CHAPTER 17

AIR-DIFFUSING EQUIPMENT

SUPPLY air outlets and diffusing equipment introduce air into a conditioned space to obtain a desired indoor atmospheric environment. Return and exhaust air is removed from a space through return and exhaust inlets. Various types of diffusing equipment are available as standard manufactured products. This chapter describes this equipment and details its proper use. Chapter 32 of the *ASHRAE Handbook—Fundamentals* also covers the subject.

SUPPLY AIR OUTLETS

Supply air outlets, properly sized and located, control the air pattern to obtain proper air motion and equalize temperature in a given space. A supply air outlet may be classified (1) according to its performance, as in Chapter 32 of the *ASHRAE Handbook—Fundamentals*, Straub and Chen (1957), and Straub et al. (1956); (2) by its physical configuration; or (3) by its mounting or installation location. Because an outlet may fall into more than one category, this chapter classifies outlets according to their general physical configuration, including slight variances of these configurations.

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 is conveyed to it in a uniform flow. Accessories may also be necessary for proper air distribution in a space, so they must be selected and used in accordance with the manufacturers' recommendations. Outlets should be sized to project air so that its velocity and temperature reach acceptable levels before entering the occupied zone.

Primary airflow from an outlet entrains room air into the jet. This entrained air increases the total air in the jet stream. Because the momentum (MV) of the jet remains constant, as the mass increases the velocity decreases. Also, the temperature in the jet equalizes as the two air masses mix.

The entrainment ratio is shown in Chapter 32 of the *ASHRAE Handbook—Fundamentals* as

$$\text{Entrainment ratio} = C\frac{V_o}{V_x}$$

where

C = constant = 1.4 for slots and 2.0 for holes
V_o = outlet velocity
V_x = jet terminal velocity at distance x from the outlet

The equation shows that for a given or selected terminal velocity, the ratio depends primarily on the outlet velocity V_o. For a given outlet type and location, the throw (distance the jet travels) is longer with a high V_o or high entrainment ratio.

The preparation of this chapter is assigned to TC 5.3, Room Air Distribution.

Comparisons between outlet locations and patterns also affect the throw, entrainment, and temperature equalization of a jet. Some general characteristics include the following:

- Grilles with straight vanes project the longest throw. When the grille is located close to a ceiling, entrainment is restricted at the ceiling and results in a longer throw. However, when the air pattern is spread horizontally, the throw is reduced and the jet is flatter so its temperature is more uniform.
- Outlets with radial airflow have a short throw and a relatively thin jet, so the temperature in the jet is fairly uniform. Temperature equalizes more readily in a cooling jet, which results in less drop.
- Single jets from ceiling outlets have a longer throw and perform like a grille.

Outlets with high entrainment characteristics can also be used advantageously in air-conditioning systems with low supply air temperatures and consequent high temperature differentials between the room air and the supply air. Radial pattern ceiling diffusers may be used in systems with cooling temperature differentials as high as 17 to 20 K and still provide satisfactory temperature equalization in the space. Linear diffusers may be used with cooling temperature differentials as high as 14 K. Grilles may generally be used in well designed systems with cooling differentials up to 11 K.

Special diffusers are available for use with low temperature air distribution systems (i.e., those with supply air temperatures of 3 to 7°C and cooling differentials as high as 22 K). Those diffusers include special features that mix the cold supply air with room air at the outlet and effectively reduce the temperature differential between the supply and room air.

PROCEDURE FOR OUTLET SELECTION

The following procedure is generally used in selecting and locating an outlet:

1. Determine the amount of air to be supplied to each room. (Refer to Chapters 28 and 29 of the *ASHRAE Handbook—Fundamentals* to determine air quantities for heating and cooling.)
2. Select the type and quantity of outlets for each room, considering such factors 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 greater than 2.4 to 3.6 m and/or exposed duct mounting, as well as product modifications and unusual conditions of room occupancy, can modify this table. Manufacturers' rating data should be consulted to determine the suitability of the outlets used.

Table 1 Guide to Use of Various Outlets

Type of Outlet	Air Loading of Floor Space, Max. L/s per m^2	Approx. Max. Air Changes per Hour for 3 m Ceiling
Grille	3 to 6	7
Slot	4 to 10	12
Perforated panel	5 to 15	18
Ceiling diffuser	5 to 30	30

3. Locate outlets in the room to distribute air as uniformly as possible. Outlets may be sized and located to distribute air in proportion to the heat gain or loss in various portions of a room.
4. Select the proper size outlet from the manufacturers' rating data according to air quantity, discharge velocity, distribution pattern, and sound level. Note manufacturers' recommendations with regard to use. In an open space, the interaction of airstreams from multiple air outlets may alter a single outlet's throw or air temperature/air velocity. As a result, the data may be insufficient to predict air motion in a particular space. Also, obstructions to the primary air distribution pattern require special study.

Chapter 32 of the *ASHRAE Handbook—Fundamentals* describes a procedure for selecting the size and location of air outlets.

