

# **2011 ASHRAE® HANDBOOK**

## **Heating, Ventilating, and Air-Conditioning APPLICATIONS**

**Inch-Pound Edition**

**American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.**

1791 Tullie Circle, N.E., Atlanta, GA 30329

(404) 636-8400

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**DEDICATED TO THE ADVANCEMENT OF  
THE PROFESSION AND ITS ALLIED INDUSTRIES**

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# ASHRAE Research: Improving the Quality of Life

The American Society of Heating, Refrigerating and Air-Conditioning Engineers is the world's foremost technical society in the fields of heating, ventilation, air conditioning, and refrigeration. Its members worldwide are individuals who share ideas, identify needs, support research, and write the industry's standards for testing and practice. The result is that engineers are better able to keep indoor environments safe and productive while protecting and preserving the outdoors for generations to come.

One of the ways that ASHRAE supports its members' and industry's need for information is through ASHRAE Research. Thousands of individuals and companies support ASHRAE Research

annually, enabling ASHRAE to report new data about material properties and building physics and to promote the application of innovative technologies.

Chapters in the ASHRAE Handbook are updated through the experience of members of ASHRAE Technical Committees and through results of ASHRAE Research reported at ASHRAE conferences and published in ASHRAE special publications and in *ASHRAE Transactions*.

For information about ASHRAE Research or to become a member, contact ASHRAE, 1791 Tullie Circle, Atlanta, GA 30329; telephone: 404-636-8400; www.ashrae.org.

## Preface

The 2011 *ASHRAE Handbook—HVAC Applications* comprises over 60 chapters covering a broad range of facilities and topics, and is written to help engineers design and use equipment and systems described in other Handbook volumes. ASHRAE Technical Committees have revised nearly every chapter to cover current requirements, technology, and design practice. An accompanying CD-ROM contains all the volume's chapters in both I-P and SI units.

This edition includes *two* new chapters:

- Chapter 4, Tall Buildings, focuses on HVAC issues unique to tall buildings, including stack effect, system selection, mechanical room location, water distribution, vertical transportation, and life safety.
- Chapter 60, Ultraviolet Air and Surface Treatment, covers ultraviolet germicidal irradiation (UVGI) systems and relevant guidelines, standards, and practices, as well as energy use and economic considerations.

Here are selected highlights of the other revisions and additions:

- Chapter 3, Commercial and Public Buildings, now covers office buildings, transportation centers, and warehouses and distribution centers, with new sections on commissioning, sustainability, energy efficiency, energy benchmarking, renewable energy, value engineering, and life-cycle cost analysis.
- Chapter 7, Educational Facilities, has added content on higher education facilities, commissioning, dedicated outdoor air systems (DOAS), combined heat and power (CHP), and sustainability and energy efficiency.
- Chapter 8, Health-Care Facilities, has been updated to reflect ASHRAE *Standard* 170-2008 and has revised discussion on design criteria for pharmacies.
- Chapter 18, Clean Spaces, has updated content on standards, filters, barrier technology, and sustainability plus a new section on installation and test procedures.
- Chapter 19, Data Processing and Telecommunication Facilities, has a new title and revised and/or new content on design temperatures, change rate, humidity, power usage effectiveness (PUE), aisle containment, economizer cycles, and computer room air-handling (CRAH) units.
- Chapter 33, Kitchen Ventilation, largely rewritten, covers key sustainability impacts and recent research results.
- Chapter 34, Geothermal Energy, has updated tables and graphs, with new, step-by-step design guidance on vertical systems, and expanded content on hybrid systems, ISO rating, and system efficiency.
- Chapter 36, Energy Use and Management, has updates on ASHRAE's Building Energy Quotient (eQ) labeling program.

- Chapter 40, Computer Applications, updated throughout, has new content on building information modeling (BIM) and wireless applications.
- Chapter 41, Building Energy Monitoring, has a new section on simplifying methodology for small projects.
- Chapter 42, Supervisory Control Strategies and Optimization, has been reorganized, with new content on thermal storage and thermally active building systems (TABS), hybrid cooling plants, and predictive control.
- Chapter 43, HVAC Commissioning, has been updated throughout to reflect ASHRAE *Guideline* 1.1-2007.
- Chapter 44, Building Envelopes, has reorganized and expanded content on nonresidential and existing buildings, durability, and common building envelope assemblies.
- Chapter 48, Noise and Vibration Control, has a new title plus reorganized and new content on noise criteria, chiller noise, and vibration measurement.
- Chapter 50, Service Water Heating, has expanded content on sizing tankless water heaters plus new data on piping heat loss.
- Chapter 55, Seismic- and Wind-Resistant Design, has a new title and reflects changes to building codes, standards for anchor bolt design, and other new requirements.
- Chapter 57, Room Air Distribution, has extensive new application guidelines plus new content on indoor air quality (IAQ), sustainability, and chilled beams.
- Chapter 59, HVAC Security, has a new title, with updates from ASHRAE *Guideline* 29-2009 and new sections on risk evaluation, requirements analysis, and system design.

This volume is published, both as a bound print volume and in electronic format on a CD-ROM, in two editions: one using inch-pound (I-P) units of measurement, the other using the International System of Units (SI).

Corrections to the 2008, 2009, and 2010 Handbook volumes can be found on the ASHRAE Web site at <http://www.ashrae.org> and in the Additions and Corrections section of this volume. Corrections for this volume will be listed in subsequent volumes and on the ASHRAE Web site.

