design

Due to high external temperatures, natural or buoyancy driven designs are rarely accepted by Civil Defence. Smoke control systems normally comprise powered extract fans with natural make-up air.

Smoke control systems for large spaces, such as indoor arenas, exhibition centres or airport terminal buildings, will typically have a design smoke layer temperature at or below external ambient temperatures. External ambient temperatures can reach 50 °C in summer and are typically 45 °C.

For very tall buildings, reverse stack effect should be considered when designing stair pressurisation systems. Stairwell pressurisation will require control that can vary the flow according to the actual pressure in the stairwell.

4.11.3.10 Cold smoke testing

Cold smoke testing is carried out to demonstrate activation sequence or smoke clearance of public spaces. It is important that the external make-up air temperature is taken into account. Make-up air at 45–55 °C will be introduced into a conditioned space where the cold smoke is at 21 °C. The hot replacement air will rise quickly to a high level where the extract fans are typically placed. The cold smoke will be forced down and away from the smoke extract fans and the system will short-circuit. As a result, the system will not perform as designed. Cool air from the main building should be used for replacement air where possible to mitigate short-circuiting.

4.11.3.11 Parking garages

Parking structures follow NFPA 88A *Standard for Parking Structures* (NFPA, 2011). Enclosed parking structures are ventilated by a mechanical system capable of providing a minimum of 0.3 $m^3/min/m^2$ of floor area per hour during hours of normal operation. Under NFPA codes there is no additional fire mode operation.

The UK code requirement for increasing from 6 air changes to 10 in a fire condition does not apply in US codes.

Ductless smoke extract systems (jet fans) are accepted in some jurisdictions in the Middle East but are not allowed in others; for example, neither Dubai nor Abu Dhabi allow ductless systems.

Underground parking garages are normally fully sprinklered.

4.11.3.12 Smokeproof enclosures (escape stairs)

In high-rise buildings, staircases need to be protected from smoke. The term ‘smoke proof’ is commonly used in US codes and can be achieved by:

- pressurisation
- lobby protection (mechanically ventilated)
- lobby protection (naturally ventilated).

US codes require pressures of only 12.5 Pa for sprinklered buildings as opposed to 50 Pa required by UK codes. Consultants should follow the pressurisation methods in NFPA and not British standards to avoid over-design.

4.11.3.13 Cooled refuge areas

Where areas of refuge are provided in a high-rise building, the inclusion of ‘cooled refuges’ consisting of spot cooling in the pressurised refuge areas by fan coil units maintained on emergency power should be considered. With outside air temperatures potentially reaching 50 °C, this measure is essential to ensure that the refuges remain tenable in the event of power loss to the building.

5 Sustainability

5.1 Introduction

Designing sustainable buildings and neighbourhoods in arid climates is a particular challenge. The shortage of water affects the designer's selection of cooling systems, water-consuming fixtures, such as toilets, taps and showers, and white goods, including washing machines and dishwashers. Choices of landscaping materials and irrigation design need to be made carefully (some of these issues have been explored in previous chapters).

Although this chapter will discuss many aspects of environmental sustainability (including resources, energy and materials), it is important to note that the shortage of water—a common feature in the climates of the Middle East, Arctic regions of Russia and Canada, southwest United States and Australia—has indirect effects on many other aspects of what is termed 'sustainable design'. Nearly every design discipline from architecture to structural engineering is affected by the direct or indirect consequences of water shortage during the design and delivery of buildings in arid climates.

The shortage of water in arid climates means that these areas are usually more sparsely populated than wetter regions of the world, which makes it more difficult to find equipment, expertise and building materials locally, and there is often a lack of available public infrastructure that the development can rely on.

Adding to this challenge is the fact that advances in water resource management and engineering in the past 100 years now enable parts of the world that were previously considered unliveable and barren to be populated, leading to an explosion of population in certain areas such as the Middle East and parts of the US.

This chapter will explore design challenges that are particular to arid climates, addressing topics and issues that have not been covered in previous chapters. It does not aim to provide a comprehensive overview of sustainability in buildings, as there are many excellent publications in print on that subject, rather to address specific issues particular to arid climates.

5.2 Measuring sustainability—benchmarking systems in arid climates

A popular way of comparing and measuring the overall performance of a building in terms of sustainability is building benchmarking systems. These systems often concentrate on the environmental aspects of sustainability at the expense of social or economic considerations and they all adopt some kind of credit and scoring system to enable comparisons among buildings.

There are many benchmarking systems around the world, varying in scope, rigour and level of verification. The most stringent systems tend to be ones that are verified by an independent, third-party organisation. The two most recognised systems are BREEAM and LEED; these are used worldwide. The Green Star and NABERS systems of Australia, the Pearl Rating System of Abu Dhabi and the QSAS system of Qatar should also be mentioned in the context of arid climates, as these systems have been developed in response to the particular climatic challenges of the countries they were developed for.

