Assuring Zone IAQ

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Introduction:

Today's building environment is a scary place. Existing and revised Standards are shaping both building designs and legal environments. Poor product selection has been the subject of at least one lawsuit, and has the potential to be a major influence in future design decisions. Individual interpretations of Standards are implicit in many design strategies, which can change as Standards are revised, adopted by code bodies and official interpretations are published.

The occupied zone of a building is where the rubber meets the road. There are selection methods available to the engineer to make informed selections, in accordance with accepted practices (typically the ASHRAE Handbooks). In addition, there are new products, which allow for a more fail-safe design, allowing more design flexibility than conventional selections.

Problems:

With the reported problems of poor indoor air quality, and the threat of litigation foremost on the minds of many in the commercial building industry, Standards relating to these issues are becoming more than guidelines. They are becoming defacto codes as the legal interpretation of "Acceptable Standard of Care" is being used to include all references to a given subject. There are a number of ASHRAE Standards, which impact the indoor environment, and while these are constantly being updated, they provide a basis of design in both their approved and in some cases their draft forms.

A number of design and selection strategies can be used to assure that the requirements of these Standards are being met. Additionally, as new Standards are being developed, and as buildings are expected to last longer than the lifetime of current Standards, both building owners and tenants are looking at long term solutions to IAQ control in buildings.

ASHRAE Standards

A number of ASHRAE Standards cover the issues of proper space ventilation and occupant comfort. These include:

- 62-1989: (Ventilation For Acceptable Indoor Air Quality)
  The Standard is currently being revised, and is expected to be out for first public review as this article is published. The current version has 29 (as we speak) interpretations in print, and others under consideration. Most of these deal with variable occupancy and multiple spaces issues.
- 55-1993: (Thermal Comfort Conditions for Human Occupancy.)
  The comfort standard is being revised, and will be written as a Code Standard. When released (in several years), it may be more easily adopted into building codes than the current Standard. It is expected that a single number rating, most likely PMV, or a derivative thereof, will be a part of the Standard. A Comfort Program is now available which includes all commonly accepted comfort models including ASHRAE's and the ISO standard, as well as a 'consensus' model created (but not adopted) by the 55R Committee. These tools will permit verification of compliance.
- 129P: (Method of Test for Air Change Effectiveness)
  The Second public review of this Standard is in progress at press time. The measurement of Air Change Effectiveness is a complicated process, and will probably be a laboratory test procedure if

any accuracy is to be expected. As available data indicates that ACE is probably always near 100% in cooling mode, perimeter zone ACE will be the subject of a lot of study in the future.

- 113: (Method Of Test for Room Air Distribution)
  Measurement of Air Diffusion Performance Index can be conducted most easily in the laboratory, where conditions are most easily controlled and measured, but has been conducted in the field in a number of instances. All published data using Standard 113 has verified the relationship between ADPI, room layout and Throw, as described in the ASHRAE Fundamentals Handbook, Chapter 31. The draft Standard 62 references this relationship. Standard 113 is now in a revision process, as well, and is expected to incorporate air supply within the occupied zone (task cooling) as well as other issues.

Effective Ventilation Rates

The ratio of outside air which enters the HVAC system, to that delivered to the occupants, is the effective ventilation rate. It incorporates a number of elements, including air mixing (and potential short-circuiting) in the HVAC air handler, mixing, and transport through the duct system to the room air outlet, and mixing in the room. The portion of ventilation air moving in the room has a separate definition, Air Change effectiveness (ACE) described below. The actual effectiveness of the HVAC system, outside of the ACE portion, is effected by duct leakage, duct air distribution and mixing, and internal air handler short-circuiting between supply and exhaust. This is compounded by the difficulty of measuring the actual quantity of outside air entering the air supply system through variable dampers, louvers and mixing stations common to air handlers. These measures are effected by wind direction and magnitude at the outside air inlets. Duct leakage has the effect of returning unused outside air back to the air handler through plenum returns, with a portion being exhausted from the building without benefiting the occupants.

