

CHAPTER 1. RESIDENTIAL SPACE CONDITIONING

RESIDENTIAL space conditioning is concerned with the most common systems for space conditioning of both single-family (i.e., traditional site-built and modular or manufactured homes) and low-rise multifamily residences, which generally follow single-family practices because site constraints favor compact designs. HVAC systems in high-rise apartments, condominiums, and dormitory buildings are often of commercial types similar to those used in hotels. Retrofit and remodeling construction typically adopt the same systems as those used in new construction, due to the lower cost of reusing existing electrical, air distribution, and controls infrastructure, but major internal or envelope reconfigurations that affect building loads, new equipment efficiency regulations, or occupant comfort preferences may call for unique designs. Residential system design and equipment selection vary with both local and application factors. Energy source availability and price (present and projected), climate, socioeconomic circumstances, and availability of skilled installers and maintenance technicians all affect distribution of equipment in local markets. Housing type, siting, construction characteristics, and building codes further solidify the range of practical system selection. As a result, many different systems can be selected to provide combinations of heating, cooling, humidification, dehumidification, ventilation, and air filtering for residential applications.²

1. SYSTEMS

The most common residential systems are listed in [Table 1](#). Four generally recognized groups are central forced air, central hydronic, zoned systems, and room or portable equipment. System selection and design involve such key decisions as (1) source(s) of energy, (2) means of distribution and delivery, and (3) terminal device(s). Design also includes total required system capacity.

Table 1 Residential Heating and Cooling Systems

	Central Forced Air	Central Hydronic	Zoned	Room or Portable
Most common energy sources	Gas Oil Electricity	Gas Oil Electricity	Gas Electricity	Electricity
Heat source/sink	Air Ground Water	Air Water	Air Ground Water	Air
Distribution medium	Air	Water Steam	Air Water Refrigerant	Air
Distribution system	Ducting	Piping	Ducting/dampers Piping or free delivery	Ducting/free delivery
Terminal devices	Diffusers Registers Grilles	Radiators Radiant panels Fan-coil units	Included with product or same as forced-air or hydronic systems	Diffuser

Climate and building design determine the types of environmental conditioning that are implemented. Heating, ventilation, and cooling are generally required. Air cleaning (by filtration or electrostatic devices, or other means) is present in most systems. Humidification is used in heating systems for thermal comfort (as defined in ASHRAE *Standard* 55), antiques or art preservation, and reducing static electricity discharges. Cooling systems usually dehumidify air as well as lowering its temperature. Introduction of outdoor (fresh) air may be required by local code in some applications, and guideline ventilation values can be found in ASHRAE *Standard* 62.2. Typical forced-air residential installations are shown in [Figures 1](#) and [2](#).

[Figure 1](#) shows a gas furnace, split-system air conditioner, humidifier, and air filter. Air from the space enters the equipment through a return air duct. It passes initially through the air filter. The circulating blower is an integral part of

the furnace, which supplies heat during winter. An optional humidifier adds moisture to the heated air, which is distributed throughout the home via the supply duct. When cooling is required, heat and moisture are removed from the circulating air as it passes across the evaporator coil. Refrigerant lines connect the evaporator coil to a remote condensing unit located outdoors. Condensate from the evaporator is removed through a drain line, with or without a condensate pump, often with a trap.

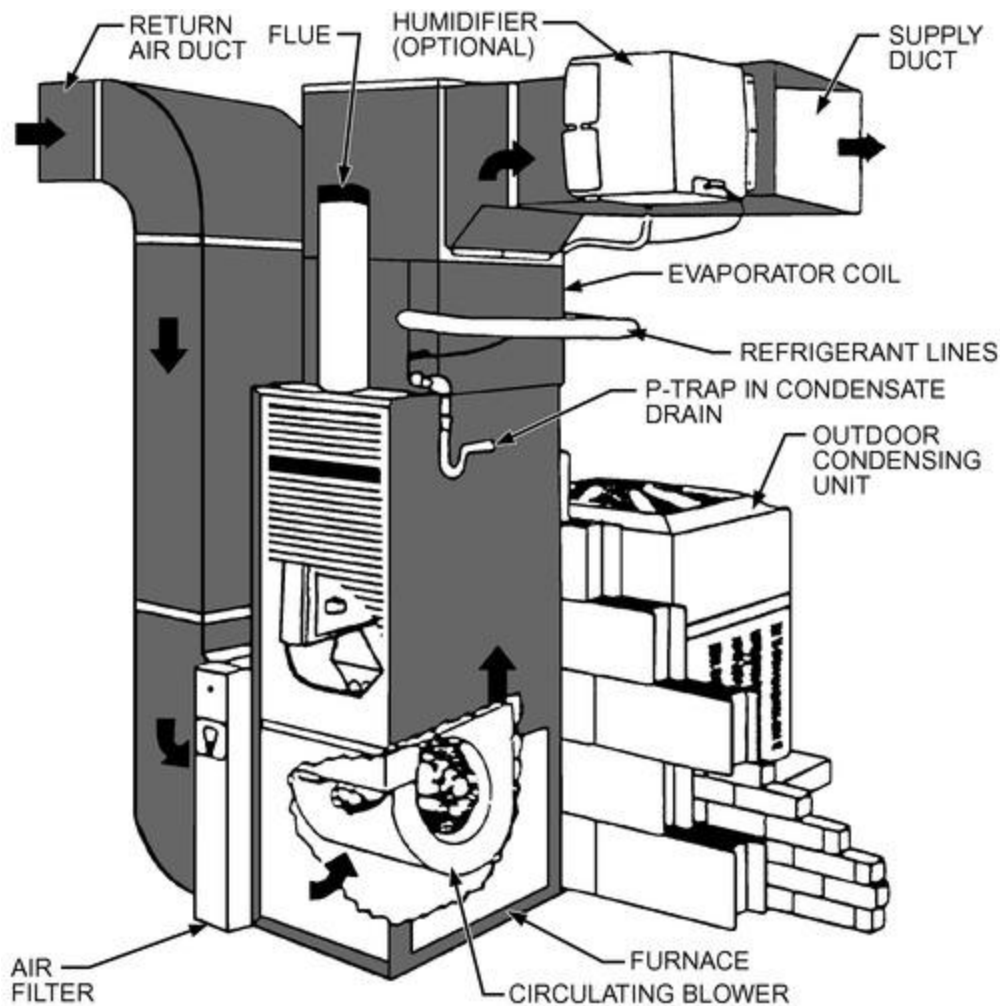


Figure 1. Typical Residential Installation of Heating, Cooling, Humidifying, and Air Filtering System

Figure 2 shows a split-system heat pump, supplemental electric resistance heaters, humidifier, and air filter. The system functions as follows: air from the space enters the equipment through the return air duct (or sometimes through an opening in the equipment itself), and passes through the air filter. The circulating blower is an integral part of the indoor air-handling portion of the heat pump system, which supplies heat through the indoor coil during the heating season. Optional electric heaters supplement heat from the heat pump during periods of low outdoor temperature and counteract indoor airstream cooling during periodic defrost cycles. This supplemental heat is also referred to as emergency heat since it may function as a back-up heat source. Some inverter-driven heat pumps ("cold-climate heat pumps") can now provide heating at even lower outdoor temperatures than traditionally. Systems referred to as "dual fuel" or "hybrid heat" combine a heat pump with a gas furnace. The gas furnace performs the same function as the electric resistance heaters. Both methods may use an outdoor air cutoff temperature, below which the heat pump's compressor is disabled and only the supplemental heat method is used. An optional humidifier adds moisture to the heated air via steam or a wetted pad and is distributed throughout the home through the supply duct. When cooling is required, heat and moisture are removed from the circulating air as it passes across the evaporator coil. Refrigerant lines connect the indoor coil to the outdoor unit. Condensate from the indoor coil is removed through a drain line, or condensate pump, usually with a trap installed.

