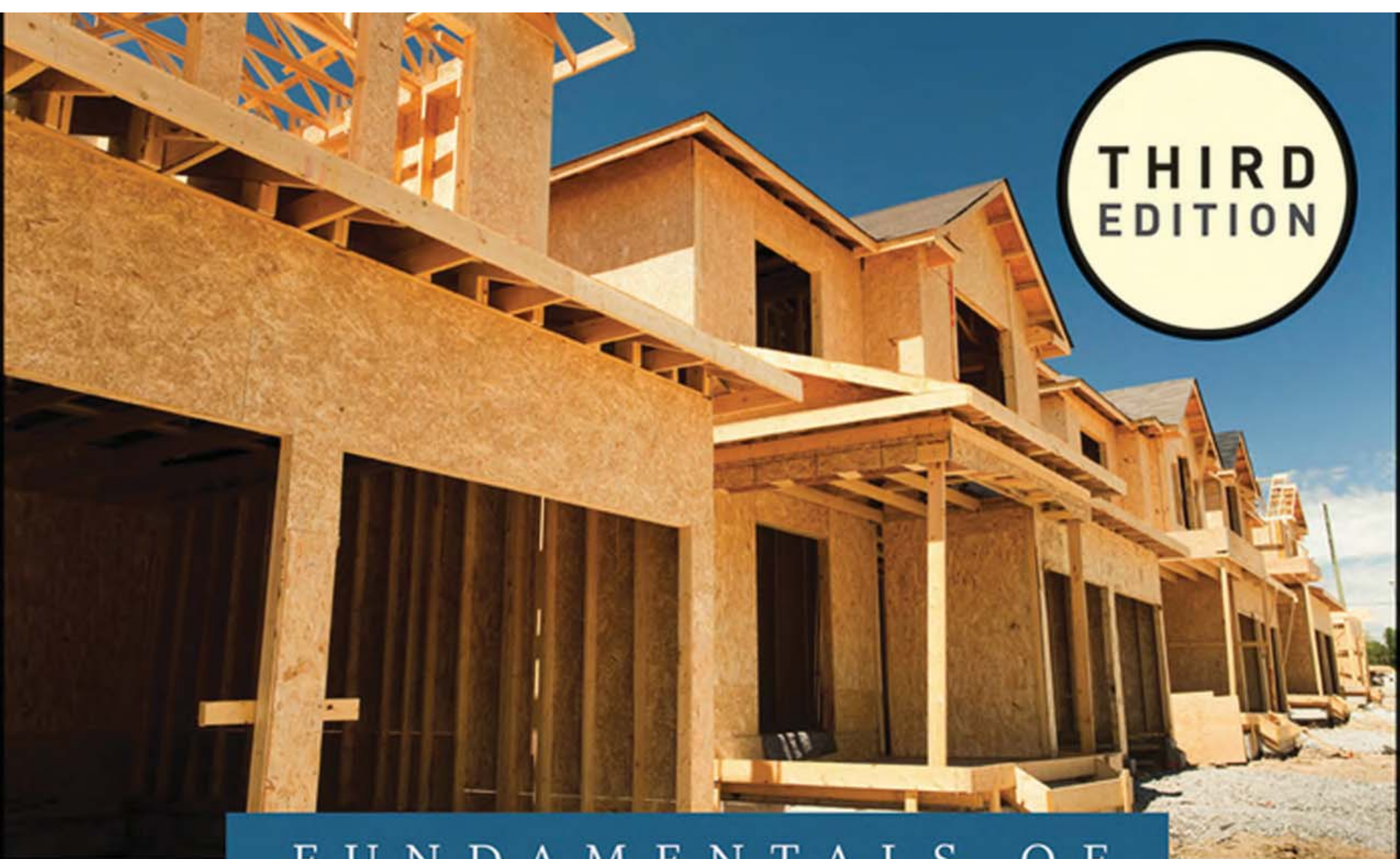

THIRD EDITION

FUNDAMENTALS OF

RESIDENTIAL CONSTRUCTION

Edward Allen   Rob Thallon

15

Heating and Cooling

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Modern heating and cooling systems, designed to maintain temperature and humidity within a zone of human comfort, are often more sophisticated than any other system in a house. They feature efficient equipment, complex distribution systems, and sensitive controls. Their installation can involve the trades of plumbing, sheet metal work, electrical work, insulation, and carpentry. The same system may be called on to heat during the winter, cool during the summer, control humidity all year long, and remove dust and pollen from the air. As a category, systems that condition the interior environment for human comfort are referred to as *heating, ventilating, and air-conditioning (HVAC) systems*.

The design of an efficient HVAC system should take place simultaneously with the design of the building itself. Simple systems such as baseboard heaters may be designed by rules of thumb, but more sophisticated systems that both heat and cool are often designed by an engineer in collaboration with the building designer. In a typical scenario, the design process starts with a proposed preliminary design by the building designer based on the needs of the client. The engineer or heating system specialist then develops the proposal sufficiently to make suggestions about the size and location of equipment and a heat distribution system. Next, the engineer and designer, working together, refine the design sufficiently to specify its details in drawings and specifications. In complicated buildings, there may be several cycles of discussion between engineer and designer, but in simpler buildings, one round of discussions may be adequate. In all cases, the building designer must integrate the system into the planning, the structure, and the finish details of the house, and the engineer will refine the details of the system as it is being installed.

A well-designed system takes into account the many energy conservation principles now well known in the house building industry. With a coordinated approach between building designer and heating engineer, the system can be both efficient and effective. Extra insulation in the envelope of the building can result in a smaller and less expensive system. For heating systems, the potential for passive solar assistance should be considered. For cooling systems, the simple principles of shading and natural cross ventilation can have a significant beneficial effect.

Choosing a System

The ideal HVAC system effectively provides for human comfort, is efficient in terms of energy consumption, and can be upgraded or extended over time. There are so many factors to consider that the choice is difficult, but consumers have firsthand experience with most systems, and design professionals are becoming more skillful in explaining the strengths and weaknesses of each (Figure 15.1). Recently, designers and contractors have begun to use *life-cycle costing*, which examines all energy-related costs over the life of the building, as an effective tool for selling responsible investment in long-term energy savings.

FIGURE 15.1
A comparison of the principal types of heating systems. Local source systems include electrical baseboard heaters, wall heaters, and radiant stoves.

	Advantages	Disadvantages
Forced air	• Rapid response time • Ability to filter air and control humidity • Ability to both heat and cool	• Relatively noisy • Ducts are bulky • Difficult to zone
Radiant panel	• Quiet • Invisible • Zoning is simple	• Slow response time • No cooling or air filtration
Hydronic baseboard	• Zoning is simple • Quiet	• Baseboard placement can limit furniture arrangements • No cooling or air filtration
Local source	• Zoning is automatic • Low first cost	• Most are relatively noisy • No air filtration

There are four basic categories of HVAC systems from which to choose:

- *Forced-air systems,* which heat (and cool) air at a central location and force it through ducts to all the rooms of a house. The process of moving heat by means of air is called *convection.*
- *Radiant panel systems,* which employ water or electricity to heat large areas such as floors or ceilings. The heat travels directly from the heated surfaces by means of *radiation* to reach the objects and occupants of a house.
- *Hydronic baseboard systems,* which operate with a centralized boiler that supplies heated water to small, locally controlled *convectors.* These systems employ both convection and radiation.
- *Local source systems,* which heat (or cool) by means of small local units such as baseboard heaters or wall heater/air conditioners built into each room of a house. These systems also employ both convection and radiation.

Each of these categories has several variations. The selection of the system most suited to the particular circumstances of each building should take all of the following into consideration:

Climate. The difference between a cold climate where heating is the dominant need and a warm climate where cooling is required will have a significant impact on the selection of a system. More subtle climatic differences such as high or low humidity, wind, and other factors will also impact system selection.

Construction system. If a house is built on a slab, the options for heating systems are quite different from those for a house with a basement or crawlspace. Radiant systems are easily incorporated into a slab, for example, whereas forced-air systems are not.

Construction cost. There is a wide range of costs associated with various heating systems. As a rule, the first cost of electric baseboard heaters is the lowest, whereas a sophisticated heat pump system can cost many times more.

Energy source. The availability of inexpensive energy often affects the selection of a heating system. Inexpensive electric baseboard heaters and wall heaters are common in areas with low electrical rates but rare in areas where electricity is expensive.

Zoning. It is often desirable to create distinct *heating zones* in a house. There may be a desire to have sleeping areas cooler, bathing and dressing areas warmer, or rooms that are seldom occupied at different temperatures. The desire to create distinct heating zones in a house will lead to the selection of systems that are reasonably simple to zone.

Air quality. Humidity control and air filtration are possible with some systems, but not with others.

Aesthetics. Some systems such as the radiant floor are free of grills, registers, or appliances and allow total flexibility of furniture arrangement. Other systems such as freestanding heaters can become the focus of a room.

Distribution system. Centralized systems can have heating and cooling distributed throughout the house by air (forced-air systems) or water (hydronic systems). Forced-air systems require relatively large ductwork, while hydronic systems require only small pipes.

