APPLYING ASHRAE STANDARD 55-2020

A Path To More Valuable, Productive, Ultralow Energy Office Buildings

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The fundamental value of an office building is the work performed by its occupants. The direct workforce costs each year that enable this value are typically as great as the one-time cost of the building's construction. Designers and equipment manufacturers should regard this overwhelming cost/benefit metric a mandate to develop and apply systems to provide indoor environments that will maximize the opportunity for occupants to perform at their best. This article discusses how exploiting newer features of ASHRAE Standard 55-2020, *Thermal Environmental Conditions for Human Occupancy*,[1] can put the industry on a path to new methods of distributing comfort and fresh air for VAV systems that will result in healthier and more comfortable office buildings. These buildings will be more environmentally attractive to their office workers, more financially beneficial for the tenants and owners, and help the industry meet its decarbonization goals with ultralow energy, occupant-centric office building operations.

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Research has found just small variations from an office worker's thermal comfort preference significantly reduce work performance,[2,3] which is generally found in more recent studies to be in the range of about a 2% to 4% reduction in work productivity for each 1°C (1.8°F) from that desired thermal condition.[4] And surveys consistently find only about half or less of office building occupants register as satisfied with their workspace thermal environment.[5,6] In addition, though evidence is still considered inconsistent, some studies now show that providing a fresher workspace environment with reduced CO_2 levels may significantly improve cognitive capacity, which leads to work performance gains that could be even larger than those from improving comfort.[7–9]

Every bit as important in terms of the effect on office work performance is the way modern offices are configured. Open plan office spaces are at times favored because they facilitate the long-standing method of mixing conditioning air with room air and reduce the likelihood of stagnant air areas. But these more open office configurations allow an easy path for pathogen transmission.[10] Also, research has found work performance reductions of more than 20% in open offices compared to partitioned private workspaces for work that requires concentration.[11] The "awfulness" of open offices is being ever widely expressed—with studies sometimes cited to back up the claim.[12]

While additional research is needed to better quantify some of these work performance factors and the interaction among them, it can be estimated with some confidence based on published averages for office building occupant density, profit margins and costs along with the performance research cited above that improving thermal comfort satisfaction alone could increase a typical office building's net financial bottom line with improved work performance by more than $\$10/\text{ft}^2$ ($\$108/\text{m}^2$) each year.[13–16]

By including conservative estimates for the effects that better overall conditioning combined with improved workspace layouts could have on all work performance, absenteeism and turnover, the total financial opportunity is easily several times this value for typical offices—a huge financial opportunity for firms that occupy these buildings. While this work performance value metric, along with a focus on occupant satisfaction, has historically been considered only indirectly—if it is considered at all, it may become increasingly important as building owners and tenants look to encourage the return of workers to the office.

Comfort Standard Developments

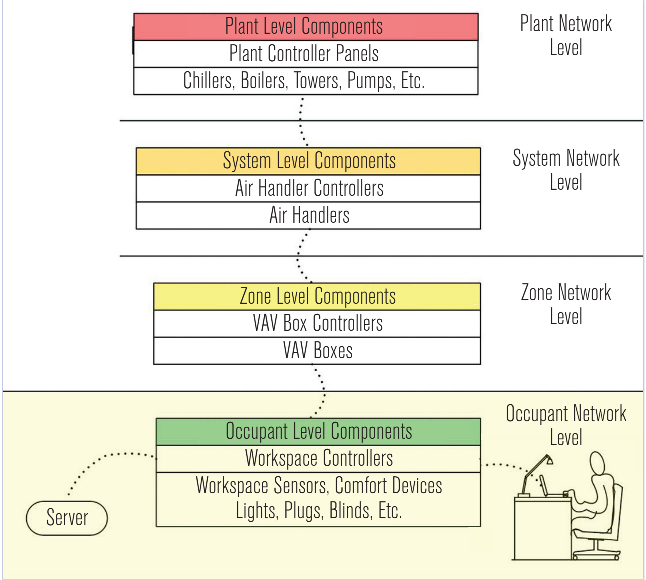
ASHRAE Standard 55 defines relationships that determine the level of thermal comfort in buildings. Four are environmental thermal comfort components or factors, space temperature, mean radiant temperature, air movement and humidity; and two are personal factors, clothing and activity levels. However, there is a developing recognition that other environmental thermal comfort factors beyond those considered in Standard 55 and differences among individuals yield variances in thermal comfort preferences[17] that can only be accommodated by some degree of individualized thermal control for each workspace.

