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IAQ APPLICATIONS
WINTER 2000

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Welcome to *IAQ Applications*. This magazine has been created by ASHRAE to provide practical, applicable information on indoor air quality, and also provide a platform for debate on issues that surround IAQ.

The magazine will be published four times each year initially and is available by subscription. Its target audience is people who design, operate and maintain building systems. The content is geared toward information that can be applied.

ASHRAE President Bill Goodman said the magazine recognizes ASHRAE's authority and leadership in indoor air quality.

"ASHRAE has the expertise that the industry needs to help identify and solve problems," said Goodman. "This magazine brings together that expertise and knowledge. We think it will be a valuable source of information, and play an important role in bridging the gap between research and application."

EACH ISSUE of *IAQ Applications* will feature peer-screened technical articles, and columns from contributing editors and medical and industry experts. The columns are starting points for discussions on the issues. Readers are encouraged to respond by e-mailing (iaq@ashrae.org) comments to a Reader Feedback section that will debut in the next issue.

A special part of each issue will be columns by chairs of ASHRAE standards committees that deal with IAQ. Of course, much of this coverage will revolve around ASHRAE Standard 62-1999. Other standards that will be covered regularly include ASHRAE's proposed residential ventilation standard and the newly revised standard on filtration.

In addition to reviewed features and columns, each issue will carry an industry calendar and other information pertinent to the magazine's focus and mission. IAQ news features will be added in subsequent issues.

THE NEW publication is led by an editorial board of Barney Burroughs, Presidential Member/Fellow ASHRAE; Dennis Stanke, Member ASHRAE; Steve Taylor, P.E., Member ASHRAE; and Kimball Ferguson, P.E., Member ASHRAE. The contributing editors are Larry Schoen, P.E., Member ASHRAE; Art Wheeler, P.E., Fellow/Life Member; and Dick Pearson, P.E., Fellow ASHRAE.

The *ASHRAE Journal* editorial staff is producing the magazine. Fred Turner is editor and Sarah Foster is managing editor. ASHRAE's Journal/Insights Committee sets editorial policy.

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Maximizing Air Change Effectiveness

By Dan Int-Hout
Member ASHRAE

Although environmentally controlled spaces can consume significant amounts of energy to maintain a stable environment within the structure, this energy cost often is insignificant when compared to occupant salary costs. (A ratio of 2,000/1 can be demonstrated for a salary/energy cost ratio.) Conditioned and ventilation air must be delivered effectively to building occupants in a manner that maximizes the mix of return and "fresh" ventilation air, and minimizes occupant discomfort.

Dan Int-Hout is with Carrier Corporation. He is the chair of ASHRAE Standing Standards Project Committee (SSPC) 55, *Thermal Environmental Conditions for Human Occupancy,* and is a consultant to SSPC 62.1P, *Ventilation for Acceptable Indoor Air Quality.* He also serves on several ASHRAE technical committees.

At a minimum, the proper selection of diffusers is necessary to ensure occupant comfort and adequate ventilation. It is possible, however, to provide more than the minimum requirement to optimize occupant satisfaction. This requires an understanding and a selection of ventilation equipment that exceeds the minimum requirements, and an understanding of the psychology of building occupants.

ASHRAE Standards for ventilation (62-1999) and comfort (55-1992) state minimum requirements for the resulting ventilation mixing, air temperatures and airspeeds, and even turbulence intensity (the rate of change of the local air speed) in the zone. Recent articles have shown methods of selecting diffusers to meet the minimum recommendations in the *ASHRAE Handbook—Fundamentals*. These articles concentrate on proper diffuser selection, location and design. Complaints of "stuffiness" finally are being diagnosed correctly as temperature, not IAQ problems. Also, the effect of occupant intervention in maintaining personal comfort is being given more consideration.

Additional ASHRAE research has shown that the mean air speed in a room, with properly selected diffusers (ones that do not "dump," or have primary or secondary air jets entering the occupied zone) is dependent more on room load than diffuser airflow rate. Thus, occupants who desire "more sensation of airflow" cannot be satisfied with changes in ceiling diffusers. Lowering the local temperature, however, often has the same effect.

