Air Distribution for Large Spaces

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Introduction

The distribution of air into large spaces has both good news and bad news. The good news is that since the spaces are so large, air distribution is spread out over a large area and localized problems are unlikely. The bad news is that because the spaces are large, diffusers can't be located everywhere.

Most of the selection process is one of experience and jet mapping. The standard commercial office axioms of ADPI and diffuser throw vs. spacing are not applicable. Rather, jet projections are analyzed and diffusers selected accordingly.

Basic Principles

There are a couple of basic principles in analyzing airflows in large (or any) spaces. The first basic rule is Newton's gravitational observations: Hot air rises and cold air falls. The question is, of course, how much? The second rule is that air which is in the form of a free jet, as opposed to one that is constrained along a surface, acts pretty much independent of the supply outlet isovel (or air pattern), following some basic rules of jet theory. Once these two principles are understood, predictions of airflow can be made with a high degree of confidence.

Vertical Jet Temperature Effects:

The effects of temperature are very predictable. Hot air rises and cold air falls. Momentum and velocity temper this effect. As a rule, air velocities above 150 fpm are not effected by temperature differences. The slower the air, the greater the effect of buoyancy. A very simple rule of thumb is that the throw (the distance for a jet to reach a stated 'terminal velocity') of at an air jet to a terminal velocity of 75 fpm is effected by about 1% / degree F delta-t. A downward jet of cold air will travel further, hot air less, than isothermal air.

For vertical jets, this effect is straightforward. Figure 1 shows this effect. This chart can be used is several ways:

1. If the outlet discharge velocity and flow rate are known, the chart can be used to estimate the downward vertical projection of a jet to 50 fpm terminal velocity (T_{50}), as a function of delta-t (difference in temperature between the discharge jet and the ambient or room temperature. For example, for a jet with a 1000 fpm discharge velocity, at 1000 cfm, the distance to 50 fpm will be about 28 feet if the jet is isothermal.
2. The chart can also be used in reverse, to predict upward jet projection by switching the delta-t values.
3. If isothermal throw is known (from standard grille performance charts), the right side of the chart can be used to estimate the effect of delta-t on 50 fpm terminal velocity, by using the isothermal data as an entering argument, and simply moving across to the indicated delta-t point. For example, if a grille has a 50 fpm terminal velocity throw of 50 ft in the catalog (isothermal), the jet will travel about 72 feet if it is 20 degrees cooler than the ambient air. It will travel only 20 feet if it is 50 degrees warmer than the surrounding air.

