

CHAPTER 10. SMALL FORCED-AIR HEATING AND COOLING SYSTEMS

THIS chapter describes the basics of design and component selection of small forced-air heating and cooling systems, explains their importance, and describes the system's parametric effects on energy consumption. It also gives an overview of test methods for thermal distribution system efficiency, and considers the interaction between the building thermal/pressure envelope and the forced-air heating and cooling system, which is critical to the energy efficiency and cost-effectiveness of the overall system. This chapter pertains to residential and certain small commercial systems; large commercial systems are beyond the scope of this chapter. Applicable standards are listed in the Standards section at the end of the chapter.

1. COMPONENTS

Forced-air systems are heating and/or cooling systems that use motor-driven blowers to distribute heated, cooled, and otherwise treated air to multiple outlets for the comfort of individuals in confined spaces. A typical residential or small commercial system includes (1) a heating and/or cooling unit, (2) supply and return ductwork (including registers and grilles), (3) accessory equipment, and (4) controls. These components are described briefly in the following sections and are illustrated in [Figure 1](#).

Heating and Cooling Units

Three types of forced-air heating and cooling devices are (1) furnaces, (2) air conditioners, and (3) heat pumps.

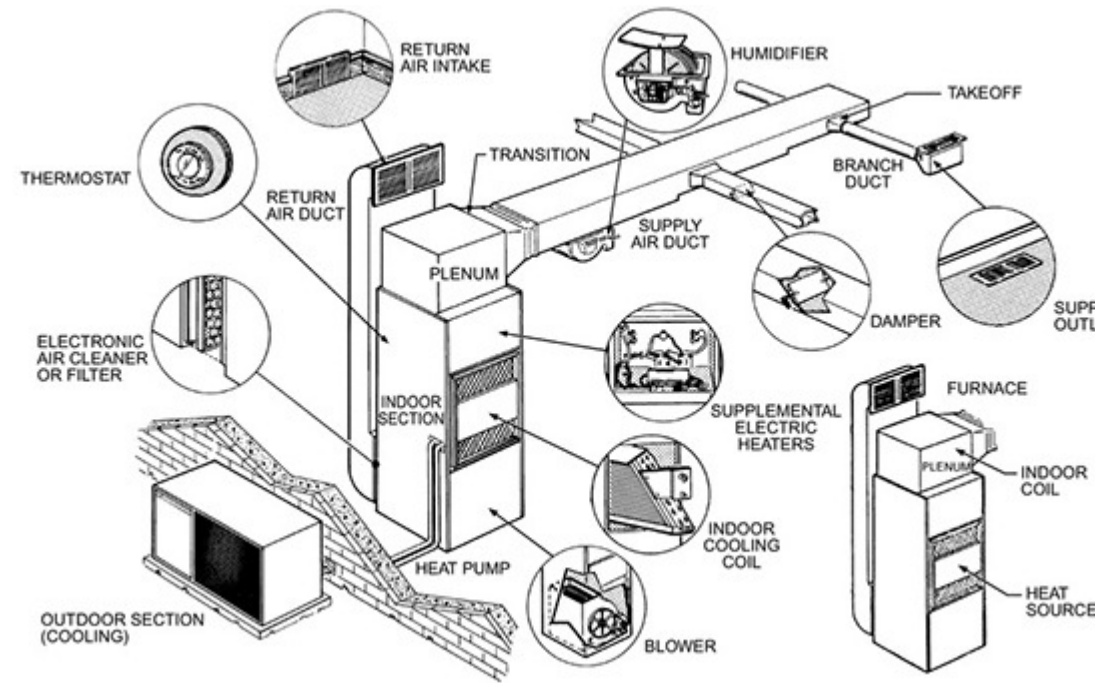


Figure 1. Heating and Cooling Components

Furnaces are the basic component of most forced-air heating systems (see [Chapter 33](#)). They are manufactured to use specific fuels such as oil, natural gas, or liquefied petroleum gas, and are augmented with an air-conditioning coil when cooling is included. The fuel used dictates installation requirements and safety considerations. Common **air-conditioning** systems use a split configuration with an air-handling unit, such as a furnace. The air-conditioning evaporator coil (indoor unit) is installed on the discharge air side of the air handler. The compressor and condensing coil (outdoor unit) are located outside the structure, and refrigerant lines connect the outdoor and indoor units. **Self-contained air conditioners** contain all necessary air-conditioning components, including circulating air blowers, and may or may not include fuel-fired heat exchangers or electric heating elements. **Heat pumps** cool and heat using the refrigeration cycle. They are available in split and packaged (self-contained) configurations. Generally, air-source heat pumps require supplemental heating; therefore, electric heating elements are usually included with the heat pump as part of the forced-air system. Heat pumps offer high efficiency at mild temperatures, but may be combined with fossil-fuel furnaces to minimize heating cost. Heat pump supplemental heating also may be provided by thermostat-controlled gas heating appliances (e.g., fireplaces, free-standing stoves). **Ground-source heat pumps (GSHPs)** are becoming more common in residential housing, especially in colder climates. Because underground temperatures are mild year-round, GSHPs typically do not use supplemental heating except in emergency mode (i.e., when the heat pump does not provide enough heat).