ANSI/ASHRAE Standard 55-1992, *Thermal Environmental Conditions for Human Occupancy* is in review. The presently accepted comfort envelopes for two clothing levels are shown in *Figure 1*. The two areas represent 1.1 clo (left side) and 0.5 clo (right side), and are no longer identified as summer or winter envelopes. Note the small area of overlap.

Even with perfect air distribution, clothing diversity alone cannot achieve complete occupant satisfaction. Differences in metabolic rate between individuals skew this curve further. Methodologies to resolve this problem are still being developed.

At least one lawsuit considered the Handbook recommendations for diffuser selection to be the "acceptable standard of care." When air distribution is provided from the ceiling, a thoroughly mixed condition throughout the space is the desired result. Research has proven that with properly selected ceiling diffusers, excellent air distribution and ventilation mix-

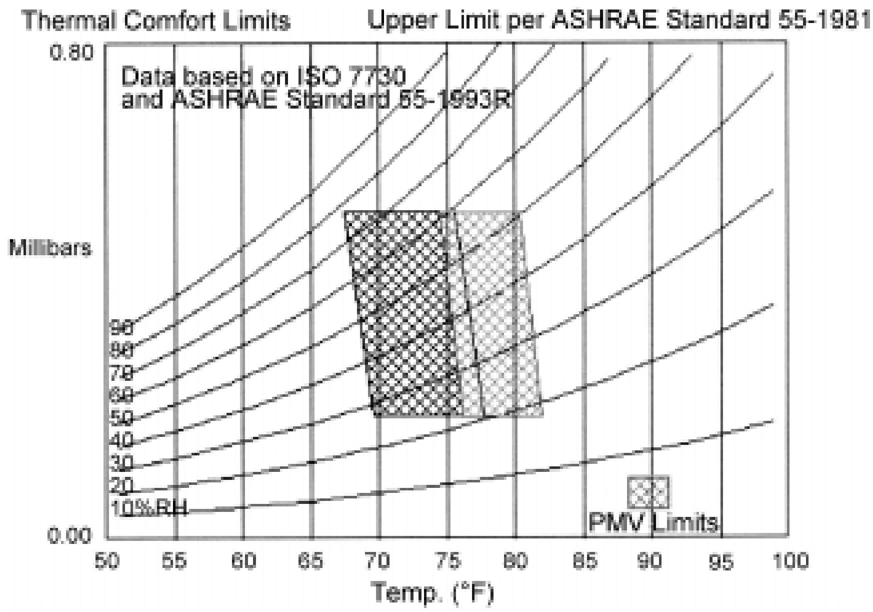

Figure 1: Proposed ASHRAE Standard 55 comfort envelopes.

ing can be achieved with many types of diffusers, and in many types of spaces, including the open landscape office, with partitions. When there are problems, it is the author's experience that there was little (or no) actual air distribution design, loads are considerably different than planned, or products were installed which did not meet the designer's specifications.

In the *Handbook—Fundamentals*, Chapter 31, the two basic rules for overhead heating and cooling are:

Cooling mode: Diffuser selection should be based on the ratio of the diffuser's throw to the length of the zone/area being supplied, at all design airflow rates, to achieve an acceptable air diffusion performance index (ADPI).

Heating mode: The diffuser to room temperature difference (Delta *T*) should not exceed 15°F (8.3°C), to avoid excessive temperature stratification. Standard 55-1992 defines the level of acceptable vertical temperature gradation.

ADPI statistically relates the space conditions of temperature and air speed to occupants' thermal comfort. This is similar to the way NC relates local conditions of sound to occupants' noise level comfort. Acceptable ADPI conditions in the *Handbook—Fundamentals* are for velocities less than 70 fpm (0.36 m/s) and velocity-temperature combinations that will provide better than the 80% occupant acceptance.

To obtain optimum comfort in the space, the Handbook recommends selecting the outlet from the throw ratios in *Table 1,* to achieve an ADPI of at least 80%. These data are reported in the *Handbook—Fundamentals*, Chapter 31, *Table 2*. They are based on a relationship between isothermal throw and ADPI under load. These data represent a typical load of about 20 Btu/h per ft^2, and represent about 20° Delta *T* at 1 cfm/ft^2 for most applications.