FACTORS THAT INFLUENCE SELECTION

Surface Effect

An airstream moving adjacent to, or in contact with, a wall or ceiling surface 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 surface effect, commonly referred to as the Coanda effect, counteracts the drop of a horizontally projected cool airstream.

Ceiling diffusers exhibit a surface effect to a high degree because a circular air pattern blankets the entire ceiling area surrounding each outlet. This effect diminishes with a directional discharge that does not blanket the full ceiling surface surrounding the outlet. Linear diffusers, which discharge the airstream in a single direction across the ceiling, exhibit less surface effect than radial pattern discharge; however, the effect is greater with longer diffusers and with diffusers that have spread accessories at the outlet face. Sidewall grilles exhibit varying degrees of surface effect, depending on the spread of the particular air pattern and the proximity and angle of airstream approach to the ceiling.

In many installations, the outlets must be mounted on an exposed duct and discharge the airstream into free space. In this case, the airstream entrains air on both its upper and lower surfaces. As a result, a higher rate of entrainment is obtained and the throw is shortened by 30% of the equivalent throw along a surface. Because there is no surface effect with diffusers installed on exposed ducts, with a cooling differential the supply air drops more rapidly toward the floor unless the outlet surface provides an upward deflection to the discharge stream. Conical and louver face diffusers with radial patterns normally exhibit this upward deflection. Linear and flush perforated face diffusers normally do not possess this characteristic.

Temperature Differential

Heated, horizontally projected air rises and then falls as it cools. Downward projection of cooling air or upward projection of heated air increases with an increase in the temperature difference. Similarly, downward projection of heated air and upward projection of cool air decreases with an increase in the temperature difference.

Low-temperature supply air (i.e., in the range of 3 to 7°C) requires special attention to the environment in which the diffusing and distribution equipment is operating. Cold starts in a saturated environment will cause condensation in all but specially treated equipment. Ramp starts, with a gradual decrease of the relative humidity of the indoor environment, avoid condensation except with an unusually high internal load or high infiltration.

Sound Level

The sound level from an outlet is a function of its discharge velocity and the transmission of system noise. For a given air capacity, a larger outlet has a lower discharge velocity and corresponding lower generated sound. A larger outlet also allows a higher level of sound to pass through the outlet, which may appear as outlet-generated sound. High-frequency sound can be the result of excessive outlet velocity but may also be generated in the duct by the moving airstream. Low-pitched sounds are generally mechanical equipment sound and/or terminal box or balancing damper sound transmitted through the duct and outlet to the room.

The cause of the sound can usually be pinpointed as outlet or system sounds by removing the outlet core during operation. If the sound remains essentially unchanged, the system is at fault. If the sound is significantly reduced, it may be caused by a highly irregular velocity profile at the entrance to the diffuser. The velocity profile should be measured. If the velocity varies less than 10% in the air outlet entrance neck, the outlet is causing the noise. If the velocity profile at the entrance indicates peak velocities significantly higher than average, check the manufacturer's data for the sound at the peak velocity. If this rating approximates the observed sound, the velocity profile in the duct must be corrected to achieve design performance. Note that a high-velocity free stream jet does not cause a high sound level until the jet impinges against an interfering surface or edge.

Smudging

Smudging is the deposition of dirt particles on the air outlet or surface that is contiguous with the outlet. Dirt particles may be either in the room air that is entrained in the discharge or in the air supply to the outlet. Smudging is more prevalent with ceiling diffusers and linear diffusers that discharge the air parallel to the mounting surface than with grilles that discharge air perpendicular to the surface.

Dirt from room air is deposited most frequently at the edge of the stream, where the entrained air comes in contact with the surface, rather than at the center of the stream, which tends to wipe the surface with clean supply air. Edges of the stream occur at interruptions in the discharge stream, such as at a blank section of a linear diffuser or at the corner of a directional rectangular diffuser.

Variable Air Volume

Special diffusers are available for use in variable air volume systems. These outlets include features that maintain a higher discharge air momentum than do conventional outlets as the supply airflow is reduced from design maximum to about 20 to 40% of the maximum. Momentum is maintained by reducing the outlet discharge area as the flow decreases, thus maintaining a constant or increased discharge velocity. Or, the supply air is discharged through two sections of the outlet; one section carries a constant, small fraction of the total at a constant discharge velocity and the second carries the remainder of the airflow, which varies from maximum to minimum turndown. The momentum of the discharge airstream is the sum of the momentum of both streams. At high turndown conditions, the combined momentum of the two streams differs little from a fixed area outlet.

Alternates to these proprietary air outlets, which require either a separate and dedicated damper actuator or a spring biased actuator counterbalanced by duct pressure, are available. Conventional air outlets should function properly over the necessary turndown range, provided that the following factors are recognized and considered in their application:

1. The throw of the jet at a terminal velocity of 0.25 m/s divided by characteristic length ($T_{0.25}/L$) should be equal to or up to 20% higher than listed in Table 2 of Chapter 32 of the 1997 *ASHRAE Handbook—Fundamentals*.
2. As a good estimate, the plan area covered by each outlet should not exceed two times the diffuser height squared; i.e., $A \le (2H)^2$.
3. Concentrated loads should be located under either the air inlet or the supply air outlet, but not at a distance between $T_{0.25}$ and $T_{0.5}$ from the supply air outlet. At reduced flow, the thermal plume from the concentrated load causes the supply air to prematurely fall into the occupied zone.