Ducts

Ducts convey air to and from the fan in a heating or cooling unit. Registers and grilles are perforated covers over the openings where ductwork meets room walls, ceilings, or floors. In the extreme, a single return grille may connect directly to the fan cabinet. Supply registers often allow control of flow volume and direction. Dampers act as adjustable valves to control flow volume; turning vanes help redirect the flow around sharp bends. Duct systems can have very significant impacts on system efficiency and occupant comfort, and should be carefully designed, not just constructed by rules of thumb.

Accessory Equipment

Forced-air systems may be equipped with accessories that further condition the air. They may modify humidity, remove contaminants, mix outdoor air with the recirculating air, or transfer energy in other ways. Disposable air filters on the return side of forced-air systems are so common that they are not considered accessories. **Humidifiers**, humidifiers add moisture to the airstream directly as steam or an atomized spray, or by evaporation from heated pans or porous media. [Chapter 22](#) of this volume contains more information on humidifiers. **Dehumidifiers**, dehumidifiers remove moisture from the airstream, typically by cooling it below the condensation point. Also see the section on Dehumidifiers in [Chapter 1 of the 2015 ASHRAE Handbook—HVAC Applications](#). **Electronic Air Cleaners**, far more effective than the passive filters normally found in forced-air systems, these units use static electricity to capture fine dust, smoke, and other particles. Electronic air cleaners usually have a washable prefilter to trap lint and larger particles as they enter the unit. The remaining particles take on an electric charge in a charging section, then travel to the collector section where they are drawn to and trapped on the oppositely charged collecting plates. These plates must be washed periodically. See [Chapter 22](#) for more information on air cleaners. **Ultraviolet Lamp Sterilizers**, short-wavelength ultraviolet lamps in the fan cabinet can kill organisms in the circulating air and prevent mold build-up on the wet cooling coil. See [Chapter 17](#) for details. **Energy/Heat Recovery Ventilators**, These devices provide ventilation air to the conditioned space and recover energy/heat from the air being exhausted outdoors. They can be operated as stand-alone devices or as part of the forced-air distribution system. **Economizer Controls**, These devices monitor outdoor temperature and humidity and automatically shut down the air-conditioning unit when a preset outdoor condition is met. Damper motors open outdoor return air dampers, letting outdoor air enter the system to provide comfort cooling. When outdoor air conditions are no longer acceptable, the outdoor air dampers close and the air-conditioning unit comes back on. **Custom Accessories**, Solar collectors, off-peak storage, and other custom systems are not covered in this chapter. However, their components may be classified as system accessories.

Controls

A simple thermostat controlling on/off cycling of central equipment may be all that is used or needed for temperature control. Such thermostats typically have a switch for automatic or continuous fan operation, and another to choose heating, cooling, or neither. More complex systems may provide control features for timed variations (from simple night setback to a weekly schedule of temperatures); multiple independent zones, power stages, or fan speeds; influence of outdoor sensors; humidity; automatic switching between heating and cooling modes, etc. (see [Chapter 47 of the 2015 ASHRAE Handbook—HVAC Applications](#)). Energy conservation has increased the importance of control, so methods that once were considered too expensive for small systems may now be cost-effective.

