ADPI, Comfort, and LEED

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ABSTRACT

With the LEED NC V2.2 change in determining Ventilation Effectiveness (by requiring compliance to Standard 62.1 as a prerequisite), the use of ADPI prediction has changed from a measure of Ventilation (for which it wasn't ideally suited) to a determinant of a critical element of compliance to ASHRAE Standard 55. At the same time, the template used to determine compliance to Standard 55 has changed the path to achieving this credit.

The USGBC is in the process of developing the 2012 versions of the various accreditation paths, and at the same time both tightening the requirements and modifying others that were impractical. In order to meet the increased complexity of LEED credits, designers must be aware of the conflicts between first cost economics, occupant productivity and life cycle costs.

From an occupant perspective however, achieving thermal comfort is often elusive. Surveys often record high levels of occupant dissatisfaction, often with simultaneous hot and cold complaints. As the cost of productivity often exceeds all other building expenses by several orders of magnitude, it is important to understand the issues involved in solving this problem. A key element is air distribution device sizing and location. ADPI is a convenient and proven tool for this purpose with overhead, well mixed systems. Other types of air distribution must use other techniques.

AIR DISTRIBUTION: SELECTING COMPONENTS & SYSTEM PARAMETERS FOR EFFECTIVE AIR MIXING

Modern environmentally controlled spaces consume significant amounts of energy in maintaining a stable environment within the structure. The demands for heating and cooling vary greatly over time, and different strategies are employed to respond to these varying loads. Ventilation requirements must also be met by the HVAC system. This conditioned and ventilated air must be effectively delivered to the building occupants.

There are two principal design conditions in HVAC systems. Perimeter zone loads vary over a broad range from heating to cooling, and are affected by both exterior and interior factors. In interior zones the heat generated by lights, occupants, and office machinery provides a continuous cooling demand.

The proper selection of diffusers is necessary to ensure that both occupant comfort and adequate ventilation mixing are provided. Both the engineer and the architect need to have input into the final selection as the choice of diffusers is based on both engineering and architectural concerns,. In addition, the ideal selection is dependent on the type and operation of the air supply to the diffuser. While there are many ways of supplying conditioned air to an office space including displacement ventilation, underfloor vertical air distribution and task cooling, this article will deal with the predominant method, the ceiling supply air diffuser.

ASHRAE continues to sponsor research into the performance of air distribution elements, and much has been written on the subject in both technical papers and magazine articles. At the same time, ASHRAE Standards for Indoor Air Quality (62.1-2004) and Comfort (55-2004) state 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. Awareness of Indoor Air Quality issues and concern over occupant complaints has increased the visibility of proper diffuser selection, location, and design. At the same time, complaints of 'stuffiness' are finally being diagnosed as temperature, not Indoor Air Quality complaints.

The ASHRAE handbook provides recommendations for diffuser selection, which have been included in at least one lawsuit as being considered to be the 'acceptable standard of care'. All available research indicates that when air distribution is provided from the ceiling, a thoroughly mixed condition, throughout the space, is the desired result. Furthermore, the research has proven that with properly selected ceiling diffusers, excellent air distribution and ventilation mixing can be achieved with many types of diffusers, and in many types of spaces, including the open landscape office.

The key element here is the term ‘properly selected’. Diffuser selection ranges from the selection of a ‘hole cover’ (or ‘architectural duct termination’) to a detailed analysis of the diffuser air supply pattern in each zone. A zone-by-zone analysis is almost always prohibitive in terms of design time, and probably not necessary for most spaces. Excellent diffuser selections made for interior open office spaces, which are typically in cooling mode year round, can often be made by characterizing them in a general way. Perimeter zones are more complicated, with both thermal and aerodynamic concerns to be considered, but again, these can often be characterized in a general way for the building design, and excellent air distribution can be achieved. When there are problems, it is our 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.

The 2009 ASHRAE Handbook of Fundamentals, Chapter 20, provides two basic rules for overhead heating and cooling:

- In 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 air flow rates, to achieve an acceptable Air Diffusion Performance Index (ADPI).

- In heating mode, the diffuser to room temperature difference (delta-t) should not exceed 15^{o} F, in order to avoid excessive temperature stratification. ASHRAE Standard 55-2004 defines the level of acceptable vertical temperature gradation at not to exceed 5^{o}F.