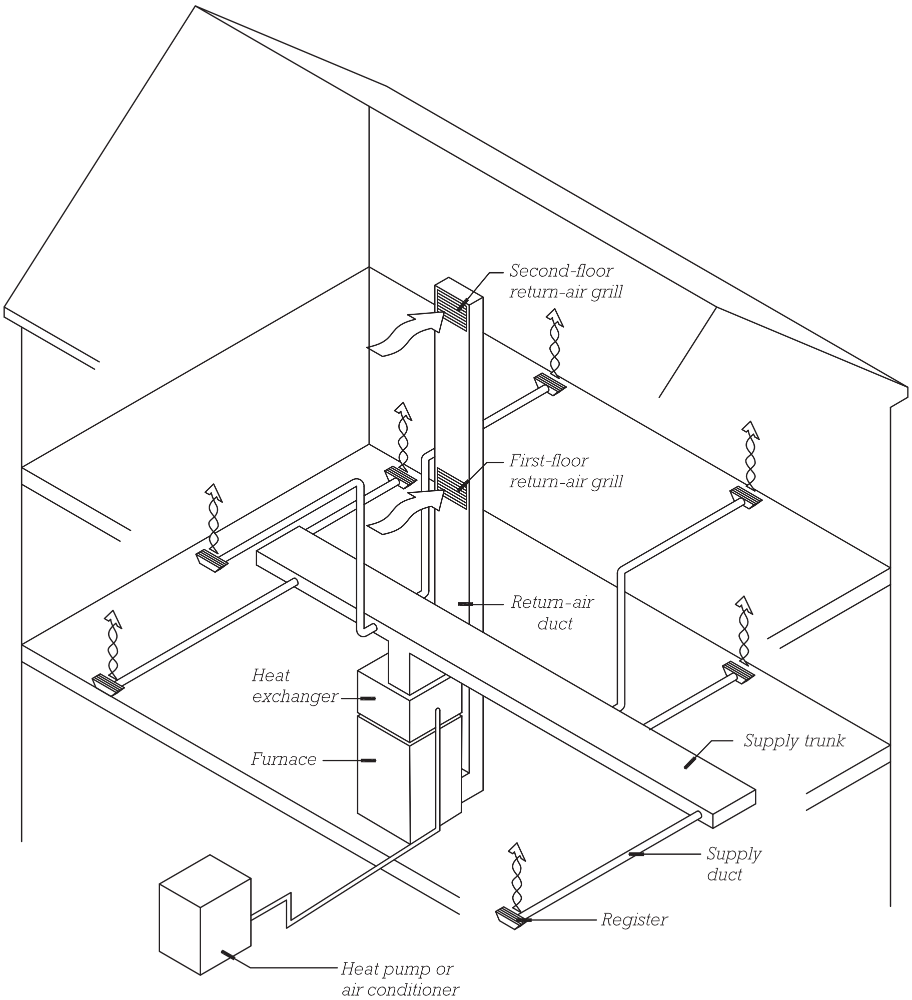

Figure 15.2
A forced-air system in a two-story house with a basement. The furnace is in the basement and blows warm air through supply ducts to registers in the floor near the exterior wall of each room. The air returns to the furnace through a centrally located return-air duct with a return-air grill near the ceiling of each floor. With the addition of a heat pump or an air conditioner, the system is capable of delivering cool air as well.

Forced-Air Systems

Forced-air heating is by far the most prevalent heating system in North America, accounting for over 60 percent of all residential heating. The *forced-air heating system* is composed of a *central furnace* that heats air and forces it through small *supply ducts* to each room. From the room, the air travels back to the furnace via a *return-air duct*. A fan located in the furnace moves the loop of heated air. The ducts that conduct the air between the furnace and the rooms are usually insulated and are sized for the volume of air passing through them (Figure 15.2).

Advantages of forced-air systems include the ability to heat a house rapidly and the potential to integrate other climate control devices with it. The most common addition to the system in moderate climates is a *heat pump* (Figure 15.3), which can increase heating efficiency by a factor of about 3. A typical heat pump works like a refrigerator in reverse and will extract heat from outdoor air even though the air is cool. Air-to-air heat pumps commonly work efficiently in air as cold as 30°F. Below this temperature, an auxiliary source of heat must be used to warm the air in the system. The same heat pump that provides heating will also provide cooling; however, cooling ducts need to be slightly larger since more air volume is required. Cooling can also be added to the system with a simpler and less expensive electric *air conditioner* (Figure 15.4). Both humidity and air quality can be controlled at the furnace with specialized equipment added to the main supply duct. A *humidifier* can add moisture to the air, and a *dehumidifier* can lower the moisture content. Both are controlled by a humidistat located strategically in the house. Every furnace has a simple filter located in the central return-air duct in order to remove dust from the air for the benefit of the occupants of the house and the longevity of the furnace. An *electronic air filter* that will eliminate much smaller particles, including pollen, can be added to the system at this same location.

The efficiency of any heating device is measured by its *coefficient of performance (COP)*. The COP is the ratio of the energy output of a heating device to its energy consumption. The COP of an electric resistance furnace, for example, is 1.0, meaning that all of the electricity consumed to produce heat is returned in the form of heat. Air-to-air heat pumps typically operate in the 3.0 COP range when outdoor temperatures are above 32°F (0°C), meaning that they produce three times as much heat as an electric resistance furnace consuming the same amount of energy. There are also water-to-air

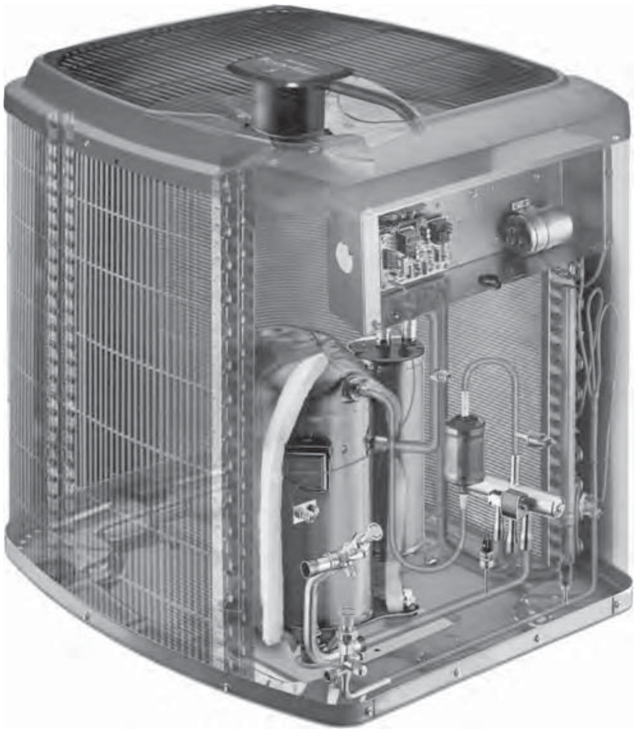

FIGURE 15.3
The residential air-to-air heat pump extracts heat from outdoor air as cold as 32°F (0°C), and this heat is transported through refrigerant lines to a heat exchanger in the furnace. The compressor unit shown here is the exterior component of a heat pump. The fan moves outdoor air across coils containing refrigerant to change the temperature of the refrigerant. The heat pump can work in reverse to cool during warm summer months. These units are generally noisy and should be located as far as possible from outdoor social spaces or bedroom windows. *(Courtesy of Carrier Corporation)*

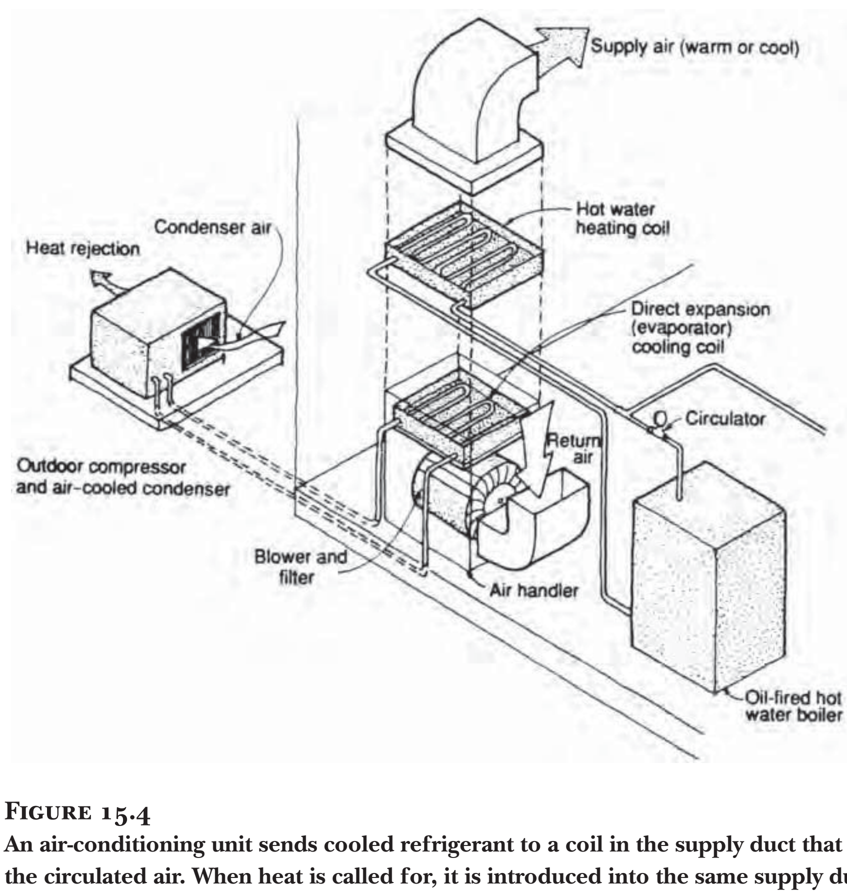

FIGURE 15.4
An air-conditioning unit sends cooled refrigerant to a coil in the supply duct that cools the circulated air. When heat is called for, it is introduced into the same supply duct with a heating coil. In this case, heat is from hot water, but electricity or a gas-fired burner can also be used. *(From Benjamin Stein and John Reynolds,* Mechanical and Electrical Equipment for Buildings, *9th ed., John Wiley & Sons, Hoboken, New Jersey, 2000)*

heat pumps and ground-source heat pumps that have COPs up to 4.0. These heat pumps extract heat from groundwater or from the ground itself. The ground is usually at approximately 55°F (13°C), making it a practical source for both heating and cooling.

A principal disadvantage of the forced-air system is that it is difficult to zone because the furnace supplies air to the supply ducts at a single temperature. Further, the moving air makes noise as it passes through the ducts, the supply registers, and the return grills. In addition, the heat of the furnace tends to dry out the air as it passes through, and the air passing through rooms can create drafts. Furniture placement is somewhat limited by the location of supply registers, and the potential for heat loss through leaky ductwork is significant. When a forced-air system incorporates a heat pump, care must be taken to keep the noisy outdoor units away from bedroom windows and other areas where tranquility is desired.