BREEAM and LEED do not specifically address building performance in arid climates. Although both systems take into account climate zone classifications to model energy performance and reward design teams for minimising water use inside and outside the building, neither system has any particular weighting factor applied to arid climates. BREEAM has a version of its rating system modified for the Gulf region; however, for arid climates outside the Middle East, BREEAM International is still the only appropriate—albeit very generic—system applicable from the BREEAM family of rating tools. Furthermore, these two systems also include several credits and credit areas that are very difficult or impractical to pursue in arid climates. One such example is stormwater management, where—in the case of arid climates with rare but severe storms—the credit threshold to reduce runoff for the project is often so high that it becomes financially unfeasible to achieve. Bicycle storage is an example of an inexpensive, but often highly impractical credit in many hot arid climates and care should be taken for projects pursuing certification to avoid including design features in a project solely for the sake of securing credits.

5.3 Integrated design

Traditional project design and procurement—a design-bid-built process—is of a linear fashion, where the client hires an architect who translates the brief into a design intent and as the design progresses and evolves, different consultants (structures, mechanical, electrical, public health, fire protection, acousticians, etc) are engaged to create a tender package that can be priced by a contractor. This type of procurement and contract process is the most prominent in Middle East and certain developing countries with extreme and arid climates.

Figure 39 demonstrates this idea. The opportunity to influence and for the design to accept changes easily always occurs during early stages of design process when there is minimum abortive work and when equipment and construction has not been procured or started yet. Design changes implemented later in the project's lifecycle often have high cost and programme implications. A practical example of this is when a developer decides to pursue sustainability goals for the project after the design is completed or towards the latter stages of detailed design, and sustainability features have to be added to the building in a hurry, as bolt-on solutions. Inevitably, this leads to the conclusion that sustainability in buildings is expensive, when in reality the problem is often with the management of the design process itself.

Realising a sustainable project that works for the client and project occupant requires the input of different parties traditionally engaged later in the design process, if at all. The client has to set up clear objectives the team needs to address and further implement.

On many occasions, neither architects nor engineers have the right skills or experience to completely fulfil the project's goals, and bringing other project stakeholders such as contractors, facilities management or even occupants, allows the project to benefit from different viewpoints, perspectives and needs. The early engagement of users and builders allows the build, handover and implementation to be smoother, as everyone becomes involved in the design process and is familiar with the design decisions. This, in turn, requires a project manager and client that realise the complexities of incorporating sustainability into building design and employ—from the very beginning—a sustainability specialist who understands the intricacies of project team relationships and can manage everyone's role in the design process, not just tick boxes for credits in a building rating system.

The traditional design process relies heavily on drafting during detailed design and tender packages documentation. As technology evolves and building information modelling (BIM) and 3D design packages are becoming available, designers are increasingly working with design tools common to all design team members; a new concept, which allows for the accountability and easier transferring of information and sharing of knowledge. These tools allow for earlier testing of design alternatives and modelling of energy conservation measures without the need

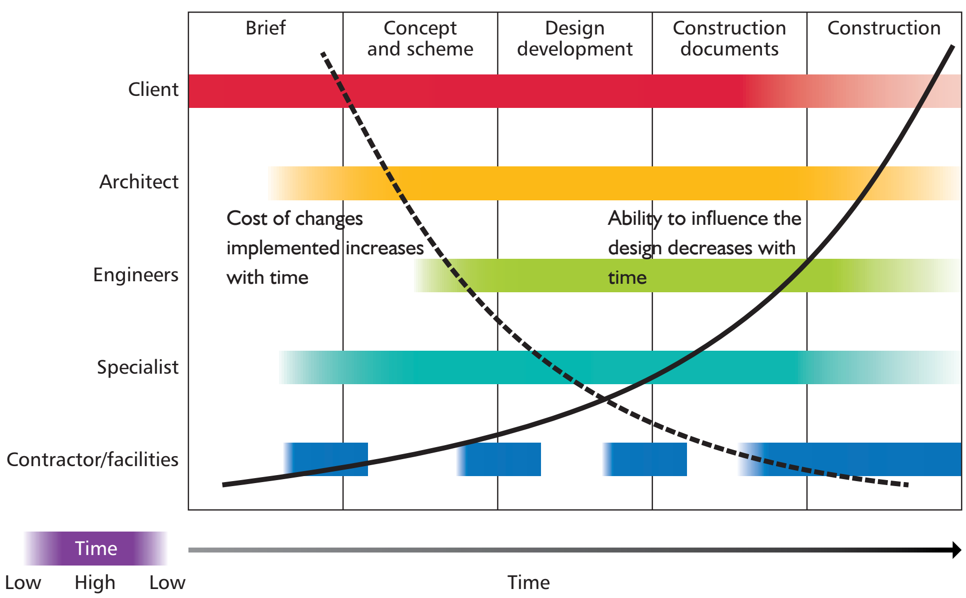


Figure 39: A modified MacLeamy curve shows the potential effort and engagement of different project stakeholders in an integrated design approach
Original concept by Patrick MacLeamy, FAIA, CEO HOK © HOK Group, Inc. 2013 All rights reserved

for these options to be fully developed. This, in turn, allows for further exploration of design alternatives and greater integration as the design continues.

LEED, the Pearl Rating System Estidama and BREEAM—among other rating systems—strive for this design approach as the preferred methodology to be achieved in sustainable design projects. Some rating systems even go beyond the design process. For instance, LEED has a 'Measurement and Verification' credit that requires the design team and the commissioning agent to be engaged with the project after one year of substantial completion of the project, and BREEAM with the Soft Landings process requires even further contact between designers and building owners and occupants. These post-occupancy evaluation analyses allow the building to get fine tuned and the design to be understood by the user but also provide the platform for the designers to understand human behaviour and lessons learnt for future designs.

