Related Commercial Resources

CHAPTER 1

RESIDENCES

SPACE-CONDITIONING systems for residential use vary with both local and application factors. Local factors include energy source availability (present and projected) and price; climate; socioeconomic circumstances; and availability of installation and maintenance skills. Application factors include housing type, construction characteristics, and building codes. As a result, many different systems are selected to provide combinations of heating, cooling, humidification, dehumidification, ventilation, and air filtering. This chapter emphasizes the more common systems for space conditioning of both single-family (i.e., traditional site-built and modular or manufactured homes) and multifamily residences. Low-rise multifamily buildings generally follow single-family practice because constraints favor compact designs; HVAC systems in high-rise apartment, condominium, and dormitory buildings are often of commercial types similar to those used in hotels. Retrofit and remodeling construction also adopt the same systems as those for new construction, but site-specific circumstances may call for unique designs.

1. SYSTEMS

Common residential systems are listed in Table 1. Three generally recognized groups are central forced air, central hydronic, and zoned systems. 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).

Climate determines the services needed. Heating and cooling are generally required. Air cleaning, by filtration or electrostatic devices, is present in most systems. Humidification, when used, is provided in heating systems for thermal comfort (as defined in ASHRAE *Standard* 55), health, and reduction of static electricity discharges. Cooling systems usually dehumidify air as well as lowering its temperature. 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 a trap.

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 a 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. An optional humidifier adds

Table 1 Residential Heating and Cooling Systems

	Central Forced Air	Central Hydronic	Zoned
Most common energy sources	Gas Oil Electricity	Gas Oil Electricity	Gas Electricity
Distribution medium	Air	Water Steam	Air Water Refrigerant
Distribution system	Ducting	Piping	Ducting Piping or Free delivery
Terminal devices	Diffusers Registers Grilles	Radiators Radiant panels Fan-coil units	Included with product or same as forced-air or hydronic systems

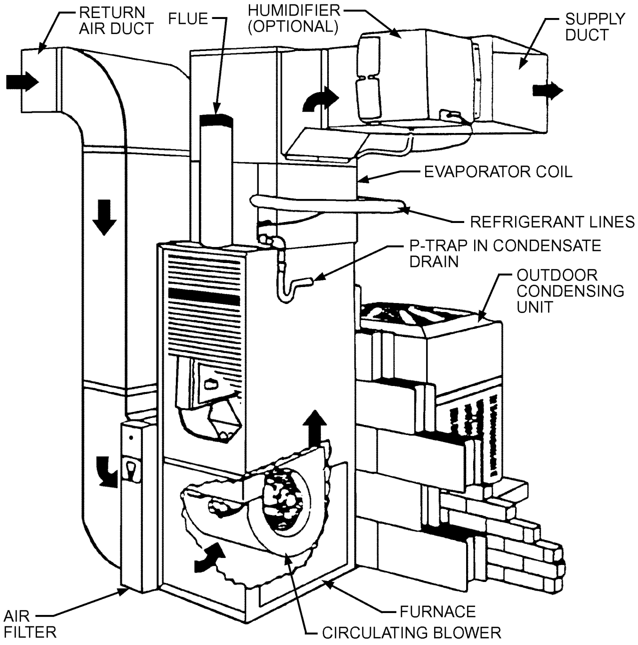

Fig. 1 Typical Residential Installation of Heating, Cooling, Humidifying, and Air Filtering System