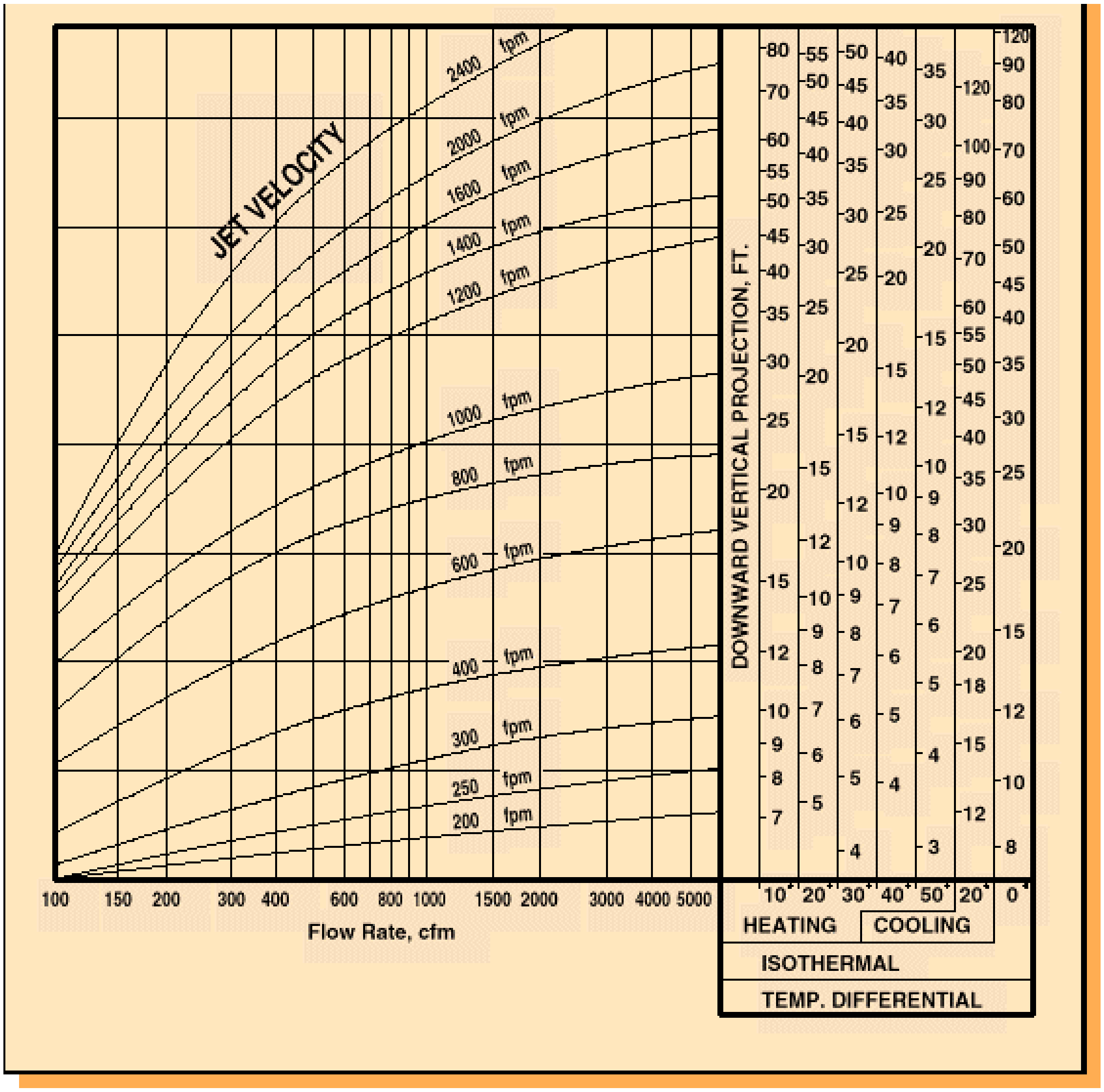

Figure 1: Vertical Jet Projection, Effect of Delta T. T_{50} Throw Distance.

4.) This chart assumes that the jet aspect ratio (width to depth) is near 1. Long linear slots may produce slightly different throws, due to their increased surface area and subsequent higher entrainment ratios. These jets will have slightly shorter throws than in Figure 1.

Horizontal Jets

Horizontal jets are more complex, as they may be effected by adjacent surfaces and grille discharge or blade angle in addition to temperature difference. In most cases, grilles are supplying cool air. The major concern in these situations is the drop of cold air into the occupied zone, and resulting cold drafts. Following are several examples, based on experimental data, for an airfoil blade sidewall grille with a discharge temperature 20 F° below the ambient temperature. In these graphs, data to a terminal velocity of 50 fpm is again shown. The shaded area on the far right of each graph indicates an NC equal to or greater than 30:

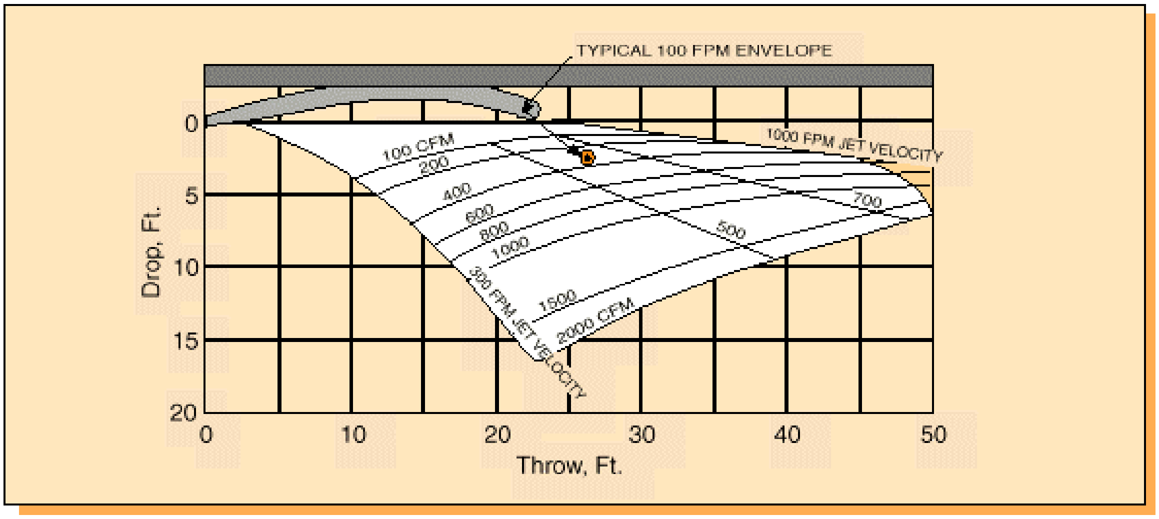

Figure 2: Throw and Drop for outlet 2-4 ft. below ceiling. 20° Vertical Deflection, 0° Spread.

If a sidewall grille is located slightly below a ceiling, with a 20-degree upward deflection, Figure 2 can be used to predict the drop of the jet, in feet, as well as the throw. Entering with the jet discharge velocity and the flow rate, a 300 cfm jet with a 600 fpm discharge velocity (0.5 sq. ft. free area) the example above shows a drop of about 3 feet below the grille location, and a throw of 27 ft. The adjacent ceiling provides some 'coanda' effect, increasing the throw beyond what would be found with no ceiling, as in the next example.