The typical valued quoted for the HVAC system overall Ventilation Effectiveness is 80%. While duct leakage values are not widely reported, we have seen a number of installations where the difference between VAV terminal flows, measured at the inlet of the unit, and that measured by several methods at the diffusers differed by over 20%, and this is in the low pressure portion of the system. It is easy to believe that a 20% leakage value may be conservative in some buildings. The Florida Solar Energy Group reports similar data in Florida.

The revision committee to Standard 62 is taking this into account in its present draft, realizing that the 20 CFM/person number required in the past is actually at the air handler, and that the rate in the room in spaces meeting the Standard may well be only 16-17 CFM/Person. This is being incorporated into the design tables of the draft standard, giving builders with proven tight duct installations an opportunity for reducing outside air quantities.

Air Change Effectiveness

Air Change Effectiveness (ACE) is defined by ASHRAE Standard 129 as the ratio of air entering a space to that in the occupied zone. ACE is in effect a measure of the % of outside air introduced by the diffuser into a room which makes it to the ‘breathing’ or occupied zone and is available to provide ‘fresh’ air and to dilute occupant generated contaminants. Studies indicate that ACE is almost always 100% when diffusers are supplying cold air. In heating, however, rates as low as 65% have been observed. It has not been conclusively proven, but seems reasonable that a high ADPI (see below) will result in a high ACE. The converse, however, is not necessarily so. Excellent ACE would be expected with an improperly adjusted diffuser ‘dumping’ directly into the occupied zone, which would result in low ADPI values. More research is needed to determine the ACE in perimeter zones when heating.