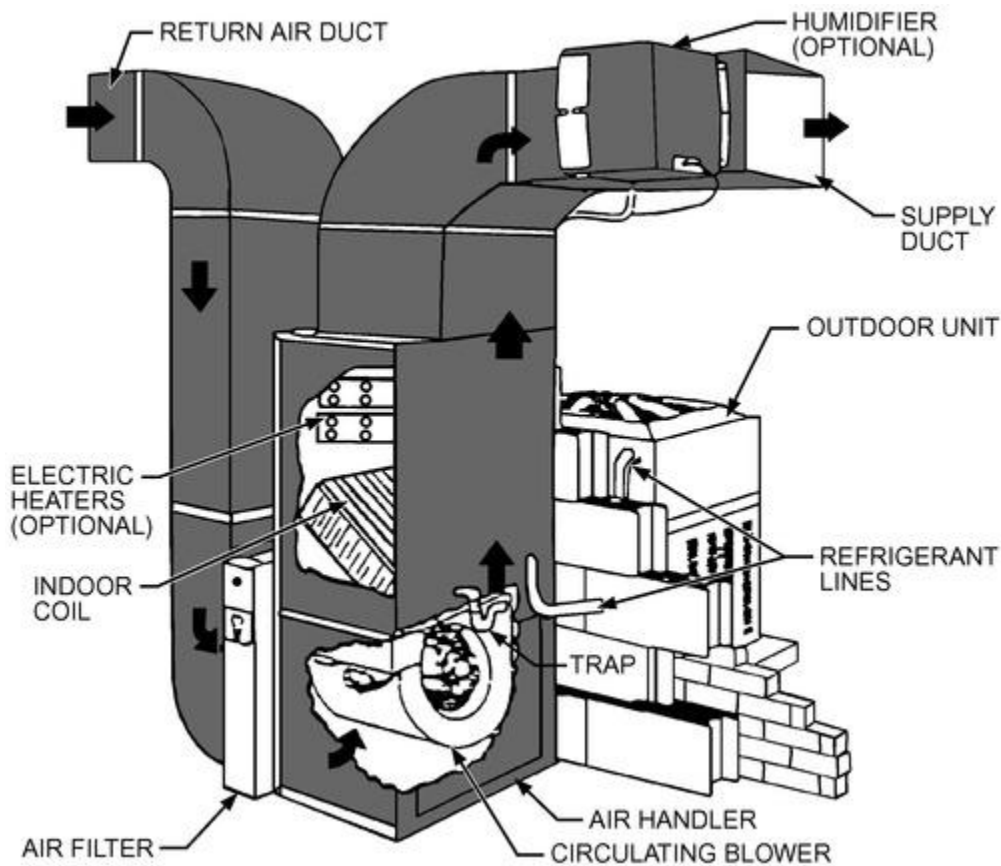


Figure 2. Typical Residential Installation of a Split-System Air-to-Air Heat Pump

Minisplit and multisplit systems are another increasingly popular equipment type worldwide. A typical two-zone, ductless multisplit system installation is shown in [Figure 3](#). This type of equipment functions similarly to split systems but is typically ductless. Some equipment offers other comfort features such as humidification or backup heat to specific zones being conditioned. [Figure 3](#) shows a three-section system: an outdoor condensing unit and two indoor air-handling units. Indoor units are typically located for ease of routing refrigerant linesets, usually on perimeter walls of the house. Floor- and ceiling-mount units are also available, as are units that mount just inside the finished wall surface and have a very short section of duct. Each indoor air handler can function independently of other indoor units and can condition one zone independently or in combination with other units in the same zone. This type of equipment uses separate indoor units to zone the conditioned space instead of the zone dampers or valves used in typical split systems. Units are typically controlled via remote control, with indoor and outdoor units communicating via serial, 24V control or an OEM-specific communication protocol. [Figure 3](#) shows a top-discharge condensing unit with a single lineset; however, side-discharge outdoor units and systems with multiple linesets are also widely applied.

Single-package unitary systems, such as window-mounted, through-the-wall, or rooftop units where the condenser, evaporator, expansion device, and other system components are all contained in one cabinet, are also popular. Ducted versions are used extensively in regions where residences have duct systems in crawlspaces beneath the main floor and in areas such as the southwestern United States, where rooftop-mounted packages connect to attic duct.

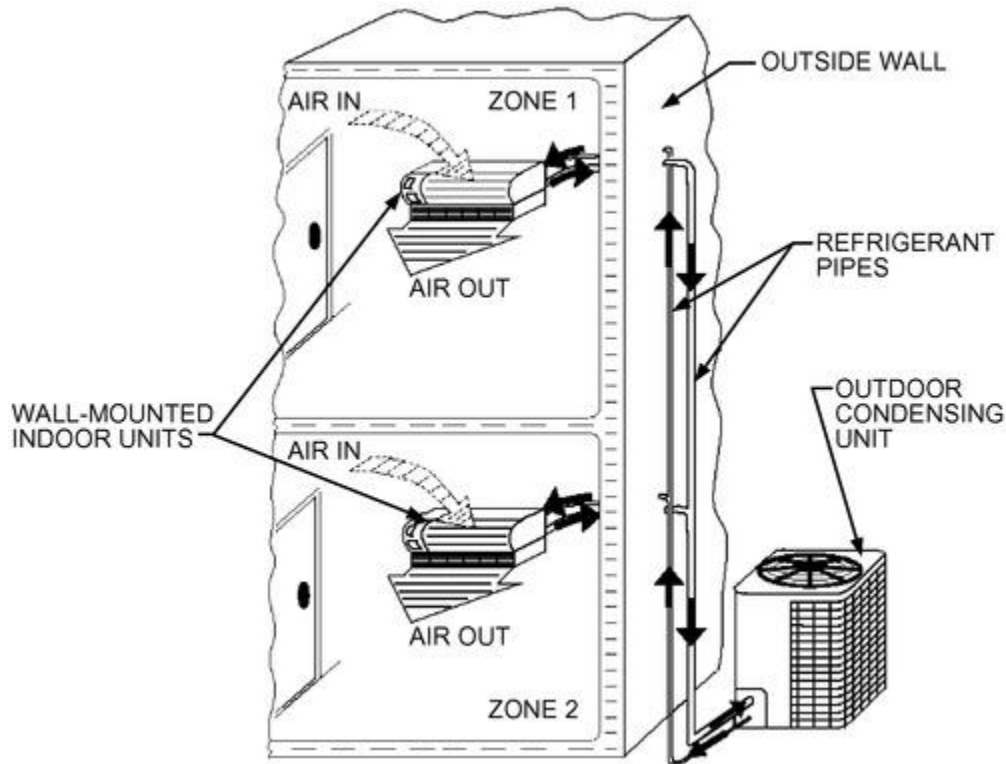


Figure 3. Example of Two-Zone, Ductless Multisplit System in Typical Residential Installation

Central hydronic heating systems are popular both in Europe and in parts of North America where central cooling has not normally been needed. These systems use a central boiler powered by natural gas, fuel oil, or electricity to provide hot water for circulation to radiators or fan-coils that distribute the heat. They may be single zone or multizone. New construction, especially in multistory homes, now typically includes forced-air cooling and heating.

Zoned systems are designed to condition only part of a home at any one time, or to condition multiple parts of the home to different temperature or humidity setpoints. Most moderate-cost residences in North America have single-thermal-zone HVAC systems with one thermostat. Multizoned systems, however, offer the potential for improved thermal comfort. Lower operating costs are possible with zoned systems because unoccupied areas (e.g., common areas at night, sleeping areas during the day) can be set back when not in use.

Common configurations are for zoning to serve individual floors, or to condition the sleeping and common areas of a home separately for single-family residences. Systems may be ducted, ductless, or hydronic. They may consist of individual room units or central systems with zoned distribution networks. Each zone must have its own thermostat. Control signals from the various zone thermostats are typically aggregated by a central controller that in turn regulates the overall output of the condenser or boiler. A method for zoned heating and cooling in central ducted systems is the **zone damper system**, which uses individual zone dampers and thermostats combined with a zone control system. Both variable-air-volume (damper position proportional to zone demand) and on/off (damper fully open or fully closed in response to thermostat) types are available. These systems sometimes include a provision to modulate to lower capacities when only a few zones require conditioning.

Airflow is especially important in centrally zoned applications. Reducing air quantity to one or more rooms may reduce airflow across the evaporator to such a degree that frost forms on the fins. Reduced airflow on heat pumps during the heating cycle can cause overloading (high discharge pressure) if airflow across the indoor coil is not typically maintained above 40 L/s per kilowatt for conventional systems. Reduced air volume to a given room reduces the air velocity from the supply outlet and can cause unsatisfactory air distribution in the room. Some systems now include controls that prevent these freezing and overpressure conditions, and manufacturers of zoned systems normally provide guidelines for avoiding such situations.

Room air conditioners are typically electrically operated. Window, room, and packaged terminal air conditioners (PTACs) provide both sensible and latent cooling. Window air conditioners are inexpensive and simple to install where a central system does not exist or does not provide sufficient comfort in one room or zone. Room air conditioners are similar to window air conditioners, except the condenser typically pulls air from the indoors rather than outdoors. The appliance is typically floor standing and ducted to a small window-mounted panel to reject condenser heat to the outdoors. PTACs may be either cooling only or heat pumps and are designed to be mounted in a framed wall opening as a permanent rather than seasonal addition to a building. In dry climates, direct-evaporative coolers ("swamp coolers") can improve comfort, and room humidifiers or dehumidifiers can be used in any climate. Ceiling and portable fans are also widely used to improve comfort within a room. Each of these room appliances typically has its own dedicated sensors and controls in the same room. Some new room equipment can be connected to the Internet, enabling coordination of service across the whole house. Matching equipment capacity to heating requirements is critical for individual room systems. Heating delivery cannot be adjusted by adjusting air or water flow, so greater attention

must be paid in room-by-room systems to ensure they are not undersized. Most individual heaters have integral thermostats that limit the ability to optimize unit control without continuous fan operation.

