# Supply Outlets for VAV Systems

## How to select and test supply outlets for VAV systems

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The purpose of an HVAC distribution system is to provide a comfortable environment for the occupants. Variable air volume (VAV) systems can provide comfort with less energy use than constant volume systems, but unfortunately, too many VAV jobs exist that do not provide the comfort they should. If comfort is not met, energy saving does not mean much to the occupants.

In my work as a testing and balancing consultant, seminar instructor, and author of a manual on balancing and troubleshooting HVAC systems, I have witnessed and heard many complaints about VAV systems. Some of these are :

- A ceiling diffuser is shooting air out at 1000 fpm with a 15 ft throw on maximum flow. On minimum flow, the outlet velocity is only 300 fpm with the throw about 4 ft. This results in a glob of cold air dropping straight down out of the ceiling diffuser and sinking frigidly on occupants below.
- Shifting VAV air volumes cause air stagnation in one area of a room and uncomfortable drafts in another.
- One diffuser is whistling loudly and another is totally noiseless.

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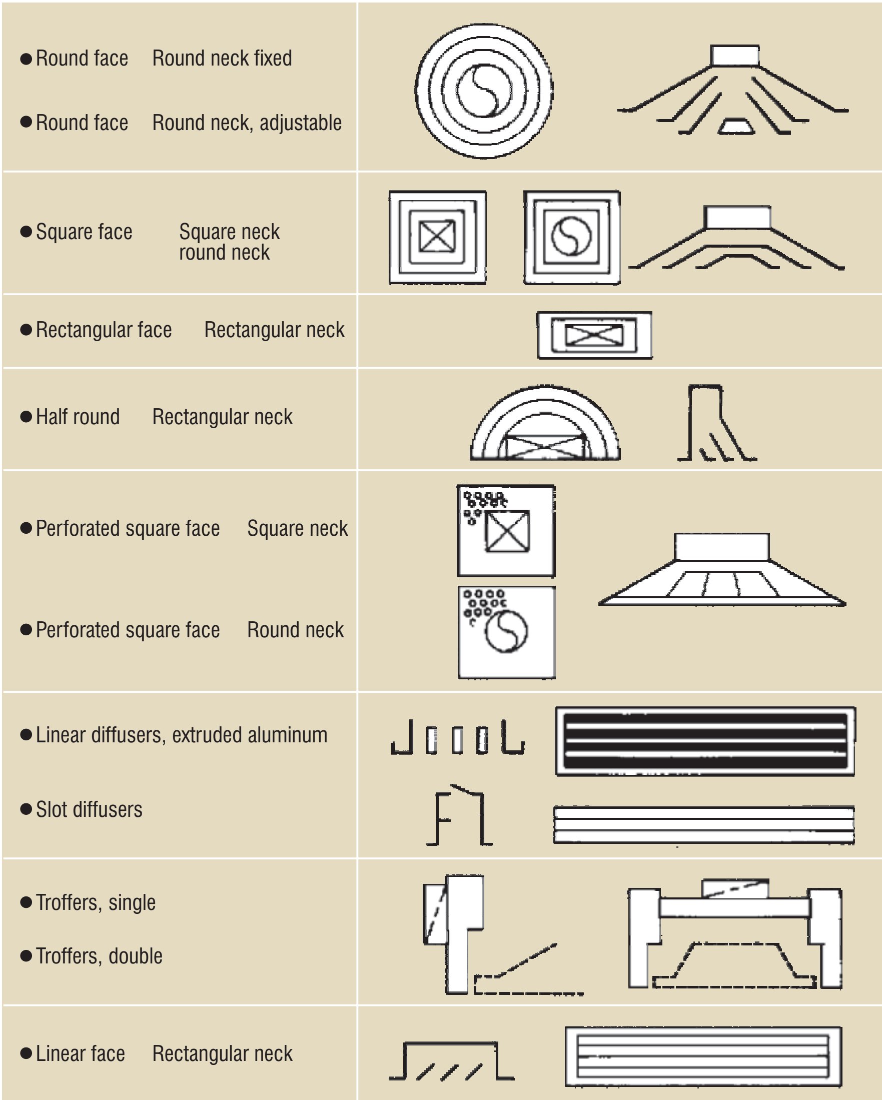