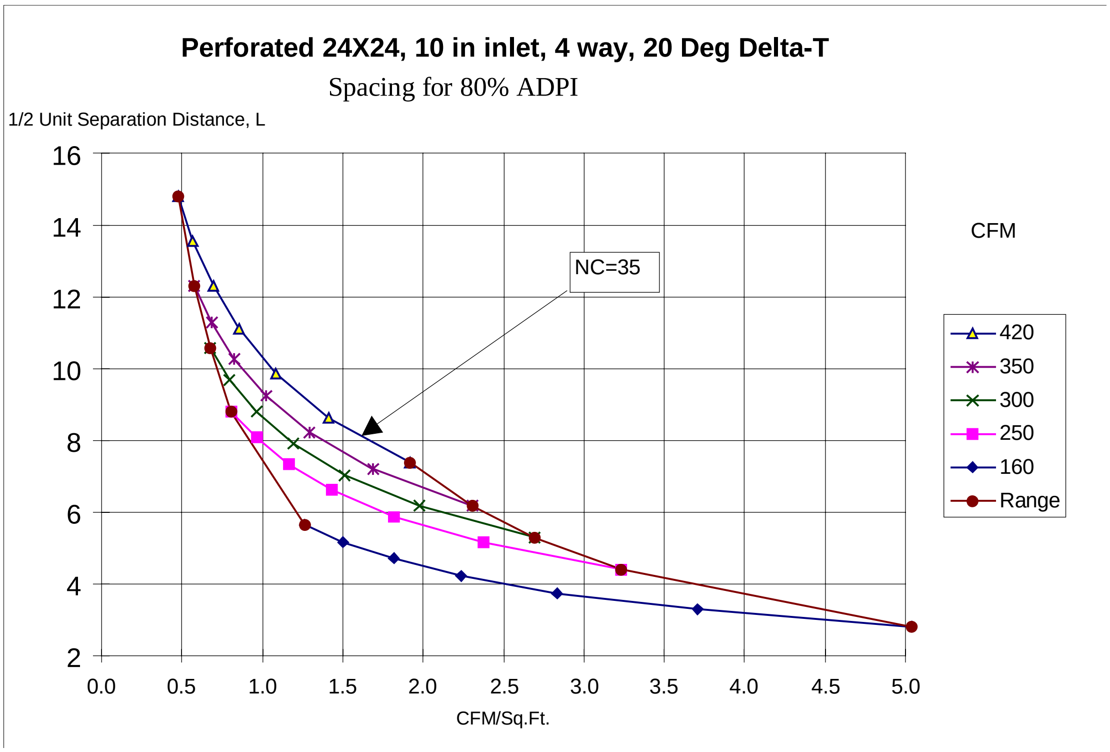
Air Diffusion Performance Index

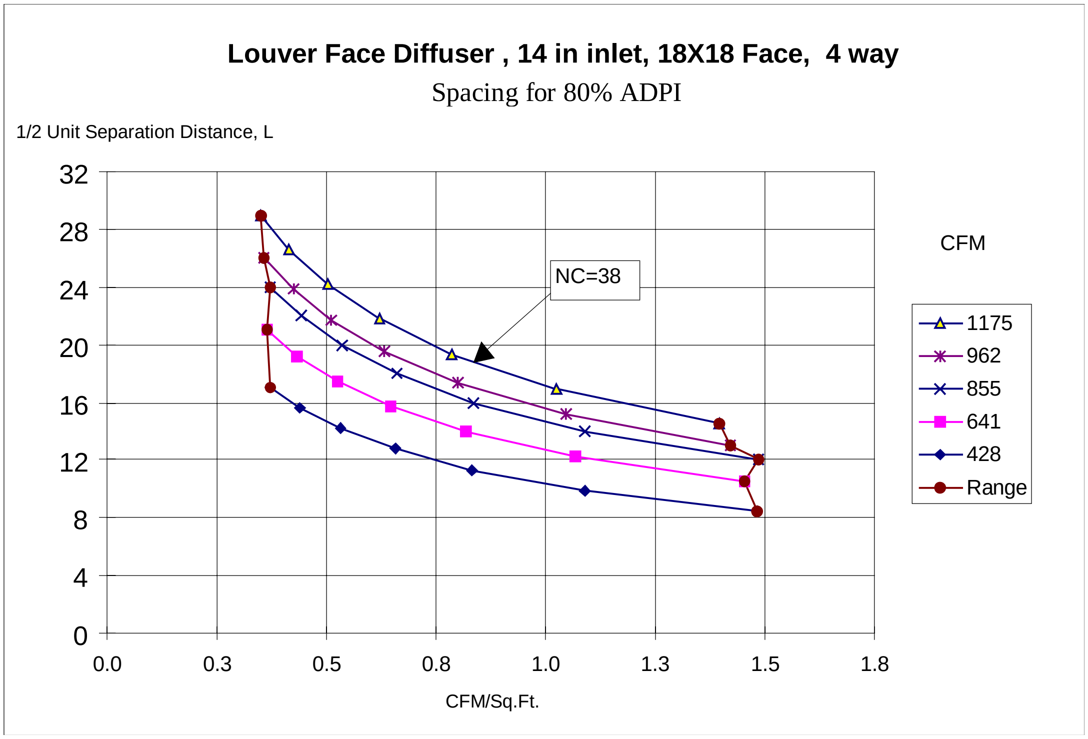
The ADPI in a space is the percentage of points in the ‘occupied zone’ which meet criteria for air speed and temperature difference (from the mean temperature). An ADPI of 100% means all points meet the criteria. ASHRAE recommends and ADPI of at least 80%. ADPI less than 70% could be indicative of either localized drafts or regions of poor air circulation (or both). Poor ADPI will likely result in a space not meeting the comfort requirements of Standard 55 in a number of locations within the space. Poor ADPI can also result in slow system response to changing loads, as the areas of poor circulation can include the thermostat, which relies on a well mixed room to properly sense room temperatures and loads.

ADPI can be measured using ASHRAE Standard 130-90. The test requires highly accurate anemometers (typically omni-directional) and 0.2C accurate temperature probes, radiant shielded. This requirement effectively precludes the use of thermocouples, and implies that multiple probes be used to shorten testing time (2 minutes at each position, minimum).

