THE DIY WIRING SYSTEM

for homes

How to do the wiring of your house on your own with the protective measures

DANIEL ABRAHAM

Table of Contents

CONCLUSION

INTRODUCTION

House electrical wiring is a process of connecting different accessories for the distribution of electrical energy from the supplier to various appliances and equipment at home like television, lamps, air conditioners, etc.

Electricity plays an essential role in our everyday life: lights, home appliances, heating systems, air conditioning, TV, telephones, computers and many other modern devices are powered by electricity.

For a long time, the best advice seemed to be “hire a professional and get it done right.” Depending on the task contemplated and the individual’s level of expertise, this notion may or may not be valid. You have to assess the situation and decide what will work for you. Even if you hire out all the work, electrical knowledge and expertise, as conveyed in this book, will be of value in completing your building project and maintaining it in the future.

CHAPTER ONE

What is Electrical Wiring?

Electrical Wiring is a process of connecting cables and wires to the related devices such as fuse, switches, sockets, lights, fans etc to the main distribution board is a specific structure to the utility pole for continues power supply.

Methods of Electrical Wiring Systems w.r.t Taking Connection

Wiring (a process of connecting various accessories for distribution of electrical energy from supplier's meter board to home appliances such as lamps, fans and other domestic appliances is known as Electrical Wiring) can be done using two methods which are

• Joint box system or Tee system

• Loop – in system

They are discussed as follows:

Joint Box or Tee or Jointing System

In this method of wiring, connections to appliances are made through joints. These joints are made in joint boxes by means of suitable connectors or joints cutouts. This method of wiring doesn't consume too much cables size.

You might think because this method of wiring doesn't require too much cable it is therefore cheaper. It is of course but the money you saved from buying cables will be used in buying joint boxes, thus equation is balanced. This method is suitable for temporary installations and it is cheap.

Loop-in or Looping System

This method of wiring is universally used in wiring. Lamps and other appliances are connected in parallel so that each of the appliances can be controlled individually. When a connection is required at a light or switch, the feed conductor is looped in by bringing it directly to the terminal and then carrying it forward again to the next point to be fed.

The switch and light feeds are carried round the circuit in a series of loops from one point to another until the last on the circuit is reached. The phase or line conductors are looped either in switchboard or box and neutrals are looped either in switchboard or from light or fan. Line or phase should never be looped from light or fan.

Advantages of Loop-In Method of Wiring

• It doesn't require joint boxes and so money is saved

• In loop – in systems, no joint is concealed beneath floors or in roof spaces.

• Fault location is made easy as the points are made only at outlets so that they are accessible.

Disadvantages of Loop-In Method of Wiring

• Length of wire or cables required is more and voltage drop and copper losses are therefore more

• Looping – in switches and lamp holders is usually difficult.

Different Types of Electrical Wiring Systems

The types of internal wiring usually used are

• Cleat wiring

• Wooden casing and capping wiring

• CTS or TRS or PVC sheath wiring

• Lead sheathed or metal sheathed wiring

• Conduit wiring

There are additional types of conduit wiring according to Pipes installation (Where steel and PVC pipes are used for wiring connection and installation).

• Surface or open Conduit type

• Recessed or concealed or underground type Conduit

Cleat Wiring

This system of wiring comprise of ordinary VIR or PVC insulated wires (occasionally, sheathed and weather proof cable) braided and compounded held on walls or ceilings by means of porcelain cleats, Plastic or wood.

Cleat wiring system is a temporary wiring system therefore it is not suitable for domestic premises. The use of cleat wiring system is over nowadays.

Advantages of Cleat Wiring:

• It is simple and cheap wiring system

• Most suitable for temporary use i.e. under construction building or army camping

• As the cables and wires of cleat wiring system is in open air, Therefore fault in cables can be seen and repair easily.

• Cleat wiring system installation is easy and simple.

• Customization can be easily done in this wiring system e.g. alteration and addition.

• Inspection is easy and simple.

Disadvantages of Cleat Wiring:

• Appearance is not so good.

• Cleat wiring can't be use for permanent use because, Sag may be occur after sometime of the usage.

• In this wiring system, the cables and wiring is in open air, therefore, oil, Steam, humidity, smoke, rain, chemical and acidic effect may damage the cables and wires.

• it is not lasting wire system because of the weather effect , risk of fire and wear & tear.

• it can be only used on 250/440 Volts on low temperature.

• There is always a risk of fire and electric shock.

• it can't be used in important and sensitive location and places.

• It is not lasting, reliable and sustainable wiring system.

Casing and Capping wiring

Casing and Capping wiring system was famous wiring system in the past but, it is considered obsolete this days because of Conduit and sheathed wiring system. The cables used in this kind of wiring were either VIR or PVC or any other approved insulated cables.

The cables were carried through the wooden casing enclosures. The casing is made up of a strip of wood with parallel grooves cut length wise so as to accommodate VIR cables. The grooves were made to separate opposite polarity. the capping (also made of wood) used to cover the wires and cables installed and fitted in the casing.

Advantages of Casing Capping Wiring:

• It is cheap wiring system as compared to sheathed and conduit wiring systems.

• It is strong and long-lasting wiring system.

• Customization can be easily done in this wiring system.

• If Phase and Neutral wire is installed in separate slots, then repairing is easy.

• Stay for long time in the field due to strong insulation of capping and casing..

• It stays safe from oil, Steam, smoke and rain.

• No risk of electric shock due to covered wires and cables in casing & capping.

Disadvantages Casing Capping Wiring:

• There is a high risk of fire in casing & capping wiring system.

• Not suitable in the acidic, alkalies and humidity conditions

• Costly repairing and need more material.

• Material can’t be found easily in the contemporary

• White ants may damage the casing & capping of wood.

Batten Wiring (CTS or TRS)

Single core or double core or three core TRS cables with a circular oval shape cables are used in this kind of wiring. Mostly, single core cables are preferred. TRS cables are chemical proof, water proof, steam proof, but are slightly affected by lubricating oil. The TRS cables are run on well seasoned and straight teak wood batten with at least a thickness of 10mm.

The cables are held on the wooden batten by means of tinned brass link clips (buckle clip) already fixed on the batten with brass pins and spaced at an interval of 10cm for horizontal runs and 15cm for vertical runs.

Advantages of Batten Wiring

• Wiring installation is simple and easy

• cheap as compared to other electrical wiring systems

• Paraphrase is good and beautiful

• Repairing is easy

• strong and long-lasting

• Customization can be easily done in this wiring system.

• less chance of leakage current in batten wiring system

Disadvantages of Batten Wiring

• Can’t be install in the humidity, Chemical effects, open and outdoor areas.

• High risk of firs

• Not safe from external wear & tear and weather effects (because, the wires are openly visible to heat, dust, steam and smoke.

• Heavy wires can’t be used in batten wiring system.

• Only suitable below then 250V.

• Need more cables and wires.

Lead Sheathed Wiring

The type of wiring employs conductors that are insulated with VIR and covered with an outer sheath of lead aluminum alloy containing about 95% of lead. The metal sheath given protection to cables from mechanical damage, moisture and atmospheric corrosion.

The whole lead covering is made electrically continuous and is connected to earth at the point of entry to protect against electrolytic action due to leaking current and to provide safety in case the sheath becomes alive. The cables are run on wooden batten and fixed by means of link clips just as in TRS wiring.

Conduit Wiring

There are two additional types of conduit wiring according to pipe installation

- Surface Conduit Wiring
- Concealed Conduit Wiring

Surface Conduit Wiring

If conduits installed on roof or wall, It is known as surface conduit wiring. in this wiring method, they make holes on the surface of wall on equal distances and conduit is installed then with the help of rawal plugs.

Concealed Conduit wiring

If the conduits is hidden inside the wall slots with the help of plastering, it is called concealed conduit wiring. In other words, the electrical wiring system inside wall, roof or floor with the help of plastic or metallic piping is called concealed conduit wiring. obliviously, It is the most popular, beautiful, stronger and common electrical wiring system nowadays.

In conduit wiring, steel tubes known as conduits are installed on the surface of walls by means of pipe hooks (surface conduit wiring) or buried in walls under plaster and VIR or PVC cables are afterwards drawn by means of a GI wire of size if about 18SWG.

In Conduit wiring system, The conduits should be electrically continuous and connected to earth at some suitable points in case of steel conduit. Conduit wiring is a professional way of wiring a building. Mostly PVC conduits are used in domestic wiring.

