

CHAPTER 33. FURNACES

FURNACES are self-enclosed, permanently installed major appliances that provide heated air through ductwork to the space being heated. In addition, a furnace may provide the indoor fan necessary for circulating heated or cooled air from a split or single-package air conditioner or heat pump (see [Chapter 10](#)). Furnaces may be used in either residential or commercial applications, and may be grouped according to the following characteristics:

- Heat source: electricity, natural gas/propane (fan assisted, condensing or noncondensing), or oil (forced draft with power atomizing burner)
- Installation location: within conditioned space (indoors), or outside conditioned space (either outdoors, or inside the structure but not within the conditioned space)
- Combustion air source: direct vent (outdoor air) or indoor air
- Mounting arrangement and airflow: horizontal, vertical upflow, vertical downflow, or multiposition

Furnaces that use electricity as a heat source include one or more resistance-type heating elements that heats the circulating air either directly or through a metal sheath that encloses the resistance element. In gas- or oil-fired furnaces, combustion occurs in the heat exchanger sections or in a combustion chamber. Circulating air passes over the outer surfaces of a heat exchanger so that it does not contact the fuel or the products of combustion, which are passed to the outdoor atmosphere through a vent.

In North America, natural gas is the most common fuel supplied for residential heating, and the central-system forced-air furnace ([Figure 1](#)) is the most common way of heating with natural gas. This type of furnace is equipped with a blower to circulate air through the furnace enclosure, over the heat exchanger, and through the ductwork distribution system. A furnace such as that in [Figure 1](#) is categorized as follows:

- Heat source: natural gas
- Mounting arrangement and airflow: vertical upflow
- Installation location: varies; usually inside the structure but not necessarily within the conditioned space
- Combustion air source: varies; high-efficiency furnaces usually are direct vent

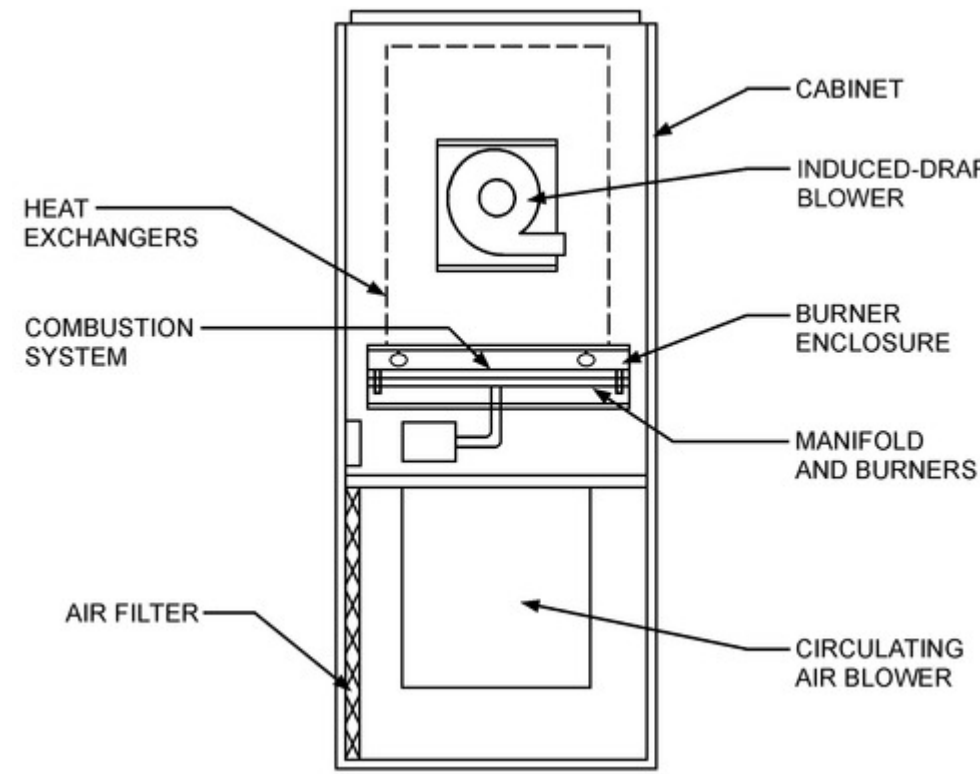


Figure 1. Induced-Draft Gas Furnace

1. COMPONENTS

A typical furnace consists of the following basic components: (1) a cabinet or casing; (2) heat exchangers; (3) heat sources, including burners and controls; (4) venting components, such as an induced-draft blower; (5) a circulating air blower and motor; and (6) an air filter and other accessories such as a humidifier, electronic air cleaner, air-conditioning coil, or a combination of these elements.

Casing or Cabinet

The furnace casing is most commonly formed from painted cold-rolled steel. Access panels on the furnace allow access to those sections requiring service. The inside of the casing adjacent to the heat exchanger or electric heat elements is lined with a foil-faced blanket insulation and/or a metal radiation shield to reduce heat losses through the casing and to limit the outer surface temperature of the furnace. On some furnaces, the inside of the blower compartment is lined with insulation to acoustically dampen the blower noise. Commercial furnace cabinets may also include the indoor and outdoor air-conditioning or heat pump components.

New scrutiny of the airtightness of system ductwork has drawn attention to the furnace casing as a common source of leakage. ASHRAE *Standard* 193-2010 provides a method of test to determine the airtightness of forced-air HVAC equipment before field installation. The standard is cited in the U.S. Department of Energy (DOE) ENERGY STAR® Program Requirements Product Specification for Furnaces, Version 4.0 (DOE 2013).

Heat Exchangers

Furnaces with gas-fired burners have heat exchangers that are typically made either of left/right sets of formed parts that are joined together to form a clamshell, finless tubes bent into a compact form, or finned-tube (condensing) heat exchangers. Standard indoor furnace heat exchangers are generally made of alloy steel. Common corrosion-resistant materials include aluminized steel and stainless steel. Furnaces certified for use downstream of a cooling coil must have corrosion-resistant heat exchangers.

Some problems of heat exchanger corrosion and failure have been encountered because of exposure to halogen ions in flue gas. These problems were caused by combustion air contaminated by substances such as laundry bleach, cleaning solvents, and halogenated hydrocarbon refrigerants.

Heat exchangers of oil-fired furnaces are normally heavy-gage steel formed into a welded assembly. Hot flue products flow through the inside of the heat exchanger into the chimney, and conditioned air flows over the outside of the heat exchanger and into the air supply plenum.

Heat Sources

Electric Heat Elements. Elements for electric furnaces are generally either open wire, open ribbon, or wire enclosed in a tube. Current is applied to the element and heats it through resistance of the material.

Burners and Internal Controls. Gas burners are most frequently made of stamped sheet metal, although cast iron is also used. Fabricated sheet metal burners may be made from cold-rolled steel coated with high-temperature paint or from a corrosion-resistant material such as stainless or aluminized steel. Burner material must meet the corrosion protection requirements of the specific application. Gas furnace burners may be of either the monoport or multiport type; the type used with a particular furnace depends on compatibility with the heat exchanger.

Gas furnace controls include an ignition device, gas valve, fan control, limit switch, and other components specified by the manufacturer. These controls allow gas to flow to the burners when heat is required. The most common ignition systems are (1) direct spark, and (2) hot-surface ignition. The section on Technical Data has further details on the function and performance of individual control components.

Oil furnaces are generally equipped with pressure-atomizing burners. The pump pressure and size of the injection nozzle orifice regulate the firing rate of the furnace. Electric ignition lights the burners. Other furnace controls, such as the blower switch and the limit switch, are similar to those used on gas furnaces.

Combustion Venting Components

Fan-assisted combustion furnaces use a small blower to induce flue products through the furnace. Induced-draft furnaces may or may not have a relief air opening, but they meet the same safety requirements regardless. Residential furnaces built since 1987 are equipped with a blocked-vent shutoff switch to shut down the furnace in case the vent becomes blocked.

Research into common venting of natural-draft appliances (water heaters) and fan-assisted combustion furnaces shows that nonpositive vent pressure systems may operate on a common vent. Refer to manufacturers' instructions for specific information.

Direct-vent furnaces use outdoor air for combustion. Outdoor air is supplied to the furnace combustion chamber by direct connections between the furnace and the outdoor air. If the vent or the combustion air supply becomes blocked, the furnace control system will shut down the furnace.

