

to the two jet centerlines increases until it equals the jet centerline velocity. From this point on, a maximum velocity of the combined jet stream is on the midway line, and the profile is almost as though emanating from a single outlet of twice the area of one of the two outlets.

Koestel and Austin¹⁸ have determined the spacing between outlets for noninterference between the jets. For a K value of 6.5 the outlets should be placed three to eight diameters apart, for V_s values from 500 to 1500 fpm.

Effect of Resistance on Return Path of Jet Air

Laboratory experiments on jets usually involve recirculated air with negligible resistance to flow on the return path of the jet air. Experience and experiments in tunnels of small cross-sectional area in mines, where considerable resistance is offered to the return flow of jet air to outlets, show that the expansion of the jet terminates abruptly at a distance that is independent of velocity of discharge and but slightly affected by size of outlet. Such distances are determined primarily by size and length of return path. In a long 5 ft $\times$ 6 ft tunnel, a jet may not travel more than 25 ft whereas in a relatively short opening, 25 by 60 ft, it may travel more than 250 ft. Few engineering data are available on this phase of jet expansion but it can be of great practical importance.¹⁹

ISOTHERMAL RADIAL FLOW JETS

In the radial jet the cross-sectional area at any distance from the outlet varies as the square of this distance, the same as for an axial jet. Experiments have shown that the centerline velocity gradients and the cross-sectional velocity profiles are similar to those of Zone 3 of axial jets and that the angles of divergence are about the same. In using Fig. 8, X/H should be used as abscissa instead of $X/\sqrt{A}$.

Jets from ceiling plaques have the same form as one-half of a free radial jet. The jet is wider and longer than a free jet, with the maximum velocity close to the wall.

For a basic equation for radial flow outlets resulting from the air distribution research at Case Institute of Technology see Reference 17.

NONISOTHERMAL AXIAL-FLOW JETS

The paths assumed by horizontally projected heated and chilled jets under the influence of buoyant forces are of great practical importance for heating and cooling with outlets located in walls. An equation describing the behavior of jets of this type has been presented by Koestel.¹⁴

VERTICALLY PROJECTED HEATED AND CHILLED JETS

Equations for outlet characteristics that affect the downthrow of heated air have been developed by investigators at Kansas State College (see Bibliography, ASHAE Cooperative Research at Kansas State College).

Equations for temperatures and velocities in heated and chilled jets based upon the research at Case Institute of Technology are given in Reference 19.

DUCT ARRANGEMENTS

Duct Approaches to Outlets

The importance of the manner in which the air stream is introduced into the outlet cannot be overestimated. To obtain correct air distribution, the velocity of the air stream must be as uniform as possible over the entire connection to

the duct, and perpendicular to the outlet face. No air outlet can compensate for improper duct approach.

A wall grille installed at the end of a horizontal duct and a ceiling outlet at the end of a vertical duct receive the air perpendicularly and at (for practical purposes) uniform velocity over the entire duct cross-section, provided the system is carefully designed. However, very few outlets are installed in this manner. Most side wall outlets are installed either at the end of vertical ducts or in the side of horizontal ducts, and most ceiling outlets are attached either directly to the bottom of horizontal ducts or to special vertical take-off ducts which connect the outlet with the horizontal duct. In all these cases, special devices for directing and equalizing the air flow are necessary to obtain proper direction and distribution of the air. (See Chapter 30.)

The influence of the duct approach on outlet performance has been investigated for vertical stack heads with plain openings²⁰ or equipped with grilles²¹ and for side outlets on horizontal ducts.²² In the tests conducted with the stack heads it was found that it is necessary to provide splitters or guide vanes in the elbows at the top of the vertical stacks regardless of the shape of the elbows, whether of rounded, square, or expanding types. Cushion chambers at the top of the stack heads have no beneficial effect. Fig. 10 shows the direction of flow, distribution and velocity (measured 12 in. from opening) of the air for various types of stack heads tested, expanding from a 14 $\times$ 6 in. stack to a 14 $\times$ 9 in. opening, without grille. The air velocity for each was 500 fpm in the stack below the elbow, but the direction of flow and the distribution pattern are generally indicative of performance obtainable with nonexpanding elbows of similar shapes for a range of velocities 200 to 1400 fpm.

In tests conducted with 3 $\times$ 10 in., 4 $\times$ 9 in., and 6 $\times$ 6 in. side outlets in a 6 $\times$ 20 in. horizontal duct at duct velocities of 200 to 1400 fpm (in the 6 $\times$ 20 in. section) it was found that multiple curved deflectors produced the best flow characteristics. Vertical guide strips in the outlet were not so effective as curved deflectors. A single scoop type deflector at the outlet did not improve the flow pattern obtained from a plain outlet, and was not desirable.

Discharge from a Long Slot

When a long slot receives its air supply from one end only, the important design factor is the ratio of the area of the slot to the area of the supply duct, and both the air stream profiles and the duct pressure requirements are determined by this ratio.²³ Fig. 11 shows the changing profile as the slot area is increased for a rounded entrance slot ($C_d = 0.83$) with constant duct cross-section.