Components of the System

The central furnace contains two principal components—the *heating element* and the *fan* (Figure 15.5). The heating element can operate with a variety of fuels, including electricity, heating oil, kerosene, natural gas, or propane. A cooling element may be added in line with the furnace for warm summer months. The fan is invariably powered by electricity; thus, the system will be inoperable during a power failure regardless of the source of heating fuel.

Many central furnaces are designed to accept the cooling coils of a heat pump. In fact, if provisions are made for refrigerant lines, it is relatively simple to add the outdoor unit of the heat pump at a later date. However, cooling typically requires a higher volume of air than does heating, so the ducts need to be sized accordingly.

Planning a Forced-Air System

The location of the furnace has a notable effect on the cost and efficiency of a forced-air system. The most important considerations are that the furnace be centrally located and be accessible for service. The center of a basement is an ideal place for a furnace because supply ducts can all be relatively small and the return-air duct can be short because of its central position. Many furnaces are located in the garage, which is good for access but requires longer and larger ducts than a central furnace location, so duct heat loss becomes an issue. Provided that there is adequate height and that the furnace may be positioned on its side, the crawlspace may also be used to harbor a furnace so long as maintenance and replacement of the furnace are considered. Furnaces may also be located in a closet or in the attic. A furnace with a combustion-fired heat source must be supplied with outdoor air and vented to the outdoors to remove the byproducts of combustion. The type and size of the required vent can play a role in the location of the furnace.

Modern furnaces capable of heating a 2500-square-foot house are generally 18 to 24 inches square by 3 to 4 feet long. They are classified according to their orientation into *upflow, downflow,* or horizontal units (Figure 15.6). Upflow units blow supply air from the top of the unit and downflow from the bottom. The type of unit needs to be matched with its position in a house. Upflow units, for example, are commonly used in a basement, and horizontal units are typical in crawlspaces or attics, where height is limited.

Coincident with planning the furnace location and of equal importance is planning the location of the return-air duct. This large duct, which draws warm air from the ceiling or floor level, must be planned for carefully, especially if it extends between floors, because it cannot fit within the standard thickness of a wall. (A return-air duct for a 2500-square-foot house is approximately 10 by 20 inches.) Too often, this duct is not accommodated in the design and must be shoehorned in during the framing phase of construction. In economical forced-air systems, the return duct draws from one or two central locations in a hallway or at the top of a stair (Figure 15.2). In this case, the supply air reaches the return-air duct by passing under doors that have been shortened (undercut) at their base to allow for the passage of air. For improved air distribution, the return duct branches out to draw air from each room supplied with warm air.

The *main supply duct* is approximately the same size as the return duct as it leaves the furnace, but it may branch immediately into two or more ducts that are proportionately smaller. Planning a route for supply ducts to individual rooms is a reasonably simple task because these ducts are small. (A supply duct for a bedroom, for example, can generally fit within the stud space of a 2 × 4 wall.) As a rule, it is most efficient to locate supply registers in the floor below a window. The rising warm air from the supply duct will counteract falling cool air from the window to reduce air movement across the glass, thus reducing heat loss (Figure 15.7). In two-story residences, supply ducts must rise vertically (on an interior wall if possible) to the second floor and often must also travel horizontally through a joist space to reach their destination. Their route

FIGURE 15.5
A forced-air furnace. Return air enters at the base of the unit, where it is filtered. From here, a fan forces the air through the elements heated by gas flames and through a cooling coil at the top of the unit. Units designed for horizontal mounting are also available. *(Courtesy of American Furnace Division, Singer Company)*

must be carefully planned in order to minimize bends and to avoid structural members, plumbing, and other possible obstructions.

Supply (or return) ducts may be eliminated altogether by using the crawlspace as a *plenum.* This is accomplished by eliminating ventilation to the crawlspace and insulating its walls and ground surface while also sealing it carefully against air infiltration and moisture from the ground. The warm supply air is then blown directly from the furnace into the crawlspace and registers are cut into the floor (Figure 15.8). The crawlspace has effectively been made into a large supply duct. Rooms on upper floors can be supplied via ducts running from the crawlspace to floor registers. Return air is ducted to the furnace as it would be in a normal fully ducted system. Advantages of this system include warm floors on the ground level and the elimination of ground-floor supply ducts from the heating budget. (The savings accrued by not having to insulate the joist floor above the crawlspace are offset by the need for crawlspace wall and floor insulation.)

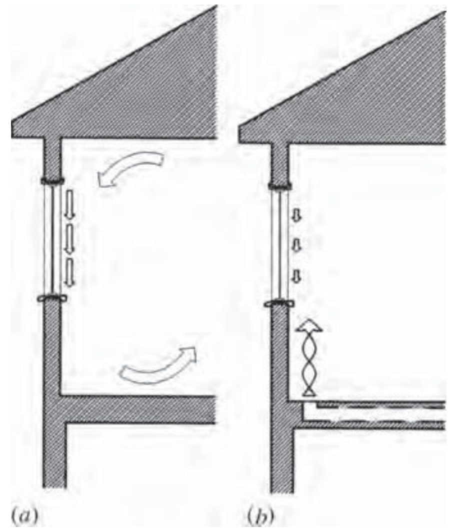

FIGURE 15.7
(*a*) Air cooled by cold glass will fall and induce a convective air current in a room, which brings more air into contact with the cold glass. (*b*) Heat released by a heat source located under a window will rise, counteracting the downward flow of cold air at the window. This reduces the flow of air across the cold glass, thereby reducing heat loss.

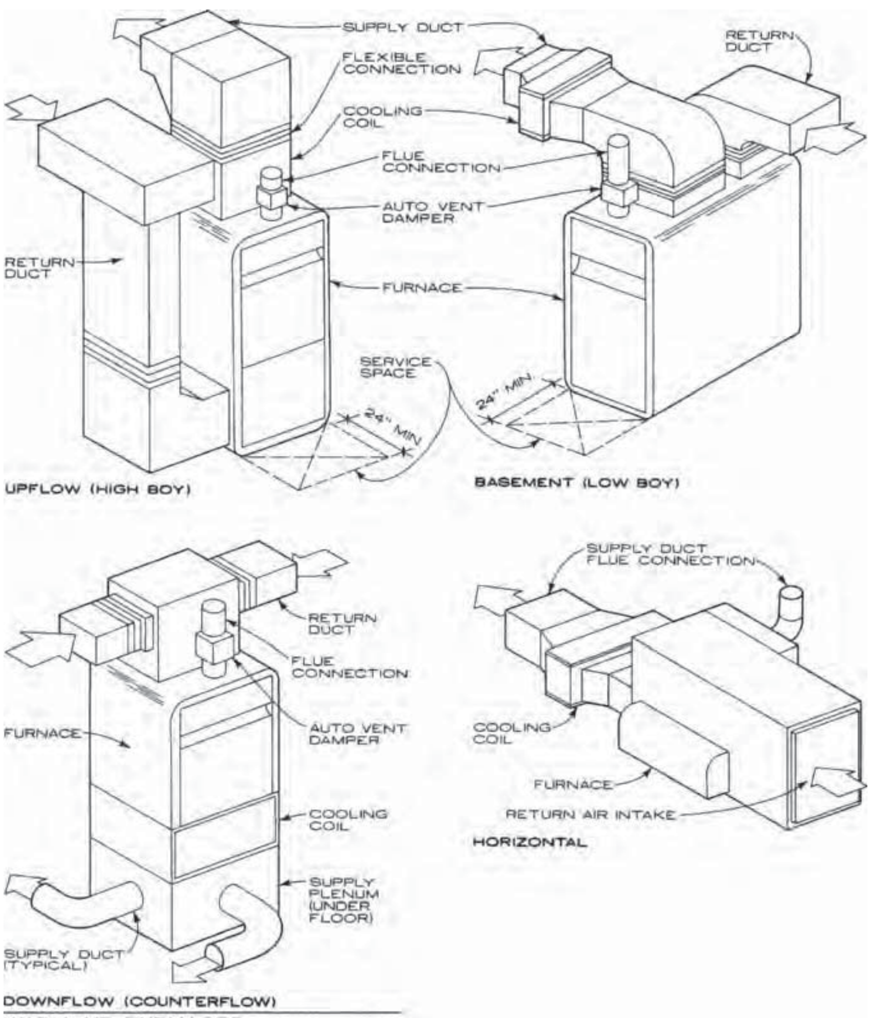

FIGURE 15.6
Warm-air furnaces are classified by orientation. Upflow furnaces are most common for basements, while downflow furnaces are most common when located on the first floor. Horizontal units are used in crawlspaces. *(Reprinted by permission from Ramsey/Sleeper,* Architectural Graphic Standards, *8th ed., John Ray Hoke, Jr., A.I.A., Editor, John Wiley & Sons, Hoboken, New Jersey, 1988)*

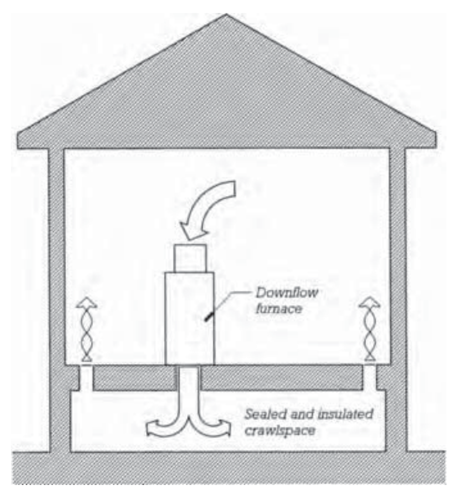

FIGURE 15.8
When using a crawlspace as a supply plenum, a downflow furnace delivers warm air to the crawlspace, which is sealed and insulated. Supply registers in the floor of the various rooms control the flow of air to the house. Return air is collected at the ceiling level and ducted back to the furnace.

Forced-Air Rough-in Construction

Installation of ducts by the forced-air heating contractor is generally scheduled just after the plumber. Both plumbing waste lines and heating ducts are large, but plumbing usually takes precedence because its location is less flexible and waste lines must have a specified slope (Figure 15.9). Like plumbers, forced-air heating contractors will want to complete their work in a crawlspace before the subfloor is applied. The remaining ductwork is installed later, after the framing has been completed. If the house has a basement (and thus good access to the area under the first floor), all the ductwork will likely be installed at one time after the roof has been dried in.