ASHRAE has recently defined a term for describing the mixing of supply and room air, replacing the somewhat ambiguous terms Ventilation Effectiveness and Ventilation Efficiency with a new term, Air Change Effectiveness, or ACE. This term is used in both ASHRAE Standard 129, the Method of Test for Air Change Effectiveness, and in Standard 62.1-2007. It was also the basis for a LEED point in the 2.1 version (the V2.2 of LEED has the Ventilation Rate Procedure of ASHRAE 62.1 as a prerequisite, and a point is no longer gained for meeting this requirement)

The data available for relationship between ADPI and ACE indicates that if a high ADPI is attained, the ACE will also be high. While there have been no reported tests where the ACE was significantly below 100% when cooling from the ceiling, it has been demonstrated that in heating mode the ACE may decrease significantly, as low as 20%, as ventilation air short circuits back to the ceiling plenum without mixing in the space.

The previous release of ASHRAE IAQ Standard, 62-1989, assumed ventilation mixing of 100% in setting minimum ventilation rates. If it can be shown that the ACE is less than 100%, then the amount of outside air must be increased above the required minimums. When a high ADPI is measured, the ACE is always high as well. ASHRAE 62.1 (2007) now includes Air Change Effectiveness in a table. When cooling from the ceiling, ACE is always assumed to be 100%. When heating from the ceiling with ceiling returns, the discharge to room delta-t must not exceed 15^{o}F, and the 150fpm throw must reach to within 4.5 ft from the floor, or the outside air ventilation rate must be increased by 25%.

While it is possible to have a high ACE and a low ADPI, especially if the HVAC system air is supplied directly into the occupied zone, uniform conditions and occupant comfort may be degraded. What is known, however, is that having a high ADPI (>80%), a space will by definition have less than 5 degrees vertical air temperature difference, meeting a key requirement of ASHRAE Standard 55. (Section 5.2.4.3).

COOLING SELECTION BASED ON ADPI

ADPI is intended as a measure of performance in cooling mode. When in heating mode, the ADPI criteria often become overly sensitive to temperature differences (due to the very low air speeds present in heating mode), and as a result ADPI is not a good means of performing heating evaluations. Heating is best analyzed as a function of vertical temperature gradients as compared to ASHRAE 55's requirements. Interior spaces however, are predominantly in a cooling mode of operation so this limitation is seldom a problem in interior zone evaluations.

Utilizing the ASHRAE Handbook table for predicting ADPI is cumbersome, and is seldom accomplished. It is possible, however, to simplify this analysis by combining a diffuser's throw performance with a cfm/sqft analysis and diffuser spacing, to produce an ADPI "Performance Envelope" graph.

An example is shown, in several Figures below. In these graphs, the x axis is flow rate/unit area, and the y axis is half the separation distance, or L, the characteristic room length. The horizontal curved lines are simply calculations of flow vs. area served, while the vertical boundaries are computed from the ASHRAE maximum and minimum T_{50}/L ratios for this type of diffuser. Performance within the area bounded by the lines should achieve an ADPI of 80% or greater.

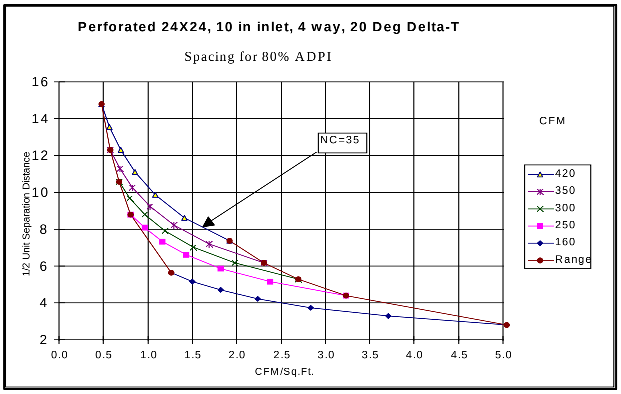


Figure 1: Low Cost Perforated Diffuser

Figure 1 shows the performance envelope of a low cost perforated diffuser with a load resulting from a room/supply differential of $20^{o}\Delta T$. (Different delta-t's will result in different load rates, and will change the location of the vertical boundaries somewhat.)

One can see that this diffuser will not have acceptable performance at reduced flows, and in a VAV application will have limited "turn down".

