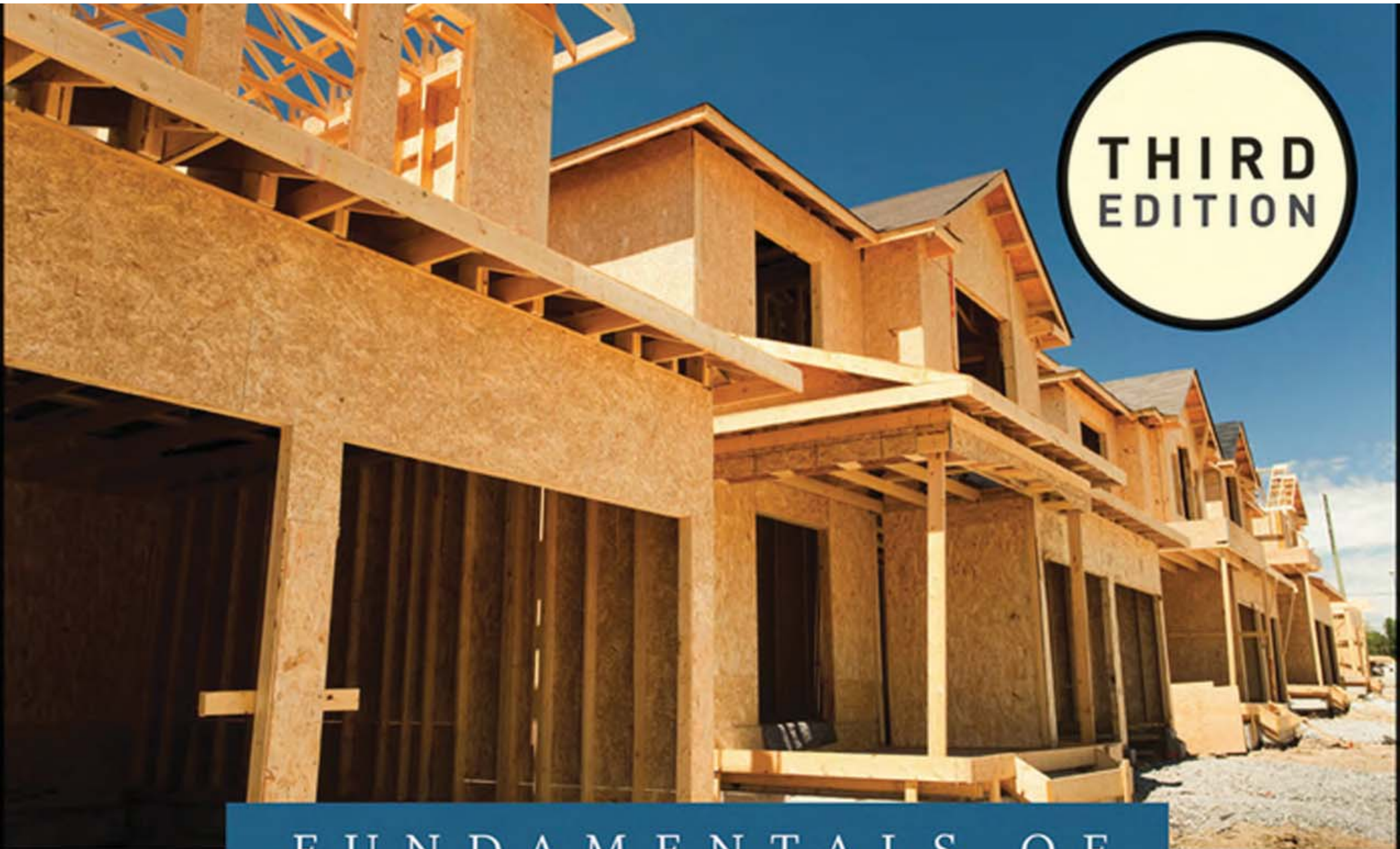

THIRD EDITION

FUNDAMENTALS OF

RESIDENTIAL CONSTRUCTION

Edward Allen Rob Thallon

16

ELECTRICAL WIRING

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Although we take it for granted, electricity has been an important part of people's lives for little over a century. In the 1890s, when electricity was first being introduced into the home, light fixtures were designed to operate on either gas or electricity because of the unreliability of electric power. Now virtually every appliance and apparatus in the house operates on electricity. Houses are so reliant on electricity that backup generators to supply energy during the occasional power outage are commonplace in some regions.

Wiring Basics

How Electricity Works

Electricity is the flow of electrons through a conductor. Because it cannot be seen, it is best described with the analogy of water under pressure in a hose. When the pressure or the hose diameter is increased, more water will pass through the hose, thus creating more force (power) as the water exits the end of the hose. An electrical system works similarly, with wire substituting for the hose and electrons for the water. In an electrical system, the pressure is called *voltage* (V), the flow of electrons is called *current* (I), and the restriction to flow is *resistance* (R). The relationship among these three elements can be expressed in a basic equation called *Ohm's law,* $V = IR$. With a constant voltage, less resistance (a larger-diameter wire) will produce a greater current. Current is measured in *amperes,* commonly referred to as *amps.*

A flashlight is an example of the simplest electrical system and can be represented by a battery connected with wires to a light (Figure 16.1). Electrical current flows in one direction through the wires from the battery through the light and back to the battery. When either piece of wire is disconnected, the circuit is broken, the electricity ceases to flow, and the light stops glowing. The electricity now exists only as potential (voltage) within the battery. The *power* (P) produced at the electrical device (the light bulb in this example) when the current is flowing is the product of the current and the voltage, $P = VI$. This type of system, with a current that flows constantly and in one direction, is called *direct current (DC).*

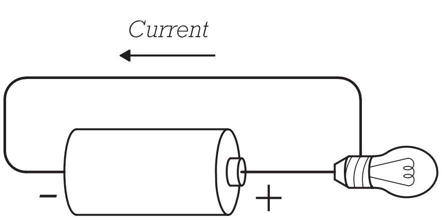


Figure 16.1
In the simplest circuit, direct current (DC) flows in a loop, starting from a source (battery), through wires to a device (light bulb), and back to the source.

The *alternating-current (AC)* system used to power buildings is not as simple as direct current. Alternating current in North America is driven by voltage that fluctuates between the positive and the negative at a rate of 60 cycles per second (the rate varies among different regions of the world) (Figure 16.2). The reason we use alternating current is that its voltage is easily increased or decreased with transformers. Electricity is transmitted most efficiently over long distances by wiring at as high a voltage and as low an amperage as possible. Thus, high voltage originating at the power plant can pass through long transmission lines with minimal voltage drop (power loss) and then be stepped down with a transformer to lower, safer voltage when it reaches its destination (Figures 16.3 and 16.4). As it enters the house, electrical power is rated as 110/220 V AC. This means that it is alternating current that can be used at either 110 or 220 volts.

Residential voltage actually varies from region to region, depending on the electrical utility company. East Coast voltage is generally 110/220 V or 115/230 V, while West Coast utilities deliver power closer to 120/240 V. In addition, voltage fluctuates locally throughout the day; voltage to a residence might range from 118 to 122 V, for example.

There are three wires that carry the electricity to a house—two *hot wires* and one *neutral wire.* Assuming a 110/220-V system, the hot wires each carry 110 volts, and the neutral wire provides the return path to complete the circuit. The potential between either of the hot wires and the neutral wire is 110 volts. The potential between the two hot wires is 220 volts (Figure 16.5). This high potential between the two hot wires is possible because the two are 180 degrees out of phase so that while one is positive, the other is negative (Figure 16.6).