The conduit protects the cables from being damaged by rodents (when rodents bites the cables it will cause short circuit) that is why circuit breakers are in place though but hey! Prevention is better than cure. Lead conduits are used in factories or when the building is prone to fire accident. Trunking is more of like surface conduit wiring. It's gaining popularity too.

It is done by screwing a PVC trunking pipe to a wall then passing the cables through the pipe. The cables in conduit should not be too tight. Space factor have to be put into consideration.

Types of Conduit

Following conduits are used in the conduit wiring systems (both concealed and surface conduit wiring) which are shown in the above image.

• Metallic Conduit

• Non-metallic conduit

Metallic Conduit:

Metallic conduits are made of steel which are very strong but costly as well.

There are two types of metallic conduits.

• Class A Conduit: Low gauge conduit (Thin layer steel sheet conduit)

• Class B Conduit: High gauge conduit (Thick sheet of steel conduit)

Non-metallic Conduit:

A solid PVC conduit is used as non-metallic conduit now a days, which is flexible and easy to bend.

Size of Conduit:

The common conduit pipes are available in different sizes genially, 13, 16.2, 18.75, 20, 25, 37, 50, and 63 mm (diameter) or 1/2, 5/8, 3/4, 1, 1.25, 1.5, and 2 inch in diameter.

Advantage of Conduit Wiring Systems

• It is the safest wiring system (Concealed conduit wring)

• Appearance is very beautiful (in case of concealed conduit wiring)

• No risk of mechanical wear & tear and fire in case of metallic pipes.

• Customization can be easily done according to the future needs.

• Repairing and maintenance is easy.

• There is no risk of damage the cables insulation.

• it is safe from corrosion (in case of PVC conduit) and risk of fire.

• It can be used even in humidity , chemical effect and smoky areas.

• No risk of electric shock (In case of proper earthing and grounding of metallic pipes).

• It is reliable and popular wiring system.

• sustainable and long-lasting wiring system.

Disadvantages of Conduit Wiring Systems

• It is expensive wiring system (Due to PVC and Metallic pipes, Additional earthing for metallic pipes Tee(s) and elbows etc.

• Very hard to find the defects in the wiring.

• installation is not easy and simple.

• Risk of electric shock (In case of metallic pipes without proper earthing & grounding system)

• Very complicated to manage additional connection in the future.

CHAPTER TWO

The Homeowner's DIY Guide to Electrical Wiring

Why Get Involved?

Homeowners choose to do their own electrical work for a variety of reasons:

• To save money. In the building trades, electricians are among the most highly paid in terms of hourly rate. No matter how fast the individual works, electrical installation is time-consuming. In 2014, expect to pay over $4,000 to have a new small residence wired, including the service but without extensive data networking or home automation and not including light fixtures or appliances.

• To impress family members, neighbors, and colleagues at work. This is where preparation really pays off. The NEC stresses throughout that electrical equipment is to be installed in a "neat and workmanlike manner."

A large portion of the job will be concealed behind building finish surfaces and sometimes underground, but the work in progress will be watched carefully by those in the area. A portion of the work will remain visible for the life of the building, and onlookers will be impressed if it is a first-rate job. Thus, beyond the issues of safety and efficiency, there is a great need to produce an outstanding product, and here again, knowledge and exper- tise are decisive factors in meeting this goal.

• To increase self-esteem. Self-esteem is an important motivation for the home crafter-electrician. We all like to consider ourselves good at what we do, and with research and practice, the general trend is to improve. Every project you undertake and bring to a successful conclusion will contribute to your ability in the future to tackle a more complex or difficult task, and for many of us, this goes way beyond the dollars saved.

• To be in touch with some fundamental processes of the universe. It is a palpable pleasure to channel electrons through conductors and watch the way these elementary particles react when we throw the switches. Completing an electrical wiring project puts us in touch with some fundamental processes of the universe, and there is a great deal to be said for that.

Applicable Mandates

Nonelectrical work, both residential and commercial, is governed by multiple building codes, and most of these are less restrictive and detailed than the NEC. The Building Officials' and Code Administrators' (BOCA) Plumbing Code, for example, lays out general principles such as those intended to ensure that drain water will not infiltrate the drinking water system, but it is a comparatively slim volume, and the requirements are less detailed and specific than the NEC. Why all this oversight of electrical work? In a nutshell, it is to protect end users from the twin demons of fire and electrical shock. The NEC has had great success in this regard. In recent years, the number of nonutility electrical shock fatalities has gone way down. This decline has been due largely to the increasingly broad NEC mandate requiring ground-fault circuit interrupters (GFCIs) in more locations. Homeowners and builders may gripe at the initial cost of installation and instances of nuisance tripping, but these are small prices to pay when you consider that in the fullness of time, little fingers will seek ways to insert metal objects into receptacles and impatient construction workers will saw off the ground prongs of power tools that may be used in wet environments. Similarly, though in an earlier stage of development, the arc-fault circuit interrupter, where installed, is a highly effective guard against electrical fires, although here again there is the issue of nuisance tripping. In Chapter 1, we'll talk about these lifesaving devices in greater detail—theory of operation, where required, where prohibited. Electrical codes are an essential part of the picture but not the whole story. They are intended to provide protection from the hazards that can arise in connection with the use of electricity. The savvy home electrician needs other intellectual tools as well. A working knowledge of high school math is essential. Don't worry about calculus or advanced trigonometry, but you will need to perform simple operations such as solving for an unknown in linear algebraic equations and finding a square root with the aid of a hand-held calculator. As we have indicated, electrical work is a big subject, but for the homeowner, where the field is limited to residential construction, it is a bit simpler. To conclude your project, you'll have to adopt a methodical, step-by-step approach. There's good news, though! It's all open-book, meaning that when a question arises, you can consult the NEC, the Internet, electronic textbooks, and this book to find the answers you need. Herein we begin with some basics and proceed into more difficult areas the home crafter-electrician is likely to encounter. If you are in an early stage in this interesting and rewarding undertaking, start at the beginning, and you will not have a problem tackling common electrical jobs in a residential setting. More advanced readers can jump around, filling in bits of knowledge here and there with a goal of seeing the picture in its entirety.

Avoid Building Fire and Shock Hazards into Your Work

As everyone knows, there are hazards inherent in the use of electricity. In residential work, they are less intense than in a factory or commercial setting, where the voltage levels and available short-circuit currents are much higher. Notwithstanding, great care is also needed in home wiring. You should remember the child who is sleeping upstairs or playing outside in a wet area near a receptacle or appliance you wired. Proper design and installation procedures will protect against fire and shock hazards and prevent tragedies from occurring. We'll examine the hazards and see how they can be mitigated.

How Electrical Fires Start

More fatalities result from electrical fires than shock, and most of them are caused by smoke inhalation. In residential work, you must keep in mind where the greatest dangers lie and take proactive measures to guard against them. Starting with the greater potential hazard, how does an electrical fire begin? The major culprits are series and parallel arc faults and conductors that overheat due to insufficient ampacity. The first of these is an installation deficiency, and the second is more likely a design miscalculation. Either can result in a fiery inferno with great property damage or, far worse, injury or loss of human life. Arcing faults, series or parallel, can initiate a fire. Series arc faults do not usually increase the load (except sometimes in the case of a motor), as seen by the overcurrent device, fuse, or circuit breaker. Therefore, they do not cause the over- current device, fuse, or circuit breaker to trip out. The fault continues until either it clears itself by burning out the connection and breaking the circuit's continuity or nearby combustible material is ignited, perhaps destroying the entire building. This can happen even where the fault is inside a metal enclosure, although such enclosures usually limit the risk. Series arc faults usually result from one of these causes:

• An errant nail or drywall screw partially penetrates a conductor, not severing it or shorting it out so as to interrupt the circuit, but reducing the current-carrying capacity and making a local hot spot.

• A termination is improperly torqued. A medium-sized residential job will involve thousands of terminations in the branch circuits, not to mention the service, which also can be problematic. The usual faults are a screw terminal in a breaker, entrance panel, or load center or a switch, light fixture, or receptacle that is not sufficiently tight (or too tight) and a wire nut that is not tight enough, contains misaligned conductors, or is disrupted when stuffed back into the box.