Large ducts are customarily fabricated in the heating subcontractor's shop. Made of sheet metal lined with sound-absorbing insulation or with insulated fiberglass *duct board,* these fabricated items typically include *trunk ducts* such as return-air ducts and main supply ducts and *adapters* to fit the central supply and return ducting to the furnace. Premanufactured fittings are available to the heating subcontractor, including branch duct adapters such as angles, elbows, and transitions from rectangular to round and *boot fittings* for the termination of ducts at the room (Figure 15.11).

Between the main supply duct and the boots are the smaller *branch ducts.* The most common material for these ducts is *flex-duct,* a flexible tube made of insulation wrapped around coiled wire and sandwiched between layers of plastic. Although most heating and cooling contractors like to use flexible duct, rigid ducts are preferred because they have smooth walls that allow the air to flow efficiently, without turbulence. Also, flexible duct is too tempting to crimp to solve a clearance problem. Rigid branch ducts are connected to the main supply duct and to the boot with sheet metal screws and sealed with duct tape. Flexible ducts

Figure 15.9
Both plumbing pipes and heating ducts are installed after the framing of a house but before finish materials are in place. The plumber is typically scheduled before the heating/cooling contractor because of the limited number of ways drain and waste piping can be installed. Good communication among the framer, the plumber, and the heating contractor is essential during this phase of construction to make their jobs run efficiently. *(Photo by Rob Thallon)*

Figure 15.10
A heating contractor specializing in forced-air systems typically has a sheet metal shop where customized ductwork is manufactured. Many standard fittings and ducts are also kept in stock. *(Photo by John Arnold)*

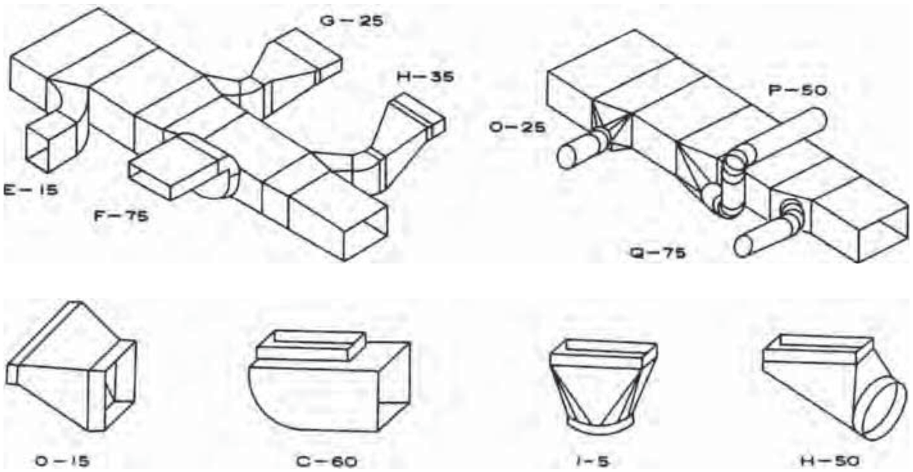

FIGURE 15.11
In the best forced-air systems, trunk ducts are reduced in size in relationship to the volume of air that they carry. Both supply and return ducts are largest at the furnace. Premanufactured boot fittings are at the ends of ducts where they enter or leave a room.

are both connected and sealed with *duct tape*. When return-air ducting extends to individual rooms, boots and flex-duct are used here also.

The heating contractor installs the largest components of the system first. The largest ducts are supported by sheet metal straps, which are nailed or screwed to the framing. The furnace is best supported on a concrete pad on the ground because this minimizes the transfer of fan vibrations to the framing. When the framing supports the furnace, rubber vibration dampers should be located between furnace and framing. In all cases, isolation of the furnace from the ducts by means of a flexible connection is recommended to minimize noise and vibration. Gas furnaces should be tied down to minimize catastrophic earthquake damage.

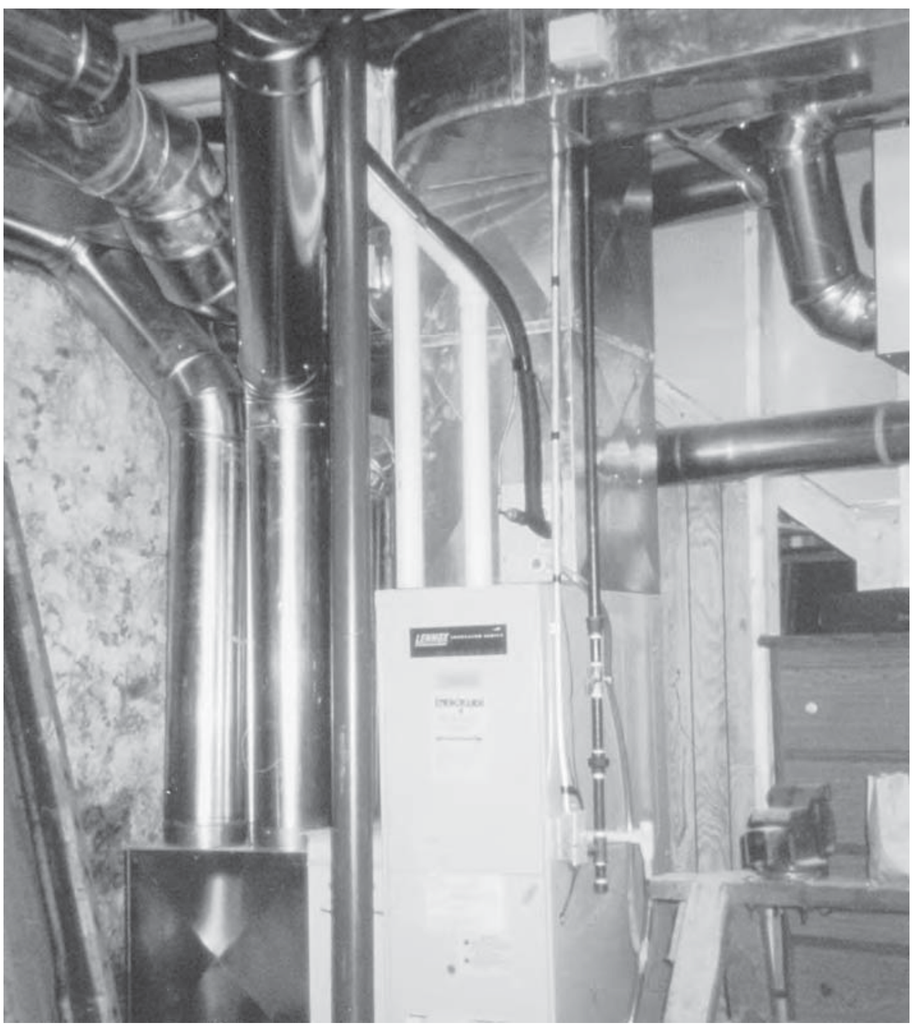

FIGURE 15.12
The installation of this warm-air furnace and air-conditioning unit has been completed. The white polyvinyl chloride (PVC) pipe running vertically from the top of the furnace carries the exhaust gases to the outside. The ductwork to the left carries conditioned air to three different zones. *(Photo by Greg Thomson)*

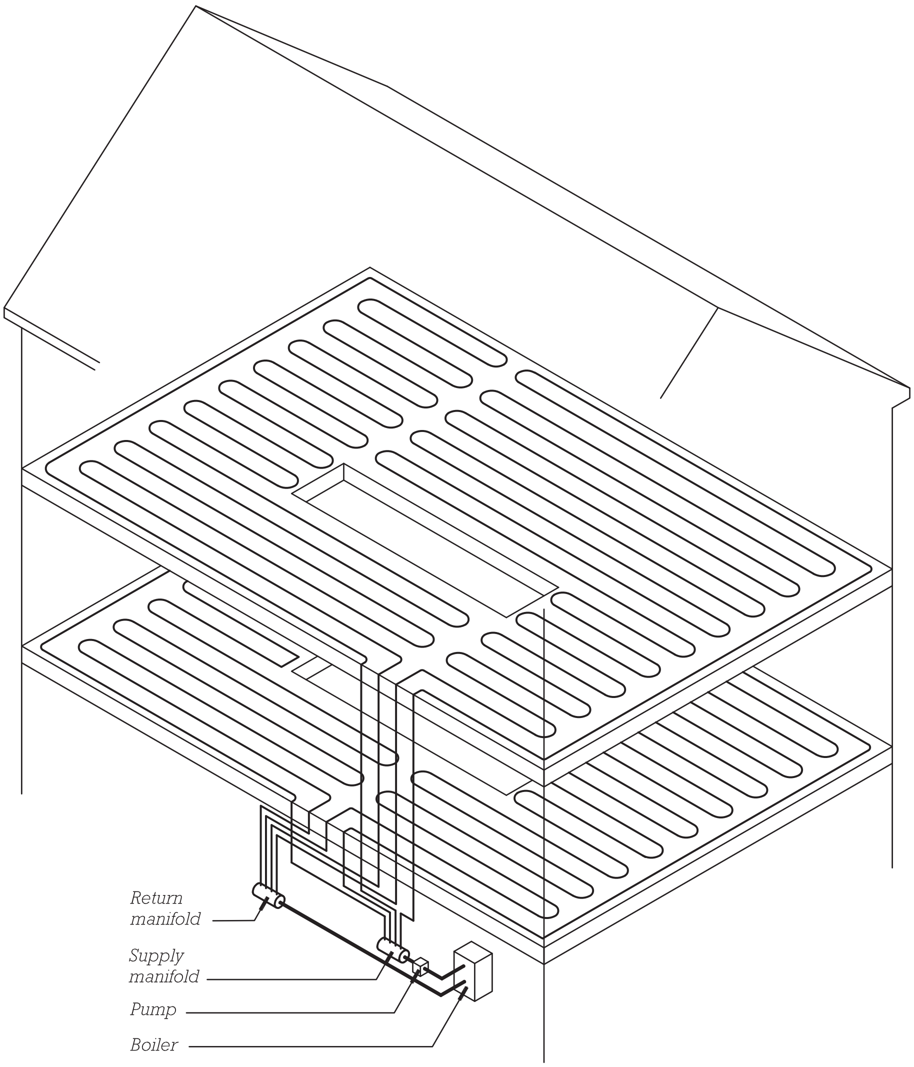

FIGURE 15.13
The radiant heating system in this two-story house uses hydronic tubes in the floor. There are four zones—two upstairs and two downstairs—each heating about a 250-square-foot (23-m^2) area. The water is heated in a boiler and pumped through a supply manifold to each of the four zones. The warmest water is routed first to the perimeter of each zone. After passing through the floor and losing heat, the water passes through a return manifold to the boiler. Zones can be controlled independently, each with a thermostat connected to a valve at the supply manifold.