The three wires (two hot, one neutral) enter the house through a *service entrance* and typically pass first through a *meter base* that holds the meter to measure power usage. From the meter base, the wires are routed to the *main panel,* called a panelboard

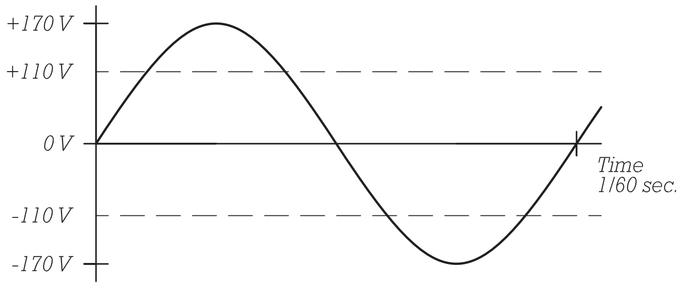


Figure 16.2
Alternating current (AC) cycles in a sine curve from positive to negative and back again at a rate of 60 cycles per second. The graph shows one cycle in which the voltage reaches both positive and negative peaks of 170 volts (positive and negative) but averages 110 volts.

Figure 16.3
Electric substations such as this use step-down transformers to convert very high voltage from long-distance transmission lines to a few thousand volts for distribution to residential neighborhoods. *(Photo by Rob Thallon)*

Figure 16.4
Typical local transmission lines carry direct-current voltage of several thousand volts that is converted with a transformer to 110/220 V AC. Communication lines are often strung between the same poles. *(Photo by Rob Thallon)*

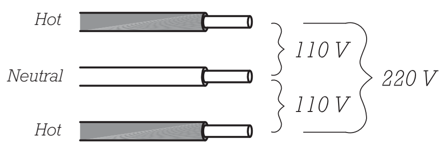


Figure 16.5
The voltage between each hot wire and the neutral wire is 120 volts. Because the sine curves of the hot wires are out of phase (Figure 16.6), the potential between these two wires is 240 volts.

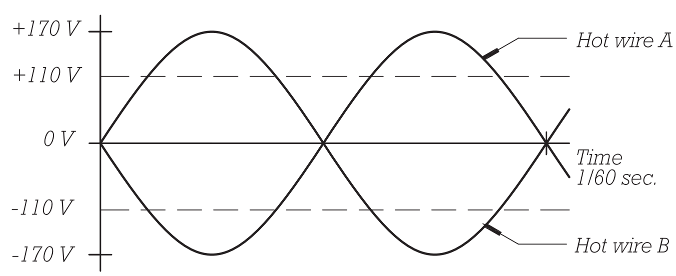


Figure 16.6
In a 110/220 V AC electrical system, the two hot wires are out of phase so that the average potential between them is 240 volts. The potential between each individual hot wire and the neutral wire averages 110 volts.

FIGURE 16.7
A typical service entrance as viewed from the inside of the house. The large cables that connect the residence to the power utility enter the house through the conduit at the left, which is connected to the meter base. From the meter base, the cables pass through another conduit, this one very short, through the studs to the 200-amp service panel at the right. The small cables at the lower left are telephone and television cables, each housed in a separate conduit. *(Photo by Rob Thallon)*

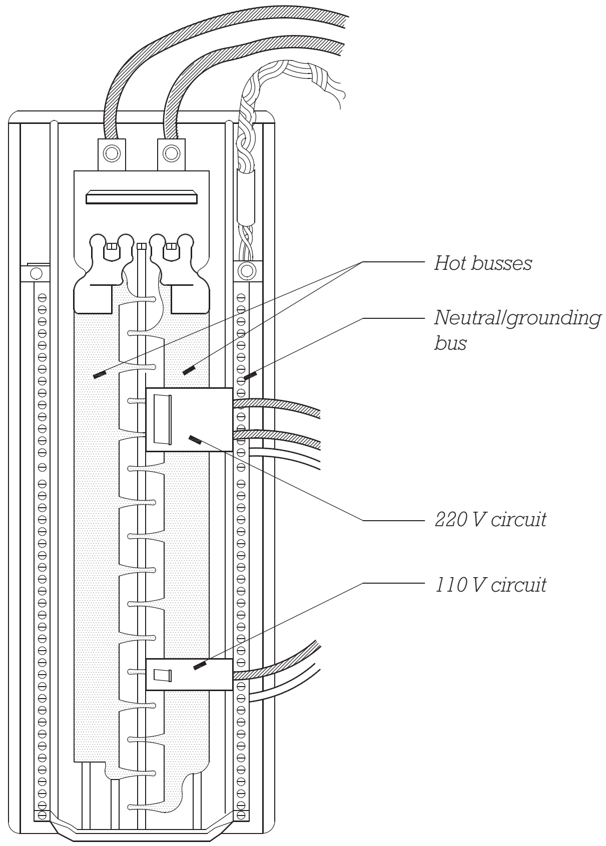


FIGURE 16.8
A typical 200-amp main panel box. The box is made of steel and receives the three main wires from the meter base. The breakers clip onto the hot busses to which the hot cables from the meter base are screwed. The neutral/grounding bus is connected to the neutral wire from the meter base and also to a ground rod driven into the soil. A 110-volt circuit is created by connecting the black (hot) wire of a cable to a breaker and the white (neutral) wire to the neutral/grounding bus. The bare grounding wire is also connected to the neutral/grounding bus. A 220-volt circuit is created by connecting two hot wires to a double breaker, which is connected to both of the hot busses.

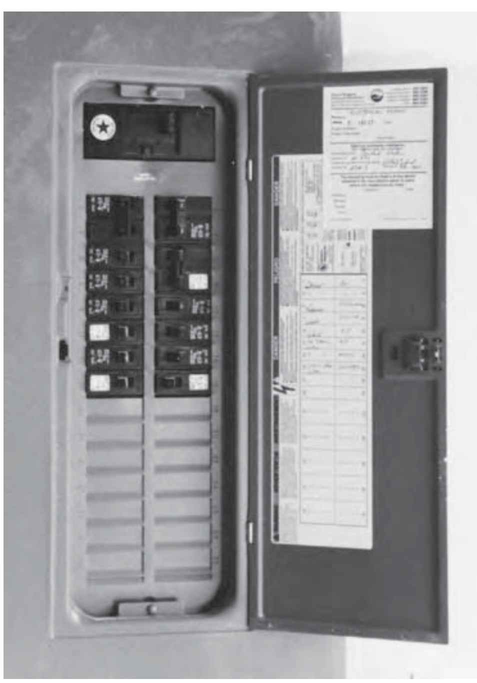


FIGURE 16.9
This 200-amp panel is typical of the average 2300-square-foot residence. The panel has a 200-amp main breaker and smaller breakers for each circuit. There are three 220-volt breakers just below the main breaker, and the remainder are 110-volt breakers. In this properly sized panel, there are 14 blank positions for the addition of future circuits. *(Photo by Rob Thallon)*

in the code (Figure 16.7). The main panel is the control center for electrical circuits in the house. It contains a *main disconnect* switch and *circuit breakers* that act as fuses for each electrical circuit (Figures 16.8 and 16.9).