Electric Shock

Although statistically less prevalent than electrical fire fatalities, those caused by electric shock are gruesome in the extreme. Children, with active minds and inquisitive fingers, find ways to make contact with lethal voltages. These also can strike unsuspecting adults who handle poorly grounded power tools or frayed wires. Such accidents are preventable. It is the responsibility of the home crafter-electrician as well as the professional to build shock- proof installations insofar as possible. This includes, when doing repairs, additions, or retrofits to existing wiring, inspecting the overall system and making sure that it is safe. The most basic aspect of a wiring system from a safety- from-shock point of view is adequate, reliable bonding and grounding. Most electrical systems are grounded. There are some specialized types of systems that are per- mitted to be ungrounded, which is to say that neither of the two conductors that are connected to the electrical supply is also connected to the earth so as to be at ground potential. Both sides of the circuit float above ground potential so to speak. (These ungrounded systems are not seen in residential occupancies.) Even where the electrical system is ungrounded, a grounding conductor is to be connected to earth with a full-scale grounding electrode system so as to be at ground potential. It is to be run along with the circuit conductors throughout the premises wiring and to be connected to all metal enclosures such as junction boxes, wall boxes, metal light fixture housings, and so on. The purpose in grounding these conductive objects is so that if, because of a fault such as a chafing wire inside a power tool or light fixture, the metal casing were to become energized, the full available fault current would rush through the entire input end of the circuit, including the fuse or circuit breaker. This would instantly trip out, interrupting the circuit and deenergizing the faulted metal enclosure. Grounding versus Bonding Grounding and bonding are two separate but related concepts. Grounding refers to connection of a wire or circuit to the earth for the purpose of setting it at ground potential. Bonding, in contrast, is an intentional connection of two or more conductive bodies together or to the electrical system neutral for the purpose of keeping them at the same potential. Many inexperienced workers throw in an extra ground rod and believe that they are doing something great, whereas bonding back to the neutral bar is often far more effective.

Grounding and the Breaker

Without the grounding conductor, the breaker would not trip. It is correct to say that the grounding conductor facilitates operation of the overcurrent device. The enclosure would remain energized until touched by a person who is also in contact with the ground (as is usually the case), and the individual would experience an electric shock. Its severity would depend on the level at which the enclosure was energized, the nature of the victim’s contact with ground, the electrical resistance of the individual’s body, the route the electric current took through the body, the duration of the shock, and other factors. As we have seen, the equipment-grounding conductor in conjunction with the overcurrent device is a wonderful safety feature, but of course, it won’t work if it is not present or if there is a break in the continuity anywhere along the line. We have all seen instances where the ground prong of an extension cord or power cord has been sawed off to make the plug fit into an old two-wire receptacle. The person who does this is either incredibly ignorant or guilty of depraved indifference to human life. In the preceding discussion, we mentioned both grounded and grounding conductors. They are both at earth potential, and they are connected to the neutral bar within the entrance panel, but they serve different purposes, and they are color-coded differently. The grounded conductor is the return or neutral side of the circuit that powers the load, and it carries the full amount of current that passes through the load. The insulation is white. The grounding conductor is that third wire that under normal nonfault conditions does not carry current and is not part of the circuit that powers the load. The wire is usually bare or has green insulation. The grounded and grounding conductors are at the same potential because they are connected together in the entrance panel by means of the main bonding jumper. This is to be the one and only connection between the grounded and grounding conductors. Additional subsequent connections between them anywhere along the line, including within the load, are prohibited and would result in dangerous circulating currents. To emphasize, the grounded and ground- ing conductors are solidly connected together within the entrance panel, never to rejoin.

Other Safety Issues

Electrical safety is always a work in progress. On the job site, be ever vigilant. The handles of insulated tools should be inspected periodically for any sign of deterio- ration. Minute punctures or cracks can hold conductive grease and moisture. Above all, ground the work, not the worker. In a damp location such as a trench, use cordless tools when possible. Otherwise, make sure that your power is GFCI protected and that the equipment- grounding conductor has continuity back to the service.

Mitigating Hazards

The key element in all of this is the NEC. This is a thick volume of requirements and mandates that cover every aspect of residential, commercial, and industrial electrical work. This code is not, as it notes, an instruction manual for untrained persons. Compliance does not necessarily mean that the end product will be efficient or suitable in all respects. The focus is on safety. It is generally acknowledged that in the use of electricity, there are potential hazards. If the installation complies with the NEC, it will be free of the hazards. The greatest dangers are shock and electrical fire, but there are other hazards as well. For example, a heavy piece of conduit high on a wall or attached to a ceiling could fall, injuring a person below. Exacting specifications as to supporting and securing metal raceways, including types of hardware and minimum spacing intervals, go a long way toward ensuring that the conduit won't come loose. The NEC is administered, revised, and published by the National Fire Protection Association® (NFPA®). A new edition is released every three years. There is an extensive review and revision procedure, with committees that debate and vote on proposed changes. The committees, composed of expert professionals from throughout the industry, meet and vote to accept or reject each proposal. A draft is compiled, and the NFPA general membership votes to accept the document, whereupon it becomes the current edition of the Code. The NFPA is a private organization, not a governmental body. Accordingly, the NEC as published has no legal standing on its own. It is offered up so that states, municipalities, and jurisdictions may pass legislation that enacts it into law. They may include revisions, add mandates, or delete portions of the document before adopting it as binding within their territory. Outside the United States, certain countries such as Mexico and Venezuela recognize the NEC. It is also used by many insurance companies, educational organizations, and overseas military bases where electrical wiring is regulated. The NEC also delineates its own applicability, and this is where questions often arise. For example, electrical wiring and equipment that are owned by a utility that generates and distributes electricity are outside the NEC’s scope. However, utility wiring and electrical equipment that are not involved in the generation and distribution of electricity, such as in utility clerical offices, are covered. Another example is that electrical wiring and equipment that are underground in mines are not covered, but nonmine underground equipment such as lighting in a traffic tunnel is covered. As you can see, there is some legalistic splitting of hairs involved here. As far as residential electrical installations are concerned, though, all wiring and electrical equipment are covered by the NEC. At first, the language may seem a little obscure, but you will quickly get used to it.

Getting Started

Even when you draw a circle so as to exclude everything that is not residential, this is still a big subject. But it won’t be too difficult if you go one step at a time. Begin with some simpler jobs, such as wiring receptacles and switches and doing some home runs to the entrance panel. At this stage, it is a good idea to work with a professional. (It may be feasible to pay $15 and get an apprentice card. Then you can learn on the job.) Before you know it, you’ll be wiring the box, building the service, installing light fixtures, and hooking up three-way switches. In this book, we’ll be looking at these and similar projects. We won’t waste time on feckless discussions about whether the ground prong goes on top or bottom, and we’ll try to refrain from presenting too much detail about harmonic distortion, magnetic resonance, and the like. The goal is to stick to residential wiring and cover as much detail as possible in a single book.

Concealed versus Exposed Wiring

Residential wiring is simpler than commercial or industrial work because it is smaller in scope, there are fewer voltage and current levels with less arc-flash hazard to worry about, and the connected electrical equipment is less complex. In one respect, however, residential work can be more difficult because a better finish appearance is usually necessary. Because most home wiring is concealed, there are accessibility issues that do not arise on the factory floor. Once the walls are filled with insulation and the wiring is covered by wall and ceiling finish, it becomes more difficult to do alterations and repairs because the cabling cannot be easily removed and replaced. In a commercial or industrial environment, even if race- ways are behind wall and ceiling material, it is a simple task to install a new cable run using the old wire as a pull rope. The home crafter-electrician must become adept at concealing wire for the sake of appearance, and where alterations or repairs are being made, this becomes high art. The NEC permits the familiar Type NM cable (Romex) to be stapled to the wall finish, but this is acceptable only in a rustic cabin or unfinished garage. In finished offices and stores, the problem is solved by running wiring above suspended ceilings. Panels can be easily popped out to access the cable so that it can be altered and repaired as needed, and new wiring can be added. Suspended ceilings often are not considered acceptable from an aesthetic point of view in residential living rooms and bedrooms, so we are back to the problems inherent in concealed wiring. One solution, for a retrofit, is to use Wiremold. This is a metal raceway that has a nice finish and is suitable for use on finished surfaces. It comes with a complete line of fittings, enclosures, and devices and very good installation instructions. Many sizes, shapes, and colors are available. It is installed like any raceway, and then conductors are pulled through it. However, it adds to the expense of the job, so it is better to conceal the wiring in the first place where possible.