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

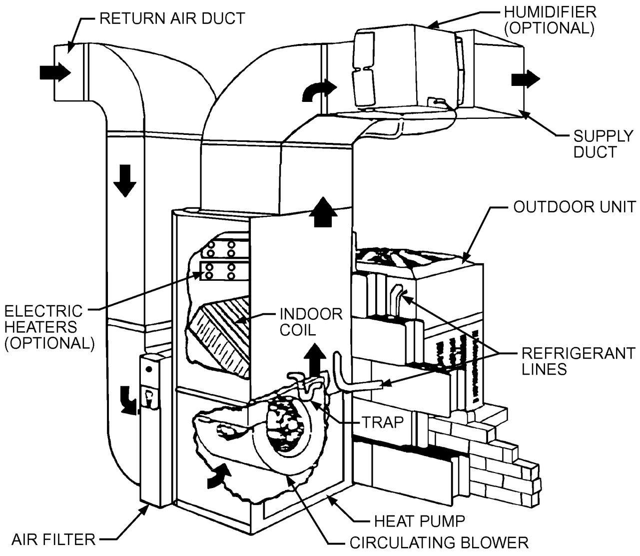

Fig. 2 Typical Residential Installation of a Split-System Air-to-Air Heat Pump

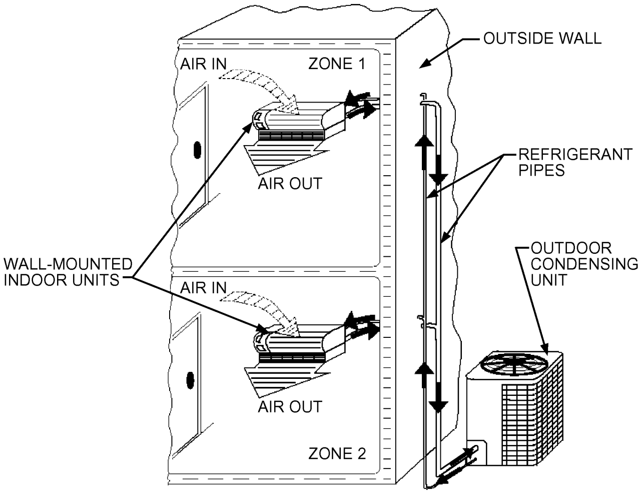

Fig. 3 Example of Two-Zone, Ductless Multisplit System in Typical Residential Installation

moisture to the heated air, which 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 with a trap.

Minisplit and multisplit systems, which are similar to split systems but are typically ductless, are increasingly popular worldwide. A typical two-zone, ductless multisplit system installation is shown in Figure 3. In this example, the system consists mainly of two parts: an outdoor condensing unit and two indoor air-handling units that are usually installed on perimeter walls of the house. Each indoor air handler serves one zone and is controlled independently from the other indoor unit.

Single-package unitary systems, such as window-mounted, through-the-wall, or rooftop units where all equipment is 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 systems.

Central hydronic heating systems are popular both in Europe and in parts of North America where central cooling has not normally been provided. New construction, especially in multistory homes, now typically includes forced-air cooling.

Zoned systems are designed to condition only part of a home at any one time. They may consist of individual room units or central systems with zoned distribution networks. Multiple central systems that serve individual floors or the sleeping and common portions of a home separately are sometimes used in large single-family residences.

The energy source is a major consideration in system selection. According to 2009 data from the U.S. Energy Information Administration (EIA 2013), for heating, about 49% of homes use natural gas, followed by electricity (34%), fuel oil (6%), propane (5%), wood (2.5%), and kerosene or other fuel (<1%). 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

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 are 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. 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. The heating capacity of air-source heat pumps is usually supplemented by auxiliary heaters, most often of the electric resistance type; in some cases, however, fossil fuel furnaces or solar systems are used.

Undersized equipment will be unable to maintain the intended indoor temperature under extreme outdoor temperatures. Some oversizing may be desirable to enable 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. Variable-capacity equipment (heat pumps, air conditioners, and furnaces) can more closely match building loads over broad ambient temperature ranges, usually reducing these losses and improving comfort levels; in the case of heat pumps, supplemental heat needs may also be reduced.

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. 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. All ventilation schemes increase heating and cooling loads and thus the required system capacity, thereby resulting in greater energy consumption. In all cases, minimum ventilation rates, as described in ASHRAE *Standards* 62.1 and 62.2, should be maintained.

3. SINGLE-FAMILY RESIDENCES

Heat Pumps

Heat pumps for single-family houses are normally centrally ducted unitary or split systems, as illustrated in Figures 2 and 3.

Most commercially available heat pumps, particularly in North America, are reversible, electrically powered, air-source systems. The direction of flow of the refrigerant can be switched to provide cooling or heating to the home.

Heat pumps may be classified by thermal source and distribution medium in the heating mode as well as the type of fuel used. The most common classifications of heat pump equipment are air-to-air and water-to-air. Air-to-water and water-to-water types are also used.