ADPI may be predicted from *Table 1,* or may be tested using the procedures outlined in ANSI/ASHRAE Standard 113-1990, *Method of Testing for Room Air Diffusion*. Thousands of tests have been conducted that consistently validate the values shown in the table.

ASHRAE describes the mixing of supply and room air as air change effectiveness, or ACE. This term is used in ANSI/ASHRAE Standard 129-1997, *Measuring Air Change Effectiveness* and in the public review draft of proposed addenda to ASHRAE Standard 62-1999, *Ventilation for Acceptable Indoor Air Quality*. While there have been no reported tests where the ACE was significantly below 100% when cooling from the ceiling, it has been demonstrated that the ACE may decrease significantly in heating mode.

Standard 62-1999 assumes a ventilation mixing of 100% in setting minimum ventilation rates. If the ACE is less than 100%, then the amount of outside air must be increased above the required minimums. With presently available information, when a high ADPI is measured, the ACE is high as well. It is possible, however, to have a high ACE and a low ADPI, especially if the HVAC system air is supplied directly into the occupied zone. Uniform comfort will not be likely in this case, however.

ADPI Selection Procedure, Typical

A typical procedure for using ADPI to select a diffuser size follows.

1. Select type of diffuser.
2. Check manufacturer's recommendations to determine if the diffuser's jet pattern will have excessive drop at the desired flow rate, using ceiling height as a parameter. (The jet should not penetrate the occupied zone.)
3. Select the characteristic length (L) from the plans. This is the distance from a diffuser to a wall, or to the centerline between two diffusers, etc.
4. Determine the desired diffuser (iso-

Table 1: ADPI range.

Device Type	T_{50}/L For Max.	Max ADPI	Range of T_{50}/L	For ADPI >
Grille	1.5	85%	1.0 to 1.9	80%
Round	0.8	93%	0.7 to 1.3	90%
Slots (T_{100})	0.3	92%	0.3 to 1.5	80%
(T_{50})	0.5	92%	0.5 to 3.5	80%
Troffers	1.0	95%	< 4.5	90%
Four Way	1.0	95%	1.0 to 3.4	80%

thermal) throw at maximum flow by multiplying the characteristic room length times the minimum throw ratio from *Table 1*.

5. From the manufacturer's performance table select a size with a T_{50} for the diffuser as close as possible to the optimum, at the required cfm.

6. Check sound levels for NC compatibility and excessive pressure drop, and increase size if excessive noise or pressure drop. (It is possible that the desired diffuser cannot meet all requirements—back to the drawing board!)

7. With VAV systems, recheck the analysis at the expected minimum occupied flow rate.

This selection will result in maximum comfort for the application. In the event that this selection cannot be made as outlined, supply jet mapping can be used to determine the discomfort areas in the space.

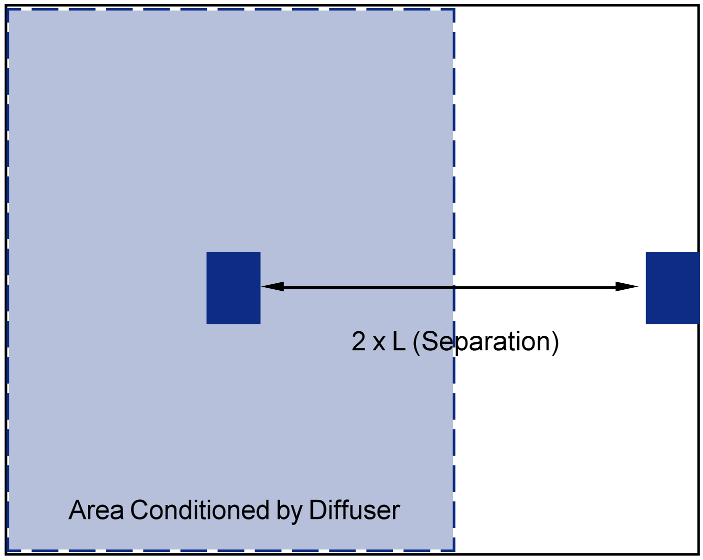

Figure 2: Diffuser area and characteristic room length.