The availability of different energy sources is a major consideration in system selection. According to 2020 data from the U.S. Energy Information Administration (EIA 2023), for heating, about 45% of homes use natural gas, followed by electricity (40%), propane (4%), fuel oil/kerosene (4%), and wood (2%). Relative prices, safety, and environmental concerns (both indoor and outdoor) are further factors in heating energy source selection. Where various sources are available, economics strongly influence the selection. Electricity is the dominant energy source for cooling.

2. EQUIPMENT SIZING

Equipment is sized based on building construction type, indoor design temperatures, and outdoor design conditions. Indoor design conditions may be selected based on occupant comfort, or on design temperatures for machinery or processes within the conditioned space. Outdoor design conditions refer to the ASHRAE design conditions for a particular geographic location (see [Chapter 14 of the 2021 ASHRAE Handbook—Fundamentals](#)). Designers can select conditions of varying levels of extremity. For example, equipment may be sized such that it will meet the indoor design conditions on 97, 99, or 99.5% of all the days of the year. The more critical or sensitive the needs of the conditioned space, the more stringent the design conditions that should be selected.

The heat loss and gain of each conditioned room and of ductwork or piping run through unconditioned spaces in the structure must be accurately calculated to select equipment with the proper heating and cooling capacity. To determine heat loss and gain accurately, the floor plan and construction details, including information on wall, ceiling, and floor construction as well as the type and thickness of insulation must be known. Window design and exterior door details area also needed. With this information, heat loss and gain can be calculated using the Air-Conditioning Contractors of America (ACCA) *Manual J*[®] or similar calculation procedures. From there, equipment selections can be made using ACCA *Manual S*[®] or other equipment selection procedures. To conserve energy, many jurisdictions require that the building be designed to meet or exceed the requirements of ASHRAE *Standard* 90.2 or similar requirements.

Proper matching of equipment capacity to the building heat loss and gain is essential. Building loads vary throughout the day and across seasons, so matching capacity to load can be a challenge. Equipment is selected to match the design load, but the building load at any given time is almost always less than the design load. Careful consideration must therefore be given to oversizing when selecting equipment. Variable and multistage equipment has a wide capacity range, so oversizing is less of an issue. The heating capacity of air-source heat pumps declines with outdoor temperature and is usually supplemented by auxiliary heaters. The type of supplemental fuel used varies by region. In colder climates, gas furnaces or boiler systems are most prevalent; in milder climates with less need for supplemental heating, electric resistance heat is most common.

Undersized equipment will be unable to maintain the intended indoor temperature at design outdoor temperatures. Some oversizing may be desirable to enable quick recovery from setback and to maintain indoor comfort during outdoor conditions that are more extreme than the nominal design conditions. Grossly oversized equipment can cause discomfort because of short on-times, wide indoor temperature swings, and inadequate dehumidification when cooling. Gross oversizing may also contribute to higher energy use by increasing cyclic losses. Excessive cycling is also a reliability concern. Variable-capacity equipment (heat pumps, air conditioners, and furnaces) can more closely match building loads over broad ambient temperature ranges. This can reduce cyclic losses and improve comfort levels. In the case of variable-speed heat pumps, supplemental heat needs may also be reduced through oversizing, but this depends on how many stages of operation are available, and the resulting increase in part-load sensible heat ratio.

Oversizing is especially important when considering low-load homes. These structures are not able to compensate as well as more traditional structures by losing or gaining heat from the outdoor environment. Cyclic losses and indoor humidity concerns are greatly exacerbated for low-load homes. Their low sensible loads and normal latent loads result in the need for systems with low sensible capacity and low sensible heat ratio. Fresh air intake, especially in hot humid climates, compounds this issue. Supplemental dehumidification may also be required to maintain acceptable indoor humidity levels.

Residences of tight construction may have high indoor humidity and a build-up of indoor air contaminants at times. Air-to-air heat recovery equipment may be used to provide tempered ventilation air to tightly constructed houses. See [Chapter 26 of the 2020 ASHRAE Handbook—HVAC Systems and Equipment](#) for additional information on air-to-air heat recovery. Outdoor air intakes connected to the return duct of central systems may also be used when reducing installed costs is important. Simple exhaust systems with or without passive air intakes are also popular. Natural ventilation by operable windows is also popular in some climates. Excessive accumulation of radon is of concern in all buildings; lower-level spaces should not be depressurized, which causes increased migration of soil gases into buildings. Where depressurization cannot be avoided (e.g., fireplaces, bathroom exhaust on lower levels), balanced ventilation is recommended. All ventilation schemes increase heating and cooling loads, resulting in higher energy consumption. Introducing unconditioned outdoor air can increase indoor humidity loads, but introducing this air directly into the system return (if possible, only while the equipment is operating) will allow the air to be dehumidified at the point of introduction instead of discharging untempered air directly into the conditioned space. In all cases, minimum ventilation rates, as described in ASHRAE *Standards* 62.1 and 62.2, as applicable, should be maintained.

3. SINGLE-FAMILY RESIDENCES

Furnaces

Furnaces are fueled either by electricity, or by combustible materials; gas (natural or propane), oil, and wood are most common. Electric furnaces are comprised of electric resistance heaters and a blower fan, and are available in the following types:

- Baseboard free-convection
- Wall insert (free-convection or forced-fan)
- Radiant panels for walls and ceilings
- Radiant cables for walls, ceilings, and floors

Combustion furnaces may draw combustion air from inside the house or from outdoors. If the furnace space is located such that combustion air is drawn from the outdoors, the arrangement is called an **isolated combustion system (ICS)**. Furnaces are generally rated on an ICS basis. Outdoor air is ducted to the combustion chamber (a direct-vent system) for manufactured home applications and some mid- and high-efficiency equipment designs. Using outdoor air for combustion eliminates both infiltration losses associated with using indoor air for combustion and stack losses associated with atmospherically induced draft-hood-equipped furnaces.

Two available types of high-efficiency gas furnaces are noncondensing and condensing. Both increase efficiency by adding or improving heat exchanger surface area and reducing heat loss during furnace off times. Noncondensing furnaces usually have combustion efficiencies below 85%, and condensing furnaces have combustion efficiencies higher than 90%. Furnace efficiency is reported as the **annual fuel utilization efficiency (AFUE)**. The higher-efficiency condensing type recovers more energy by condensing water vapor from combustion products. Condensate is formed in a corrosion-resistant heat exchanger and is disposed of through a drain line. Care must be taken to prevent freezing the condensate when the furnace is installed in an unheated space such as an attic. Noncondensing furnaces use metallic vents, whereas condensing furnaces generally use PVC for vent pipes and condensate drains due to the lower flue gas temperatures.

[Chapters 31](#) and [33 of the 2020 ASHRAE Handbook—HVAC Systems and Equipment](#) include more detailed information on furnaces and furnace efficiency.

Hydronic Heating Systems

With the growth of demand for central cooling systems, hydronic heating systems have declined in popularity in new construction. However, they still account for a significant portion of existing systems in colder climates. The fluid is heated in a central boiler and distributed by piping to terminal units in each room. Terminal units can include radiators, baseboard convectors, fan-coils, and radiant panels. Most recently installed residential systems use a forced-circulation, multiple-zone hot-water system with a series-loop piping arrangement. Some hydronic systems use valve manifolds near the boiler to provide hydronic heat on a zonal basis. Each room's radiator or convector is served by dedicated piping from the valve manifold, with a common return pipe. The variable valves are all independently controlled by room thermostats, based on thermal demand.

[Chapters 13](#) and [36 of the 2020 ASHRAE Handbook—HVAC Systems and Equipment](#) have more information on hydronics, and [Chapter 32 of the 2020 ASHRAE Handbook—HVAC Systems and Equipment](#) provides more information on boilers.

Design water temperature is based on economic, equipment, and comfort considerations. Generally, higher temperatures result in lower first costs because smaller terminal units are needed. However, losses tend to be greater, resulting in higher operating costs and reduced comfort because of the concentrated heat source. Typical design temperatures for radiator systems range from 80 to 95°C. For radiant panel systems, design temperatures range from 45 to 75°C. The preferred control method allows the water temperature to decrease as outdoor temperatures rise. Provisions for expansion and contraction of the fluid and the piping and heat distributing units and for eliminating air from the hydronic system are essential for quiet, leak-tight operation.