2. COMMON SYSTEM PROBLEMS

An idealized forced-air heating or cooling system would be virtually unnoticed by occupants. It would maintain a comfortable indoor environment at all times, with negligible noise, no noticeable odors, no circulating allergens or other pollution, and no localized temperature differences. In addition, it would need no maintenance, would never fail in any way, and would be extremely efficient. Real systems, of course, can vary from this ideal in many ways. One of the most common problems is an **oversized cooling system** that does not need to run very long to cool the air, so it does not have time to remove much moisture. High humidity is uncomfortable, and also can encourage mold growth. **Too-small ducts** create high resistance to airflow that can cause excess power consumption, high pressures, and low flow rates, especially if combined with an oversized system. High pressures can increase noise from airflow and from the fan itself, and can make it difficult to balance the system for appropriate distribution to all rooms. Low flow rates can result in ice formation on the cooling coil (possibly shutting off flow completely) and even on refrigerant piping; when that ice eventually melts, water can enter places that should stay dry. **Long ducts** running to perimeter walls not only increase resistance, but often run through unconditioned space where they can be exposed to extreme temperatures. **Leaky ducts** are, unfortunately, very common. Leaks not only reduce efficiency, they can draw in humidity, dust, pollen, etc. Leaks also can allow relatively humid indoor air to leak out to cold surfaces where the water can condense, causing staining, mold, rot, and other problems. In cold climates, an air leak in the attic can result in ice formation and the potential for significant damage. Ducts should be in the conditioned space. **Poor installation practices** primarily affect duct systems, but condensate removal also can be a problem area. Air leakage problems as described previously, come from failure to seal properly all openings in an air-handling cabinet, joints in the duct system, joints where ducts meet register flares, and openings where register flares penetrate the room. Crude duct-taped joints sometimes come apart after a few years. Flexible ductwork is easy to install, but is also easy to install sloppily, with kinks and unnecessary bends that restrict flow. Cooling systems installed above ground level commonly have a gravity drain for condensate, and a catch pan under the unit as a backup, with its own gravity drain. Sometimes an installed drain that is nearly horizontal actually runs uphill. If the main condensate drain runs uphill, the problem becomes evident almost immediately. If the problem is with the catch pan drain, it may be years before a major freeze-up generates enough water to overflow the pan and cause significant damage. Over time, mold and dirt can build up enough to block a drain line. Periodic cleaning may be necessary. **Dirty filters** are common because homeowners neglect to clean or replace them. This may be from a lack of homeowner education or from the filters not being readily accessible (e.g., if the air handler filter rack is in the attic). They are not merely an air cleanliness problem; they can cut down airflow enough to raise fan power and even cause cooling coils to freeze up. Air-source heat pumps in colder climates typically are equipped with auxiliary electric heat strips. Since resistance heating normally is much less efficient than a heat pump, less-sophisticated control systems can result in **unnecessary electric resistance heating** and higher electric bills. The resistance heating is necessary when continuous operation of the heat pump is insufficient to maintain indoor temperature; however, it may also come on when the thermostat setting is raised (manually, or automatically after night setback). Control systems may turn on resistance heating each time the system is reversed to deheat the outdoor coil, in order to prevent indoor coil blow. If outlets are located on the floor or low on the wall, avoid locations likely to be blocked by furnishings or opened doors. This is by no means an exhaustive list of the types of problems to watch out for in forced air heating and cooling systems, but it should alert designers to some of the most common ones.

3. SYSTEM DESIGN

The size and performance characteristics of components are interrelated, and the overall design should proceed in the organized manner described. For example, furnace selection depends on heat gain and loss and is also affected by duct location (attic, basement, etc.), duct materials, night setback, and humidifier use. Here is a recommended procedure:

1. Estimate heating and cooling loads, including target values for duct losses.
2. Determine preliminary ductwork location and materials of ductwork and outlets.
3. Determine heating and cooling unit location.
4. Select accessory equipment. Accessory equipment is not generally provided with initial construction; however, the system may be designed for later addition of these components.
5. Select control components.
6. Select heating/cooling equipment.
7. Determine maximum airflow (cooling or heating) for each supply and return location.
8. Determine airflow at reduced heating and cooling loads (two-speed and variable-speed fans).
9. Finalize heating/cooling equipment.
10. Finalize control system.
11. Finalize duct design and size.
12. Select supply and return grilles.
13. When the duct system is in place, measure duct leakage and compare results with target values used in step 1.

This procedure requires certain preliminary information such as location, weather conditions, and architectural considerations. The following sections cover the preliminary considerations and discuss how to follow this recommended procedure.

Estimating Heating and Cooling Loads

Design heating and cooling loads can be calculated by following the procedures outlined in [Chapters 17, 18, and 19 of the 2013 ASHRAE Handbook—Fundamentals](#). When calculating design loads, heat losses or gains from the air distribution system must be included in the total load for each room. In residential and commercial applications, local codes often require outdoor air ventilation, which is added to the building load. Target values for duct losses may be set by codes, voluntary programs, or other recommendations. If ducts are located in the conditioned space, losses can be reduced essentially to zero. If this is not possible, losses should be limited to 10% of the heating or cooling load.