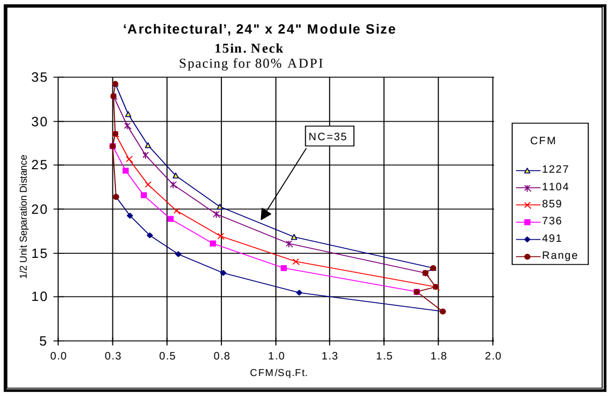


Figure 2: Architectural Diffuser

Figure 2 shows the performance of an Architectural (plaque) diffuser with a similar 4 jet pattern. Here one can see that this diffuser will both have better performance at low flows, and will have greater turn down in a VAV situation.

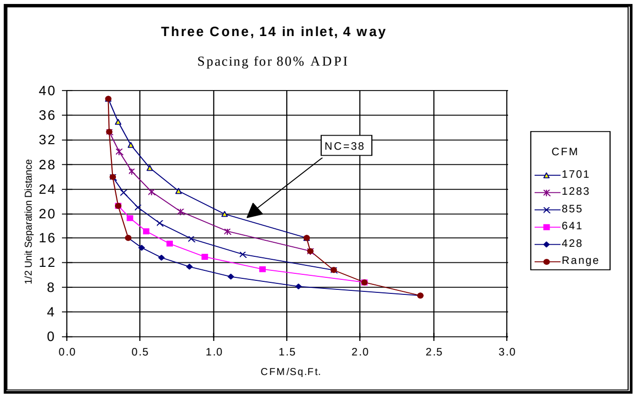


Figure 3: Cone Diffuser

In figure 3, we show the performance for a circular pattern, three cone diffuser. This diffuser performs well in all applications.

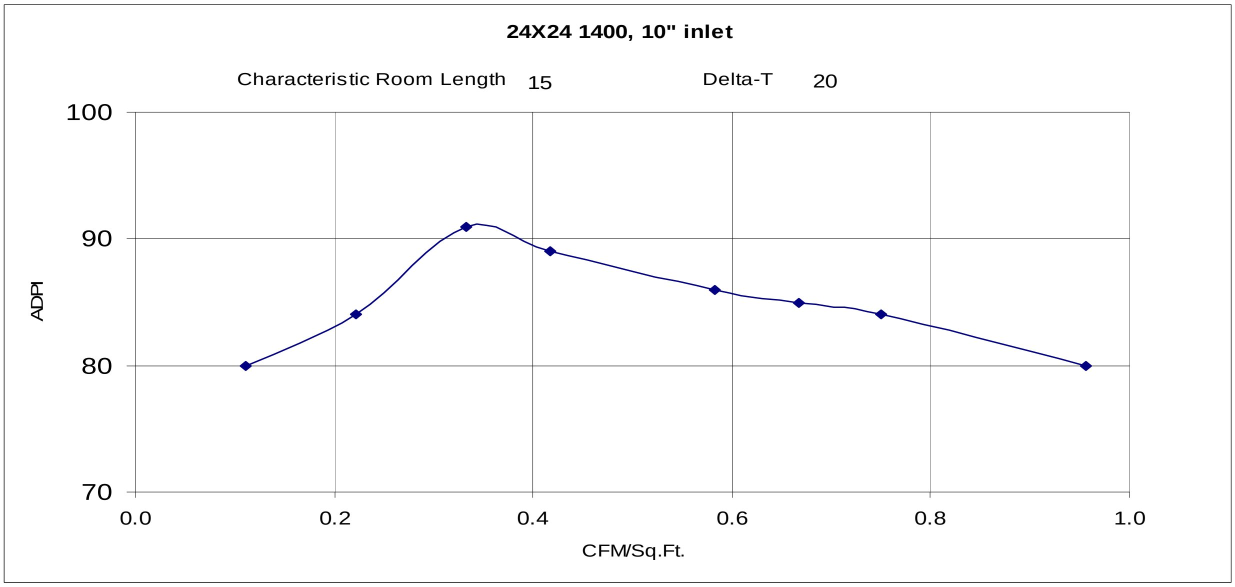
Analyzing these charts, it can be seen that they have quite different 'turn down' limits. The perforated diffuser shown has quite a high flow capability, but can't be used below 0.7 cfm/sq.ft. On the other hand, the others shown will operate down as low as 0.2 cfm/sq.ft but are limited above 1 cfm/sq.ft. at this separation. If different neck areas are analyzed, a different separation distance results, but it will be seen that the flow/unit area limits don't change appreciably.