ADPI can also be estimated, and this estimate used in a design. ASHRAE's Handbook of Fundamentals, Chapter 31, describes the use of a 'Characteristic Room Length', and a diffuser's cataloged throw, to determine ADPI. The Characteristic Room Length, 'L', as defined by ASHRAE, is 1/2 the distance between opposed diffusers, or the distance to an adjacent wall. By using diffuser performance data, and the range of throw/room length table (Table 2), one can calculate the effective flow range for a given diffuser, as cfm/sf (Flow rate per unit area) supply rate. Using this type of analysis, an engineer can know in advance where a given type of diffuser will perform in a VAV situation, and what the turn down will be. The Draft of Standard 62 currently advises that this methodology be used in selecting diffusers.

When plotted, however, we see that there is a potential problem in many spaces. As air supply rates decrease along with reduced loads, many interior spaces have design flow rates less than 1.0 cfm/sf., at full load. Many spaces only require 0.6 cfm/sf or less at typical loads. During light loads, the demand will fall to 0.3 or less. When most commercial diffusers are analyzed at reduced flows, many cannot meet the ADPI requirements. Two examples are shown here:





The Perforated face diffuser can be seen to have an effective minimum flow rate of between 0.5 and 1 cfm/sf. The louver face diffuser has a somewhat lower effective range and a different 'shape'. In a VAV situation, the selected diffuser has to work over a broad range of flows.

Multiple Spaces & Minimum Ventilation Rates

ASHRAE Standard 62-1989 defines rules for both minimum ventilation rates and for multiple spaces. These are problematic with VAV systems, as well as with several types of spaces. Some examples in office spaces:

- **Conference rooms**: Many conference rooms will qualify for the ASHRAE Standard 62 rule of 3 hour occupancy. If occupied for less than three hours, a space may be designed at 1/2 occupancy for system ventilation rate calculation purposes. This one room, however, may drive the outside air fraction in computing quantities.
- **Perimeter offices**: Thermostats cannot differentiate between unoccupied rooms and ones where the exterior skin loss equals the internal heat gain. Providing design minimum air quantities to these spaces is a challenge to the designer, if unnecessary reheat is to be avoided.
- **Training rooms**: These may not qualify for the three-hour rule. Many training sessions are all-day affairs, if only occasionally, and must be designed to deliver ventilation for full occupancy.

Legal Issues

Many legal issues surround the IAQ question. It is becoming apparent that the legal standard may be defined in court under the clause "acceptable standard of care". Under this principal, ASHRAE Standards have been used in litigation, even though not a part of the local code. There is a great deal of concern that draft standards may even fall under this concept (explaining the level of concern over what is written in an unapproved public review draft.)

It is clear, however, that approved ASHRAE Standards are becoming de-facto codes, and in fact are being adopted without revision by code bodies. Several ASHRAE standards are being rewritten in code language to avoid the ambiguity that often occurs when a non-code language standard is attempted to be adopted into a code.

In any case, designers are encouraged to be aware of all applicable Standards in designing a building, as are building operators in managing one, to avoid lawsuits. It is also becoming apparent that when the codes are met, there are fewer complaints. The Standards do work. A majority of thoroughly investigated problem IAQ buildings find that the ASHRAE Standards have not been met.

Solutions:

In order to assure building owners that they will have acceptable spaces, as well as spaces that will meet current and upcoming standards, designers have a number of options to choose from. Engineers, moreover, are now going to be expected to make recommendations based on 'Best Knowledge'. In looking at these issues, several new products designs are available to satisfy both the owner and engineer's needs.

Proper Diffuser Selection

The current draft of the revision to ASHRAE Standard 62 includes a requirement that diffusers be selected to achieve an acceptable ADPI, in order to assure good ventilation mixing. In addition, this will assure the uniform temperatures required for acceptable thermal comfort under Standard 55. It will be seen that at today's reduced loads, many types of diffusers cannot meet these requirements over the full range of flows found with many VAV system designs.