Locating Outlets, Returns, Ducts, and Equipment

The characteristics of a residence determine the appropriate type of forced-air system and where it can be installed. The presence or absence of particular areas in a residence directly influences equipment and duct location. The structure's size, room or area use, and air-distribution system determine how many central systems will be needed to maintain comfort temperatures in all areas. Supply outlets fall into three general discharge patterns: (1) horizontal, (2) vertical nonspreading, and (3) vertical spreading. Straub and Chien (1957) and Wright et al. (1963) describe these types and their performance characteristics under controlled laboratory and actual residence conditions. [Table 1](#) lists the general characteristics of supply outlets. It includes the performance of various outlet types for cooling as well as heating, because one of the advantages of forced-air systems is that they may be used for both heating and cooling. However, as indicated in [Table 1](#), no single outlet type is best for both heating and cooling. The best outlets for heating traditionally have been located near the floor at outer walls and provide a vertical spreading air jet, preferably under windows, to blanket cold areas and counteract cold drafts. Called **perimeter heating**, this arrangement mixes warm supply air with both cool air from the area of high heat loss and cold air from infiltration, preventing drafts. In newer, more energy-efficient homes having well-insulated envelopes with low air leakage rates, it is no longer necessary to locate outlets near exterior walls. Instead, locating outlets as close as possible to the heating/cooling equipment allows for shorter duct runs, reducing duct leakage and pressure losses. This is especially important if it is not possible to locate the ducts in the conditioned space. See the section on Detailing the Duct Configuration for further information. If outlets are located on the floor or low on the wall, avoid locations likely to be blocked by furnishings or opened doors. Weather should be considered when locating equipment and ductwork. Packaged outdoor units for houses in severely cold climates must be installed according to manufacturer recommendations. Most houses in cold climates have basements, making them well-suited for indoor furnaces and split-system air conditioners or heat pumps. In mild and moderate climates, ductwork frequently is located in the attic or crawlspace, but the conditioned space still is best.

Locating and Selecting Outlets and Returns. Although the principles of air distribution discussed in [Chapter 20](#) of this volume and [Chapter 20 of the 2013 ASHRAE Handbook—Fundamentals](#) apply in forced-air system design, simplified methods of selecting outlet size and location generally are used. Supply outlets fall into three general discharge patterns: (1) horizontal, (2) vertical nonspreading, (3) vertical spreading, and (4) horizontal low. Straub and Chien (1957) and Wright et al. (1963) describe these types and their performance characteristics under controlled laboratory and actual residence conditions. [Table 1](#) lists the general characteristics of supply outlets. It includes the performance of various outlet types for cooling as well as heating, because one of the advantages of forced-air systems is that they may be used for both heating and cooling. However, as indicated in [Table 1](#), no single outlet type is best for both heating and cooling. The best outlets for heating traditionally have been located near the floor at outer walls and provide a vertical spreading air jet, preferably under windows, to blanket cold areas and counteract cold drafts. Called **perimeter heating**, this arrangement mixes warm supply air with both cool air from the area of high heat loss and cold air from infiltration, preventing drafts. In newer, more energy-efficient homes having well-insulated envelopes with low air leakage rates, it is no longer necessary to locate outlets near exterior walls. Instead, locating outlets as close as possible to the heating/cooling equipment allows for shorter duct runs, reducing duct leakage and pressure losses. This is especially important if it is not possible to locate the ducts in the conditioned space. See the section on Detailing the Duct Configuration for further information. If outlets are located on the floor or low on the wall, avoid locations likely to be blocked by furnishings or opened doors. The best outlet types for cooling are located in the ceiling and have a horizontal air discharge pattern. For year-round systems, supply outlets are located to satisfy the more critical load.

Table 1. General Characteristics of Supply Outlets

Group	Outlet Type	Outlet Flow Pattern	Conditioning Mode	Most Effective Application	Selection Criteria
1	Ceiling and high sidewall	Horizontal	Cooling	Ceiling outlets	
				Full-circle or widespread type	Select for throw equal to distance from outlet to nearest wall at design flow rate and pressure limitations.
				Narrow spread type	Select for throw equal to 0.75 to 1.2 times distance from outlet to nearest wall at design flow rate and pressure limitations.
				Two adjacent ceiling outlets	Select each so that throw is about 0.5 times distance between them at design flow rate and pressure limits.
2	Floor diffusers, baseboard, and low sidewall	Vertical, nonspreading	Cooling and heating	High sidewall outlets	Select for throw equal to 0.75 to 1.2 times distance to nearest wall at design flow rate and pressure limits. If pressure drop is excessive, use several smaller outlets rather than one large one to reduce pressure drop.
					Select for 6 to 8 ft throw at design flow rate and pressure limitations.
3	Floor diffusers, baseboard, and low sidewall	Vertical, spreading	Heating and cooling		Select for 4 to 6 ft throw at design flow rate and pressure limitations.
4	Baseboard, and low sidewall	Horizontal	Heating only		Limit face velocity to 300 fpm.