Figure 1: Types of air diffusers. *Courtesy of the Ventilation and Air Conditioning Contractors Association of Chicago.*

*continued on page 94*

*continued from page 91*

## Air distribution principles, definitions

A*k area* is the unobstructed air flow area of a diffuser or register (or grille when used as an air outlet) corrected for vena contracta area losses and for the instrument used to measure the air flow or velocity

- A*k* is the area term in the formula Q = *v* × A*k*.
- *Coefficient of discharge* for an air diffuser is the ratio of net (or effective) area at the vena contracta of an orificed air stream to the free area of the opening.
- *Drop* is the vertical distance the air moves between the time it leaves the outlet and the time it reaches the end of its throw.
- *Envelope of air* is the boundary surface of points of equal velocity that configure the terminal velocity profile.
- *Induction* is the mixing of room secondary air with the primary air ejected from the outlet and is a function of the velocity of the outlet air.

Because throw is a function of velocity and the rate of decrease of velocity is dependent on the rate of induction, the length of blow is dependent on the amount of induction that occurs. The amount of induction for an outlet is a direct function of the perimenter of the primary air stream cross-section.

- *Outlet velocity* is the velocity at the outlet of a supply diffuser of register (or grille).
- *Spread* is the angle of divergence of the air stream after it leaves the outlet. Horizontal spread is divergence in the horizontal plane, and vertical spread is divergence in the vertical plane.
- *Surface effect* is the tendency of air to remain substantially in contact with a ceiling or wall througout the length of throw. This surface effect counteracts the drop of a horizontally projected cool air stream.

*Terminal temperature* is a thermal distribution profile of the temperature of air at the borderline of the terminal envelope.

*Terminal velocity (radius of diffusion)* is the velocity of the air when it has reduced to a selected 150, 200, or 50 fpm. The radius of diffusion forms a terminal velocity borderline.

*Throw* is the horizontal or vertical distance that an air stream travels on leaving an air outlet. This distance is measured from the outlet to a point at which the velocity of the air stream has reached a definite terminal value. This velocity may be 50, 100 or 150 fpm as required for comfort.

Throw is proportional to the velocity of the primary air as it leaves the outlet but independent of the temperature difference between the supply air and the room air.

- There is excessive and unbalanced horizontal or vertical temperature stratification in a space as well as unacceptable air speed stratification.

The problems above stem from the changing of air volumes through the VAV terminals from maximum to minimum and the resultant effect on air flow out of outlets and on air and temperature distribution in the spaces. Primary causes include : poor supply outlet selection, sizing, and placement; ineffective testing and balancing of outlets or none whatsoever; and a lack of knowledge and skill in troublshooting room air currents, etc.