5.4 Sustainability considerations in arid climates

5.4.1 Site and masterplanning

Sustainable design balances human needs (rather than human wants) with the limits of acceptable change of the natural and cultural arid environments. It minimises environmental impact, import of goods and energy, and waste generation.

Building services engineers should strive to ensure the project has minimal impact on the natural environment. The complexity of site preparation and construction can be magnified in an arid environment by the value of the resource, physical remoteness and limited availability of craftsmen and materials.

Local construction techniques and building materials should be used as long as they do not adversely affect the natural and cultural resources of the area. The methods and techniques used should ensure that there will be no residual signs of construction or environmental damage.

Infrastructure availability should be considered well before any design activity starts and the site's geology and topography should also be investigated. Proposals should consider the development's visual and acoustic impact on the surrounding areas.

5.4.2 Water use

5.4.2.1 Water use outside the building

Water is a scarce resource in most parts of arid regions, so a key design objective should be to minimise or eliminate impacts on natural surface and groundwater flows.

Typically, the building services engineer will be involved with the provision of irrigation water particularly associated with landscaping, but possibly to assist in the growing of agricultural crops and revegetation of disturbed soils in dry areas and during periods of inadequate rainfall. Water efficiency needs to be carefully considered and water balance calculations should be part of the design early on. Water practices developed for temperate climates may not work as well in arid regions for technological, environmental, economic and cultural reasons. There are two fundamental approaches to water management in the context of buildings: increasing the supply of usable water and reducing the demand for water.

Increasing the supply of usable water could be achieved by the following methods.

- Irrigation with brackish water: brackish water is widely available and with care and under certain favourable conditions, it can be profitably used for irrigation of certain types of plants; however this needs to be carefully and professionally planned and managed, as not many plant species can tolerate high salt concentrations for a prolonged period.
- Reuse of water: using recycling and advanced waste treatment.
- Wells: hand-dug wells, which began thousands of years ago, are regaining popularity with the help of new materials and construction equipment. Examples are qanats and horizontal wells—methods for tapping underground water without using pumps, illustrated in Figure 40.
- Other approaches include groundwater mining, desalination, solar distillation, the use of satellites and aircraft for detecting water in arid lands, rainfall augmentation, the possibility of using icebergs as a source of water and dew and fog harvesting.

