

SUPPLY air outlets, terminal units, chilled beams, fan-coil units, and air curtain units introduce air into a conditioned space to obtain a desired indoor atmospheric environment. Return and exhaust air are removed from a space through return and exhaust inlets (*inlet* and *outlet* are defined relative to the duct system and not the room, as shown in [Figure 1](#)). This chapter describes this equipment, details its proper use, and is intended to help HVAC designers select room air distribution equipment applicable to the air distribution methods outlined in [Chapter 57 of the 2015 ASHRAE Handbook—HVAC Applications](#).

Room air distribution systems can be classified according to their primary objective and the method used to accomplish that objective. The objective of any air distribution system is to condition and/or ventilate the space for occupants' thermal comfort, or to support processes within the space, or both.

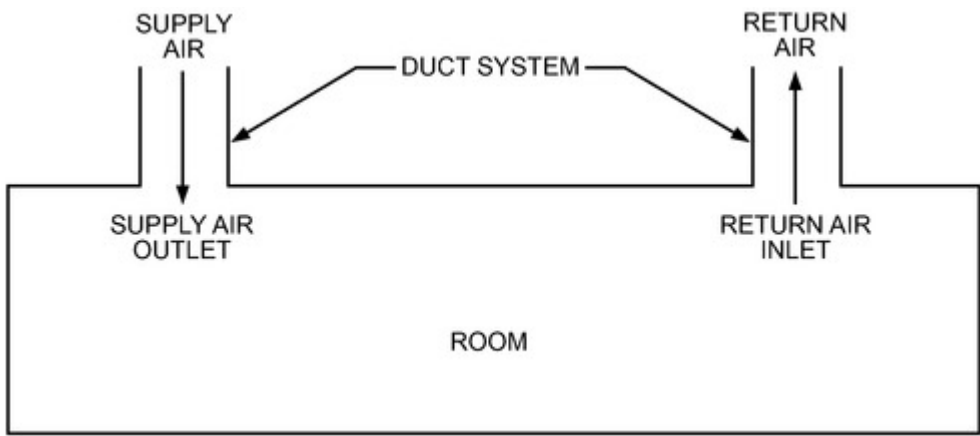


Figure 1. Designations for Inlet and Outlet

Methods used to condition a space can be classified as one of the following:

- **Fully mixed** systems have little or no thermal stratification of air within the occupied and/or process space. Overhead air distribution is an example of this type of system.
- **Fully stratified** systems have little or no mixing of air within the occupied and/or process space. Thermal displacement ventilation is an example of this type of system.
- **Partially mixed** systems provide some mixing of air in the occupied and/or process space while creating stratified conditions in the volume above. Most underfloor air distribution designs are examples of this type of system.
- **Task/ambient** air distribution focuses on conditioning only a portion of the space for thermal comfort and/or process control. Examples of task/ambient systems are personally controlled desk outlets and spot-conditioning systems. Because task/ambient distribution requires a high level of individual control, it is not covered in this chapter, but is discussed in [Chapter 20 of the 2013 ASHRAE Handbook—Fundamentals](#). Additional design guidance is also provided in Bauman (2003).

[Figure 2](#) illustrates the spectrum between the two extremes (fully mixed and fully stratified) of room air distribution strategies. Review the following publications when selecting systems and equipment for room air distribution:

- ANSI/ASHRAE *Standard* 55-2013 establishes indoor thermal environmental and personal factors for the occupied space.
- ANSI/ASHRAE *Standard* 62.1-2013 specifies ventilation requirements for acceptable indoor environmental quality. This standard is adopted as part of many building codes.
- ANSI/ASHRAE/IES *Standard* 90.1-2013 provides minimum energy efficiency requirements that affect supply air characteristics.

Local codes should also be checked for applicability to each of these subjects.

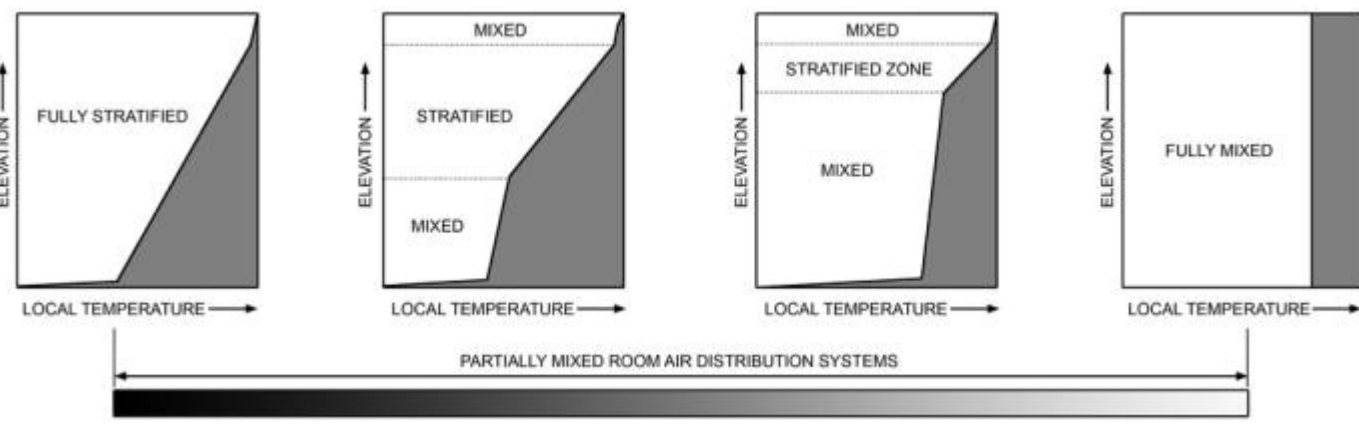


Figure 2. Classification of Air Distribution Strategies

Other useful references on selecting air distribution equipment include AMCA *Standard* 222-2008, [Chapter 20 of the 2013 ASHRAE Handbook—Fundamentals](#), [Chapter 57 of the 2015 ASHRAE Handbook—HVAC Applications](#), ASHRAE's (2013) *UFAD Guide: Design, Construction and Operation of Underfloor Air Distribution Systems*, Chen and Glicksman (2003), Rock and Zhu (2002), Skistad et al. (2002), and ASHRAE/REHVA's *Active and Passive Beam Application Design Guide* (Woollett and Rimmer 2014).

1. SYSTEM CLASSIFICATIONS

1.1 FULLY MIXED SYSTEMS

In fully mixed systems, supply air outlets, properly sized and located, control the air pattern to obtain proper air mixing and temperature equalization in the space.

Accessories used with an outlet regulate the volume of supply air and control its flow pattern. For example, an outlet cannot discharge air properly and uniformly unless the air enters it in a straight and uniform manner. Accessories may also be necessary for proper air distribution in a space, so they must be selected and used according to the manufacturers' recommendations.

Supply airflow from an outlet entrains room air into the jet. This entrained air increases the total air in the jet stream. The momentum of the jet remains constant, so velocity decreases as the mass increases. As the two air masses mix, the temperature of the jet approaches the room air temperature (Rock and Zhu 2002). Outlets should be sized to project air so that its velocity and temperature reach acceptable levels before entering the occupied zone. Outlet locations and patterns also affect a jet's throw, entrainment, and temperature equalization capabilities. Some general characteristics include the following:

- When outlets are located close to a surface, entrainment may be restricted, which can result in a longer throw.
- When the air pattern is spread horizontally, throw is reduced.
- Outlets with horizontally radial airflow patterns typically have shorter throws than outlets with directional patterns.

Ceiling or sidewall outlets in cooling applications are most commonly selected with supply air temperatures at or above 52°F. Special high-induction outlets are available for use with low-temperature air distribution systems (i.e., those with supply air temperature below 52°F). These outlets include special features and rapidly mix cold supply air with room air at the outlet and effectively reduce the temperature differential between the supply and room air. For further information, designers can consult ASHRAE's (1996) *Cold Air Distribution System Design Guide*.

Factors That Influence Selection

Coanda (Surface or Ceiling) Effect. An airstream moving adjacent to or in contact with a wall or ceiling creates a low-pressure area immediately adjacent to that surface, causing the air to remain in contact with the surface substantially throughout the length of throw. This **Coanda effect**, also referred to as the **surface or ceiling effect**, counteracts the drop of a horizontally projected cool airstream.

Round and four-way horizontal-throw ceiling outlets exhibit a high Coanda effect because the discharge air pattern blankets the ceiling area surrounding each outlet. This effect diminishes with a directional discharge that does not blanket the full ceiling surface surrounding the outlet. Sidewall outlets exhibit varying degrees of Coanda effect, depending on the spread of the particular air pattern and the proximity and angle of airstream approach to the surface.

When outlets are mounted such that they discharge into a free space not near an adjacent surface (e.g., exposed duct-mounted grille applications), the airstream entrains air around the entire perimeter of the jet. As a result, the rate of entrainment is higher and the throw is shortened. More information on jet behavior can be found in [Chapter 20 of the 2013 ASHRAE Handbook—Fundamentals](#).

Temperature Differential. The greater the temperature differential between the supply air projected into a space and the air in the space, the greater the buoyancy effect on the path of the supply airstream. Heated, horizontally projected air rises and cooled air falls, so this effect should be considered during outlet selection. See [Chapter 20 of the 2013 ASHRAE Handbook—Fundamentals](#) for further discussion of the buoyancy effect.

Low-temperature supply air or cold building start-up in a humid environment may cause condensation. Consider the effect of condensation on outlet and space surfaces during outlet selection.

Sound Level. The sound level from an outlet is largely a function of its discharge velocity and transmission of system noise. For a given air capacity, a larger outlet has a lower discharge velocity and correspondingly lower generated sound. However, a larger outlet also allows more sound to pass through the outlet, which may appear as outlet-generated noise. High-frequency noise can result from excessive outlet velocity but may also be generated in the duct by the moving airstream. Low-frequency noise is generally airborne sound transmitted through the duct and outlet to the room.

The cause of the noise can usually be pinpointed as outlet or system sounds by removing the outlet core during operation. If the noise remains essentially unchanged, the system is the source. If the noise is significantly reduced, the outlet is likely the source. The noise may be caused by a highly irregular velocity profile at the entrance to the outlet. See ASHRAE research project RP-1335 (Landsberger et al. 2011) or [Chapter 57 of the 2015 ASHRAE Handbook—HVAC Applications](#) for more details on the effects of inlet conditions on air outlets.

Smudging. Smudging is the deposition of particles on the air outlet or a surface near the outlet. Particles are entrained into the primary discharge jet and impinged into the device or ceiling surface in areas of lower pressure. Smudging tends to be heavier in high-traffic areas near building entrances, where particulates are brought into a space. In well-maintained systems, filtered supply air contributes little to ceiling smudging. Smudging is typically more prevalent with ceiling-mounted outlets and linear outlets that discharge parallel to the mounting surface than with outlets that discharge perpendicular to the surface.

Variable-Air-Volume (VAV) Outlet. Select outlets based on the total range of airflow for the space served. Outlet performance characteristics should be evaluated at both minimum and maximum flow. More information regarding selection of outlets can be found in [Chapter 57 of the 2015 ASHRAE Handbook—HVAC Applications](#).

Outlet Selection Procedure

The following procedure is generally used in selecting and locating an outlet in a fully mixed system. More details and examples are available in Rock and Zhu (2002).

1. Determine the amount of air to be supplied to each room. (See [Chapters 17 and 18 of the 2013 ASHRAE Handbook—Fundamentals](#)) to determine air quantities for heating and cooling.)
2. Select the type and quantity of outlets for each room, considering factors such as air quantity required, distance available for throw or radius of diffusion, structural characteristics, and architectural concepts. [Table 1](#), which is based on experience and typical ratings of various outlets, may be used as a guide for using outlets in rooms with various heating and cooling loads. Special conditions, such as ceiling height less than 8 or greater than 12 ft, exposed duct mounting, product modifications, and unusual conditions of room occupancy, should be considered. Manufacturers' performance data should be consulted to determine the suitability of the outlets used.
3. Outlets may be sized and located to distribute air in the space to achieve acceptable temperature and velocity in the occupied zone. Select and locate outlets such that the air supplied reaches the breathing zone (as defined by ASHRAE *Standard* 62.1-2013) for heating and cooling.
4. Select the proper size outlet from the manufacturers' performance data according to air quantity, neck and discharge velocity, throw, distribution pattern, and sound level. Note manufacturers' recommendations with regard to use. Also, obstructions to the primary air distribution pattern require special study. In an open space, the interaction of airstreams from multiple air outlets may alter a single outlet's throw, air temperature, or air velocity. As a result, manufacturers' data may be insufficient to predict air motion in a particular space. The **air diffusion performance index (ADPI)** is a useful tool in predicting outlet performance for fully mixed systems; see [Chapter 57 of the 2015 ASHRAE Handbook—HVAC Applications](#) for more information.