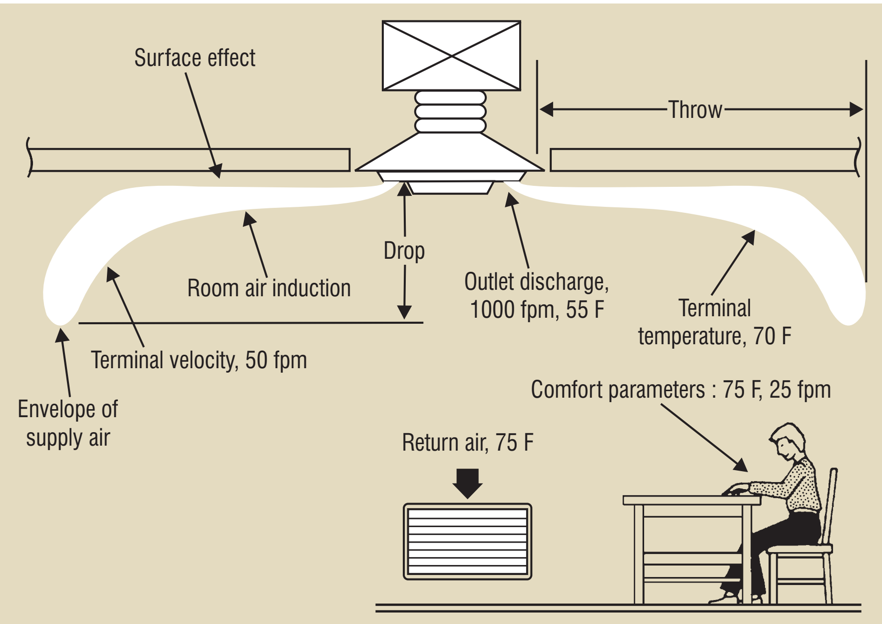


Figure 2: VAV discharge pattern at minimum flow.

### Diffusers, registers, grilles

A diffuser is a circular, square, rectangular, or linear slot air distribution outlet generally located in the ceiling. The slot type also may be installed in floors or window sills. It is comprised of deflecting vanes in various directions and planes arranged to promote mixing of primary air with secondary room air.* These types of supply air outlets are the ones most commonly used with VAV systems.

There are many types of supply diffusers available for HVAC systems, and they come in all shapes and sizes (*Figure 1*):

- Round face louvered diffusers with round or square necks and fixed or adjustable cones.
- Square and rectangular faced louvered diffusers with square or round necks.

** Other definitions relating to diffuser, registers, and grilles are shown in the box above.*

*continued on page 96*

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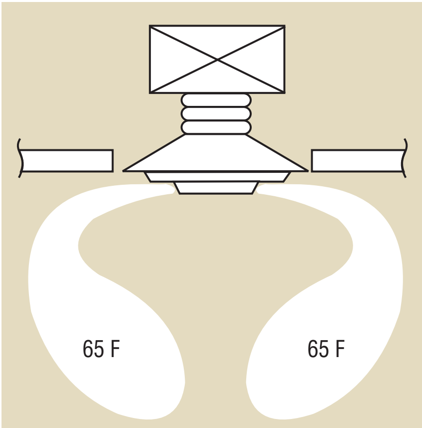


Figure 3: VAV design pattern at minimum flow.

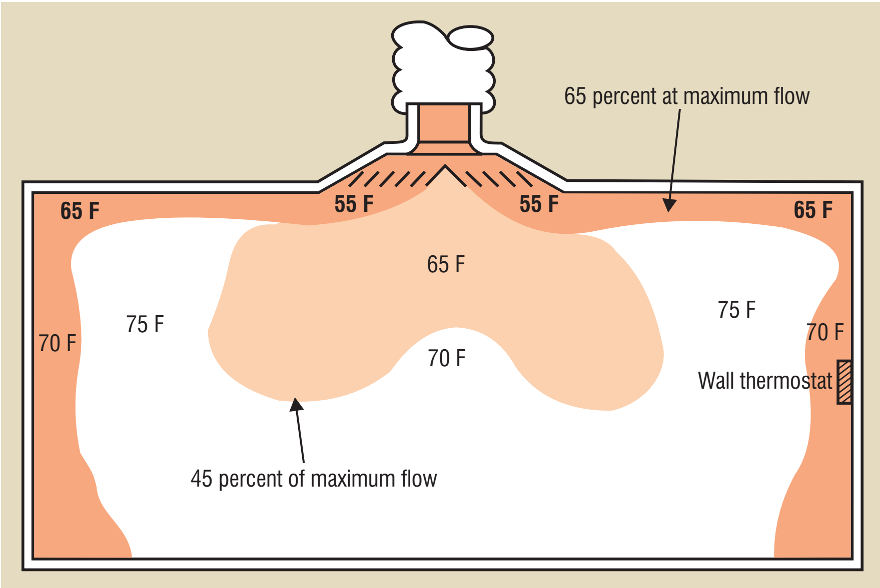


Figure 4: Diffuser temperature distribution at reduced flows.