Residential Work

Now we'll take a tour through a typical residential electrical installation begin- ning upstream. We won't say too much right now about the service because Chapter 4 is devoted to that topic. Suffice it to mention that the service consists of that portion of the premises wiring starting at the utility point of connection and ending at the input terminals of the main overcurrent device, which may be in the entrance panel or in a separate main disconnect enclosure, either inside or outside the building. The utility often requires that the service be built or at least certified by a licensed electrician, but in any case, the home crafter-electrician should be familiar with this part of the electrical structure because it contains the grounding means and constitutes the jumping-off place for the entire premises wiring. The usual procedure for wiring a house is to begin by mounting the enclosures (with knock- outs removed) in place. Then, if the house is wood framing, drill the holes in the studs and framing members using the correct size drill bit. Pull the wires through the holes, staple them to the framing at NEC-specified intervals, and insert the cable ends through the connectors, leaving sufficient free wire at both ends. At the wall boxes, the NEC specifies that 6 inches of free conductor beyond the inner rim of the enclosure be left for making connections. Some workers cut the ends shorter in the belief that it will reduce box fill, but this is a mistake because it is more difficult to make good terminations.

Wiring the Box

At the entrance panel, you need enough length of the black conductor to reach the breaker. The white conductor must be long enough to reach its breaker for a 240- volt circuit or the ground bar for a 120-volt circuit. The bare or green equipment- grounding conductor has to be long enough to reach the grounding terminal. In all cases, leave your whips long enough so that they can be pushed back into the corners of the box. Make all bends right angles, as opposed to taking shortcuts through the available space. In this way, the first few circuits won't overfill the box, making it difficult to add others. When it comes time to make terminations, if you find that one of your wires is too short, it is acceptable to make a splice using wire nuts inside an entrance panel. It is better, however, to leave enough free conductor in the first place. In new construction, it is best to put in the service and heat up the entrance panel at the outset. In this way, there is power to work with, and the temporary service can be removed. The entrance panel can be in the basement or upstairs, conceivably on the second floor. The NEC prohibits the installation of overcurrent devices (hence entrance panels) in bathrooms, clothes closets, and on stairways, but outside of that, it is your choice. We’ll have much more to say about the location of entrance panels in Chapter 4. It is best to wire the service entrance conductors into the entrance panel before terminating the branch circuits. In this way, the branch-circuit conductors are not blocked, and they can be shifted around later if the need arises. The usual location for the entrance panel is in the basement. Then the branch circuits and feeders can be run along joists or sills. They remain accessible for troubleshooting purposes or if changes must be made. Cabling can be run any- where in the basement and stubbed up through the floor. A centrally located chase inside an interior wall can be built to bring cable runs to the second floor. If holes are drilled in load-bearing framing members, they should be as small as possible to permit easy installation of cable. A 5⁄8-inch hole is suitable for 12 American Wire Gauge (AWG) Romex. Large holes should be avoided because they weaken the framing members. A hole drilled near the middle of a long span will weaken it more than if the hole is drilled closer to where the span is sup- ported. A long floor joist will tend to sag near the middle. The top edge of the timber is in compression, and the bottom edge is in tension, that is, trying to stretch. The center is neither in compression nor in tension. Therefore, any holes should be drilled near the center so that there is less tendency to weaken the framing member. This has the added advantage of providing more isolation in regard to nail penetration. If the entrance panel is to be mounted on a concrete wall, the usual procedure is to make a ¾-inch exterior-grade plywood backing panel that should be about 10 inches wider than the box all around so that cables can be stapled in place. All bends should be 90 degrees for a neat appearance, with the turns gentle enough to comply with the minimum bending radius for the type of cable. This work should be precise and neat in order to impress family members and visitors and to facilitate any future wire tracing. It is customary to paint the backing board a low-gloss black.

• In a service entrance panel, the neutral bar must be bonded to the metal enclosure. The connection is to be made by means of the main bonding jumper, which is attached at the time the box is installed. The reason that it is not part of the box as it comes from the factory is that it is not always required. In fact, it is prohibited when the box is used as a load center downstream from the main disconnect. As stated earlier, such bonding would violate the injunction against multiple bonding of the neutral and equipment-grounding conductors.

This connection must be made only once, inside the service entrance panel, and never anywhere else. The main bonding jumper usually takes the form of a threaded screw attached to a card included with the entrance panel. The card reads, “Attach this main bonding jumper in the entrance panel when required.” In the neutral bar, there is a threaded hole for the main bonding jumper. When the box is used as a service-entrance panel, screw the main bonding jumper tightly in place so that it cuts through the paint and digs into the metal of the enclosure, making an electrical connection. If you neglect this simple screw, your enclosure will not be bonded, and if a live wire were to chafe any- where inside, the box would become energized, creating a hazard. Here’s another very important item that is often neglected by novices: any metal water piping in or on the building must be bonded to the grounding sys- tem. To do this for a 100-amp service, use 6 AWG copper wire, solid or stranded, bare or with green insulation. For a 200-amp service, 2 AWG copper is required. Insert one end into the oversize hole in the neutral bar. Run it out through the miniature punch-out at the bottom of the enclo- sure, and connect it to the nearest metal water pipe using a pipe-grounding clamp made for the purpose. Using this same 6 or 2 AWG wire, make a jumper around the water meter, if there is one, so that if the meter is removed, ground continuity will be preserved. Also jump around any non- metallic housings, such as associated with water filters, and jump around any short runs of plastic piping that may separate metal segments.

• Fill out the directory, usually attached to the inside of the cover that opens to access the breakers. It is a Code violation to neglect the directory. The printing should be neat and legible. If you use ink, it will be difficult to erase when alterations are made in the future, as is usually the case.

Branch circuits and feeders originate in the panel. A branch circuit runs from the final overcurrent device to the load. A feeder runs from one overcurrent device to another, as in a load center. In other words, a feeder has overcurrent devices at both ends. A mistake novices make is that they place unneeded load centers throughout the occupancy, with local branch circuits emanating spider-web- fashion from each one. This is an expensive variant with no upside unless it is needed in an unusually large building to mitigate voltage drop. When a circuit trips out, it makes for more difficulty in finding the overcurrent device. Branch circuits are individually wired into separate breakers in the entrance panel. Except for the main, the breakers are purchased separately. Square D, which makes high-quality products, and some other makers require unique breakers that are not compatible with other brands. Many makes are compatible with ITE breakers, which means that the breakers fit the mounts and clip into the bus bar correctly. However, the metal alloys may differ so that over a period of time a cor- rosion could be a problem. Consult the Underwriters Laboratories (UL) listing, the manufacturer, and the electrical distributor to resolve this problem. Be sure to include an equipment-grounding conductor. Terminate it at the grounding-terminal strip in a load center or the neutral bar in a service-entrance panel. Put the breaker in place, and route the ungrounded conductor(s) to it. Cut the conductor(s) to length, and strip off just enough insulation so that there is bare wire inside the lug but no copper showing outside. Pull the breaker out, connect the conductor(s) with sufficient torque, and then replace the breaker, making sure that it is seated correctly. Each branch circuit should be completed before tying it into the box to avoid working on live wires. Grounding conductors and grounded conductors are wired to the neutral bar or the grounding bar. More than one grounding conductor may go into a single lug, but the grounded conductors may not be doubled up. This is so because at some time in the future one of the grounded conductors may have to be removed, at which time the circuit sharing the neutral termination would lose ground con- tinuity, destabilizing the voltage with respect to ground. The exact height of receptacles is not specified by the NEC. A good height is 10 inches from the subfloor to the bottom of the wall box. Throughout any house, the receptacles all should be the same. Switch heights should be such that the switches can be operated with the forearm level. A good height is 46 inches to the bottom of the box. Thermostats, which take a standard wall box, should be eye level, 60 inches to the bottom of the box. You can make gauges to aid in setting wall boxes to the appropriate heights. Wall boxes should extend beyond the inside of the framing so that they will be flush with the anticipated finish wall material. Some wall boxes have a mark or ridge to aid in positioning them when ½-inch sheetrock is to be used. Be sure that the wall box does not extend too far out, or the wall plate will not seat on the finish wall, leaving an unsightly gap. There are several mounting styles for wall boxes. Choose one that works for you. A common type mounts using two 16-penny nails. Boxes are available in metal or plastic. Plastic is a little cheaper, and in a big subdivision or in the life of an electrical contracting firm, the savings would be substantial.