1.2 FULLY STRATIFIED SYSTEMS

Stratified room air distribution systems, typically called **thermal displacement ventilation**, generally rely on supply outlets with very low discharge velocities (50 to 70 fpm based on total face area) to produce minimal room air entrainment so that much of the temperature difference between supply and ambient air is preserved. Thus, cool supply air accumulates in the lower levels of the space. Horizontal movement of air in the space occurs at minimal velocities that are insufficient to produce mixing with room air; thus, the supply airstream maintains its thermal integrity. Heat sources in the space create convection plumes that originate around the boundaries of the heat source and rise naturally because of their buoyancy. If these sources are near the supply airstream, supply air is entrained to fill the void of the rising convection plume.

Table 1. Typical Applications for Supply Air Outlets

Outlet Types	Fully Mixed			Fully Stratified			Partially Mixed		
	Ceiling Mounted	Wall Mounted	Floor/Sill	Wall Mounted	Floor/Sill	Ceiling Mounted	Wall Mounted	Floor/Sill	
Grilles									
Adjustable blade	+	•	⊙	⊙	⊙	⊙	⊙	⊙	
Fixed blade	⊙	+	•	+	⊙	⊙	⊙	•	
Linear bar	⊙	•	•	+	+	⊙	⊙	•	
Nozzle	+	•	⊙	⊙	⊙	⊙	⊙	⊙	
Diffusers									
Round	•	⊙	⊙	⊙	⊙	⊙	⊙	⊙	
Square	•	⊙	⊙	⊙	⊙	⊙	⊙	⊙	
Perforated face	•	⊙	⊙	⊙	⊙	⊙	⊙	⊙	
Louvered face	•	⊙	⊙	⊙	⊙	⊙	⊙	⊙	
Plaque face	•	⊙	⊙	⊙	⊙	⊙	⊙	⊙	
Hemispherical	•	⊙	⊙	⊙	⊙	+	⊙	⊙	
Laminar flow	•	⊙	⊙	⊙	⊙	⊙	⊙	⊙	
Linear slot	•	•	⊙	⊙	⊙	⊙	⊙	⊙	
T-bar slot	•	⊙	⊙	⊙	⊙	⊙	⊙	⊙	
Light troffer	•	⊙	⊙	⊙	⊙	⊙	⊙	⊙	
Swirl	•	⊙	⊙	⊙	+	⊙	•	•	
Displacement	⊙		⊙	•	•	⊙	⊙	⊙	
Air dispersion duct	•	+	⊙	+	+	+	+	⊙	

• = often used
• = sometimes used
⊙ = seldom used
⊙ = not recommended

The temperature differential between supply and room air is generally less than that commonly used for fully mixed systems. Exhaust air is generally higher temperature compared to fully mixed systems, especially with high ceilings. Stratified systems used in transient spaces where thermal comfort is less critical may, however, use air temperature differentials similar to those in fully mixed systems.

Factors That Influence Selection

Space Considerations. To maximize system efficiencies, typical locations for supply outlets are in the low side wall or floor. These supply outlets typically take up considerably more space than outlets used in fully mixed systems. Wall recessed outlets are typical; however, to increase the face area, outlets are often configured as quarter-round, semicircular, or cylindrical. The latter configuration is generally mounted in open space, whereas the other configurations are mounted in corners, adjacent to the side wall, or flush with the wall.

Space Heating Considerations. Skistad et al. (2002) reported that displacement ventilation can be combined successfully with radiators and convectors at exterior walls to offset space heat losses. Radiant heating panels and heated floors also can be used with displacement ventilation. When a secondary heating system is used, displacement outlets can supply air with a supply-to-room cooling differential as low as 4°F and still maintain a displacement airflow to the space.

System and Terminal Considerations. Low-velocity supply air outlets used in fully stratified systems can function properly with either constant- or variable-air-volume (VAV) supply air systems. For VAV applications, the supply air volume should be determined by a thermostat located in the space at a height of 4 to 5 ft. Because stratification results in cooler temperatures below the thermostat, its set point can be maintained 2.5 to 3°F warmer than is typical in fully mixed systems.

For fully stratified systems in humid climates, using series fan-powered terminal units or other mixing zone devices may allow supply air to be delivered from the central HVAC system at conventional temperatures and then blended with return/plenum air in the terminal to bring the air to an appropriate discharge temperature. However, this may compromise the space contaminant removal benefits of the displacement system.

Outlet Selection Procedure

Supply outlets used in stratified air systems tend to be mounted in low sidewall or floor locations. To produce adequately low discharge velocities, the outlets also tend to be quite large. Because discharge velocities are very low, the supply airstream produces little momentum, and small obstacles (other than heat sources) in its path have little effect on its travel. Selection and application of air outlets for these systems is based primarily on the following considerations:

- Maintaining **vertical temperature gradients** within the occupied space that conform to ASHRAE *Standard* 55. Further guidance on designing for conformance to this standard is presented in [Chapter 57 of the 2015 ASHRAE Handbook—HVAC Applications](#).
- Maintaining a **clear zone** (also called **adjacent zone**) to the outlets that is acceptable to the use and occupancy of the space.
- Providing **acoustical performance** that conforms to the requirements of the space.

Supply outlets used in fully stratified systems are typically selected for a maximum face velocity of 50 to 70 fpm. Limitation of the face velocity is determined by noise requirements and proximity of occupants to the outlet. Where space noise requirements are not so stringent and stationary occupants are far away from diffusers, higher face velocities can be used. It is also important that the supply air outlet be designed to distribute airflow evenly across its entire discharge area to avoid excessive velocity deviations.

The area adjacent to the supply outlet where local velocities may exceed 50 fpm is defined as the clear zone, where local velocity/temperatures may combine to create drafty conditions. Manufacturers of outlets specifically intended for fully stratified systems publish predicted clear-zone values that depend on the outlet supply airflow rate and the initial temperature difference between the supply and room air. Stationary occupants should not be located in the clear zone.

For applications requiring very low noise criteria, such as broadcast or recording studios or performing arts venues, acoustical performance can be an important consideration. Because of their low-velocity discharge, these supply outlets can generally be selected to meet acoustical criteria for these applications.

1.3 PARTIALLY MIXED SYSTEMS

Partially mixed room air distribution systems are those whose design intent is to create mixed conditions in a portion of the room while maintaining thermal stratification in the remainder of the space. Supply outlets for these systems are usually designed and selected to discharge cool supply air from low sidewall or floor locations. These outlets produce high room air entrainment such that velocity and temperature differentials between supply and room air can be quickly dissipated. This results in relatively well-mixed room air conditions in some or all of the occupied space, while stratified conditions are maintained throughout the remainder. Although most underfloor air distribution systems should be classified as partially mixed systems, underfloor air delivery can also produce fully mixed or fully stratified room air distribution.

Because supply air is introduced into the occupied zone, the supply air temperature is generally above 62°F for cooling.

Factors That Influence Selection

Space Considerations. Partially mixed air distribution systems often rely on a pressurized plenum to deliver conditioned air to the supply air outlets; therefore, most of these outlets are not individually ducted. For example, underfloor air distribution systems commonly use the cavity beneath a raised access floor as a pressurized plenum. The supply outlets are mounted in the access floor tiles and can easily be relocated in response to space changes and workstation relocation.

Most supply outlets used in pressurized floor plenum applications can be easily adjusted for airflow by the space occupant. In such applications, it is usually effective to provide an adjustable outlet in every office or workstation to afford occupants control of their own environment. Many of these outlets can also be fitted with a thermostatically controlled damper that provides variable air volume to the space.

System and Terminal Considerations. Supply air outlets designed specifically for partially mixed room air distribution systems can function properly with either constant- or variable-air-volume (VAV) systems. For VAV applications, the supply air volume should be determined by a thermostat located in the space at a height of 4 to 5 ft. Because stratification typically results in cooler temperatures below the thermostat, its set point can usually be maintained slightly warmer than is typical in fully mixed systems.

Outlet Selection Procedures

Supply outlets used in partially mixed air systems tend to be mounted in the low sidewall or floor. They may also be mounted in the floor or risers beneath seats in public assembly facilities. Because of their high degree of mixing supply and room air, these outlets can be selected for much higher discharge velocities than those used in fully stratified systems, resulting in significantly smaller outlet discharge areas. Selection and application of air outlets for partially mixed systems is based primarily on the following considerations:

- Maintaining **vertical temperature gradients** in the occupied space that conform to ASHRAE *Standard* 55. Further guidance on designing for conformance to this standard is presented in [Chapter 57 of the 2015 ASHRAE Handbook—HVAC Applications](#).
- Maintaining a **clear zone** adjacent to the outlets that is acceptable to the use and occupancy of the space.
- Providing **acoustical performance** that conforms to the requirements of the space.

Supply outlets should be selected such that their vertical projection achieves comfort and ventilation objectives. Limiting the vertical projection (to a terminal velocity of 50 fpm) of the supply air to below the respiration level, typically 4.5 ft per ASHRAE *Standard* 62.1, allows convective heat plume formation around occupants to convey respiratory contaminants out of the occupied zone. This creates breathing-level CO₂ concentrations similar to those associated with fully stratified room air distribution systems. Projections that exceed this level discourage formation of such plumes and result in space ventilation similar to that of fully mixed systems.

The area adjacent to the supply outlet where local velocities may exceed 50 fpm is defined as the clear zone. This is the area where local velocity/temperatures may combine to create drafty conditions. Manufacturers of outlets specifically intended for partially mixed systems publish predicted clear-zone values that depend on the outlet supply airflow rate and initial temperature difference between supply and room air. Stationary occupants should not generally be located in the clear zone.

For applications requiring very low noise criteria, such as broadcast or recording studios or performing arts venues, acoustical performance can be an important consideration. These supply outlets may be suitable to meet acoustical criteria for these applications.

2. EQUIPMENT

2.1 SUPPLY AIR OUTLETS

[Table 1](#) shows the types of supply air outlets and provides guidance for best use practices. This table is for guidance only; designers should consult manufacturers' literature for additional application information.

Grilles

An air grille usually consists of a frame enclosing a set of either vertical or horizontal vanes (for a single-deflection grille) or both (for a double-deflection grille). These are typically used in sidewall, ceiling, sill, and floor applications.

Types.

Adjustable-Blade Grilles. This is the most common type of grille used as a supply outlet. A single-deflection grille includes a set of either vertical or horizontal vanes or blades. Vertical vanes deflect the airstream in the horizontal plane; horizontal vanes deflect the airstream in the vertical plane. A double-deflection grille has a second set of vanes typically installed behind and at right angles to the face vanes, and controls the airstream in both the horizontal and vertical planes.

Fixed-Blade Grilles. These grilles are similar to the adjustable-blade grille except that the vanes or blades are not adjustable and may be straight or angled. The angle(s) at which air is discharged depends on the deflection of the vanes.

Linear Bar Grilles. These outlets have fixed bars at the face. The bars normally run parallel to the length of the outlet and may be straight or angled. These devices supply air in a constant direction and are usually attached to a separate supply air plenum that has its own inlet. Linear bar grilles can be installed in multiple sections to achieve long, continuous lengths or installed as a discrete length. Typically designed for supply applications, they are also commonly used as return inlets to provide a consistent architectural appearance. Also commonly used in underfloor air distribution systems, some linear bar grilles allow the discharge pattern to be changed using removable cores. Many also incorporate a damper/actuator for automatic control of the supply air volume by a space thermostat.