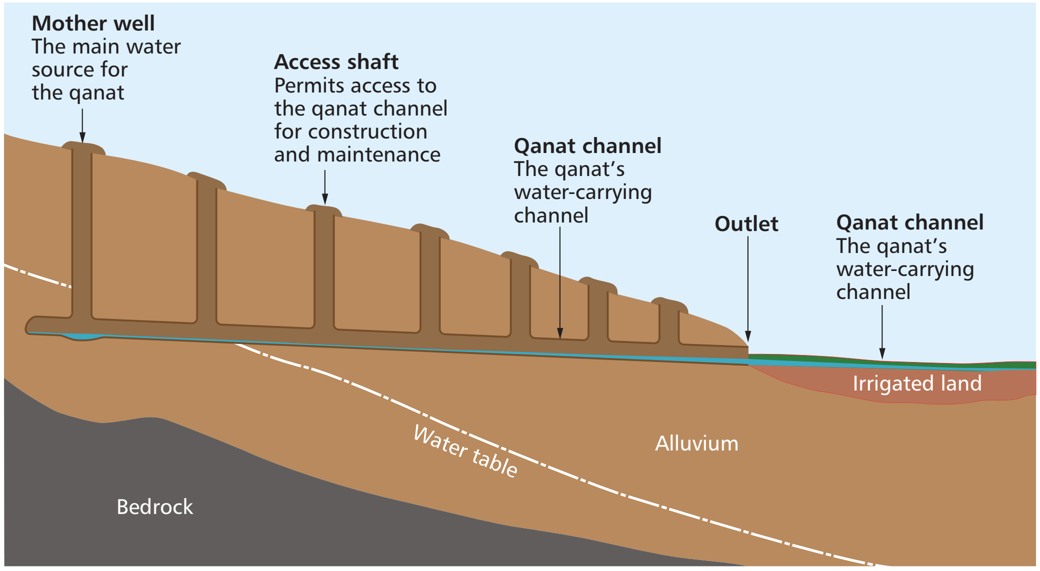


Figure 40: Principles of a qanat

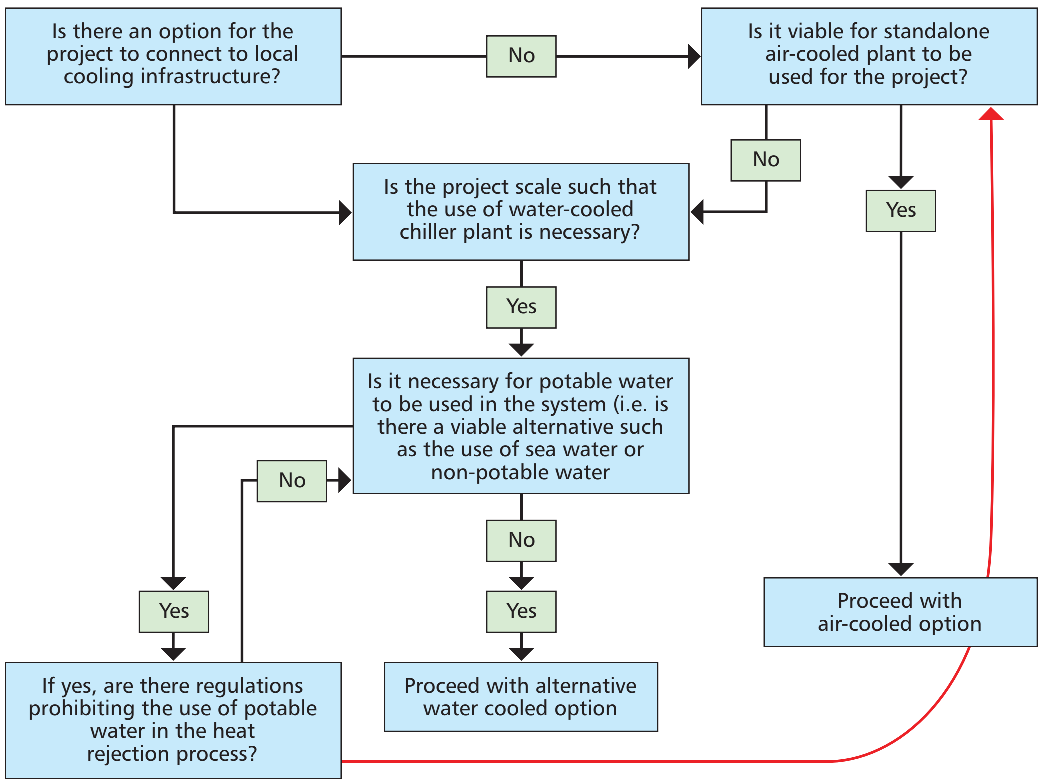


Figure 41: Decision flow diagram for a cooling system

In addition to increasing the supply of freshwater, designers should also consider minimising water demand. Examples for reducing water demand include the following methods:

- Efficient irrigation design, including minimising leakage and reducing the rate of evaporation for irrigation water. Drip irrigation techniques for suitable plant species can ensure delivery of water directly to the plant's roots, rather than onto the soil surface.
- Improving the capacity of the soil to hold water and nutrients via mulch covers on the soil surface help to reduce erosion, retain moisture and minimise the fluctuation in soil temperature.
- Xeriscaping and xerogardening—landscaping and gardening in ways that reduce or eliminate the need for supplemental water from irrigation through the use of appropriate plant species and careful siting to minimise evaporation and transpiration by exposure to wind. This is often promoted as a sustainability concept in arid regions.

- Operational considerations such as night-time irrigation and adaptive mowing of lawns.
- Treated wastewater effluent can also be used to irrigate landscaped areas: this will reduce demand for potable water and provide a means of disposing of treated wastewater effluent. However, in some countries the use of wastewater effluent for irrigation may be prohibited by local regulations. Often these regulations have no scientific or engineering basis and should be challenged by engineers.
- Alternative landscaping that relies less on vegetation should also be considered.

5.4.2.2 Water use inside the building

The timing of a project's construction in relation to the future provision of utilities can be critical. The source of water supply may change during the design, construction and subsequent occupation of the building. Therefore, it may be necessary to develop contingency plans (such as space for temporary treatment plant), which may or may not be required by the time that the building is occupied.

Where water is provided from desalination plants, the designer should check the pH range of the water produced. Local supplementary water treatment may be required.

The Authority Having Jurisdiction (AHJ) should be consulted about available information relating to public health engineering before commencing design and construction. Copies of local building regulations and water authority regulations should be obtained, if available.

In general, the consumer cost of water does not reflect the higher production and distribution costs in many arid climates, however the conservation of water should be a priority on projects. Ideally, the strategy for the delivery of a project in an arid climate will address the main areas of water consumption.

As a heat rejection strategy is a critical aspect of many projects in arid climates, it is necessary to consider the full picture. This design process would follow a decision-making process that considers environmental impacts, the project's financial plan (ideally covering both capital and operational costs). A simple flow diagram (Figure 41) depicts the process.

In addition to heat rejection, the project team will also need to consider the use of low and ultra-low flow water fixtures and aerators, as these will contribute to lowering water demand.

Generally, on-site water treatment (greywater and blackwater) requires careful deliberation to address cultural, technical and cost issues. The use of treatment plants may also require system registration and operator licensing at the start of the project.

Condensate recovery is generally permissible, provided the product is to be used only for irrigation. There are several studies that identify condensate recovery as a viable option for projects. As a guide, in Doha the condensate recovery calculations show an annual average of 1 L of condensate per 100 kW·h of cooling. In addition, condensate water can be used for capturing energy, which could be used for pre-cooling fresh air.

5.4.2.3 Energy

(*a*) Energy conservation

Energy conservation is the minimisation of energy required on a project without compromising the performance of the systems. This topic is not specific to arid climates. Most of the energy conservation measures employed in established markets can be satisfactorily utilised in arid climates, although different economic and logistical considerations will apply.

Ideally, energy conservation measures, such as building orientation and form, should be considered during the concept phase of a project. In an integrated design process, this is achieved through collaboration by all stakeholders in the project: client, engineer, architect, commissioning authority, facilities manager, operator and, where applicable, the general contractor.