Wiring the Devices

It is possible to strip the insulation from a conductor using a utility knife with a new sharp blade. Whittle off the insulation as you would sharpen a pencil with a knife. Under no circumstances can the copper be nicked. If that happens, when the circuit is heavily loaded, there will be a hot spot in the wire right next to the ter- mination—and that is a fire waiting to happen! If you nick a wire, cut it back, restrip, and if necessary, connect a short jumper. Rather than using a knife, a wire stripper does a better job. The automotive type works, but it is bulky and difficult to get into tight places. The professional electrician's stripping tool is perfect for this job. When stripping the end of a con- ductor, look at the termination and carefully judge how much insulation to remove. This is critical. The idea is to remove enough insulation so that none of it will get caught under the screw, which would compromise the electrical connec- tion. On the other hand, if you remove too much insulation, there will be exposed copper, which could arc to ground or be a shock hazard. Some devices have a back-wiring option. The stripped end is inserted into a hole in the back of the device, where it is held in place by spring tension. This type of termination does not have as great ampacity as a good screw termination that is torqued properly. There is rarely a good reason for using the back-wiring option. It goes without saying that receptacles have to be polarized properly. The grounded (white) conductor is connected to the screw that has a silver finish, and the black conductor is connected to the screw that has the brass finish. Devices that have holes for terminations have the word White or the letter W for the grounded conductor terminal. Devices with separate inputs and outputs, such as GFCIs, are marked with the words Line and Load. When wiring a residential occupancy, whether it is an entire new building, an addition, or an out- building such as an attached garage, the object should be to create a Code-compliant product, and one of the important tasks is to have the correct switch and receptacle placement. Code requirements are exacting. For example, in habitable rooms such as living rooms and bedrooms, there is a pre- scribed maximum spacing between receptacles. But how do you handle doorways, large archways, glass sliders, and the like? You have to know where in the NEC to find these mandates. These requirements are maximum intervals, so you are free to install additional receptacles. Receptacles versus Outlets Often customers in a hardware store ask for a dozen outlets. The proper term is receptacles. An outlet is any device or equipment that is attached to a branch circuit so that it may be powered up. A hard-wired light fixture is an outlet. So is a receptacle. A receptacle is a device, often duplex, into which an attachment plug may be inserted. A receptacle on a store shelf is a device. Wired into a branch circuit in the home, it becomes an outlet.

Nonelectricians sometimes ask what maximum number of receptacles is permitted on a single branch circuit. This is not the way it works. Seven is sometimes mentioned as a rule of thumb, but adding more receptacles does not increase the load, and it is permitted without limit. Additional receptacles provide more loca- tions for cord and plug connections. The primary hazard is not overloading the circuit because the overcurrent device will take care of that. The primary hazard is overuse of extension cords, so, within reason, the more receptacles the merrier.

Switches

Switches are a vital part of any electrical installation, and every home has many of them. They should be provided as the NEC mandates, wired correctly and located for maximum convenience for the end user. Every habitable room should have a ceiling light. It must be controlled by a switch on the inside wall on the knob side, not the hinge side, of the door. Roughing in the wiring, the electrician should find out which way the door will swing. If there are to be other switches at this same location, they should be grouped in a single two- or three-gang wall box. In this type of configuration, the switch near- est the door should control the light fixture for the convenience of the end user entering the darkened room. The other switches, if there are more than one, should be arranged in some kind of logical order. The NEC permits, where for any reason it is desired not to have a ceiling light fixture, that this switch may control instead a dedicated receptacle that will supply power to a lamp. Switching may be in either of two configurations. One is the in-line switch, and the other is the switch loop. The one you choose depends on the layout of the room with regard to the location of the power source, switch, and load. You need to decide which alternative is more economical of wire, and that one usually will require less installation labor. If the switch is between the power source and the load, the in-line configuration is better. If the load is between the power source and the switch, a switch-loop configuration is used. In both instances, we are talk- ing about locations along the wire run, not necessarily spatial relations. To wire an in-line switch, bring cable from the source to the switch. This is called live power. Then run cable from the switch to the load. This is called switched power. A load could be switched by breaking the grounded conductor (neutral, white), but this would be a Code violation and very dangerous. The load would be turned off, but the ungrounded (hot, black) conductor and internal circuitry would be live. This would create a shock hazard for a maintenance worker who would assume that the equipment is powered down. An in-line switch always should be placed in the grounded conductor. And, of course, the equipment ground is never to be switched. If the load is 240 volts, it is powered by the two hot legs from the single-phase supply. In this instance, it is necessary to break both ungrounded conductors simultaneously, again without affecting the neutral, if there is one. (Some 240-volt loads require neutrals; others do not. Single-phase motors, baseboard heat, and hot water heaters do not require neutrals. Most electric ranges and similar appliances require neutrals because they contain 120-volt circuits such as lights and/or clocks. In no event is the neutral to be switched.) The other configuration is the switch loop. Here the live power is brought directly to the load, such as a light fixture, from the entrance panel or load center. The grounded connector is not connected to the switch. Instead, it goes to the load. At the switch, the live power ungrounded conductor is connected to the switch. It is customary to connect this wire to the bottom terminal for consistency and to facilitate troubleshooting and repair, but it will work the same either way. The NEC requires that a neutral be present in every switch enclosure. It is not necessary for a simple switch to operate. In the case of an in-line switch, it is already there, but for a switch loop, an extra neutral must be provided for future use. To comply with this rule, 14-3 AWG Romex is generally used. In this way, there is an extra neutral (white), the hot supply to the switch (black), and a return hot conductor (red) back to the load. This wire is connected to the hot terminal of the load. The spare neutral is tapped from the neutral line within the load enclo- sure. The purpose of the extra neutral run to a switch that is on a switch loop is so that if sometime in the future it is decided to upgrade to home automation or energy-saving electronics that require power, it is available. The in-line configuration is more economical because you don't have to bother with the three-wire cable, so it is often the better choice even when the layout of the room would seem to point to a switch loop.

Wiring Three- and Four-Way Switches

If it happens that a room has two entries, say, at opposite ends, special arrange- ments are needed. If there were two separate standard single-pole, single-throw switches, one at each end, this would not be satisfactory. If the two switches were in series (like a digital AND gate), both would have to be on to light up the room. If the two switches were in parallel (like a digital OR gate), both would have to be off to turn off the light(s). Either way, there would be instances where the user would have to cross the room in darkness to control the room lighting. The solution to this dilemma is the three-way switch circuit. This ingenious arrangement allows the user to control the load from either of two locations. The addition of four-way switches permits control from any number of additional locations. Other applications for three-way switch pairs include stairways, out- buildings so that lights can be controlled from inside either building, attached garages, outdoor lighting including porch lights so that it can be controlled from the house or an outbuilding, and so on. Many individuals have problems wiring these switches together with the source and load and having the final product work correctly. They have to call in a professional to straighten out the terminations and/or cable runs. Even some experienced electricians, if they haven't done three-way switches in awhile, have to learn them all over. The whole thing becomes simple and easy to remember if you keep a few basic principles in mind. There are two basic situations with subdivisions. One is the in-line configura- tion, and the other is the switch-loop configuration. The subdivisions involve whether power from the entrance panel or load center is initially furnished to either the first or the second three-way switch or to the load. Three-way switches are specialized devices. The handle has no marked on or off position because this varies depending on the state of the other three-way switch. It has three terminals, all colored brass because there is never a neutral (white) connected to it. On one end of the body is a single terminal, marked "com- mon." On the other end of the body are two terminals that are not marked. Electricians call the conductors that are connected to them travelers. If you have a three-way switch on hand, set your multimeter to the ohms function, and ring it out. You will see that regardless of the position of the handle, there is never continuity between the traveler terminals. Between the common and one of the traveler terminals, there is continuity when the handle is thrown one way and no continuity when the handle is thrown the other way. Between the common and the other terminal, there is continuity only when the handle is thrown the opposite way.