It has become increasingly clear that the industry's long-standing practice of configuring large multi-workspace zones with limited local control cannot ensure the thermal preferences of many occupants will be satisfied. As a result, Section 6 of Standard 55-2020 requires designers to designate the classification of thermal environmental control that is to be provided in each occupied space type. The classification ranges from 5: no occupant control, to 1: control of at least two separate comfort factors or measures for each occupant with minimum thermal comfort corrective power (CP) requirements specified in the standard.

This, for the first time, encourages designers to consider how individual occupants at their workspaces are to be thermally satisfied instead of presuming a conventional zone-wide diffused mixed air-conditioning arrangement will achieve suitable thermal comfort conditions for occupants throughout each zone. And this new feature of Standard 55-2020 encourages systems that control more than just space temperature for thermal comfort in office spaces.

To assist designers and manufacturers, work is being done to estimate the CP of personal devices that can manipulate comfort factors beyond air temperature. Of these, the use of localized low velocity air movement is best understood and is already incorporated into the Center for the Built Environment's online Thermal Comfort Tool,[18] which is a web-based tool for thermal comfort calculations according to ASHRAE Standard 55-2020. Information is now available to calculate air movement and CP for small ceiling fans,[19] or desk fans, along with an

FIGURE 1 VAV system control network levels.



evaluation of CP for other potential individual thermal comfort devices.[20]

Effective integration of devices that can adjust local thermal comfort levels separately for each workspace into the HVAC system can ensure each will achieve its occupant's desired comfort level. Further, such integration offers the opportunity to couple this improvement in comfort with improved ventilation that together can achieve dramatic reductions in energy consumption and help meet ASHRAE sustainability and decarbonization goals for new office buildings. And it can be a highly effective energy reduction retrofit strategy for existing office buildings, while providing very attractive financial returns by improving the office building's fundamental economic value—occupant work performance.

Using Standard 55-2020 Most Effectively

Despite an improved understanding of human physiology and the technological advances that have occurred over the last few decades, methods of distributing comfort conditioning to workspaces in office buildings with VAV systems have experienced surprisingly few improvements. Achieving the highest Standard 55-2020 thermal environmental control classification in VAV systems with maximum efficiency requires a method of coordinating occupant thermal comfort preferences with the operation of comfort measures in each workspace as well as those in adjacent workspaces and with the HVAC system.[21]

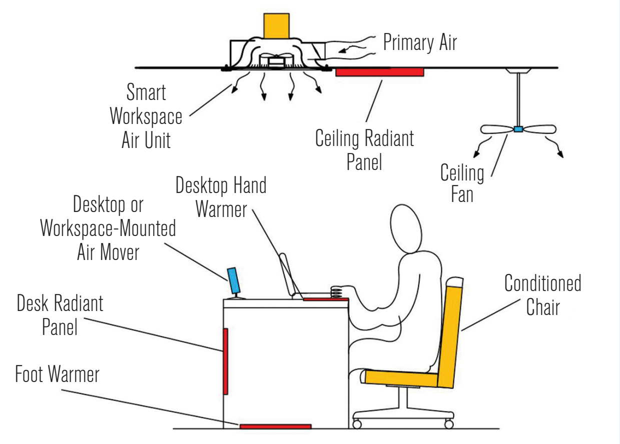
Research by the author has found substantial benefits from combining personal workspace comfort measures of Standard 55-2020 with two additional features: first, adding a new network in occupant areas that connects the thermal comfort controls and instrumentation in each workspace with its occupant(s), other workspaces and with the VAV system serving each workspace; and second, replacing zone-wide distribution of conditioning with a method of directing and controlling the distribution of primary VAV conditioning directly to individual workspaces, controlled together with other thermal comfort control measure(s) at each workspace to achieve the local desired thermal comfort level.

Figure 1 shows diagrammatically a VAV system with this new occupant network level highlighted. The equipment configuration down to the zone level components is essentially unchanged from conventional VAV systems. What is different is the occupant network level of communication with the locally controllable thermal comfort and ventilation resources and workspace sensors and devices in each workspace that ensure each occupant's comfort and air quality needs are satisfied.