- Linear and slot diffusers.
- Air troffers, which set over fluorescent light fixtures, available in single or double throw.
- Thermal type diffusers with a self-powered temperature control device within the unit that modulates the blades of the diffuser to control the volume of air supplied.

A properly selected ceiling diffuser for a VAV system will, at maximum flow, discharge the air so that it hugs the ceiling for a prescribed distance and then falls horizontally at equal terminal velocities (*Figure 2*).

A properly selected diffuser for a VAV system at minimum flow will discharge air so that it hugs the ceiling for a sufficient distance to mix with enough room air to change the terminal temperatures and distribute itself sufficiently for the occupants' comfort (*Figure 3*).

Typical temperature distribution problems that can occur with ceiling diffusers at 65 and 45 percent of maximum flow are illustrated in *Figure 4*.

Registers and grilles are vaned air distribution devices. They may be located in walls, ceilings, or floors and occassionally in window sills.

They are flat faced, square, or rectangular, set in frames and have one or two sets of vanes or bars running accross the face horizontally, vertically, or both ways, through which the air passes.

A grille is comprised of vanes only and has no control damper behind it. A register has the vanes and a control damper behind the vanes.

The vanes or bars may be fixed in position or adjustable at different angles of deflections, of different design configurations, and spaced closely together or far apart.

Typically, grilles are used more often as return air openings or direct exhaust air openings. Registers are used both as supply and return air devices.

Manufacturers' catalogs provide ratings to assist in the proper selection of air outlets. Published data include air volume, throw, drop, outlet velocity, terminal velocity, surface effect, noise criteria, and pressure drop of the outlet.

## Space comfort

There are three basic parameters governing comfort in a space that people involved in HVAC work can analyze and control:

- *Air velocity* – the general range of comfort is between 20 and 45 fpm depending on the air temperature and relative humidity.
- *Air temperature* – the general range of comfort is between 68 and 78 F, again depending on the other two factors, velocity and humidity.
- *Relative humidity* – the general range of comfort is between 20 and 70 percent RH, also depending on where the other two comfort factors are within their ranges.

For example, in a typical office space, normally dressed persons not exposed to any special radiant heat will generally feel comfortable with air passing over them at 25 fpm, 72 F, and 40 percent RH. However, increase the air speed to 40 or 45 fpm at the same temperature and RH, and they will sense a draft. Conversely, decrease the air speed to 10 or 15 fpm, and they will likely feel warm and uncomfortable.

There are, of course, many other external factors, which may or may not be controllable, that influence the physical comfort for any particular individual, such as :

- Radiation heat exposure. An occupant may be exposed directly to the rays of the sun, a heat emitting

*continued on page 98*

*continued from page 96*

| Application | Outlet velocity, fpm |
|---|---|
| Broadcost studios | 300-500 |
| Residences | 500-750 |
| Apartments | 500-750 |
| Churches | 500-750 |
| Hotel bedrooms | 500-750 |
| Legitimate theatres | 500-750 |
| Private offices, acoustically treated | 500-750 |
| Private offices, not treated | 500-800 |
| Motion picture theatres | 1000 |
| General offices | 1000-1250 |
| Department stores, upper floors | 1500 |
| Department stores, main floors | 2000 |

**Teble 1 : Recommended outlet velocities.**

device of some sort, etc.

- Level of physical activity.
- Amount, thickness, and type of clothing.
- Metabolic rate. This variable is based on a person's bodily process, food and drink consumption, etc.
- Physical and architectural obstructions.