Special Features.

Security Grilles. Various grille types are available for high-security applications. Security grilles are available with additional features like heavy-duty construction, suicide deterrents, lattice faces, and tamperproof (nonremovable blades) designs.

Heavy-Duty Grilles. Robust, heavy-duty designs are available for applications that require greater durability (e.g., industrial, gymnasium, institutional).

Accessories. Various accessories, designed to modify the performance of grille outlets, are available:

- **Dampers** can be attached to the backs of grilles or installed as separate units in the duct to regulate airflow. (The combination of a supply air grille and a damper is called a **register**.) **Opposed-blade** damper vanes rotate in opposite directions ([Figure 3A](#)). **Parallel-blade** damper vanes rotate in the same direction ([Figure 3B](#)). Dampers deflect the airstream, and when located near the grille, they may cause nonuniform airflow and increase pressure drop and sound.
- **Extractors** are installed in collar connections to the outlet and are used to improve the flow distribution into the grille or register. The device shown in [Figure 3C](#) has vanes that pivot such that the supply airflow to the grille or register remains perpendicular to the face of the outlet. The device shown in [Figure 3D](#) has fixed vanes. Both devices restrict the area of the duct in which they are installed and should be used only when the duct is large enough to allow the device to open to its maximum position without unduly restricting airflow to the downstream duct. These devices may increase the system pressure requirement, thereby limiting downstream airflow and increasing the sound level.
- The device shown in [Figure 3E](#) has individually **adjustable vanes**. Typically, two sets of vanes are used. One set equalizes flow across the collar, and the other set turns the air. The vanes should not be adjusted to act as a damper, because balancing requires removing the grille to gain access and then reinstalling it to measure airflow.
- Other miscellaneous accessories, such as **remote control devices** to operate the dampers, and **travel limit stops**, are also available.

Applications. Typically, supply air grilles are used in high-side-wall, ceiling, sill, or floor applications.

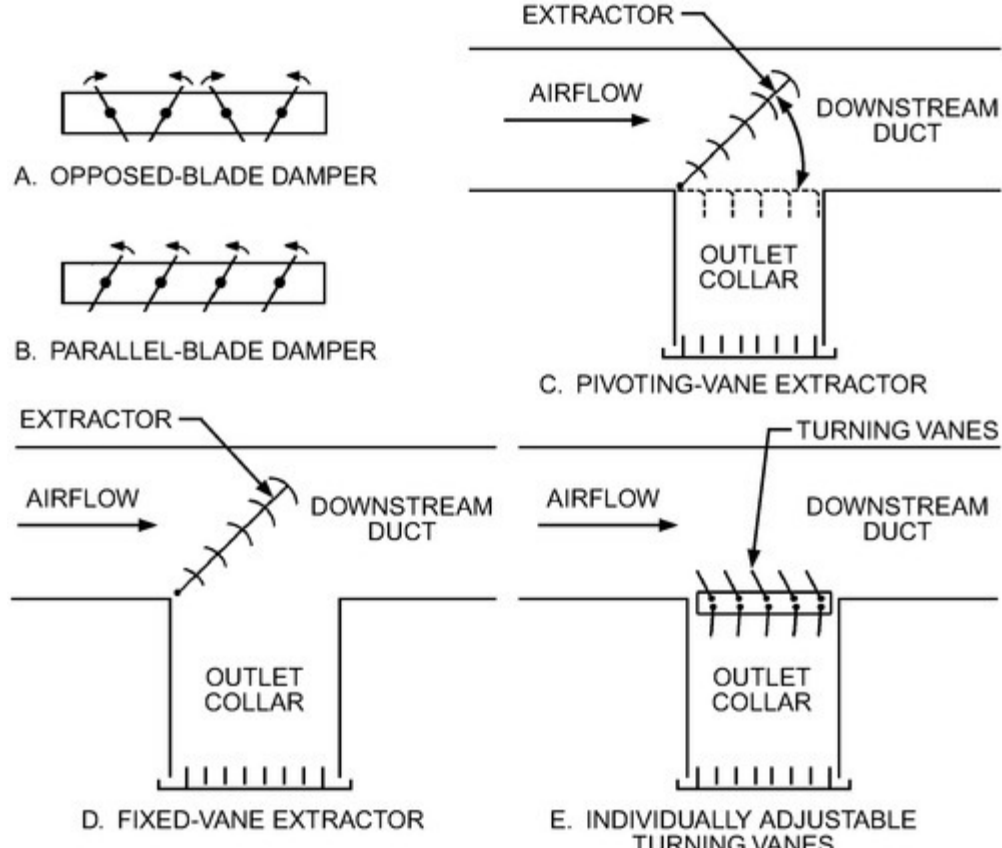


Figure 3. Accessory Controls for Supply Air Grilles

High Sidewall. An adjustable double-deflection grille usually provides the most satisfactory solution. The vertical blades of the grille can be set for approximately 50° maximum deflection to either side, which can usually cover the conditioned space. Horizontal blades can be set to control the elevation of the discharge pattern. Upward deflection minimizes thermal drop in cooling applications.

Ceiling. Such installation is generally limited to grilles with curved vanes that discharge parallel to the mounting surface. For high mounting locations (greater than 10 ft above the occupied zone), vertical discharge may be the preferred application. Grilles installed in 8 to 10 ft high ceilings, discharging the airstream into occupied zone, usually result in unacceptable comfort conditions. Satisfactory performance can be obtained if special allowances are made for terminal velocities and temperature differentials in the occupied space. Grille or register selectors for heating and cooling applications from the same device should be carefully examined for use in both applications.

Sill. Linear bar grilles are commonly used in sill applications. The grille should be installed with the supply air jet directed vertically away from the occupied space. When the device is mounted 12 in. or less from the wall, a device with 0° deflection is suitable. If the device is installed more than 12 in. from the vertical surface, a linear bar grille with a fixed 15 to 30° deflection is recommended. This device should be installed with the jet directed toward the wall. These grilles can be available with doors, removable cores, or other means of access to mechanical equipment that may be installed in the sill enclosure. The presence of window draperies or blinds and the effect of an impinging airstream must be considered in the selection.

Floor. Linear bar grilles are often used for floor applications. The designer should determine the traffic and floor loading on the grille (consult local building code for minimum rating requirements) and consult the manufacturer's load limit for the grille. The grille should be placed in low-traffic areas. A floor-mounted grille is usually selected to discharge supply air along a wall or exterior surface. Install with the supply air jet directed vertically away from the occupied space. When the device is mounted 12 in. or less from the wall, a device with 0° deflection is suitable. If the device is installed more than 12 in. from the vertical surface, a linear bar grille with a fixed 15 to 30° deflection is recommended. This device should be installed with the jet directed toward the wall. The presence of window draperies or blinds and the effect of an impinging airstream must be considered in the selection.

Nozzles

Ball, drum, and adjustable nozzles allow air jets to be directed. These devices typically have no or few vanes in their airflow paths. Low pressure losses, moderate sound generation, and long throws are commonly produced by nozzles. They are often installed in buildings as horizontally discharging high-side wall outlets, in fur-downs (interior duct soffits), or in ductwork. Nozzles are typically used in large spaces. Aircraft and automobile ventilation systems also use these types of outlets (Rock and Zhu 2002).

The equations in [Chapter 20 of the 2013 ASHRAE Handbook—Fundamentals](#) can be used to estimate throw from many such simple duct terminations or orifices. For complex situations, physical experiments or computational fluid dynamics (CFD) modeling may be helpful in selection and design.

Diffusers usually generate a radial or directional discharge pattern. For ceiling applications, this pattern is typically parallel to the mounting surface (horizontal pattern). Diffusers may also include adjustable deflectors that allow discharge to be directed perpendicular to the mounting surface (vertical pattern). A diffuser typically consists of an outer shell, which contains a duct collar, and internal deflector(s), which define the diffuser's performance, including discharge pattern and direction.

Types.

- Round Diffusers.** This diffuser is a series of concentric conical rings flush with the ceiling plane or with dropped inner cones, typically installed either in gypsum-board ceilings or on exposed ducts. Round ceiling diffusers are available in a broad range of sizes and capacities, with adjustable inner cones that allow the diffuser to discharge air either horizontally or vertically.
- Square Diffusers.** This diffuser consists of concentric square, drawn louvers that radiate from the center of the diffuser. Available with faces that are flush with the ceiling plane or with dropped inner cones, these diffusers have a fixed horizontal radial discharge pattern or an adjustable discharge pattern that allows the direction to be either horizontal or vertical. Special borders can be selected to accommodate various mounting applications.
- Perforated Diffusers.** This diffuser consists of a duct collar and a single perforated plate that forms the diffuser's face, with typical free area of about 50%. The perforated face tends to create a slightly higher pressure drop and sound than other square ceiling diffusers. They are available with deflection devices mounted at the neck or on the face plate. The deflectors may be adjustable, to provide horizontal air discharge in one, two, three, or four directions. Special borders can be selected to accommodate various mounting applications.
- Louvered-Face Diffusers.** This diffuser consists of an outer border, which includes an integral duct collar, and a series of louvers or curved blades. Louvered-face diffusers typically provide a horizontal discharge perpendicular to the louver length. The louvers may be arranged to provide four-way, three-way, two-way opposite, two-way corner, or one-way discharge. Special borders can be selected to accommodate various mounting applications. Some louvered-face diffusers are available with adjustable louvers that can change the discharge direction. Special borders are available to accommodate various mounting applications.
- Plaque-Face Diffusers.** This diffuser is constructed with a duct collar and a single plaque that forms the diffuser's face. This air outlet typically has a horizontal, radial discharge pattern. Special borders can be selected to accommodate various mounting applications.
- Hemispherical Flow Diffusers.** This diffuser provides a vertically radial air discharge pattern. The discharge penetrates the conditioned space perpendicular to the mounting surface. These diffusers are typically used for applications needing high air change rates, and/or low local velocities. Some outlet models are flush to the mounting surface; others protrude into the space below the ceiling. Most function similarly with or without an adjacent ceiling surface.
- Laminar-Flow Diffusers.** This diffuser provides a unidirectional discharge perpendicular to the mounting surface. The free area of the perforated face is typically less than 35%. Most outlets are designed to develop a uniform velocity profile over the full face of the diffuser. This minimizes mixing with surrounding ambient air and reduces entrainment of any surrounding contaminants. These diffusers are typically used in hospital operating rooms, cleanrooms, or laboratories.
- Linear Slot Diffusers.** Linear slot diffusers may be installed in multiple sections to achieve long, continuous lengths or installed as a discrete length. They can consist of a single slot or multiple slots, and are available in configurations that provide vertical to horizontal airflow. Typically, a supply air plenum is provided separately and attached during installation. Other applications include field mounting the linear slot diffuser directly into a supply duct.
- T-Bar Slot Diffusers.** This diffuser is manufactured with an integral plenum and normally is installed in modular T-bar ceilings. Available with fixed-deflection or adjustable-pattern controllers, these devices can discharge air from vertical to horizontal.
- Light Troffer Diffusers.** A light troffer diffuser serves as the combined plenum, inlet, and attachment device to an air-handling light fixture, which has a slot to receive the diffuser at or near the face of the lighting device, to discharge supply air into the space. Only the air-handling slot is visible from the occupied space.
- Swirl Diffusers.** These diffusers feature a series of openings arranged in a radial pattern around the center of the diffuser face. This promotes a high degree of entrainment of room air, resulting in very high induction ratios, which maximize mixing in the area adjacent to the diffuser face. Swirl diffusers may be mounted in ceiling, sidewall, or floor locations. When mounted in floor locations, care should be taken to ensure that the diffuser can meet the floor loading requirements.
- Displacement Diffusers.** Typically located in floor or sidewall locations, these diffusers are designed to limit discharge velocities to 50 to 70 fpm, to minimize mixing between supply and room air. These outlets tend to be large, to generate the low velocities required for thermal displacement ventilation. The low-velocity discharge allows the cooler supply air to fall to the floor and remain there because its buoyancy is lower than that of the ambient room air above it. These outlets are available in various shapes and sizes to facilitate flush or adjacent mounting to the sidewall or floor of the space.
- Textile Air Dispersion System.** This outlet system is designed to both convey and disperse air within the space being conditioned. Diffusion options include outlets selected for a full range of entrainment. The supply air is delivered through (1) the weave of the fabric, (2) microperforations, (3) a long and narrow pattern of small jets, (4) orifices, and/or (5) nozzles. Typically, these systems are made of fabric, sheet metal, or plastic film.