Fossil fuel boiler systems that condense water vapor from the flue gases for return to the boiler must be designed for return water temperatures in the range of 50 to 55°C for most of the heating season. Noncondensing systems must maintain high enough water temperatures in the boiler to prevent this condensation. If rapid heating of the conditioned space is required, both terminal unit and boiler size must be increased, although gross oversizing should be avoided.

Another concept for multi- or single-family dwellings is a combined water-heating/space-heating system that uses water from the domestic hot-water storage tank to provide space heating. Water circulates from the storage tank to a hydronic coil in the system air handler. Space heating is provided by circulating indoor air across the coil. A split-system central air conditioner with the evaporator located in the system air handler can be included to provide space cooling. Split systems that provide domestic water heating by using a desuperheater are also available.

Solar Heating

Both active and passive solar thermal energy systems are sometimes used to heat residences. In typical active systems, flat-plate collectors heat air or water. Air systems distribute heated air either to the living space for immediate use or to a thermal storage medium (e.g., a rock pile). Water systems pass heated water from the collectors through a heat exchanger and store heat in a water tank. Because of low delivered-water temperatures, radiant floor panels requiring moderate temperatures are often used. A water-source heat pump between the water storage tank and the load can be used to increase temperature differentials.

Trombe walls, direct-gain, and greenhouse-like sunspaces are common passive solar thermal systems. Glazing facing south (in the northern hemisphere), with overhangs to reduce solar gains in the summer, and movable night insulation panels reduce heating requirements.

Some form of back-up heating is generally needed with solar thermal energy systems. Solar electric systems are not normally used for space heating because of the high energy densities required and the economics of photovoltaics. However, hybrid collectors, which combine electric and thermal capabilities, are available. [Chapter 37 of the 2020 ASHRAE Handbook—HVAC Systems and Equipment](#) has information on sizing solar heating equipment.

Heat Pumps

Heat pumps for single-family houses are normally centrally ducted or ductless unitary split systems, as shown in [Figures 2](#) and [3](#). Most commercially available heat pumps, particularly in North America, are reverse-cycle, electrically powered, air-source systems. The direction of flow of the refrigerant can be switched to provide cooling or heating to the home. Equipment is typically referred to by noting the thermal source/sink and distribution medium to the conditioned space as well as the type of fuel used. Air-source or ground-source refers to the energy source in heating mode. The thermal sink in cooling mode is generally assumed to be the same as the thermal source in heating. The most common types of heat pump equipment are air-to-air and water-to-air. Air-to-water and water-to-water types are also used.

The multisplit heat pump consists of a central compressor and an outdoor heat exchanger to serve multiple indoor zones. Each zone uses one or more fan-coils, with separate thermostatic controls for each zone or for each unit. These systems are used in both new and retrofit construction. These are also known as variable-refrigerant-volume (VRV), variable-refrigerant-flow (VRF) systems or inverter-driven. Some units may include a heat recovery mode where some indoor units operate in heating and some in cooling simultaneously. For more information on VRF systems, see [Chapter 18 of the 2020 ASHRAE Handbook—HVAC Systems and Equipment](#).

Air-Source Systems. Air-source air-to-air systems using ambient air as the heat source and sink can be installed in almost any application and are generally the least costly to install and thus the most commonly used. Air-to-water systems use an intermediate heat exchanger to transfer energy to a water loop within the building that then transfers energy back to the air.

Ground-Source (Geothermal) Systems. Ground-source systems usually use water-to-air heat pumps to extract heat from groundwater, ponds, or directly from the earth via a buried heat exchanger. As a heat source/sink, groundwater (from individual wells or supplied as a utility from community wells) offers several advantages over ambient air:

- Heat pump capacity is independent of ambient air temperature, reducing supplemental heating requirements.
- Capacity depends on groundwater temperature, which is fairly constant. No defrost cycle is required.
- Although operating conditions for establishing rated efficiency are not the same as for air-source systems, seasonal efficiency is usually higher for heating and for cooling.
- Peak heating energy consumption is usually lower.

Two other system types are ground-coupled and surface-water-coupled systems. **Ground-coupled systems** offer the same advantages as groundwater systems but are more subject to soil moisture content. Where soil moisture content is poor, heat transfer and efficiency are degraded. **Surface-water-coupled systems** that extract heat from surface water (e.g., lakes or rivers) or city (tap) water are sometimes used where local conditions allow. These have the advantage of lower installation costs since less digging is required. However, these installations experience wider temperature fluctuations in their heat source/sink temperatures and may not offer the same benefits as ground-source systems. Both system types circulate brine or water in a buried or submerged heat exchanger to transfer heat from the ground or water. See [Chapter 48 of the 2020 ASHRAE Handbook—HVAC Systems and Equipment](#) for further information.

Water supply, quality, and disposal must be considered for groundwater systems. Caneta Research (1995) and Kavanaugh and Rafferty (2014) provide detailed information on these subjects. Secondary coolants for ground-coupled systems are discussed in Caneta Research (1995) and in [Chapter 31 of the 2021 ASHRAE Handbook—Fundamentals](#). Buried heat exchanger configurations may be horizontal or vertical, with the vertical including both multiple-shallow- and single-deep-well configurations. Ground-coupled systems avoid water quality, quantity, and disposal concerns but

are sometimes more expensive than groundwater systems. However, ground-coupled systems are usually more efficient, especially when pumping power for the groundwater system is considered. Proper installation of the ground coil(s) is critical to success. **Direct-expansion ground-source systems**, with evaporators buried in the ground, also are available but are seldom used.

Hybrid or Dual-Fuel Systems. Dual-fuel or hybrid systems pair a heat pump (often as a retrofit) to an existing furnace or boiler/fan-coil system. The heat pump and combustion device are operated in one of three ways: (1) alternately, depending on which is most cost-effective, or by outdoor temperature when the heat pump can no longer meet the space heating load; (2) in parallel; or (3) with the heat pump coil located upstream of the combustion coil, thus providing preheated air to the furnace. Bivalent heat pumps, factory-built with the heat pump and combustion device grouped in a common chassis and cabinets, provide similar benefits at lower installation costs.

Fuel-Fired Heat Pumps. Fuel-fired heat pumps for residential applications are available in North America and Europe. Usually, these systems take the form of absorption cycles. For results of one investigation on these heat pumps, see Grossman et al. (1995).

Domestic Hot-Water-Heating Options. Heat pumps may be equipped with desuperheaters (either integral or field-installed) to reclaim heat from the condensing refrigerant in cooling mode for domestic water heating. Integrated space-conditioning and water-heating heat pumps with an additional full-size condenser for water heating are also available. ASHRAE *Standards* 124 and 206 provide methods of test for these combined systems.

Occupant Control. Occupants should be able to make seasonal or more frequent adjustments to the air distribution system to improve comfort. Adjustments may involve opening additional outlets in second-floor rooms during summer and throttling or closing heating outlets in some rooms during winter. Manually adjustable balancing dampers may be provided to facilitate these adjustments. Supplemental stand-alone systems may be necessary for spaces with unusual load profiles such as sun porches or wine cellars. Operable windows and shades are also valuable controls for comfort.

Unitary Air Conditioners

In forced-air systems, the same air distribution duct system can be used for both heating and cooling. Split-system central cooling, as shown in [Figure 1](#), is the most widely used forced-air system. Upflow, downflow, and horizontal-airflow indoor units are available. Condensing units are installed on a noncombustible pad outdoor and contain a motor- or engine-driven compressor, condenser coil, condenser fan and fan motor, and controls. The condensing unit and evaporator coil are connected by refrigerant tubing that is normally field-supplied. However, precharged, factory-supplied tubing with quick-connect couplings is also common where the distance between components is not excessive.

A distinct advantage of split-system central cooling is that it can readily be added to existing forced-air heating systems. Airflow rates are generally set by the cooling requirements to achieve good performance, but most existing heating duct systems are adaptable to cooling and motor speed may be selectable between heating and cooling modes of operation. Airflow rates of 40 to 60 L/s per kilowatt of refrigeration are normally recommended for good cooling performance. Specialty systems such as small-duct high-velocity (SDHV) systems have lower airflows and are used in applications where retrofitting larger supply ducts is not possible, or where equipment with a lower sensible heat ratio is desired. As with heat pumps, split-system central cooling may be fitted with desuperheaters for domestic water heating.

Some cooling equipment includes forced-air heating as an integral part of the product. Year-round heating and cooling packages with a gas, oil, or electric furnace for heating and a vapor-compression system for cooling are available.

Distribution. Duct systems for cooling (and heating) should be designed and installed in accordance with accepted practice. Useful information can be found in ACCA *Manuals* D[®] and S[®].