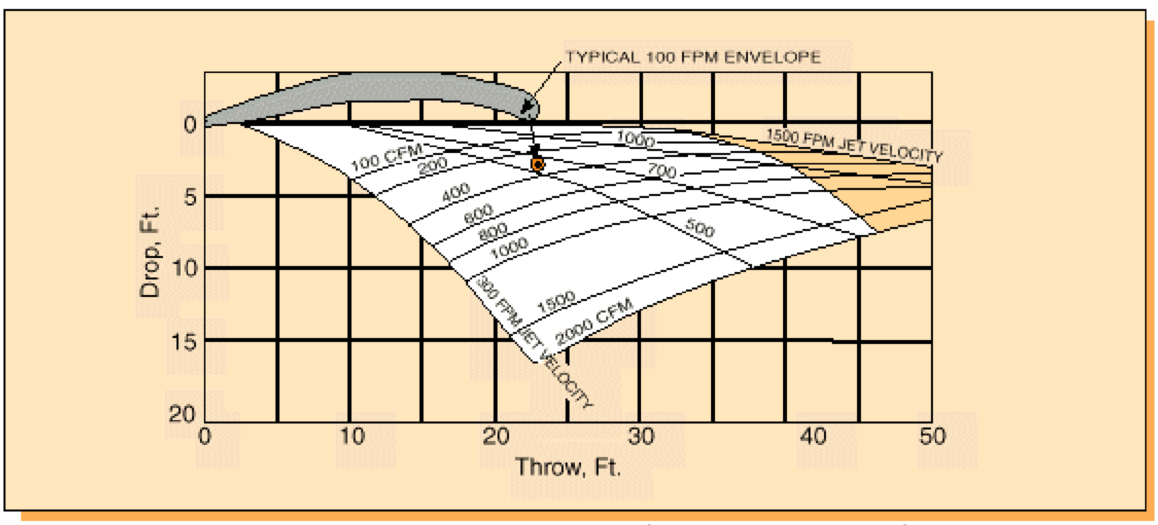

Figure 3: Throw and Drop for outlet without ceiling. 20° Vertical Deflection, 0° Spread.

In figure 3, with the same grille located with no adjacent ceiling, the jet does not travel nearly as far, only 23 ft., and drops 3 feet below the grille location. When there is no adjacent ceiling, the jet has more surface area, entrains more air, and loses momentum faster. There is no ceiling for the jet to cling to, so drop is increased.

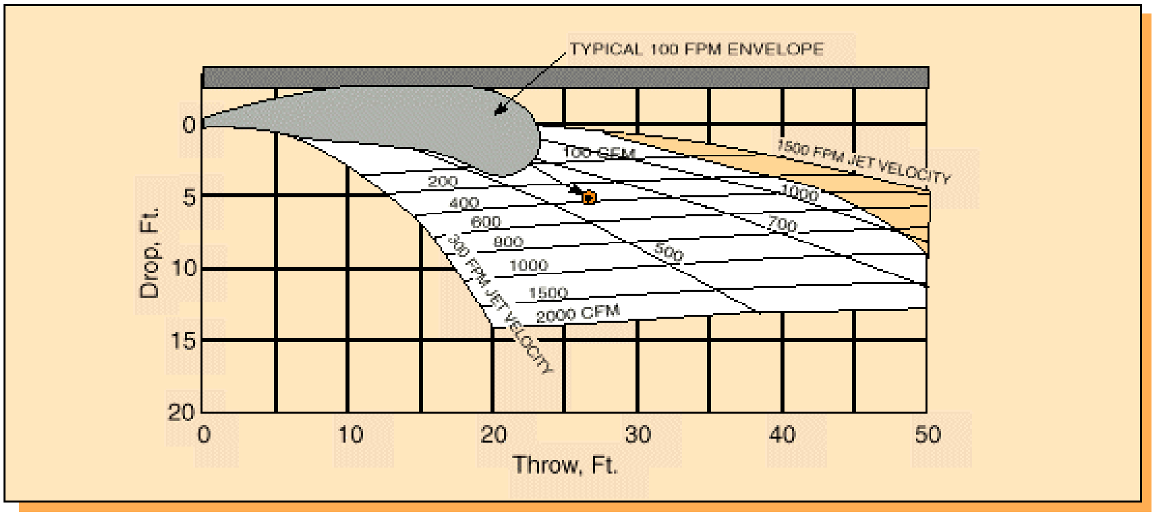

Figure 4: Throw and Drop for outlet 1 ft. below ceiling. 0° Deflection, 0° Spread.

In figure 4, the grille is located close to an adjacent ceiling, and is set with no upward deflection. Our example here has about the same throw, 27 ft., as the first example, but has over 5 ft. of drop below the grille. This is a result of the natural vertical spread of the jet. Note that the actual drop below the ceiling is similar to Figure 2 (the grille is closer to the ceiling in this example).

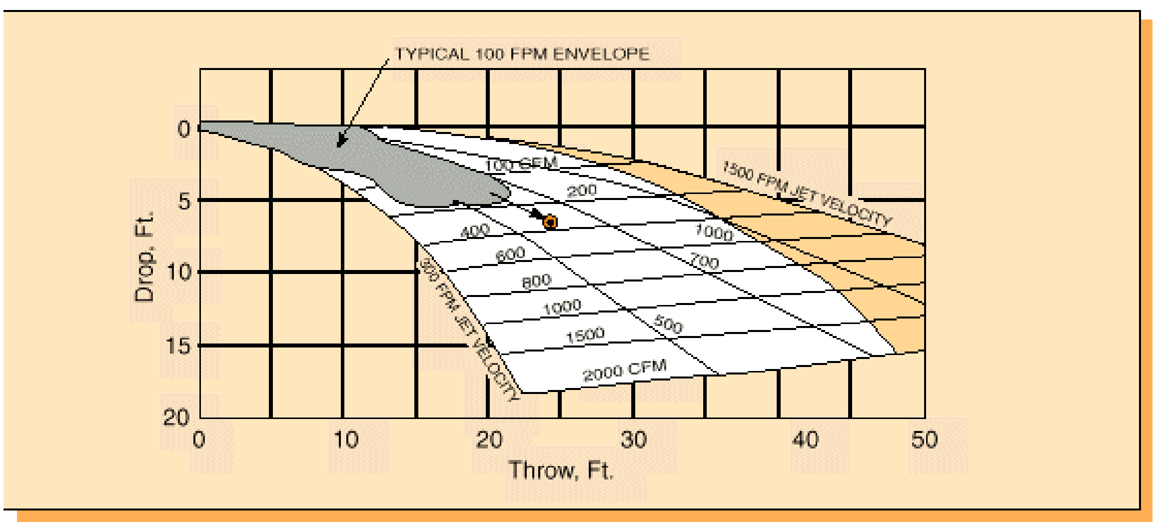

Figure 5: Throw and Drop for outlet with no ceiling. 0° Deflection, 0° Spread.