Three-Way Switch Loop Configuration

Three-way switch loops accomplish the same results with somewhat different cir- cuit wizardry. A switch loop is useful in a situation where it is more economical to run power from the source directly to the load and from there cable down to the three-way switches and any four-way switches along the way. Connect the neutral (white) of the 12-2 AWG from the source directly to the neutral terminal of the load. Do not connect the ungrounded conductor to the load. Instead, wire-nut it through the nearer three-way switch and onto the farther three-way switch, where it connects to the common terminal, becoming the input to the black box. Here's the part that causes difficulty: if the whites in the loop are reidentified and used as return hot wires, this leaves us with no conductor to provide the neu- tral for future use. Therefore, it is necessary to run a 14-3 AWG wire from the load to the first three-way switch and a 14-4 AWG wire between the two three-way switches. The 14-4 AWG wire will have one white conductor and three conductors that are other than white or green. Use two of these colored conductors as travelers, one as the supply for the common that is the input and the white as the extra neutral. What if you want to bring power from the source to the first three-way switch? Then you won't need an extra neutral there because you already have it. You will need 14-4 AWG wire to get a spare neutral, two travelers, and a return hot wire to the second three-way switch. In view of the expense (14-4 AWG wire costs twice as much as 14-3 AWG wire), it is best to avoid switch loops. Note also that the spare coils and wire nuts increase box fill, so be sure to use deep boxes. Most of the time, in-line switching is best even if the runs are a little longer. Dimmer switches are wired using the same circuits. Three- and four-way dimmers are available.

Sizing Feeders and Services

When it comes to sizing residential electrical work, some NEC navigation with table reading and number crunching is needed.

Type of Occupancy
Volt-Amperes per Square Foot

Armories and auditoriums 1

Banks 3½

Barber shops and beauty parlors 3

Churches 1

Clubs 2

Court rooms 2

Dwelling units 3

Garages, commercial (storage) ½

Hospitals 2

Hotels and motels, including apartment houses without provision for cooking by tenants 2

Industrial commercial (loft) buildings 2

Lodge rooms 1½

Office buildings 3½

Restaurants 2

Schools 3

Stores 3

Warehouses (storage) ¼

In any of the preceding occupancies except one-family dwellings and individual dwelling units of two-family and multifamily dwellings:

Assembly halls and auditoriums 1

Halls, corridors, closets, stairways ½

Storage spaces ¼

In the left appear 18 types of occupancies with load per unit of area. The right column inch-pound numbers rather than metric. Notice that there is a substantial difference in the electrical lighting load for different occupancies. At the low end are storage warehouses at ¼ volt-amp per square foot. This is so because most of the time, for most of the building, the lights are off. At the other end of the scale are banks and office buildings, both of which are rated at 3½ volt-amps per square foot. Dwelling units are not far behind, at three volt-amps per square foot. For dwelling units, the calculated floor area does not include open porches, garages, or unused or unfinished spaces not adaptable for future use. For dwellings, unlike other occupancies, this general lighting load includes the receptacles, which for nondwellings after derating have to be added in separately. So what remains is to make a list of all appliances and nonreceptacle/lighting loads together with applicable rules and derating factors. This subtotal is added to the general lighting load to find the total connected load. The total is divided by the system voltage to obtain the number of amps, which determines the size of the service for a new building. For an addition, you will be able to determine whether it is necessary to upgrade to a larger service. Many existing buildings have a 100-ampere service that is filled to capacity, so a new service is always a distinct possibility.

Where Is the Point of Connection?

As far as the point of connection is concerned, that is for the utility to define. In most cases, it is where the utility workers actually connect their conductors prior to powering up the permanent service. This varies depending on whether the service is aerial or underground. If it is aerial, the point of connection is about 16 inches upstream from the weather head, where the utility crimps its triplex con- ductors to the customer-supplied service-entrance conductors, as shown in Figure 4-1. If it is an underground service, the point of connection is at the input lugs of the meter socket. The reason for this is that the underground cable is a single unspliced run from the meter to the transformer. It would not be good to have the home crafter-electrician (or even a professional electrician without high-voltage training) climbing the pole to make these connections. As mentioned previously, the utility may require a licensed electrician to build the service and get it ready to be powered up. It may be possible for the home crafter-electrician to do the work, provided that a licensed electrician is willing to take responsibility for the installation with some degree of oversight. Regardless of who does the work, the home crafter-electrician should understand what is involved if for no other reason than because that provides perspective on the rest of the installation.

Designing the Service

First, it must be emphasized that the utility should be contacted during the plan- ning stage. If you build the service without utility consultation, it is possible that the installation will not be satisfactory from the utility's point of view, so expen- sive rework will be necessary before the utility will connect. Most utilities have a detailed book of specifications that they give to electri- cians. This book has diagrams with explanatory wording on every conceivable service type and configuration, including labor and materials to be supplied by the customer. The utility will have an engineer whose job is to view jobs prior to construc- tion. It is not unusual for this individual to make more than one visit to the site to

Underground Services

Underground services are somewhat more expensive to build, but they contribute to making an upscale building. There is no service drop to impede the view and no service-entrance cable or weather head to clutter the finish wall. With a back-to- back meter and entrance-panel hookup, the underground service makes for a simple and elegant final product, and it will enhance the value of your real estate. Generally speaking, a backhoe is needed to dig the trench from the utility pole to the meter location. The question that always arises is, how deep does an electrical line have to be buried? Assuming that it is a back-to-back configuration, the underground hookup is quite simple, although more labor is involved than for an aerial service. The consultation with the utility representative will nail down the details. Generally, the customer digs the trench and furnishes the underground run of conduit, cemented with a pull rope in place. The conduit should be installed as a complete system, hooked up to the meter socket, and the trench backfilled and graded. The utility usually furnishes the service lateral conductors. The utility pulls them through the conduit and makes the terminations. The telephone line should be buried in the same trench with maximum separation from the power line. Use 2-inch PVC with sweeps and a pull rope. Leave stubs 1 foot above grade at both ends. The telephone company, subject to prior consultation, will pull in its line, put an interface box on the wall, and make all terminations, including bonding to your intersystem-bonding terminal. If the soil is at all rocky, the conduit should be bedded in screened sand to a height of 6 inches above the conduit. Then another 6 inches of native fill is added by hand to make sure that no big rocks damage the conduit. If you place the conduit against the edge of the trench and machine backfill from that side, there is less exposure to damage. The service lateral remains the property of the utility, and if there is a problem in the future (such as lightning burnout), it is the responsibility of the utility to make the repair. Because the service lateral is in conduit, it can be replaced even if the ground is frozen with no digging required. For this reason, even if the conductors are rated for direct burial, they are always put in raceway. PVC is the conduit of choice for almost all underground work. In consultation with the utility, you probably will use steel 90-degree sweeps and expansion joints to allow for ground movement if subject to freezing. At the building, place the sweep so that the stub will come up perfectly plumb with the meter-socket knockout. You can finish this prior to drilling through the building for the back-to-back stub so that the meter socket location can be adjusted laterally to make for a straight riser. The expansion joint should be put in with the outer part of the slider at the top so that it will shed water. Position the expansion joint midway between maximum and minimum length. Grounding and wiring to the entrance panel are the same as for an aerial service. At the utility pole, details should be worked out in advance. Typically, to a height of 8 feet above finish grade, Schedule 80 PVC is used. (All other PVC is Schedule 40.) Because the sweep contributes some rise, a 10-foot length of Schedule 80 PVC ordinarily will do. Most utilities want to see this piece installed by the electrician. Then the utility furnishes the rest of the run, using Schedule 40 PVC up to the transformer, where there is a weather head and a strain relief with a drip loop. Regardless of the type of service, the back-to-back arrangement of meter socket and entrance panel or main disconnect is preferable. There is less clutter inside and outside the building, and minimal conduit and wire are needed to get into the building. Moreover, both boxes are held very firmly in place and will never work loose. Sometimes, usually because of the vertical layout of the building, a back-to- back configuration is not possible. In such cases, we have already mentioned the need to install a separate disconnect if the indoor portion of the service-entrance conductors are of any significant length. In a non-back-to-back installation, the service-entrance conductors can be run as Type SE concentric cable or in a raceway. If cable, it is best to come out of the meter socket at the bottom. Such an arrangement is preferable because water infiltration is not an issue. It will drain straight out of the bottom. Where the cable enters the building, a small piece of hardware known as a sill plate is used. It is sized to fit the cable. The cable should enter the sill plate from below so as to shed water. Fill around the cable with silicone caulk. These conductors also can be run in a raceway. PVC, RMC, or EMT can be used. PVC conduit (gray UL listed, never white PVC water pipe) should not be used in long horizontal runs on the outside of a building because thermal changes will make it sag and buckle. EMT, if used outdoors, must have compression fittings. Set-screw fittings would allow water to enter, and they are used indoors only.