Special Features.

- Variable-Geometry.** These diffuser assemblies can vary their discharge area in response to changes in space or supply air temperature while minimizing changes in face velocity.
- Variable-Air-Volume (VAV).** These diffuser assemblies can modulate airflow in response to room conditioning demands.

Accessories. Various performance-modifying devices are available for use with diffusers:

- **Dampers** can be attached to the inlets of diffusers or installed as separate units in the duct, to regulate the volume of air being discharged. **Opposed-blade** damper vanes rotate in opposite directions ([Figure 3A](#)) and are available for round, square, or rectangular necks. **Parallel-blade** dampers rotate in the same direction ([Figure 3B](#)). **Adjustable-vane** dampers have individually adjustable vanes. **Butterfly** dampers are constructed with opposing damper plates that move in opposite directions and are adjusted from a center point ([Figure 4B](#)). A **splitter** damper is a single-blade device, hinged at one edge and usually located at the branch connection of a duct or outlet ([Figure 4C](#)). The device is designed to allow adjustment at the branch connection of a duct or outlet to adjust flow. **Radial** dampers are made up of multiple overlapping flat blades that rotate in the horizontal plane to restrict the airstream. When installed on the diffuser inlet, these dampers are operated through the face of the diffuser. When these dampers are located near the diffuser, they may cause nonuniform airflow and increase pressure drop and sound. Refer to Chapter 48 of the 2011 *ASHRAE Handbook—HVAC Applications* for the effects of damper location on sound level.
- **Equalizing or flow-straightening devices or grids** allow adjustment of the airstream to obtain more uniform flow to the diffuser.
- **Quadrant blank-off flat plates** restrict airflow in one or more quadrant(s) of the diffuser inlet.
- **Other balancing devices** are available. Consult manufacturers' literature as a source of information for other air-balancing devices.

Applications. For the following applications, the manufacturer's catalog data should be checked to select the air outlet that meets throw, pressure, and sound requirements. See [Chapter 57 of the 2015 ASHRAE Handbook—HVAC Applications](#) for more details.

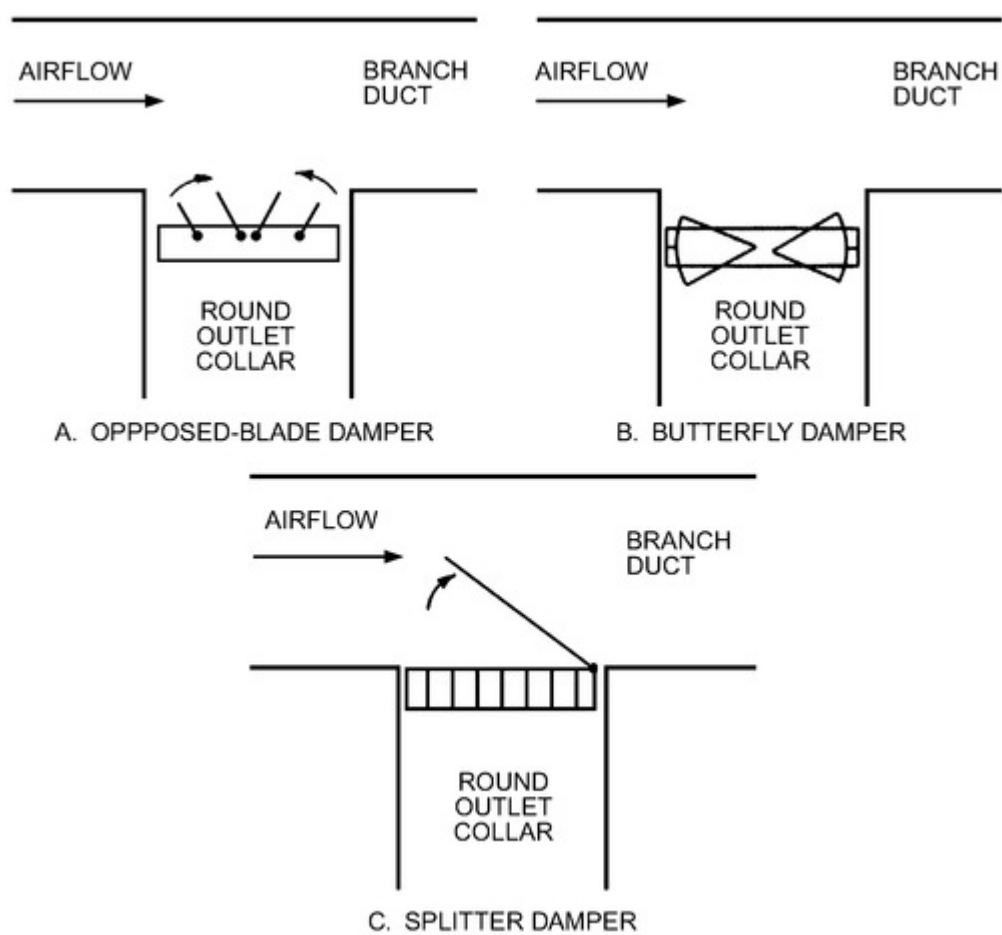


Figure 4. Accessories for Ceiling Diffusers

2.2 RETURN AND EXHAUST AIR INLETS

Return air inlets may either be connected to a duct or simply cover openings that transfer air from one area to another. Exhaust air inlets remove air directly from a building and, therefore, are most always connected to a duct. Velocity, sound, and pressure requirements for inlets are determined by size and configuration. In general, the same type of equipment, grilles, slot diffusers, and ceiling diffusers used for supplying air may also be used for air return and exhaust. However, inlets do not require the deflection, flow equalizing, and turning devices necessary for supply outlets. See the section on Supply Air Outlets for a description of these devices. Return and exhaust inlets may be mounted in practically any location (e.g., ceilings, high or low sidewalls, floors, and doors). Dampers such as the one shown in [Figure 3A](#) are sometimes used in conjunction with grille return and exhaust inlets to aid system balancing.

V-Bar Transfer Grilles

Made with bars in the shape of inverted Vs stacked within the grille frame, these grilles have the advantage of being sightproof. The airflow capacity of the grille decreases with increased sight-tightness.

Lightproof Transfer Grilles

These grilles are used to transfer air to or from darkrooms. The bars of this type of grille form a labyrinth and are painted black. The bars may be several sets of v-bars or be an interlocking louver design to provide the required labyrinth.

Eggcrate Grilles

These return grilles typically have large free areas, which typically exceed 90%.

2.3 TERMINAL UNITS

In air distribution systems, special control and acoustical equipment is frequently required to introduce conditioned air into a space properly. Airflow controls for these systems consist principally of terminal units (historically called "VAV boxes"), with which the airflow can be varied by modulating valves, fan controls, or both. Terminal units such as those listed here are supplied with or without cooling, fans, heat, or reheat, and having either constant or variable primary airflow rate. Terminal units may use plenum or room air induction to affect space temperature control while maintaining a constant or variable discharge airflow rate and/or temperature. Terminal units may include sound reduction devices, heaters, reheaters, fans, diffusers, or cooling coils.

This section discusses control equipment for forced air conditioning systems. [Chapter 48 of the 2015 ASHRAE Handbook—HVAC Applications](#) includes information on sound control in air-conditioning systems and sound rating for air outlets. Terminal units are factory-made assemblies for air distribution. A terminal unit manually or automatically performs one or more of the following functions: (1) controls air velocity, airflow rate, pressure, or temperature; (2) mixes primary air from the duct system with air from the treated space or from a secondary duct system; and (3) heats or cools the air. To achieve these functions, terminal unit assemblies are made from an appropriate selection of the following components: casing, mixing section, manual or automatic air control device, heat exchanger, induction section (with or without fan), sound reduction devices, and flow controller.

Terminal units are typically classified as constant- or variable-volume devices. They are further categorized as either pressure-dependent, where airflow through the assembly varies in response to changes in system pressure, or pressure-independent (pressure-compensating), where airflow through the device does not vary in response to changes in system pressure.

Terminal units with VAV reset controllers regulate airflow to a constant, fixed amount or to a variable, modulating amount calculated by room demand. These controllers can be electric (pressure dependent), analog or digital electronic (pressure independent), or pneumatic (pressure dependent or pressure independent). Pressure-independent controllers require an indication of actual airflow to reset the VAV airflow control device. Temperature inputs are also required for calculating room demand for comfort conditioning.

Terminal unit controls are categorized as (1) system-powered, in which the airflow control device derives the energy necessary for operation from supply air within the distribution system; or (2) externally powered, in which the airflow control device derives its energy from a pneumatic or electric outside source. Terminal units may be furnished with all necessary controls for their operation, including actuators, regulators, motors, and thermostats or space temperature sensors, or the controls may be furnished by someone other than the manufacturer.

The unit's flow control device can be adjusted manually or automatically. If the unit is adjusted automatically, it is actuated by a control signal from a controller, thermostat, flow regulator, or building management system (BMS), depending on the desired function of the terminal unit.

Single-Duct Terminal Units

Single-duct terminal units can be cooling only, cooling/heating if the primary air unit provides both or reheat if a heater is present. Reheat terminal units add sensible heat to the supply air. Water or steam coils or electric resistance heaters are placed in or attached directly to the air discharge of the unit. This type of equipment can provide local individual reheat.

The basic single-duct unit consists of an insulated casing, airflow regulator, and possibly also an actuator, airflow-measuring device, and selected controls. Accessory discharge attenuators, silencers, and multiple outlet attenuators are also common.

Typical applications include

- Where the supply air system is not tasked with the space heating requirements
- With VVT or other auto-changeover controls
- Constant air volume
- Constant pressure control

A **single-duct unit with reheat** has an added heating coil (hot water or electric). They are typically applied in zones where heat losses create a need for heating. The terminal unit usually reheats at the minimum airflow setting. An auxiliary higher heating setting may be available as an option with additional controls.

Interior zones, where ventilation requirements may be larger than the desired heating airflow, may require additional reheat.

A **single-duct exhaust** consists of an insulated casing, airflow regulator, and possibly also an actuator, airflow-measuring device, and selected controls. Accessory inlet attenuators or silencers are sometimes used. Specialty materials may be needed for corrosion resistance. The designer should consider pressure drop and system effects.

Dual-Duct Terminal Units

Dual-duct terminal units are typically controlled by a room thermostat. They receive warm, cold, return, or ventilation air from separate air supply ducts to provide desired room control. Volume-regulated units have individual airflow control devices to regulate the amount of warm and cold air. Dual-duct units use reheat when they simultaneously provide heating and cooling air to the space. When a single temperature control device regulates the relative amounts of both warm and cold air to control temperature, a separate airflow control device may function to control and limit airflow. Specially designed baffles may be required inside the unit or at its discharge to mix varying amounts of warm and cold air and/or to provide uniform temperature distribution downstream. Dual-duct units can be equipped with constant- or variable-flow control. These are typically pressure independent, to provide precise volume and temperature control. Dual-duct terminals may also be used with dedicated outdoor air supplied to the terminals such that the outdoor air inlet is used to control and maintain the required volumetric flow of ventilation air into the space. Dual-duct units with cooling and outdoor air may need a local heating device.

A **nonmixing dual-duct unit** is effectively two single-duct terminal units side by side. The basic unit incorporates separate cold and hot (sometimes neutral) air inlets. They are usually applied in exterior zones in buildings where overhead heating and cooling are desired but not auxiliary heat, and zero minimum flow is acceptable during changeover between heating and cooling. Proper discharge configurations are required to reduce the likelihood of improper mixing.