High-quality duct design is essential to system design, because it can make a large difference in the efficiency and effectiveness of the residential unitary cooling and heating system. There is a trend toward placing as much ductwork as possible in the conditioned space, to reduce duct thermal losses and lessen the effect of any leaks that exist. For a given diameter, flexible ducts have higher pressure drop than metal ducts, and this should be taken into consideration. Flexible duct must be stretched and properly supported or it can sag, increasing airflow resistance. Minimizing duct system airflow resistance helps minimize energy consumption throughout the life of the system.

[Chapter 21 of the 2021 ASHRAE Handbook—Fundamentals](#) provides the theory behind duct design. In the 2020 ASHRAE *Handbook—HVAC Systems and Equipment*, [Chapter 10](#) discusses air distribution design for small heating and cooling systems, [Chapter 19](#) addresses duct construction and code requirements, and [Chapter 48](#) provides more detailed information on unitary air conditioners and heat pumps.

Special Considerations. In residences with more than one story, cooling and heating are complicated by air buoyancy, also known as the **stack effect**. In many such houses, especially with single-zone systems, the upper level tends to overheat in winter and undercool in summer. Installing multiple air outlets in each room, some near the floor and others near the ceiling, has been used with some success to improve temperature uniformity on all levels. To control airflow, the homeowner opens some outlets and closes others from season to season, thereby altering the proportional distribution of heating and cooling to each level. Free air circulation between floors can be reduced by locating returns high in each room and keeping doors closed.

When increasing equipment capacity in existing homes, the capacity that can be added is limited by the air-handling capacity of the existing duct system. Although the existing duct system size is usually satisfactory for normal occupancy, it may be inadequate during large gatherings. When new cooling (or heating) equipment is installed in existing homes,

supply air ducts and outlets should be checked for acceptable air-handling capacity and air distribution. Maintaining upward airflow at an effective velocity is important when converting existing heating systems with floor or baseboard outlets to both heat and cool since cold air does not benefit from the natural buoyancy of warm air. It is not necessary to change the deflection from summer to winter for registers located at the perimeter of a residence. Registers located near the floor on the indoor walls of rooms may operate unsatisfactorily if the deflection is not changed from summer to winter.

A residence without a forced-air heating system may be cooled by one or more central systems with separate duct systems, by individual room air conditioners (window-mounted or through-the-wall), or by minisplit room air conditioners.

Cooling equipment must be located carefully. Because cooling systems require higher indoor airflow rates than most heating systems, sound levels generated indoors are usually higher. Thus, indoor air-handling units located near sleeping areas may require sound attenuation. Outdoor noise levels should also be considered when locating the equipment. Many communities have ordinances regulating the sound level of mechanical devices, including cooling equipment. Manufacturers of unitary air conditioners often rate the sound level of their products according to an industry standard (Air-Conditioning, Heating, and Refrigeration Institute [AHRI] *Standard* 270). AHRI *Standard* 275 gives information on how to predict the sound level in dBA when the AHRI sound rating number, the equipment location relative to reflective surfaces, and the distance to the property line are known.

An effective and inexpensive way to reduce noise is to put distance and natural barriers between sound source and listener. However, airflow to and from air-cooled condensing units must not be obstructed. Plantings and screens must be porous and placed away from units so as not to restrict intake or discharge of air. Most manufacturers provide recommendations on acceptable distances between condensing units and natural barriers. Outdoor units should be placed as far as is practical from porches and patios, which may be used while the house is being cooled. Locations near bedroom windows and occupied spaces of neighboring homes should also be avoided. In high-crime areas, consider placing units on roofs or other semisecure areas.

Evaporative Coolers

In climates that are dry throughout the entire cooling season, evaporative coolers can be used to cool residences. They must be installed and maintained carefully to reduce the potential for water fouling and thus air quality problems. Further details on evaporative coolers can be found in [Chapter 41 of the 2020 ASHRAE Handbook—HVAC Systems and Equipment](#) and in [Chapter 52](#) of this volume.

Humidifiers

For improved winter comfort, equipment that increases indoor relative humidity may be needed. In a ducted heating system, a central whole-house humidifier can be attached to or installed within a supply plenum or main supply duct, or installed between the supply and return duct systems. When applying supply-to-return duct humidifiers on heat pump systems, take care to maintain proper airflow across the indoor coil. Self-contained portable or tabletop humidifiers can be used in any residence. Even though this type of humidifier introduces all the moisture to one area of the home, moisture migrates and raises humidity levels in other rooms.

Overhumidification should be avoided because it can cause condensate to form on the coldest surfaces in the living space (usually windows). Also, because moisture migrates through all structural materials, vapor retarders should be installed near the warmer indoor surface of insulated walls, ceilings, and floors in most climates. Lack of attention to this construction detail allows moisture to migrate from indoors to outdoors, condensing inside the wall, causing damp insulation, mold, possible structural damage, and exterior paint blistering. [Chapters 25 to 27 of the 2021 ASHRAE Handbook—Fundamentals](#) provide further details.

Central humidifiers may be rated in accordance with AHRI *Standard* 611. This rating is expressed in the number of litres per day evaporated by 49°C entering air. Selecting the proper size humidifier is important and is outlined in AHRI *Guideline* F.

Humidifier cleaning and maintenance schedules must be followed to maintain efficient operation and prevent bacteria build-up.

[Chapter 22 of the 2020 ASHRAE Handbook—HVAC Systems and Equipment](#) contains more information on residential humidifiers.

Dehumidifiers

Many homes also use dehumidifiers to remove moisture and control indoor humidity levels. In cold climates, dehumidification is sometimes required during the summer in basement areas to control mold and mildew growth and to reduce zone humidity levels. Traditionally, portable dehumidifiers have been used to control humidity in this application. Although these portable units are not always as efficient as central systems, their low first cost and ability to serve a single zone make them appropriate in many circumstances.

In hot, humid climates, providing sufficient dehumidification along with sensible cooling is important. Although conventional air-conditioning units provide some dehumidification as a consequence of sensible cooling (usually around

20% of their total cooling capacity), in some cases space humidity levels can still exceed comfortable levels and supplemental dehumidification may be required. These problems are further exacerbated in low-load homes, where the ratio of sensible cooling load to total load is very low. Residential dehumidifiers almost exclusively rely on direct-expansion refrigeration systems, operating with evaporator temperatures below the process air's dew point, to dehumidify the air through condensation.

Several dehumidification enhancements to conventional air-conditioning systems are possible to improve moisture removal characteristics and lower the space humidity level. Some simple improvements include lowering the supply airflow rate to overcool the airstream, and eliminating off-cycle fan operation. Additional equipment options such as condenser/reheat coils, sensible-heat-exchanger-assisted evaporators (e.g., heat pipes), and subcooling/reheat coils can further improve dehumidification performance. Desiccants, applied as either thermally activated units or heat recovery systems (e.g., enthalpy wheels), can also increase dehumidification capacity and lower the indoor humidity level. Each of these modifications produces a system with a lower sensible heat ratio. Some dehumidification options add heat to the conditioned zone that, in some cases, increases the load on the sensible cooling equipment. Small-duct high-velocity equipment operates with a sensible heat ratio lower than that of conventional equipment and may eliminate the need for supplemental dehumidifiers in some applications. Dehumidifiers are rated in accordance with Association of Home Appliance Manufacturers (AHAM) *Standard* DH-1. [Chapter 25 of the 2020 ASHRAE Handbook—HVAC Systems and Equipment](#) contains more information on residential dehumidifiers.

Air Filters

Most comfort conditioning systems that circulate air incorporate some form of air filter. Air filters are mounted in the return air duct or plenum and operate whenever air circulates through the duct system. Usually, they are disposable or cleanable filters that have relatively low air-cleaning efficiency. Alternatives with higher air-cleaning efficiencies include pleated media filters and electronic air filters. These filters may have higher static pressure drops. The air distribution system should be carefully evaluated before installing such filters so that airflow rates are not overly reduced with their use. Airflow must be evaluated both when the filter is new and when it is in need of replacement or cleaning. Consult manufacturer literature to determine the minimum acceptable airflow and maximum allowable static pressure for the equipment.

Air filters are rated in accordance with AHRI *Standard* 681, which was based on ASHRAE *Standard* 52.2. Atmospheric dust spot efficiency levels are generally less than 20% for disposable filters and vary from 60 to 90% for electronic air filters. However, increasingly, the minimum efficiency rating value (MERV) from ASHRAE *Standard* 52.2 is given instead; this rating is based on the percentage removal from the airstream of particulates of various sizes. A higher MERV rating implies greater particulate removal.