Reader comments are enthusiastically invited. To suggest improvements for a chapter, **please comment using the form on the ASHRAE Web site** or, using the cutout pages at the end of this volume's index, write to Handbook Editor, ASHRAE, 1791 Tullie Circle, Atlanta, GA 30329, or fax 678-539-2187, or e-mail [mowen@ashrae.org](mailto:mowen@ashrae.org).

Mark S. Owen  
Editor

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## 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 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.

### 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, which is commonly added to all but the most basic systems, is provided in heating systems for thermal comfort (as defined in ASHRAE *Standard 55*), health, and reduction of static electricity discharges. Cooling

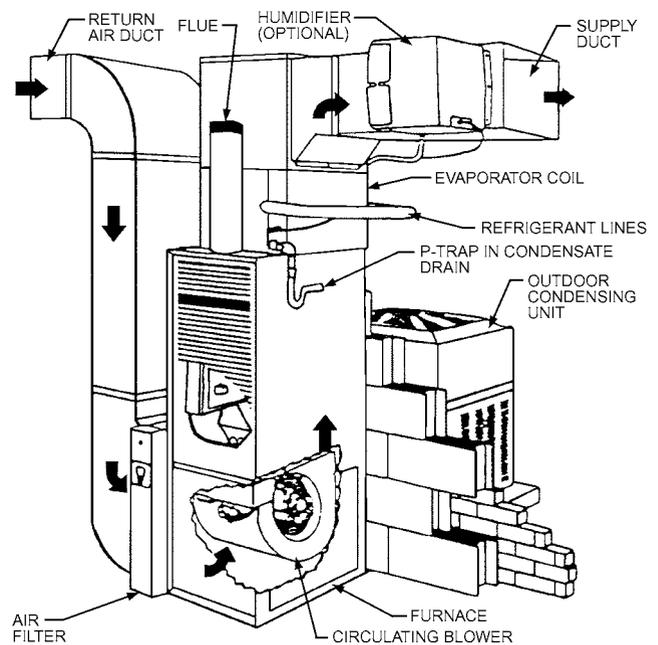
systems usually dehumidify air as well as lowering its temperature. Typical forced-air residential installations are shown in Figures 1 and 2.

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 drainline 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, 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

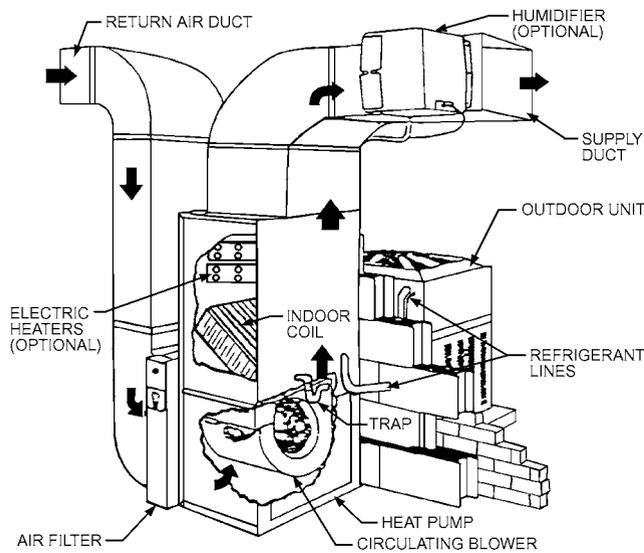
**Table 1 Residential Heating and Cooling Systems**

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

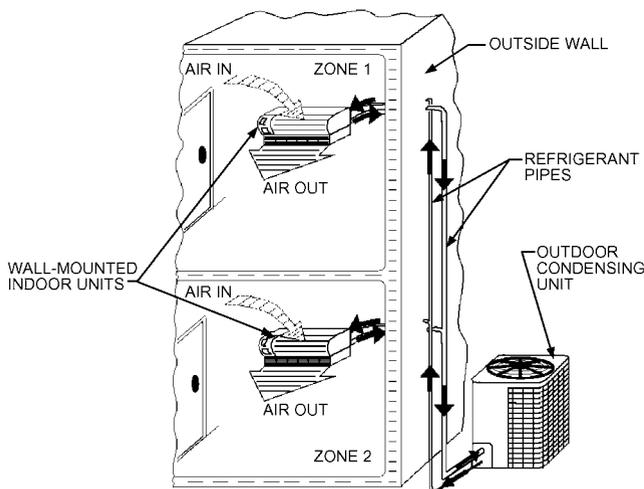


**Fig. 1 Typical Residential Installation of Heating, Cooling, Humidifying, and Air Filtering System**

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



**Fig. 2 Typical Residential Installation of Air-Coupled Heat Pump**



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

humidifier adds 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 drainline with a trap.

Minisplit systems, which are similar to split systems but are typically ductless, are increasingly popular worldwide. A typical two-zone, ductless minisplit system is shown in Figure 3. In this example, the minisplit system consists mainly of two parts: an outdoor condensing unit, which is installed outside, 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.

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. For heating, natural gas and electricity are most widely used in North America, followed by fuel oil, propane, wood, corn, 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 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*<sup>®</sup> 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 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 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 the most important task. 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.

## SINGLE-FAMILY RESIDENCES

### Heat Pumps

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

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 back-up heat is provided by electric resistance heating elements.

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 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 using 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, 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. Further information may be found in Chapter 48 of the 2008 *ASHRAE Handbook—HVAC Systems and Equipment*.

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 31 of the 2009 *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. 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. More information may be found in Chapter 48 of the 2008 *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 outside 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. The higher-efficiency condensing type also 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.

Wood-, corn-, 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 30 and 32 of the 2008 *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 12 and 35 of the 2008 *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 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, leak-tight operation.