Circuits are branches of electrical service within the house. All circuits originate at the main panel (Figure 16.10). A circuit may serve a single piece of equipment such as a water heater (equipment circuit), a set of receptacles designed for appliances (appliance circuit), or a collection of lights or receptacles in a number of rooms (general-purpose circuit). Each circuit is supplied by a single cable connected to a circuit breaker in the main panel. The cable for a 110-volt circuit contains three wires—a hot, a neutral, and a grounding wire.

The *grounding wire* is a safety device that provides a route for electricity other than the human body should a *short circuit* occur anywhere in the system. A short circuit results from a hot wire touching (and thus energizing) any conductor other than the part of the electrical equipment to which it is designed to supply power. Short circuits can occur when electrical motors fail, when wire insulation fails, or for any number of other reasons. In a 110-volt circuit, the electrical potential between the shorted equipment and the ground becomes 110 volts,

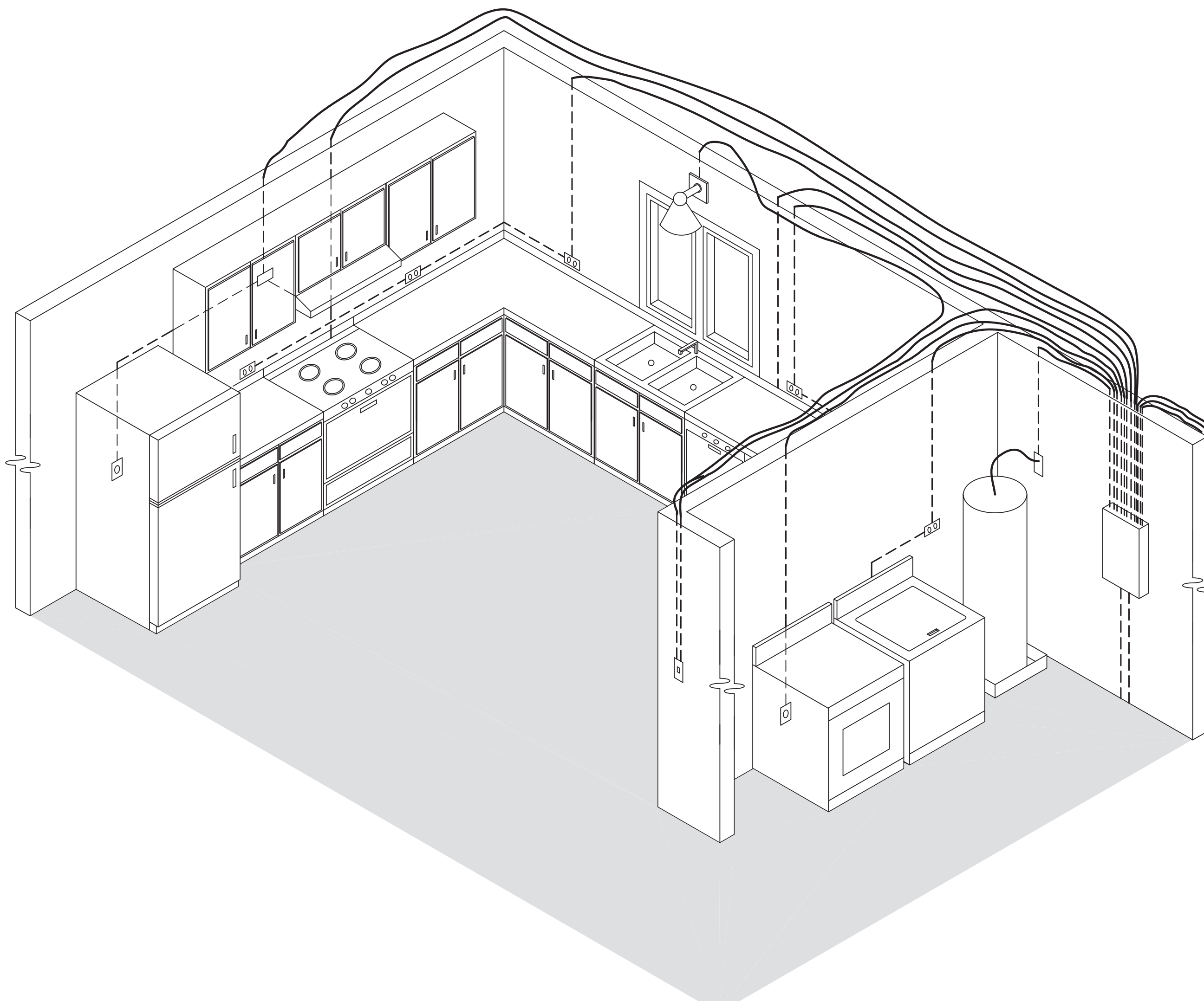
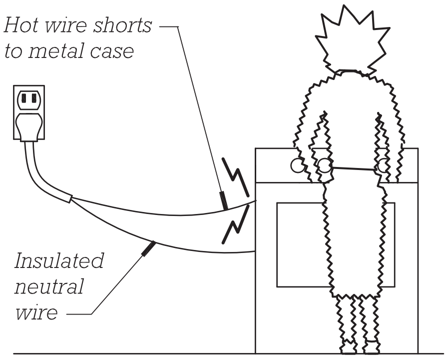
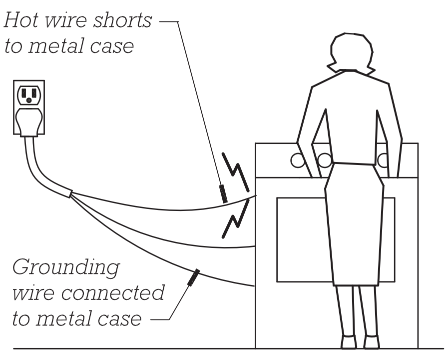


Figure 16.10

Circuits in a portion of a small house. Each circuit originates with a single cable at the main panel. Circuits are most concentrated in the kitchen, where there are numerous appliances. Some circuits serve only one appliance, while others may connect together many receptacles, switches, and lights. In a larger residence, there would be more circuits, but each circuit would be limited to the same maximum electrical load as in the smaller house.



(*a*)



(*b*)

Figure 16.11
An ungrounded appliance (*a*) is deadly dangerous. Current from a shorted hot wire will find a path to the ground through a person, if possible. A grounded appliance (*b*), on the other hand, will pass the current from a shorted hot wire through the grounding wire, causing the circuit breaker to trip.

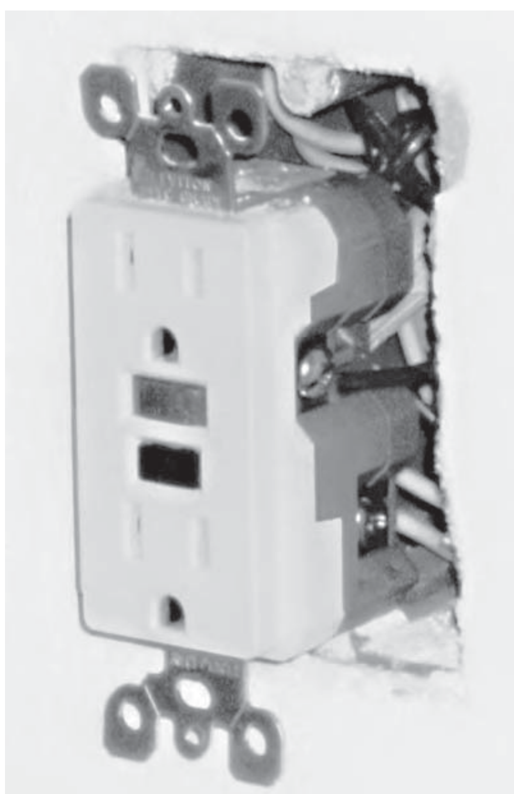


Figure 16.12
A GFI receptacle provides an extra degree of safety for electrical power outlets that must be located near sinks or in other dangerous locations where water is likely to ground a user. The GFI receptacle will shut down instantly upon detecting a small change in the current flowing through it. *(Photo by Greg Thomson)*

and any electrical conductor touching both the equipment and the ground will become the conduit for 110 volts. This much voltage can easily kill a person, so a grounding wire is connected to the metallic cases of electrical equipment. The grounding wire leads back to the main panel, where it is connected directly into the ground. If a short circuit occurs, the grounding wire rather than a person will carry the 110 volts to the ground (Figure 16.11).