Establishing measurable energy targets early on provides clarity for the project team. Building designs should incorporate energy-saving features such as thermal buffer areas, fenestration shading and the utilisation of heavyweight building materials. Benchmarking the performance of the project can be achieved at each phase of the development through standards such as ANSI/ASHRAE/IES (2013) Standard 90.1 *Energy Conservation in New Buildings Except Low Rise and Residential Buildings*.

The integrated approach to energy conservation needs to consider the performance of the building's facade in terms of thermal insulation, extent of glazing, external shading devices and the overall air tightness of the façade.

A less quantifiable, but nevertheless critical, consideration is that of the quality of the installation and maintenance personnel, since energy-saving devices may require skills not readily available locally. This risk may result in the practice of incorporating higher design margins into a project, rather than addressing the source of the problem. Higher design margins will result in less efficient plant operation.

Sophisticated energy conservation systems should generally be avoided. Experience has shown that system reliability and simplicity of operation are the dominant criteria for applications in arid climates. Sensitive equipment may be prone to failure due to extreme temperature and humidity combined with dust and saline atmosphere in certain arid climates. It may be necessary to operate the air conditioning plant continuously to prevent condensation occurring on interior surfaces of the building during the evenings.

In coastal areas, the combination of high ambient temperature and humidity results in high cooling loads for fresh air cooling plants. The use of dedicated outside air system (DOAS) to provide preconditioned ventilation air is a common approach to most designs. The DOAS provides centralised plant to precondition air whilst recovering sensible and latent energy from the relief or exhaust air. The fresh air quantity may be controlled automatically through CO_2 sensors to provide substantial energy savings.

Thermal wheels and other energy transfer devices may be utilised for energy recovery, although due regard should be given to corrosion arising from the saline atmosphere in coastal areas.

Heat pipes, passive heat transfer devices, have been used in various applications ranging from orbiting satellites to the Alaskan pipeline ground spikes. By applying heat pipes to standard air conditioning coil systems, the dehumidification performance and efficiency was greatly enhanced, with no increase in energy use.

Building energy costs over the life of the building can be as high as 10 times the capital cost of building services systems, and therefore energy metering must be considered during design. The provision of energy meters into a project will provide the operator with the tools to measure, record and better manage the building.

Load demand limiting may be applied to refrigeration plant during peak cooling load periods but care should be taken to ensure that the resulting deviation from indoor design conditions is not too abrupt or excessive.

Energy tariffs should be examined to determine whether a project will benefit from off-peak electricity strategies such as thermal energy storage (TES) systems.

Building management systems (BMS) incorporating energy management functions are regularly installed in most projects. The inter-operability of the various systems should be considered early in the project.

Although intelligent BMSs may be installed in a project, the transfer of knowledge (design intent) together with training the building operators and facilities management staff remains an area for attention. Structured training sessions, ideally occurring during the final stages of construction, will allow the operators to better understand the design intent and the building's control strategies. Training must be structured to be successful. Ensuring the operating staff are suitably skilled remains a challenge.

(*b*) Renewables

Renewable energy studies should form part of the design process for all arid climate projects. Although renewable energy is a topic gaining attention throughout the world, there are several factors that may impact the adoption of renewable energy systems for arid climates, including the following points:

- Low consumer charges for baseline electricity.
- Limited or no tariff structure for peak energy consumption.
- Extreme environmental conditions (dust, haze, humidity and fog), which will impact on the system performance and also reduce the economic life of components.

Table 21: Potential renewable energy systems to be used in arid climates

System	Description	Advantages	Disadvantages
Geothermal	The geothermal energy system uses energy from within the Earth's crust to generate steam to drive turbines or to generate hot water. The opportunity for implementing a geothermal system is subject to location of 'hot spots', whereby the facility captures steam energy as it escapes from cracks and holes in the underground rocks.	Renewable energy. No localised pollution. Day and night.	The viability of the geothermal system will be dependent on the project location. Preliminary research and trial tests will be required to establish the feasibility of a geothermal system. High capital cost—well drilling and associated testing for ground conductivity may account for a third to a half of the overall cost.
Hydropower	Using the natural force of gravity, falling or flowing water is used to turn turbines to produce electricity. Hydropower systems can be adapted from large-scale to micro and pico systems for remote projects.	No atmospheric pollution. Renewable energy.	This technology is not likely to be available in arid climates or in climates with seasonal water flow.
Solar hot water	The fundamental requirement for a solar system is to have a sunny location where the solar collectors can be located. Thermal collectors absorb the sun's radiation to produce hot water. The collector can be either flat plate or evacuated tube type. The location and orientation of the solar collectors should ensure that the collectors have full sun from 9am to 3pm. The collectors should face south at approximately the same angle as the latitude of the project.	Renewable energy. No localised pollution.	Relatively high embodies energy. Keeping them clean can be a challenge.
Photovoltaic	Photovoltaic (PV) cells utilise the sun's light to create an electric current and generate electricity. The two most important factors when considering the size of a system are the sunlight intensity in the region and the average power consumption of the project. Even though the sun may be above the horizon for 14 hours a day, the site may only receive 6 hours of equivalent full sun.	Renewable energy. No localised pollution.	It is important to note that system performance is dependent on ambient conditions such as temperature and dust. In a high temperature environment (above 25 °C) the performance of the PV cells starts to deteriorate. A 'rule of thumb' for this deterioration is a 2.5% reduction in output power for every 5 °C increase from standard temperature of 25 °C. Similarly, as dust settles on the panels, the overall performance of the system will be reduced. This is addressed by regular cleaning, but this in turn requires a source of clean water and for the panels to be located in an accessible location.
Wind	Wind energy converts kinetic energy that is present in the wind into mechanical energy or electricity. The amount of potential energy depends primarily on the wind speed and wind speed generally increases as height above ground increases. Average wind speeds above 4–5 m/s are required to make small-scale wind-powered electricity generation a viable option.	Free energy. Low maintenance. No localised pollution. Day and night.	The reliability of wind must also be considered in the feasibility assessment process. Although wind delivers renewable energy, the reliability of wind is presumed to be 30%. This then requires a baseload plant to be provided that is capable of covering the times when there is no wind generated.
Concentrated solar power	These systems are made up of a large array of mirrors to concentrate solar energy to generate steam to drive turbines, which create electricity. There are many variations in applying this technology.	Large generation capacity. Higher efficiencies than flat plate solar collectors.	Due to high capital cost, the plant is used for large-scale power generation (100 MWe). Pilot projects show 1 km^2 of panels will generate 80 MWe.