ANSI *Standard* Z21.47/CSA 2.3 classifies venting systems. Central furnaces are categorized by temperature and pressure attained in the vent and by the steady-state efficiency attained by the furnace. Although ANSI *Standard* Z21.47/CSA 2.3 uses 83% as the steady-state efficiency dividing central furnace categories, a general rule of thumb is as follows:

- Category I:** nonpositive vent pressure and flue loss of 17% or more
- Category II:** nonpositive vent pressure and flue loss less than 17%
- Category III:** positive vent pressure and flue loss of 17% or more
- Category IV:** positive vent pressure and flue loss less than 17%

Furnaces rated in accordance with ANSI *Standard* Z21.47/CSA 2.3 that are not direct vent are marked to show that they are in one of these four venting categories.

Ducted-system, oil-fired, forced-air furnaces are usually forced draft.

Circulating Blowers and Motors

Centrifugal blowers with forward-curved blades of the double-inlet type are used in most forced-air furnaces. These blowers overcome the resistance of furnace air passageways, filters, and ductwork. They are usually sized to provide the additional air requirement for cooling and the static pressure required for the cooling coil. The blower may be a direct-drive type, with the blower wheel attached directly to the motor shaft, or it may be a belt-drive type, with a pulley and V-belt used to drive the blower wheel.

Electric motors used to drive furnace blowers are usually custom designed for each furnace model or model series. Direct-drive motors may be shaded-pole, permanent split-capacitor (PSC), or brushless permanent magnet. Speed may be varied by taps connected to extra windings in the motor. Belt-drive blower motors are normally split-phase or capacitor-start. The speed of belt-drive blowers is controlled by adjusting a variable-pitch drive pulley.

Electronically controlled, variable-speed motors using a brushless permanent magnet design are inherently more efficient than shaded-pole or PSC motors. The motor is controlled electronically by a microprocessor and electronic controls, which provides the ability to increase or decrease motor speed and maintain efficiency across a wide range of operating speeds.

In the United States, the DOE regulates energy efficiency of residential furnace fans. DOE has initiated a rulemaking to consider new energy conservation or use standards for furnace fans. For the current status of DOE regulations, visit energy.gov/eers/buildings/appliance-and-equipment-standards-program.

Filters and Other Accessories

Air Filters. An air filter in a forced-air furnace removes dust from the air that could reduce the effectiveness of the blower and heat exchanger(s), and may also help provide cleaner air for the indoor environment (see ASHRAE *Standard* 52.2). Filters installed in a forced-air furnace are often disposable. Permanent filters that may be washed or vacuum-cleaned and reinstalled are also used. The filter is always located in the circulating airstream ahead of the blower and heat exchanger. Because the air filter keeps airflow components of the furnace clean, it should be cleaned or replaced regularly to extend the life of the furnace components. See [Chapters 10](#) and [22](#) for further information on air filters.

Humidifiers. These are not included as a standard part of the furnace package. However, one advantage of a forced-air heating system is that it offers the opportunity to control the relative humidity of the heated space at a comfortable level. [Chapter 22](#) addresses various types of humidifiers used with forced-air furnaces.

Electronic Air Cleaners. These air cleaners may be much more effective than the air filter provided with the furnace, and they filter out much finer particles, including smoke and pollen. Electronic air cleaners create an electric field of high-voltage direct current in which dust particles are given a charge and collected on a plate having the opposite charge. The collected material is then cleaned periodically from the collector plate by the homeowner. Electronic air cleaners are mounted in the airstream entering the furnace. [Chapter 29](#) has detailed information on filters.

Airflow Variations

The components of a forced-air furnace can be arranged in a variety of configurations to suit a residential heating system. The relative positions of the components in the different types of furnaces are as follows:

- Upflow furnace.** In an upflow furnace ([Figure 2](#)), the blower is located beneath the heat exchanger and discharges vertically upward. Air enters through the bottom or the side of the blower compartment and leaves at the top. This furnace may be used in closets and utility rooms on the first floor or in basements, with the return air ducted down to the blower compartment entrance.
- Downflow furnace.** In a downflow furnace ([Figure 3](#)), the blower is located above the heat exchanger and discharges downward. Air enters at the top and is discharged vertically at the bottom. This furnace is normally used with a perimeter heating system in a house without a basement. It is also used in upstairs furnace closets and utility rooms supplying conditioned air to both levels of a two-story house.
- Horizontal furnace.** In a horizontal furnace, the blower is located beside the heat exchanger ([Figure 4](#)). Air enters at one end, travels horizontally through the blower and over the heat exchanger, and is discharged at the opposite end. This furnace is used for locations with limited head room such as attics and crawlspaces, or is suspended under a roof or floor or placed above a suspended ceiling. These units are often designed so that the components may be rearranged to allow installation with airflow from left to right or from right to left.
- Multiposition (multipoise) furnace.** This furnace can be installed in more than one airflow configuration (e.g., upflow or horizontal; downflow or horizontal; or upflow, downflow, or horizontal). In some models, field conversion is necessary to accommodate an alternative installation.
- Basement furnace.** The basement furnace ([Figure 5](#)) is a variation of the upflow furnace and requires less head room. The blower is located beside the heat exchanger at the bottom. Air enters the top of the cabinet, is drawn down through the blower, is discharged over the heat exchanger, and leaves vertically at the top. This type of furnace has become less popular because of the advent of short upflow furnaces.
- Gravity furnace.** These furnaces are no longer available, and they are not common. This furnace has larger air passages through the casing and over the heat exchanger so that the buoyancy force created by the air being warmed circulates the air through the ducts. Wall furnaces that rely on natural convection (gravity) are discussed in [Chapter 34](#).

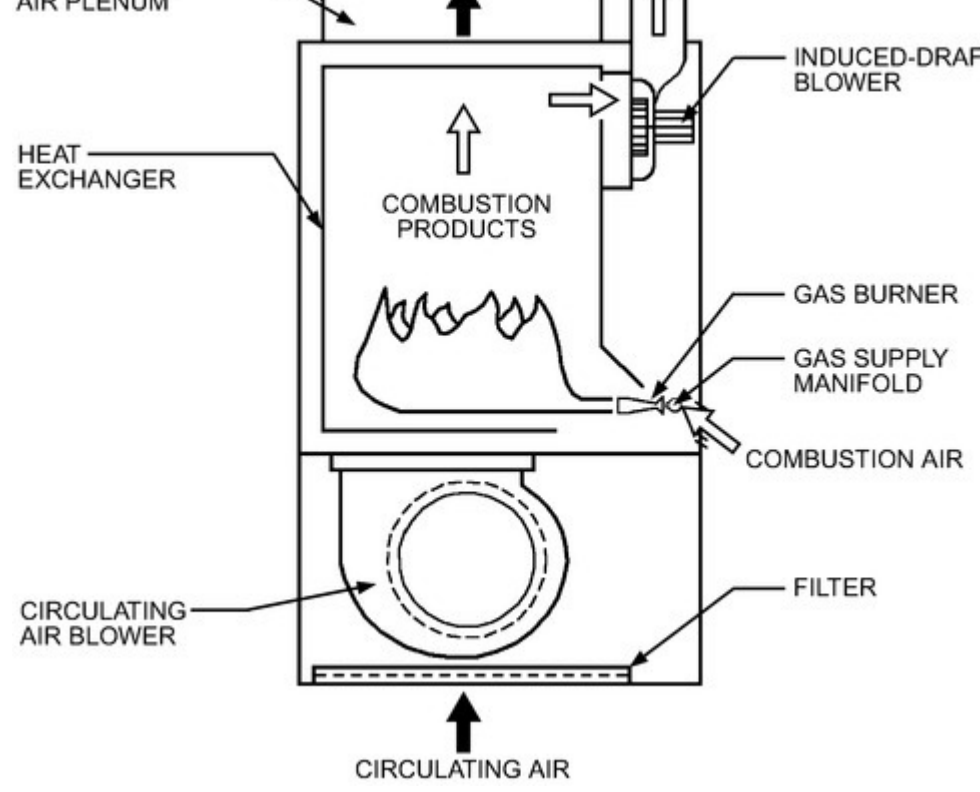


Figure 2. Upflow Category I Furnace with Induced-Draft Blower

Combustion System Variations

Gas-fired furnaces use a fan-assisted combustion system. Fan-assisted combustion furnaces have a combustion blower, which may be located either upstream or downstream from the heat exchangers ([Figure 6](#)). If the blower is located upstream, blowing the combustion air into the heat exchangers, the system is known as a forced-draft system. If the blower is downstream, the arrangement is known as an induced-draft system.