The danger to humans of short circuits is especially high near kitchen and bathroom sinks, where plumbing provides a strong potential electrical conductor to the ground. If a person were touching both a shorted appliance and a faucet, it would take several seconds before the breaker in the main panel tripped to shut off the power to that circuit. In these especially dangerous locations, therefore, codes require special *ground fault interrupter (GFI)* receptacles (Figure 16.12) that detect small current changes such as occur when a person becomes an electrical conductor and respond by instantly shutting down the power to the circuit.

Arcing faults, which are caused by shorts in damaged or deteriorated wiring or electrical appliance cords, are another hazard of electrical systems. Arcing faults can produce temperatures approaching 10,000°F, and it is estimated that they cause over 40,000 residential fires in the United States each year. Although they produce intense heat, these events do not necessarily draw much current, so they do not usually trip a standard circuit breaker, which is designed to trip when a circuit becomes overheated due to overload or when a major short causes a sudden increase in current. A relatively new device, the *arc fault circuit interrupter (AFCI),* does protect against arcing faults. AFCIs are typically incorporated into conventional circuit breakers, allowing this single device to provide protection against overloads, short circuits, and arc faults. As of 2008, the National

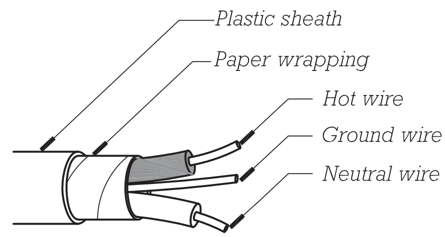


Figure 16.13
Nonmetallic (NM) cable is virtually the only cable used in residential wiring today. It consists of two or more insulated wires plus a bare grounding wire, all wrapped in a paper insulation and sheathed in a waterproof thermoplastic jacket. Early versions of this cable without the grounding wire have been around since before 1920.

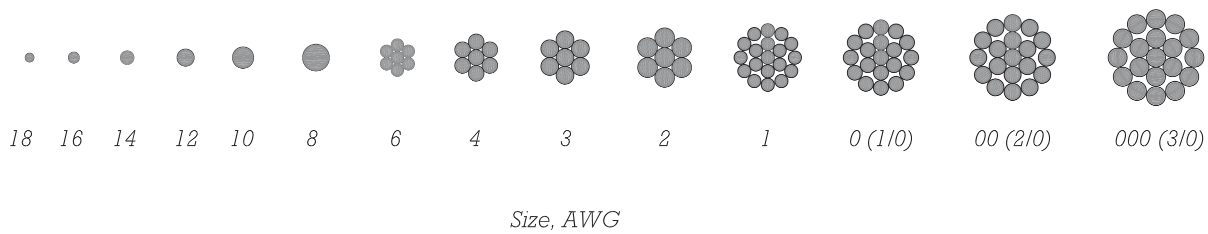


Figure 16.14
The chart depicts at full scale the American Wire Gauge (AWG) size of copper and aluminum wires commonly used in residential wiring. Typically, 18- and 16-gauge are used for low-voltage wiring; 14-, 12-, and 10-gauge for common lighting, receptacle, and appliance circuits; and the larger gauges for the service entrance and major equipment and appliances.

Electric Code requires AFCI protection for all 15- and 20-amp branch circuits installed in dwelling units.

Wiring Materials

The wires that carry the electricity are made of copper or aluminum—the most highly conductive metals that are affordable. (Silver is a better conductor than copper or aluminum but is too costly to be used in wiring.) Aluminum is usually used for the larger-diameter conductors leading to the house, whereas copper is used within the house for normal wiring. Aluminum has a cost advantage over copper, especially in large-diameter wire, but it corrodes when exposed to air, so it must be carefully coated with an anticorrosion agent wherever a connection is made. This makes it impractical for local circuits within a house, where multiple connections are required.

The wires are sheathed in an insulative coating that protects them from their surroundings and vice versa. Until the 1930s, each wire (hot and neutral) was run through the building independently, isolated from the structure by porcelain knob and tube fasteners. Now the most common wiring is a single *nonmetallic (NM) cable*—a thermoplastic jacket containing insulated hot, insulated neutral, and an unsheathed grounding wire (Figure 16.13). There are two types of NM cable—NMB for common use and UF with a plastic-sheathed grounding wire for underground or wet locations. In some locations, such as a water heater or electric range, wires require more protection from physical abrasion than NM cable can provide. In these situations, a flexible *metal-clad cable* or metal or plastic *conduit* is employed.

Wire size is described by *gauge*—the larger the gauge designation, the smaller the wire (Figure 16.14). The most common wire sizes in residential construction are 12-gauge, used for most receptacle circuits, and 14-gauge, used for lighting circuits. Ten-gauge and 8-gauge wire are required for many large appliances. The main wires connecting the residence to the power grid are the largest, the most common size being 3/0 for a 200-amp service. The relationship of wire size to amp ratings is shown in Figure 16.15.

	Allowable Ampacities	
Wire Gauge	**Copper**	**Aluminum**
14	20	—
12	25	—
10	35	—
8	50	40
6	65	50
4	—	65
3	—	75
2	—	90
1	—	100
1/0	—	120
2/0	—	135
3/0	—	155
4/0	—	180

Figure 16.15
The relationship of AWG size to allowable ampacities of insulated conductors at 167°F (75°C). For safety, circuits using 12-gauge cable typically are connected to a 20-amp breaker and circuits using 14-gauge cable to a 15-amp breaker.
(Source: 1999 National Electric Code, Table 310–16)

Electrical System Design

The Electrical Plan

The design of the electrical system is primarily the responsibility of the building designer. A plan drawing of the electrical system prepared by the designer is required in order to obtain a building permit and provides the basic information for the electrical contractor to install the electrical system (Figure 16.16). Using standardized symbols, the plan shows the location of *receptacles, switches, lighting fixtures,* the electric meter, and the main panel. In addition, the locations in the house of electrical equipment such as furnace, water heater, space heaters, washer, dryer, and kitchen appliances are noted in the electrical plan because they require wiring to supply electrical power. A good designer will cross-reference electrical plans with framing plans to ensure that joist locations do not conflict with the placement of lighting fixtures or other electrical devices. When combined with the electrical specifications, the electrical drawings allow the electrical contractor to estimate the cost of construction.