- There is no rebate scheme to overcome the high capital cost for the implementation of renewable technology. Small-scale and decentralised renewable energy systems are more capital intensive per kW of energy when compared with large-scale renewable energy projects and in some countries, systems parallel to the grid are not allowed.

When considering the implementation of renewable energy systems, the design team should consider all attributes including capital cost, maintenance, energy tariff structures and decommissioning of the systems.

The main types of renewable energy systems that may be appropriate for arid climates are shown in Table 21.

(*c*) Metering

The operational performance of a building over its life has significant financial and environmental capital attached to it. In order to maximise efficiencies, it is important for the building owner/operator to have the tools and opportunity to undertake diagnostics and also fine tuning, including intelligent energy and water meters, which measure and record consumption within the project. These meters are integrated through the project's building management system.

The design team should consider metering of utilities such as chilled water energy, electricity, gas and water. These categories can then be further broken down to include potable and non-potable water, utility and renewable energy and other attributes appropriate for the particular project.

Understanding the employer's aspirations and requirements is a key part of the integrated approach to metering. This is reflected in the complexity of the metering strategy and is also project specific—too complex and it will not be utilised by building operators; too simple and the plan will not permit diagnostics. A simple block diagram, as shown in Figure 42, is a recommended tool to establish and agree on the metering strategy.

(*c*) Commissioning

Commissioning is a key ingredient of a strategic plan to deliver a high performance building. The commissioning process covers system design, plant selection, procurement, storage, installation, operation and ongoing performance and involves the project design team as well as the contractor and project owner, as illustrated in Figure 43.

There are many detailed handbooks and literature on commissioning, so this section is only intended to provide an overview of commissioning.

One aspect of commissioning in an arid climate is considering activities outside of the peak conditions on the schedule. Regardless of scheduling, it is likely that the commissioning activities will be performed whilst the project is subject to the ingress of dust and if they are performed during the warmer months, condensation is likely to be an issue.

Ideally, the commissioning process itself represents an integrated approach whereby project team participants—employer, engineer, contractor and operator—are involved. This process commences in establishing project goals, ideally at the start of the project, developing plans to achieve the goals within design and construction and finally the implementation of activities to demonstrate that the goals are achieved.

The commissioning plan ensures that the intellectual knowledge, decision-making processes and stakeholder sign-offs during the various phases of the project (e.g. from the concept phase to the operational acceptance phase) are documented in an exact and usable manner that will provide a smooth and transparent transfer of responsibility from design and construction teams to the building operations team. The transfer of knowledge must be performed in such a documented manner to allow the operation of the facility without impacting the building occupants or deviating from the original design intent. Understandably, the management of this process requires an experienced team player, who carries the title of (or is known as) the commissioning authority (CxA).

The function of the commissioning plan is to provide a structured process whereby the contractor demonstrates to the commissioning authority, as the employer's representative, that the equipment and systems they have installed function in accordance with the design intent. The commissioning plan (which incorporates the commissioning specifications, commissioning forms, commissioning systems test protocols and other documents) provides a protocol for testing the equipment and systems, which will demonstrate that they function as intended.

This commissioning plan represents the framework for the procedures and processes necessary to test and validate the individual system components through to the integration of the systems. These activities are conducted throughout the construction period to identify and resolve system issues and deficiencies and to verify stable operation for these complex projects.

The commissioning plan provides the following:

- the format and approach to assist the contractor in developing system summary
- prefunction checklists
- functional performance tests (FPT)
- checklist data sheet for each system that details the tests to be undertaken to demonstrate correct operation under all modes of control
- all specified sequences of operation and the applicable pass/fail criteria.

5.4.2.4 Materials and waste

(*a*) Sourcing of materials

Typically, the rate of development in arid areas means that there are difficulties sourcing materials locally/responsibly because of the low population density in these areas and the lack of development. However, using local materials should be considered. If there are no local materials available, it would be prudent to import environmentally friendly foreign materials. Alternatively, projects may choose to stimulate the local economy by working with local suppliers to improve the range/quality of local products offered.