RADIANT PANEL SYSTEMS

Radiant panel heating, introduced into house construction in the 1920s, heats spaces by producing large heated surfaces (floors, walls, or ceilings) that radiate heat to other surfaces, objects, and people in the space. The most common form of radiant panel heating is the *radiant floor*—a form of which was developed over 2000 years ago by the early Romans. Radiant floors were popular in the 1950s, when they were used extensively in single-story tract houses. Interest in radiant floors waned as the joints in the copper or wrought iron hot water pipes embedded in the slabs began to fail due to corrosion caused by impurities in the water. However, there has been a dramatic resurgence of interest in radiant panel systems recently with the introduction of noncorrosive flexible plastic tubing, which allows piping to be placed in long, continuous runs without joints.

Radiant heating panels operate by emitting heat in the form of infrared waves that pass through the air without heating it and are absorbed by solid objects that are within "view" of the radiant source (Figure 15.13). A fire, the simplest example of a radiant source, heats our bodies, our furniture, and the surfaces of our rooms without directly heating the air in the space. The air is ultimately heated indirectly, however, as it passes over the warm surfaces. A radiant floor operates like a fire except that the heat is spread over a much larger area at a much lower temperature.

The advantages of radiant panel systems are numerous as long as it is the floor and not the ceiling that is heated. The comfort of radiant systems is mentioned most frequently by those who have experienced them. Radiant floor systems keep the feet warm while the air within a room remains cool and fresh. Stratification of heated air caused by the natural tendency of warm air to rise is negligible with radiant panels because the air is not heated directly. In addition, because radiant heat is absorbed directly by the body, radiant systems can operate at air temperatures 6 to 8°F (3 to 4°C) lower than those of convective systems. Radiant heating systems are more easily zoned than forced-air systems, adding both comfort and efficiency. When the energy-saving features of radiant panels mentioned previously are combined with the facts that glass (especially low-e glass) reflects radiant heat back into the building and air infiltration is reduced due to lower operating temperatures, an overall reduction in heat loads of 15 to 20 percent can sometimes be achieved with radiant panel systems.

There are architectural benefits of radiant panel systems as well. The panels are essentially invisible—buried within the floors, ceilings, or walls of a space—so that no registers, grills, radiators, or baseboards are visible (Figure 15.14). There is also more flexibility in the placement of furniture because there are no localized heat sources to obstruct. Finally, the systems are silent, eliminating the sounds of moving air or expanding metal that occur with other common systems.

The primary disadvantage of radiant panel systems is that it is difficult and expensive to include a cooling option. Coupled with the fact that the initial cost of the basic system is often higher than that of a comparable forced-air system, the need for cooling often leads potential clients away from a radiant panel system. However, hybrid systems with radiant panel heat and a simple centralized cooling system are not uncommon. Another disadvantage is the fact that radiant systems have a slow response to thermostatic changes compared to other systems. Radiant systems are therefore recommended for situations that demand a reasonably constant temperature and are not affected by sudden exterior temperature swings.

Types of Radiant Panel Systems

There are two basic methods of supplying heat to radiant panel systems—*electric heating cables* and (hot water) *hydronic tubing*. The most common installations for new construction are hydronic floors. Electric radiant ceiling systems were recently popular for low-cost work, but today electric radiant panels are primarily employed in floors for remodeling work. Both electric and hydronic systems can be used in walls, but this is uncommon, primarily because occupants frequently drive nails and screws into walls to hang pictures and other items. Radiant ceilings are also highly susceptible to damage by remodelers or owners unaware of cables just beneath the surface.

Hydronic floor systems may be located in either a concrete slab on grade or a wood-framed floor (Figure 15.15). For a slab-on-grade installation, tubing carrying the hot water is positioned in the slab itself—about 2 inches below the surface. For framed floors, the tubing may be located either above the subfloor or below it. When above the subfloor, the hydronic tubes are typically installed in what is called a *thin slab*. Here, the tubes are stapled to the subflooring and covered with a thin layer of lightweight concrete or gypsum. When

FIGURE 15.14
One advantage of radiant floor heating is that there are no registers or radiators to limit the placement of furniture. A staple-up system was installed in this house without any adjustments to the framing, and maple was employed as a finish flooring. *(Courtesy of The Energy Service Company, Eugene, Oregon)*

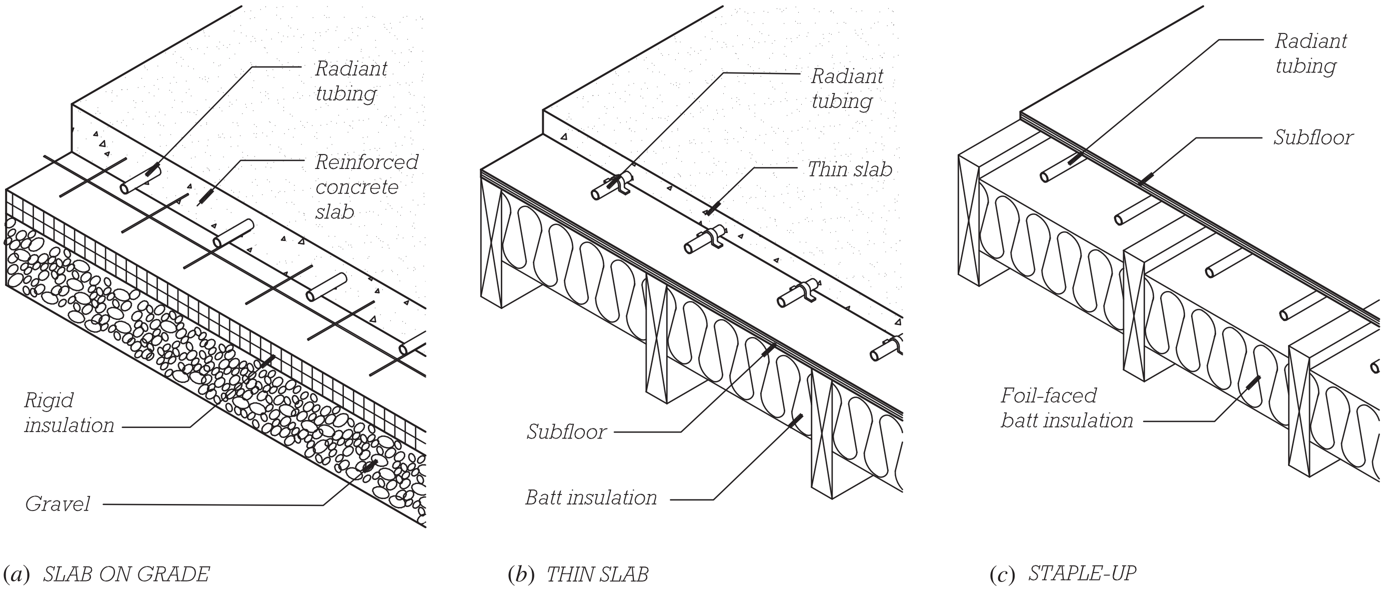

FIGURE 15.15
Three hydronic radiant floor systems. (*a*) Radiant tubes are embedded in a concrete slab on grade. (*b*) Radiant tubes are fastened to the top of a subfloor and covered with lightweight concrete or gypsum. (*c*) Radiant tubes are stapled up to the underside of a subfloor.

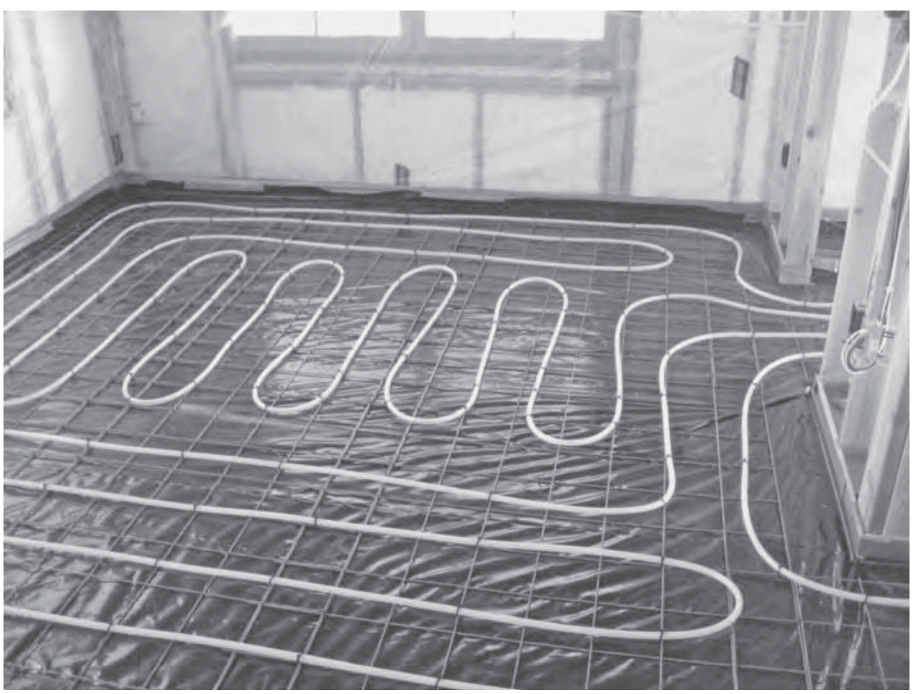

FIGURE 15.16
Hydronic tubes for a 3-inch thin-slab system are fastened with plastic ties to reinforcing mesh at approximately 9 inches on center. The mesh will be supported 1 inch above the subfloor just before the concrete is poured. *(Photo by Rob Thallon)*

below the subfloor, the tubes are fastened to the underside of the subfloor with clips or within aluminum plates. This is called a *staple-up* application. In all framed floor applications, a layer of foil-faced insulation is installed below the subfloor to prevent heat from escaping downward. In all cases, the radiant floor may be covered with a finish floor of tile, wood, resilient flooring, or even some carpets with low insulative values. The thinner and denser the finish floor, the better.