Heat pump systems are generally described as air-source or ground-source. The thermal sink for cooling is generally assumed to be the same as the thermal source for heating.

Air-Source Systems. Air-source systems using ambient air as the heat source/sink can be installed in almost any application and are generally the least costly to install and thus the most commonly used.

Ground-Source (Geothermal) Systems. Ground-source systems usually use water-to-air heat pumps to extract heat from the ground using groundwater or a buried heat exchanger. As a heat source/sink, groundwater (from individual wells or supplied as a utility from community wells) offers the following advantages over ambient air: (1) heat pump capacity is independent of ambient air temperature, reducing supplementary heating requirements; (2) no defrost cycle is required; (3) 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; and (4) 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, but because surface water temperatures track fluctuations in air temperature, **surface-water-coupled systems** may not offer the same benefits as other 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. **Direct-expansion ground-source systems**, with evaporators buried in the ground, also are available but are seldom used. **Water-source systems** that extract heat from surface water (e.g., lakes or rivers) or city (tap) water are sometimes used where local conditions allow. See Chapter 49 of the 2012 *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 2013 *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.

Add-On Heat Pumps. In add-on systems, a heat pump is added (often as a retrofit) to an existing furnace or boiler/fan-coil system. The heat pump and combustion device are operated in one of two ways: (1) alternately, depending on which is most cost-effective, or (2) in parallel. 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. Extensive research and development has been conducted to develop fuel-fired heat pumps. They have been marketed in North America. More information may be found in Chapter 49 of the 2012 *ASHRAE Handbook—HVAC Systems and Equipment*.

Water-Heating Options. Heat pumps may be equipped with desuperheaters (either integral or field-installed) to reclaim heat for domestic water heating when operated in cooling mode. Integrated space-conditioning and water-heating heat pumps with an additional full-size condenser for water heating are also available.

Furnaces

Furnaces are fueled by gas (natural or propane), electricity, oil, wood, or other combustibles. Gas, oil, and wood furnaces may draw combustion air from 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%. 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. Condensing furnaces generally use PVC for vent pipes and condensate drains.

Biofuels and coal-fueled furnaces are used in some areas as either the primary or supplemental heating unit. These furnaces may have catalytic converters to enhance the combustion process, increasing furnace efficiency and producing cleaner exhaust.

Chapters 31 and 33 of the 2012 *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 systems have declined in popularity in new construction, but 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 are typically either radiators or baseboard convectors. Other terminal units include 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. Chapters 13 and 36 of the 2012 *ASHRAE Handbook—HVAC Systems and Equipment* have more information on hydronics.

Design water temperature is based on economic 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 piping and heat distributing units and for eliminating air from the hydronic system are essential for quiet, leak-tight operation.

Fossil fuel systems that condense water vapor from the flue gases 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 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.

Zoned Heating Systems

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 kept at lower temperatures in the winter.

One form of this system consists of individual heaters located in each room. These heaters are usually electric or gas-fired. Electric heaters are available in the following types: baseboard free-convection, wall insert (free-convection or forced-fan), radiant panels for walls and ceilings, and radiant cables for walls, ceilings, and floors. 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 precision in room-by-room sizing is needed. Most individual heaters have integral thermostats that limit the ability to optimize unit control without continuous fan operation.

Individual heat pumps for each room or group of rooms (zone) are another form of zoned electric heating. For example, two or more small unitary heat pumps can be installed in two-story or large one-story homes.

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. These systems are used in both new and retrofit construction. These are also known as **variable-refrigerant-volume (VRV)** or **variable-refrigerant-flow (VRF) systems**, and may include a heat recovery mode where some indoor units operate in heating and some in cooling simultaneously.

A method for zoned heating in central ducted systems is the zone-damper system. This consists of 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 heating.

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 35 has information on sizing solar heating equipment.

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 illustrated 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, 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. Airflow rates of 45 to 60 L/s per kilowatt of refrigeration are normally recommended for good cooling performance. As with heat pumps, these systems 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. Air-to-air and water-source heat pumps provide cooling and heating by reversing the flow of refrigerant.