The occupant network also communicates with the workspace occupant(s) via smart devices and is incorporated into or interfaced with the building automation system (BAS) control network. It incorporates an extensive database in a server that collects and analyzes data to direct this and the other system levels to satisfy occupant comfort expectations with optimum overall operating efficiency. The second key to maximize effective and efficient operation is to use this new network level to direct and control the delivery of the primary VAV thermal and ventilation conditioning to each occupied workspace instead of applying conventional zone-wide conditioning.

Controlling the delivery and mixing of the system's primary air directly within each workspace provides many advantages. Such a distribution configuration will provide fresher air more directly to each occupant and enable the use of partitions or walls for acoustical and visual privacy without concerns of stagnant air. Workspace-based primary air distribution can also reduce the likelihood of airborne pathogen transmission by confining much of the room air mixing to within each workspace. And workspace-based VAV distribution saves energy by focusing conditioning on the occupied spaces, while those that are unoccupied are maintained only in a standby condition that is dependent on the likelihood

FIGURE 2 Workspace-based personal comfort device options.



of imminent occupancy based on historic patterns.

However, unless the workspace is a closed-door office, adjusting local thermal comfort conditions using control of space temperature alone can conflict with surrounding workspace conditions; it's one reason Standard 55-2020 requires multiple thermal comfort measures for an improved thermal environmental control classification. Coordinated control among adjacent workspaces is necessary to prevent workspaces from thermally battling one another. The control and coordination of each workspace's multiple comfort measures can best be accomplished by the workspace controller of *Figure 1*, with which communication is shown by the dashed lines. The workspace controller in *Figure 1* also incorporates or is in communication with a sensor array in the workspace that at a minimum includes the ability to sense local temperature, humidity, occupancy and certain air quality parameters.

Figure 1 is meant to be illustrative only. There are several different control architectures that can be used. It is essential that the controls for each workspace are not only in communication with the occupant and the workspace's sensing and comfort measures, but also with a zone collector and processor that is either part of or communicates with the BAS zone controller. This device aggregates information from all workspaces in each zone to regulate the airflow from the zone VAV box and provides information to the HVAC system that can be used to establish optimal primary air temperature and fresh air volume from the air handler as occupancy patterns and the occupants' environmental expectations in each zone fluctuate.

Such a robust occupant network can incorporate data management and analysis to optimize the operation of the HVAC system in surprising new ways. Devices and equipment needed to develop individual thermally controllable workspaces are now available, and more are being developed. *Figures 2* and *3* show some of the variety of devices and systems now available or under development, one or several of which can be used to provide localized individual thermal comfort adjustments at office workspaces.

Figure 3 is a CFD model of a ceiling-mounted personal comfort unit that fits in place of a standard diffuser. It regulates primary airflow and mixes it with workspace air within the unit. It then delivers a combination of air temperature and air movement to the occupant below as required to satisfy the occupant's thermal

FIGURE 3 CFD picture of smart workspace air unit providing adjustable air temperature and movement to workspace.