Ceiling systems are economical but suffer from the fact that warm air rises and tends to stratify at the ceiling where the heat source lies, so there is no natural convection loop, as there is in a radiant floor system. *Radiant ceiling panel* systems constructed with electric resistance cables stapled to the underside of drywall and then covered with plaster used to be common but are now rare. Radiant electric cables and mats for use on floors are now available and are often used in remodeling work because their thin profile allows the buildup over existing floors to be minimal.

Radiant Rough-in Construction

The radiant slab is the most economical of all radiant panel systems and the most easily integrated with standard residential construction. The *cross-linked polyethylene (PEX) tubing* that distributes the hot water in the slab is simply wired to reinforcing steel located just below the surface of the slab (Figure 15.16). Perimeter insulation will likely need to be thicker than that required for a nonradiant slab and will need to extend at least 4 feet (1.2 m) into the building. Insulation under the entire slab is recommended to reduce the response (lag) time of the floor and where groundwater or conductive soils would continuously siphon off the heat of the floor. This increase in the amount of insulation material does not require a scheduling adjustment or the addition of a subcontractor.

For framed floors, the staple-up method is least disruptive of standard construction practice. Aside from taking precautions not to nail down through the PEX tubing, the general contractor needs to make very few adjustments. Although not the easiest installation for the radiant heating contractor, the system is reasonably straightforward if there is good access to the underside of the floor and floor construction is not cluttered with closely spaced joists or excessive blocking.

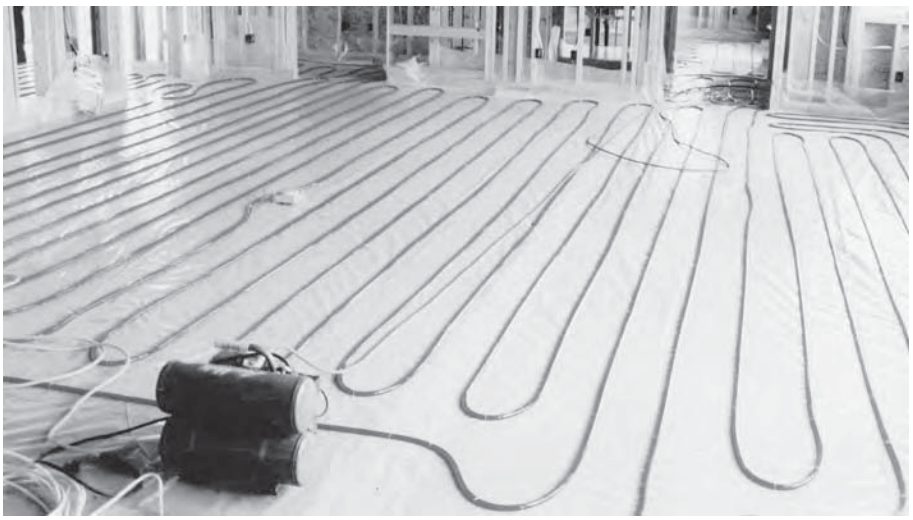

Figure 15.17
A thin-slab hydronic tube installation before the installation of poured gypsum. A polyethylene sheet has been installed on the subfloor to contain the moisture from the poured gypsum. *(Courtesy of The Energy Service Company, Eugene, Oregon)*

Figure 15.18
A typical radiant hydronic system heater and controls. In this case, the water is heated by a factory-installed heat exchanger within the water heater. The heated water is pumped through the two upper manifolds with zone valves to 10 separate zones in the house. The water returns to the heater through the two lower manifolds. *(Photo by Rob Thallon)*

The thin-slab system is simplest for the radiant heating subcontractor, but for the general contractor it represents a number of complications to the construction process. First, it requires the installation of double sole plates to provide a continuous edge for the slab. The construction schedule will have to be adjusted to allow the slab to be poured and to cure, and it may take weeks before the moisture from the wet concrete has stabilized such that flooring or cabinets may be installed on it (Figure 15.17).

The boiler and control valves for hydronic systems are often mounted on a wall and cannot be installed until the wall has been covered with gypsum wallboard, which is a late stage of construction. The boiler supplies hot water to manifolds that, in turn, connect the loops of tubing for each zone. (For small areas, a standard water heater can serve as a heat source, but heating tubes operate under 60 psi in this case instead of 20 psi.) Zone valves controlled by thermostats in each zone control the flow of hot water to the manifolds and, ultimately, to each zone (Figure 15.18). All hydronic tubes must be pressure tested and inspected before they are covered by concrete or other construction.

For electric heating cables, the timing of the installation is similar to that of hydronic systems. Cables are stapled and/or taped on 15-pound felt laid on the subfloor for floor applications. These floor cables are then covered with 1½ inches (40 mm) of lightweight concrete similar to that used in the thin-slab system for hydronic tubes. For electric radiant ceilings, the cables are stapled up to the gypsum wallboard ceiling and are then covered with plaster or sprayed texture.

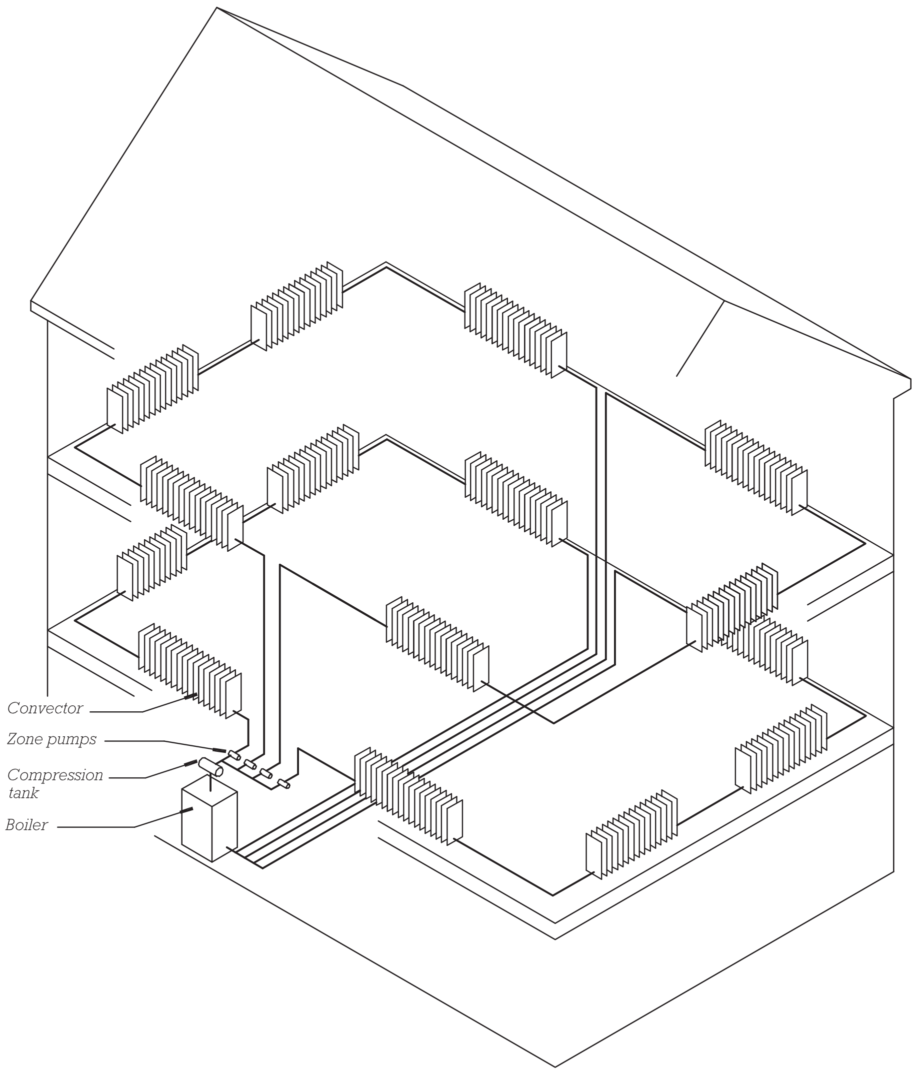

FIGURE 15.19
The hydronic baseboard heating system in this two-story house uses fin-tube convectors located in each room of the house. There are four zones—two upstairs and two downstairs. Water is heated in a central boiler and pumped through insulated pipes to each of the four zones. The flow through each convector can be controlled to adjust the temperature in each room. After losing heat to the convectors, the water returns to the boiler to be reheated.

HYDRONIC HEATING SYSTEMS

In *hydronic heating systems,* a central boiler and circulating pumps supply hot water to *fin-tube convectors,* which are horizontal pipes fitted with closely spaced vertical aluminum fins and mounted in a simple metal enclosure with inlet louvers below and outlet louvers above (Figure 15.19). The most common form of convector is the *baseboard convector,* which is designed to replace wood baseboards around the perimeters of rooms (Figures 15.21 and 15.22). The heated fins set up convection currents that draw cool room air into the enclosure from below, heat it, and discharge the warm air out the top. Instead of baseboard units, *fan-coil units* may be used. A fan-coil unit is a compact sheet metal housing with a coil of hot water piping inside and a small electric fan to blow room air past the coil. Such units furnish relatively large amounts of heat from a small fixture, which makes them especially useful in kitchens, bathrooms, and other rooms where there may not be enough baseboard length available to supply the required amount of heat. They are available in several basic forms, including wall-mounted cabinets and flat units that may be recessed in the toe space of a base cabinet in kitchens or bathrooms.