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

There is renewed interest in quality duct design, because it can make a large difference in the 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 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 2013 *ASHRAE Handbook—Fundamentals* provides the theory behind duct design. Chapter 10 of the 2012 *ASHRAE Handbook—HVAC Systems and Equipment* discusses air distribution design for small heating and cooling systems. Chapter 19 of the 2012 *ASHRAE Handbook—HVAC Systems and Equipment* addresses duct construction and code requirements.

Because weather is the primary influence on the load, the cooling and heating load in each room changes from hour to hour. Therefore, the owner or occupant 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. Other possible refinements are installing a heating and cooling system sized to meet heating requirements, with additional self-contained cooling units serving rooms with high summer loads, or separate central systems for the upper and lower floors of a house. Alternatively, zone-damper systems can be used. Another way of balancing cooling and heating loads is to use variable-capacity compressors in heat pump systems.

Operating characteristics of both heating and cooling equipment must be considered when zoning is used. For example, a reduction in 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 season can cause overloading if airflow across the indoor coil is not maintained above 45 L/s per kilowatt. Reduced air volume to a given room reduces the air velocity from the supply outlet and might cause unsatisfactory air distribution in the room. Manufacturers of zoned systems normally provide guidelines for avoiding such situations.

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. Multiple air outlets, some near the floor and others near the ceiling, have been used with some success on all levels. To control airflow, the homeowner opens some outlets and closes others from season to season. Free air circulation between floors can be reduced by locating returns high in each room and keeping doors closed.

In existing homes, the cooling that can be added is limited by the air-handling capacity of the existing duct system. Although the existing duct system 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 must 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. 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 inside walls of rooms may operate unsatisfactorily if the deflection is not changed from summer to winter.

Occupants of air-conditioned spaces usually prefer minimum perceptible air motion. Perimeter baseboard outlets with multiple slots or orifices directing air upwards effectively meet this requirement. Ceiling outlets with multidirectional vanes are also satisfactory.

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 dBA sound level 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; for example, 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 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 and thus air quality problems. Further details on evaporative coolers can be found in Chapter 41 of the 2012 *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: 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 inside surface of insulated walls, ceilings, and floors in most temperature climates. Lack of attention to this construction detail allows moisture to migrate from indoors to outdoors, causing damp insulation, mold, possible structural damage, and exterior paint blistering.

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. Some manufacturers certify the performance of their product to the AHRI standard. 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 2012 *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 with sensible cooling is important. Although conventional air-conditioning units provide some dehumidification as a consequence of sensible cooling, in some cases space humidity levels can still exceed comfortable levels.

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 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. Some dehumidification options add heat to the conditioned zone that, in some cases, increases the load on the sensible cooling equipment.

Air Filters

Most comfort conditioning systems that circulate air incorporate some form of air filter. Usually, they are disposable or cleanable filters that have relatively low air-cleaning efficiency. Higher-efficiency alternatives include pleated media filters and electronic air filters. These high-efficiency filters may have high 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.

Air filters are mounted in the return air duct or plenum and operate whenever air circulates through the duct system. Air filters are rated in accordance with AHRI *Standard* 680, 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; a higher MERV implies greater particulate removal, but also typically increased air pressure drop across the filter.

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 2012 *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 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 air streams without increasing duct pressure losses. The power required by each UV lamp might range between 30 and 100 W, depending on the intensity and exposure time required to kill the various microorganisms. Chapter 17 of the 2012 *ASHRAE Handbook—HVAC Systems and Equipment* and Chapter 60 of this volume cover the design and application of UV lamp systems in more detail.

Controls

Historically, residential heating and cooling equipment has been controlled by a wall thermostat. Today, simple wall thermostats with bimetallic strips are often replaced by programmable microelectronic models that 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. Chapter 47 contains more details about automatic control systems.

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 and registers.

Communicating systems are a relatively recent addition to residential HVAC, after having shown their usefulness in commercial HVAC. The advent of electronics to control the evaporator coil and the condensing unit made communications possible. Communicating systems are easier to install than noncommunicating systems and offer more options for the HVAC engineer.

In traditional (noncommunicating) systems, the thermostat uses relay logic, or discrete *on*/*off* voltage signals, to control the operation of the HVAC system. This results in having to run many wires from the thermostat to the indoor unit and outdoor unit. Some residential systems require 12 wires to be connected and therefore have high risk of being miswired during installation. Figure 4 shows typical field wiring of a residential heat pump.