The stagnant layer develops near the floor during heating and near the ceiling during cooling. Returns help remove air from this region if the return face is placed in the stagnant zone. Thus, for heating, returns should be placed low; for cooling, returns should be placed high. However, in a year-round heating and cooling application, a compromise must be made by placing returns where the largest stagnant zone develops. With low supply outlets, the largest stagnant zone develops during cooling, so returns should be placed high or opposite the supply locations. Conversely, high supply outlets do not perform as well during heating; therefore, returns should be placed low to be of maximum benefit. If central return is used, the airflow between supply registers and the return should not be impeded even when interior doors are closed. This can be accomplished by undercutting doors or by providing alternative paths such as louvers or crossover ducts.

Selecting Heating and Cooling Equipment

[33](#) Furnace heating output should match or slightly exceed the estimated design load. The Air Conditioning Contractors of America (*ACCA Manual S*) recommends a 40% limit on oversizing for fossil fuel furnaces. This limit minimizes venting problems associated with oversized equipment and improves part-load performance. Note that the calculated load must include duct loss, humidification load, and night setback recovery load, as well as building conduction and infiltration heat losses. [Chapter 33](#) has detailed information on how to size and select a furnace. To help conserve energy, manufacturers have added features to improve furnace efficiency. Electric ignition has replaced the standing pilot; vent dampers and more efficient motors are also available. Furnaces with fan-assisted combustion systems (FACs) and condensing furnaces also improve efficiency. Two-stage heating and cooling, variable-speed heat pumps, and two-speed and variable-speed blowers are also available. Research on the effect of blower performance on residential forced-air heating system performance suggested reductions of 180 to 250 kWh/yr for automatic furnace fan operation and 2600 kWh/yr for continuous fan operation by changing from permanent split capacitor (PSC) blower motors to brushless permanent electronically commutated magnet motors (ECMs) (Phillips 1998). A system designed to both heat and cool and that cycles cooling equipment on and off by sensing dry-bulb temperature alone should be sized to match the design heat gain as closely as possible. Oversizing under this control strategy could lead to higher-than-desired indoor humidity levels. [Chapter 17 of the 2013 ASHRAE Handbook—Fundamentals](#) recommends that cooling units not be oversized. Other sources suggest limiting oversizing to 15% of the sensible load. A heat pump should be sized for the cooling load with supplemental heat provided to meet heating requirements. Size air-source heat pumps in accordance with the equipment manufacturer recommendations. *ACCA Manual S* can also be used to assist in the selection and sizing of equipment.

Determining Airflow Requirements

After equipment is selected and before duct design, the following decisions must be made:

1. Determine air quantities required for each room or space during heating and cooling based on each room's heat loss or heat gain. The air quantity selected should be the greater of the heating or cooling requirement.
2. Determine number of supply outlets needed for each space to supply the selected air quantity, considering discharge velocity, spread, throw, terminal velocity, occupancy patterns, location of heat gain and loss sources, and register or diffuser design.
3. Determine type of return (multiple or central), availability of space for grilles, filtering, maximum velocity limits for sound, efficient filtration velocity, and space use limitations.

Finalize Duct Design and Size

Duct design too often is ignored in residences, and simply is left to a contractor to install in the traditional way. Because of the significant effect ducts can have on system efficiency, this topic is discussed extensively here.

Selecting Supply and Return Grilles and Registers

Grilles and registers are selected from a manufacturer's catalog with appropriate engineering data after the duct design is completed. Avoid rule-of-thumb selection. Carefully determine the suitability of the register or grille selected for each location according to its performance specification for the quantity of air to be delivered and the discharge velocity from the duct. Generally, in small commercial and residential applications, selection and application of registers and grilles is particularly important because system size and air-handling capacity are small in energy-efficient structures. Proper selection ensures satisfactory delivery of heating and/or cooling. [Table 1](#) summarizes selection criteria for common types of supply outlets. Pressure loss is usually limited to 0.03 in. of water or less. Return grilles are usually sized to provide an exit velocity at their face of 400 to 600 fpm, or 2.7 to 4.1 cfm per square inch of free area. Some central return grilles are designed to hold an air filter. This design allows the air to be filtered close to the occupied area and also allows easy access for filter maintenance. Easy access is important when the furnace is in a remote area such as a crawlspace or attic. The air velocity through a filter grille should not exceed 300 fpm, which means that the volume of air should not exceed 2.1 cfm per square inch of free filter area. Free area may range from 30 to 70% of total grille area.

4. DETAILED DUCT DESIGN

Detailing the Duct Configuration

The next major decision is to select a generic duct system. In order of decreasing efficiency, the three main types are

1. Ducts in conditioned space
2. Minimum-area ductwork (minimum run length results in minimum surface area)
3. Traditional designs

Ductwork costs and system energy use can be reduced when the home designer/architect, builder, subcontractors, and HVAC installer collaborate to place **ducts in conditioned spaces** and minimize duct runs. Residential duct systems in unconditioned spaces can lose a significant percent of the energy in the air they distribute. These losses can be almost entirely eliminated simply by locating ducts in the conditioned space (insulated building envelope), which is a cost-effective way to increase heating and cooling equipment efficiency and lower utility bills (Modera 1989). Benefits include improved comfort, improved indoor air quality, and lower utility bills and equipment cost.