A **mixing dual-duct unit** is the same, with an integral mixing/attenuation section on the downstream end of the terminal unit to minimize temperature stratification in the discharge airstream. They are often used in interior and exterior zones in buildings (e.g., hospitals) where overhead heating and cooling are desired but an auxiliary heating coil is not, and zero minimum flow is unacceptable during changeover between heating and cooling. Evaluate mixing performance to fit the application, and consider the additional pressure drop of mixing/attenuators sections.

Air-to-Air Induction Terminal Units

Induction terminals supply primary air or a mixture of primary and recirculated air to the conditioned space. They achieve this function with a primary air jet that induces air from the ceiling plenum or individual rooms (via a return duct). Cool primary air is ducted to the terminal unit and used as the inducing energy source. The induction unit contains devices that are actuated in response to a thermostat to modulate the mixture of cool primary air and induced air. Reheat coils may be required to meet interior load requirements.

Fan-Powered Terminal Units

Fan-powered terminal units are used in HVAC systems as secondary-level air handlers, and are typically installed in return air plenums. They differ from air-to-air induction units in that they include a blower, driven by a small motor, which draws air from the conditioned space, ceiling plenum, or floor plenum, that may be mixed with the cool air from the main air handler. The characteristics of fan-powered units are (1) in heating mode, the primary air is mixed with warmer plenum air to increase the air temperature entering the heater, thus reducing or eliminating reheat; (2) downstream air pressure can be boosted to deliver air to areas that otherwise would be short of airflow; (3) perimeter zones can be heated without operating the main air handler when building cooling is not required; (4) main air handler operating pressure can be reduced with series units compared to other terminal units, reducing the air distribution system's energy consumption; and (5) in thermal storage and other systems with relatively low supply air temperatures, series fan-powered terminal units may be used to mix supply air with induced return or plenum air, to moderate the discharge air temperature. Some units are equipped with special insulation and a vapor barrier to prevent condensation with these low supply temperatures.

Fan-powered terminal units can be divided into two categories: (1) series, with all primary and induced air passing through a blower operating continuously during the occupied mode; and (2) parallel, in which the blower operates only on demand when induced air or heat is required.

A **series** unit typically has two inlets, one for cool primary air from the central fan system and one for secondary or plenum air. All air delivered to the space passes through the blower. The blower operates continuously whenever the primary fan is on and can be cycled to deliver heat as required when the primary fan is off. As cooling load decreases, an airflow control device throttles the amount of primary air delivered to the blower. The blower makes up for this reduced amount of primary air by drawing air in from the conditioned space or ceiling plenum through the return or secondary air opening. Sometimes a series unit has two ducted inlets, like a dual-duct terminal unit, in addition to the induction air inlet. The second duct is typically used for dedicated outdoor air systems. Fan airflow and primary air can be varied when the units are in part-load condition, but fan airflow should never be less than the total amount of air supplied by the ducted inlets.

Fan-Powered Series Flow. The basic unit consists of a single-duct unit, blower/motor, and selected controls where the motor and primary damper are arranged such that mixing occurs upstream of the blower. They also have been called **constant-volume** or **constant-fan** units. Supplemental heating coils (hot water or electric) are generally required. Electric heaters are typically located on the discharge of the unit; water coils may be on the discharge or the induction port. Heating coils on the induction port increase ambient temperature at the motor and decrease motor life. Supplemental cooling coils are sometimes located on the induction port for some applications like when utilized in conjunction with dedicated outdoor air systems.

Fan-powered series-flow units generally are used in the following situations:

- Exterior zones where heating and cooling loads may vary considerably
- Buildings where heating is desired when the central system is shut down during unoccupied hours
- To allow lower central system static pressure
- Where occupant comfort can be optimized, because the high- (sometimes constant-) volume variable-temperature air delivery produces consistent air distribution, acoustics, and ventilation

Low-Profile Fan-Powered Series. Similar in construction to the standard series flow terminal, these units are typically less than 12 in. high for all sizes, to minimize the depth of ceiling space required. Unlike standard fan-powered terminals, the fan/motor assembly is installed flat on its side with the wheel rotating in a horizontal plane.

Typical applications are the same as for regular series, but low-profile versions are commonly used where zoning requirements limit building height and the architect wishes to maximize the number of floors, because these units fit in a shallow ceiling plenum. Designers should pay special attention to available space and unit heights.

Ventilation Air Inlet Fan-Powered Series Flow. These units are similar in construction to the standard series-flow terminal, but have an additional air inlet that provides a direct connection to the terminal unit for ventilation air. They are commonly used in buildings where ventilation air is piped in a dedicated ventilation duct system to each terminal unit; this is generally done where it is desirable to monitor ventilation air quantities to each zone.

Low-Temperature Fan-Powered Series Flow. These units are the same as fan-powered series flow, but have special construction to minimize the potential for condensation. They can be used with cold-water/ice storage systems that provide low-temperature central system air distribution to the zone terminals when there is potential for condensation, or where standard terminals may be exposed to high humidity.

Underfloor Fan-Powered Series Flow. This unit is a fan-powered series flow terminal designed to fit between the pedestal support grids of a raised- or access-floor HVAC system without modifying the floor. They are available in several unit sizes, but with limited height and width.

Primary and induction ports, if any, to the unit may or may not be ducted. Typically, air under the raised floor is cool air supplied directly to the unit. In these cases, a control system is required to select the proper damper sequence to control room air distribution to maintain the proper ambient conditions in the occupied space.

Parallel fan-powered terminal units supply the cool primary air directly to the mixing plenum, bypassing the fan, so that the primary air flows directly to the space. The blower section draws in plenum air and is mounted in parallel with the primary airflow control device. A backdraft damper is included to limit the amount of primary air flowing through the blower section when the blower is not energized. The blower in these units is generally energized after the primary airflow has reached the minimum flow rate. Typically, the parallel unit provides constant-volume heating and variable-volume cooling. Parallel units are typically limited to one ducted supply inlet.

One weakness in parallel fan-powered terminals is uncontrolled leakage of primary air through the fan's backdraft damper and the mixing chamber housing. ASHRAE research project RP-1292 (David et al. 2007) demonstrated that much of the energy saving associated with intermittent fan cycling is offset, and in fact may be significantly less than the energy loss caused by uncontrolled leakage.

Fan-Powered Parallel Flow. Sometimes called **variable-volume** or **intermittent-fan units**, these consist of a single-duct unit, blower/motor, backdraft damper, and selected controls; the motor and primary damper are arranged such that mixing occurs downstream of the blower. Supplemental heating coils (either hot water or electric) are generally required. Electric heaters are typically located on the discharge of the unit. Water coils may be on the discharge or the induction port, although the discharge location adds to the supply air system's static pressure requirements and increases leakage through the backdraft damper, as shown in ASHRAE research project RP-1292 (Davis et al. 2007). Heating coils on the induction port increase ambient temperature at the motor and decrease motor life.

Fan-powered parallel-flow units are used in exterior zones where heating and cooling loads may vary considerably, and in buildings where heating is needed when the central system is shut down during unoccupied hours.

Bypass Terminal Units. A bypass terminal unit handles a constant supply of primary air through its inlet. The unit bypasses primary air to the ceiling plenum or to ducts leading to the air handler's return to meet the needs of the conditioned space. Primary air, diverted into the ceiling plenum, will return to the central air handler. This method provides a low first cost with minimum controls, but it is energy inefficient compared to other systems.

The basic bypass terminal consists of a diverter-type damper, actuator, bypass port, and selected pressure-dependent controls. A balancing damper is recommended ahead of the inlet. Reheat coils are discouraged, and electric reheat should be prohibited because of the potential fire hazard.

Bypass terminals are used primarily with packaged rooftop air conditioning equipment with a direct-expansion (DX) coil where zoning is desired, but relatively constant airflows across the system components (e.g., coils, fans) are required to minimize the potential for freeze-up. The system offers an economical VAV supply design with low first cost. It does not provide the energy-saving advantages of variable fan volume, but avoids the expense of a more sophisticated system.

Chilled Beams

Active ([Figure 5A](#)) and passive ([Figure 5B](#)) beams are room air recirculation devices that transfer sensible heat to/from the space using water. In addition, active beams deliver conditioned air from the central air-handling unit. The primary air must satisfy the ventilation and latent requirements of the space. Chilled-water inlet temperatures should be maintained at or above the air dew point to prevent condensation on the heat transfer coil(s).

Active beams are ceiling-mounted induction terminals that consist of a primary air duct connection, series of induction nozzles, hydronic heat transfer coil(s), supply outlet(s), and air inlet section. Primary air discharged through the induction nozzles entrains air from the room or from above the suspended ceiling, through the inlet section, and across chilled- and/or hot-water coil(s), where it is conditioned before being mixed with primary air. The mixture of primary and reconditioned induced air is then discharged to the space. This mixture's temperature and/or flow rate is modulated in accordance with the space demand and control strategy. Active beams generally produce a fully mixed room air distribution.

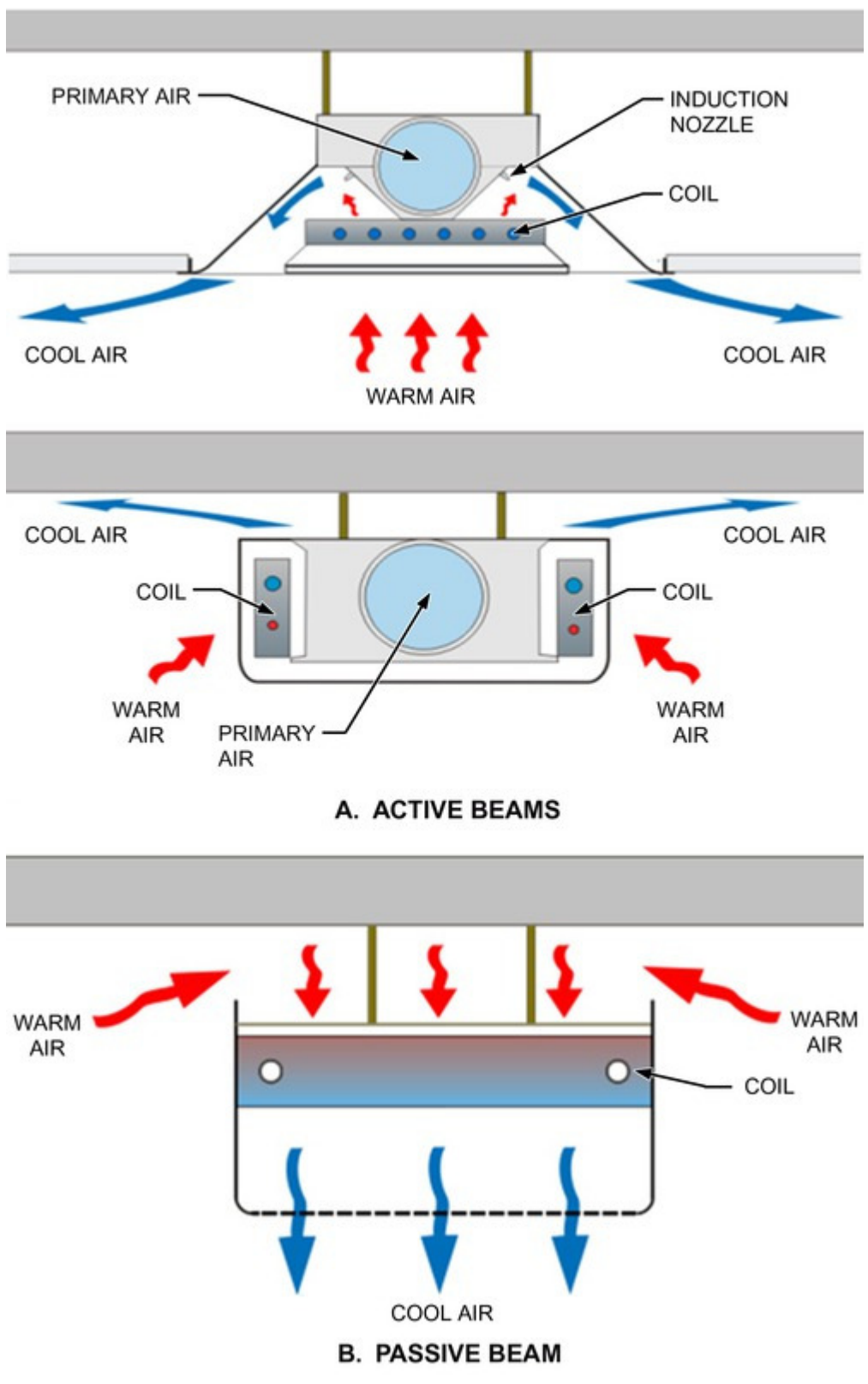


Figure 5. (A) Active and (B) Passive Beams

Passive beams consist of a coil (heat exchanger), a casing, and sometimes a face plate. They provide cooling mainly by convection. The coil provides heat exchange between the chilled water and room air. When cool water is circulated through the coil, air between the fins is cooled and falls naturally into the room, drawing air through the coil behind it. As long as cool water circulates through the coil, sensible cooling continues. Space ventilation, dehumidification, and heating needs must be provided by complementary systems.