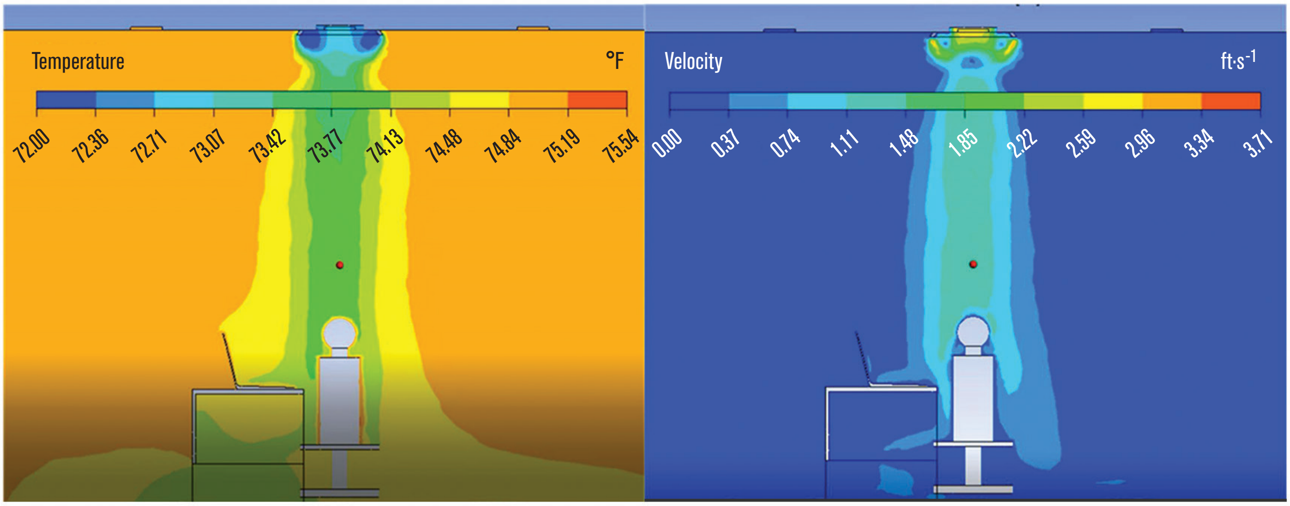


TABLE 1 Ten-story professional office building: occupancy—workspace types.

TYPE	WORKSPACE OCCUPANCY TYPE DESCRIPTION	ASHRAE STANDARD 55 THERMAL CONTROL CLASSIFICATION LEVEL	NUMBER OF TYPE IN BUILDING	AVERAGE AREA EACH TYPE (ft^2)	TOTAL AREA EACH OCCUPANCY TYPE (ft^2)	% OF TOTAL FLOOR AREA	NUMBER OR PERSONS		
							DESIGN ASSIGNED	TOTAL DESIGN ASSIGNED	OCCUPIED RANGE
1	Private Office	1	120	225	27,000	15.0%	1	120	1 to 2
2	Private Cubicle	1	1,020	72	73,440	40.8%	1	1,020	1
3	Collaboration Cubicle	3	70	144	10,080	5.6%	1	70	2 to 4
4	Conference Room	3	40	285	11,400	6.3%	0	0	2 to 8
5	Break Room, Reception Filing/Printing	4	10	1,000	10,000	5.6%	2	20	1 to 5
6	Restrooms/ Lobbies/Corridors	5	10	4,808	48,080	26.7%	0	0	1
TOTALS			1,270		180,000	100.0%		1,230	

preference without adversely affecting thermal comfort levels at adjacent workstations. This CFD model shows the comfort unit using a combination of localized air temperature (left panel) and low velocity air movement (right panel) to provide a cooler workspace environment in accordance with its occupant's preference.

The zone temperature in the *Figure 3* CFD model is 75°F (23.9°C). But the occupant, due to clothing and/or activity level, desires cooler workspace conditions than those in adjacent workspaces. *Figure 3* illustrates how the unit might react. The unit surrounds the occupant with an average 74°F (23.3°C) workspace air temperature, which, with the elevated level of air movement, yields a thermal condition equivalent to a 72°F (22.2°C) air temperature at normal air movement conditions in accordance with the Thermal Comfort Tool—a 3°F (1.7°C) of corrective power (CP).

Versions of the unit in *Figure 3* have automatically adjusting outlet vanes and controls with the ability to locate where occupant(s) are in the space below and direct conditioning accordingly.

Energy Optimization and Grid Flexibility

Building HVAC systems have traditionally lacked direct connection with the occupants they serve. They are designed and operated to react as conditions change to achieve a stable space temperature in each zone, but whether space temperature conditions are uniform throughout the zone or will satisfy all or most occupants at any time is largely unknown. Rather, it is regularly left up to a building operator to investigate and try by adjusting system parameters to improve local space conditions when occupants complain.

Connecting the VAV system and controls directly with each occupant through an occupant network that incorporates local workspace-based primary air distribution and one or more added workspace thermal comfort control measures can allow the control loop between system operation and occupant expectations to be closed. This can result in substantial comfort, environmental, operational and energy-saving benefits. Information can be passed throughout the system to ensure not only that each occupant's environmental requests are satisfied, but that it is with the most efficient combination of the workspace comfort measures available. Furthermore, such communication can engage with occupants to help them understand and minimize their workspace energy use and mitigate the consequences when grid constraints arise, resulting in both lower and far more flexible building energy use.[22]

Work is underway by the industry to develop occupant networks with equipment and software that close this traditionally open loop by providing feedback directly from each occupant and the local conditions to the HVAC system. These software packages, as they are being developed and becoming available, have the advantage of requiring far less customized programming because the scheduling, setpoints and equipment operating criteria are all established by real-time feedback of the location and environmental expectations of occupants present in the building.

