

## CHAPTER 1

# RESIDENCES

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**S**PACE-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 the 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, 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. Retrofit and remodeling construction also adopt the same systems as those for new construction, but site-specific circumstances may call for unique designs.

### 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) can be added to most systems. Humidification, which can also be added to most systems, is generally provided in heating systems only when psychrometric conditions make it necessary for comfort and health (as defined in ASHRAE *Standard 55*). Cooling systems usually dehumidify as well. Typical residential installations are shown in [Figures 1](#) and [2](#).

[Figure 1](#) shows a gas furnace, a split-system air conditioner, a humidifier, and an air filter. The system functions as follows: Air from the space enters the equipment through a return air duct (1).

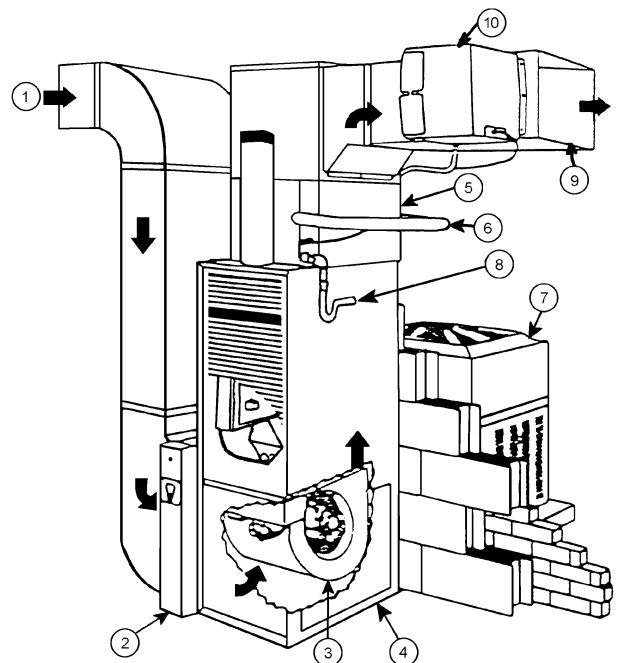
It passes initially through the air filter (2). The circulating blower (3) is an integral part of the furnace (4), which supplies heat during winter. An optional humidifier (10) adds moisture to the heated air, which is distributed throughout the home via the supply duct (9). When cooling is required, the circulating air passes across the evaporator coil (5), which removes heat and moisture from the air. Refrigerant lines (6) connect the evaporator coil to a remote condensing unit (7) located outdoors. Condensate from the evaporator is removed through a drainline with a trap (8).

[Figure 2](#) shows a split-system heat pump, supplemental electric resistance heaters, a humidifier, and an air filter. The system functions as follows: Air from the space enters the equipment through the return air duct (1) and passes through a filter (2). The circulating blower (3) is an integral part of the indoor unit (or air handler) of the heat pump (4), which supplies heat via the indoor coil (6) during the heating season. Optional electric heaters (5) supplement heat from the heat pump during periods of low ambient temperature and counteract airstream cooling during the defrost cycle. An optional humidifier (10) adds moisture to the heated air, which is distributed throughout the home via the supply duct (9). When cooling is required, the circulating air passes across the indoor coil (6), which removes heat and moisture from the air. Refrigerant lines (11) connect the indoor coil to the outdoor unit (7). Condensate from the indoor coil is removed through a drainline with a trap (8).

Single-package systems, where all equipment is contained in one cabinet, are also popular in the United States. They are used

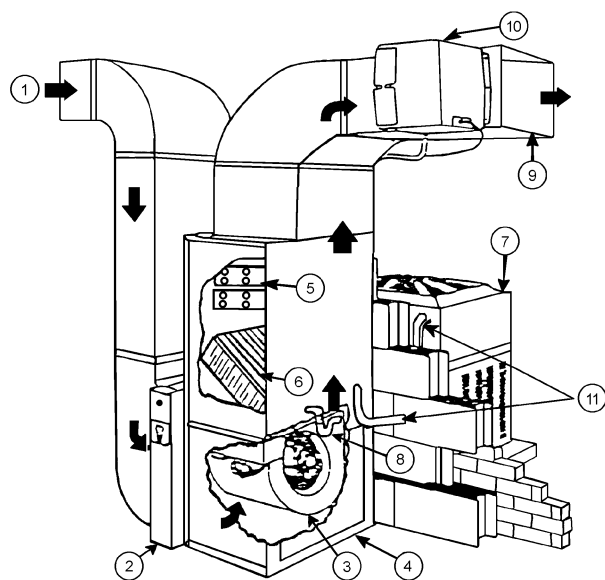
**Table 1 Residential Heating and Cooling Systems**

	Central Forced Air	Central Hydronic	Zoned
Most common energy sources	Gas Oil Electricity Resistance Heat pump	Gas Oil Electricity Resistance Heat pump	Gas Electricity Resistance Heat pump
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**

The preparation of this chapter is assigned to TC 7.6, Unitary and Room Air Conditioners and Heat Pumps.