TYPES OF SUPPLY AIR OUTLETS

GRILLE AND REGISTER OUTLETS

A grille 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). The combination of a grille and a damper is called a register.

Types

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

Fixed Bar Grille. This grille is similar to the single-deflection grille, except that the vanes are not adjustable—they may be straight or set at an angle. The angle at which the air is discharged from this grille depends on the type of deflection vanes.

Security Grille. This grille is available for various levels of tamper resistance and access through the grille. Fastening may be concealed or from the rear. When a single-piece stamped plate covers the grille face, the discharge direction is limited to flow normal to the mounting surface as the plate thickness increases and its free area decreases.

Variable Area Grille. This grille is similar to the adjustable double-deflection grille but can vary the discharge area in response to an air volume change. At constant duct static pressure, the variation in throw is minimized for a given change in supply air volume.

Accessories

Various accessories, designed to improve the performance of grille outlets, are available as standard equipment.

- Opposed blade dampers can be attached to the backs of grilles or installed as separate units in the duct (Figure 1A). Adjacent blades of this damper rotate in opposite directions and may receive air from any direction, discharging it in a series of jets without adversely deflecting the airstream to one side of the duct. Refer to Chapter 46 of the *ASHRAE Handbook—Applications* for the effects of damper location on sound level.
- Multishutter dampers have a series of gang-operated blades that rotate in the same direction (Figure 1B). This uniform rotation deflects the airstream when the damper is partially closed. Most dampers are operated by removable keys or levers.
- Gang-operated turning vanes are installed in collar connections to branch ducts. The device shown in Figure 1C has vanes that pivot and remain parallel to the duct airflow, regardless of the setting. The second device has a set of fixed vanes (Figure 1D). Both devices restrict the area of the duct in which they are installed. They should be used only when the duct is wide enough to allow the device to open to its maximum position without causing undue restriction of airflow in the duct, which would limit downstream airflow and increase the sound level.

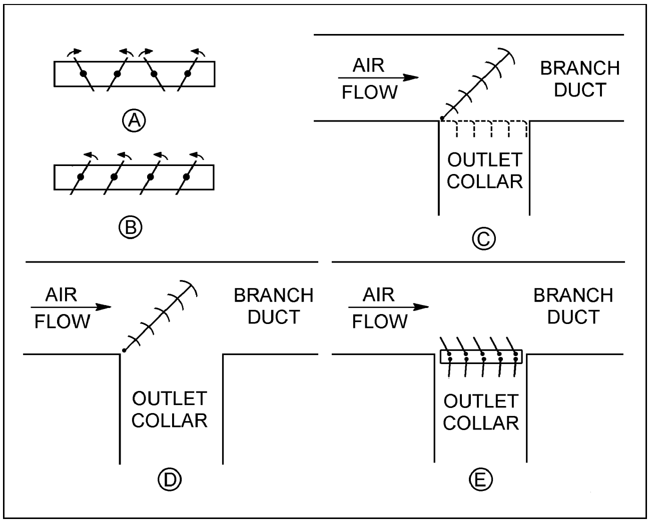

Fig. 1 Accessory Controls for Grille and Register Outlets

- Individually adjusted turning vanes are used in the device shown in Figure 1E. Two sets of vanes are used. The downstream set equalizes flow across the collar, while the upstream set turns the air. The vanes can also be adjusted at various angles to act as a damper, but use as a damper is not practical because balancing requires removing the grille to gain access and then reinstalling it to measure airflow.
- Other miscellaneous accessories available as standard equipment include remote control devices to operate the dampers and maximum to minimum stops to limit damper travel.

Applications

Properly selected grilles operate satisfactorily from high sidewall and perimeter locations in the sill or floor. Grilles installed in 2.4 to 3 m high ceilings, which discharge the airstream down, are generally unacceptable in comfort air-conditioning installations. Satisfactory performance can be obtained with higher mounting heights if special allowances are made for the supply air capacities and temperature differentials. Heating and cooling from the same grille must be carefully examined and is normally not recommended.

High Sidewall. A double-deflection grille usually provides the most satisfactory solution. The vertical face louvers of a well-designed grille deflect the air approximately 50° to either side and amply cover the conditioned space. The rear louvers deflect the air at least 15° in the vertical plane, which is ample to control the elevation of the discharge pattern. This upward deflection minimizes the thermal drop in an application with a high cooling differential (8 to 14 K).

Ceiling Installation. Such installation is generally limited to grilles with curved vanes that discharge parallel to the mounting surface. For high mounting locations, generally above 4.6 to 6 m, vertical discharge may be the optimum condition.

LINEAR SLOT OUTLETS

A linear slot outlet is a long narrow supply air grille or diffuser outlet with an aspect ratio generally greater than 10 to 1. Linear outlets can be installed in multiple sections to achieve long, continuous lengths or installed as a discrete length in a modular ceiling. It can consist of a single slot or multiple slots. Linear outlets are typically designed for supply applications, but they are also commonly used as a return inlet to provide a consistent architectural appearance.