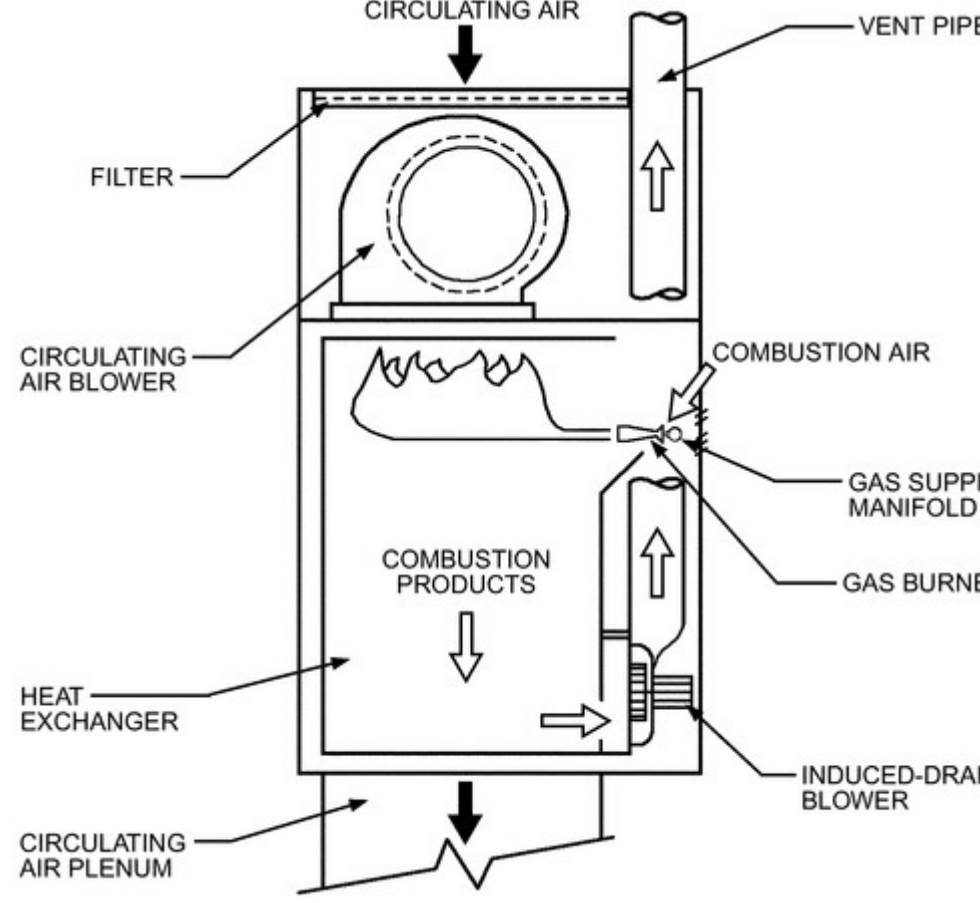


Figure 3. Downflow (Counterflow) Category I Furnace with Induced-Draft Blower

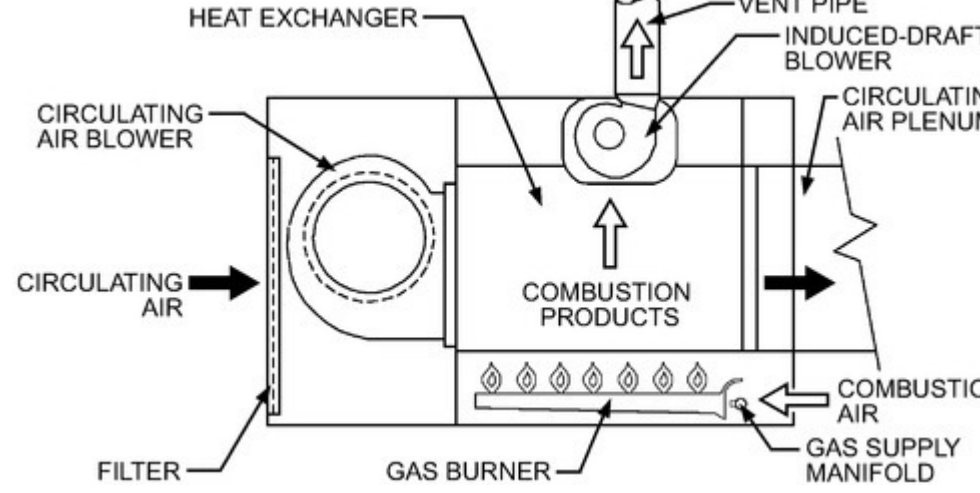


Figure 4. Horizontal Category I Furnace with Induced-Draft Blower

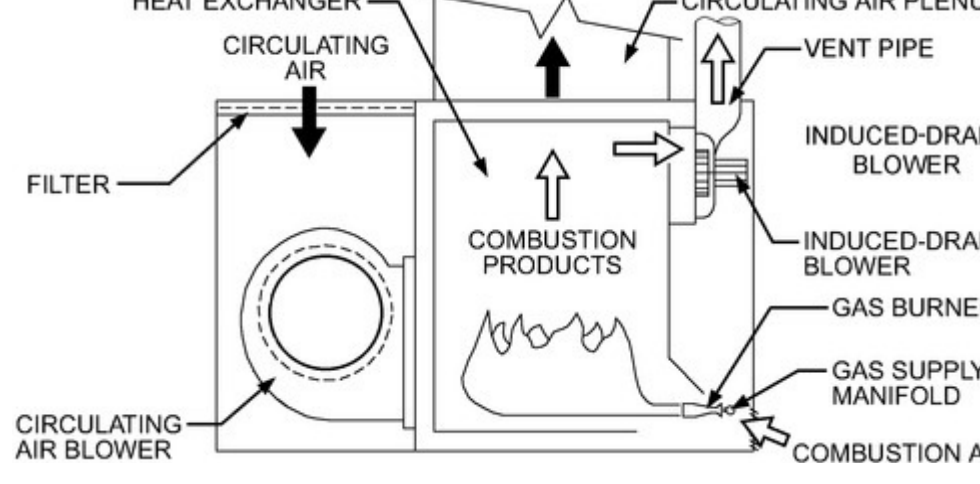


Figure 5. Basement (Lowboy) Category I Furnace with Induced-Draft Blower

Direct-vent furnaces obtain combustion air from outside the structure. Mobile home furnaces must be of the direct-vent type.