**Fig. 2 Typical Residential Installation of Heat Pump**

extensively in areas where residences have duct systems in crawl-spaces beneath the main floor and in areas such as the Southwest, where typically 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 central 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 houses.

The source of energy is a major consideration in system selection. For heating, gas and electricity are most widely used, followed by oil, wood, solar energy, geothermal energy, waste heat, coal, district thermal energy, and others. 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.

### 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 in order to select equipment with the proper heating and cooling capacity. To determine heat loss and gain accurately, the floor plan and construction details must be known. The plan should include information on wall, ceiling, and floor construction as well as the type and thickness of insulation. 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*, *Energy-Efficient Design of New Low-Rise Residential Buildings*, 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 conditions of 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 thermal losses and off-cycle losses. Variable-capacity equipment (heat pumps, air conditioners, and furnaces) can more closely match building loads over specific ambient temperature ranges, usually reducing these losses and improving comfort levels; in the case of heat pumps, supplemental heat needs may also be reduced.

Recent trends toward tight building construction with improved vapor retarders and low infiltration may cause high indoor humidity conditions and the buildup of indoor air contaminants in the space. 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 the most important task. Simple exhaust systems with passive air intakes are also becoming popular. However, all ventilation schemes increase the building load and the required system capacity, thereby resulting in greater energy consumption. In all cases, minimum ventilation rates, as outlined in ASHRAE *Standard 62*, should be maintained.

## SINGLE-FAMILY RESIDENCES

### Heat Pumps

Heat pumps for single-family houses are normally unitary systems; that is, they use single-package units or split systems as illustrated in [Figure 2](#).

Most commercially available heat pumps (particularly in North America) are electrically powered air-source systems. Supplemental heat is generally required at low outdoor temperatures or during defrost. In most cases, supplemental or backup heat is provided by electric resistance heaters.

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 commonly used classes 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, as contrasted to the heat pump equipment, 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 using ambient air as the heat source/sink are generally the least costly to install and thus the most commonly used. Ground-source systems usually use water-to-air heat pumps to extract heat from the ground via groundwater or a buried heat exchanger.

**Ground-Source (Geothermal) Systems.** 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, the 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. Direct-expansion ground-source systems, with evaporators buried in the ground, are rarely 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 permit.

Water supply, quality, and disposal must be considered for groundwater systems. Caneta Research (1995) and Kavanaugh and Rafferty (1997) provide detailed information on these subjects. Secondary coolants for ground-coupled systems are discussed in Caneta Research (1995) and in Chapter 21 of the 2001 *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 plus 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. In unitary bivalent heat pumps, the heat pump and combustion device are grouped in a common chassis and cabinets to 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.

**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 the 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. When outdoor air is ducted to the combustion chamber, the arrangement is called a direct vent system. This latter method is used for manufactured home applications and some mid- and high-efficiency equipment designs. Using outside air for combustion eliminates both the infiltration losses associated with the use of indoor air for combustion and the 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. The higher-efficiency condensing type also recovers more energy by condensing water vapor from the combustion products. The condensate is developed in a high-grade stainless steel heat exchanger and is disposed of through a drain line. Condensing furnaces generally use PVC for vent pipes and condensate drains.

Wood-fueled furnaces are used in some areas. A recent advance in wood furnaces is the addition of catalytic converters to enhance the combustion process, increasing furnace efficiency and producing cleaner exhaust.

Chapters 28 and 29 of the 2000 *ASHRAE Handbook—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 12, 27, and 32 of the 2000 *ASHRAE Handbook—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 due to the concentrated heat source. Typical design temperatures range from 180 to 200°F. For radiant panel systems, design temperatures range from 110 to 170°F. 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, leaktight operation.