Any losses (air or conductive) from ducts in conditioned space still provide space conditioning. Ducts in conditioned space are also subjected to much less severe conditions, reducing conductive losses and the effect of return air leaks. There are a number of approaches that can be used to accomplish this:

- Trunks and branches can be located between floors or at a two-story residence or along the wall-ceiling intersections in a single-story dwelling. Care must be taken to seal the rim joint between floors, and/or the wall-to-ceiling intersection.
- In some houses, the ceiling in a central hallway can be lowered. The air barrier is still provided at the higher level, bringing the space between the ceiling and air barrier into conditioned space. Ducts are installed in this space, with supply registers located on the walls of adjacent spaces. The ceiling can be dropped in closets, bathrooms, or, if necessary, a soffit to get ducts to rooms that are not adjacent to the central hallway. [Figures 2A and 2B](#) illustrate the planning required for locating ductwork between floors in a two-story residence and in a townhouse.
- A slab-on-grade foundation is common in mild or moderate climates. With this type of foundation, supply air ducts are typically located in the attic. During the winter, attic air temperatures tend to match outdoor air temperatures. During the summer, solar heat gains can raise attic air temperatures over 150°F. These temperature extremes increase heat losses and gains from conduction and radiation and decrease duct efficiency. In addition, any conditioned air that leaks out of the duct is lost into the attic. If return ducts also are in the attic, return leaks pull unconditioned air into the system (particularly detrimental in hot, humid climates).
- [Figures 2A, 2B, and 2C](#) show that constructing a ceiling plenum in the hallway allows ducts to be located in the conditioned space. Air temperatures in this location are typically between 55 and 85°F, which minimizes conduction and radiation losses. Air that leaks out of the ducts goes into the conditioned space.
- Attics can be heated in the conditioned space by relocating the thermal barrier to the roof and eliminating ridge and soffit vents to provide an air barrier at the roof line. Insulation can be installed at the roofline by, for example, installing netting material between trusses, and installing blown-in cellulose insulation. Ductwork can then be installed in the attic in conditioned space. In cold climates, care must be taken to avoid condensation on the inside of the roof deck; in hot climates, the lack of roof venting may argue against using asphalt-shingle roofing. One roofing option is a composite board consisting of thick, rigid foam insulation, vertically aligned spacing strips, and a solid plywood upper layer, fastened with very long screws onto the roof trusses. The spacing strips allow airflow under the main deck (but above the insulation) from soffits to ridge vents. It is important that no gaps be left between the insulation slabs of adjacent boards.
- A plenum space can be created in the attic by using roof trusses that do not have a traditional flat bottom chord. A modified scissors truss design, which provides space between the bottom chord of the truss and the top chord of the wall framing, provides a duct space that can be brought into conditioned space. The bottom chord of the trusses is used to install an air barrier, with insulation blown in on top. Ductwork is installed in the plenum space, with supply registers located near interior walls (because the space may not extend all the way to the exterior walls).
- It is important that the ducts be located inside thermal and air barriers, and that the air barrier be well sealed to minimize air communication with the outdoors. The duct space is rarely completely in conditioned space (other than in exposed ductwork systems). When there is an air barrier between the ducts and the occupied space, some fraction of air and thermal losses from the duct system goes to the outdoors rather than to the occupied space. High-quality air sealing on the exterior air barrier minimizes these losses to the outdoors.

Many new buildings have well-insulated envelopes or sufficient thermal integrity so that supply registers do not have to be located next to exterior walls. Placing registers in interior walls can reduce duct surface area by 50% or more, with similar reductions in leakage and conductive losses. This option also offers significant first-cost savings. **Minimum-area ductwork systems** are used in most houses built with ducts in conditioned space, including those using a dropped ceiling.