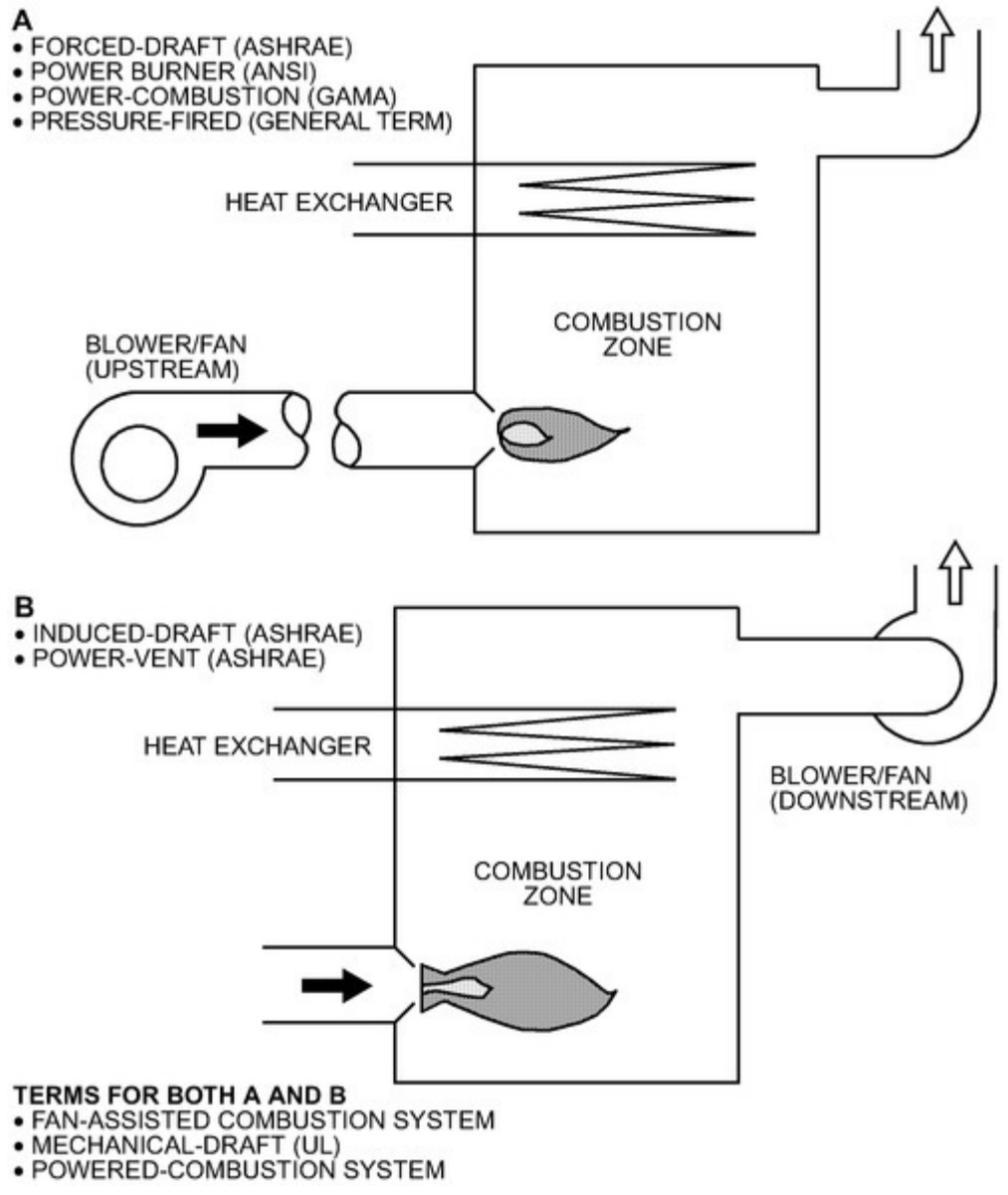


Figure 6. Terminology Used to Describe Fan-Assisted Combustion

Indoor/Outdoor Furnace Variations

Central system residential furnaces are designed and certified for either indoor or outdoor use. Outdoor furnaces are normally horizontal flow and convertible to downflow. The heating-only outdoor furnace is similar to the more common indoor horizontal furnace. The primary difference is that the outdoor furnace is weatherized; the motors and controls are sealed, and the exposed components are made of corrosion-resistant materials such as galvanized or aluminumized steel. A common style of outdoor furnace is the combination package unit. This unit is a combination of an air conditioner and a gas or electric furnace built into a single casing. The design varies, but the most common combination consists of an electric air conditioner coupled with a horizontal gas or electric furnace. The advantage is that much of the interconnecting piping and wiring is included in the unit.

2. HEAT SOURCE TYPES

Natural Gas and Propane Furnaces
Most manufacturers have their furnaces certified for both natural gas and propane. The major difference between natural gas and propane furnaces is the pressure at which the gas is injected from the manifold into the burners. For natural gas, the manifold pressure is usually controlled at 3 to 4 in. of water; for propane, the pressure is usually 10 to 11 in. of water. Because of the higher injection pressure and the greater heat content per volume of propane, there are certain physical differences between a natural gas furnace and a propane furnace. One difference is that the burner orifices must be smaller for propane furnaces. The gas valve regulator spring is also different. Sometimes it is necessary to change burners, but this is not normally required. Manufacturers sell conversion kits containing both the required parts and instructions to convert furnace operation from one gas to the other.

Oil Furnaces
Indoor oil furnaces come in the same configurations as gas furnaces. They are available in upflow, downflow, horizontal, and lowboy configurations for ducted systems. Oil-fired outdoor furnaces and combination units are not common. The major differences between oil and gas furnaces are in the combustion system, heat exchanger, and barometric draft regulator.

Electric Furnaces
Electric-powered furnaces come in a variety of configurations and have some similarities to gas- and oil-fired furnaces. However, when a furnace is used with an air conditioner, the cooling coil may be upstream from the blower and heaters. On gas- and oil-fired furnaces, the cooling coil is normally mounted downstream from the blower and heat exchangers so cold air leaving the cooling coil does not contact the heat exchangers, which could cause premature corrosion from condensation. If the cooling coil is upstream of the heat exchangers on a gas- or oil-fired product, the heat exchanger may require a mechanism to remove the condensed moisture. Figure 7 shows a typical arrangement for an electric forced-air furnace. Air enters the bottom of the furnace and passes through the filter, then flows up through the cooling coil section into the blower. The electric heating elements are immediately above the blower so that the high-velocity air discharging from the blower passes directly through the heating elements.

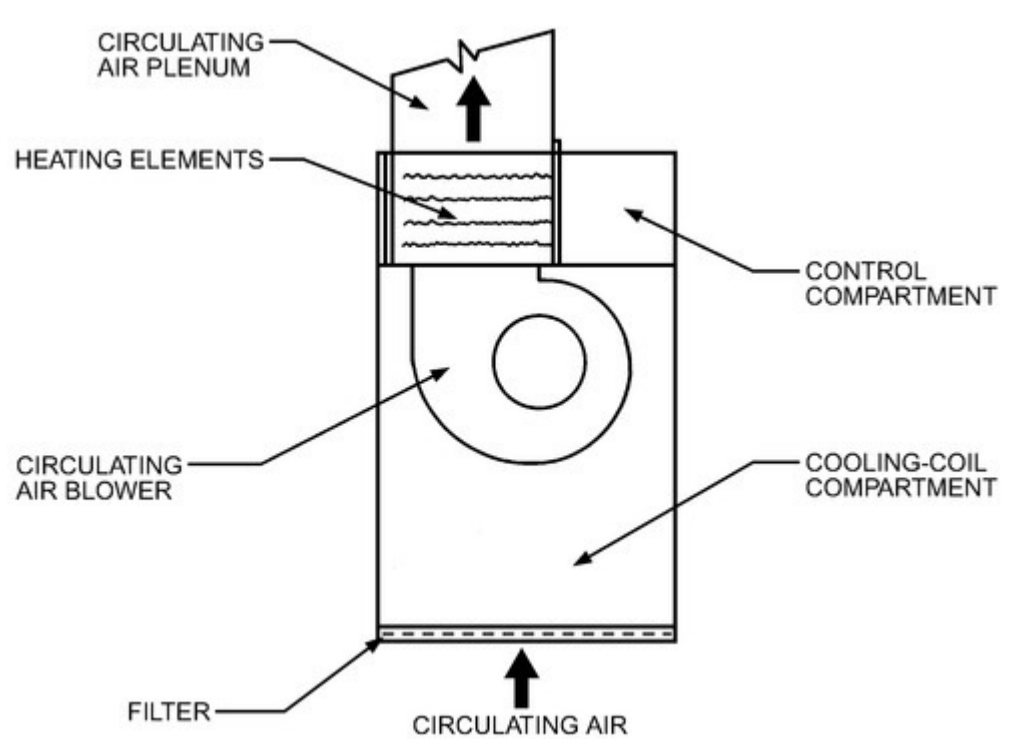


Figure 7. Electric Forced-Air Furnace

The furnace casing, air filter, and blower are similar to equivalent gas furnace components. The heating elements are made in modular form, with 5 kW capacity being typical for each module. Electric furnace controls include electric overload protection, contactor, limit switches, and a fan control switch. The overload protection may be either fuses or circuit breakers. The contactor brings the electric heat modules on. The fan control switch and limit switch functions are similar to those of the gas furnace, but one limit switch is usually used for each heating element. Frequently, electric furnaces are made from modular sections; for example, the coil box, blower section, and electric heat section are made separately and then assembled in the field. Regardless of whether the furnace is made from a single-piece casing or a modular casing, it is generally a multiposition unit. Thus, the same unit may be used for upflow, downflow, or horizontal installations. When an electric heating appliance is sold without a cooling coil, it is known as an electric furnace. The same appliance is called a fan-coil air handler when it has an air-conditioning coil already installed. When the unit is used as the indoor section of a split heat pump, it is called a heat pump fan-coil air handler. For detailed information on heat pumps, see Chapters 9 and 49. Electric forced-air furnaces are also used with packaged heat pumps and packaged air conditioners.

3. COMMERCIAL EQUIPMENT

The basic differences between residential and commercial furnaces are available options such as economizers, outdoor air dampers, and the type of electrical service required (three-phase). Commercial heating equipment comes in almost as many flow arrangements and design variations as residential equipment. Some are identical to residential equipment, whereas others are unique to commercial applications. Some commercial units function as a part of a ducted system, and others operate as unducted space heaters.