Types

Linear Bar Grille or Diffuser. This outlet has fixed bars at its face. The bars normally run parallel to the length of the outlet. This device supplies air in a constant direction. Typically, linear bar grilles or diffusers are attached to a separate supply air plenum that has its own inlet.

T-Bar Slot Diffuser. This diffuser is manufactured with an integral plenum. It normally is installed in modular T-bar ceilings and may be concealed behind the ceiling grid suspension. T-bar slot diffusers are available with either fixed deflection or adjustable pattern controllers. These devices are available in configurations that discharge air from fully vertical to fully horizontal.

Linear Slot Diffuser. This diffuser is an elongated air outlet, available with single or multiple linear slot openings. It is commonly used to achieve a long, continuous appearance. Linear slot diffusers are typically available with options such as angle cuts at the ends or mitered corner pieces to allow the device to meet architectural requirements. These devices are available in configurations that provide vertical to horizontal airflow. Typically, a supply air plenum is supplied as a separate device and attached to the linear slot diffuser during installation.

Light Troffer Diffuser. This device is a plenum integrated with an air-handling light fixture. A light troffer diffuser serves as the combined plenum, inlet, and attachment device to the air-handling light fixture, which has a slot opening to receive the diffuser at the face of the lighting device to discharge supply air into the space. Normally, only the air-handling slot opening is visible from the occupied space.

Accessories

Damper. This is an air volume adjuster installed directly on the rear of a linear diffuser outlet, either at the entrance to the outlet plenum or remote near the branch-trunk duct junction. The means to adjust the damper is normally accessible through the face of the linear outlet.

Installation on the outlet, while probably the most convenient, is the least desirable for two reasons: (1) At this location, the damper covers the duct with the largest cross section and requires maximum throttling for flow adjustment; and (2) when the damper is throttled, it causes high-velocity air to impinge unnecessarily on the vanes or elements of the linear diffuser, which increases the sound level. (Chapter 46 of the *ASHRAE Handbook—Applications* discusses the amount of this increase.) Ideally the damper should be placed at the entrance to the branch duct, with a remote adjustment, so that the air exiting the damper at higher velocity does not impinge on adjacent duct walls or outlet vanes.

Flow Equalizing Vane. This vane is commonly used with linear diffusers to increase the spread or adjust the direction of the air jet from the diffuser. The equalizing vane consists of a series of individually adjustable blades, positioned normal to the longest blades of the linear diffuser, either attached to the rear of the linear or within the throat of the attached supply boot or plenum.

Applications

High sidewall installation with device mounted no more than 150 to 300 mm below ceiling. A slot diffuser with flow perpendicular to the mounting surface is best suited to high sidewall installations. A linear bar diffuser with fixed, 0° deflection may be applied. With the device mounted just below the ceiling, the surface effect of the supply air jet tends to keep the supply air on the ceiling, allowing longer throw distances and less chance of the jet separating from the ceiling and falling into the occupied zone.

High sidewall installation with device mounted 300 mm or more below ceiling. A slot diffuser with some angular deflection is best suited to these high sidewall installations. To keep the supply air jet out of the occupied zone, the device should allow the supply air to be directed toward the ceiling. A linear bar diffuser with a 15 to 30° upward deflection is recommended. A linear slot diffuser with directional adjustability is an alternate choice.

Perimeter ceiling. In this application, the device must handle the exterior surface load as well as the interior zone load generated along the perimeter. The perimeter surface load is especially critical in cold climates during the winter. Diffusers should be installed so they direct air toward both the exterior surface and the interior. Both plenum slot diffusers and linear slot diffusers are able to meet this requirement. These devices can be selected and installed with pattern controllers that allow changes in discharge direction from horizontal to vertical throw.

Interior ceiling. Generally, interior ceiling applications require a device that produces a horizontal pattern along the ceiling. Devices that can meet this criterion include plenum slot diffusers, linear slot diffusers, and light troffer diffusers. These devices should be sized to keep the supply air jet from reaching the occupied zone.

Sill. In sill applications, a linear bar grille works best. The grille should be installed with the supply air jet directed vertically away from the occupied space. When the device is mounted 200 mm or less from the wall, a device with 0° deflection is suitable. The presence of window draperies or blinds and the effect of an impinging airstream must be considered in the selection.

If the device is installed more than 200 mm from the vertical surface, a linear bar grille with a 15 to 30° deflection is recommended. This device should be installed with the jet directed toward the wall. These grilles are typically available with doors or other means of access to mechanical equipment that may be installed within the sill enclosure.

Floor. For floor applications, a linear bar grille works well. The designer must determine the traffic and floor loading on the grille and consult the manufacturer’s load limit for the grille.The grille should be placed in low-traffic areas with limited access. A floor-mounted grille is usually selected to bring air up along a wall or exterior surface. A floor grille is appropriate along exterior surfaces for heating in cold climates. Then the airflow performance should be considered with reference to the manufacturer’s catalog data. If the device is less than 300 mm from the surface, a 0° deflection grille should be used. If the grille is 300 to 600 mm from the vertical surface, a 15 to 30° deflection toward the surface is recommended.