Beam Types and Configurations. Overhead beams may be integrated with acoustic ceilings, or independently mounted. Although active beams are usually installed in the upper part of the space, they can also be located in side walls. Both active and passive chilled beams can be configured with additional space services (e.g., lighting, fire protection) as required.

There are two basic types of passive beams: exposed and recessed. **Exposed passive beams** are commonly used in spaces with low ceiling heights or when there is a wish to create a perception of an extra-high ceiling.

Recessed passive beams are generally integrated into a suspended ceiling system. When passive beams are installed above a ceiling, a minimum clearance between the top of the beam and any surface above it should be provided to ensure a sufficient return air path. Shadow gaps, dummy beam sections, and/or transfer grilles are recommended for creating the return air path.

Detailed information on active and passive beams can be found in REHVA/ASHRAE (2014).

Fan-Coil Unit Systems

This section discusses the use of hydronic and direct-expansion (DX) fan-coil units to control the volume and temperature of air delivered to the space as required to maintain occupant thermal comfort and/or ventilation. [Chapter 5](#) discusses how fan-coil units are integrated into the design of the building.

Designers have various fan-coil systems to choose from when designing a building. Choosing which one to use depends on the owner's needs (e.g., installation, application, operational cost, sustainability, thermal and acoustic performance, capacity, reliability, spatial requirements, code restrictions, water or refrigerant piping distribution, maintenance, and unit accessibility).

Fan-coil units are factory-made assemblies. The fan-coil performs some combination of the following functions: (1) temperature and humidity control, (2) ventilation of the conditioned space, (3) filtration, and (4) room air distribution. Fan-coil units are available in various configurations, including vertical or horizontal airflow paths and exposed or concealed mounts. A temperature control device regulates the fan-coil airflow and discharge air temperature.

As shown in [Figure 6](#), the basic components of fan-coil units are a heating or cooling coil, filter, fan, and temperature control device. The fan recirculates air from the conditioned space through the coil, which then transfers heat to or from the air. Heat transfer devices include finned-tube coils (chilled or hot water, DX, or steam) or electric resistance elements. A filter at the unit's inlet captures and minimizes particulates in the air downstream of the filter. The fan and motor assembly are generally arranged for quick removal for servicing. If the unit includes a dehumidifying cooling coil, it should be equipped with an insulated drain pan. Fan-coil casings are typically galvanized steel, and may be painted. The casing may be internally insulated for both thermal and acoustic considerations.

Additional components are offered on fan-coil units for specific applications. Sophisticated fan controls are available (e.g., modulating fan controls, thyristor control, electronically commutated motors [ECMs]). The coil's water valve piping package can include such components as flow controls (manual or automatic), pressure-independent water valves, strainers, unions, pressure-temperature ports, air vents, hose connections, drains, and balancing valves. The coil in a DX system includes an expansion device such as a fixed orifice device or thermal expansion valve. Electric heating controls include magnetic contact closure or solid state relays.

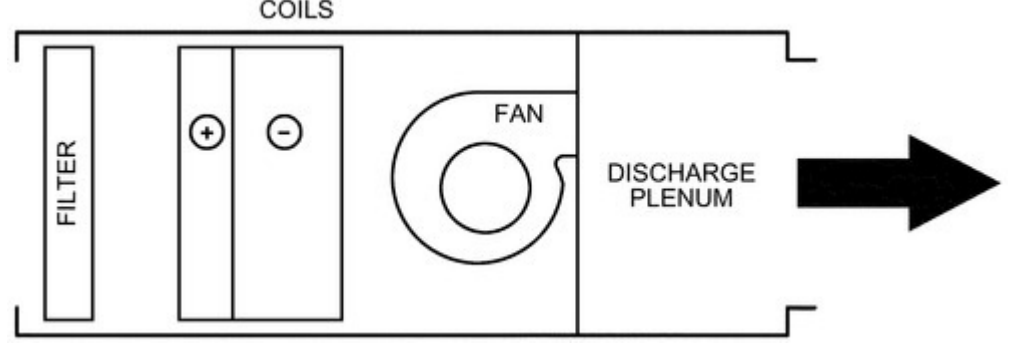


Figure 6. Basic Fan-Coil Unit

Fan-coil units are generally available in nominal sizes from 200 to 2400 cfm or 0.5 to 6 tons, with direct-drive or belt-driven permanent split capacitor (PSC) fan motors or ECMs for a wide range of applications. These units can be used in ducted or nonducted single or multiroom applications. They typically have multiple-row cooling, and may have single- or multiple-row heating coils. The hydronic heating and cooling coils may be separate or contained in a single fin pack (excluding steam). In a DX system, the coil uses multiple rows and circuits for refrigerant distribution in cooling and heating.

- Fan-coil unit systems
- Require less building interstitial space, because the water/refrigerant delivery system has a higher energy density per unit volume than an all-air system
 - Provide individual-zone temperature and humidity control
 - Enable retrofits to expand capacity beyond that of an existing air system
 - Allow individual dwellings in multifamily buildings to have individual electrical meters
 - Provide independent dwellings with independent temperature control (e.g., in residential, commercial, and industrial spaces)

DX fan-coil systems also eliminate the need for a central chiller plant. However, for DX fan-coil units in high-rise buildings, the space required for mounting condensing units and the lift required for oil in refrigerant lines must be considered.

Two- and Four-Pipe Hydronic Distribution Systems. When the heating and cooling media are supplied to a common coil, it is called a two-pipe system (one supply and one return pipe) or a heating/cooling changeover system. A four-pipe distribution system has dedicated supply and return piping for each coil or each circuit within a common coil. The four-pipe system generally has a higher initial cost; however, it provides (1) all-season availability of heating and cooling at each unit, (2) no summer/winter changeover requirement, (3) controllability to maintain a dead band between heating and cooling, and (4) heating coil arrangements for either preheat or reheat.

A two-pipe system can only heat or cool, depending on the supply water temperature. During intermediate seasons or when the building requires simultaneous heating and cooling, supplemental electric heat is usually provided. The coil is typically sized for cooling, so careful consideration of the heating water temperature is required. For these reasons, the designer should consider the limitations of the two-pipe system carefully; many installations of this type waste energy, and have been unsatisfactory in climates where temperatures vary widely from morning to afternoon.

Motors and Controls. When selecting a motor type, consider features such as control type, control scheme, and sequence of operation. The differences between a permanent split capacitor (PSC) versus an electronically commutated motor (ECM) affect the sequence of operation, which in turn dictates type of room thermostats, controls, and water valves. When an ECM is used in a fan-coil, both the fan motor and water control valve are typically modulated by a controller based on room demand. This can provide superior comfort levels and improved energy efficiency.

The most common control for fan-coils is a room thermostat. These thermostats come in both line voltage (i.e., same voltage as motor) and 24 V. They offer simple on/off or multispeed control of fan motors and open/close control of water control valves.

Analogue controllers provide a higher level of control, modulating components such as ECMs, water valves, and silicon-controlled rectifier (SCRs). The most advanced level of building control is provided by direct digital control (DDC), which adds communication ability through a building automation system (BAS).

Additional information on fan-coil unit motors and controls can be found in [Chapter 57 of the 2015 ASHRAE Handbook—HVAC Applications](#).

Unit Types and Configurations. Fan-coil units are available in many different configurations; however, not all configurations discussed here are available for all types of units. Orientation of airflow from return to supply, unit features, and dimensional characteristics constitute the major differences between configurations. Outdoor air can be mixed with return air at the fan-coil unit or delivered directly to the space. Changes in industry standards have increased the use of coupling ventilation air to fan-coil units. The outdoor air can be pretreated or unconditioned, and ducted or nonducted. Fan-coil units are available with a variety of options to handle outdoor air, such as mixing boxes, outdoor air duct collars, air measuring devices, or air control devices.

Vertical Units. Low-profile vertical fan-coil units (all units) are typically used beneath or adjacent to windows in concealed or exposed cabinets. The low silhouette sometimes limits filter area, serviceability, capacity, and cabinet geometry. Air is discharged vertically through grilles mounted on the top face of the enclosure. This type of fan-coil unit is available for rooms with lower window sills. Controls and water valves are typically located in the enclosure, with access from the room for maintenance.

Vertical, high-output fan-coil units are designed for larger spaces or multiple rooms. The units are typically located in a closet, where a door allows easy access. Ducted discharge air supplies multiple outlets located throughout the space. The return is typically located near the floor of the closet and may or may not be ducted. Typically one thermostat controls the air supplied to all the spaces.

Floor-to-ceiling, vertical stack fan-coil units are typically supplied with chilled- and/or hot-water risers and a condensate drain riser. Vertical stack fan-coils with integral prefabricated risers directly one above the other can reduce installation labor. Evaluation of floor-to-ceiling centerlines is critical for riser and unit heights.

Vertical stack fan-coil units ([Figure 7](#)) are typically mounted in walls of the conditioned space. Air is discharged into the space from high sidewall grilles or ducted to outlets throughout the zone. Multiple stack units may be connected to a common set of risers to serve adjacent spaces. The pipes can be located in a cavity protected by a fire-rated wallboard partition separating multiple adjacent zones.