Techniques for Quality Electrical Work

Along with a good selection of quality tools, a good selection of quality techniques is essential for successful electrical projects. Some of this is mental and some is physical. By mental, we mean planning the project and proceeding in an efficient manner so that you are not pushing in the wrong direction. This has to do with performing in the right order the many small tasks that make up a complete job so that one completed phase of the work does not block another. By physical, we mean handling tools and materials in a skillful and precise manner so that the correct amount of force is brought to bear in ways that produce good results.

From Service to Finished Installation

Some examples will clarify these points. Building an electrical service is not too difficult, but if the job is not planned carefully, there is the potential for error and costly rework. We have previously stressed the need to consult with the utility representative prior to starting an installation. The utility will want the meter to be located where it is not exposed to damage (meters are very expensive), where it can be read easily (even if it is a smart meter), and if the service is aerial, where the service drop can connect to the power pole without an obstruction. This is an example of where prior planning makes sense. Moreover, you have to make sure that your service-entrance conductors can get into the building. If it is a back-to-back installation, make sure that the location of the entrance panel will work on the inside of the building. This enclosure has to be located so that the required dedicated and working spaces are provided; the door can open at least 90 degrees; there is no Code violation such as placing the entrance panel within a bathroom, clothes closet, or on a stairway; there is no potential conflict with water piping or duct work; and prefer- ably it is not necessary to move a framing member.

Possibilities for Error

This is an example of planning for an electrical installation, and it is similar to many other situations that arise. For every switch or receptacle that you place, there is the possibility for error. Often there is a good, better, and best solution. Even minor decisions can affect the quality of the job and the efficiency of the workflow favorably or adversely.

Appearance is very important. A conduit riser must be plumb to a very tight tolerance or the job will appear shoddy, even if electrically the error is inconsequential. In the case of an underground service lateral where the raceway connects to a 90-degree sweep and then rises vertically to enter a meter socket, if you complete and backfill the trench before mounting the meter socket, more precise positioning of the vertical riser will be possible. When doing raceway work this is a general principle for the placement of surface-mounted receptacles, switch boxes, light fixtures, and so on. Following this procedure will save a lot of work and make for more accurate raceway installations. As for the physical aspect, you should always be looking for easier and more efficient ways of doing things. The object is to reduce the amount of labor necessary to complete each task without compromising the quality of the installation. Always strive for accuracy. It takes less energy to make a straight and true cut than to make a crooked one.

Learning the Trade

If possible, watch other workers as they ply their trade. If you have the good fortune to work along with a skilled electrician for a period of time, that will be a great help. If you are a school teacher with the summer off, think about it. If working with or observing a professional is not an option, there are always YouTube videos. This is a wonderful way to pick up skills and expertise very quickly. With over 100 hours of video uploaded per minute, there is new material coming online constantly, so check frequently. Type into the search bar, “How to wire an entrance panel,” and take it from there. You’ll find some misinformation, but the extensive comments section helps to sort it all out. Overall, it’s quite lively and worthwhile. As you gain experience and expertise, even vicariously, as explained earlier, you will become adept at a wide variety of tasks, and you will find that knowledge and skills learned for one type of work can be applied in other areas as well. Use tools to their best advantage. For example, a metal wall box can be grounded by removing at least one of the square cellulose washers from the bolt in the yoke. Instead of slowly unscrewing them from that mile-long bolt, snip them off with your diagonal cutter. And while we are on the subject, removing concentric knockouts from a heavy-duty box such as a meter socket can be laborious in the extreme, but large diagonal cutters (dikes) make quick work of this task.

Some Labor-Saving Tips

Become ambidextrous. Most people favor one hand over the other for intricate tasks that require any degree of dexterity, but you can easily become ambidextrous. All it takes is a little practice. Try hammering nails with your off hand. You will soon get so that you can do it equally well either way. This is a valuable skill when, high on a ladder, you have to reach a long way to both sides. If you have two pieces to cut and install (it may be wire, raceway, lumber, or something else), always cut the longer piece first. Then, if you make a mistake and the piece proves to be too short, it can be cut down to make the short piece, and you will have a second shot at the long one. The end of a fish tape will snap off if you try to bend it sharply because it is semihardened. If the end breaks off, heat it with a propane torch to anneal or soften it so that a new hook can be formed.

Often you will want to use electrical tape to temporarily join two or more items. To aid in getting them apart later, spin the end of the tape between your fingers to leave a tail. When a device bolt breaks off in a wall box, it is a tough situation if the wall- board has been installed. If it is too short to grab with Vise-Grips, drill the broken bolt out, and tap the next size bigger threads. Chuck the tap into your cordless drill, and it will feed in nicely. Use thread-cutting lubricant if you want your tap to last. If you are going to mount a fluorescent strip fixture on a drywall ceiling, you will have to screw through the enclosure and ceiling material into the framing. The predrilled holes rarely coincide. Screw right through the metal without regard to the predrilled holes, a job for your cordless drill, as shown in Figure 7-7. Where possible, wire nuts in an enclosure should be positioned with the open- ings pointed down so that any moisture will drain. If you need to work on a light fixture over a sink, first close the drain so that dropped hardware will not be lost.

Use of 1/0 AWG and larger conductor terminations in a meter socket or entrance panel, shown in Figure 7-8, are difficult. Make use of the hole, with its rounded edges, at the end of the handle of a large adjustable wrench. The moving parts of these tools eventually wear out, so cut off the handles and save them as wire-bending tools. A partially severed wire buried in a wall will cause an arc-fault breaker to trip out. Temporarily(!) replace it with a standard breaker. A transistor radio tuned to no station with the volume turned high can be moved along the wall. A burst of static will indicate that you have found the fault. If it is a series fault, you will need a load connected at the last receptacle. When removing Romex, never pull it out from the middle of the roll. It will be full of twists. Instead, take the roll out of the wrapper, and set it up on a short length of pipe supported at both ends so that it can be unreeled. If you are installing Romex through drilled studs, start at the middle and go to the end that is the more difficult route. Then you can unroll enough to get to the other end, allowing for error, and finish the installation. Romex, shown in Figure 7-9, comes with various color jackets depending on the manufacturer and the lot. If you use different colors for branch circuits, tracing and troubleshooting will be much easier. In addition, Romex handles better when it is warm. If it is cool, turn up the heat in the room or warm the roll using a small electric heater immediately before installation. A cable ripper is an inex- pensive little tool that allows you quickly to slit the outer jacket of Romex with- out danger of nicking the conductor insulation. Most wiring can be done without junction boxes. Wherever possible, use daisy-chain rather than spider-web configurations. (The opposite, as we shall see in Chapter 11, is true for communication and data wiring.) Where a junction box is necessary, use a 4 × 4 box, shown in Figure 7-10, rather than an octagonal box. In basements and utility areas, mark the contents of a junction box on the cover. We won't have much to say in this book about conduit bending because most residential wiring is not in raceways. EMT in small diameters is easy to bend using a conduit bender, as shown in Figure 7-11, but for complex jobs, the routing becomes a daunting challenge—part science and part art. You need a good eye for what will work and look good, as well as a certain body of knowledge. Complex jobs even call for the use of trigonometric functions and other advanced math. An excellent reference on this topic is the well-known Benfield Conduit Bending Manual, 2nd edition (Overland Park, Kansas, EC&M Books, 1993). On the Internet, www.porcupinepress.com also provides lots of useful information on bending conduit. There are some residential applications where raceways can be used to good effect. We have already mentioned how PVC conduit is perfect for underground services and feeders and above-ground outdoor applications where long horizon- tal runs are avoided. Indoors, PVC also can be used, but EMT is not expensive in small quantities and has a better appearance. It should be secured using the proper hardware, as shown in Figure 7-14. Anytime you have a wiring drop, such as in a basement or utility room, through the air to a hot-water heater or similar appliance, it should be run in a raceway, preferably EMT. You can transition from Romex to EMT by going through the correct connectors and splicing the conductors using wire nuts inside a 4 × 4 box. Don't forget that the enclosure, at least the cover, must be accessible, although not necessarily readily accessible.