CEILING DIFFUSER OUTLETS

Ceiling diffuser outlets usually have either a radial or directional discharge parallel to the mounting surface. Diffusers with adjustable deflectors that allow the discharge to be directed perpendicular to the mounting surface are available, as are round, square, and rectangular ceiling diffusers. A ceiling diffuser typically consists of an outer shell, which contains a duct collar, and an internal deflector, which defines the diffuser’s performance, including the discharge pattern and direction.

Types

Round Ceiling Diffuser. This diffuser is a series of flaring concentric or expanding truncated conical rings. Typically it is installed either in gypsum-board ceilings or on exposed ducts. Round ceiling diffusers are available in a broad range of sizes and capacities. These devices are available with adjustable deflectors that allow the diffuser to discharge the air either parallel or perpendicular to the ceiling or mounting surface.

Rectangular and Square Ceiling Diffusers. These diffusers are designed to integrate into various ceiling systems. They are most commonly selected for installation in grid suspension ceilings.

Square ceiling diffusers are also available for surface mounting, spline ceiling, and other ceilings. This diffuser is largely selected based on performance, appearance, and cost. Square ceiling diffusers can be categorized as perforated face, louvered face, and plaque face.

Perforated Diffuser. The perforated face of this diffuser typically has a free area of about 50%. This unit is normally selected to meet architectural demands for air outlets that blend into the ceiling. The perforated face tends to create a slightly higher pressure drop and more sound than other square ceiling diffusers. Perforated diffusers also tend to cost less than other devices. Perforated diffusers are available with deflection devices mounted at the neck or on the face plate. The deflectors are adjusted to provide a horizontal air discharge in one, two, three, or four directions. Special faces accommodate adjacent ceiling tile or channel slot grid systems.

Louver Face Diffuser. This diffuser consists of an outer frame, which includes an integral rectangular duct collar, and a series of louvers parallel with the outer frame vanes. Louver face diffusers typically provide a directional discharge pattern with horizontal air discharging 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 to permit the supply air to be directed toward the load source. Louver face diffusers are available with special edges to accommodate adjacent ceiling tile or channel slot grid systems. Some louver face diffusers are available with adjustable louvers that can change the discharge direction from horizontal to vertical.

Rectangular louver face diffusers are available to further match the air discharge direction to the load location. Round-to-square fittings are available to fit the louver face to a round air supply duct.

Plaque Face Diffuser. This diffuser is constructed with a backpan that includes a duct collar and a single plaque that forms the diffuser's face. This air outlet typically has a horizontal, radial discharge pattern. A plaque face diffuser is most often selected for its architectural appearance. The flat plaque face of the diffuser provides a clean, uniform appearance. Typically, the performance of a plaque face diffuser is similar to that of a square face, round neck diffuser.

Square Face, Round Neck Diffuser. This diffuser is constructed of a series of concentric square, drawn louvers that radiate from the center of the diffuser. It is most commonly available with a face that is flush with the ceiling plane. Square face ceiling diffusers are available with various configurations including dropped face and beveled face. These diffusers have a fixed horizontal radial discharge pattern. Some are available with an adjustable discharge pattern that allows the direction to be either horizontal or vertical.

Rectangular Modular Diffuser. This diffuser is available to provide a vertical fan-shaped air discharge pattern. The fan-shaped discharge penetrates the conditioned space perpendicular to the mounting surface. These diffusers are used for high air change, low to moderate cooling differential applications where high airflow is generally required as makeup air for laboratory hood exhaust or a process. Some outlet models are flush to the mounting surface; others intrude into the space below the ceiling. Most function similarly with or without an adjacent ceiling surface. The diffusers normally match 600 mm by 1200 mm ceiling modules, with other sizes available. Manufacturers' catalogs list specific characteristics.

Laminar Flow Type Rectangular Modular Perforated Face Diffuser. This diffuser provides a unidirectional or laminar discharge that is perpendicular to the mounting surface. The free area of the perforated face is typically about 10 to 20%. Most outlets include a means to develop a uniform velocity profile over the full face. This minimizes mixing with the surrounding ambient air and reduces the entrainment of any surrounding contaminants. These diffusers are generally used in hospital operating rooms, clean rooms, or laboratories.