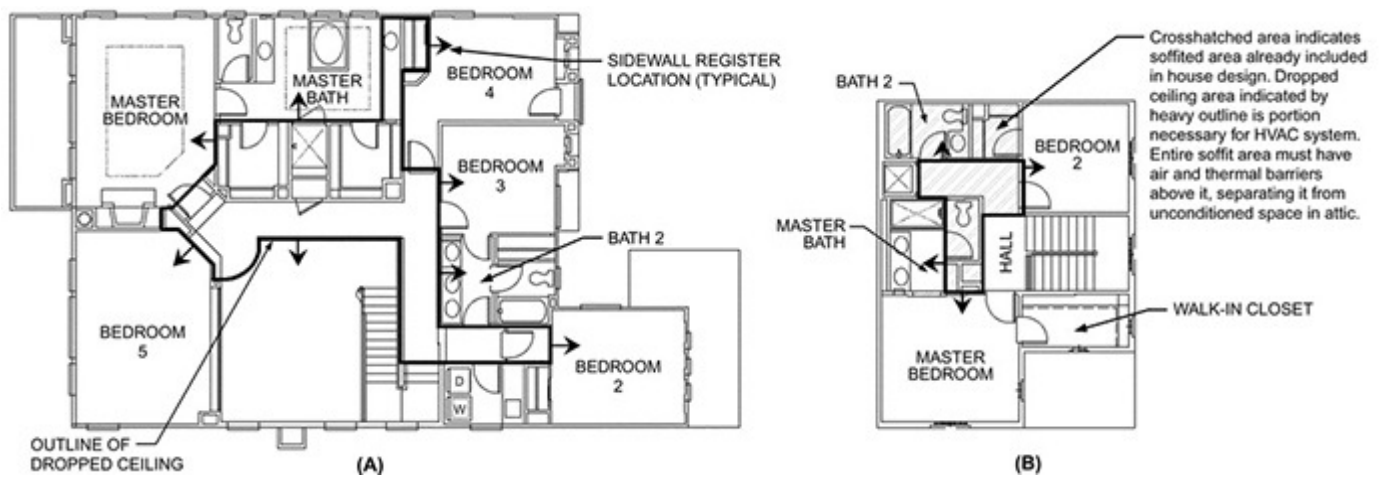


Figure 2. Sample Floor Plans for Locating Ductwork in Second Floor of (A) Two-Story House and (B) Townhouse (Hedrick 2002)

[Figures 2 and 3](#) are improved duct designs for new energy-efficient residential construction. These residences are designed with tighter envelopes/ducts, increased insulation, and high-performance windows, resulting in wall, window, floor, and ceiling temperatures that are warmer in winter and cooler in summer, and are more comfortable and less drafty. In **traditional designs** for standard residential construction, supply ducts are typically run in unconditioned spaces, with supplies located near the perimeter of a house to offset drafts from cold exterior surfaces, especially windows. Compare [Figures 4A and 4B](#) with [3B and 3C](#). Because this is the least efficient option overall, take particular care to seal and insulate the ductwork. Any air leaks on the supply side of the system allow conditioned supply air to escape to the outdoors. Return-side leaks draw air at extreme temperatures into the system instead of tempered room air. Return leaks can also have indoor air quality effects if the return ducts are located in garages or other spaces where contaminants may be present. In humid climates, return leaks bringing in humid outdoor air can raise the humidity in the space, increasing the risk of mold and mildew.

Airflow control should be a key objective in designing small commercial buildings. Designers and builders can plan for proper airflows at the outset. The following design goals are recommended:

- *Design the building envelope to minimize effects of uncontrolled airflows.* Place the air and thermal barriers together in the roof, with ducts inside the conditioned zone. There are several good options for placing insulation at the roof level, including sprayed polymer foam, rigid insulation board on the roof deck beneath a rubber membrane, and insulating batts attached to the underside of the roof.
- *Minimize duct leakage to outdoors.* Make sure as much ductwork as is in the conditioned envelope as possible. Do not vent the ceiling space. If possible, dispense with the dropped ceiling altogether and use exposed ductwork. Avoid using building cavities as part of the air distribution system.
- *Minimize unbalanced return air.* The best way is to provide a ducted return for each zone, and then balance these with the supply ducts serving the respective zones. Where that is not possible, transfer ducts or grilles may be provided to link a zone without a return duct to another zone with a return duct, provided that these have a minimum of 70 in² of net free area per 100 cfm of return airflow. This approach should be used only if the thermal and air barriers are in the same plane (roof or ceiling).
- *Minimize unbalanced airflows across building envelope.* Design the exhaust system with the smallest airflow rates necessary to capture and remove targeted air contamination sources and meet applicable standards. Ensure that the sum of makeup and outdoor airflow rates exceeds the exhaust airflow rate, not only for the building as a whole but also for any zones that can be isolated. Unconditioned makeup air should equal 75 to 85% of exhaust airflow, where possible. In buildings where continuous ventilation is required and the climate is especially humid, special design options may be needed (e.g., a dedicated makeup air unit could be provided with its own desiccant dehumidifier).
- *Ensure proper operation of outdoor air dampers.* Outdoor air dampers on air handlers or rooftop air-conditioning units are frequently stuck or rusted shut, even on recently installed equipment. Proper performance helps ensure proper air quality and thermal comfort. Inspect space conditioning equipment annually to ensure proper operation of these dampers.