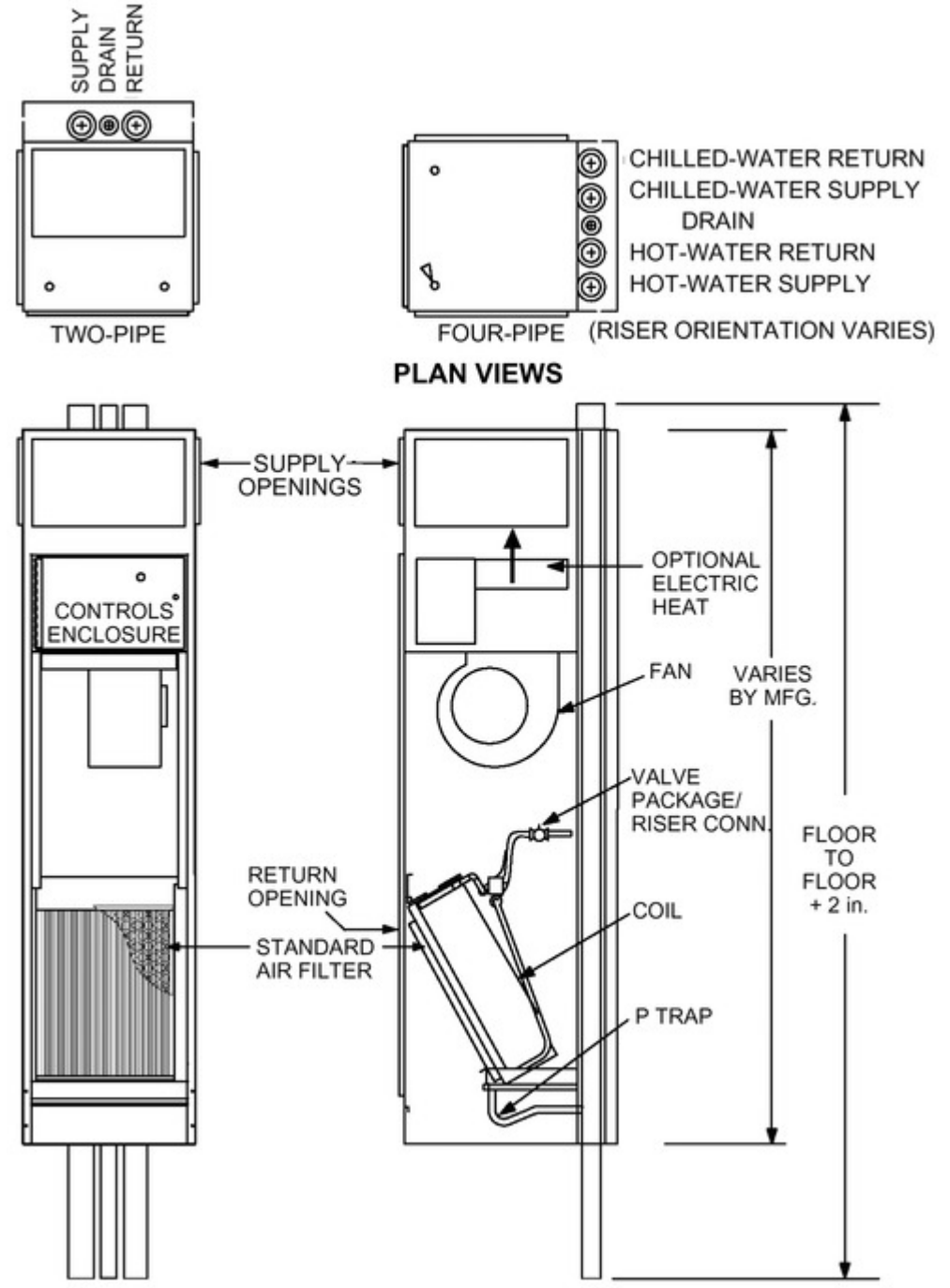


Figure 7. Typical Vertical Fan-Coil Unit

Horizontal Units. Horizontal overhead units may be concealed or exposed, and some have discharge or return ducts. Discharge ducts may supply several outlets in one or more rooms. Ducted units must be designed to handle higher external static pressure. Horizontal models conserve floor space, but when located in furred ceilings, consideration should be given to access and condensate removal.

[Figure 8](#) shows a typical low-profile horizontal fur-down fan-coil unit. Horizontal fur-down units are generally less than 11 in. in height, and mounted in a fur-down below the ceiling level or in a soffit area. The return is nonducted; the interstitial area of the soffit is the return plenum. Horizontal fan-coil types are generally used in space-constrained applications. A variation of the horizontal fur-down unit includes a return plenum, which has filter accommodations and may be ducted to a return grille. Addition of the return plenum with an externally finished cabinet allows the unit to be installed below the ceiling. Pay careful attention to the plenum pressure drop and grille locations.

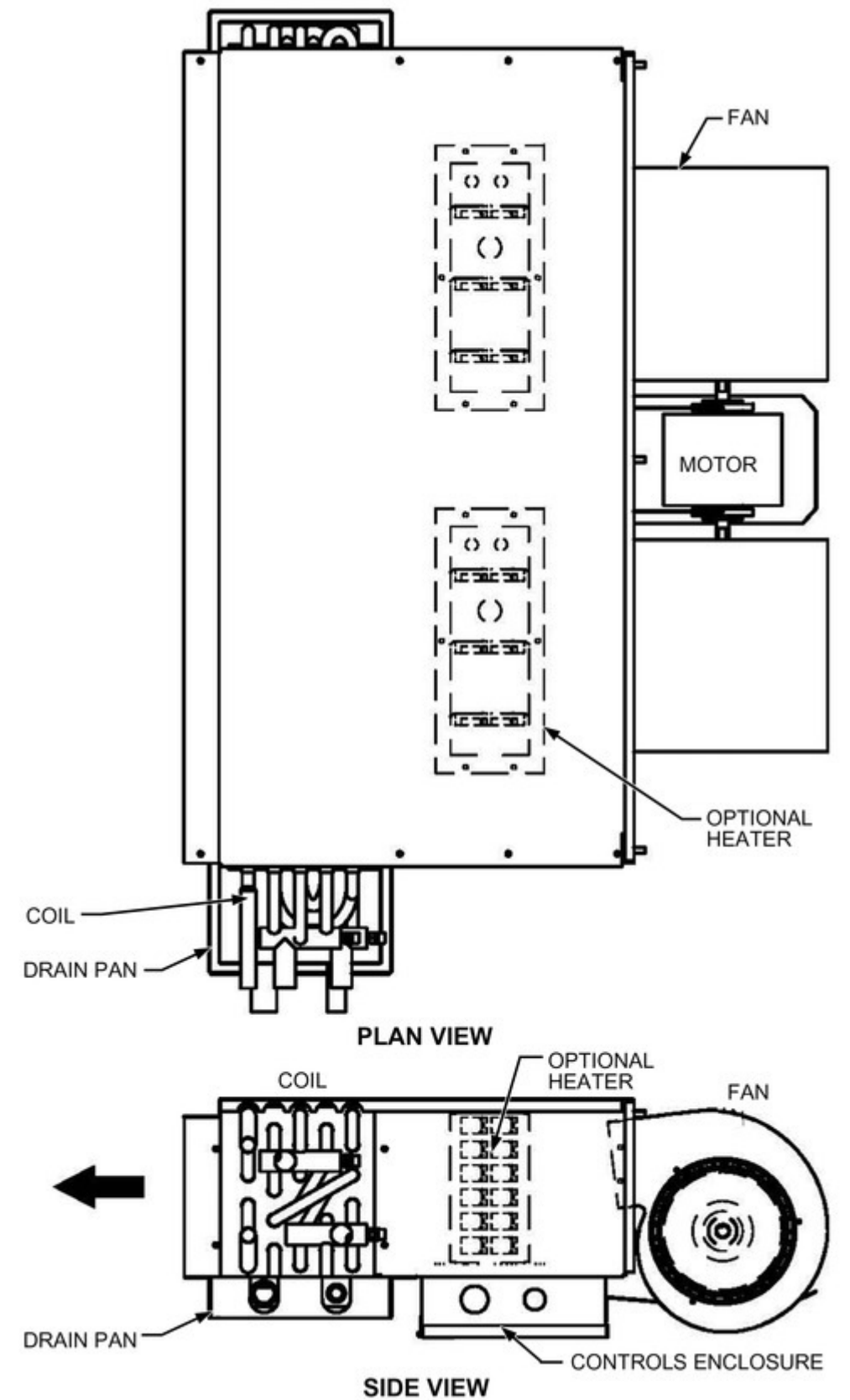


Figure 8. Typical Horizontal Fan-Coil Unit

High-capacity, horizontal fan-coil units are generally 15 to 18 in. tall and mounted above the ceiling in a return air plenum. These models have a higher capacity than fur-down low-profile units, and generally serve multiple rooms with a ducted supply. The unit may have multiple plenum arrangements, like fur-down models do, but the interstitial area is typically the return plenum.

Maintenance. Fan-coil systems require maintenance, which is generally done in occupied areas. Unit accessibility is important when performing routine maintenance such as filter replacement, coil cleaning, and motor servicing. For this reason, fan-coil units should be selected and located with consideration for required maintenance.

Air Curtain Units

Air curtain units are local ventilation devices that supply a high-velocity planar stream of air to reduce airflow through apertures in building shells (Asker 1970; Powlesland 1971, 1973; Stroilzdat 1992; Strongin 1993) and in process equipment (Bintzer and Malehom 1976; Goodfellow 1985; Ivanitskaya et al. 1986; Strongin and Nikulin 1991). An air curtain unit's primary purpose is to act as a controlled barrier for environmental and thermal separation and wind resistance when a building's doors or windows are opened.

As an environmental separation barrier, air curtains are used to minimize migration of gaseous and/or airborne particulate near their sources, and to convey contaminants toward local exhaust systems (Posokhin 1985; Posokhin and Broda 1980; Stoler and Savelyev 1977). They are also used to deter flying insects from entering a building or a protected indoor area.

As a thermal barrier, the air curtain reduces cross migration of warm, lighter air flowing through the upper part of the opening and cold, heavier air flowing through the lower part of the opening. As a wind resistance barrier, it minimizes the effect of outdoor wind blowing into a building's openings. An air curtain can reduce the energy consumption of HVAC systems when areas of different temperatures are separated.

Air curtain unit energy effectiveness is defined by the amount of energy saved (i.e., the energy loss through an opening prevented with an air curtain) divided by the amount of energy that would have been lost without an air curtain. It is represented as a percentage, and the amount of energy is reduced by the energy consumed by the unit. Research has demonstrated that air curtains can range in effectiveness from 60% to 90%, depending on the type of unit and application. See the updated online version of [Chapter 57 of the 2015 ASHRAE Handbook—HVAC Applications](#) for more information.

Construction uses a motor and fan, or a system of motors and fans, mounted inside a cabinet. The fan draws air in through a ducted or nonducted intake, and discharges it at a high velocity as an air curtain.

The unit is usually mounted above or beside a door or window opening. Discharge across the opening is either vertically (when the unit is mounted above the opening) or horizontally (when the unit is mounted beside the opening).

Unit Types and Configurations. Air curtain units are classified by two different types of construction: non-recirculating and recirculating. The major differences between the two systems are the airflow path, cabinet construction, range of effectiveness, and purchase and installation costs.

A non-recirculating system draws air into the unit directly from the surrounding environment in both horizontal and vertical applications ([Figure 9](#)). An air curtain equipped with inlet ductwork, which draws air from outside the surrounding environment, is also considered to be non-recirculating. This configuration is recommended for doorways that open frequently (e.g., 10 times per hour or a total of an hour per day). Flying insect control applications use this type of unit exclusively because of its ability to generate a high-velocity airstream. It is the most commonly used system for environmental separation, because of its low initial purchase and installation costs. Non-recirculating systems are typically used for special applications, owing to their flexibility in construction and installation.

A recirculating system draws air from ductwork, which primarily collects and returns the discharge air back to the inlet ([Figure 10](#)). Applications often use a plenum with a floor return that is connected to the inlet with ductwork. An alternative construction includes horizontal flow, which discharges and returns from side to side. These systems are recommended for doorways that are opened for extended periods of time, with a high rate of traffic. Although its effectiveness rating is higher, this system is only suitable for thermal separation applications. Recirculating systems use lower velocities and are perceived as less obtrusive than non-recirculating systems.