Hydronic baseboard systems are quiet and efficient and provide excellent wintertime comfort. They are easy to zone, using separate thermostats in different parts of the house to control either zone pumps or zone valves at

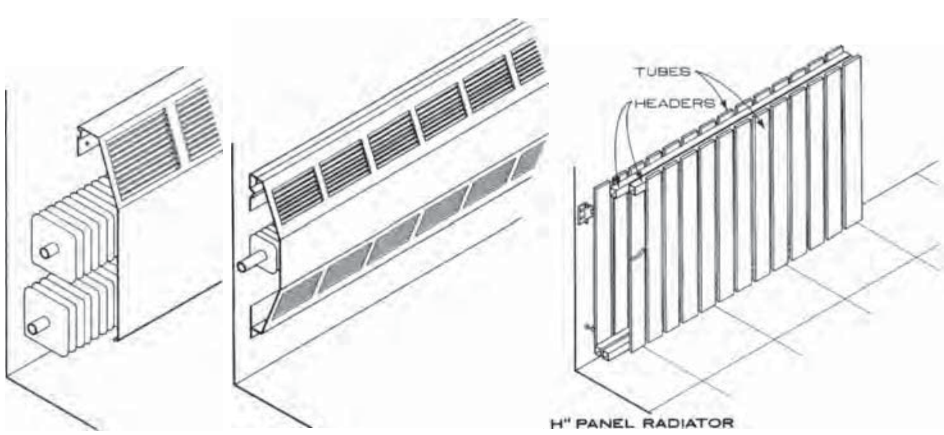

FIGURE 15.20
Hydronic heat sources come in many shapes and sizes. *(Reprinted by permission from Ramsey/Sleeper,* Architectural Graphic Standards, *10th ed., John Ray Hoke, Jr., A.I.A., Editor, John Wiley & Sons, Hoboken, New Jersey, 2000. © 2000 by John Wiley & Sons)*

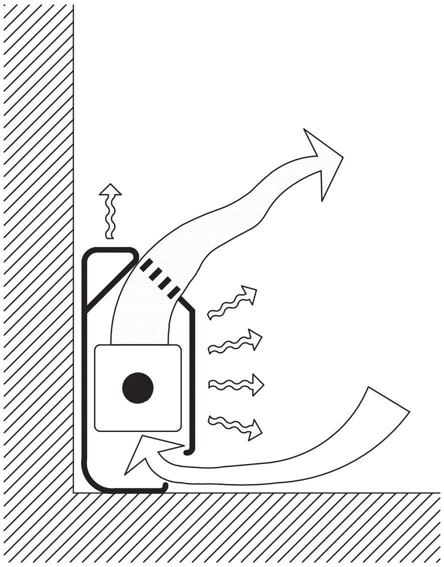

Figure 15.21
A baseboard heater works primarily by heating local air. The heated air rises, creating convection currents that circulate heat throughout the room. Some heat is also transmitted by direct radiation from the heated surface of the convector enclosure.

Figure 15.22
The best place to locate a baseboard heater is under a window, where heat rising from the unit will counteract the flow of cold air adjacent to the glass. *(Photo courtesy of Cadet Manufacturing)*

the boiler. Their chief disadvantage is their inability to provide summertime cooling or dehumidification. Also, baseboard convectors can interfere with furniture placement.

Local Source Heaters

There are a number of heating devices that produce heat or cool locally, independent of a central system or boiler. These devices are called *local source heaters* and include baseboard heaters, wall heaters, in-floor heaters, through-the-wall air conditioners and heat pumps, radiant stoves, and fireplace heaters. They heat and/or cool by means of radiation (radiant stoves), convection (wall heaters and through-the-wall units), or a combination of the two (electric baseboard heaters). A wide variety of fuels, including electricity, natural gas, heating oil, and wood, operate these appliances. Because they are not connected to a central source of heat, they act independently to heat one room at a time.

The advantage of having a heating device with its own thermostat in each room is that the temperatures of the various rooms may be controlled independently. Parts of the house such as bedrooms that are used only occasionally can be heated to a lower temperature, and considerable energy savings can be realized overall. Other rooms used for specialized purposes can have individualized settings. This kind of zoning can be provided by other types of heating systems (radiant panels), but not usually with the ease or the economy afforded by direct source heaters. Especially in superinsulated and passive solar houses, direct source heaters can be the most efficient long-term way to provide heat.

The most common local source heater is the ubiquitous *electric baseboard heater.* These heaters are extremely popular even where electricity rates are high because they are the least expensive to install of all types of heating devices. They heat with a combination of direct radiation and convection, which is induced by openings at the top and base of the device. Warm air rising from the baseboard heater is replaced by cooler air that is allowed to flow in at the bottom. Fins that enlarge the heated area over which the convection current passes enhance this induced convection current (Figure 15.21). The convection loop from electric baseboard heaters can counteract the cool air falling from windows. This is why these heaters are located below windows when practical (Figure 15.22).

Local source heaters located in walls are also common. These devices,

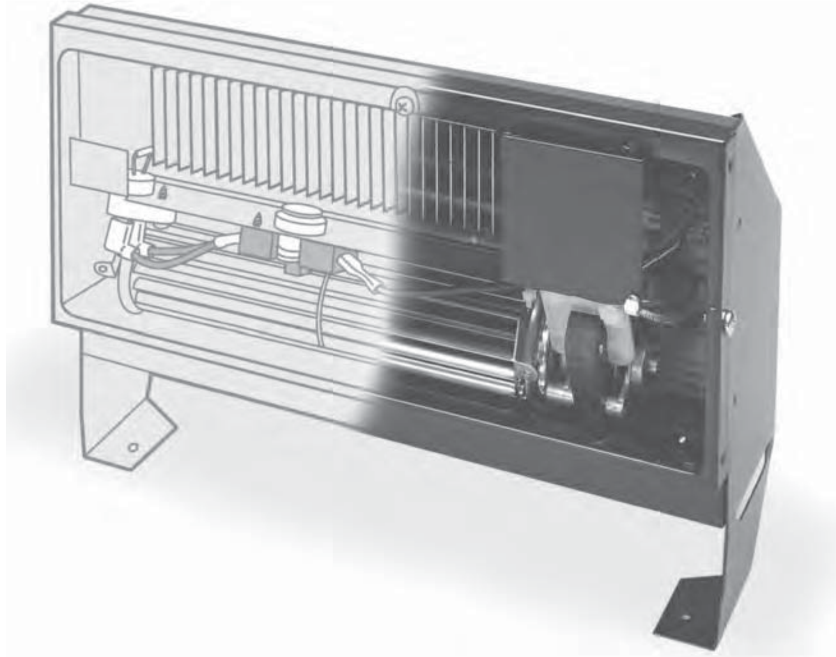

Figure 15.23
An electric wall heater warms by convection as a small fan forces air over a heated electric element and out into the room. Most electric wall heaters are designed to fit within a framed wall cavity, so it is best to avoid locating them in exterior insulated walls because their presence would interrupt the insulation. *(Photo courtesy of Cadet Manufacturing)*

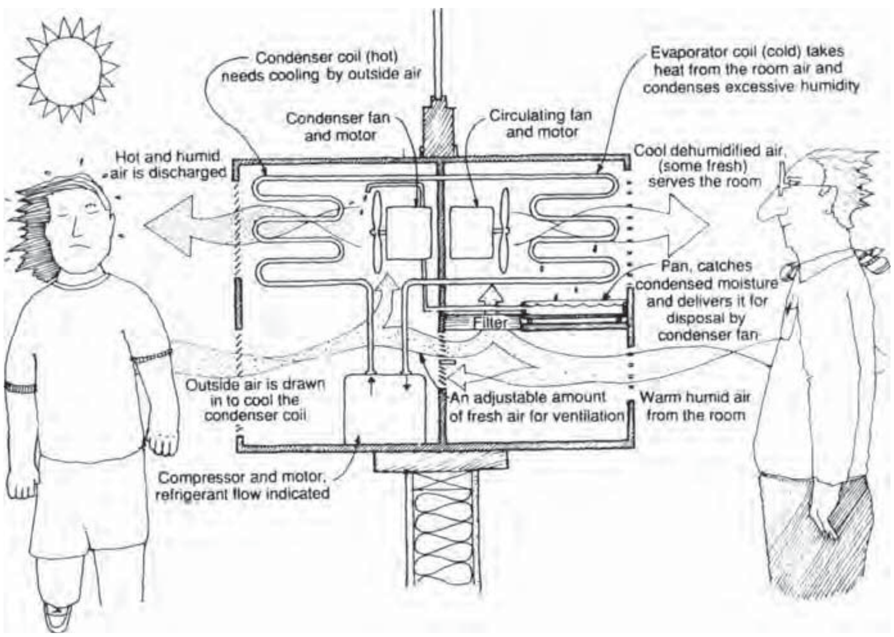

Figure 15.24
A self-contained through-the-wall air conditioner works on the same principles as a larger air conditioner, but the cold air is discharged into the room on the wall directly opposite the condenser. *(From Benjamin Stein, John Reynolds, Walter Grondzik, and Alison Kwok* Mechanical and Electrical Equipment for Buildings, *10th ed., John Wiley & Sons, Hoboken, New Jersey, 2006)*

Figure 15.25
A through-the-wall air conditioner that mounts permanently to the wall. This type of unit is designed to cool an individual room. *(Courtesy of Carrier Corporation)*

called *wall heaters,* generally have a fan-forced convection air current to distribute the heat (Figure 15.23). The most prevalent fuel sources for these heaters are electricity, natural gas, or propane—all of which are easily distributed to the heating devices. Most combustion-type primary heaters (all except electrically powered) must be vented to the exterior of the building, which can add considerably to the installation cost. Wall-mounted air-conditioning units are also common (Figure 15.24), and in-floor heaters similar to the wall heaters are also available.