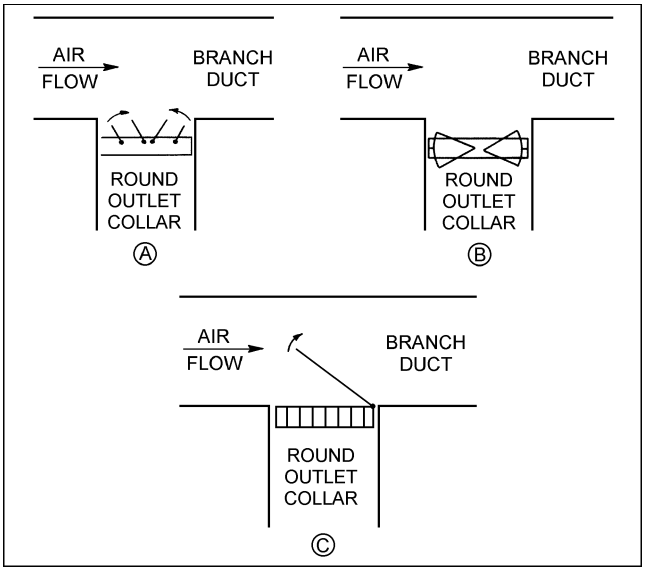

Fig. 2 Accessory Controls for Ceiling Diffuser Outlets

Accessories

Multilouver Damper. Consisting of a series of parallel blades mounted inside a round or square frame, multilouver dampers are installed in the diffuser collar or the takeoff. The blades are usually arranged in two groups rotating in opposite directions and are normally key-operated from the face of the diffuser (Figure 2A). This arrangement equalizes airflow in the diffuser collar.

Opposed Blade Damper. This damper is available for both round and rectangular air diffusers. For a round diffuser, the opposed blade damper consists of a series of vanes mounted inside a round frame and installed on the diffuser collar (Figure 2B). The vanes are typically operated through the face of the diffuser. For diffusers with a rectangular inlet neck or collar, the opposed blade damper consists of a series of parallel blades mounted in a rectangular frame and installed on the neck of the diffuser.

Splitter Damper. 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 2C). The device is designed to allow adjustment at the branch connection of a duct or outlet to adjust flow.

Equalizing Device. This device allows adjustment of the airstream to obtain uniform flow to the diffuser.

Other Balancing Devices. Many balancing devices are available, including radial dampers, butterfly dampers, and dampers integral with an air outlet. Manufacturers' literature is a source of information for other air-balancing devices. Table 5 in Chapter 46 of the *ASHRAE Handbook—Applications* summarizes the effects of damper location on sound level.

Applications

For all the following applications, the manufacturer's rating data should be checked to select the air outlet that meets throw, pressure, and sound requirements.

Perimeter Zone Ceiling. In perimeter ceiling applications, the air outlet must handle the exterior surface load as well as the interior zone load generated along the perimeter. Refer to Chapter 32 of the *ASHRAE Handbook—Fundamentals* for more details

Interior Zone Ceiling. Generally, interior ceilings require an air outlet that produces a horizontal pattern along the ceiling. Ceiling diffusers are well suited for this application. Selection can be made based on performance, appearance, and cost. The air outlet selected should be sized to keep the supply air jet above the occupied zone.

Vertical Projection. Vertical projection from the outlet is often required in a high-ceiling application or in a high-load area. Vertical projection may be selected to meet an individual's comfort requirements. When selecting an outlet for vertical projection with heating differentials, its performance under both heating and cooling differentials must be taken into consideration. This is especially required on heating systems with an outdoor air supply, or when the air outlet discharge characteristics are not automatically changed as the supply air temperature changes from heating to cooling.

Spot Heating or Cooling. Spot heating or cooling typically requires the use of an outlet that projects the air jet vertically. In this application, the designer can select an air outlet that projects a jet of air to cover the defined area. Most ceiling diffusers are available with a configuration that allows spot heating or cooling. If the diffuser configuration is not changed with a change in supply air from heating to cooling, then the effect of heating and cooling differential must be determined based on manufacturer's data for the respective conditions.

Large-Capacity Area. These areas normally require a ceiling diffuser with a horizontal discharge that handles large air capacities. Applications include open atriums, warehouses, and gymnasiums. Ceiling diffuser outlets typically selected for this application are round and rectangular diffusers.

Exposed Duct. In exposed duct applications, a diffuser outlet is typically selected that discharges the supply air in a horizontal pattern. Most ceiling diffusers can be used, but throw or radius of diffusion distance for exposed duct applications is 70% of the distance listed for a ceiling-mounted rating. The air outlets most commonly selected are diffusers with round discharge patterns.

EQUIPMENT FOR AIR DISTRIBUTION

In high-velocity air distribution systems, special control and acoustical equipment may be required to introduce conditioned air into a space properly. Airflow controls for these systems consist principally of terminal boxes (air terminals), with part of the equipment considered as pressure reducing valves. Terminal boxes may be classified as single or dual duct, with or without reheat, and having either constant or variable primary volume. The constant primary air volume may provide for a variable discharge air volume to the conditioned space. Terminal boxes may also include air induction or fan induction that provides an essentially constant volume with a variable volume primary air capacity.

This section discusses control equipment for single duct and dual duct air conditioning systems. Chapter 16 covers duct construction details. Chapter 46 of the *ASHRAE Handbook—Applications* includes information on sound control in air-conditioning systems and sound rating for air outlets.

TERMINAL BOXES

The terminal box is a factory-made assembly for air distribution. A terminal box, without altering the composition of the treated air from the distribution system, manually or automatically performs one or more of the following functions: (1) controls velocity, pressure, or temperature of the air; (2) controls rate of airflow; (3) mixes airstreams of different temperatures or humidities; and (4) mixes, within the assembly, air at high velocity and/or high pressure with air from the treated space. To achieve these functions, terminal box assemblies are made from an appropriate selection of the following component parts: casing, mixing section, manual or automatic damper, heat exchanger, induction section (with or without fan), and flow controller.