Ducted Equipment
Upflow Gas-Fired Commercial Furnaces. These furnaces are normally incorporated into a system in conjunction with a commercial split-system air-conditioning unit and are available in either propane or natural gas. Oil-fired units may be available on a limited basis. **Horizontal Gas-Fired Duct Furnaces.** Available for built-up light commercial systems, this type of furnace is not equipped with its own blower but is designed for uniform airflow across the entire furnace. Duct furnaces are normally certified for operation either upstream or downstream of an air conditioner cooling coil. If a combination blower and duct furnace is desired, a package called a blower unit heater is available. Duct furnaces and blower unit heaters are available in natural gas, propane, oil, and electric models. **Electric Duct Furnaces.** These furnaces are available in a large range of sizes and are suitable for operation in upflow, downflow, or horizontal positions. These units are also used to supply auxiliary heat with the indoor section of a split heat pump. **Package Units.** The most common commercial furnace is the package unit, sometimes known as a **rooftop unit (RTU)**. These are available as air-conditioning units with propane and natural gas furnaces, electric resistance heaters, or heat pumps. Combination oil-heat/electric-cool units are not commonly available. Package units of 15 tons and under are available as single-zone units. The entire unit is used in either heating mode or cooling mode. All air delivered by the unit is at the same temperature. Frequently, the heating function is staged so that the system operates at reduced heat output when the load is small. Large package units in the 15 to 50 ton range are available as single-zone units, as are small units; however, they are also available as multizone units. A multizone unit supplies conditioned air to several different zones of a building in response to individual thermostats controlling those zones. These units can supply heating to one or more zones at the same time that cooling is supplied to other zones.

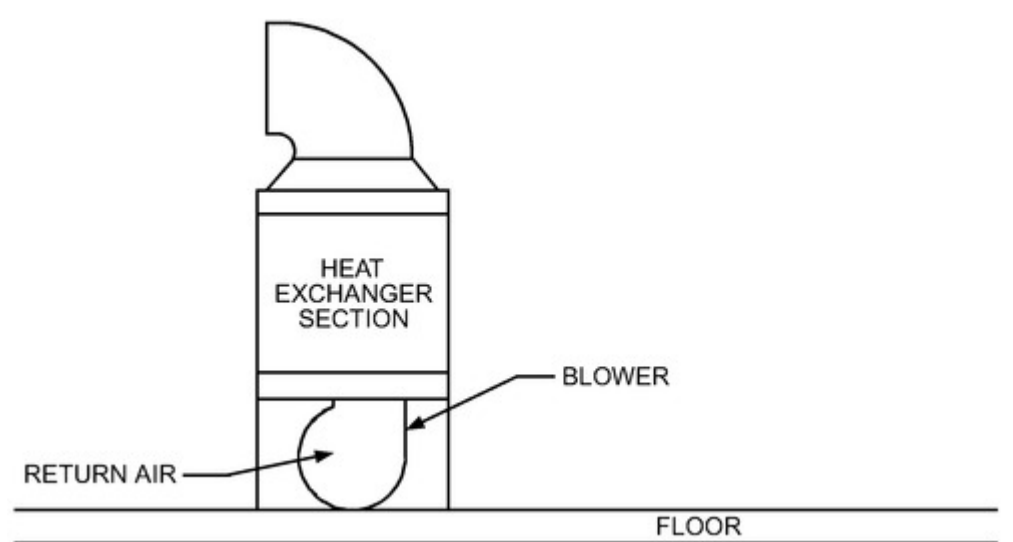


Figure 8. Standing Floor Furnace

Large package units are normally available only in a curbed configuration (i.e., units are mounted on a rooftop over a curbed opening in the roof). Supply and return air enters through the bottom of the unit. Smaller units may be available for either curbed or uncurbed mounting. In either case, the unit is usually connected to ductwork in the building to distribute the conditioned air.

Unducted Heaters

Ductless furnaces, floor furnaces (Figure 8), and wall furnaces are discussed in Chapter 34. Infrared heating equipment is covered in Chapter 16.

4. CONTROLS AND OPERATING CHARACTERISTICS

External to Furnace
Externally, the furnace is controlled by a low-voltage room thermostat. Chapter 7 of the 2013 ASHRAE Handbook—Fundamentals discusses thermostats in detail. In North America, a furnace that is not part of a package unit is commonly installed with a split-system air conditioner. The furnace control receives input from the room thermostat, which determines the mode of operation. The furnace blower is used to circulate air through the ducts in the heating, cooling, and circulating modes of operation.

Internal to Furnace
Several types of gas valves perform various functions within the furnace. The type of valve available relates closely to the type of ignition device used. **Two-stage valves**, available on some furnaces, operate at full gas input or at a reduced rate, and are controlled by either a two-stage thermostat or a software algorithm programmed in the furnace control system. They provide less heat at the reduced input and, therefore, may produce less space temperature variation and greater comfort during mild weather conditions when full heat output is not required. Two-stage control is used frequently for zoning applications. Fuel savings with two-stage firing rate systems may not be realized unless both the fuel and the combustion air are controlled. The **fan control switch** controls the circulating air blower. This switch may be temperature-sensitive and exposed to the circulating airstream in the furnace cabinet, or it may be an electronically operated relay. Blower start-up is typically delayed about 1 min after burner start-up. This delay gives the heat exchangers time to warm up and reduces the flow of cold air when the blower comes on. Blower shutdown is also delayed several minutes after burner shutdown to remove residual heat from the heat exchangers and to improve the annual efficiency of the furnace. Constant blower operation throughout the heating season is sometimes used to improve air circulation; however, this increases fan motor energy consumption, duct conductive losses, and air distribution system air leakage losses. Electronic motors that provide continuous but variable airflow use less energy. Both strategies may be considered when air filtering performance is important. The **limit switch** prevents overheating in the event of severe reduction in circulating airflow. This temperature-sensitive switch is exposed to the circulating airstream and shuts off the heat source (e.g., gas valve or electric element) if the temperature of air leaving the furnace is excessive. The fan control and limit switches are sometimes incorporated in the same housing and may be operated by the same thermostatic element. In the United States, the **blocked-vent shutoff switch** and **flame rollout switch** have been required on residential furnaces produced since November 1989; they shut off the gas valve if the vent is blocked or when insufficient combustion air is present. Furnaces using fan-assisted combustion feature a **pressure switch** to verify the flow of combustion air before opening the gas valve. Electronic control systems are available in furnaces to provide sequencing of the inducer prepurge, ignition, circulating air blower operation, and inducer postpurge functions according to an algorithm provided by the manufacturer.

5. EQUIPMENT SELECTION

Many options are available to consumers, and careful planning is needed when selecting equipment. Some decisions can be very basic, whereas others may require research into the various kinds of equipment and features that are available. Several selection considerations are presented here.

Distribution System

A fundamental question in the selection process is whether the space to be heated uses a circulating forced-air system or a hydronic system. These two types of systems are vastly different with respect to equipment selection. For hydronic systems, refer to Chapter 36. Forced-air systems vary widely. A forced-air distribution system typically has a central air duct, with branches feeding air to numerous supply registers. The duct branches are designed to proportion the air to the different spaces in the building, so that temperatures are best managed by a central thermostat location. Some systems are zoned, with different thermostat sensors; in these systems, dampers with electrical motors are placed at strategic branches of the distribution system and are opened or closed according to each zone's demand for heat. Choosing a zoned system affects the type of equipment selected. Chapter 10 discusses the overall design configuration and efficiency of forced-air systems.

Equipment Location

Furnaces can be installed inside or outside a building. For ideal air distribution, locate the unit in the center of the structure being heated. Furnaces are typically located in a closet, mechanical room, basement, attic, crawlspace, garage, or outdoors. As minimum efficiency levels have increased for residential air-conditioning systems, evaporator coils have increased in height to accommodate additional coil surface area. Compact furnaces have been introduced that allow the evaporator coil and furnace system components to be installed as a replacement without structural modification in some cases. For installations that cannot be accommodated by the more compact furnace designs, the furnace and evaporator coil are more often located in attic or garage spaces. Installation locations are characterized as either indoors, outdoors (weatherized), or isolated combustion systems (ICS). **Indoor furnaces** are installed in the heated structure, such as in a basement that is connected to the internal living space, in a utility room, or in a closet. In these locations, air that directly surrounds the furnace is in communication with the air of the heated space. Heat that is lost from the cabinet and adjacent ducts by conduction or air leakage is largely recaptured, helping to preserve furnace efficiency. Some furnaces use combustion air from inside the building. In these applications, room air is used for combustion and exhausted to the outdoors. Additionally, dilution air is also drawn from the room. Combustion/dilution makeup air is provided to the combustion appliance zone by infiltration or by a duct designed specifically to provide makeup air, as required by installation codes. Furnaces located **outside** the conditioned space (e.g., crawlspace, attic, garage, outdoors) regain little or none of the conductive or air leakage energy losses. Outdoor installations require furnaces to be qualified as weatherized. Outdoor installation locations are on rooftops, platforms, or on a pad adjacent to the heated structure. Ducts for supply and return air connections may also be exposed to the elements and should be weatherized appropriately or moved inside to the conditioned space. **Isolated combustion systems (ICS)** are within the structure being heated, but the air that directly surrounds the furnace does not communicate with the heated space. Air needed for combustion and ventilation is admitted through grille openings or ducts (NFPA Standard 54). Heat given off from the casing is not considered usable heat, and is subtracted from the furnace efficiency. Typical ICS locations include garages, attics, crawlspaces, and closets that are directly ventilated to the outdoors. Furnaces are protected from the elements (but not temperature) by the surrounding structure.