Further information can be found in Andrews et al. (2002).

6. TESTING FOR DUCT EFFICIENCY

ASHRAE Standard 152-2014 describes ways of measuring duct leakage and of calculating the impact of all sorts of energy transfer mechanisms. It applies to single-family detached and attached residences with independent thermal distribution systems. A major complication in the standard's lengthy development effort was the fact that, in contrast to heating or cooling units, which are mass-produced, duct systems are one of a kind. When determining the efficiency of a home duct system, it is therefore not possible to use the result of a laboratory test on a sample of the same model. Tests on a duct system must be performed in situ. The task before the committee was to produce a procedure that would be credibly accurate yet not too time-consuming to apply. A detailed history of the standard's development is given in Andrews (2003).

ASHRAE Technical Committee 6.3, which is responsible for the standard, investigates possible revisions and extensions on an ongoing basis. ASHRAE and other research organizations have conducted significant research and published numerous articles about methods for testing, and measured performance of the design and seasonal efficiencies of residential duct systems in the heating and cooling modes. A compilation of this research is provided in the Bibliography. Although duct leakage is a major cause of duct inefficiency, other factors, such as heat conduction through duct walls, influence of fans on pressure in the house, and partial regain of lost heat, must also be taken into account. Following is a summary of information needed to evaluate the efficiency of a duct system using *Standard 152* and a description of the results that the test method provides.

Data Inputs

Variables that are known or can be measured to provide the basis for calculating duct system efficiency include the following:

- **Local Climate Data.** Three outdoor design temperatures are needed to describe an area's climate: one dry-bulb and one wet-bulb temperature for cooling, and one dry-bulb for heating.
- **Dimensions of Living Space.** The volume of the conditioned space must be known to estimate the impact of the duct system on air infiltration. Typical, average values have been developed and if default options are used, the floor area of the conditioned space must be known.
- **Surface Areas of Ducts and R-Values of Insulation.** The total surface area of supply and return ducts and the insulation R-value of each are needed for calculating conductive heat losses through the duct walls. Also needed is the fraction of supply and return ducts in each type of buffer zone (e.g., an attic, basement, or crawlspace).
- **Fan Flow Rate.** *Standard 152* allows a choice between two ways of measuring this quantity. An adjustable, calibrated fan flowmeter is the most accurate device for measuring airflow. The alternative method in the standard is to use a calibrated flow grid.
- **Duct Leakage to Outdoors.** Air leakage from supply ducts to the outdoors and from the outdoors and buffer spaces into return ducts is another major factor that affects efficiency. Typically, 17% or more of the total airflow is leakage.

Data Output

Distribution efficiency is the main output of *Standard 152*. This figure of merit is the ratio of the input energy that would be needed to heat or cool the house if the duct system had no losses to the actual energy input required. Distribution efficiency also accounts for the effect the duct system has on equipment efficiency and the space conditioning load. Thus, distribution efficiency differs from delivery effectiveness, which is the simple output-to-input ratio for a duct system. Four types of distribution efficiencies are considered. They relate to efficiency during either heating or cooling and for either design conditions or seasonal averages.

- Design distribution efficiency, heating
- Seasonal distribution efficiency, heating
- Design distribution efficiency, cooling
- Seasonal distribution efficiency, cooling

Design values of distribution efficiency are peak-load values that should be used when sizing equipment. Seasonal values should be used for determining annual energy use and subsequent costs.

STANDARDS

AHRI	
<i>Standard 260</i>	Sound Rating of Ducted Air Moving and Conditioning Equipment
<i>Standard 610</i>	Performance Rating of Central System Humidifiers for Residential Applications

ASHRAE	
<i>Standard 90.2</i>	Energy Efficient Design of New Low-Rise Residential Buildings
<i>Standard 103</i>	Methods of Testing for Annual Fuel Utilization Efficiency of Residential Central Furnaces and Boilers
<i>Standard 152</i>	Method of Test for Determining the Design and Seasonal Efficiencies of Residential Thermal Distribution Systems

ASTM	
<i>Standard E1554</i>	Standard Test Methods for Determining External Air Leakage of Air Distribution Systems by Fan Pressurization

NFPA	
<i>Standard 90A</i>	Standard for the Installation of Air-Conditioning and Ventilating Systems
<i>Standard 90B</i>	Standard for the Installation of Warm Air Heating and Air-Conditioning Systems
<i>Standard 501</i>	Standard for Manufactured Housing

ACCA	
<i>Manual D</i>	Residential Duct Systems
<i>Manual J</i>	Residential Load Calculations
<i>Manual S</i>	Residential Equipment Selection

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