A terminal box commonly includes a sound chamber to reduce sound generated within it by the damper or flow rate controller. At the same time the terminal box reduces the high-velocity, high-pressure inlet air to low-velocity, low-pressure air. The sound attenuation chamber is typically lined with thermal and sound insulating material and is equipped with baffles.

Additional sound absorption material may be required in the low-pressure distribution ducts connected to the discharge of larger boxes. Smaller boxes may not require additional sound absorption; however, manufacturers' catalogs should be consulted for specific performance information.

Terminal boxes are typically classified according to the function of their flow controllers, which are generally categorized as constant flow or variable flow devices. They are further categorized as either pressure-dependent, where the airflow through the assembly varies in response to changes in system pressure, or pressure-independent (pressure compensating), where the airflow through the device does not vary in response to changes in system pressure.

Constant flow controllers may control the volume mechanically by balancing the static pressure in the primary duct system with an adjustable spring bias for the flow set point. This unit requires no outside source of power, and its static pressure requirement is in the range of 75 to 200 Pa. Constant flow controllers may also be pneumatically or electrically actuated, which requires sensing an internal differential pressure. They also require an electric or pneumatic control source to operate the damper actuator.

Variable flow controllers may also be mechanical, pneumatic, electric, or digital. These devices include a means to reset the volume automatically to a different control point in response to an outside signal such as a thermostat. Boxes with this feature are pressure-independent and may be used with reheat components. Variable flow may also be obtained by decreasing the flow through a constant volume regulator with a modulating damper ahead of the regulator. This arrangement typically allows for variations in flow between the high- and low-capacity limits or between a high limit and shutoff. These boxes are pressure-dependent and volume limiting in function.

Terminal boxes can be further categorized as being (1) system powered, in which the assembly derives all the energy necessary for its operation from the supply air within the distribution system; or (2) externally powered, in which the assembly derives part or all of the energy from a pneumatic or electric outside source. In addition, assemblies may be self-contained (when they are furnished with all necessary controls for their operation, including actuators, regulators, motors, and thermostats or space temperature sensors) or non-self-contained assemblies (when part or all of the necessary controls for operation are furnished by someone other than the assembly manufacturer). In the latter case, the controls may be mounted on the assembly by the assembly manufacturer or mounted by others after delivery of the equipment.

The damper or flow controller in the box can be adjusted manually, automatically, or by a pneumatic or electric motor. The unit is actuated by a signal from a thermostat or flow regulator, depending on the desired function of the box.

Air from the box may be discharged through a single opening suitable for connection to a low-pressure rigid branch duct, or through several round outlets suitable for connection to flexible ducts. A single supply air outlet connected directly to the discharge end or bottom of the box is an optional arrangement; however, the acoustic performance of this close-coupled arrangement must be carefully considered.

REHEAT BOXES

Reheat boxes 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 box. These boxes typically are single-duct boxes that can operate as either constant or variable volume units. However, if they are variable volume, they must maintain some minimum airflow for the reheat function. Some are arranged with a dual minimum flow, with one minimum being either zero during the no-occupancy cooling cycle or the airflow required for minimum ventilation during the cooling cycle, and the second minimum being the capacity required for reheat capacity during the reheat cycle. This type of equipment can provide local individual reheat without a central equipment station or zone change.

DUAL DUCT BOXES

Dual duct boxes are typically under control of a room thermostat. They receive warm and cold air from separate air supply ducts in accordance with room requirements to obtain room control without zoning. Pneumatic and electric volume-regulated boxes often have individual modulating dampers and operators to regulate the amount of warm and cool air. When a single modulating damper operator regulates the amount of both warm and cold air, a separate pressure reducing damper or volume controller (either pneumatic or mechanical) is needed in the box to reduce pressure and limit airflow. Specially designed baffles may be required inside the unit or at the box discharge to mix varying amounts of warm and cold air and/or to provide uniform flow and temperature equalization downstream. Dual duct boxes can be equipped with constant or variable flow devices. These are usually pressure-independent in order to provide a number of volume and temperature control functions. Dual duct terminals may also be used as outside air terminals in which the warm air inlet is used to control and maintain the required volumetric flow of ventilation air into the space.

CEILING INDUCTION BOXES

Ceiling induction boxes supply either primary air or a mixture of primary air and relatively warm air to the conditioned space. It achieves this function with a primary air jet and venturi that induces air from the ceiling plenum or from individual rooms via a return duct. A single duct supplies primary air at a temperature cool enough to satisfy all zone cooling loads. The ceiling plenum air induced into the primary air is at a higher temperature than the room because heat from the recessed lighting fixtures enters the plenum directly.

The induction box contains dampers that are actuated in response to a thermostat to control the amount of cool primary air and warm induced air. As less cooling is required, the primary airflow is gradually reduced, and the induced air rate is generally increased.