This problem is compounded when diffusers are oversized. In many cases, a sound specification requires diffuser NC levels to be less than a NC 35. When allowances for installation effects, inlet dampers, etc., are included, diffusers are often installed at a NC=25 or less. As diffuser mixing effectiveness is usually proportional to it's noise characteristics, diffusers should be selected as noisy as possible. When a diffuser is too noisy, however, there will be occupant complaints.

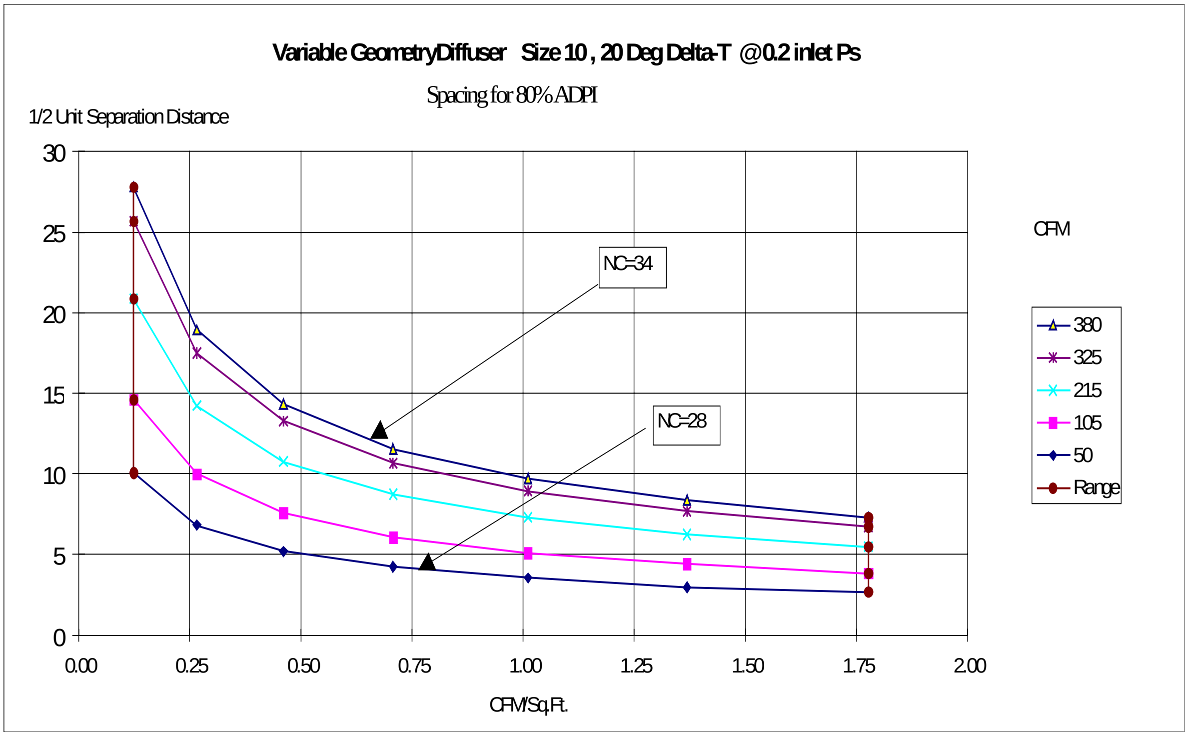
A case can be made for having diffusers make some noticeable (but not objectionable) noise at full flow with VAV systems. As an interior zone in a VAV system is usually sized at a capacity of 95% of design load, they should be at full flow only a small percentage of the time. Room temperatures will almost always be at the high side of their temperature control range when at design load. Many studies have shown that occupant complaints in warm rooms tend to be of 'Stuffiness', rather than of 'warmness'. From this, we may conclude that occupants will complain less if they can hear the diffuser operating when they are 'slightly warm', as they will be assured that there is indeed some ventilation being delivered.