Forced-Air System Primary Use

Forced-air systems have many benefits, the most significant of which is that they can be used for both heating and cooling without needing separate duct systems and separate air-handling units. A primary function of the furnace is to circulate air through the forced-air distribution system. Heating the air is an inherent function of a furnace. Cooling is typically a modular add-on, although some furnaces are included as a part of a packaged furnace-and-air-conditioner combination appliance. Forced-air systems also make it possible to add humidifiers and air filters or purifiers. In some cases, forced-air systems can also be connected to an additional appliance to bring clean air from the outdoors through air-to-air energy recovery heat exchangers. Proposed central-fan-integrated ventilation systems would use the furnace blower to pull in and distribute a controlled amount of outdoor air. Air distribution system design must take into account all the system's intended functions. The air-handling capacity must be designed to meet the demand of the highest airflow and static pressure needs. Typically, the airflow needed for heating is less than that needed for cooling. Manufacturers provide information on furnace performance capabilities, including how much airflow it can deliver at different static pressures. Furnace specification data typically describe the gas input for heating and the airflow (or cooling capacity) for which the unit is designed.

Fuel Selection

The type of fuel selected for heating is based on relative fuel cost, number of heating degree-days, and availability of utilities in the area. The most common fuel is natural gas because of its clean burning characteristics, and because of the continuous supply of this fuel through underground distribution networks to most urban settings. Propane and oil fuels are also commonly used. These fuels require on-site storage and periodic fuel deliveries. Electric heat is also continuously available through electrical power grids and is common especially where natural gas is not provided, or where the heating demand is small relative to the cooling demand. Furnaces are clearly marked for the type of fuel to be used. In some cases, a manufacturer-approved conversion kit may be necessary to convert a furnace from one fuel type to another. If the fuel type is changed after the original installation, the conversion must be done by a qualified service person per the manufacturer's instructions and using the manufacturer's specified conversion kit. After conversion, the unit must be properly inspected by the local code authority.

Combustion Air and Venting

All fuel-burning furnaces must be properly vented to the outdoors. Metal vents, masonry chimneys, and plastic vents are commonly used for furnaces. Manufacturers provide installation instructions for venting their furnaces, and Chapter 35 has a detailed discussion on venting. Air for combustion enters the combustion zone through louvers or pipes. Outdoor air usually has lower levels of pollutants than are typically found in air from indoors, garages, utility rooms, and basements. If the furnace is not exposed to pollutants, the heat exchanger material will have a long life.

Equipment Sizing

The furnace's heating capacity (i.e., the maximum heating rate the furnace can provide) is provided on the appliance rating plate; it is also available through the Air-Conditioning, Heating, and Refrigeration Institute directories (AHRI 2016) and manufacturers' product literature. The heating load for the intended space must be determined; variables that must be considered when calculating space load include heat gains or losses through walls, floors, and ceiling; infiltration; fenestration; ventilation; internal loads; and humidification. Chapters 12 to 19 in the 2013 ASHRAE Handbook—Fundamentals provide the information necessary to determine residential and nonresidential heating loads. Other factors should be considered when determining furnace capacity. Thermostat setback recovery may require additional heating capacity. On the other hand, supplemental heat sources or off-peak storage devices may offset some of the peak demand capacity. Increasing furnace capacity may increase space temperature swing, and thus reduce comfort. Two-stage or step-modulating equipment could help by using the unit's maximum capacity to meet the setback recovery needs, and providing a lower stage of heating capacity at other times. If cooling is included, the cooling load must be considered, especially in climates that have substantial cooling loads but minimal heating loads. When a large cooling load necessitates a large airflow rate, heating capacity may be greater than necessary. Two-stage or modulating heating may be a suitable alternative to reduce the potentially large temperature swings that can occur with excessively oversized furnaces.

Types of Furnaces

Fuel-burning furnaces are typically subdivided into two primary categories: noncondensing and condensing. **Condensing** furnaces typically have high efficiencies, ranging from 89 to 98%, because they have a specially designed secondary heat exchanger that extracts the heat of vaporization of water vapor in the exhaust. Such heat exchangers may collect soot in small passages if the burners are not set up properly for the heating value of the gas used. The dew-point temperatures of flue gases of condensing furnaces are significantly above the vent temperature, so plastic or other corrosion-resistant venting material is required. Condensing furnaces must be plumbed for condensate disposal. Provisions must be taken to prevent the condensate trap and drain line from freezing if installed in a location that is likely to be below freezing at some point in the year. **Noncondensing** furnaces have generally less than 82% steady-state efficiency. This type of furnace has higher flue gas temperatures and requires either metal, masonry, or a combination of the two for venting materials. Because there is no water management, noncondensing furnaces do not need freeze protection.

Consumer Considerations

Safety and Reliability. Gas furnaces sold in North America are tested and certified to ANSI Standard Z21.47/CSA 2.3 requirements. Oil furnaces are tested in accordance with UL Standard 727, and oil burners in accordance with UL Standard 296. These standards are intended to ensure that consumer safety and product reliability are maintained in appliance design. Because of open-flame combustion, the following safety items need to be considered: (1) the surrounding atmosphere should be free of dust or chemical concentrations; (2) a path for combustion air must be provided for both sealed and open combustion chambers; and (3) the gas piping and vent pipes must be installed according to the NFPA/AGA National Fuel Gas Code (NFPA Standard 54), local codes, and the manufacturer's instructions. For electric furnaces, safety primarily concerns proper wiring techniques. Wiring should comply with the National Electrical Code® (NEC) (NFPA Standard 70) and applicable local codes. **Efficiency, Operating, and Life-Cycle Costs.** Annual operating costs of furnaces must take into account both the cost of the heating fuel as well as the electrical efficiency of the blower motor. Life-cycle cost determination includes initial cost, maintenance, energy consumption, design life, and price escalation of the fuel. Annual fuel utilization efficiency (AFUE) and energy consumption data to help calculate the annual cost for heating a building are available in the AHRI (2016) directory. AFUE and fuel cost are primary drivers in the operating cost. Electric furnaces are listed as nearly 100% AFUE (site-based) because all of the electrical energy is converted into heat, and the only inefficiency is from cabinet conduction and air leakage losses. Cabinet leakage can affect energy consumption and indoor air quality when furnaces are installed outside the conditioned living space, especially when the home and distribution system are otherwise of tight construction. Air leakage should be taken into account during system design and location. Care should also be taken to install equipment according to the manufacturer's instructions, and that gaps are not overlooked by the installer where service entries or attachments are made to the cabinet. The ENERGY STAR qualification specifications for furnaces require that cabinet leakage be less than or equal to 2% of the maximum airflow, measured according to ANSI/ASHRAE Standard 193-2010. **Design Life.** Typically, heat exchangers made of aluminumized steel have a design life of approximately 15 years. Some furnaces now have a 20 year warranty, or even a "lifetime" warranty on the heat exchanger. The design life of electric furnaces depends on the durability of the contactors and heating elements. The typical design life is approximately 15 years. **Comfort.** Consumer options of comfort vary quite a bit. Thermal comfort is affected by supply air temperature, air velocity leaving the supply registers, and proximity of the supply airflow stream to occupants. Complaints of draftiness are common when delivered supply air temperatures are low and register velocities are high. A common solution is to reduce the blower speed to get more temperature rise, while staying within the rated temperature rise range listed on the rating plate. However, reducing blower speed can lead to distribution problems. System design, including register selection and placement, should take these issues into account to avoid comfort problems. Large temperature swings may also cause discomfort. Factors that affect temperature swing include oversizing, thermostat cycling characteristics related to the number of cycles per hour, and thermostat control. Two-stage or step-modulating heating can improve comfort by reducing the wide, variable temperature swings. These control schemes reduce furnace capacity through gas and blower modulation, which reduces the amount of oversizing for the current demand. Comfort can also be affected by the indoor air quality. Adding air filters with high minimum efficiency reporting value (MERV; see ASHRAE Standard 52.2) ratings reduces airborne particulate matter and allergens. Winter months typically cause drier indoor air conditions, which can be offset by adding duct-integrated humidifiers. Both filters and humidifiers affect duct resistance, which in turn affects electrical energy consumption, and therefore must be considered in system design. Many options can be classified as a comfort consideration. Chapter 48 of the 2015 ASHRAE Handbook—HVAC Applications outlines procedures for determining acceptable noise levels. Some levels are available to increase comfort or economy. To manage comfort and cost of operation, a fuel-burning furnace can be combined with a heat pump; this takes advantage of the heat pump's relatively high efficiency during mild weather, and switches to fuel heating when outdoor temperatures drop and it becomes more difficult for heat pumps to meet the demand. To reduce peak demand for energy, off-peak storage devices may be used to decrease the required capacity of the furnace. The storage device can supply the additional capacity required during the morning recovery of a night setback cycle or reduce the daily peak loads to help in load shedding. Detailed calculations can determine the contribution of storage devices.