To maintain optimum performance, the collector cells of electronic air filters must be cleaned periodically. Automatic indicators are often used to signal the need for cleaning. Electronic air filters have higher initial costs than disposable or pleated filters, but generally last the life of the air-conditioning system. Also available are gas-phase filters such as those that use activated carbon. [Chapter 29 of the 2020 ASHRAE Handbook—HVAC Systems and Equipment](#) covers the design of residential air filters in more detail.

Ultraviolet (UV) germicidal light as an air filtration system for residential applications has become popular recently. UV-C is the band used for germicidal applications. UV light has been successfully used in health care facilities, food-processing plants, schools, and laboratories. It can break organic molecular bonds, which translates into cellular or genetic damages for microorganisms. Single or multiple UV lamps are usually installed in the return duct or downstream of indoor coils in the supply duct. Direct exposure of occupants to UV light is avoided because UV light does not pass through metal, glass, or plastic. This air purification method effectively reduces the transmission of airborne germs, bacteria, molds, viruses, and fungi in the airstreams without increasing duct pressure losses. The power required by each UV lamp might range between 18 and 100 W, depending on the intensity and exposure time required to kill the various microorganisms. [Chapter 17 of the 2020 ASHRAE Handbook—HVAC Systems and Equipment](#) and [Chapter 62](#) of this volume cover the design and application of UV lamp systems in more detail.

Ventilation

Historically, residential buildings have not required active mechanical ventilation. They were built without focus on airtightness, so in general natural infiltration with some use of spot ventilation was sufficient to maintain indoor air quality at a safe and comfortable level. More recent construction codes require that buildings be more airtight in an effort to reduce heating and cooling loads associated with infiltration. This reduction in natural ventilation has led to an increased need for mechanical ventilation to ensure suitable air quality in energy-efficient housing. ASHRAE *Standard* 62.2 provides guidance on selecting ventilation airflow rates, based on the number of occupants, number of bedrooms, and method used for distributing that air throughout the home. [Chapter 16 of the 2021 ASHRAE Handbook—Fundamentals](#) provides additional information on residential ventilation.

Controls

Residential heating and cooling equipment is controlled by one or more thermostats, which call for heating and cooling from the equipment's embedded control board, or a zone control system if installed. Zone control panels typically aggregate the signals from multiple zones before passing along the control signal to the embedded controls. A useful guideline is to install thermostats on an interior wall in a frequently occupied area, about 1.5 m from the floor and away from exterior walls, direct sunlight, and supply registers to avoid unintended short-cycling of the equipment when cold or hot air blows on the thermostat. A typical simple wall thermostat contains a temperature sensor and microelectronics that request the heating and cooling equipment operate when the measured temperature falls outside of a dead band, typically ± 0.56 K centered at the owner's desired set point.

Programmable thermostats can set heating and cooling equipment at different temperature levels, depending on the time of day or week. This has led to night setback, workday, and vacation control to reduce energy demand and operating costs. For heat pump equipment, electronic thermostats can incorporate night setback with an appropriate scheme to limit use of resistance heat during recovery. Several manufacturers offer thermostats that measure and display relative humidity and actively change the evaporator blower speed to improve latent cooling during times of high humidity.

Modern thermostats use additional sensors, such as remote room temperature, humidity, and motion sensors, or integrate with external computing platforms (e.g., mobile phones) to monitor occupants' locations and enable automatic return to setpoint when people enter a geographic radius from the home. The use of machine learning, geofencing, and other emerging features is very promising for reducing energy consumption and costs while maintaining or improving user comfort. These so-called **smart thermostats** can be integrated with both noncommunicating and communicating HVAC systems. Some communicating systems require a smart thermostat, often by the same manufacturer, to take advantage of the improved efficiency and fault detection and diagnostic features that a communicating HVAC system provides. For example, most minisplit heat pumps are accompanied by a remote controller that contains the system thermostat, a display, and other user controls. [Chapter 47](#) contains more details about automatic control systems.

In traditional (noncommunicating) systems, the thermostat uses relay logic, or discrete on/off voltage signals, to control the operation of the HVAC system. This requires the use of multiconductor cable between the thermostat, the indoor unit, and the outdoor unit. Residential systems typically require between 4 and 12 color-coded wires to be connected.

A communicating system replaces the many wires with serial communications over two, three, or four wires only, as shown in [Figure 4](#). In a communicating HVAC system, the indoor unit, outdoor unit, and thermostat act as nodes on a network that send and receive messages to and from each other across a limited number of wires. Each node (device) has its own unique electronic address. Messages are packaged into a common format called a communications protocol and transported to their destinations on the network. In retrofits, these systems offer the ease of plug-and-play installation using existing wiring. A homeowner can replace an existing single-stage furnace and air conditioner with two-stage or variable-capacity equipment and not need to run additional wires. In theory, communications between nodes could also be wireless if they were equipped with radio transceivers.

Communicating systems are a relatively recent addition to residential HVAC, having shown their usefulness in commercial HVAC. The advent of electronics to control the evaporator coil (by modulating both the electronic expansion valve and the blower) and the condensing unit (primarily through monitoring and modulating the compressor) enable systems to take advantage of communications. Communicating systems can offer more options to the HVAC engineer, but most use proprietary communication protocols, which can limit the use of dissimilarly branded products for optional equipment.

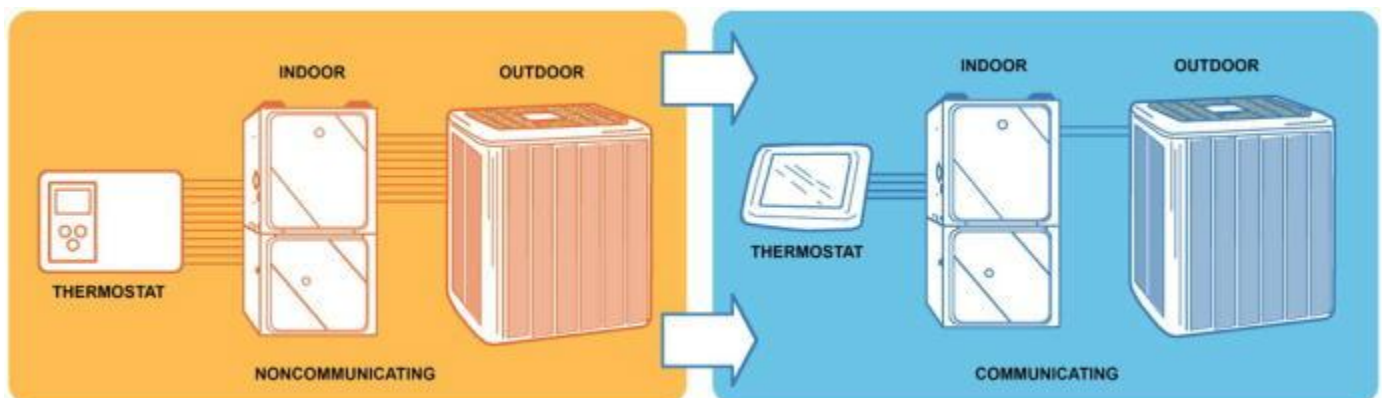


Figure 4. Communicating HVAC Systems Simplify Wiring

Communicating HVAC systems also allow an advanced level of system diagnostics. Because nodes communicate in messages, not signals, unlimited amounts of information could be transferred across the few wires of a communicating system. Messages could convey commands or just carry information. This contrasts with having to add a new wire for each additional (analog) signal, as is the case of noncommunicating systems. For example, in a communicating system, the outdoor unit could announce that it has a variable-capacity compressor and the thermostat could command the compressor to turn on and to ramp to a certain speed. The thermostat could ask the outdoor unit for the measured

ambient temperature to display it on its screen, or the outdoor unit could send a message to the thermostat to alert the homeowner that a pressure switch is open.

For an HVAC system to be communicating, each device (node) must have an electronic circuit board with a microprocessor. The board gets data from sensors and other HVAC components that are connected to it (e.g., compressor contactor, pressure switches, reversing valve, blower fan, indoor electric heater). The microprocessor packages the data collected from those components into messages and sends them to other nodes on the network. Most new residential HVAC systems have some type of electronics in them. Although most communicating systems use proprietary protocols and do not allow matching indoor and outdoor equipment using different protocols, some manufacturers offer equipment that can be controlled either by traditional 24V thermostat signals or by proprietary serial communication.

Networking the components of a residential HVAC system to form a communicating system provides a framework for sharing information within the network as well as with external devices. A wired or wireless gateway, either stand-alone or integrated into any of the communicating nodes, is often used to facilitate data transfer. This enables the HVAC system to be remotely accessible to networked devices such as smart phones, laptops, mobile devices, the electric utility company's smart meter, or cloud services. This remote accessibility, together with the wealth of system information available in a communicating system, allows innovations in the way HVAC systems are maintained and managed. For example, a homeowner could monitor the sensed temperature at the thermostat, check/set the thermostat set-point temperature, change thermostat schedules, and receive maintenance notifications using a smart phone. Electric utilities can supply a signal to reduce electrical demand, and the communicating control system can acknowledge and act on this signal.

