Trends Toward More User-Friendly Building Environments

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One very cold winter morning, I was touring an office building with its operating engineer when a tenant approached to ask if it would be possible to raise the temperature in her office for a short time each morning during this cold weather. The building engineer patiently explained how costly it would be, and the tenant departed disappointed but accepting of the explanation. I was reminded that years ago, when my parents remodeled our home, my mother had been convinced that her new all-electric kitchen would be so expensive to operate that she stopped much of her baking for a time. When we finally did an analysis to determine the costs, we were all surprised at how little baking actually cost. This tenant's request was in truth much less costly than suggested by the engineer. I mused to myself that an hour's extra warmth was certainly far less than the premium she had paid for the latte she carried with her. So why, I wondered, hasn't our industry—like the coffee industry—begun catering to individual desires?

Sophisticated occupants

HVAC designers are beginning to realize that building occupants

HVAC designers are beginning to realize that building occupants are demanding more from their environment

have become much more demanding and sophisticated. In recent years, a lot of industry discussion has revolved around the sophisticated building owner, but owners are just trying to keep up with their tenants' demands. Building owners are faced with demanding environmental requirements from prospective tenants. And when a tenant's employee has a complaint about comfort or air quality, the building owner often finds him- or her-self in a face-to-face discussion with a whole troupe of "experts" retained by the tenant to represent just such issues.

It is not difficult to understand why tenants are so concerned about comfort and air quality issues. Employers are interested in creating an accommodating workplace to hold valued employees, build or improve company morale, and improve worker performance. Employers have heard of the disruptive horrors that air quality complaints cause. Meanwhile, building occupants are not waiting for their employers to act. Publicity over the last few years has begun to raise occupants' concerns about the building environment in which they work. Building engineers are learning to take occupant complaints seriously as they are increasingly challenged with probing questions aimed at ensuring that the building's environment will not contribute to long-term health problems.

Renewed focus on comfort

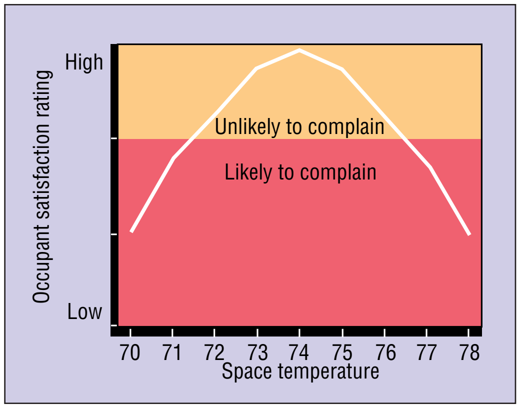
This renewed focus on building environments forces engineers to also face the nagging issue of occupant comfort. Studies are beginning to show a strong link between comfort and worker performance and an even stronger link between individual control of building environments and worker performance. Several studies have shown us that workplace performance does improve when comfort is improved or when occupants perceive control over their environment. Further, it is suggested by a recent survey that sick leave may be dramatically reduced when occupants are afforded control over their workplace environments.

The building industry has for too long adhered to the dated concept that a building environment acceptable to at least 80 percent of the occupants is adequate. The industry must evolve from this rule of thumb because it is well known that a single-space thermal condition leaves a lot of building occupants unsatisfied. There is a misconception among many designers and building operators about human comfort. A widely held view by occupants of commercial buildings is that they demand very precise space temperature conditions that are best provided by a sophisticated centralized control system. Those who view building operation in these terms often applaud the trend away from local thermostat control as a positive development that will, in the long run, lead to fewer comfort complaints.

Individual comfort criteria

Though I am sympathetic to the plight of building operators, I also know that people have difficulty distinguishing any thermal difference at all when space temperatures are changed by up to 1 F. So the problem of satisfying more building occupants is not solved by tighter space temperature control but rather by accepting and accommodating the variations in thermal environments required by the variety of building occupants in each building. Let us consider the interaction of individual comfort requirements in populations to see why many building operators have been sidetracked by the "tight control" solution and discover a more effective solution to raising comfort levels in buildings.

Generally, it is accepted that when holding other contributing factors constant, an individual's response to space temperature conditions is represented by a curve similar to that in Fig. 1. On the X-axis is space temperature. The Y-axis records the individual's perception of comfort at each space temperature. A boundary separates levels of perceived comfort for which the individual is unlikely to complain from the levels at which the individual is likely to complain. The range for which an individual is unlikely to complain about comfort is about 4 to 6 F. The individual whose comfort



1 Typical occupant comfort curve.

curve is represented in Fig. 1 is unlikely to complain as long as the temperature range remains between 72 and 76 F. The center point of this individual comfort curve is 74 F. Generally, it is assumed that differences such as clothing, physical size, conditioning, metabolism, gender, culture, and perhaps a number of other factors do not significantly change the shape of the curve in Fig. 1 but may alter where on the curve the space temperature spectrum falls. So, for example, if the individual upon whom Fig. 1 is based were to put on a sweater or jacket, we would expect the curve to move to the left so it is centered on a lower space temperature. If the individual were to change into light summer clothing, we would expect the curve to move to the right.