If there is no ceiling, and the grille has no deflection, then the drop is more pronounced, 7ft, and the throw is slightly less, to 25 ft. This scenario would approximate a situation where there was no grille at the duct termination, as well.

If a grille has vertical bars, some spread can be applied to decrease the throw. In Figure 6, the same grille is shown with the adjacent ceiling and the vertical blades adjusted to give about 45° of spread, and the horizontal blades are set to direct the jet 20° upward.

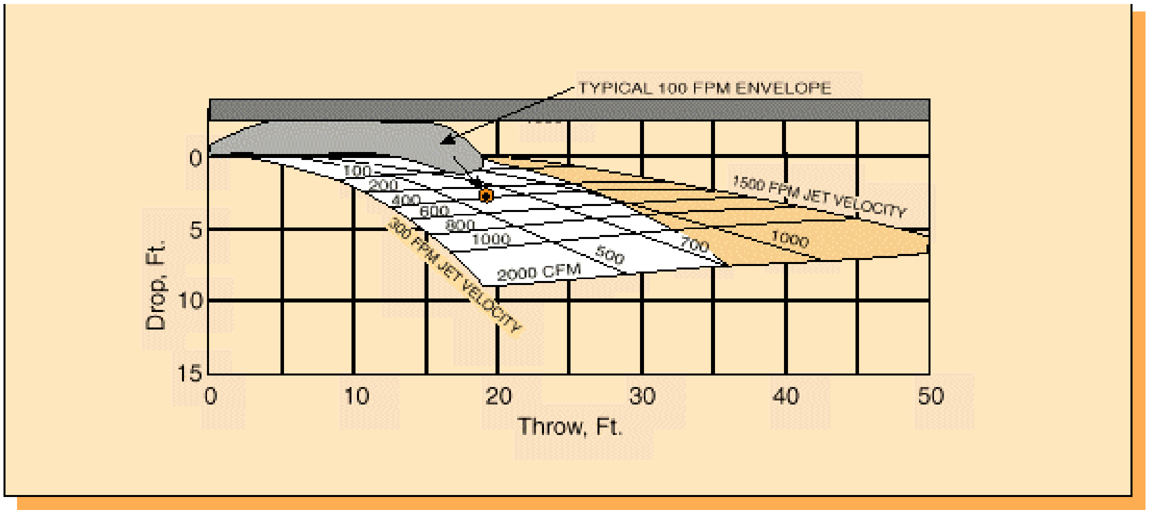

Figure 6: Throw and Drop for outlet 1-1/2 ft. below ceiling. 20° Vertical, 45° Spread.

As seen in figure 6, the throw is shorter, less than 20 ft, and the upward projection and adjacent ceiling keep drop to 3 feet or less. The combination of vertical deflection and spread also increases the area of the NC>30 band, on the right.

If there is no ceiling nearby, the throw is shortened significantly, to less than 15 feet, as shown in Figure 7, where only spread is employed. In this case, the ceiling is too far away for the airstream to attach to the ceiling.

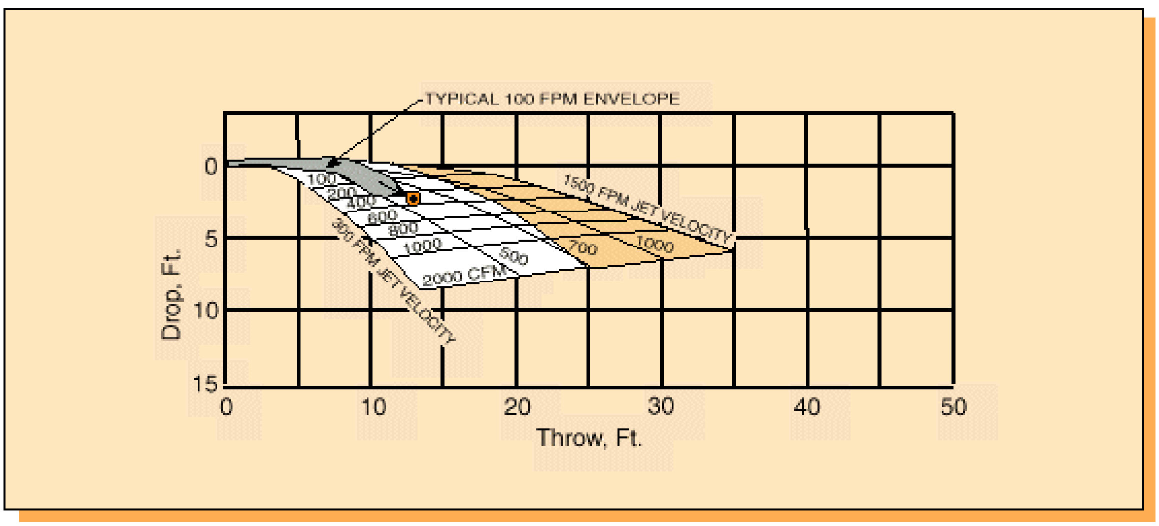

Figure 7: Throw and Drop for outlet 2-4 ft. below ceiling. 0° Vertical Deflection, 45° Spread.