ADPI Selection Procedure, cfm/ft²

Selecting for ADPI in each room can be tedious, and may not be possible at the time of diffuser selection because the room layout may not be known (moveable full height partitions and walls may lead to uncertainty about final zoning). In addition, when VAV systems are used, the diffuser must be selected that operates at design flow rates (typically at designed maximum loads) and at reduced load and flow rate. As an alternative to determining the T_{50}/L for each room and load, it is possible to determine some characteristic curves for different diffuser types based on the airflow rate/unit area. This allows an "operational envelope" to be predicted for different diffuser types.

The process requires that a typical diffuser supply area be defined, and that this area be combined against a flow rate/unit area and the diffuser's throw performance, and the result plotted on a graph. When this is done, the envelope of acceptable operation of a diffuser based on cfm/ft² is presented.

The diffuser spacing is twice the value of "L," or equal to the (average) distance between the diffuser and the adjacent wall. The area served by a four-way pattern diffuser is therefore $(2 \times L)^2$.

Using catalog performance data, a graph can be created for any diffuser as a function of flow/unit area and diffuser spacing, for a given load.

In the example shown in *Figure 3*, the x-axis is flow rate/unit area, and the y-axis is half the separation distance, or L, the characteristic room length. The curved lines identified by flow rate are simply calculations of flow vs. area served, while the boundaries (indicated as "Range") are computed from the ASHRAE maximum and minimum T_{50}/L ratios for this type of diffuser. The flow rate where NC = 35 is identified. Performance within the area bounded by the lines should achieve an ADPI of 80% or greater, a minimum requirement.

A procedure to calculate diffuser spacing using these charts follows:

1. Determine the cfm/ft² range for the space based on loads and desired supply temperatures. (Minimum flow rate should be based on minimum occupied loads, not ventilation minimums.)

2. From the 80% ADPI range charts for a given diffuser (*Figures 4* and *5*), select a diffuser type that works over the range of expected airflow rates, checking at both maximum and minimum occupied rates.

3. Check manufacturer's recommen-

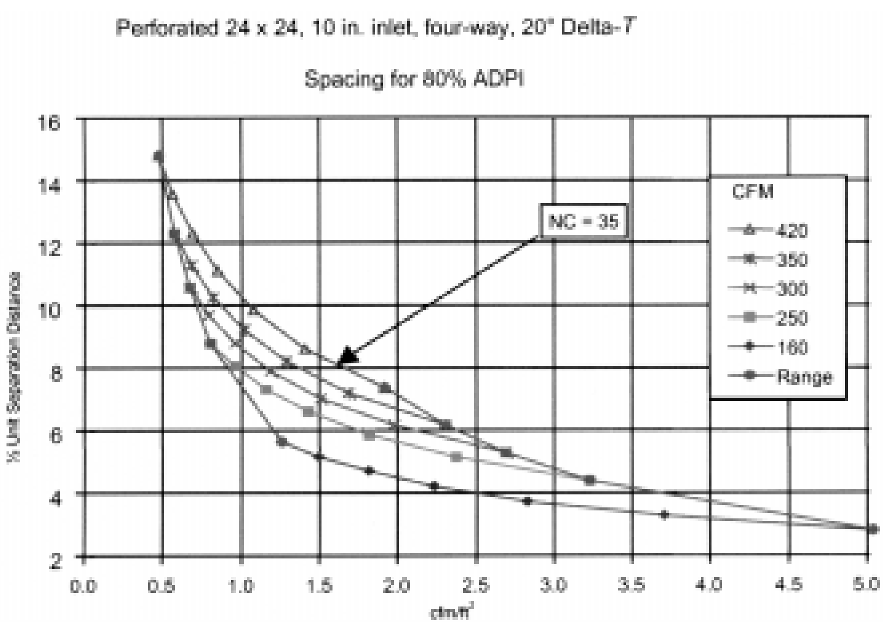

Figure 3: cfm/ft² chart for a perforated diffuser.

dations to determine if the diffuser's jet pattern will have excessive drop at the desired flow rate, using ceiling height as a parameter. (The jet should not penetrate the occupied zone.) If it does, use a lower flow rate (and more diffusers).