The code specifies that receptacles must be spaced along each wall such that an electrical device with a 6-foot-long (2-m) cord can always be plugged in no matter where the device is positioned along the wall. Effectively, this means that receptacles can be located no farther than 6 feet from the end of a wall and no more than 12 feet apart along the wall (Figure 16.17). With increasingly widespread use of computers and electronic entertainment devices in the home, many more receptacles than this are advisable. More receptacles are required in a kitchen where electrical usage can reasonably be expected to be higher than in a typical room.

One of the most challenging tasks for the designer of a house is the lighting design. Lights can be *surface mounted* or *recessed,* incandescent or fluorescent, line voltage or low voltage (Figure 16.18). Beyond these basic decisions, there is a vast array of fixture designs and light bulb types. With so many variables, the selection of appropriate fixtures, as well as their sensitive location within a room and in relation to other fixtures, has become an art. In commercial work, lighting design is a specialized field.

Switching for lighting must be indicated on the electrical plan as well. The basic toggle switch next to the door to turn on the light in a room is simple to locate (Figure 16.17). *Three-way switches* that allow a light to be turned on or off from two locations are useful at the top and bottom of a stair, the ends of a corridor, or two entrances to a room. Finally, *four-way switches* that allow switching from multiple locations offer even more options.

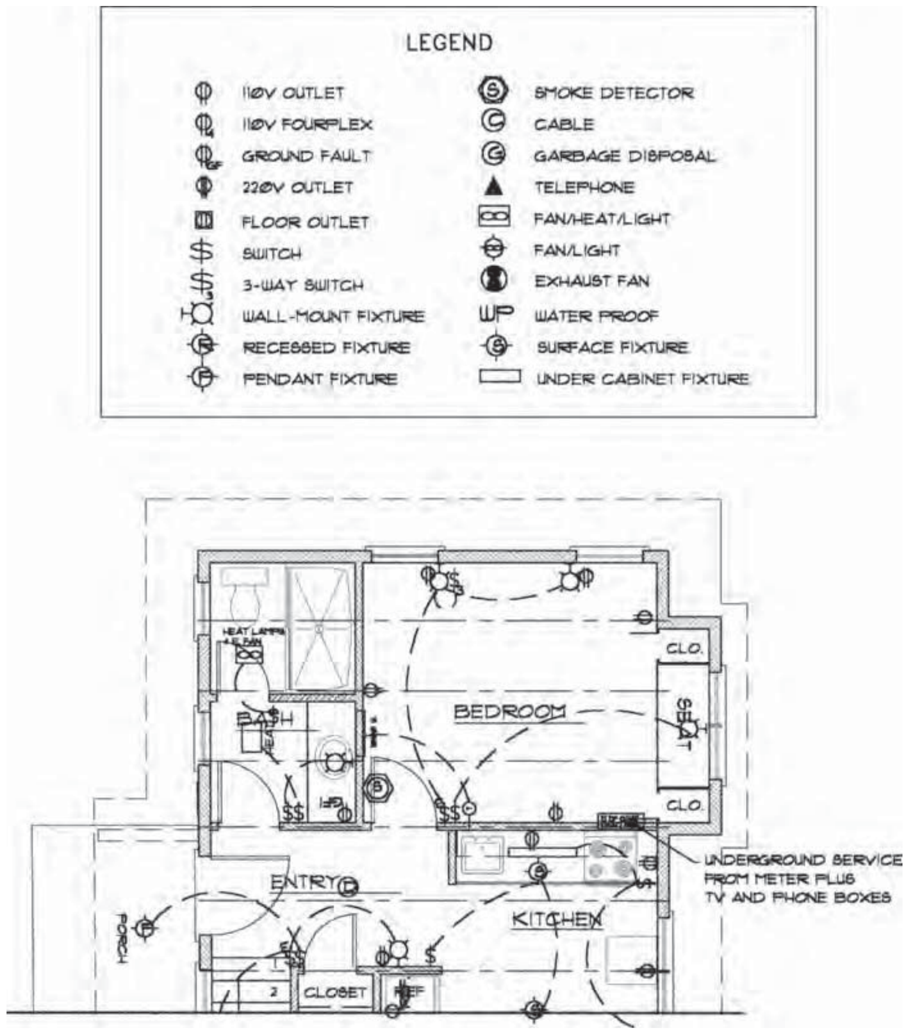


Figure 16.16
The electrical plan is drawn by the designer and serves as a guide for the electrical wiring. Standardized symbols show the types of electrical devices and how they are wired. The curved dashed lines show what connects to what and do not indicate actual wire routings. *(Courtesy of David Edrington, Architect)*

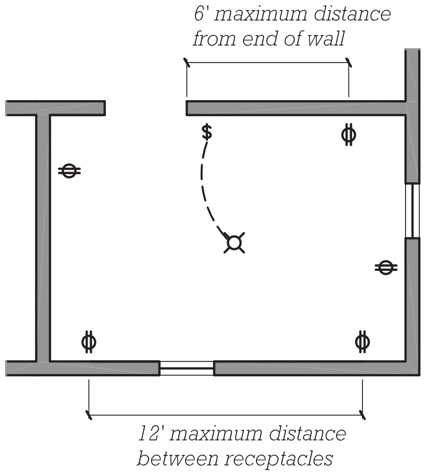


FIGURE 16.17
Plan drawing showing typical electrical requirements for a simple room. The light fixture is not required by code but is standard.

FIGURE 16.18
A wholesale electrical distributor displays a few of the hundreds of surface-mounted light fixtures available. These fixtures mount to standard electrical boxes located in the ceiling or the wall. Recessed fixtures are also available for ceiling locations. *(Photo by Rob Thallon)*

The location and size of the main panel are also determined before plans are submitted for approval. Because the wires between the meter base and the main panel are large and expensive, these two elements are located back to back on an exterior wall when possible. Most residential panels are rated at 200 amps, although smaller (125 amps) and larger (400 amps) panels are not uncommon. The designer may consult with an electrical subcontractor to select a practical size based on the present needs of the proposed building plus room for future expansion.

Sometimes it is advisable to install a *subpanel*. A subpanel is a separate panel with its own circuit breakers and is connected to the main panel with a single large wire. It is useful when a number of circuits are required at a location remote from the main panel. A subpanel might be used, for example, for the circuits in the top floor of a two-story house with the main panel in the basement. A subpanel might also be used for all the circuits in a house when the main panel is located in a detached garage.

Deciding on overhead or underground service and locating the meter base and the service entrance, where the electric service enters the building (Figure 16.7), are responsibilities of the designer. These decisions are best made in consultation with an engineer from the local utility company. The utility company typically provides the labor and materials to run wires from the local power line to the building, but trees may have to be cut down or trimmed to provide clearance for overhead service, and trenching for underground service may be complicated by rugged terrain, groundwater, or rocky soil. Locating the meter base for easy monthly inspection is also something that should be discussed with a utility company representative.

Planning the Circuits

Before the electrical system can be installed, the circuits must be planned. The intent of a circuit is to divide the electrical system into subsystems, each of which can be safely served with a single reasonably sized cable (Figure 16.10). Each circuit is protected against electrical overload with a circuit breaker at the main panel. Circuit breakers are designed to disconnect the circuit when amperage exceeds normal designed usage. Excessive current (amperage) can occur when too many devices are operating simultaneously on a single circuit, when there is a *direct short* (the hot and neutral wires are touching), or when there is a *ground fault* (the hot wire touches a ground or grounded conductor). Any of these conditions could cause the cable to overheat and ignite a fire if allowed to continue.