Fossil fuel systems that condense water vapor from the flue gases must be designed for return water temperatures in the range of 120 to 130°F 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

Zoned systems offer the potential for lower operating costs, because unoccupied areas can be kept at lower temperatures in the winter. Common areas can be maintained at lower temperatures at night and sleeping areas at lower temperatures during the day.

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 service up to eight indoor zones. Each zone uses one or more fan coils, with separate thermostatic controls for each zone. Such systems are used in both new and retrofit construction.

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. Such systems sometimes include a provision to modulate to lower capacities when only a few zones require heating.

## Solar Heating

Both active and passive solar 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 through a secondary heat exchanger and store extra heat in a water tank. Due to low delivered water temperatures, radiant floor panels requiring moderate temperatures are generally used.

Trombe walls and sunspaces are two common passive systems. Glazing facing south (in the northern hemisphere), with overhangs to reduce solar gains in the summer, and movable insulated panels can reduce heating requirements.

Some form of backup heating is generally needed with solar energy systems.

[Chapter 32](#) 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 outside 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 350 to 450 cfm per nominal ton 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 G*. Chapter 9 of the 2000 *ASHRAE Handbook—Systems and Equipment* also discusses air distribution design for small heating and cooling systems.

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 obtain improved comfort. Such adjustments may involve opening additional outlets in second-floor rooms during the summer and throttling or closing heating outlets in some rooms during the winter. Manually adjustable balancing dampers may be provided to facilitate these adjustments. Other possible refinements are the installation of a heating and cooling system sized to meet heating requirements, with additional self-contained cooling units serving rooms with high summer loads, or of separate central systems for the upper and lower floors of a house. On deluxe applications, zone-damper systems can be used. Another way of balancing cooling and heating loads is by using 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 the air quantity to one or more rooms may reduce the 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 350 cfm per ton. Reduced air volume to a given room would reduce

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 split-level houses, cooling and heating are complicated by air circulation between various levels. In many such houses, the upper level tends to overheat in winter and undercool in summer. Multiple 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 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. In all cases where 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, the 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 certify the sound level of their products in an ARI program (*ARI Standard 270*). *ARI Standard 275* gives information on how to predict the dBA sound level when the ARI 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. Most manufacturers provide recommendations regarding 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.

## Evaporative Coolers

In climates that are dry throughout the entire cooling season, evaporative coolers can be used to cool residences. Further details on evaporative coolers can be found in Chapter 19 of the 2000 *ASHRAE Handbook—Systems and Equipment* and in [Chapter 50](#) of this volume.

## Humidifiers

For improved winter comfort, equipment that increases indoor relative humidity may be needed. In a ducted heating system, a



central 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, care should be taken to maintain proper airflow across the indoor coil. Self-contained humidifiers can be used in any residence. Even though this type of humidifier introduces all the moisture to one area of the home, moisture will migrate and raise humidity levels in other rooms.

Overhumidification, which can cause condensate to form on the coldest surfaces in the living space (usually the windows), should be avoided. 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 inside to outside, causing damp insulation, possible structural damage, and exterior paint blistering.

Central humidifiers may be rated in accordance with ARI *Standard* 610. This rating is expressed in the number of gallons per day evaporated by 140°F entering air. Some manufacturers certify the performance of their product to the ARI standard. Selecting the proper size humidifier is important and is outlined in ARI *Guideline* F.

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

Chapter 20 of the 2000 *ASHRAE Handbook—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 the ability to serve a single zone make them appropriate in many circumstances.

In hot and humid climates, the importance of providing sufficient dehumidification with sensible cooling is increasingly recognized. Although conventional air conditioning units provide some dehumidification as a consequence of sensible cooling, in some cases space humidity levels can still exceed the upper limit of 60% relative humidity specified in *ASHRAE Standard* 55.

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.

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 ARI *Standard* 680, which is based on *ASHRAE Standard* 52.1. Atmospheric dust spot efficiency levels are generally less than 20% for disposable filters and vary from 60 to 90% for electronic air filters.

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. Chapter 24 of the 2000 *ASHRAE Handbook—Systems and Equipment* covers the design of residential air filters 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 microelectronic models that can set heating and cooling equipment at different temperature levels, depending on the time of day. This has led to night setback 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. [Chapter 45](#) contains more details about automatic control systems.

## 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.

### Forced-Air Systems

High-rise multifamily structures may also use unitary 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, or it may be placed in a soffit or above a drop ceiling over a hallway or closet.