It is expected that such control software can be preprogrammed, set up and commissioned more expeditiously than many building control sequences are now. And owing to the automatic adjustment of the various HVAC system components to meet the

FIGURE 4 Office building with personal air distribution in Atlanta climate.

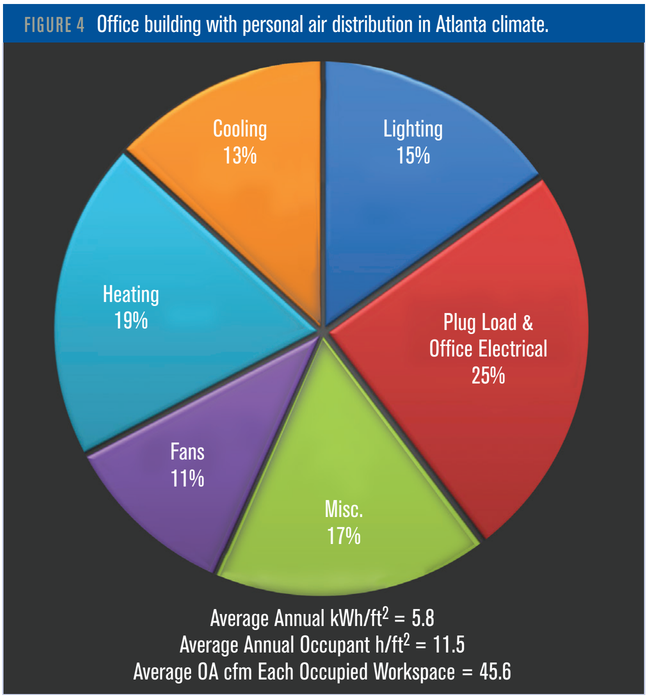
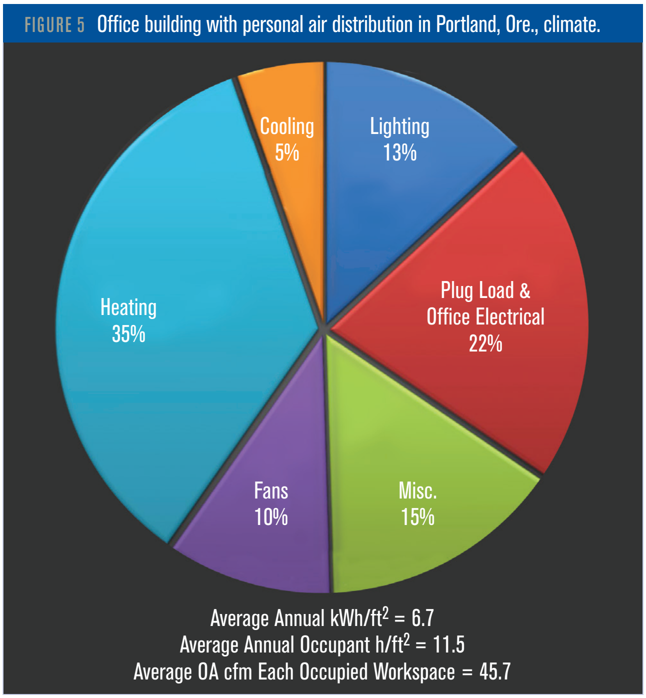


FIGURE 5 Office building with personal air distribution in Portland, Ore., climate.



specific comfort requirements of each occupant, the need for manual intervention under normal operating conditions will be greatly reduced.

Such occupant-centric closed loop VAV control systems can reduce energy use by directing conditioning according to actual occupancy conditions and by continuously comparing and optimizing the marginal energy cost of the multiple measures available to thermally satisfy each workspace. At the system and plant levels, information from the occupant network is aggregated and used to optimize operations by simultaneously adjusting both flow and temperature outputs from the water and airside system components with direct multivariable control[23] that optimizes these systems in accordance with constraints of the currently occupied space conditioning requirements. Significant energy performance improvements are shown to result in simulations discussed below.