Variable Geometry Diffusers

One solution for the problem of limited air change effectiveness is to have a diffuser whose geometry changes to optimize throw as the flow reduces, or a variable geometry diffuser (VGD). Studying the relationship between throw, mass and discharge velocity as presented in the ASHRAE Handbook, it can be seen that it is not sufficient merely to maintain a constant discharge velocity with changing flows. Mass has an effect on throws, and at a constant discharge velocity, throw will decrease with flow rate.

It is possible; however, to change the pattern as well as the outlet area, and result in a diffuser that maintains a relatively constant throw over a broad operating range. A side effect of this is that a relatively constant sound level is produced as well. When the throw remains constant, the predicted ADPI will remain constant as well, in a given installation. This also means that the ASHRAE Standard 62's proposed rules can be met over a broader flow range than for a fixed geometry diffuser.

Analysis of the performance of a VGD with these characteristics can be expressed in the same manner as shown previously:



Here is can be seen that the effective range of this diffuser extends down to less than 0.2 CFM/SF, probably below any occupied minimum ventilation rate. This diffuser has the added advantage of allowing occupant selection of the space operating temperature, further guaranteeing compliance to Standard 55.

Series Flow Fan Terminals

Series Flow Fan Powered Boxes (SFPB) have been used in a large number of successful applications over the past 15 years. Reasons for the successful implementation of these devices are several fold:

- Because the flowrate to the space does not vary with load, the diffuser selection is not as critical as it is with VAV systems. A broad range of styles (satisfying many different architectural 'looks') is possible while meeting the ASHRAE ADPI and ACE requirements.
- Fan Powered terminals re-use plenum ventilation air. Although the data base is not very 'robust' at present, there are indications that the ACE can be higher with fan powered units at partial loads, than with comparable VAV systems which return all unused air back to the central system, including any duct leakage.

As Fan Powered terminals provide essentially constant noise to the space, they can provide part of a 'background sound masking' effect, increasing occupant acoustical privacy. It can also be argued that the sound levels from these units can serve the purpose of assuring occupants of an operating ventilation system, reducing the sensation of 'stuffiness' at high loads.

- SFPB's have significantly lower inlet pressure requirements than conventional VAV systems. The local fan handles the highly unpredictable pressure requirements from the terminal unit to the diffuser. The significantly reduced central fan operating pressure saves energy and reduces the impact of duct leakage. Any duct leakage effects are further reduced by the recirculation operation of fan terminals.

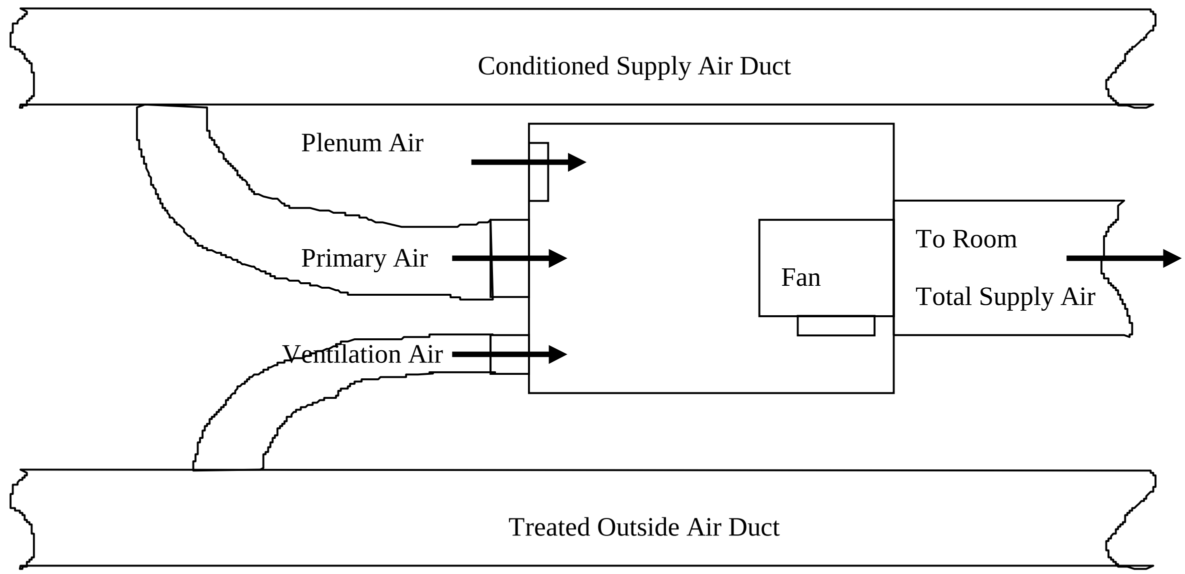
For these reasons, SFPB's have been selected for a number of high profile occupied because of the advantages in comfort and ventilation effectiveness.