For a building inhabited by a variety of occupants with differences in clothing and other factors, one would expect a variety of individual comfort curves centered around different space temperatures. From these, it would be easy to calculate the number of expected complaints if one knew the center point of each individual's comfort curve. Fig. 2 shows what percentage of occupants would be likely to complain at various space temperatures if there were a normal distribution of individual temperature curves for building occupants. In Fig. 2, the line plot shows the number of people whose individual comfort curves are centered on the various space temperatures, and the bar graph shows the percent of occupants who would be likely to complain when the building is operated at that space temperature. Surprisingly, the curve in Fig. 2 does not correlate well with the experience of many building operators because it does not predict the large increase of comfort complaints originating from very small changes in building space temperature.

If, however, it is assumed that the occupants of buildings generally fall into two groups, one that likes the space warmer than the current set point and one that likes the space cooler than that set point, the resulting satisfaction curve takes on the appearance of Fig. 3. Note that in Fig. 3, nearly two-thirds of the building occupants' individual comfort curves are assumed to be centered on two space temperatures that, rather than being next to one another, are about 4 F apart (72 and 76 F). The temperature/complaint graph in Fig. 3 looks much more like what one would expect from the experience of building engineers. Comfort complaints are low as long as building space temperature is maintained within an extremely narrow temperature range. If the building temperature varies only slightly, the number of occupants likely to complain rises rapidly. So despite each individual's tolerance for a rather wide variation of space temperatures, a group of people can require a very narrow space temperature range.

Satisfying all occupants

Many explanations have been presented for a polarized distribution of comfort curves in buildings. I suggest that it is the uniform conditions themselves that our industry struggles to maintain in buildings that tends to polarize individual groupings. By understanding the dynamic nature of comfort curves (*e.g.,* they change with activity and/or stress), one does not need to make a great leap in faith to see that subjecting these dynamic individual curves to a static environment can act to exaggerate their comfort curves away from that static set point condition.

Whatever the true distribution of comfort curves in buildings, the industry has begun to realize we're nearing the end of the era of uniform conditions in buildings for many reasons. First among them is that despite improvements in control technologies, occupants do not appear to complain less about comfort than they did decades ago!

Another problem with uniform building conditions is that the work many in the industry have done with dynamic control has shown that operating buildings at constant thermal conditions is not the most energy-efficient mode of operation. And finally, polarization as represented in Fig. 3 requires a space temperature that provides only marginal satisfaction for most of those who do not complain.

Rather than pursue technologies that are aimed at maintaining uniform fixed space thermal conditions in buildings, it is far more prudent now to seize the opportunity to develop technologies and HVAC designs that offer individual environmental control for building occupants. Individual control concepts provide the opportunity of operating buildings more comfortably with lower energy use. The first cost of individual control system concepts is improving as the economy of the controls technologies upon which they are based improve. In my view, individual environmental control is indeed a concept whose time has come.

Development of individual control

Our firm first started working with individual control concepts nearly two decades ago. At that time, we designed and tested a small air conditioning unit to be mounted in the modesty panel of office desks with outlets on the front edge of the desk. The unit drew air from the floor and discharged the condenser cooling air vertically from the rear of the desk. For heating, it employed a small radiant panel on the modesty panel. The occupant could adjust cooling air flow and set the radiant panel to any power setting. Maximum power drawn off the unit was a mere 175 watts, and tests determined that the unit could provide a perceived thermal sensation of ±3 to 5 F from the ambient space tem-