Selecting Furnaces for Commercial Buildings

The procedure for design and selection of a commercial furnace is similar to that for a residential furnace. First, the design capacity of the heating system must be determined, considering heat loss from the structure, recovery load, internal heat gains, humidification, off-peak storage, waste heat recovery, and back-up capacity. Because most commercial buildings use setback during weekends, evenings, or other long periods of inactivity, the recovery load is important, as are internal loads and waste heat recovery. The furnace should be sized according to the load per ACCA (2004). Efficiency of commercial units is about the same as for non-condensing residential units. Two-stage gas valves are frequently used with commercial furnaces, but the efficiency of a two-stage system may be lower than for a single-stage system. At a reduced firing rate, excess combustion airflow through the burners increases, decreasing the steady-state operating efficiency of the furnace. Multistage furnaces with multistage thermostats and controls may be used to more appropriately match load conditions. The design life of commercial heating and cooling equipment is about 20 years. Most gas furnace heat exchangers are either coated steel or stainless steel. Because most commercial furnaces are made for outdoor application, the cabinets are made from corrosion-resistant coated steel (e.g., galvanized or aluminumized). Blowers can be direct- or belt-driven and can deliver air at higher static pressure. The noise level of commercial heating equipment is important in some applications, such as schools, office buildings, churches, and theaters. Unit heaters, for example, are used primarily in industrial applications where noise is less important. Duct design can greatly affect noise levels. In many jurisdictions, safety requirements are the same for light commercial systems and residential systems. Above 400,000 Btu/h gas input, ANSI Standard Z21.47/CSA 2.3 requirements for gas controls are more stringent.

6. CALCULATIONS

Performance Criteria. Residential furnaces and boilers manufactured and distributed in commerce, as defined by 42 U.S.C. 6291 (16), must meet the energy conservation standards specified in the Code of Federal Regulations, 10 CFR 430.32(e)(1)(i) and (e)(2)(i). This information is also available in the Electronic Code of Federal Regulations, and is published in the AHRI (2016) directories. To calculate the furnace's rated heating capacity, the steady-state efficiency must be determined. In the United States, manufacturers may publish only the AFUE as an efficiency measure. The unit capacity is proportional to the steady-state efficiency when compared to the fuel input rate. U.S. federal law requires manufacturers of furnaces to use AFUE as determined using the isolated combustion system method to rate efficiency. Since January 1, 1992, all furnaces produced have a minimum AFUE (ICS) level of 78%. Table 1 gives efficiency values for different furnaces.

7. TECHNICAL DATA

Detailed technical data on furnaces are available from manufacturers, wholesalers, and dealers. The data are generally tabulated in product specification bulletins printed by the manufacturer for each furnace line. These bulletins usually include performance information, electrical data, blower and air delivery data, control system information, optional equipment information, and dimensions.

Table 1. Historical and Typical Values of Efficiency

Type of Gas Furnace	AFUE, %	
	Indoor	ICS ^a
1. Natural-draft with standing pilot	64.5	63.9 ^b
2. Natural-draft with intermittent ignition	69.0	68.5 ^b
3. Natural-draft with intermittent ignition and auto vent damper	78.0	68.5 ^b
4. Fan-assisted combustion with standing pilot or intermittent ignition	80.0	78.0
5. Same as 4, except with improved heat transfer	82.0	80.0

6.	Direct vent, natural-draft with standing pilot, preheat	66.0	64.5 ²
7.	Direct vent, fan-assisted combustion, and intermittent ignition	80.0	78.0
8.	Fan-assisted combustion (induced-draft)	80.0	78.0
9.	Condensing	90.0	88.0
Type of Oil Furnace		Indoor	ICS²
1.	Standard: pre-1992	71.0	69.0 ²
2.	Standard: post-1992	80.0	78.0
3.	Same as 2, with improved heat transfer	81.0	79.0
4.	Same as 3, with automatic vent damper	82.0	80.0
5.	Condensing	91.0	89.0

² Isolated combustion system (estimate).
³ Pre-1992 design (pilot lights and natural draft systems are now obsolete).

Natural Gas Furnaces
Capacity Ratings. ANSI *Standard* Z21.47/CSA 2.3 requires that the heating capacity be marked on the rating plates of commercial furnaces in the United States. The heating capacity of residential furnaces, less than 225,000 Btu/h input, is required by the Federal Trade Commission and can be found in furnace directories provided by AHRI at www.ahridirectory.org. Capacity is calculated by multiplying the input by the steady-state efficiency. Residential gas furnaces with heating capacities ranging from 35,000 to 175,000 Btu/h are readily available. Some smaller furnaces are manufactured for special-purpose installations such as mobile homes. Smaller-capacity furnaces are becoming common because new homes are better insulated and have lower heat loads than older homes. Larger furnaces are also available, but these are generally considered for commercial use. Because of the overwhelming popularity of the upflow furnace, or multiposition including upflow, it is available in the greatest number of models and sizes. Downflow furnaces, dedicated horizontal furnaces, and various combinations are also available but are generally limited in model type and size. Residential gas furnaces can be installed as heating-only systems or as part of a heat/cool system. The difference is that, in the heat/cool system, the furnace operates as the air-handling section of a split-system air conditioner. Heating-only systems typically operate with enough airflow to yield a 40 to 70°F air temperature rise through the furnace. Condensing furnaces may be designed for a lower temperature rise (as low as 35°F). Furnaces have blowers capable of multiple speeds. When the furnace is used as the air handler for a cooling system, the blower is typically capable of delivering about 400 cfm per ton of air conditioning. Furnaces are generally available to accommodate 1.5 to 5 ton air conditioners. The blower speed for each mode of operation should be selected to provide the required airflow for both heating and cooling operation. Controls of furnaces used in a heat/cool system can be installed to operate the multispeed blower motor at the most appropriate speed for either heating or cooling when airflow requirements vary for each mode.

Efficiency Ratings. Currently, gas furnaces have steady-state efficiencies that vary from about 78 to 98%. Natural-draft and fan-assisted combustion furnaces typically range from 78 to 80% efficiency, whereas condensing furnaces have over 90% steady-state efficiency.

Propane Furnaces
Most residential natural gas furnaces are also available in a propane version with identical ratings. The technical data for these two furnaces are identical, except for gas control and burner and pilot orifice sizes. Orifice sizes on propane furnaces are much smaller because propane has a higher density and may be supplied at a higher manifold pressure. The heating value and specific gravity of typical gases are listed as follows:

Gas Type	Heating Value, Btu/ft ³	Specific Gravity (Air = 1.0)
Natural	1030	0.60
Propane	2500	1.53
Butane	3175	2.00

As in natural gas furnaces, the ignition systems have a required pilot gas shutoff feature in case the pilot ignition fails. Pilot gas leakage is more critical with propane or butane gas because both are heavier than air and can accumulate to create an explosive mixture in the furnace or furnace enclosure. Besides natural and propane, a furnace may be certified for manufactured gas, mixed gas, or propane/air mixtures; however, furnaces with these certifications are not commonly available. Mobile home furnaces are certified as convertible from natural gas to propane.

Oil Furnaces
Oil furnaces are similar to gas furnaces in size, shape, and function, but the heat exchanger, burner, and combustion control are significantly different. Input ratings are based on oil flow rate (gph), and heating capacity is calculated by the same method as that for gas furnaces. The typical heating value of oil is 140,000 Btu/gal. Fewer models and sizes are available for oil than are available for gas, but residential furnaces in the range of 64,000 to 150,000 Btu/h heating capacity are common. Air delivery ratings are similar to gas furnaces. The efficiency of an oil furnace can drop during normal operation if the burner is not maintained and kept clean. In this case, the oil does not atomize sufficiently to allow complete combustion, and energy is lost up the chimney in the form of unburned hydrocarbons. Because most oil furnaces use power burners and electric ignition, the annual efficiency is relatively high. Oil furnaces are available in upflow, downflow, and horizontal models. The thermostat, fan control switch, and limit switch are similar to those of a gas furnace. Oil flow is controlled by a pump and burner nozzle, which sprays the oil/air mixture into a single-chamber drum-type heat exchanger. The heat exchangers are normally heavy-gage cold-rolled steel. Humidifiers, electronic air cleaners, and night setback thermostats are available as accessories.