4. Check product performance tables sound levels for NC compatibility, and check for acceptable pressure drop. If too high, consider larger sizes.

5. Determine diffuser spacing from selected chart.

Linear Diffusers

For linear diffusers (or any one- or two-way pattern diffusers), the analysis is a little different. The side-to-side spacing becomes a variable in the equation, and the result is a graph with multiple x-axis.

For most linear diffusers, the side to side spacing should not exceed 8 ft (2.44 m) for the analysis to be valid.

The cfm/ft^2 must be selected with the side-to-side spacing as a parameter. With an 8 ft (2.44 m) spacing, the above diffuser can operate down to 0.1 cfm/ft^2.

Note that ASHRAE's selection chart uses the 100 fpm (0.51 m/s) throw (T_{100}) as the selection criteria for linear diffusers.

Selecting diffusers using these charts will result in selections that meet the requirements of the *Handbook—Fundamentals*. When these guidelines are followed, excellent air distribution, uniform temperatures and no objectionable drafts should be expected in the space. Providing that acceptable temperatures are established as a function of the occupant's clothing and activity levels, occupant comfort should be assured as well. IAQ, which is often a perception issue, will less likely be perceived as a problem as well.

Several published research papers have shown the 5 ft or 6 ft (1.5 m or 1.8 m) high partitions (in a 9 ft [2.7 m] high room) do not adversely affect air circulation if the diffusers meet the ADPI criteria. The heat loads generated in cubicles create convection circuits that mix the air fairly well. However, if the diffusers have excessive drop, or if there is insufficient mixing at the ceiling due to low airflow or diffuser throws, then localized regions of discomfort can result, regardless of the partition height.

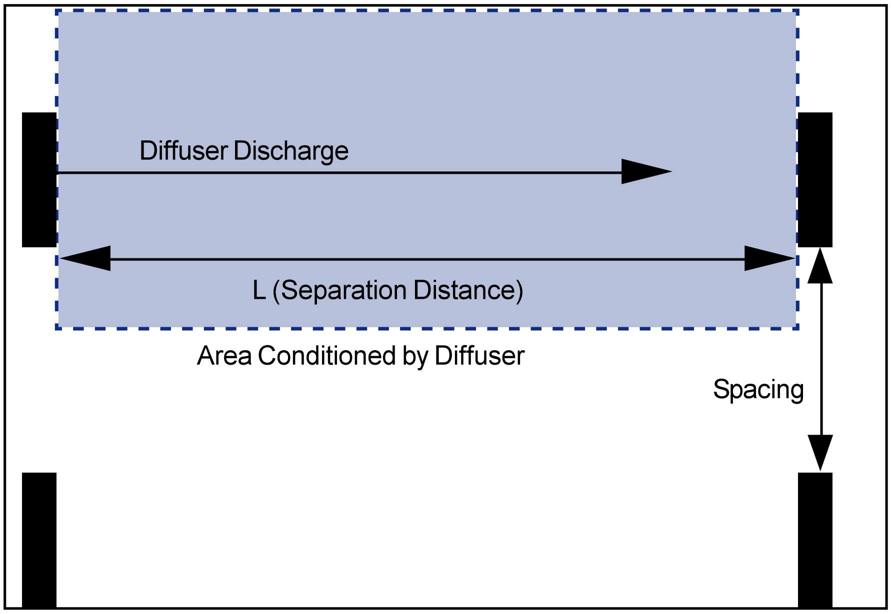

Figure 4: Linear diffuser area relationships.