With these operational strategies, improved occupant environmental satisfaction—along with the increased efficiency of part-load operation and reductions in overall conditioning energy requirements—can result from focusing conditioning and control on occupants instead of the building. A preliminary energy analysis of an ASHRAE Standard 90.1-2022[24] compliant office building envelope with 10 floors of office space totaling 180,000 ft^2 (16 723 m^2) was developed with an in-house hourly simulation program.

The simulated VAV system uses control of two local workspace comfort measures (air temperature and air movement) with individualized, informed occupant-centric control. Air-to-water electric heat pumps provide heating and cooling conditioning for the building perimeter and interior space heating. Interior space cooling is provided by water-cooled chilling. Heat recovery is applied to building exhaust.

The space types and the ASHRAE Thermal Control Classification for each are shown in *Table 1* (page 33). In operation, the building perimeter is thermally neutralized with convection conditioning. Workspace thermal comfort is achieved by ensuring the space air temperature is adequate to satisfy the occupied workspace in each zone that requests the warmest conditions; then a combination of reduced air temperature and air movement is applied to satisfy the zone's other occupied workspaces. The simulation program uses probability functions each hour to establish realistic workspace occupancy status and the number of occupants in each occupied workspace type from the occupancy range listed in *Table 1* over the course of each day. Occupancy probability for each space type is based on office workspace occupancy pattern research.[25]

The simulation results in *Figures 4* and *5* illustrate the potential for low energy use with this individualized workspace operation strategy. These figures show the simulated energy use intensity (EUI) in kWh/ft^2, occupant density in occupant hours/ft^2, and average occupied workspace outdoor ventilation in cfm/person from multiple simulations for such a building in Atlanta, and Portland, Ore., climates. The pie charts also show the percentage of the total building energy use for various categories. In these models, unoccupied spaces are maintained at a standby condition, ready for immediate occupancy, weekdays from 5 a.m. to 10 p.m. At other hours, a short duration of extra conditioning during initial workspace occupancy may be required to achieve desired thermal conditions.

The 5.8 kWh/ft^2 and 6.7 kWh/ft^2 simulated for Atlanta and Portland, Ore., respectively, are near the lowest in the range in EUI that could be expected for high-performance office buildings of this size. Despite the low energy use, this system provides individualized comfort control and an average rate of ventilation for each occupant that is about double the prescribed minimum. These results, while preliminary, do illustrate that a system that provides personalized thermal conditioning where and when each space is occupied can also lead to very low energy use and higher levels of ventilation for its building occupants.

While the integration of the occupant network and multiple individual comfort measures will very likely cause an increase in the cost of an HVAC tenant improvement, the combination of lower energy cost and increased economic return from improved workforce performance make such an investment in workspace-based conditioning a very compelling step toward net zero energy operation.

Summary and Conclusion

Maximizing the financial bottom line of office buildings requires an emphasis on occupant comfort, environmental quality and reduced distractions at each workspace. Achieving these objectives with the greatest energy efficiency to meet decarbonization goals demands new approaches to distributing conditioning in office buildings. The application of new ASHRAE Standard 55-2020 features can help by using multiple workspace-based comfort control measures that include local workspace control of the primary HVAC conditioning. Changing from distribution systems that provide zone-level conditioning to one that focuses on workspace conditioning control by each occupant, with an occupant-level network that connects and coordinates the control of multiple local comfort measures directly with its occupants, allows the environmental desires of each occupant to be automatically achieved with maximum efficiency.

Such an informed occupant-centric closed loop method of thermal comfort control can use strategies that minimize energy use by automatically adjusting systems and setpoints optimally for current conditions. This eliminates or greatly reduces the need for the intervention that operators otherwise often use to try to minimize occupant complaints. The result is a more efficient and valuable facility, and one that requires less human supervision to operate. Occupant networks in accordance with *Figure 1* that include features outlined herein are now being developed and becoming available.

Architecture and engineering teams should be encouraged to promote the large financial value individual environmental control features Standard 55-2020 offers to their owner and tenant clients. HVAC designers and equipment manufacturers must accelerate incorporating workspace-based thermal comfort control concepts and components into their designs and product offerings. To support a transition to more valuable and efficient office buildings, the industry also needs to continue research and studies on the relationships among energy use and work performance, with workplace thermal comfort, air quality and other personal well-being parameters.

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