4. MULTIFAMILY RESIDENCES

Attached homes and low-rise multifamily apartments generally use heating and cooling equipment comparable to applications used in single-family dwellings. Separate systems for each unit allow individual control to suit the occupants and facilitate individual metering of energy use; separate metering and direct billing of occupants encourages energy conservation.

Small residential warm-air furnaces may also be used in multifamily residences, but a means of providing combustion air and venting combustion products from gas- or oil-fired furnaces is required. It may be necessary to use a multiple-vent chimney or a manifold-type vent system where the exhaust from multiple units must be combined due to space constraints. Local codes must be consulted. Direct-vent furnaces that are placed near or on an outer wall are also available for apartments.

Hydronic Systems

Individual heating and cooling units are not always possible or practical in high-rise structures. In this case, applied central systems are used. Two- or four-pipe hydronic central systems are widely used in high-rise apartments. Each dwelling unit has either individual room units or ducted fan-coil units.

An on-demand water heater may also be used as a source of heat for the hydronic coil instead of a central system. In these applications, the on-demand water heater serves as a source of heat and hot water for the individual apartment. Cooling may come from a central hydronic system, window air conditioner, or typical unitary condenser.

The most flexible hydronic system with usually the lowest operating costs is the four-pipe type, which provides heating or cooling for each apartment dweller. The two-pipe system is less flexible because it cannot provide heating and cooling simultaneously. This limitation causes problems during the spring and fall when some apartments in a complex require heating while others require cooling because of solar or internal loads. This seasonal problem may be overcome by operating the two-pipe system in a cooling mode and providing the relatively low amount of heating that may be required by means of individual electric resistance heaters.

[Chapter 13 of the 2020 ASHRAE Handbook—HVAC Systems and Equipment](#) discusses hydronic design in more detail.

Through-the-Wall Units

Through-the-wall room air conditioners, packaged terminal air conditioners (PTACs), packaged terminal heat pumps (PTHPs), single-package vertical air conditioners (SPVACs), and single-package vertical heat pumps (SPVHPs) can be used for conditioning single rooms. Each room with an outer wall may have such a unit. These units are used extensively in renovating old buildings because they are self-contained and typically do not require complex piping or ductwork renovation.

Room air conditioners have integral controls and may include resistance or heat pump heating. PTACs and PTHPs have special indoor and outdoor appearance treatments, making them adaptable to a wider range of architectural needs. PTACs can include gas, electric resistance, hot water, or steam heat. Integral or remote wall-mounted controls are used for both PTACs and PTHPs. Further information may be found in [Chapter 49 of the 2020 ASHRAE Handbook—HVAC Systems and Equipment](#) and in AHRI *Standard* 310/380.

Water-Loop Heat Pumps

Any mid- or high-rise structure having interior zones with high internal heat gains that require year-round cooling can efficiently use a water-loop heat pump. Such systems have the flexibility and control of a four-pipe system but use only two pipes. Water-source heat pumps allow individual metering of each apartment. The building owner pays only the utility cost for the circulating pump, cooling tower, and supplemental boiler heat. Existing buildings can be retrofitted with heat flow meters and timers on fan motors for individual metering.

Special Concerns for Apartment Buildings

Many ventilation systems are used in apartment buildings. Local building codes generally govern outdoor air quantities. ASHRAE *Standard* 62.2 provides guidance on selecting ventilation airflow rates based on the method used for distributing that air throughout the building. [Chapter 16 of the 2021 ASHRAE Handbook—Fundamentals](#) provides additional information on residential ventilation.

Buildings using exhaust and supply air systems may benefit from air-to-air heat or energy recovery devices (see [Chapter 26 of the 2020 ASHRAE Handbook—HVAC Systems and Equipment](#)). Such recovery devices can reduce energy consumption by transferring 40 to 80% of the sensible heat and some equipment latent heat between the exhaust air and supply airstreams. In some buildings with centrally controlled exhaust and supply systems, the systems are operated on time clocks for certain periods of the day. In other cases, the outdoor air is reduced or shut off during extremely cold periods. If known, these factors should be considered when estimating heating and cooling loads.

Frequently, long refrigerant lineset lengths and elevation changes may be required. Refrigerant charge migration, pressure drop, and oil return to the compressor must all be considered. For further information, see [Chapter 49 of the 2020 ASHRAE Handbook—HVAC Systems and Equipment](#).

Another important load, frequently overlooked, is heat gain from piping for hot-water services.

Infiltration loads in high-rise buildings without ventilation openings for perimeter units are not controllable year-round by general building pressurization. When outer walls are penetrated to supply outdoor air to unitary or fan-coil equipment, combined wind and thermal stack effects create other infiltration problems.

Interior public corridors in apartment buildings need conditioning and smoke management to meet their ventilation and thermal needs, and to meet the requirements of fire and life safety codes. Stair towers, however, are normally kept separate from hallways to maintain fire-safe egress routes and, if needed, to serve as safe havens until rescue. Therefore, great care is needed when designing buildings with interior hallways and stair towers. [Chapter 53](#) provides further information.

Air-conditioning equipment must be isolated to reduce noise generation or transmission. The design and location of cooling towers must be chosen to avoid disturbing occupants within the building and neighbors in adjacent buildings. Also, for cooling towers, prevention of *Legionella* is a serious concern. Further information on cooling towers is in [Chapter 40 of the 2020 ASHRAE Handbook—HVAC Systems and Equipment](#).

In large apartment complexes, a central building energy management system may allow individual apartment air-conditioning systems or units to be monitored for maintenance and operating purposes.

5. MANUFACTURED HOMES

Manufactured homes are constructed in factories rather than site built. In 2020, they constituted approximately 10% of all housing units in the United States (EIA 2023). Heating and cooling systems in manufactured homes, as well as other facets of construction such as insulation levels, are regulated in the United States by the Department of Housing and Urban Development (HUD) Manufactured Housing Construction and Safety Standards Act. Each complete home or home section is assembled on a transportation chassis, which is used to transport the home from the factory to the home site and serves as the base of the structure. Manufactured homes vary in size from small, single-floor section units starting at 37 m² to large, multiple sections, which when joined together can provide over 280 m² and have an appearance similar to site-constructed homes.

Heating systems are factory-installed and are primarily forced-air downflow units feeding main supply ducts built into the subfloor, with floor registers located throughout the home. A small percentage of homes in the far southern and southwestern United States use upflow units feeding overhead ducts in the attic space. Typically, there is no return duct system. Air returns to the air handler from each room through door undercuts, hallways, transfer grilles, or louvered panels. The complete heating system is a reduced-clearance type with the air-handling unit installed in a small closet or alcove, usually in a hallway. Sound control measures may be required if large forced-air systems are installed close to sleeping areas. Gas, oil, and electric furnaces or heat pumps may be installed by the home manufacturer to satisfy market requirements.

Gas and oil furnaces are compact direct-vent types approved for installation in a manufactured home. The special venting arrangement used is a vertical through-the-roof concentric pipe-in-pipe system that draws all air for combustion directly from the outdoors and discharges combustion products through a windproof vent terminal. Gas furnaces must be easily convertible from liquefied petroleum gas (LPG) to natural gas and back as required at the final site. In the

United States, 71% of manufactured homes use electricity for their heat source, around 24% use natural gas, and 12% use propane (EIA 2023). (Percentages exceed 100 because some heat with dual fuels.)

Manufactured homes may be cooled with add-on split or single-package air-conditioning systems when supply ducts are adequately sized and rated for that purpose according to HUD requirements. The split-system evaporator coil may be installed in the integral coil cavity provided with the furnace. A high-static-pressure blower is used to overcome resistance through the furnace, evaporator coil, and compact air distribution system. Single-package air conditioners are connected with flexible air ducts to feed existing factory in-floor or overhead ducts. Flexible ducts are installed underneath the mobile home to connect multiple sections. Due to their location, these ducts may be susceptible to damage by water or animals. Dampers or other means are required to prevent the cooled, conditioned air from backflowing through a furnace cabinet.

A typical installation of a downflow gas or oil furnace with a split-system air conditioner is shown in [Figure 5](#). Air enters the furnace from the hallway, passing through a louvered door on the front of the furnace. The air then passes through air filters and is drawn into the top-mounted blower, which during winter forces air down over the heat exchanger, where it picks up heat. For summer cooling, the blower forces air through the furnace heat exchanger and then through the split-system evaporator coil, which removes heat and moisture from the passing air. During heating and cooling, conditioned air then passes through the floor base via a duct connector before flowing into the floor air distribution duct. The evaporator coil is connected with refrigerant lines to a remote air-cooled condensing unit. The condensate collected at the evaporator is drained by a flexible hose, routed to the exterior through the floor construction, and connected to a suitable drain. Cooling equipment sizing guidelines are provided by the Department of Energy through the ENERGY STAR program for manufactured homes in the continental United States (DOE 2005).