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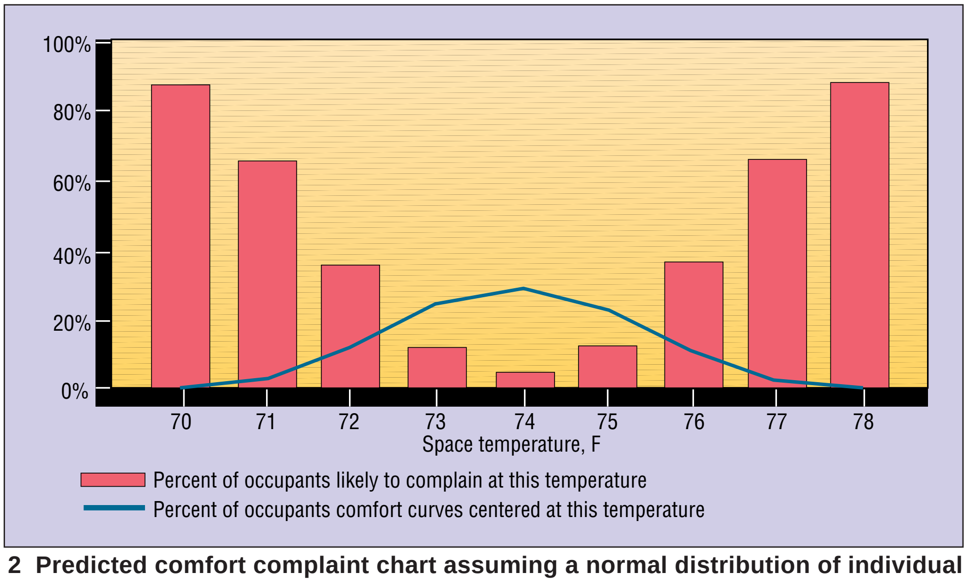
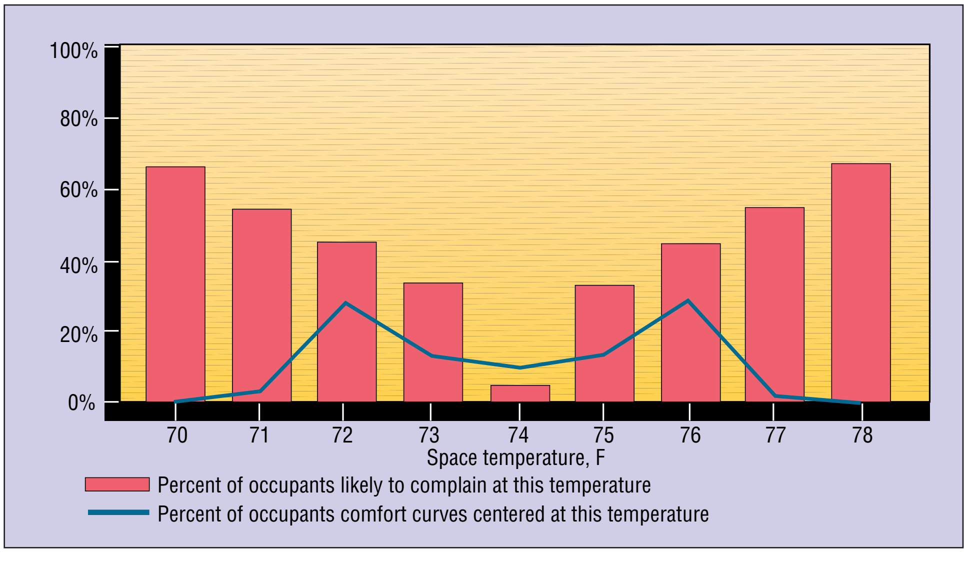


2 Predicted comfort complaint chart assuming a normal distribution of individual comfort curves within the building.



3 Predicted comfort complaint chart assuming a polarized distribution of individual comfort curves within the building.

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perature. We were pleased with the result, but the office furniture manufacturer with whom we were working lost interest in the concept, and it was never integrated into their office furniture.

By the mid 1980s, workstation-based comfort control systems that connected directly to the building's air distribution system were becoming available. Today, the workstation-based individual control system still offers the best capacity for satisfying individual environmental requirements, especially in open office areas. But this type of system also has some drawbacks. The requirement that the workstation be connected to the air system may limit the space designer's flexibility. Such systems may also negatively affect the esthetics of the space and make even minor rearrangements costly. Furthermore, adding HVAC components to and around workstations adds clutter to space the occupants would often like to use to store their clutter!

In the last few years, a number of new approaches to individual control have been advanced by manufacturers and design engineers. Workstation-focused individual control products available today range from systems that provide a totally stand-alone HVAC system for each workstation to those that simply employ fans in the workstations and permit the occupants to direct more or less ambient air over and around them. Other approaches, such as underfloor air distribution systems that afford occupants the ability to adjust the flow of air around their workstation, have also been successfully employed.

Personal diffuser technologies

About the same time the workstation-based individual control concepts were being introduced, work began on other paths toward meeting the growing demand for more individual control within buildings. Most air-based HVAC systems employ a single terminal unit for every two to four offices. A single controlling thermostat is placed in just one of the offices, and the rest operate with essentially no control at all. This loose zone control is based on the premise that offices sharing a common building exposure experience nearly identical heat load characteristics. However, improvements in building envelope technologies over the last several decades together with variations of internal heat loads now make the heat balance equations of offices widely variable even when they share the same perimeter exposure.