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 should be consulted. Direct vent furnaces that are placed near or on an outside 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 due to 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 12 of the 2000 *ASHRAE Handbook—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 outside wall may have such a unit. These units are used extensively in the renovation of 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 46 of the 2000 *ASHRAE Handbook—Systems and Equipment* and in ARI 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 while using only two pipes. Water-source heat pumps allow for 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 air quantities. ASHRAE Standard 62 requires minimum outdoor air values of 50 cfm intermittent or 20 cfm continuous or operable windows for baths and toilets, and 100 cfm intermittent or 25 cfm continuous or operable windows for kitchens.

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 outside 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 44 of the 2000 *ASHRAE Handbook—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 on a year-round basis by general building pressurization. When outer walls are pierced 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 positive ventilation with at least two air changes per hour. Conditioned supply air is preferable. Some designs transfer air into the apartments through acoustically lined louvers to provide kitchen and toilet makeup air, if necessary. Supplying air to, instead of exhausting air from, corridors minimizes odor migration from apartments into corridors.

Air-conditioning equipment must be isolated to reduce noise generation or transmission. The design and location of cooling tow-

ers 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 36 of the 2000 *ASHRAE Handbook—Systems and Equipment*.

In large apartment houses, a central panel may allow individual apartment air-conditioning systems or units to be monitored for maintenance and operating purposes.

## MANUFACTURED HOMES

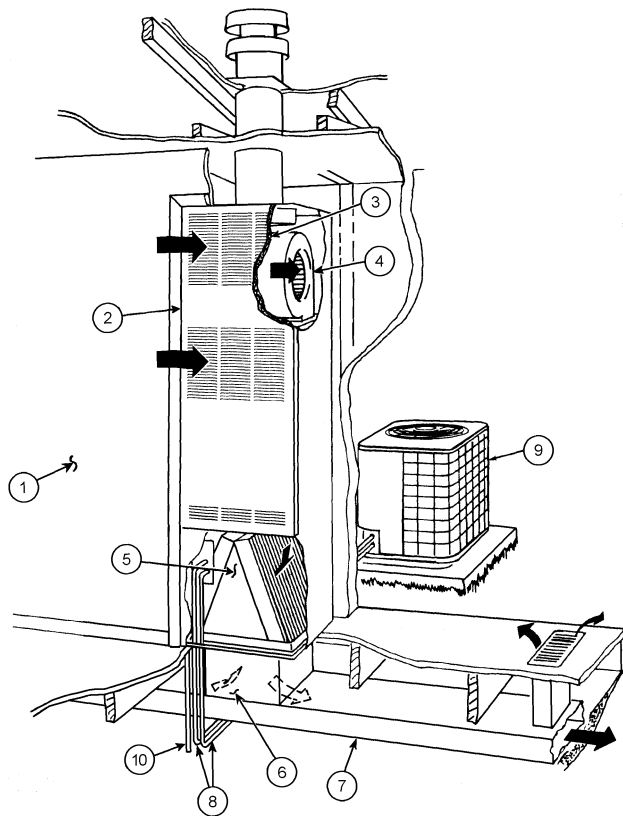
Manufactured homes are constructed at a factory and in 1999 constituted over 7% of all housing units and about 21% of all new single-family homes sold. In the United States, heating and cooling systems in manufactured homes, as well as other facets of construction such as insulation levels, are regulated 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 400 ft<sup>2</sup> to large, multiple sections, which when joined together can provide over 2500 ft<sup>2</sup> 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 South and in the Southwest 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 hallways. The complete heating system is a reduced clearance type with the air-handling unit installed in a small closet or alcove usually located 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 that have been 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 the combustion products through a wind-proof vent terminal. Gas furnaces must be easily convertible from liquefied petroleum 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 the 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, the evaporator coil, and the compact air duct 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 3. Air enters the furnace from the hallway (1), passing through a louvered door (2) on the front of the furnace. The air then passes through air filters (3) and is drawn into the top-mounted blower (4), which during the 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 (5), which removes heat and moisture from the passing air. During heating and cooling, the conditioned air then passes through a combustible floor base via a duct connector (6) before flowing into the floor air distribution duct (7). The evaporator coil is connected via quick-connect refrigerant lines (8) to a remote air-cooled condensing unit



**Fig. 3 Typical Installation of Heating and Cooling Equipment for a Manufactured Home**

(9). The condensate collected at the evaporator is drained by a flexible hose (10), routed to the exterior through the floor construction, and connected to a suitable drain.

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