Another type of local source heater is the freestanding *radiant stove.* Descendants of wood- or coal-fired potbelly stoves, these devices now operate on almost every variety of heating fuel. Common fuels include natural gas, propane, heating oil, and wood. Advantages of the freestanding stove are that the radiant source can be closer to the center of a room where it is most effective and that the stoves themselves are often quite handsome—revealing the soothing warmth of a flame inside (Figure 15.26). For wood-burning stoves, advantages include the low cost of fuel, but there are disadvantages of the mess (bark, sawdust, insects, and ashes), the effort of tending the fire, and the increased air pollution. All radiant stoves take up

Figure 15.26
A freestanding radiant stove that uses propane as a fuel. The flue pipe is a double chamber that vents combustion gases to the outside and provides combustion air for the fire. Clearances from this appliance to combustible surfaces are stipulated by the manufacturer based on code-approved testing. *(Courtesy of Midgley's, Eugene, Oregon)*

floor space, and because they involve combustion, most must be vented to the exterior. Radiant stoves and fireplaces are discussed further in Chapter 18.

Disadvantages of local source heaters are that they take up space and can make furniture placement difficult. Electric baseboard heaters cannot have furniture placed against them because of fire danger, and radiant stoves also require clearances from combustible materials. Injuries can also occur from contact with hot stoves.

Installation of Local Source Heating Devices

With the exception of electric heaters, which are usually installed by an electrician, local source heaters are installed by a specialized heating contractor affiliated with the vendor or by the general contractor. Most heaters may be installed once the house is dried in (tight to the weather), but often the installation will be delayed in order to coordinate with finishing operations. When the heating appliance serves as the sole source of heat, it is installed as early as possible in cold climates in order to furnish comfortable working conditions, to provide a stable environment for finish materials, and to promote drying of plaster and paint.

Finishing a Heating/Cooling System

The equipment for most heating/cooling systems is installed during the rough-in phase of construction. This includes the furnace, the heat pump, and all the ducts in forced-air systems. For radiant systems, equipment to be installed would include the boiler, the valves, the tubing, and all the insulation. Heat-resistant wires would be installed for electric radiant panel systems. Local source heaters, depending on their type, may be installed at the rough-in phase or the finish phase.

To complete the installation of a heating system, the *registers,* grills, convector covers, and *thermostat(s)* must be installed, and the system must be *balanced.* This is done by the heating contractor during the finish phase of construction. It is common practice to provide a temporary thermostat during construction because the permanent thermostat is a sensitive instrument that tends to get clogged with dust and sprayed with paint if installed at the same time as the equipment it controls. The temporary thermostat provides crude control over the system for the purpose of controlling temperature during construction.

Centralized systems usually need to be balanced once construction has been completed. This is best done after the users of the space have had a chance to experience the system. It is daily use that will indicate if a particular room or part of a room is too warm or too cool. In forced-air systems, balancing consists of adjusting airflow through each supply register. This can be accomplished by adjusting fan speed at the furnace, by adjusting *air volume dampers* in the ducts, or by adjusting the openings at the supply registers. In hydronic radiant systems, balancing is accomplished by adjusting the flow of water through each zone by means of *balancing valves.*

Heating and Cooling Systems and the Building Codes

The 2009 International Residential Code (IRC) devotes 13 chapters and one-sixth of its pages to heating and cooling systems. The code relies heavily on approved testing agencies such as the American National Standards Institute (ANSI) and Underwriters Laboratories to provide specifications for the installation of equipment. The chapters in the IRC are based on the International Mechanical Code and the International Fuel Gas Code, both of which are cited as references for equipment and systems not addressed in the IRC.

The IRC requires minimum clearances to equipment for inspection, service, repair, and replacement. It also specifies minimum distances from equipment to combustible materials and requires that the equipment be labeled with the manufacturer's name, the model number, the serial number, and the approved testing agency. Each type of equipment must be labeled with information about its capacity, its output, and required clearances. Fuel-burning units, for example, must list hourly rating in British thermal units (Btu)/hour, type of approved fuel, and required clearances.

Green Strategies for Heating and Cooling Buildings

- An effective strategy for heating and cooling begins with a building design and a site design that are responsive to the climate. For example, in cold northern climates with plenty of sunshine, it is best to place the building on a wind-sheltered part of the site with full exposure to winter sunlight. Shade trees are desirable if they shade the building in the summer but not in the winter.
- Orientation of the building is important. In climates with cold winters, the long side of the building and the major windows should face as near due south as possible. South-facing windows have maximum solar heat gain in winter and minimum in summer. East- and west-facing windows should be shaded because they have maximum heat gains in summer and minimum gains in winter.
- South-facing windows will have almost no summer heat gain if they are

provided with properly proportioned horizontal sunshades or roof overhangs above. Heat from the low winter sun, which is desirable, will enter the windows under these sunshades.

• To maximize the benefits of winter sun, dense materials such as concrete should be located within the house such that the sun shines directly on them. These materials, referred to as *thermal mass,* will absorb the heat of the sun, store it, and release it slowly into the space.

• Thermal insulation with high R-values should be used to minimize heating and cooling loads.

• Because windows are so important to the overall thermal performance of a building, the best available windows with a high R-value and a low solar heat gain coefficient should be used.

• To minimize heat losses and gains, the building should be as airtight as possible.

• After designing a building with a minimal demand for mechanical heating and/or cooling, provide the needed residual heating and cooling with the most efficient heating and cooling equipment.

• In regions where outdoor temperatures seldom dip below freezing, electric heat pumps are economical. By extracting heat from the outdoor air, a heat pump can release several times as much heat into the building as the heat value of the electricity it consumes. Averaged over the heating season, heat pumps should produce at least twice as much heat as the heat content of the electricity they use. During the cooling season, this ratio should be about 10.

• Ground source heat pumps are more costly to install than air source pumps, but they easily produce four times as much heat as the heat content of the electricity that they use. They are also much more efficient during the cooling season.

• Gas or oil furnaces or boilers should have efficiencies of 90 percent or more in converting fuel to usable heat. These devices generally do not need chimneys because their exhaust is cool and clean and is discharged via a plastic pipe through the side wall of the building.

• Fuel-burning furnaces and boilers should have combustion air intakes that bring air directly from outdoors. This avoids using heated or cooled indoor air for combustion.

• Electric resistance heating devices have a low first cost but are costly to operate except in areas served by hydroelectric power. Electricity is turned into heat within the building at an efficiency of 100 percent. Because of losses in boilers, generators, and transmission lines, the efficiency of generating and transmitting electricity is only 35 to 40 percent. Although electric generating plants have state-of-the-art pollution control devices, they still discharge unwanted heat into waterways and pollutants into the atmosphere. This means that "clean" electric resistance heat does more damage to the environment than heat produced by burning fossil fuels in the building.

• Annual maintenance of heating and cooling equipment is needed to keep it working safely and at maximum efficiency.

C.S.I./C.S.C.
MasterFormat Section Numbers for Heating and Cooling

23 00 00	HEATING, VENTILATING, AND AIR-CONDITIONING (HVAC)
23 07 00	HVAC Insulation
23 09 00	Instrumentation and Control for HVAC
23 20 00	HVAC Piping and Pumps
23 30 00	HVAC Air Distribution
23 40 00	HVAC Air Cleaning Devices
23 50 00	Central Heating Equipment
23 52 00	Heating Boilers
23 54 00	Furnaces
23 56 00	Solar Energy Heating Equipment
23 60 00	Central Cooling Equipment
23 70 00	Centralized HVAC Equipment
23 72 00	Air-to-Air Energy Recovery Equipment
23 80 00	Decentralized HVAC Equipment

Selected References

1. Bobenhausen, William. *Simplified Design of HVAC Systems.* Hoboken, NJ: John Wiley & Sons, 1994.

Starting with a practical overview of what to consider, this book describes the theory and concepts of HVAC design. There are chapters on warm-air systems, hot water systems, and cooling systems—all with an emphasis on sizing of the system.

2. Stein, Benjamin; Reynolds, John; Grondzik, Walter; and Kwok, Alison. *Mechanical and Electrical Equipment for Buildings* (10th ed.). Hoboken, NJ: John Wiley & Sons, 2006.

Chapter 7 of this monumental work contains an excellent explanation of both the principles behind heating and cooling systems and the details of their design and operation.

3. In Chapter 6 of *Builder's Guide,* which is reference 1 in Chapter 17, there is a good discussion of the principles of heating and cooling with an emphasis on environmental responsibility.

Key Terms and Concepts

HVAC systems
life-cycle cost
convection
radiation
heating zones
convector
forced-air heating system
central furnace
supply duct
return-air duct
heat pump
air conditioner
humidifier
dehumidifier
electronic air filter
coefficient of performance (COP)
heating element
fan
upflow furnace
downflow furnace
main supply duct
crawlspace plenum
duct board
trunk duct
duct adapter
boot fitting
branch duct
flex-duct
duct tape
radiant panel
radiant floor
electric heating cable
hydronic tubing
thin-slab radiant floor
staple-up radiant floor
radiant ceiling panel
cross-linked polyethylene (PEX) tubing
hydronic heating system
fin-tube convector
baseboard convector
fan-coil unit
local source heaters
electric baseboard heater
wall heater
radiant stove
register
thermostat
system balancing
air volume damper
balancing valve
thermal mass

Review Questions

1. What are the differences between a central forced-air fuel-burning furnace and a forced-air heat pump system?

2. Explain why a hydronic radiant floor system is more practical than a forced-air system for a single-story house built on a slab on grade. What other heating systems are practical for this type of foundation?

3. What are the advantages and disadvantages of using a crawlspace as a supply plenum for a forced-air system?

4. Discuss the advantages of zoning for a heating system.

5. Explain in detail the differences between a hydronic radiant panel system and a hydronic baseboard system.

6. Discuss the reasons for selecting a thin-slab radiant floor as opposed to a staple-up radiant floor.

Exercises

1. Call a local heating contractor and try to determine the relative percentages of the various types of heating and cooling systems installed in new houses in your area. What do you suppose are the principal reasons for the percentage breakdown?

2. Call a local architect with a reputation for incorporating passive solar heating and/or cooling into residential designs. Try to elicit a list of principles that can be applied in your geographical area.

3. Visit the site of a house under construction and make a diagram of the heating/cooling system. Compare this system with other systems studied by your classmates. What components of the system were not yet installed when you visited the site?