There are other factors that go beyond the scope of this article. The point is that HVAC personnel can select and adjust supply outlets to deliver proper air speeds, along with adjusted and controlled supply air temperatures and humidities, to produce comfort for the occupants.

## VAV outlet selection

Generally, for best results, diffusers should be selected based on maximum flows, maximum permissible outlet velocities, and correct throws to allow for leeway on minimum flows.

Round or square louvered diffusers or slot diffusers with horizontal flows are recommended for VAV systems. When ceiling outlets with horizontal discharge patterns are being selected, the following factors should be considered.

- High entrainment outlets should be used. These achieve higher air velocity at minimum flow.
- Outlets should be chosen with smaller quantities of air. It is recommended that round and square diffusers should not generally exceed 400 to 450 cfm. Absolute values of throw will then vary minimally with the variation in flow rate.

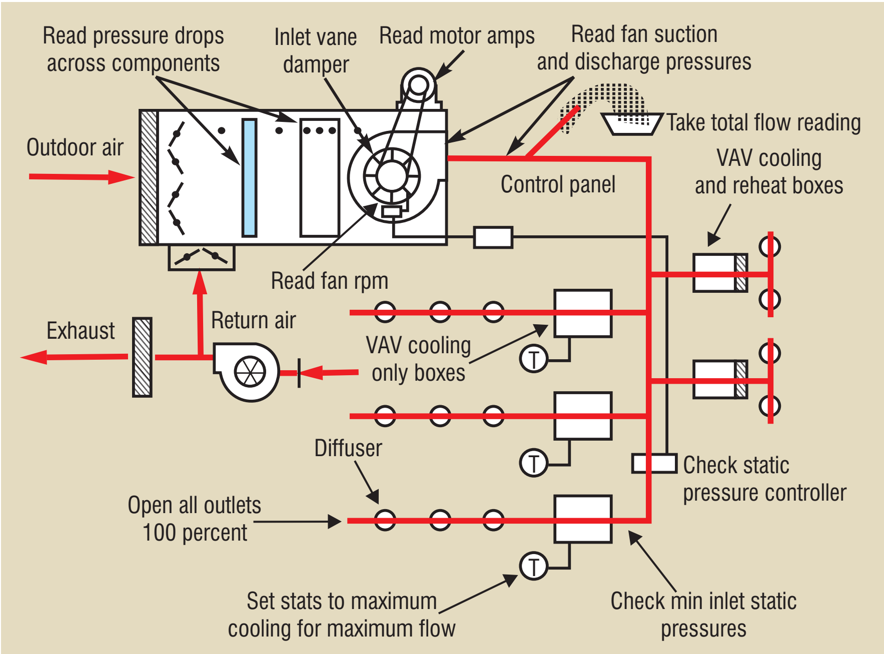


**Figure 5: Main items to check when balancing a VAV system.**

- For small flow reductions, all types of supply outlets have a tolerance in throw and drop that permits their use without concern. Volume reductions for round or square diffusers should not exceed the 25 to 50 percent range.
- For under-window types of distribution, vertical throw outlets with nonspreading patterns should be used. To prevent cool air from dropping back into the occupied space at minimum flow conditions, the outlet discharge velocity should be 500 fpm minimum. The throw coefficient should be higher to project air up to the ceiling.
- Ceiling slot type differsers are considered to have the most desirable characteristics for large volume reductions. Impinging velocities between diffusers should not exceed 100 fpm.
- Plenum slot diffusers can handle reduction in air flow that approach 0 cfm without dumping and still maintain horizontal air flows.
- Room air currents at occupied levels should range between 20 and 45 fpm for comfort. Under 20 fpm results in a sense of stagnation; over 45 fpm causes feelings of drafts.
- Special consideration must be given to air distribution and to sound levels at maximum and minimum flow in VAV systems. The combined sound level of the terminal unit and diffuser at maximum flow should be at least 3 dBA below the room ambient sound level. The sound level of an outlet is a function of the discharge velocity and system noise transmission, which is a function of outlet size. *Table 1* gives recommended air outlet velocities for various applications.