From these examples, it can be seen that both grille adjustment and location have a significant effect on the resultant patterns. The goal in most designs is to provide coverage of all areas without excessive drafts.

Distributing from overhead

'Location, Location, Location'. Just as with real estate, the location of supply diffusers can make all the difference. Diffusers in open spaces can provide horizontal, vertical, or a mix of patterns. There are some typical diffuser characteristics that need to be understood here.

With ceiling diffusers, we must consider different airflow patterns than with side wall outlets. Ceiling diffusers, except for linear diffusers, typically exhibit flow in one of two patterns: circular or cross flow. The diagrams in **Figure 8** below show the main differences between circular and cross flow patterns.

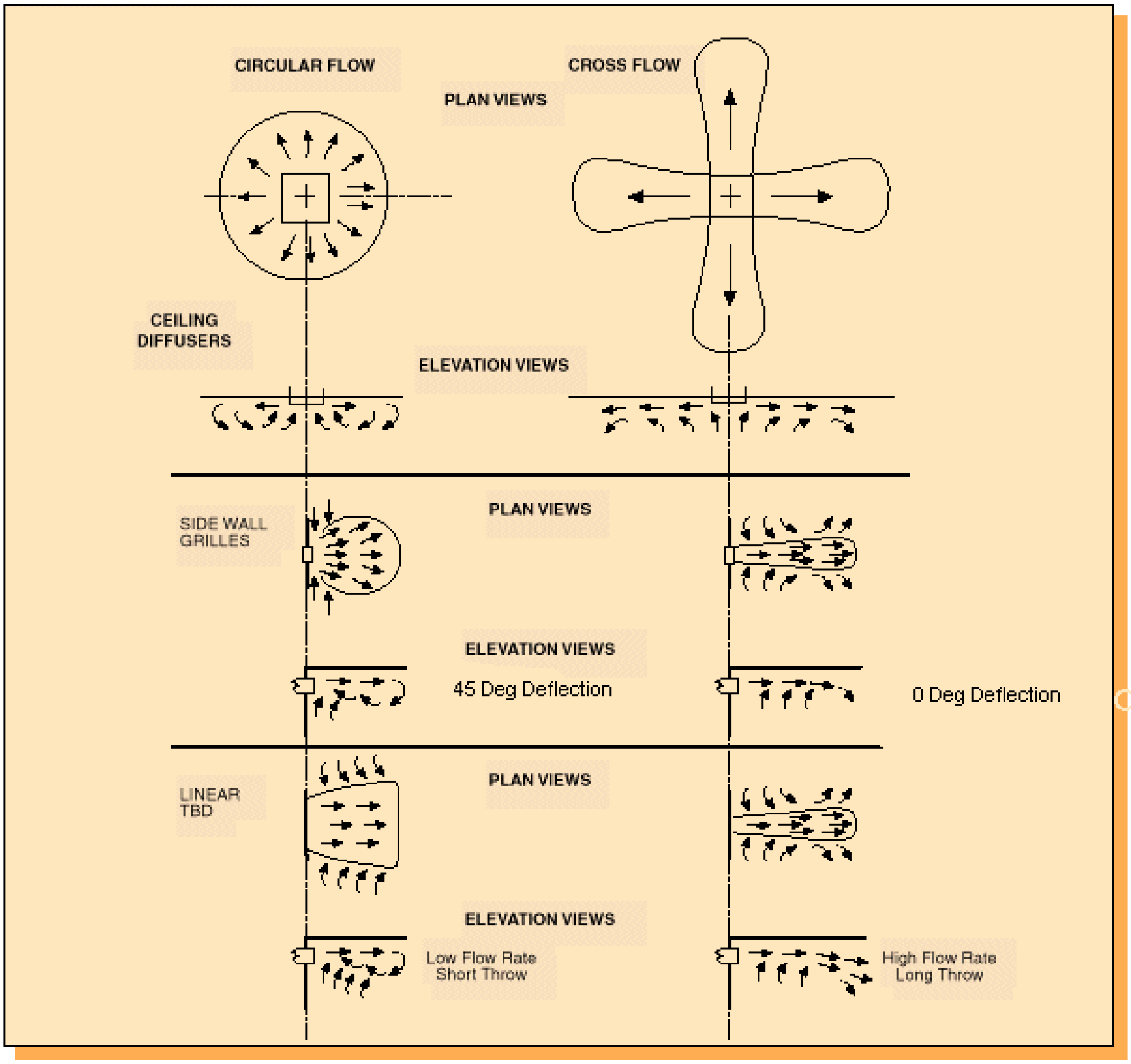

Figure 8: Specific airflow characteristics at high and low airflow rates.

In general, the circular pattern has a shorter throw than the cross flow. With the circular pattern, the discharge velocity is equal in all directions, while the cross flow has 4 higher velocity jets. The vertical diagram shows that during cooling the circular pattern has a tendency to curl back from the end of the throw toward the diffuser. This action reduces dumping and ensures that cool air remains near the ceiling, resulting in uniform temperatures throughout the space.

Cross-flow patterns with longer throw and individual side jets react in a manner similar to side wall jets. Near the end of the throw, during cooling, cross flow patterns continue in the direction away from the diffuser. The drop can also be dependent only on the airflow from each diffuser side. Both patterns are usually centered in equal spaces in large open areas.