To meet interior load requirements, water reheat coils can be installed in the primary supply air duct, or electric reheat coils can be installed in the discharge duct.

FAN-POWERED CEILING INDUCTION BOXES

Fan-powered ceiling induction boxes differ from air-to-air induction boxes in that they include a blower. This blower, driven by a small motor, draws air from the space or ceiling plenum (secondary air) to be mixed with the cool primary air. The advantage of fan induction boxes over straight VAV boxes is that for a small energy expenditure and increased terminal maintenance, constant air circulation can be maintained in the space. Fan-powered induction boxes operate at a lower primary air static pressure than air-to-air induction boxes; and perimeter zones can be heated without operating the primary fan during unoccupied periods. The warm air in the plenum can be used for low to medium heating loads (depending on construction of the building envelope). As the load increases, heating coils in the perimeter boxes can be activated to heat the recirculated plenum air to the necessary level.

Fan-powered induction boxes can be divided into two categories: (1) constant volume or series type with all the primary and induced air passing through the continuously operating blower and (2) variable volume or parallel flow type in which the blower operates only on demand when induced air or heat is required. For the most efficient thermal operation, only primary air should be delivered to the conditioned space at peak cooling load because the induced air acts as unnecessary reheat.

In thermal storage and other systems with supply air temperatures in the range of 3 to 9°C, fan induction boxes are used to deliberately mix cold supply air with induced return or plenum air to moderate the supply air temperature. Some boxes are equipped with special insulation to prevent condensation with these low supply temperatures. Manufacturers' catalogs can provide further information on these special features.

Constant volume, or series type, fan-powered induction boxes are used when constant air circulation is desired in the space. The unit has two inlets, one for cool primary air from the central fan system and one for the secondary or plenum air. All air delivered to the space passes through the blower. The blower operates continuously whenever the primary air fan is on and can be cycled to deliver heat, as required, when the primary fan is off.

As the cooling load decreases, a damper 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 space or ceiling plenum through the return or secondary air opening.

Parallel flow or variable volume fan-powered induction boxes are sometimes called bypass boxes because the cool primary air bypasses the blower portion of the unit and flows directly to the space. The blower section draws in only plenum air and is mounted in parallel with the primary air damper. A backdraft damper keeps primary air from flowing into the blower section when the blower is not energized. The blower in these units is generally energized after the primary air damper is partially or completely throttled. Some electronically controlled units gradually increase the fan speed as the primary air damper is throttled in order to maintain constant airflow while permitting the fan to shut off when it approaches the full cooling mode.

BYPASS OR DUMP BOX

A bypass box handles a constant supply of primary air through its inlet; and, with a diverting damper, it bypasses the primary air to the ceiling plenum so that the amount of cooling delivered to the conditioned space meets the thermal requirement. The bypass air is diverted into the ceiling plenum and returned to the central air handler. The pressure requirement through the supply air path to the conditioned space and through the bypass or dump path is adjusted to be equal so that the fan handles a constant flow. This method provides a low first cost with minimum fan controls; but it is energy-inefficient as compared to a VAV fan system. Its most frequent application is on small systems.

STATIC PRESSURE CONTROL

To prevent static pressure imbalance in dual duct systems and/or to achieve efficient operation with VAV systems, some type of fan discharge capacity and/or pressure control is necessary. Variations in the duct static pressure can be limited by the following:

- Mechanical or electrical variable speed fan controls
- Zoning and changing air supply temperature in response to static pressure changes
- Static pressure controllers operating fan inlet vane dampers

Other control means, such as duct dampers within the system, are not efficient. They merely transfer the location of the pressure loss from the terminal box to another point in the duct system and do not change the overall system pressure requirement.

AIR CURTAINS

In its simplest application, an air curtain is a continuous broad stream of air circulated across a doorway of a conditioned space. It inhibits the penetration of unconditioned air and insects into a conditioned space by forcing an air layer of predetermined thickness and velocity over the entire entrance. The airstream layer moves with a velocity and angle such that any air that tries to penetrate the curtain is entrained. The air layer or jet can be redirected to compensate for pressure changes across the opening. If air is forced inward because of a difference in pressure, the jet can be redirected outward to equalize the pressure differential. Chapter 28 of the *ASHRAE Handbook—Applications* covers the principles of air curtain design.

Both vertical flow (usually downward) and horizontal flow air curtains are available. The vertical flow air curtain may have either a ducted or a nonducted return.

The air curtain is a high energy user, so this factor should be considered in its application. Air curtain effectiveness in preventing infiltration through an entrance generally ranges from 60 to 80%. The effectiveness is the comparison of infiltration rate or heat flux through an opening when using an air curtain as opposed to the transmission that would take place through a simple opening with no restriction. Lawton and Howell (1995) analyzed the savings of several air curtains versus an open door in a warm, humid climate.

Two important factors influence the pressure differential against which an air curtain must work—the height and the orientation of the structure. In high-rise structures, the possibility of using an air curtain depends mainly on the magnitude of the pressure differential caused by the structure's height or the stack effect. The orientation of the particular building and the location of adjacent buildings should also be studied and considered.

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