Electric Furnaces
Residential electric resistance furnaces are available in heating capacities of 5 to 35 kW. Electric resistance furnaces are typically part of a heat/cool system and provide the appropriate airflow for both heating and cooling modes. The only losses associated with an electric resistance furnace are the conductive and air leakage losses in the cabinet. If the furnace is located fully within the heated space, then the seasonal efficiency would be 100%. Although the efficiency of an electric furnace is high, electricity is generally a relatively expensive form of energy. The operating cost may be reduced substantially by using an electric heat pump in place of a straight electric resistance furnace. Heat pump systems are discussed in [Chapter 9](#). Electric furnaces are available in upflow, downflow, or horizontal models. Internal controls include overload fuses or circuit breakers, overheat limit switches, a fan control switch, and contactors to bring on the heating elements at timed intervals.

Commercial Furnaces
Furnaces with capacities above 150,000 Btu/h are classified as commercial furnaces. The 1992 U.S. Energy Policy and Conservation Act (EPCA) prescribes minimum efficiency requirements for commercial furnaces based on ASHRAE *Standard* 90.1. Some efficiency improvement components, such as intermittent ignition devices, are common in commercial furnaces.

8. INSTALLATION

Installation requirements call for a forced-air heating system to meet three basic criteria: (1) the system must be safe, (2) it must provide comfort for the occupants of the conditioned space, and (3) it must be energy efficient. Location of equipment and ducts, materials selected for the distribution system, and installation practices all affect the total system efficiency. Conduction and air leakage losses can result in substantial energy and system performance degradation and deserve special attention. For maximum safety, comfort, and efficiency, proper treatment of distribution system air leakage is necessary. A few significant considerations for installing furnaces are discussed here; for additional issues, see [Chapter 10](#). Generally, the following three categories of installation guidelines must be followed to ensure the safe operation of a heating system: (1) the equipment manufacturer's installation instructions, (2) local installation code requirements, and (3) national installation code requirements. Local code requirements may or may not be available, but the other two are always available. Depending on the type of fuel being used, one of the following national code requirements apply in the United States:

• NFPA 54 (also AGA 2223.1)	<i>National Fuel Gas Code</i>
• NFPA 70	<i>National Electrical Code[®]</i>
• NFPA 31	<i>Standard for the Installation of Oil-Burning Equipment</i>
Comparable Canadian standards are	
• CAN/CSA-B149.1	<i>Natural Gas and Propane Installation Code</i>
• CSA C22.1	<i>Canadian Electrical Code</i>
• CAN/CSA B139	<i>Installation Code for Oil Burning Equipment</i>

An additional source is the *International Fuel Gas Code[®]* (IFGC[™]) (ICC 2015). These regulations provide complete information about construction materials, gas line sizes, flue pipe sizes, wiring sizes, and so forth. Proper design of the air distribution system is necessary for both comfort and safety. [Chapter 21 of the 2013 ASHRAE Handbook—Fundamentals](#), [Chapter 1 of the 2015 ASHRAE Handbook—Practic Applications](#), and [Chapter 10](#) of this volume provide information on the design of ductwork for forced-air heating systems. Forced-air furnaces provide design airflow at a static pressure as low as 0.12 in. of water for a residential unit to above 1.0 in. of water for a commercial unit. The air distribution system must handle the required volumetric flow rate within the pressure limits of the equipment. If the system is a combined heating/cooling installation, the air distribution system must meet the cooling requirement because more air is required for cooling than for heating. It is also important to include the pressure drop of the cooling coil. The Air-Conditioning, Heating, and Refrigeration Institute (AHRI) maximum allowable pressure drop for residential cooling coils is 0.3 in. of water. Condensing furnaces generate a large amount of relatively low-temperature water. It is important that the exhaust vent be sloped so that water runs back into the furnace. All furnace condensate should go into a drain and not be discharged where it might freeze. If there is not a gravity path to a drain, an adequate-capacity condensate pump is required.

9. AGENCY LISTINGS

Construction and performance of furnaces are regulated by several agencies. AHRI, in cooperation with its industry members, sponsors a certification program relating to gas- and oil-fired residential furnaces and boilers. This program uses an independent laboratory to verify commercial and residential furnace and boiler manufacturers' certified AFUEs and heating capacities, as determined by testing in accordance with the U.S. DOE's *Uniform Test Method for Measuring the Energy Consumption of Furnaces and Boilers* (Title II, 10 CFR 430, Subpart B, Appendix N). Gas and oil furnaces with input ratings less than 225,000 Btu/h and gas and oil boilers with input ratings less than 300,000 Btu/h are currently included in the program. Also included in the program are the online consumers' directories, which identify certified products and list the input rating, certified heating capacity, and AFUE for each furnace. Participating manufacturers are entitled to use the AHRI certification symbol. ANSI *Standard* Z21.47/CSA 2.3 (CSA America is secretariat) gives minimum construction, safety, and performance requirements for gas furnaces. The CSA maintains laboratories to certify furnaces and operates a factory inspection service. Furnaces tested and found to be in compliance are listed in the CSA directory and carry the seals of certification. Underwriters Laboratories (UL) and other approved laboratories can also test and certify equipment in accordance with ANSI *Standard* Z21.47/CSA 2.3. Gas furnaces may be certified for standard, alcove, closet, or outdoor installation. Standard installation requires clearance between the furnace and combustible material of at least 6 in. Furnaces certified for alcove or closet installation can be installed with reduced clearance, as listed. Furnaces certified for either sidewall venting or outdoor installation must operate properly in a 31 mph wind. Construction materials must be able to withstand natural elements without degradation of performance and structure. Horizontal furnaces are normally certified for installation on combustible floors and for attic installation and are so marked, in which case they may be installed with point or line contact between the jacket and combustible constructions. Upflow and downflow furnaces are normally certified for alcove or closet installation. Gas furnaces may be listed to burn natural gas, mixed gas, manufactured gas, propane, or propane/air mixtures. A furnace must be equipped and certified for the specific gas to be used because different burners and controls, as well as orifice changes, may be required. Sometimes oil burners and control packages are sold separately; however, they are normally sold as part of the furnace package. Pressure-type or rotary burners should bear the Underwriters Laboratory label showing compliance with ANSI/UL *Standard* 296. In addition, the complete furnace should bear markings indicating compliance with UL *Standard* 727. Vaporizing burner furnaces should also be listed under UL *Standard* 727. UL *Standard* 1995 gives requirements for the listing and labeling of electric furnaces and heat pumps. The following list summarizes important standards issued by Underwriters Laboratories, the Canadian Gas Association, and the Canadian Standards Association that apply to space-heating equipment:

ANSI/ASHRAE 103	Method of Testing for Annual Fuel Utilization Efficiency of Residential Central Furnaces and Boilers
ANSI Z21.66/CGA 6.14	Automatic Vent Damper Devices for Use with Gas-Fired Appliances
ANSI Z83.4/CSA 3.7	Non-Recirculating Direct Gas-Fired Industrial Air Heaters
ANSI Z83.18	Recirculating Direct Gas-Fired Industrial Air Heaters
ANSI Z83.19/CSA 2.35	Gas-Fired High-Intensity Infrared Heaters
ANSI Z83.20/CSA 2.34	Gas-fired Low-Intensity Infrared Heaters
ANSI Z83.8/CGA 2.6	Gas Unit Heaters, Gas-Packaged Heaters, Gas Utility Heaters, and Gas-Fired Duct Furnaces
ANSI Z21.47/CSA 2.3	Gas-Fired Central Furnaces
ANSI/UL 296	Oil Burners
ANSI/UL 307A	Liquid Fuel-Burning Heating Appliances for Manufactured Homes and Recreational Vehicles
ASHRAE 90.1	Energy Standard for Buildings Except Low-Rise Residential Buildings
ICC	<i>International Fuel Gas Code[®]</i>
NFPA 70	<i>National Electrical Code[®]</i>
UL 307B	Gas-Burning Heating Appliances for Manufactured Homes and Recreational Vehicles
UL 727	Oil-Fired Central Furnaces
UL 1995/CSA C22.2 No. 236	Heating and Cooling Equipment
CGA 3.2	Industrial and Commercial Gas-Fired Package Furnaces
CSA B140.4	Oil-Fired Warm Air Furnaces

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