Lighting Fundamentals

In new residential construction and remodeling, it is said that premium upscale lighting is the least expensive way to enhance the value of a building. Consider what the addition of a few high-end outdoor fixtures can do for an otherwise nondescript building! Then there is the whole concept of low-voltage landscape lighting. The object in residential lighting is to create designs that will be comfortable, aesthetically pleasing, and energy efficient. A great many types of fixtures are available from electrical distributors or in "big box" stores. As opposed to large commercial or industrial work, it is not necessary to have a specialized lighting engineer on the job. If you look over some existing installations, perhaps in the homes of neighbors, and make notes on what seems to work and what does not, you will be off to a good start. There are some very basic principles that apply to the lighting in different areas. In Chapter 3, we discussed three- and four-way switches in some detail. Be certain that you are placing these switches correctly. Everything should be optimized for the end user. In the interest of energy efficiency, the easiest way to cut costs when it comes to lighting is to facilitate turning off the fixtures when the light is not needed or perhaps dimming them.

Lighting Control

Besides manual switching, lights may be controlled in a variety of ways, and this is particularly applicable to outdoor lighting, although there are distinct advantages in optimizing the indoor part of the installation as well. A simple device is the photovoltaic (PV) sensor. It is frequently built into outdoor fixtures, or it may be deployed remotely. When the ambient light declines below a certain level, the solid-state switch conducts so that the fixture lights up. Like a thermostat that controls a furnace or a pressure switch for a water pump or air compressor, there is a certain differential between cut-in and cut-out to prevent short cycling. Often a PV sensor has a sliding sheet-metal shield that may be moved to partially block the ambient light for the purpose of adjusting the on-off times. An inexpensive PV sensor works well for a while, but eventually it fails by shorting out so that the light remains on during daylight hours. Generic replacements are available and attach by means of a locknut at a suitable knockout. Electrically, it is a simple two-wire device that connects in series with the fixture’s hot terminal. Another common and very simple arrangement is a timer. An inexpensive unit plugs into a receptacle and may power a lamp through its cord. (Beware of using an extension cord as a form of permanent wiring.) There is also a larger, higher-amperage timer in a metal enclosure that is intended to control 120- or 240-volt loads such as a hot-water heater. It is useful for lighting as well. Still another variety of lighting control is accomplished by means of a motion sensor that is built into the fixture. It can be a little difficult to calibrate so that it does what it is supposed to do. It’s just a question of tweaking the on-board sensitivity, range, and duration controls and adjusting the motion detector. Because it also has a PV sensor that prevents it from lighting during daylight hours, you may have to return to the fixture more than once. Occupancy sensors save energy by turning off interior fixtures if there is no activity in the room for a prescribed period of time. There are a number of other means for controlling lights. Door switches at one time were widely used to control closet lights, and in commercial and industrial facilities, battery-powered emergency lights come on instantly when the main power fails, bridging the interval before the backup source comes online. Another energy-saving strategy is to use the type and size lighting that is appropriate for the setting. When energy was cheap, incandescent bulbs with electrically heated filaments produced abundant light that, at 10 cents per kilowatt- hour, made sense. The next generation was fluorescent light, specifically low-pressure mercury vapor in long tubes. To get an overview of what is involved in residential lighting, here are some definitions used by professionals:

• Astronomical time switch. A lighting control device that switches lights on at dusk and off at dawn irrespective of the actual clock time.

• Chandelier. A high-end ceiling-mounted or suspended decorative light fixture, frequently used in dining rooms, that is composed of glass, crystal, or other ornamentation in addition to the lamps.

• Continuous dimmer switch. A lighting control that varies lamp brightness gradually from maximum output to off.

• Stepped dimmer switch. A lighting control that varies lamp brightness in discrete steps from maximum output to off.

• Fluorescent. A low-pressure mercury vapor electric discharge light fixture in which the phosphor coating on the inside surface of the lamp emits visible light when exposed to the ultraviolet (UV) radiation produced by the ionized gas.

• General lighting. Also called ambient lighting and opposed to task lighting, it provides a uniform level of illumination throughout a large area.

• High-intensity discharge (HID) lighting. This includes metal halide and high-pressure sodium lights.

• Incandescent. A lamp that contains a metal filament, usually tungsten, that emits copious light when electrically energized.

• Lamp. Commonly called a light bulb, this generally consists of a glass envelope that contains a gas that can be ionized or a vacuum so that there will be no oxygen that would allow the filament to burn.

• Light-emitting diode (LED). A semiconducting device that emits light when forward biased.

• Lumen. A measurement of the quantity of light emitted by a light source.

• Multilevel lighting control. A device that reduces light in a series of steps as an energy-saving strategy. • Pendant. A light fixture that hangs from the ceiling, often supported by a metal raceway that contains the electrical supply conductors.

• Sconce. An attractive wall-mounted light fixture.

The larger the building, the more removed it is from everyday experience, especially in terms of lighting design. We cannot all become lighting design engi- neers overnight, but as we peruse the literature and become familiar with the ter- minology (e.g., lumens, color rendition, and the like) and sizing conventions, light- ing design begins to make sense. Certain other aspects of the finished product are important. One of these is interior painting. Ceiling and walls should be white— use matte instead of high-gloss paint to minimize glare. The floor should be light colored and low gloss. These seemingly minor building decisions can greatly aug- ment good lighting choices to create a more comfortable home.

Kitchen Lighting

In a kitchen, significantly more lighting is required for the countertop area than for the floor space. Lighting should be provided as needed for specific tasks. The cooking area should be well lighted with good color rendition. Recessed lighting is the way to go, with under-cabinet lighting that is task specific and controlled by separate switching. Recessed cans should be in the ceiling directly above the edge of the counter so that the user's shadow will not block illumination of the task at hand. Three-way switching is essential at room entries.

Bathroom Lighting

If there is an occupancy sensor, a second light fixture should be provided that is not controlled by that sensor so that a user, taking a bath, will not be left in dark- ness. No light fixture should be located over the bath or shower. At least two fixtures should be provided on either side of the sink.

Lighting in Other Rooms

Install multiple fixtures that are controlled by separate switches as an energy-saving strategy. Branch circuits should not exactly correspond to room division so that if an overcurrent device trips, the room will not be left in total darkness. In hallways, three-way switching is essential. Low-output lighting is sufficient and economical. In a workshop, adequate well-placed, cool-white fluorescent lighting is the best choice. Workbench areas should be lighted and switched separately.

Living Room, Dining Room, and Bedroom Lighting

Wall sconces with low-wattage lamps provide excellent mood lighting that uses less electricity. Be sure that three- and four-way switching is in place. Track lighting is used to illuminate wall pictures and other items of special interest. A chandelier over the dining room table will be a thing of beauty at moderate cost. Be sure to install a dimmer switch!

In a bedroom, consider wall sconces and track lighting, if appropriate. A ceiling fan with lamp and fan motor on separate switches is desirable. It should not be located over the bed.

Outdoor Lighting

Timer switches located indoors, perhaps adjacent to the entrance panel or in a separate closet, are an effective means to control outdoor lighting and permit bet- ter regulation than a PV sensor. For example, outdoor lighting can be set to switch off at 1 a.m. A motion sensor will provide the end user with outdoor illumination where access to a switch is not practical. Any lighting installed in the vicinity of a pool or pond must comply with the National Electrical Code (NEC), Article 680.

Fluorescent Fixture Maintenance

If a fluorescent fixture is not lighting, don’t measure the voltage as delivered to the bulb socket. A high-impedance measurement taken by multimeter in voltage mode will be inconclusive, and it is hazardous to handle those thin wires when they are live. If a bulb is out, flickering, or at less than full brightness,

• Check power to the fixture.

• Twist the bulbs to see if they are firmly in the sockets.

• Change the bulbs.

• Check the internal wiring and sockets for loose connections.

• Replace the ballast.

Old bulbs draw more current and overload the ballast, causing it to overheat. Inevitably, the ballast will fail. Because the ballasts are more expensive than bulbs and more time-consuming to replace, fluorescent bulbs should be replaced proactively.

CONCLUSION

The main purpose of an electrical wiring system is to satisfy the user's needs and requirements, while coordinating the various components, such as the lighting, heating, and other systems, always complying with protection and safety standards. A good electrical wiring system doesn't only need to fulfill the purposes for which it was installed, but must feature a very high level of safety, quality, and flexibility, that will allow an easy maintenance in time, while guaranteeing a continuous and reliable power supply.

The most important feature of a well-functioning electrical wiring system is the reliability.

The system must always and at any time, be reliable and nothing can be left to chance. Electricity is transported from power stations to homes and businesses, through a series of underground power lines, common utility ducts and utility poles. The transmission network operates by lowering tension while getting closer to the final user: energy is directly delivered through insulated cables, to the private electricity meter.