REFERENCES

ASHRAE members can access *ASHRAE Journal* articles and ASHRAE research project final reports at technologyportal.ashrae.org. Articles and reports are also available for purchase by nonmembers in the online ASHRAE Bookstore at www.ashrae.org/bookstore.

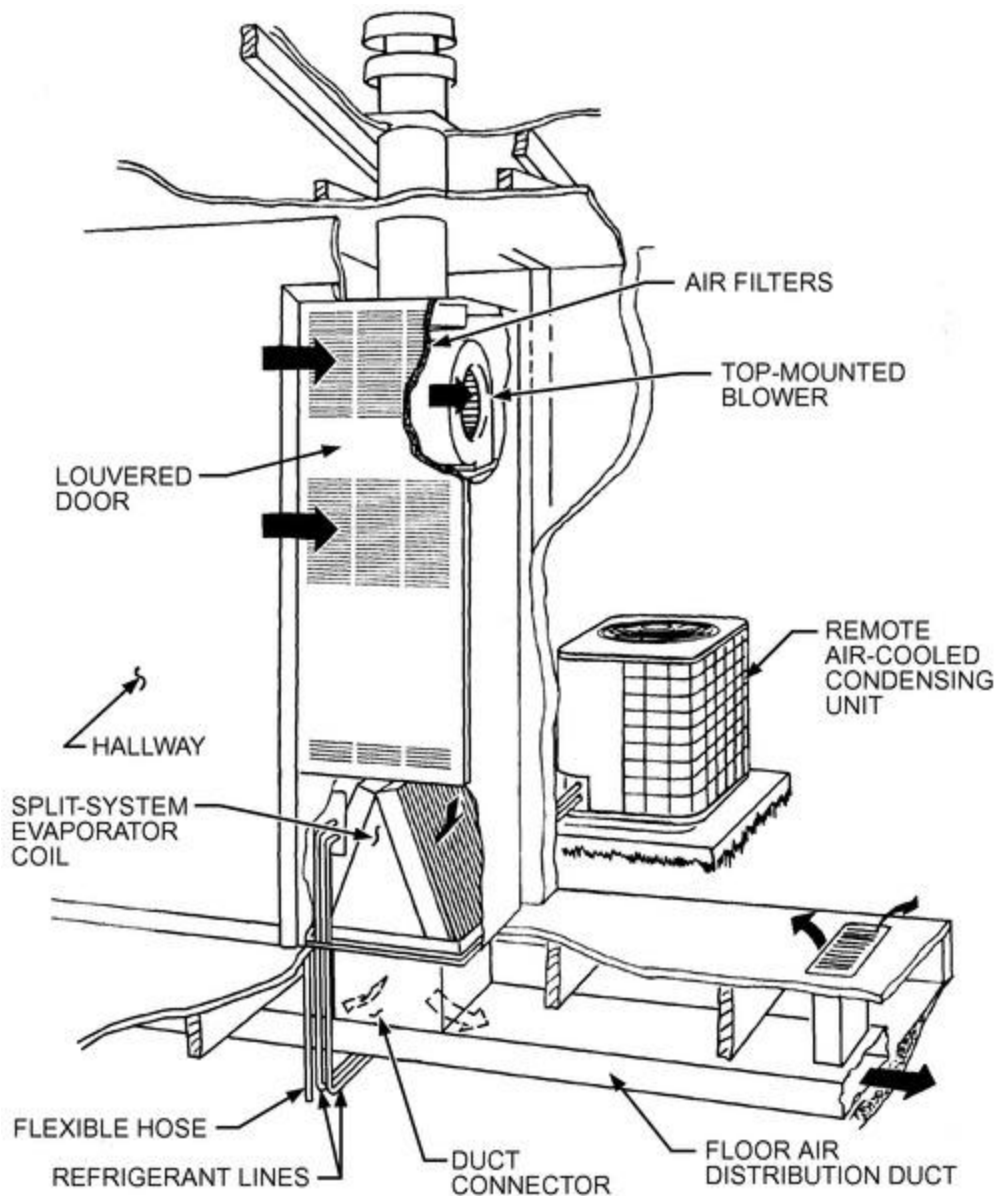


Figure 5. Typical Installation of Heating and Cooling Equipment for Manufactured Home

- ACCA. 2016. Residential duct systems. ANSI/ACCA 1 *Manual D*[®]. Air Conditioning Contractors of America, Arlington, VA.
- ACCA. 2016. Residential load calculation, 8th ed. ANSI/ACCA 2 *Manual J*[®]. Air Conditioning Contractors of America, Arlington, VA.
- ACCA. 2014. Residential equipment selection, 2nd ed. ANSI/ACCA 3 *Manual S*[®]. Air Conditioning Contractors of America, Arlington, VA.
- AHAM. 2008. Major appliance performance standard for residential dehumidifiers. ANSI/AHAM *Standard DH-1-2008*. Association of Home Appliance Manufacturers, Washington, D.C.
- AHRI. 2015. Selection, installation and servicing of residential humidifiers. *Guideline F-2015*. Air-Conditioning, Heating, and Refrigeration Institute, Arlington, VA.
- AHRI. 2015. Sound rating of outdoor unitary equipment. *Standard 270-2015*. Air-Conditioning, Heating, and Refrigeration Institute, Arlington, VA.
- AHRI. 2010. Application of sound rating levels of outdoor unitary equipment. ANSI/AHRI *Standard 275-2010*. Air-Conditioning, Heating, and Refrigeration Institute, Arlington, VA.
- AHRI. 2017. Packaged terminal air-conditioners and heat pumps. *Standard 310/380-2017*. Air-Conditioning, Heating, and Refrigeration Institute, Arlington, VA.
- AHRI. 2014. Performance rating of central system humidifiers for residential applications. ANSI/AHRI *Standard 611-2014*. Air-Conditioning, Heating, and Refrigeration Institute, Arlington, VA.
- AHRI. 2017. Performance rating of residential air filter equipment. *Standard 681-2017*. Air-Conditioning, Heating, and Refrigeration Institute, Arlington, VA.
- ASHRAE. 2017. Method of testing general ventilation air-cleaning devices for removal efficiency by particle size. ANSI/ASHRAE *Standard 52.2-2017*.
- ASHRAE. 2020. Thermal environmental conditions for human occupancy. ANSI/ASHRAE *Standard 55-2020*.

- ASHRAE. 2022. Ventilation for acceptable indoor air quality. ANSI/ASHRAE *Standard* 62.1-2022.
- ASHRAE. 2022. Ventilation and acceptable indoor air quality in low-rise residential buildings. ANSI/ASHRAE *Standard* 62.2-2022.
- ASHRAE. 2018. Energy-efficient design of low-rise residential buildings. ANSI/ASHRAE *Standard* 90.2-2018.
- ASHRAE. 2016. Methods of testing for rating combination space-heating and water-heating appliances. ASHRAE *Standard* 124-2007 (RA 2016).
- Caneta Research. 1995. *Commercial/institutional ground-source heat pump engineering manual*. ASHRAE.
- DOE. 2005. *Manufactured home cooling equipment sizing guidelines*. U.S. Department of Energy, Washington, D.C. www.energystar.gov/ia/partners/bldrs_lenders_raters/downloads/SizingGuidelines.pdf?8fd5-1967.
- EIA. 2023. *2015 residential energy consumption survey (RECS)*, Release: February 2017. U.S. Energy Information Administration, Washington, D.C. www.eia.gov/consumption/residential/data/2020.
- Grossman, G., R.C. DeVault, and F.A. Creswick. 1995. Simulation and performance analysis of an ammonia-water absorption heat pump based on the generator-absorber heat exchange (GAX) cycle. *ASHRAE Transactions* 101(1):1313-1323. *Paper* CH-95-21-1.
- Kavanaugh, S.P., and K. Rafferty. 2014. *Geothermal heating and cooling: Design of ground-source heat pump systems*. ASHRAE.

BIBLIOGRAPHY

- ACCA 2015. *HVAC quality installation specification*. ANSI/ACCA 15 QI-2015. Air Conditioning Contractors of America, Arlington, VA.
- AHRI. 2017. Performance rating of unitary air-conditioning and air-source heat pump equipment. *Standard* 210/240-2017. Air-Conditioning, Heating, and Refrigeration Institute, Arlington, VA.
-

The preparation of this chapter is assigned to TC 8.11, Unitary and Room Air Conditioners and Heat Pumps.