(*b*) Product transparency and eco-labelling

Environmental performance is becoming an increasingly important differentiation tool for product manufacturers around the world. As a result, many construction industry products now feature some kind of (and in some cases many different types of) product certification labels. These labels are intended to give the buyer the impression that the product is of superior environmental performance:

Figure 42: Relationship between building energy and water systems

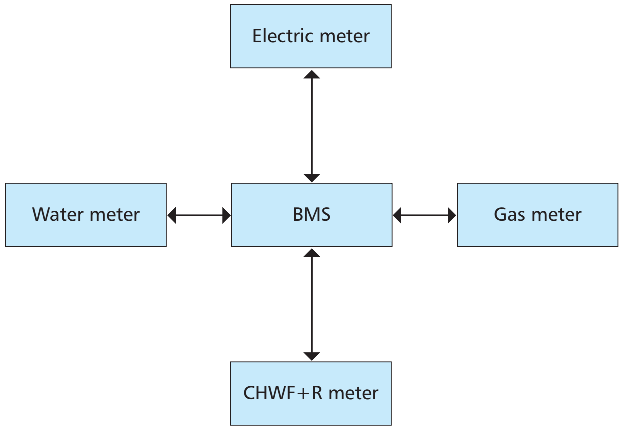
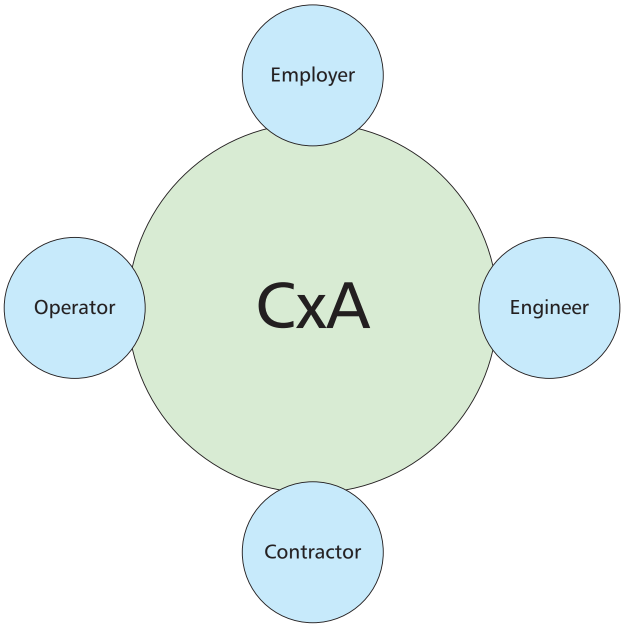


Figure 43: Relationship between the commissioning authority (CxA) and other project participants



either it is made of recycled materials, is free from volatile organic compounds (VOCs) or carcinogens, such as formaldehyde, or its manufacturer operates an environmental management system (EMS).

While some product labels are verified by a third-party auditor and, as such, are reasonably rigorous and transparent, other claims are uncontrolled and are often difficult to substantiate. A typical example of this is recycled content, where many producers include scrap from their own manufacturing process in their calculations of recycled content. It should be noted that the internationally accepted ISO definition of recycled content does not include industrial scrap, as re-incorporating scrap back into the original manufacturing process is considered merely good economic sense. Therefore, design teams should be careful of relying on claims about the environmental performance of building materials and, if necessary, ask the supplier to verify their claims.

(*c*) Adaptive reuse of buildings

By definition, arid climates are generally less populated than moist or wet regions and although many arid regions have been populated for thousands of years, a population boom is a relatively new phenomenon in most arid climates and is a result of advances in engineering that only became financially viable in the past 70–80 years.

As a result, most construction projects in these areas have limited or no opportunity to reuse existing buildings, either because these building do not exist or they are not of suitable condition or specification to be reused.

Nonetheless, opportunities for adaptive reuse should be found when possible, as the reward and public support for these projects can be enormous.

(*d*) Designing for sustainable waste management

Sustainable waste management aims to address the long-term pressures that arid climates face through the recovery, recycling and reuse of resources, and the minimisation of waste streams, with a focus on reducing what ends up in landfill. Processes that produce less waste will be preferred, if cost, schedule and exploration or production goals are not adversely affected.

As arid environments tend to currently be underdeveloped, typical challenges to sustainable waste management include:

- an absence of in-country contractors that recycle and handle hazardous, non-hazardous and mixed waste
- the logistical challenges of transporting waste long distances
- historical ad-hoc disposal practices by previous parties that create waste liabilities.

Culturally, it can be a new experience that requires substantial stakeholder education, especially if there is a low population density, which may not create a market to drive up landfill prices, so there may be little incentive to do this.

Examples of possible sustainable waste management opportunities include:

- converting biodegradable waste to compost,
- waste-to-energy systems,
- utilising the biomass in worm farming or sending the waste to anaerobic digestion systems
- collaborating with suppliers to minimise waste.

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Appendix Design conditions for selected locations

BWh classification

Group B: Dry (arid and semiarid) climates: If the annual precipitation is less than half the threshold for Group B, it is classified as BW (desert climate); h signifies low latitude climate (average annual temperature above 18 °C).