The air discharge from a slot in a tapered duct will be uniform (Fig. 12) for a relationship between discharge angle and slot-duct dimensions.²⁴

$$\cot \theta = \frac{A_s C_d}{A_d} \quad (15)$$

where

- θ = discharge angle, degrees
- A_s = slot area, square feet
- A_d = duct cross-sectional area at upstream end, square feet
- C_d = coefficient of discharge

RETURN AND EXHAUST INTAKES

The selection of return and exhaust intakes depends on: (1) velocity in occupied zone near intake; (2) permissible pressure drop through intake; and (3) noise.

Space Air Distribution

1. **Velocity.** The control of the room air motion for the maintenance of comfort conditions depends on the proper selection of the supply outlets. The effect of air flow through return intakes upon air movement in the room is slight. Air handled by the intake approaches the opening from all directions and its velocity decreases rapidly as the distance from the opening increases. Therefore, drafty conditions will rarely be encountered near return intakes. Recommended return intake face velocities are given in Table 3.

2. **Permissible Pressure Drop.** The permissible pressure drop will depend on the choice of the designer. Table 4 gives pressure drop through plain lattice intakes as a function of free area and face velocity.

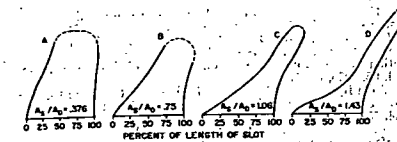


Fig. 11 Shape of Air-Stream Envelopes as Slot Area is Increased

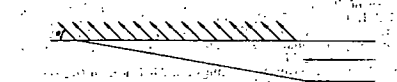


Fig. 12 Uniform Air Flow from a Slot Supplied by a Tapered Duct

Proper pressure drop allowance should be made for control or directive devices.

3. **Noise.** The problem of noise generated by return intakes is the same as that for supply outlets. In computing resultant room noise levels from the operation of an air-conditioning system, the return intake must be included as a part of the total grille area. The major difference between the supply outlets and return intakes is the frequent installation of the latter at ear level. When so located, it is recommended that the return intake velocity be not in excess of 75 percent of the maximum permissible outlet velocity.

The location of return and exhaust intakes does not critically affect air motion, unless room air velocities in the occupied zone near the intake exceed comfort limits. The locations of return or exhaust intakes are, however, important for obtaining the desired room temperature equalization.

Ceiling locations for exhaust outlets are recommended for bars, kitchens, lavatories, dining rooms, club rooms, etc. where warm air will rise to the ceiling level. In heating installations, location of the return grilles in the ceiling or high on the wall is not recommended, as it may result in stratification of the conditioned air, and—depending on the relative location of supply and return outlets—in short-circuiting.

Some ceiling outlets combine the supply and return openings in a single unit. This method is used for heating as well as for cooling applications. However, the application for heating is more critical and requires consideration of ceiling

Table 3 Recommended Return Intake Face Velocities

Intake Location	Velocity Over Grille Area fpm
Above occupied zone	800 up
Within occupied zone, not near seats	600-800
Within occupied zone, near seats	400-600
Door or wall louvers	200-300
Undercutting of doors (through undercut area)	200-300

height, amount of outside wall area, and number of air changes required. In some cases, stratification of warm air may cause short-circuiting.

Floor locations of returns are used in heating installations for ceiling or side-wall supply. When located so that air is drawn across exposed walls, the performance of the system may be somewhat improved. In general, floor locations tend to collect dirt and refuse.

Wall and door locations of exhaust outlets depending on their elevation, have the characteristics of either floor or ceiling returns. In large buildings with many small rooms, the return air may be brought through door grilles or door undercuts into the corridors, and then to a common return or exhaust. The pressure drop through door returns should not be excessive; otherwise the air distribution to the room may be seriously unbalanced with the opening or closing of the doors. Outward leakage through doors or windows cannot be counted upon for dependable results. (See Chapter 30.)

BALANCING THE SYSTEM

In designing a system, the engineer aims to size ducts and outlets in such a manner that the supply of air is properly distributed. He may, however, feel it necessary to oversize certain trunks, branches, or outlets to allow flexibility or to permit future redistribution, so that the system as designed may not be self-balancing. Even if ducts are designed for self-balancing and outlets are properly selected, all air systems must be balanced, that is, the amount of air through supply ducts, supply outlets, outdoor air intakes, exhausts, return outlets, and ducts must be properly adjusted so that the air quantities correspond closely with the design quantities. Balancing, therefore, is part of the field test procedure to which each air-conditioning system should be subjected in order to determine whether the capacity and performance of the equipment correspond with the design.

Table 4 Approximate Pressure Drops for Lattice Return Intakes

Inches Water Gauge—Standard Air		Face Velocity, Fpm							
Percent Free Area		400	500	600	700	800	900	1000	
50	0.06	0.09	0.13	0.17	0.22	0.28	0.35		
60	0.04	0.06	0.09	0.12	0.16	0.20	0.24		
70	0.03	0.05	0.07	0.09	0.12	0.15	0.18		
80	0.02	0.03	0.05	0.07	0.09	0.11	0.14		