Comparing the plan views of the circular and cross flow ceiling diffusers, the circular pattern has a much shorter throw than the cross flow for a given flow rate. The elevation views indicate that the circular supply jet at the end of its trajectory has a tendency to return to the diffuser being reinduced into the primary air. On the other hand, cross flow jet projection continues after the low terminal velocity just like the airflow from sidewall registers at 0° deflection. During cooling, the circular recirculating airflow results in less drop than with cross flow jets.

The wide spreading 45° deflection from the side wall grilles is very similar to ½ of the circular pattern and the 0° deflection grille is a pattern followed by all single nonspreading patterns. The horizontal projection from diffusers and grilles has been used extensively in commercial applications. Perimeter heating may need special treatment over the conventional horizontal air discharge at the ceiling level. Because of the extreme changes and critical comfort locations, we have included a special section on perimeter distribution.

Linear diffusers have a tendency to fold back like the circular pattern. This reaction results in less drop than expected during cooling from the linear diffusers as the airflow is reduced.

During cooling the air will often drop to the floor. A stratification zone can be formed near the ceiling, which may result in nonuniform temperatures below the stratification layer. The size of the stratification zone will vary, depending on the primary air and the natural heat sources in the space. With a constant heat source, a VAV system that reduces the flow will allow a larger stratification zone to form. This type of distribution allows high level stratification where air must be introduced from the ceiling. Return intakes can be located between supply sources.

Applications of this type of cooling can be used to maintain constant temperatures around machinery by projection to the floor near the machines with return over the machines. For example, a high-speed printing press may be handled this way. Projection may be obtained at low jet velocities with the machines located in a near equal temperature. Projecting more or less air to the floor level, providing more air to floor if the main heat source is at the floor level can control controlled heat loss over the machines.

During heating, the warm supply air demonstrates less projection, spreading out, rising toward the ceiling. The floor level becomes cooler and a stratification layer and zone can be formed at some level above the floor. Heat sources near the floor or the air projected all the way to the floor helps to reduce the neutral zone. Return intakes located at the floor in stratification zones will help.

Some diffusers (check with the manufacturer) can provide a good horizontal circular pattern, when located below the ceiling. With these designs, the jet will project upward toward the ceiling. This action is caused by a low pressure region being formed above the diffuser, allowing the higher pressure in the room to push the air up, in a manner similar to the effect often called the 'coanda' effect. It is also possible for some of these diffusers to allow adjustment of the air pattern so that air can come down in a variety of vertical patterns.

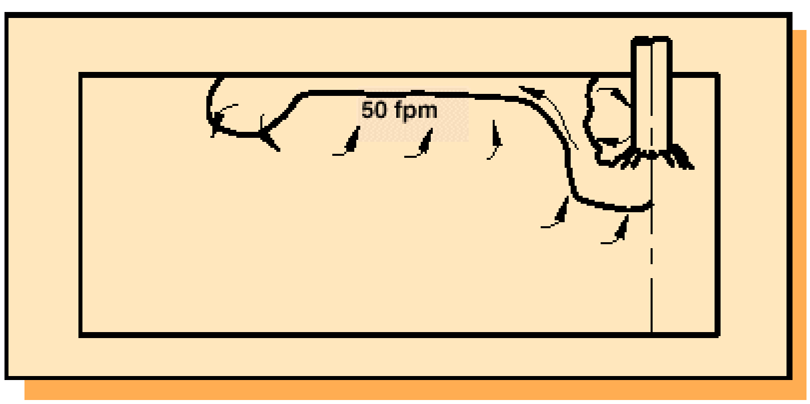

Figure 9: Circular ceiling pattern diffuser

It may be advantageous to locate a circular pattern diffuser upside down on top of an exposed duct. If near a ceiling, entrainment may be achieved. With no ceiling nearby, the diffuser will now tend to dump without dumping.

Cross flow pattern diffusers are not capable of causing the airflow to go upward when set for a horizontal pattern because the air pressure between the jets is equal to that in the room and, therefore, no low pressure is developed above the diffusers.

On the other hand, a cross flow pattern diffuser generally produces a better intermediate vertical projection than that of a circular pattern diffuser. Vertical projections from the cross flow jet pattern and with the velocities can be spread out almost uniformly from the center to the outside edges of these jets.

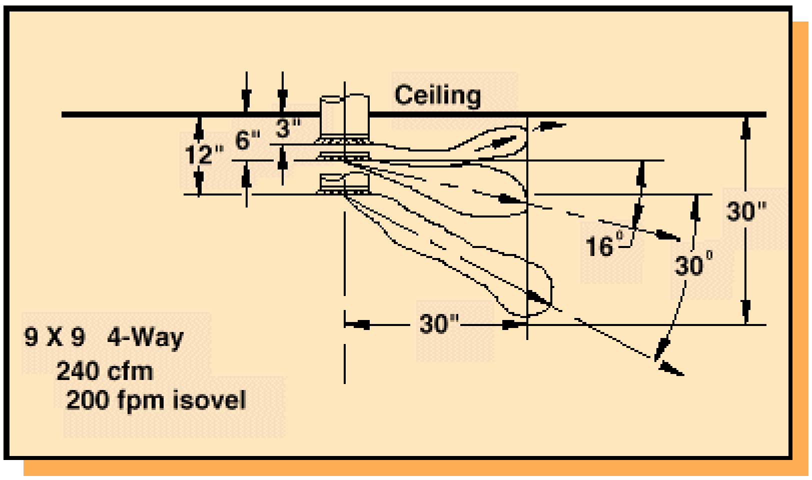

Figure 10: Cross flow pattern diffuser

Stratifying a high space

As a general rule, one should avoid conditioning spaces where there are no occupants. Stratification is often a useful strategy in large spaces. This requires, however, that the location of the diffusers be such that the diffuser jet does not break up the desired stratification layer. This is often a problem in very large spaces, such as atria, where the required ducts are preferred not to be seen. Sidewall grilles or slots are often employed, at around 15 feet above the floor, projecting over the occupied areas. Careful consideration of the previous grille jet parameters must be employed to avoid drafts in the occupied space. Heating is seldom a practical application of this technique. Also, as a rule, cold air will make it to the floor, regardless of where it is supplied.