To deal with heat load variations in different spaces served by a single terminal unit, engineers began developing designs that could change the balance of air flow from the terminal unit among the individual offices or areas it served based on the thermal conditions of each area. For example, if one office was at its thermal set point, a damper at the diffuser supplying air to that room (or area) would close, directing most of the terminal unit's supply air to the other offices or areas served by that terminal unit. This concept has evolved to what is today called personal diffuser technologies.

4 Personal diffuser installed in an office. This style provides air diffusion by injecting a stream of air into the room. Inset photo is a closeup of the diffuser. *Photos courtesy of Zero Complaints.*

Originally, personal diffusers were connected to standard VAV boxes and employed to redistribute air among the areas served by the box. However, the technology has evolved to one where the VAV box now regulates the downstream static pressure and switches from heating to cooling, depending on commands from the personal diffusers it serves. Typically, when configured with low pressure rooftop air supply systems, personal diffusers require no intermediate control boxes or devices at all. As personal diffuser technologies have matured, a number of approaches have been taken to improve control capabilities. One important improvement is the use of wireless infrared remote controls that allow occupants to make temperature adjustments with ease. Fig. 4 shows a personal diffuser in an office application. Here, two personal diffusers are employed in a master/subordinate configuration. An in-depth explanation of this system concept appears in the March 1995 issue of *HPAC*. A more typical personal diffuser, which usually fits in a 2 by 2 ft ceiling grid, is shown in Fig. 5.

Most personal diffuser designs do not offer complete individual control because personal diffusers are typically connected to an air supply system serving several offices or spaces and cannot simultaneously provide heating to one diffuser and cooling to another. But personal diffuser technology does go a long way toward improving building environments from the days of one thermostat for every three or four offices. Each personal diffuser employs an integrated space temperature sensor to provide local temperature control. Furthermore, the personal diffuser technology can be easily added to any type of standard overhead air distribution system common in office buildings today. And it is an economical technology, often adding only modestly, if at all, to the overall cost of a traditional HVAC system. In some ways, the personal diffuser is a true crossroads product. Although its name suggests individual control, it really cannot provide distinct thermal environments, especially in open office environments. What the technology can do is provide a more precise, uniform space temperature throughout the building. The question is, will this technology be enough to satisfy building occupants, or will they be captivated by the possibilities it suggests and want more?

5 Technician installing a lay-in style of personal diffuser. This unit mixes supply air with room air by maintaining a fixed outlet velocity at reduced supply air flows. *Photo courtesy of Warren Technology.*

Industry developments

There is by no means a consensus on the future of individual environmental control in buildings. As indicated earlier in this article, some still believe it is more useful to apply advanced control technologies to maintain rigidly uniform thermal conditions in buildings. Others are concerned that the cost premium for individual control will keep it out of mainstream designs for the foreseeable future. Those involved in the individual control market are experiencing an expanding demand for such systems, but the market share for these products is still quite small. Few anywhere in the industry will go on record with predictions for the role of individual control.

Since our firm's experiences with an individually controllable desk-based comfort system, I have been convinced that a confluence of trends would some day make individual control-based HVAC/lighting the obvious choice for commercial buildings. Emerging digital control and network technologies have continuously reduced controls costs for individual control concepts while at the same time, building occupants have been increasing their demands for better comfort and control over their work environments. Also, building owners and managers have been looking for amenities to attract potential tenants who are increasingly working at their homes. These trends increase the attractiveness of individual environmental control. Now, the emergence of deregulated electric utilities, some of which are anxious to invest in high-quality building comfort systems, may radically shift the way engineers view HVAC system design.

Buildings in the next century

The term *human habitat* is used to describe the places where we spend our time because they are the places where we feel most comfortable. Office buildings have historically not been seen as conformable environments. Instead, people flock to them simply because their jobs require it. Now, modern technology offers us choices. We can now be nearly as "connected" from our homes as at our offices. This trend to forsake the office environment and, despite the problems of isolation and disruptions, have employees work primarily at home is growing. If office buildings are to retain their economic viability and flourish into the next century, we engineers must sharpen our focus on comfort. To do so, we must reach beyond a design methodology that sees comfort as a simple matter of maintaining heat balances. Instead, we must implement designs that make buildings more environmentally attractive. Individual comfort control is an obvious vehicle for turning unfriendly offices into desirable worker habitats. **HPAC**

Background information on technologies discussed in this article are available at www.hartmanco.com/engr. Any questions or comments about this article may be addressed to Mr. Hartman at tomh@hartmanco.com or Compuserve 104067,3463. Thomas Hartman is a member of HPAC*'s Board of Consulting and Contributing Editors.*