Selecting diffusers using the above charts will result in selections which meet the requirements of the ASHRAE Handbook of Fundamentals, and will also meet ASHRAE Standard 55's limitation of 5^{o}F Degrees vertical air temperature stratification. In fact, using ADPI analysis is the only proven method of demonstrating compliance to the Standard 55 requirement, at the design stage.

Unfortunately, ADPI analysis can only be applied to overhead air distribution systems in cooling mode. Other types of air distribution (and heating and cooling) either cannot, or have not been correlated with, the ASHRAE ADPI selection guidelines. Fully Stratified, and Partially Stratified air systems, as described in the 2009 ASHRAE Fundamentals Chapter on air distribution (Chapter 20) are not able to be verified, or predicted, in existing ASHRAE publications. Chilled Beam systems, which are essentially horizontal throw slot diffusers, are likely to be correlated in the near future. Displacement Ventilation (DV) and Underfloor Air Distribution (UFAD) systems must rely on published data and manufacturer's software.

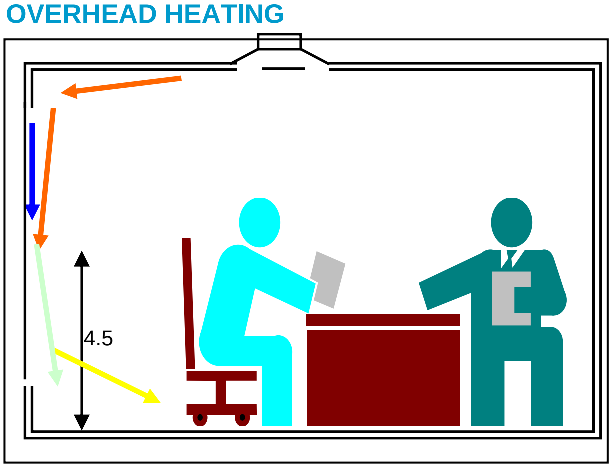
Krueger's newest release of the KSelect GRD Selection program will include an output option to assist meeting the LEED comfort point using ADPI. After determining a diffusers ADPI in the program at design conditions, the program then allows the preparation of a graph showing the performance of this diffuser, at the set spacing and delta-t, at reduced airflows. Submission of the prepared graph (based on ASHRAE ADPI selection data) to the LEED certification officials will demonstrate proof of compliance to the vertical temperature difference item in the Standard 55 Compliance template. The following text is included for clarity:

"V2009 LEED-NC Credit 7.1 may be awarded for complying with ASHRAE Standard 55-2004. This Standard limits vertical air temperature difference, within the occupied zone, to be no greater than 5^{o} F. Assuring an ADPI no less than 80% will comply with this requirement."



Experience has shown that when these guidelines are followed, excellent air distribution, uniform temperatures and no objectionable drafts should be expected in the space when cooling with overhead air distribution systems. Providing that acceptable temperatures are established as a function of the occupant's clothing and activity levels, occupant comfort should be assured as well. Indoor Air Quality, which is many times a perception issue, will also be assured.

OVERHEAD HEATING



Heating perimeter zones from the ceiling became possible when perimeter glass became better, and in response to needs for better space utilization along the glass. A number of technical papers presented in the late 70's defined the parameters of this design, and established a repeatable method of test for evaluation of these spaces (ASHRAE113). The ASHRAE Fundamentals Handbook (now Chapter 20) incorporated these results in the early 80's, and overhead heating became a 'standard' method of heating perimeter zones.

Today we see a surprising number of designs which do not comply with the recommendations from these studies. The cfm and kW settings often specified on VAV terminals, as well as design discharge temperature for small package units, often evidence this lack of understanding. Discharging low velocity, highly heated air may work in residential applications with low returns, but it will ensure highly stratified, poorly ventilated spaces with uncomfortable occupants in commercial applications with overhead returns.

The ASHRAE Handbook of Fundamentals has since 1979 provided specific guidance on the maximum room discharge temperature difference (not to exceed 15^{o}F) for effective control of the perimeter environment. ASHRAE Standard 62.1 2007 now requires that ventilation rates be increased by 25% when discharging air that exceeds this limitation, and when the diffuser discharge velocity is insufficient to get the heated air to within 4.5 feet of the floor.