Figure 11 below shows heating and cooling from a spreading horizontal projection at floor level. This performance compares to previous outlet types and locations with heating and cooling loads. Today a displacement system will use larger air quantities at low temperature differentials and low discharge velocities. These applications can be used under seats in theaters, around walls to form a ring of air around a space with people, or internal loads forming the rising plume up to the ceiling returns. It should be remembered that temperatures and velocities will be relatively low and uniform in occupied zones. This distribution system has been used extensively in Europe and is being promoted on the basis of the reduced energy consumption realized by the availability of economizer in that climate. **Note:** Vertical jet floor diffusers, which produce well mixed air in the occupied zone rather than displacement flow, do not qualify for this credit. These may be an option for some large spaces, but few are known to have been actually used except in some theater situations.

Spreading horizontal projection at floor level permits considerable stratification at high levels during cooling while maintaining uniform temperatures in the occupied zone. Although high velocities in the occupied zone may preclude use of this type of distribution for comfort cooling, application to situations with high internal loads or where occupant comfort is not of primary concern could be considered.

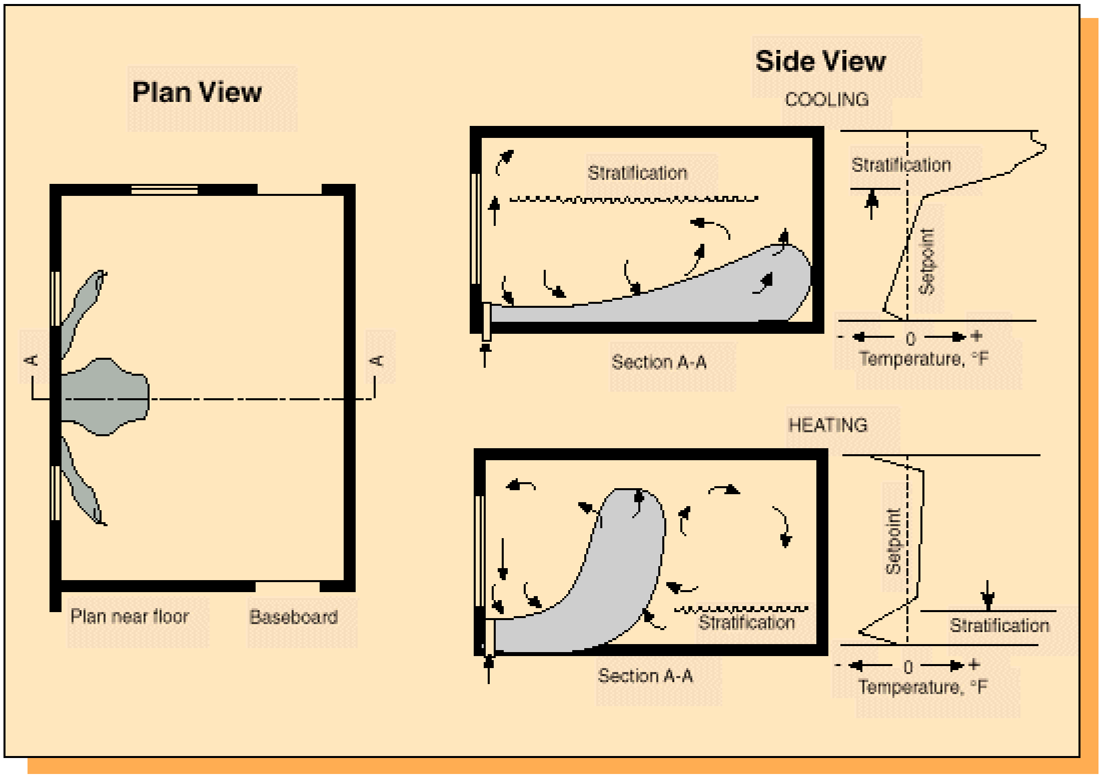

Figure 11: Spreading Horizontal Projection

Figure 12 below matches the actual definition given for displacement ventilation. Defined as a low velocity, low temperature differential air distribution across the floor level, displacement ventilation utilizes natural convection currents within the space to cause air to rise and form a neutral zone above a stratification level. The stratification level usually occurs at a level where the room load and air loading match.