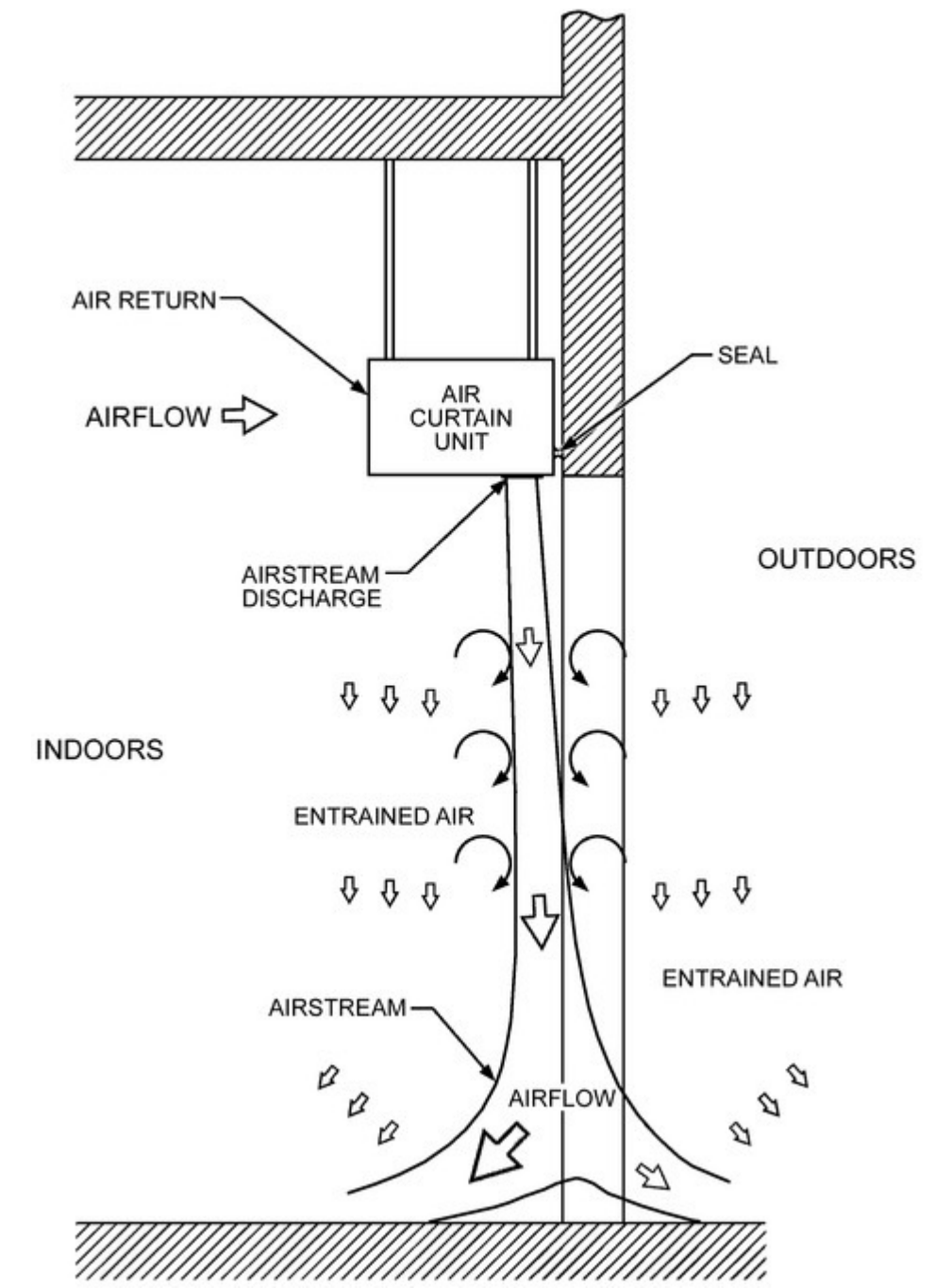


Figure 9. Non-Recirculating, Horizontal-Mount High-Velocity Air Curtain Unit
(Source: AMCA Standard 222)

Non-recirculating systems are normally self-contained systems that can be easily installed or retrofitted to existing openings with minimal planning and impact to the opening and its sequence of operation. Recirculating systems require preplanning and comprise a combination of components, including discharge and return plenums, which require integration into the construction of the opening and its sequence of operation.

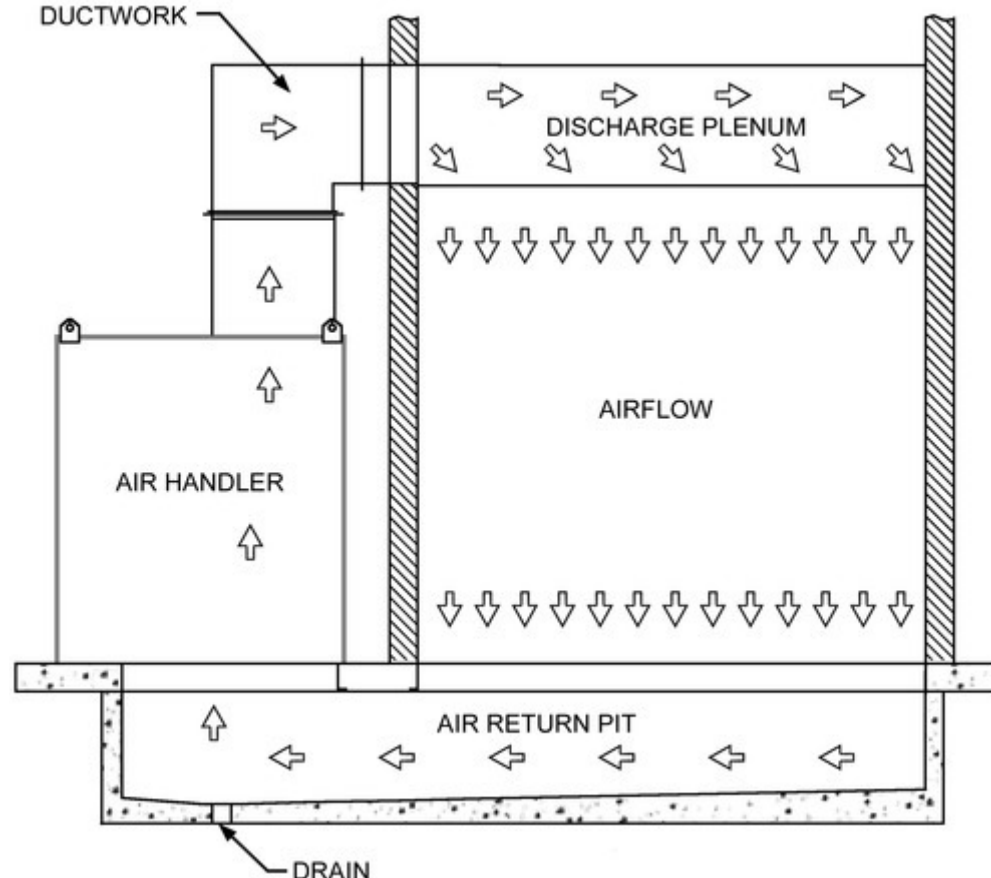


Figure 10. Recirculating, Horizontal-Mount Air Curtain Unit
(Source: AMCA Standard 222)

Typically, the range of effectiveness for non-recirculating systems is 60 to 80%, whereas recirculating systems range between 80 to 90%. Non-recirculating systems also have a relatively low purchase and installation cost; recirculating systems can have significantly higher installed cost. Optional features available for air curtain units include heating, cooling, filters, and special controls. Special casing material and/or casing coatings may be required for outdoor mounting or harsh environmental applications. Air curtain units may be offered with various heating and cooling options, depending on the intended application and cabinet construction. Note that a heating or cooling option may not improve the air curtain's effectiveness; it generally serves as an enhancement to the application, independent of the protection provided by the airstream. A heat source may be added for use as supplemental heat to reduce the windchill effect of the air curtain. The most common heating types are

- Electric heating coils: open (helical) or fin-tube element
- Hydronic coil: hot water or steam
- Indirect gas-fired: furnace uses heat exchanger to separate combustion air from heated air curtain
- Direct gas-fired: burner fires directly into airstream being heated
- DX evaporator coil: direct-expansion vapor compression refrigeration cycle system

Cooling options are used for the same general reasons as the heating options: usually for customer comfort, supplemental cooling, or dehumidifying. Special care is needed in cooling applications to remove the condensate generated in the cooling apparatus. The most common types are

- Hydronic coil: chilled water
- DX evaporator coil: direct-expansion vapor compression refrigeration cycle system

Factors that Influence Selection. Air curtains are typically considered for four different applications:

- Energy savings: indoor applications where doors or windows are used for pedestrian traffic or the transporting of goods where they would be open for a period of time long enough to impact the designed load of the HVAC system. Examples include front or customer entry doors, loading docks, service windows, ovens, and coolers or freezers.
- Insect control (sanitation): indoor applications where doors or windows could allow for the entrance of flying insects that would create an unsanitary environment.
- Code requirements: buildings that are being constructed to meet a jurisdictional code requirement.
- Process/special application: applications where the separation of two distinct environments is required to prevent cross contamination, fume/odor control or a process that requires a direct stream of air to accomplish a specified task. Examples include cleanrooms, car washes, and assembly line drying.

The updated online version of [Chapter 57 of the 2015 ASHRAE Handbook—HVAC Applications](#) provides details on these categories. **Product Selection.** Air curtain unit selection is dependent on the width and height of the opening. To maximize effectiveness, the air curtain unit at a minimum must cover the entire opening and if possible should slightly overlap. On wide openings, two vertically mounted, low-air-velocity units can be used as an alternate solution to a single horizontally mounted, high-air-velocity unit. The air curtain unit discharge must have a free and clear path to the entire opening for optimum performance. Recent studies suggest that the minimum air velocity required at the floor to create an effective barrier is 400 ft/min (Wang and Zhong 2014). When selecting air curtains, commercially available products are offered and designed specifically based on the opening size and application. Manufacturers' performance data should be consulted to determine the suitability of the air curtain units used. Data to determine air curtain unit performance should be obtained from recognized test standards such as ANSI/AMCA Standard 220.

Principles of Air Curtain Design. The velocity of the supplied air can be calculated from the following equation:

$$V_o = \sqrt{\frac{2\Delta p f g}{\beta_o \rho E} (60 \times 5.2)} = 1098 \tag{1}$$

where
 V_o = velocity of supply air, fpm
 Δp = average pressure difference between indoor and outdoor air near the aperture with the air curtain turned on, in. of water
 f = ratio of area A_w of air supply slots to door area A_d ; for air curtains with heated air or unheated indoor air and for combined air curtains, $f = 10$ to 20 ; for those supplying outdoor air or protecting air-conditioned spaces, $f = 20$ to 40
 β_o = Boussinesq coefficient (describes uniformity of air velocity in opening cross section); for air curtain supply nozzle, $\beta_o = 1.05$ to 1.1
 ρ = density of air supplied by air curtain, lb_m/ft³
 E = coefficient of air curtain dynamic efficiency (given in [Table 2](#))
 g = acceleration of gravity = 32.2 ft/s²

Airflow G_o (lb/min) supplied by shutter-type air curtains can be calculated from the following equation:

$$G_o = \rho V_o A_d \tag{2}$$

where A_d is the door area in ft².
The temperature t_o of the supplied air can be estimated from the heat balance equation for the aperture under consideration:

$$t_o = t_{out} + m_1(t_{mix} - t_{out}) + m_2(t_{oz} - t_{out}) \tag{3}$$

where
 t_{out} = normative air mixture temperature, °F
 Δt_{out} = leaving air temperature, °F
 t = air temperature in occupied zone, °F
 m_1, m_2 = coefficients for air curtain ([Table 3](#))

Table 2. Air Curtain Dynamic Efficiency Coefficient E

sin(α)		Air Curtain Supplying Heated Air, Unheated Air, and Combinations		Air Curtains Supplying Outdoor Air or Protecting Air-Conditioned Spaces	
0.1		0.10		0.15	
0.2		0.15		0.20	
0.3		0.20		0.25	
0.4		0.25		0.30	
0.5		0.30		0.40	
0.6		0.35		—	

Table 3. Coefficients m_1 and m_2 in [Equation \(3\)](#)

f	m_1	m_2
10	2.0	−0.6
15	2.3	−1.0
20	2.5	−1.3

Controls. Air curtain unit controls are essential to provide the correct air curtain velocity, temperature, and depth. They are also used to prevent unnecessary energy usage and overheating in the building entrance. Although supplemental heating can be provided by an air curtain unit, it should not be seen as the primary heat source for warming internal areas. If an air curtain unit is used for supplemental heating or cooling, the energy consumed during these control sequences should not be considered in the effectiveness rating of the unit. For convenience, user-operated controls are normally remotely mounted and configured to satisfy the building occupants' needs. At the simplest level of control, only manual operation of the fan(s), fan speed, and heat output may be required; however, more advanced control options may be included, such as

- Room thermostat
- Door contact switch
- Timer
- Step or modulating control of electric or water heating
- BMS control interface

Besides the inputs, where these control options are connected, the control unit may also have outputs for signaling failures. For instance, the control unit can also provide for the correct communication between the air curtain units and the central heating system, sliding door system, variable-refrigerant-flow (VRF) system (e.g., heat pump), etc. Air curtain units can be equipped with controls as simple as a mechanical multispeed switch, or as sophisticated as an integrated interface (printed circuit board) with a touchpad or LCD panel. The LCD panel can display values such as discharge speed and temperature, room temperature, failures, and filter contamination level.

Maintenance. Air curtain units require annual periodic maintenance, which may increase based on the application. Some designs may have motors and bearings that require periodic lubrication. Many designs use motors with sealed bearings and have fan impellers mounted directly on the motor shafts, which do not require periodic lubrication. Air curtain units require only occasional cleaning of the blower impeller(s) and heating apparatus as well as filter change-out (if so equipped).

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