## TBA of VAV outlets

Outlet flows and room air distribution can be effectively controlled in VAV systems with proper outlet selection, sizing, and location. Problems with outlet flows and temperatures and room air currents can be detected with proper outlet performance information, knowledge of

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*continued from page 98*

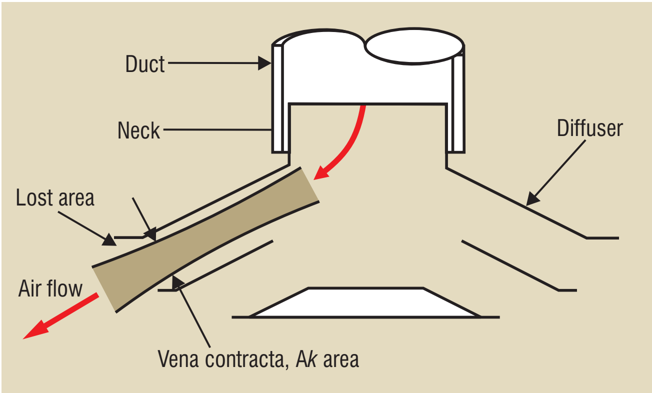


Figure 6: *Ak* illustrated for a diffuser.

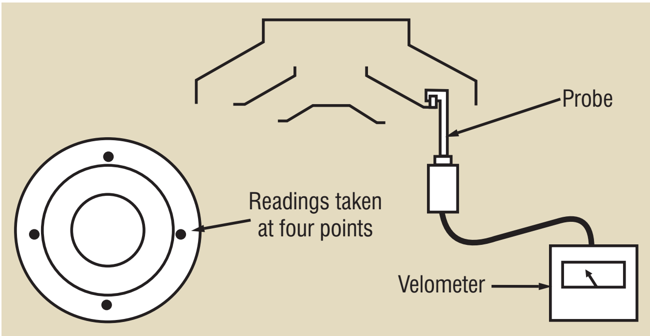


Figure 8: Typical method of taking velocity measurement of air diffuser.

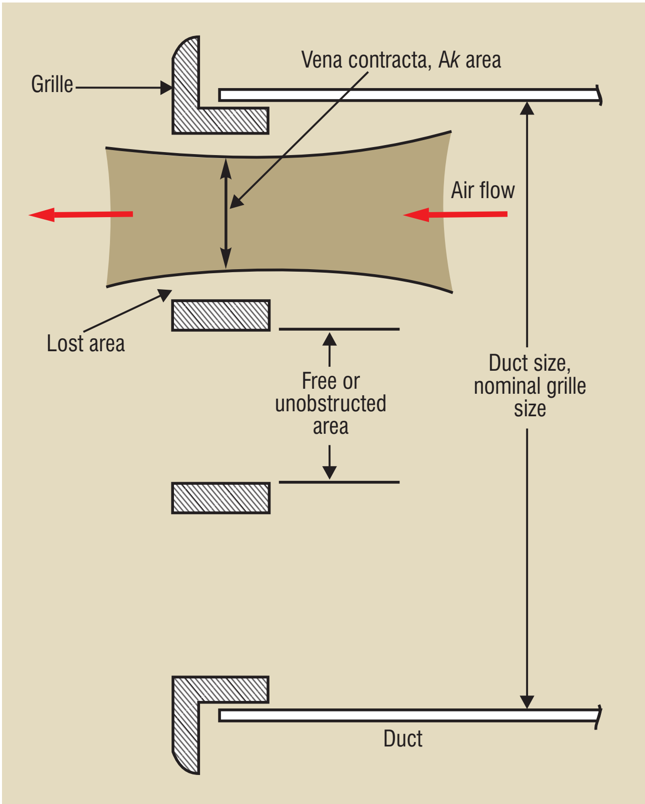


Figure 7: *Ak* illustrated for a grille (or register).

physical comfort parameters, the correct testing instruments, and effective testing procedures.