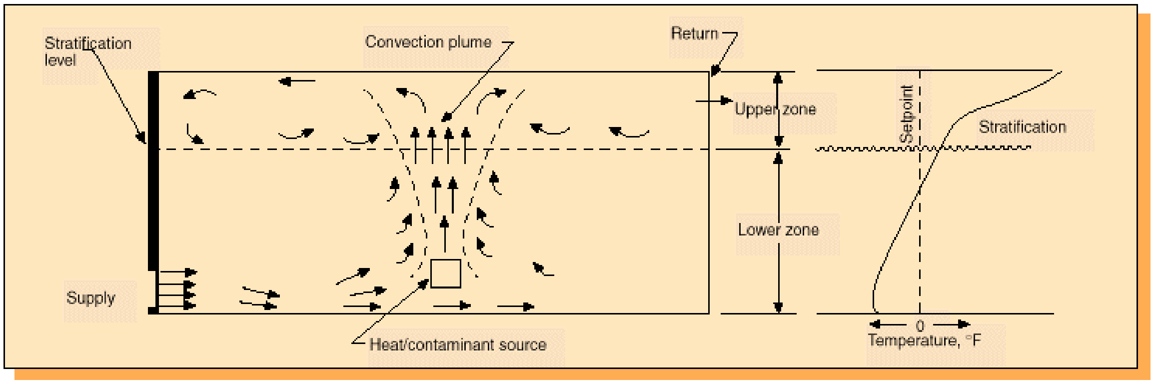

Figure 12: Displacement Ventilation

Displacement ventilation has a limited ability to handle high cooling or heating loads. The range of supply air temperatures and discharge velocities are limited to avoid discomfort, as the jet is located in the occupied zone. European office designs often use chilled ceilings or heated floors to overcome this limitation. Chilled ceilings, at least, are seldom an option in large open spaces, because of the distance from the occupant and temperature limits to avoid condensation.

Return Air Locations.

In most cases in offices, the location of a return is of little concern. In large spaces, however, returns can assist in controlling stratification. Returns should be placed in the occupied zone, if stratification is desired. This causes heated air to rise, and cooler air circulated in the HVAC system, saving energy and creating a more uniform environment in the occupied zone. See comments below on return grille acoustics.

The influence of the return air device on air movement is very subtle. We have seen a number of CFD analyses where many arrows point towards the return opening from great distances away. Those researchers need to get another model, as in the real world, air movement towards return openings is imperceptible except within a couple of inches of the opening.

Air Distribution noise recommendations and how to meet them.

Sound is not nearly as critical in many large spaces as it is in offices, where the noise source is very close to the occupants. There are obvious exceptions, such as museums, where air conditioning noise may be considered objectionable. Libraries, however, while traditionally very quiet, can benefit from a consistent background sound level, which may provide a level of speech privacy, and actually enhance the experience. In stadiums, air conditioning noise is probably of minimum concern.

In many cases, the acoustical consultant will request octave band data in order to perform a detailed analysis when designing auditoriums, concert halls, theatres, etc. Octave band data on most grilles is not available, but a close approximation can be determined using the following analysis method:

1. The sound power in the 5^{th} octave band (1000 Hz) = NC +10 dB.
2. The sound power in the 4^{th} octave band (500 Hz) = 5^{th} band +3 dB.
3. The sound power in the 6^{th} octave band (2000 Hz) = 5^{th} band -5 dB.

NC is a convenient tool, used industry wide, for providing a single number rating of terminal units and diffusers. If reasonable attenuation assumptions are employed, (such as provided in ARI Standard 885,) the use of NC can provide an excellent means of determining the suitability of these devices in a given application. Air Terminals typically cause the NC to be determined in the lower frequencies, with the result that the NC value is useful in room sound analysis only at the lower frequencies. Diffusers, on the other hand, typically peak in the mid frequencies, and NC values are typically in the speech interference regions. In most cases, NC values from Diffusers and Terminals cannot, therefore, be considered to be additive. In large spaces. VAV terminal noise is seldom a problem, except that there is a tendency to use very large sizes, where generated sound levels may be surprisingly high. Manufacturer's catalogs (or computer programs) can provide guidance. Be sure that all the assumptions stated in determining NC levels are understood.

While RC ratings may be an excellent tool for evaluating all sound in a space, they are not as practical as a means of rating air terminals. (For diffusers, they usually result in a value identical to the determined NC value.) When a terminal is rated against RC requirements, a low numerical value, with an 'R' rating usually results. The numerical value that results (the average of the 500, 1000 and 2000 frequency bands) is typically so low that it has no impact on sound quality in the space, and the resultant 'R' rating, gives no discrimination between units. RC is not therefore recommended, or practical, as a means of single number rating an Air Terminal.

Large spaces are often very reverberant due to hard surfaces, geometry, etc, and an acoustical consultant should be employed. The manufacturer's traditional assumption that the room will absorb 10 dB, is usually over conservative. Most large spaces will have more attenuation than this. More importantly, large spaces seldom experience 'near field' sounds, but more often sound is in a reverberant field, and calculations can be convoluted.

ARI-885 suggests the use of the 'Shultz' equation to determine room effect. Unfortunately, this equation assumes some sound absorption resulting from ceiling tile, furniture, or some other absorbing elements. Often, in large spaces, these are not present. For this reason, the Shultz equation is not a recommended method in large spaces.

Finally, the return air path is often overlooked as a source of noise in a space. The quantity of air being returned is always nearly the same as being supplied, but usually through many fewer air devices and shorter duct runs.

Summary:

As with most HVAC designs, common sense rules. Air distribution in large spaces can be summed up with a few of simple axioms:

- Cold air falls, hot air rises -The effect is about 1%/DegF delta-t for 75 fpm terminal velocity
- Don't condition spaces where people aren't
- Return air is just as noisy as supply air
- You can't suck out a match - returns have little direct influence on air patterns.
- Noise is not always bad - libraries and other spaces can benefit from constant background noise.

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