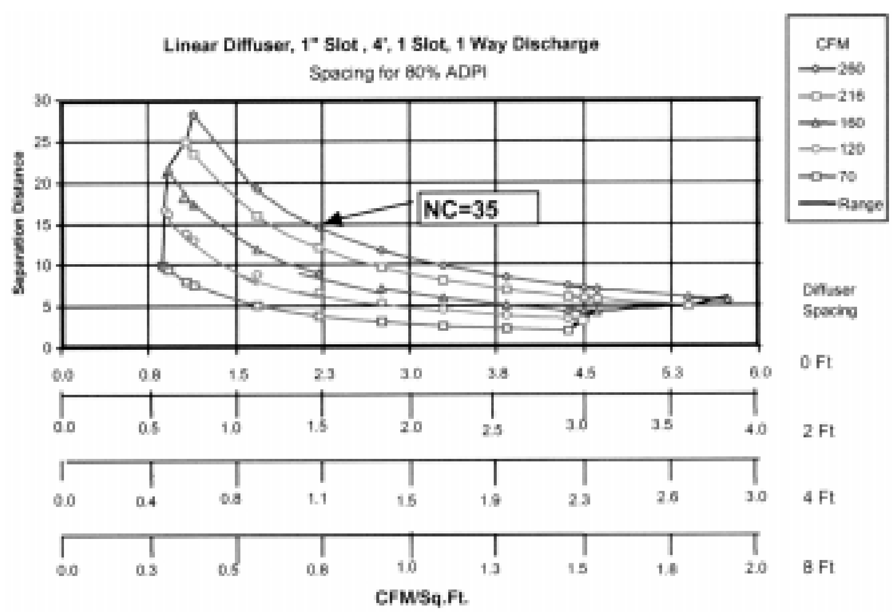

Figure 5: Linear diffuser (one-way pattern shown).

Post Design Changes

The previous rules work well if the office is inhabited and loaded as designed. Office space layouts, however, are often revised in response to changing needs, reorganizations, equipment and changing tenants. When space use changes are anticipated, diffuser selections should be reconsidered, as well. Significant changes in required airflow may push the installed diffusers out of their recommended operating range, and full height partitions may require reanalysis of the room's characteristic length.

Alternately, loads may be significantly less than originally designed, and diffusers with VAV systems may be operating at or below the lower limit of the performance envelope. Smaller diffusers, or sometimes more small diffusers, may be required to achieve acceptable air change effectiveness rates. It may be worth considering active discharge temperature control as a strategy to assure diffuser airflows stay within limits. Raising or lowering the discharge temperature will cause a VAV system to respond accordingly with increased or decreased airflow. A study commissioned by EPRI shows that standard diffusers work well with low temperature air, when selected in accordance with the above ASHRAE table, on the basis of isothermal throw. Condensation is an issue with some designs, and the diffuser manufacturer should be contacted to determine which diffusers would work with very cold air. In most cases, building humidity levels are reduced as the supply air temperature drops. This is a concern only near outside entrances.

Occupant Control

There is evidence that when occupants have control of their environment, satisfaction levels go up, even when the measured conditions would indicate discomfort. The revised ASHRAE comfort standard may well address this issue. There are cautions to be considered, however, in applying occupant control to a design. If all occupants have control over their space's airflow rate, and for some reason a significant number of them close their air supply dampers, the system will be unable to control the overall space temperature, and ventilation air will not be adequate.

An ideal occupant control strategy for a large building might include both a VAV system for general space temperature control and ventilation, along with individual control elements for occupants. Open and closed office environments will have differing designs, with open offices maintained at a generally higher temperature and occupants having local "cooler" zones to avoid the use of expensive "foot warmers."

Summary

Diffuser selection is becoming recognized as a critical issue in avoiding problems with a building's design. Designing in accordance with ASHRAE's recommendations can help to avoid the creation of a "litigation-rich environment." The *Handbook—Fundamentals,* Chapter 31, along with manufacturer's recommendations and guidelines, provide tested ways of designing to avoid complaints or problems. Failure to select diffusers with regard to proper design can result in discomfort and concerns over poor indoor air quality.

Diffusers are created with specific performance parameters inherent in each design. These parameters need to be understood, and used in selecting the size and type of unit for each situation. Additional consideration for occupant clothing differences and space use changes suggest that system flexibility, occupant control, and occasional design reviews are mandatory.

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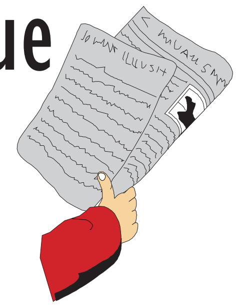

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