More importantly, when discharging hot air at the ceiling, with cold windows, a space is seldom in compliance with the occupied zone vertical air temperature limitation of Standard 55. Several hundred tests of perimeter designs in full-scale mock-ups have been conducted by many manufacturers, all confirming the relationship between discharge temperature, velocity, diffuser spacing and compliance with ASHRAE Standard 55. Excessive vertical air temperature difference can occur in both heating and cooling situations, with all types of systems.

THERMAL COMFORT: DETERMINING OPTIMUM OCCUPANT COMFORT STRATEGIES

Many IAQ complaints, especially those characterized by the expressions ‘STUFFY’ and “DRAFTY” are probably misdiagnosed thermal comfort problems. The ASHRAE Standard on comfort (Std 55-2004) can be misleading in terms of occupant comfort. The older versions of this standard assumed both a ‘Winter’ and a ‘Summer’ condition, shown as comfort envelopes on a psychometric chart. These envelopes are shown with some overlap, suggesting that there is a single temperature which may satisfy both conditions.

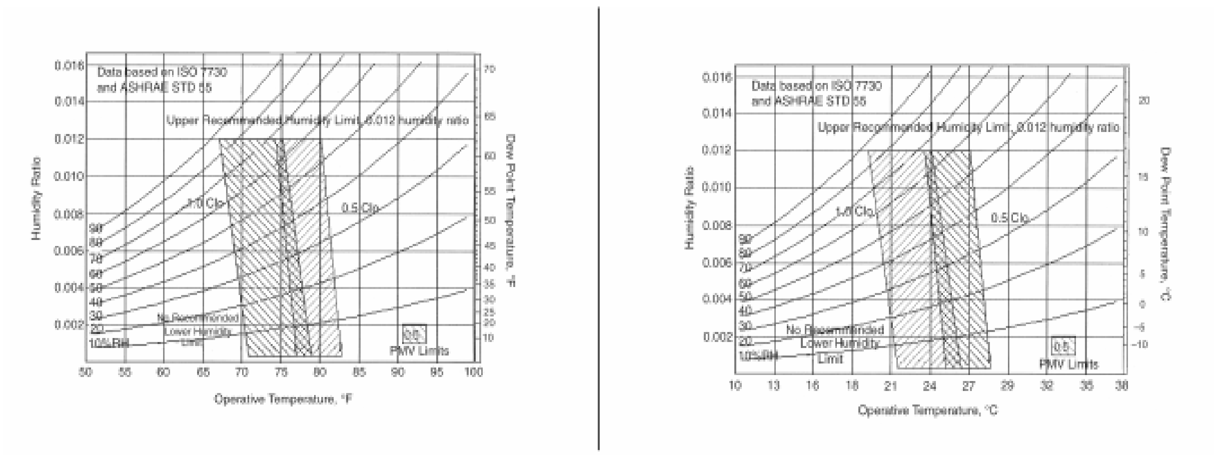


Figure 5.2.1.1, Standard 55-2004, Acceptable range of operative temperature and humidity for spaces that meet the criteria specified in Section 5.2.1.1.

In practice, however, differences in metabolic rate (Internal heat gain) resulting from both inherent metabolism and occupant activity causes a wide occupant thermal preference variability. Research indicates that most individuals, when slightly warmer than their “comfort zone”, will probably not complain of being too warm, but will more likely complain of being ‘Stuffy’. A slight drop in temperature, however, will result in comments of how much ‘fresher’ the air seems now.

An individual who is slightly cool will probably complain of drafts before complaining of being too cold. The women in the office will be the most sensitive to this phenomenon due to the fact that they are less likely than men to wear socks, and it is coldest at the floor. Cures often involve cardboard and/or tape on the diffusers, interfering with building air balance.

The solution, when the air distribution system is properly designed and operated, is to modify either the temperature or the occupant’s clothing. The latter is easier said than done, of course.

Even though occupant productivity is a difficult thing to measure, the economics of thermal comfort are easily calculated. Several factors illustrate why it is important to maintain occupant comfort.