A typical set of circuits for an all-electric 2000-square-foot (200-m^2) house might include the following:

Dryer	30 A	240 V
Range	50 A	120/240 V
Dishwasher	20 A	120 V
Water heater	30 A	240 V
Heat pump	100 A	240 V
Kitchen plugs, 2 or 3 circuits at	20 A	120 V
Bath heater	20 A	120 V
Lights and receptacles, 6 or 7 circuits at	15 A	120 V
Garage	20 A	120 V

All these circuits can be wired to a 200-amp main panel even though their total amperage adds to over 400 amps because the code recognizes that only a fraction of the capacity will ever be used simultaneously.

With knowledge of the electrical code and practical experience in the field, it is the electrician who generally determines the number of circuits and their organization. This is done during the bidding process and refined when the system is being installed. The designer usually specifies circuits only when they are for a particular purpose, such as a designated computer circuit.

Rough-in Electrical Installation

The rough-in electrical work begins when the house is framed and dried in. The electrician is generally scheduled after the plumber (and the heating subcontractor, if there is one) because electrical cable is small and easily routed around obstructions. The small cables are also numerous and would likely interfere with plumbing and other utilities if they were installed first. All electrical wiring must be performed by a licensed electrician unless it is done personally by the owner.

Setting the Boxes

The first stage of the rough-in electrical work involves attaching the *boxes* (including the main panel box) to the framing. The main panel is made of steel and is designed to fit between studs, to which it is typically screwed (Figure 16.7). Boxes for receptacles, switches, and lights are made of steel or plastic and are nailed to the framing (Figure 16.19). There are accepted standards for the heights of receptacles and switches, but these are interpreted loosely by electricians whose principal goal in setting boxes is to do it rapidly. The size of each box is prescribed by code and depends on the number and size of wires that enter the box and the type of electrical device that it houses. Decisions about box size are made by the electrician at the site.

There generally needs to be a dialogue among the electrician, the designer, and the owner at the time the boxes are set. The electrician will locate boxes according to the electrical plan, but will have to make some adjustments because the boxes are attached to framing, which cannot be entirely laid out to accommodate electrical boxes. Occasionally, the electrician will have to add more receptacles than are shown on the electrical plan in order to meet code requirements. The designer must inform the electrician of the dimensions of trim, backsplashes, and other finish details that might interfere with electrical boxes. The faces of the boxes are typically set to project ½ inch (12.7 mm) from the framing in order to be flush with the finish wall, so the electrician needs to be informed if any finish wall thickness will vary from this standard.

Boxes on exterior walls are potential sources of air infiltration (discussed in Chapter 17) because they penetrate both the gypsum board finish and the polyethylene vapor barrier—both of which are used commonly as an air infiltration barrier. There are various schemes for sealing electrical boxes against air infiltration, and the responsible designer in cold climates will specify one of these schemes or locate the air infiltration barrier at the exterior of the wall.

Running the Cable

After the panel and boxes have been attached to the framing, the cable is strung between them. The cable for each circuit starts at the main panel and extends from box to box, linking all the boxes in a circuit together. Small holes are drilled in framing members to allow cable to pass through them. When running parallel to a framing member, the cable is stapled to it at frequent intervals as specified by code. Cable must also be stapled to a stud or other support just before it enters a box. At the box, the cable is cut—leaving sufficient length projecting from the box to connect the electrical device (receptacle,

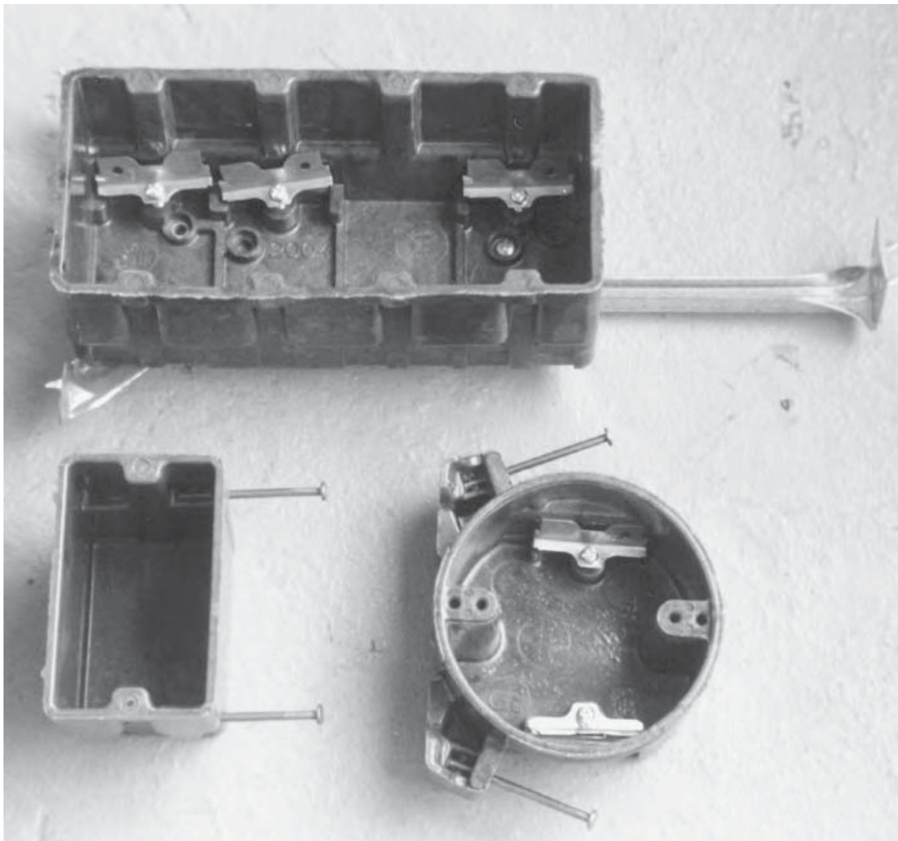


Figure 16.19
The most common electrical boxes: At the bottom left, a receptacle box is nailed to studs and accommodates a single duplex receptacle or a switch. At the bottom right, a light fixture box is designed to nail to a joist. Light fixture boxes with adjustable brackets to position the light fixture between ceiling joists are also available. At the top is a four-gang box for four switches. Multiple-gang boxes for two or three switches (or duplex receptacles) are also common. *(Photo by Rob Thallon)*

switch, light, or other device) at a future date (Figure 16.20).

Making Up the Boxes

When all the cables have been run, the wires are connected to one another and tucked into the boxes in preparation for the later installation of the receptacles, switches, and lights. This phase of the electrical work is referred to as *making up the boxes.* The first step in making up a box is to strip the plastic sheathing off the cables that project from the box, exposing the individually insulated wires. The wires are then cut to length according to their function, the insulation is stripped from them where required, and wires are connected to one another with *wire nuts.* The grounding wires of each cable entering a box are always connected during the make-up phase.

After the connections have been made, wires are folded back into each box to complete the process of making up the circuits (Figure 16.21). At this time, the temporary power is usually disconnected, and the main panel is connected to the permanent service entrance. Circuit breakers are installed in the panel, and some circuits are usually activated in order to provide electricity for construction tools and lights.