The general procedure for testing, balancing, and adjusting a VAV system is to set all the terminal boxes and the fan to maximum flow. This in effect makes the system a constant volume one.

Then, the fan, other central equipment, VAV terminals, and ductwork are tested to ensure that they are performing properly. Inlets on VAV boxes are checked for sufficient pressure to operate them (*Figure 5*).

When the VAV boxes are operating properly, the outlets are read and proportionately balanced for each terminal unit separately, as if they were independent systems. The technician balances the farthest outlets first, then works backward toward the VAV terminal.

After the low pressure side of the system (between the outlets and the VAV terminal) is balanced at maximum flow, all terminals are then set to minimum flow, and outlets and ductwork are balanced at minimum flow. The fan flow and pressure is checked first; then the inlet pressures at the terminals are checked for sufficient operating pressure.

When the fan and terminals operate properly at minimum flows, the low pressure outlets and ductwork are spot checked to see if they are delivering proportionate amount of air and that they have held their proportionate balance.

It is at this point that outlet flows and temperatures and room air distribution currents and temperatures are checked to determine if there are comfort or noise problems.

A flow hood is the preferred instrument to use to determine delivered air outlet volumes. The flow hood's advantage is that it gives direct cfm readings. This is faster and more accurate than using a velometer to obtain outlet velocities and applying *Ak* factors to determine air volume from the formula :

$Q = v \times Ak$

where

$Q$ = volumetric air flow, cfm

$v$ = air velocity, fpm

$Ak$ = corrected air flow area (see side bar for more detailed definition), sq ft.

At times, a velometer and the formula must be used if it is not practical to use a flow hood in a certain location or one is not available. If the *Ak* factors of the outlets are known, use a velometer and the above formula. *Figure* 6 and 7 illustrate *Ak* factors for a diffuser and a grille, respectively. *Figure* 8 shows the recommended procedure for measuring outlet velocities of a circular diffuser.

Every model air outlet has its own *Ak* factor for every applicable test instrument. When a flow hood cannot be used and the *Ak* factors

*continued on page 104*

*continued from page 100*

are not known (as may be the case in existing buildings), the following alternatives can be used :

- If the manufacturer and model of the diffuser are known, call the manufacturer or his representative to get the A*k* factor.
- Study the configuration and dimensions of the diffuser and use the Ak factor of a similar one from a different manufacturer.
- Take a pitot tube traverse of the branch duct leading to the particular diffuser to determine the air volume, and take a velocity reading at the diffuser itself with a velometer. Then calculate the A*k* factor using the formula A*k* = *Q*/*v*.
- Take a flow hood reading elsewhere on the same type and size outlet, if possible, for the air volume, and then take a velocity reading with a velometer. Plug this into the formula A*k* = Q/*v* and calculate A*k*.

When the A*k* value is determined, use the air flow formula to determine Q.

Instruments to use for troubleshooting room air currents and temperatures are :

- *Velometer* for checking outlet velocities to see if they meet design specifications and manufacturers' recommendations.
- *Hot wire anemometer* for checking temperatures and air current velocities in the problem areas of the space.

Read air speeds and temperatures all around the occupants who are sensing discomfort. Take four point readings at the points of the compass, N, E, S, W, around the occupant and at several levels to detect air speeds and temperatures that fall outside the parameters of 20 to 45 fpm and 68 to 78 F.

Take air current and temperature gradient readings at minimum and maximum flows.

Check outlet temperatures to make sure they conform to design and do not vary substantially. Check temperatures surrounding the thermostat and in other areas of the room to see that they substantially agree.

Check if supply outlets have been under or oversized. Check if return air outlets are poorly located or incorrectly sized. Check if there is diversity between the total air volume of the terminals and maximum fan air volume. ❖