A communicating system replaces the many wires with serial communications over two, three, or four wires only, as depicted in Figure 5. 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-stage equipment and not need to run additional wires. In theory, communications between nodes could also be wireless if they were equipped with radio transceivers.

For the HVAC designer, communicating HVAC systems 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 is in contrast to having to add a new wire for each additional signal, as is the case of noncommunicating systems. For example, in a communicating system, the outdoor unit could announce that it has a variable-speed 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. The microprocessor of each node also receives messages from other nodes intended for that node. Although many new residential HVAC systems have some electronics in them, to be considered communicating, the microprocessor must be able to handle the additional burden of implementing the communications protocol as well as handling the traffic of messages on the network.

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.

Data transfer to any other medium such as TCP/IP, ModBus®, BacNet™, Bluetooth®, wifi, Z-Wave®, or ZigBee® is possible using a gateway with an embedded local server. This gateway can either be a stand-alone device or integrated into any of the communicating nodes. This enables the HVAC system to be remotely accessible through interconnected 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, allow 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 that used in single-family dwellings. Separate systems for each unit allow individual control to suit the occupant and facilitate individual metering of energy use; separate metering and direct billing of occupants encourages energy conservation.

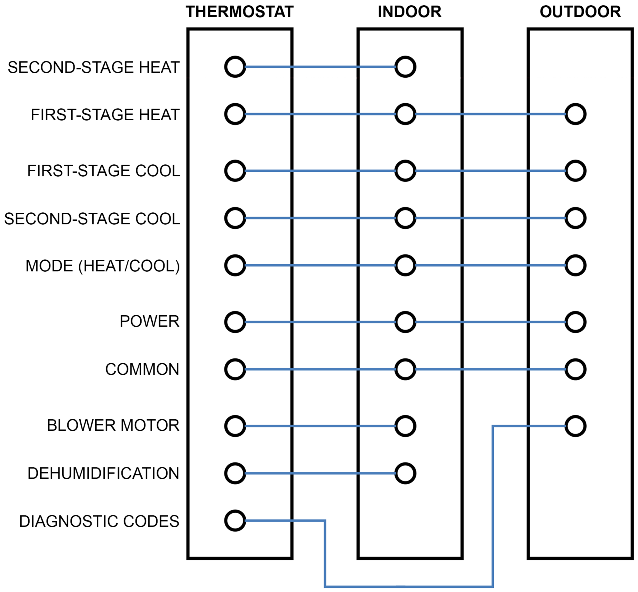

Fig. 4 Typical Field Wiring Diagram of Heat Pump

Forced-Air Systems

High-rise multifamily structures may also use unitary or mini-split heating and cooling equipment comparable to that used in single-family dwellings. Equipment may be installed in a separate mechanical equipment room in the apartment, in a soffit or above a dropped ceiling over a hallway or closet, or wall-mounted. Split systems' condensing or heat pump units are often placed on roofs, balconies, or the ground.

Small residential warm-air furnaces may also be used, 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. 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.

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 spring/fall 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.

See the section on Hydronic Heating Systems for description of a combined water-heating/space-heating system for multi- or single-family dwellings. Chapter 13 of the 2012 *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), and packaged terminal heat pumps (PTHPs) 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.