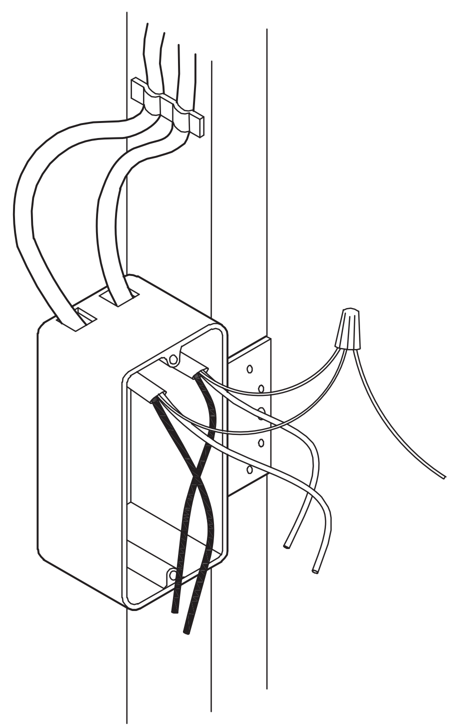


Figure 16.20
To make up this receptacle box, the outer plastic sheathing is stripped back from the two entering cables, revealing the individual wires inside. The grounding wires are connected, and then all the wires are folded back into the box.

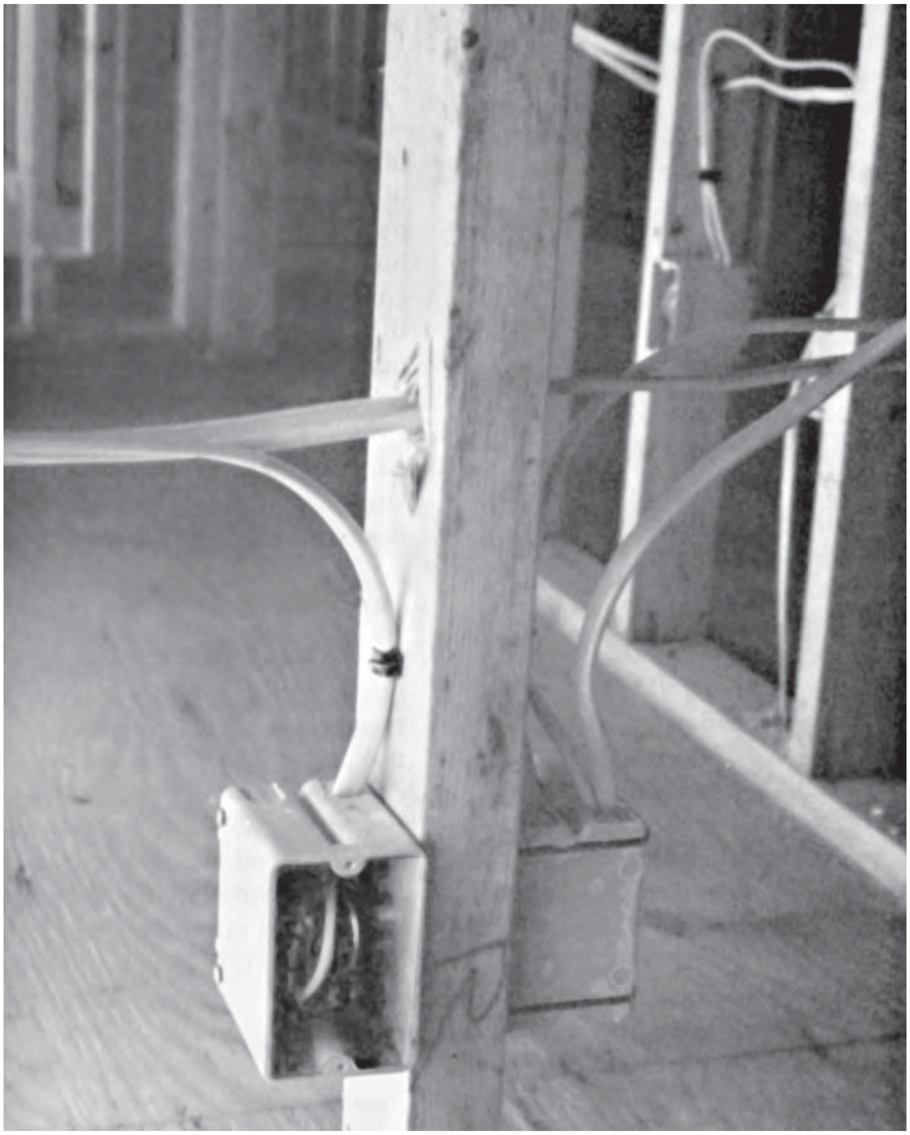


FIGURE 16.21
The made-up box has all of the wiring complete except for the connection of the electrical device. The wires are folded back into the box until the device is connected. Notice that the face of the box is set forward from the face of the stud so it will be flush with the surface of the (future) finished wall. *(Photo by Edward Allen)*

Rough Inspection

A rough-in electrical inspection is scheduled once the rough-in wiring has been completed. At this time, the electrical inspector verifies clearances from the ground to overhead service wires and from the service entrance to the building. If there is an underground service, the depth of the cable is scrutinized. Connections to the power supply at the meter base and the main panel are also checked. The main panel is checked to see that breakers are properly sized, located, and connected and that there is adequate clearance around the panel. For local wiring, the inspector looks to see that there is an adequate number of circuits and receptacles and that the cables are properly supported, fastened, and protected.

FINISH ELECTRICAL

The electrician returns near the end of construction to finish the system. At this point, the cabinets have been installed, the trim is done, and all the painting has been completed. The finish electrical work involves installing all of the receptacles and switches, along with their cover plates; installing the lighting fixtures; and connecting appliances and equipment. The electrician tests all circuits and equipment before their final inspection.

General-Purpose and Appliance Circuits

Receptacles and switches are the most straightforward devices to install. Each is connected to the hot, neutral, and grounding wires; screwed into the box; and, finally, covered with the protective *cover plate* (Figure 16.22). Receptacles and switches are available in several colors and in a wide variety of styles and range of quality. The designer stipulates in the specifications the type to use.

Lighting fixtures present somewhat more of a challenge to the electrician, because there is such a wide variety of fixture types, each having its own idiosyncrasies. Surface-mounted fixtures are easier to install than recessed ones. Heavy fixtures need to be attached to framing adequate for their support. Recessed fixtures fit into housings that have to be installed during the rough-in phase. Recessed lighting fixtures located in insulated ceilings must be of a design that is approved for such locations to prevent overheating. Low-voltage lights must have a *transformer*, ideally concealed but accessible, to step down the voltage.