Dual Duct Series Flow Fan Boxes

If the owner and designer want to insure that the required ventilation air is delivered to each occupied zone, a separate ventilation air duct and flow measuring station is required at each control point. This can be accomplished with a number of dual duct terminal designs. The mixing required in a properly designed dual duct terminal, however, often requires significant inlet pressure, in excess of 0.5”. When combined with diffuser and flexible duct pressure drop, system minimum pressures of 1” are typical.

Analysis of Standard 62’s ‘critical zone’, ‘Z’, has been the subject of a number of official interpretations, and is being modified in the new standard because of the ambiguities of the requirement. While others are developing control algorithms based on assumptions of the requirement, there is always some interpretation of the Standard required.

A dual duct series flow fan terminal, (DD-SFPB) however, has the advantage of excellent mixing at very low (<0.2”) minimum inlet pressures, as well as all the above series fan terminal advantages. Using a dual duct SFPB, moreover, eliminates any assumptions about the ‘critical zone’, simplifying system control strategies, and reducing the potential of over ventilation implicit in any ‘critical zone’ analysis.



Dual Duct Series Fan Powered Terminal Schematic

Additional advantages over pure dual duct application include the ability to utilize pre-conditioned ventilation air at a temperature and humidity which does not include the requirement for zone heating, which can be accomplished at a fan terminal. This results in a smaller (and less expensive) second duct and a lower cost air handler than with heating/cooling dual duct designs. By using prudent judgement in locating fan boxes near the core, the designer can minimize the amount of dual duct on a project. Minimal first cost impacts now can be weighed against potential liability and potential customer dis-satisfaction with other designs.

The dual duct fan terminal allows a number of interesting control options without overly complicated mechanical designs and. allows a full range of diffuser designs. A DD-SFPB can allow a high degree of design and architectural flexibility at a low risk of violating actual or perceived Standards and ‘ Acceptable Standards of Care’.

Conclusions / Summary

As we have seen, properly selected diffusers should result in both acceptable thermal comfort and sufficient Air Change effectiveness, while meeting all ASHRAE Standard requirements and recommendations. The selection of diffusers at low flows, however, limits the selection to only a few styles of diffuser, and puts a relatively high lower limit regardless of the diffuser type.

VGD's, however, extend the effective range of acceptable performance to very low levels, while at the same time providing a measure of occupant control over the environment. In addition, there are acoustical advantages to at least one style of variable geometry diffuser.

SFPB's allow diffusers to be selected without worrying about the effects of turn down, provide a remix of plenum air (including any unused duct leakage air), and reduce pressure requirements in the supply ducts.

Dual Duct SFPB's allow 'critical' spaces to become demand ventilation spaces, without critical diffuser selections limiting the appearance of the space.

REFERENCES

ASHRAE Handbook of Fundamentals, 1993, Chapter 31.

ASHRAE Std. 55-1993 "Thermal Environmental Conditions For Human Occupancy", ASHRAE

ASHRAE Std. 113-1990 "Method of Test of Room Air Distribution.", ASHRAE

ASHRAE Std. 62-1989 "Ventilation for Acceptable Indoor Air Quality", ASHRAE

D. Int-Hout, "Thermal Comfort Calculations / A computer model", ASHRAE Transactions, V96, Pt 1. (1990)