- Occupants who occupy 150 sq.ft. and are paid $30K / year, cost $200/Sq.Ft., annual salary.
- Buildings seldom cost more than $2.00/Sq.Ft.-year to heat and cool.
- Adjusting thermostats to save energy is unlikely to save more than 5% (interior and perimeter zone) HVAC energy use, or 1/2000 of the salary cost.
- We seldom spend more than $30/Sq.Ft. on HVAC, First Cost, on a building. (In Europe, they often spend as much as $90 / sq.ft.)
- Any heat produced in a commercial building will be paid for twice (once to make the heat, once to pass it through the cooling coils)
- Occupants will do whatever they can to maintain their own comfort levels.

An article in the ASHRAE in June of 2008 showed this in a graph:

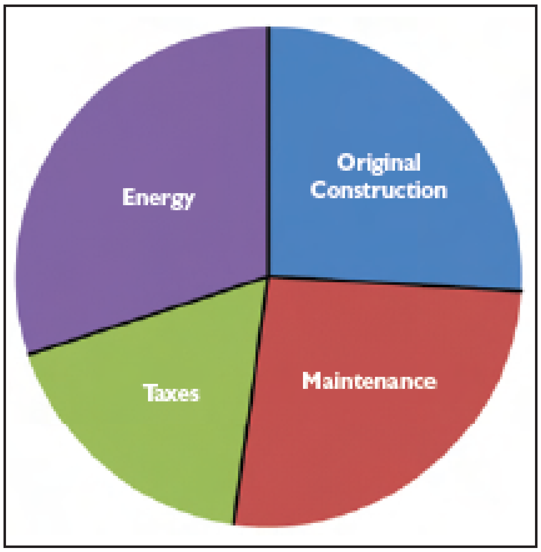


Figure 1: Life-cycle building costs breakdown.

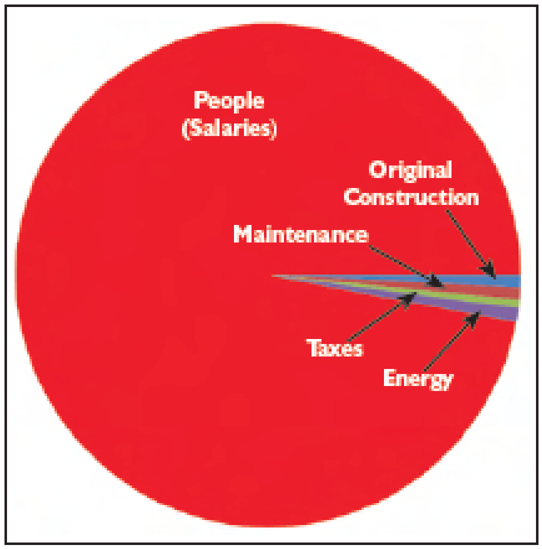


Figure 2: Life-cycle building costs breakdown with people (salaries).

Obviously, we cannot afford to have people uncomfortable in buildings.

SUMMARY

In summary, a number of issues need to be understood in providing an acceptable indoor environment. These include a number of non-IAQ items that have a strong influence on perceived air quality. Issues include a need for occupant education and awareness of their own response to slight hot and cool environments ('Stuffy' & 'Drafty' are key terms). Don't fix the wrong thing. Occupant control of their environment is a major step forward. Don't worry about the energy spent in providing comfort; it is insignificant compared to salary costs (or the costs of what occupants will do to maintain comfort).

Overall, we need to understand how our buildings operate. We need to train operators on what is happening, how occupants respond, and we need to design systems that can be understood. We are finding that cutting costs and saving energy can be very expensive.

As an industry, we have conducted significant research into the proper way to apply systems to buildings to maintain energy efficiency, first costs, comfort and productivity. These lessons have all to often been lost on many in the design community, as well as the agencies and politicians affecting the operation of buildings. The information is available, often in the ASHRAE Handbooks, and certainly in the body of ASHRAE sponsored research.

Manufacturers are often being asked to provide products that we know will not perform well when installed. We often have no choice but to meet the flawed specifications with products that we would predict will cause discomfort when applied as specified.

Manufacturer's do, however, know the proper way to apply their products, and often provide excellent tools for use by engineers and architects. The use of ADPI to determine compliance to a critical part of Standard 55 is one example. Other systems use validated CFD programs to predict space temperature variations. Failure to utilize these tools, however, all too often results in spaces with excessive vertical temperatures in the occupied space, in both heating and cooling situations. The result is non-compliance to Standard 55, (and the loss of that LEED credit) but more importantly, reduced occupant productivity.