Equipment Circuits

Heat pumps, furnaces, water heaters, dryers, ranges and ovens, range hoods, dishwashers, garbage disposals, submersible pumps, and garage door

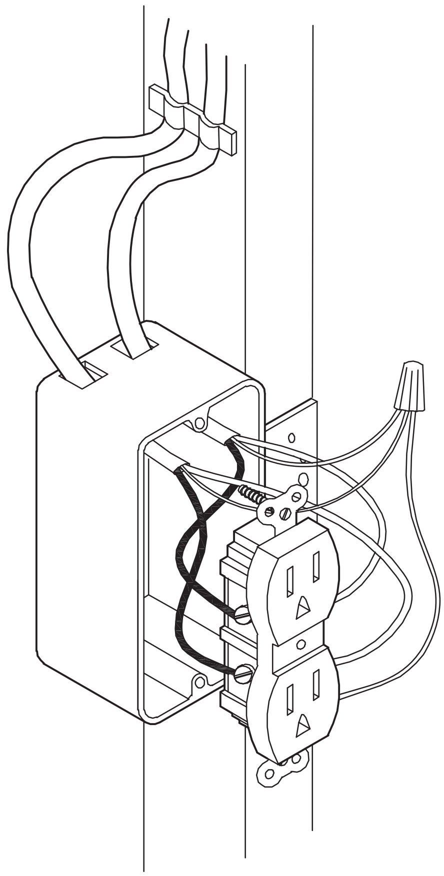


Figure 16.22
A receptacle that has been wired but not yet screwed to its box. Connections may be made at push-in terminals on the back of the receptacle or screw terminals on the sides. The screw terminals are safer and are used in all high-quality work because the contact area between wire and receptacle is much greater. Once connected electrically, the receptacle is screwed to the face of the box, and the cover plate is attached to its face to trim the device.

openers are among the most frequently installed electrical equipment. Each may be supplied by a different manufacturer, and each may have different requirements for electrical connection. For this reason, wiring is most efficient if this equipment is specified before the rough-in wiring is installed. When this is not possible (which is frequently the case), the electrician can allow for a range of possibilities by leaving extra length of wire at the equipment location. Connections to appliances such as the water heater, dishwasher, furnace, heat pump, and garbage disposal often require flexible metal tubing to protect the wires. Coordination with the plumber and the cabinetmaker may also be necessary for some equipment.

Final Inspection

Once the wiring has been completed, a final inspection is arranged. The municipal electrical inspector will spot-check some of the receptacles to be sure that they are operational and will flip some switches to ensure that they work. In addition, all GFIs are checked, some equipment is spot-checked, and the main panel is examined to verify its completion, including the labeling of circuits. The successful completion of a final electrical inspection is required as part of the final building inspection and is necessary for granting the certificate of occupancy.

Electrical Wiring and the Building Codes

Regulations governing the installation of electrical systems in residences are currently contained in the International Residential Code, Chapters 33–42. The regulations are derived from the National Electric Code, a more comprehensive code covering electrical work in buildings of all types and sizes.

The electrical codes are primarily concerned with safety. For example, clearances around the main panel are dictated to allow access in emergencies, and a maximum spacing between receptacles is specified to eliminate extension cords and dangerous long runs of small wire. The code-writing organizations work with approved testing agencies to set minimum standards for electrical equipment and devices. These organizations also work with licensing agencies to train qualified electricians and to require their supervision of electrical work at the site.

Low-Voltage Wiring

In addition to electrical power, several other residential systems require wiring that runs through the framing. The most common of these are telephone, cable television, and satellite television. Other such systems include Internet cabling, low-voltage lighting, security, sound, intercom, heating and cooling thermostats, and the old-fashioned doorbell or chime. Many require installation by specialized subcontractors.

Each of these systems operates on electricity of such low voltage that it cannot give a fatal shock or start a fire. Therefore, they need not be installed by a licensed electrician. None is regulated by code, and thus no inspections are required. Telephone, cable television, and Internet systems are powered by their service providers, but low-voltage electricity must be produced for other systems by a small step-down transformer within the house. Often, this transformer, generally about the size of a single-serving package of breakfast cereal, is located inside a piece of equipment such as a central control panel for a security system.

Low-voltage wiring systems are roughed in and finished at approximately the same time as the conventional wiring. In addition to the conventional electrical contractor, a high-end house may require the services of a home theater installer; a specialized lighting contractor; and installers of a security system, cable television, Internet wiring, and an intercom.

Building Green with Electrical Systems

- The metals used for electric wires, copper and aluminum, are both produced with the expenditure of great amounts of energy from ores that are gradually being depleted. These ores are obtained by open-pit mining, which destroys wildlife habitat, disrupts drainage patterns, and leaves ugly scars on the land.
- Wiring that is removed from buildings being demolished, and scraps of wiring from new installations, can be recycled.
- Experience over the past century has shown a consistent pattern: No matter how many electrical outlets we provide in a new building, there will not be enough of them at some point in the near future. It is difficult to sustain an argument in favor of reducing the amount of wiring in a building.
- The consumption of electricity in a building can be minimized by using high-efficiency lighting sources and appliances. Occupants can be trained to turn off lights and machines when they are not needed. Lights can be controlled by devices that sense whether a room is occupied or not.
- Houses and workplaces designed for daylighting use much less electricity than ones that are not. Daylighting involves careful placement and orientation of the building on the site, purposeful placement and sizing of windows, provision of suitable reflecting surfaces, and installation of closure devices such as curtains, blinds, or shades to control direct sunlight.
- Except in areas that use hydroelectric power, electric resistance heat is wasteful of energy because two-thirds of the energy in the fuel consumed by a power plant is lost in generation and transmission.
- Electric smoke alarms save hundreds of lives each year by alerting sleeping occupants of a fire within the building before they are overcome by smoke. Most building codes require them.

C.S.I./C.S.C.
MasterFormat Section Numbers for Wiring

26 00 00	ELECTRICAL
26 50 00	LIGHTING
26 51 00	Interior Lighting
26 56 00	Exterior Lighting
27 00 00	COMMUNICATIONS
27 40 00	Audio-Video Systems
28 00 00	ELECTRONIC SAFETY AND SECURITY

Selected References

1. Richter, H. P.; Schwan, W. C.; and Hartwell, F. P. *Wiring Simplified* (42nd ed.). New Richmond, WI: Park Publishing, Inc., 2008.

A classic reference for those who choose to learn how to wire their own house, and an excellent reference for those who want to learn about the principles of residential wiring and the practical methods of installation.

2. Mullin, Ray C. *Electrical Wiring Residential* (17th ed.) Chicago: Delmar, 2010.

A widely used textbook explaining how residential electrical systems work, how they are designed, and how they are installed.

Key Terms and Concepts

voltage
current
resistance
Ohm's law
amperes
amps
power
direct current (DC)
alternating current (AC)
hot wire
neutral wire
service entrance
meter base
main panel
main disconnect
circuit breaker
circuit
grounding wire
short circuit
ground fault interrupter (GFI)
arc fault circuit interrupter (AFCI)
nonmetallic (NM) cable
metal-clad cable
conduit
gauge
electrical plan
receptacle
switch
lighting fixture
surface-mounted fixture
recessed fixture
three-way switch
four-way switch
subpanel
direct short
ground fault
electrical box
making up a box
wire nut
cover plate
transformer
low-voltage wiring

Review Questions

1. Explain the relationship among voltage, current, and resistance.

2. What are the differences between a neutral wire and a grounding wire?

3. Trace the path of electricity from the municipal power supply at the street to a light bulb in a house. Use specific terms for all the cables and devices through which the electricity flows.

4. What are the steps involved in rough wiring a house? Discuss why each step is in its particular sequence.

5. What are the typical wire sizes used in residential construction? For what purpose is each employed?

6. Explain the differences between line voltage and low-voltage systems. Make a list of typical uses of low-voltage systems.

Exercises

1. Obtain a residential wiring plan from a local architect or builder and discuss with your class the symbols used to describe the work of the electrician. Can you think of improvements to the drawing or to the design?

2. Make a wiring plan for a simple house plan taken from a newspaper or magazine.

3. Visit a house under construction with the rough wiring exposed. Sketch or photograph installed components such as a switch box, subpanel, main panel, and meter base and annotate the illustrations with procedures performed by the electrician in order to install the component. Include such procedures as the drilling of holes, stapling of cables, stripping of wires, and so on.