Index of location used (ASHRAE, 2009)

	WMO#	Lat	Long	Elev
Algeria				
Adrar	606200	27.88°N	0.18°W	283
Bechar	605710	31.50°N	2.25°W	816
Ghardaia	605660	32.40°N	3.80°E	469
Australia				
Alice Springs Airport	943260	23.80°S	133.88°E	547
Boulia Airport	943330	22.92°S	139.90°E	158
Cobar Airport AWS	947100	31.53°S	145.80°E	218
Halls Creek Airport	942120	18.23°S	127.67°E	424
Tennant Creek Met Office	942380	19.63°S	134.18°E	377
Azerbaijan				
Lankaran	379850	38.73°N	48.83°E	−12
Zakatala	375750	41.67°N	46.65°E	490
Bahrain				
Bahrain (International Airport)	411500	26.27°N	50.65°E	2
Bolivia				
Cochabamba	852230	17.42°S	66.18°W	2548
La Paz/Alto	852010	16.52°S	68.18°W	4038
Viru-Viru	852440	17.63°S	63.13°W	373
Botswana				
Seretse Khama International	682400	24.55°S	25.92°E	1005
China				
Ruoqiang	517770	39.03°N	88.17°E	889
Turpan	515730	42.93°N	89.20°E	37
Egypt				
Kharga	624350	25.45°N	30.53°E	73
Luxor	624050	25.67°N	32.70°E	99
Mersa Matruh	623060	31.33°N	27.22°E	30
Iran, Islamic Republic of				
Esfahan	408000	32.47°N	51.67°E	1550
Khoy	407030	38.55°N	44.97°E	1103
Shiraz	408480	29.53°N	52.53°E	1481
Jordan				
Amman Airport	402700	31.98°N	35.98°E	779
Maan	403100	30.17°N	35.78°E	1069
Kazakhstan				
Shymkent	383280	42.32°N	69.70°E	604

	WMO#	Lat	Long	Elev
Turkestan	381980	43.27°N	68.22°E	207
Kuwait				
Kuwait International	405820	29.22°N	47.97°E	48
Libyan Arab Jamahiriya				
Tripoli International	620100	32.70°N	13.08°E	63
Zuara	620070	32.88°N	12.08°E	3
Mali				
Bamako/Senou	612910	12.53°N	7.95°W	381
Mauritania				
Nouadhibou	614150	20.93°N	17.03°W	3
Nouakchott	614420	18.10°N	15.95°W	3
Namibia				
Walvis Bay (Pelican Bay)	681040	22.88°S	14.43°E	0
Windhoek	681100	22.57°S	17.10°E	1700
Niger				
Agadez	610240	16.97°N	7.97°E	502
Maradi	610800	13.47°N	7.08°E	373
Niamey-Aero	610520	13.48°N	2.17°E	227
Tahoua	610430	14.90°N	5.25°E	391
Zinder	610900	13.78°N	8.98°E	453
Oman				
Buraimi	412440	24.23°N	55.78°E	299
Fahud	412620	22.33°N	56.48°E	170
Masirah	412880	20.67°N	58.90°E	19
Salalah	413160	17.03°N	54.08°E	23
Seeb International Airport	412560	23.58°N	58.28°E	15
Sohar Majis	412460	24.47°N	56.63°E	4
Sur	412680	22.53°N	59.47°E	14
Thumrait	413140	17.67°N	54.02°E	467
Pakistan				
Islamabad Airport	415710	33.62°N	73.10°E	508
Karachi Airport	417800	24.90°N	67.13°E	22
Lahore Airport	416410	31.52°N	74.40°E	217
Peru				
Arequipa	847520	16.33°S	71.57°W	2520
Lima-Callao/Airport	846280	12.00°S	77.12°W	13
Qatar				
Doha International	411700	25.25°N	51.57°E	10
Saudi Arabia				
Al-Jouf	403610	29.78°N	40.10°E	689
Arar	403570	30.90°N	41.13°E	549
Jeddah (King Abdul Aziz International)	410240	21.70°N	39.18°E	17
Riyadh OBS. (OAP)	404380	24.70°N	46.73°E	620
Turaif	403560	31.68°N	38.73°E	852
South Africa				
Springbok	685120	29.67°S	17.90°E	1007

	WMO#	Lat	Long	Elev
Upington	684240	28.40°S	21.27°E	836
Syrian Arab Republic				
Aleppo International Airport	400070	36.18°N	37.20°E	384
Damascus International Airport	400800	33.42°N	36.52°E	609
Palmyra	400610	34.55°N	38.30°E	404
Tunisia				
Gabes	607650	33.88°N	10.10°E	5
Gafsa	607450	34.42°N	8.82°E	314
Turkmenistan				
Ashgabat Keshi	388800	37.92°N	58.33°E	312
United Arab Emirates				
Abu Dhabi Bateen Airport	412160	24.43°N	54.47°E	3
Abu Dhabi International Airport	412170	24.43°N	54.65°E	27
Al Ain International	412180	24.27°N	55.60°E	262
Dubai International	411940	25.25°N	55.33°E	5
Fujairah	411980	25.10°N	56.33°E	28
Ras Al Khaimah International	411840	25.62°N	55.93°E	31
Sharjah International Airport	411960	25.33°N	55.52°E	33
Uzbekistan				
Samarkand	386960	39.57°N	66.95°E	724
United States of America				
Yuma International Airport	722800	32.65°N	114.60°W	63
Yuma MCAS	699604	32.65°N	114.62°W	65

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