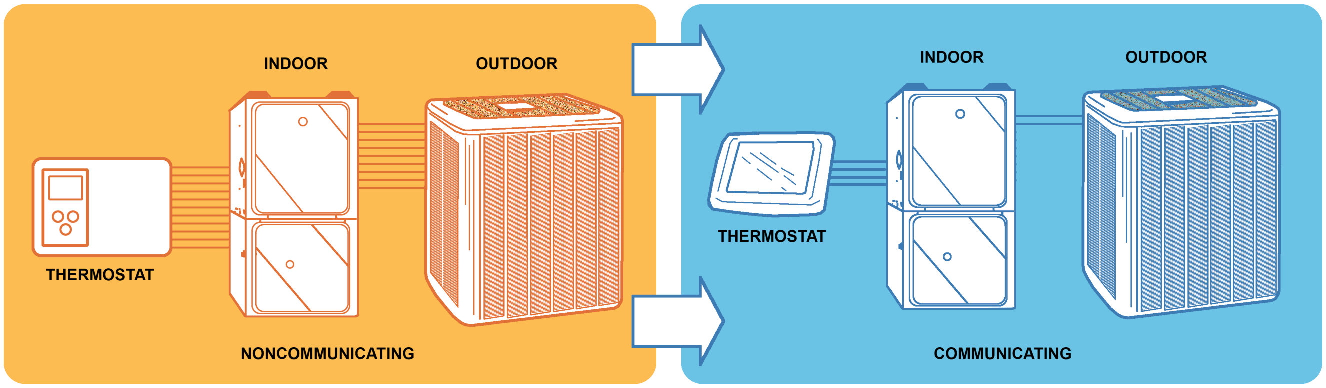

Fig. 5 Communicating HVAC Systems Simplify Wiring

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 50 of the 2012 *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. Economics permitting, solar or ground heat energy can provide the supplementary heat in lieu of a boiler. The ground can also provide a heat sink, which in some cases can eliminate the cooling tower. In areas where the water table is continuously high and the soil is porous, groundwater from wells can be used.

Special Concerns for Apartment Buildings

Many ventilation systems are used in apartment buildings. Local building codes generally govern outdoor air quantities. ASHRAE *Standard* 62.2-2010 lists required minimum outdoor air quantities for low-rise buildings.

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 load.

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

Buildings using exhaust and supply air systems 24 h/day may benefit from air-to-air heat recovery devices (see Chapter 26 of the 2012 *ASHRAE Handbook—HVAC Systems and Equipment*). Such recovery devices can reduce energy consumption by transferring 40 to 80% of the sensible and latent heat between the exhaust air and supply air streams.

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 2012 *ASHRAE Handbook—HVAC Systems and Equipment*.

In large apartment houses, 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. For the period 2005-2010, they constituted about 6% of all new single-family homes sold in the United States, down from about 10% for the 2000-2004 period (DOE 2012). 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 HUD Manufactured Home Construction and Safety Standards. Each complete home or home section is assembled on a transportation frame (a chassis with wheels and axles) for transport. Manufactured homes vary in size from small, single-floor section units starting at 37 m^2 to large, multiple sections, which when joined together can provide over 230 m^2 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, and a grilled door or louvered panel. 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.

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. 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 illustrated in Figure 6. 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 a combustible floor base via a duct connector before flowing into the floor air distribution duct. The evaporator coil is connected with quick-connect 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.

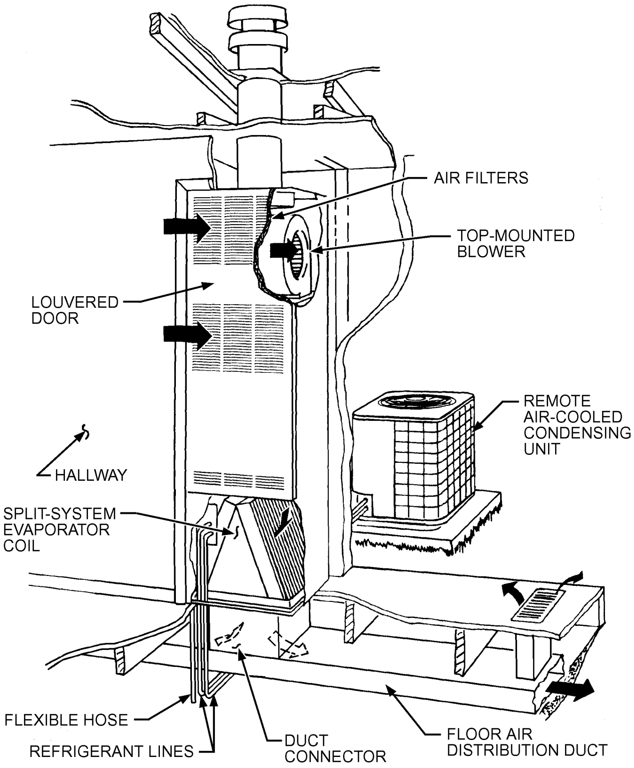

Fig. 6 Typical Installation of Heating and Cooling Equipment for Manufactured Home

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