#6743

N/s

Air movement, comfort and ventilation in partitioned workstations

Office partitions do not necessarily present a significant barrier to effective circulation or ventilation efficiency

By *Fred S. Bauman, P.E.;* Member ASHRAE
Randall S. Helm; Associate Member ASHRAE
David Faulkner, P.E.;
Edward A. Arens, Ph.D.; Member ASHRAE
and *William J. Fisk, P.E.* Member ASHRAE

Today's office designs, technologies and work processes make it increasingly difficult for conventional HVAC systems to satisfy the environmental needs of office workers —especially as those workers more openly express personal preferences about air quality and comfort.

In an open-plan office workplace, the design and configuration of furniture and partitions can, in certain cases, influence the thermal and airflow conditions in workstations. Some researchers believe that partitions separating workstations may obstruct airflow, resulting in poorly ventilated workstations.

Modern offices may also have large amounts of heat-generating equipment within workstations, requiring substantial airflow for heat removal. Frequent reconfiguration of the geometric layout and thermal loads of open-plan offices places additional demands on the HVAC system.

Data from several recent surveys of occupants of large office buildings identify indoor air quality and air circulation as two significant elements that contribute to worker comfort and satisfaction.[1-5] A 1989 Environmental Protection Agency survey of its own buildings found that 48% of the respondents from one facility brought portable fans to their offices.[6]

This body of research seems to indicate that lack of air movement is one of the most common complaints in office environments. The lack of air movement is frequently attributed to the configuration of workstations in open-plan designs.

This article presents the major results of a study examining the comfort and ventilation conditions in workstations surrounded by partitions and ventilated by a conventional ceiling supply-and-return air distribution system.[7,8] The study investigated a wide range of partition configurations and environmental parameters in an attempt to bring greater thoroughness to the testing methodology and to yield a more clearly substantiated conclusion on the role of partitions in air circulation.

The overall objectives of this study were: to evaluate the conditions under which partition designs can improve or degrade air movement, ventilation performance and worker comfort; and to evaluate the effects of an airflow gap near

Continued on page 44

About the authors

Fred S. Bauman is a research specialist in the Department of Architecture and Center for Environmental Design Research, University of California, Berkeley. He received his BS in mathematics from Harvey Mudd College and his MS in mechanical engineering from the University of California, Berkeley. Bauman is a member of ASHRAE TC 5.3 (Room Air Distribution), SPC 55-81R (Thermal Environmental Conditions for Human Occupancy) and TC 2.5 (Air Flow Around Buildings).

Randall S. Helm is a research engineer for Steelcase Inc., Grand Rapids, Michigan. He received his BS in architectural engineering from Penn State University and his MBA from Grand Valley State University.

David Faulkner is a principal research associate in the Indoor Environment Program, Energy and Environment Division, Lawrence Berkeley Laboratory, Berkeley, California. He received his BS and MS degrees in mechanical engineering from the California Institute of Technology.

Edward A. Arens is a professor in the Department of Architecture and director of the Center for Environmental Design Research, University of California, Berkeley. He received his PhD in architectural science from the University of Edinburgh. Arens is a member of ASHRAE TC 2.1 (Physiology and Human Environment), SPC 55-81R and a past-chairman of TC 2.5.

William J. Fisk is a staff scientist in the Indoor Environment Program, Lawrence Berkeley Laboratory. He received his BS from the University of New Mexico and his MS from the University of California, Berkeley, both degrees in mechanical engineering. Fisk is a member of ASHRAE SPC 129P (Standard Method of Test of Ventilation Effectiveness).

Partitioned workstations

Continued from page 42

the bottom of partitions on air movement, ventilation performance and worker comfort.

Experimental methods

Experiments were performed in a full-scale controlled environment chamber (CEC), with a conventional ceiling supply-and-return air distribution system (see *Figure 1*). The CEC measures 18 ft by 18 ft by 8 ft, 4 in. (5.5 m by 5.5 m by 2.5 m). It is designed to resemble a modern office space while still allowing a high degree of control over the test chamber's thermal environment.[9]

Three workstations were installed in the CEC using typical modular office furniture and partitions (see *Figure 2*). The range of partition configurations and environmental parameters were as follows.

- Partition heights: 75 in. (1.9 m); 65 in. (1.65 m); 42 in. (1.1 m); and no partitions
- Airflow gap sizes: 12 in. (0.3 m); 4 in. (0.1 m); 2 in. (0.05 m); and solid (no gap)
- Supply air volume: 0.2 to 1.0 cfm/ft² (1.0 to 5.0 L/s·m²)
- Return/supply temperature difference: 10° to 22°F (5.6°F (5.6° to 12.3°C)
- Supply/diffuser location
- Heat load density: 11 and 18 Btu/h·ft² (35 and 55 W/m²)
- Workstation floor area: 60 in. × 75 in. (1.5 m × 1.9 m) and 120 in. × 75 in. (3.05 m × 1.9 m)
- Cooling and heating mode

To compare the performance of solid versus airflow partitions, replacement panels (see *Figure 3*) for each airflow gap were fabricated out of 0.25 in. foam core, with velcro strips to secure them over the gap. The replacement panel could be positioned to completely cover the airflow gap (creating a solid partition) or to produce different sized airflow gaps.

Also shown in *Figure 3* are 10 in. (0.25 m) extension panels that were designed and fabricated to fit on top of the 65 in. (1.65 m) partitions, thereby increasing the overall partition height to 75 in. (1.9 m). The replacement and extension panels allowed partition configurations to be quickly changed without replacing entire partitions.

Heat loads were provided to simulate typical office distributions and densities. This included overhead lighting, and a personal computer, computer monitor and task light at each workstation.

During thermal measurements, the sensible heat load from a typical office

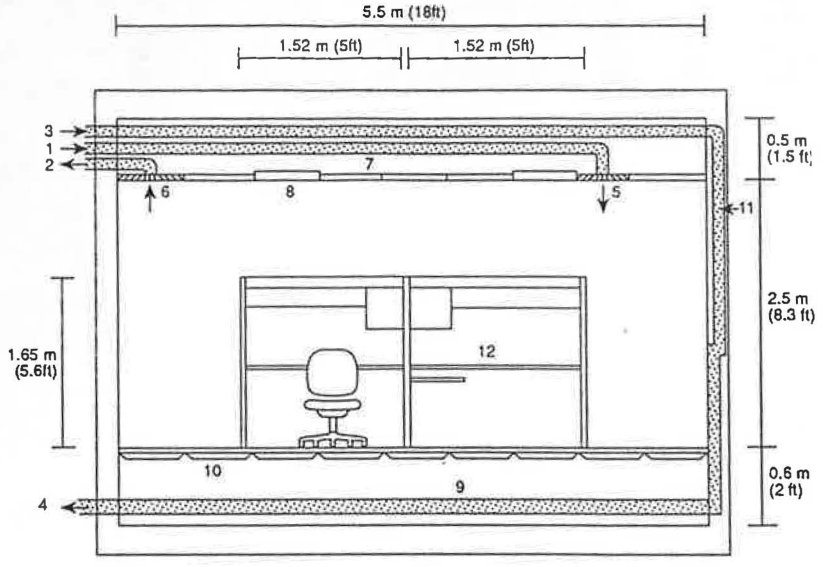

Figure 1. Controlled environment chamber with ceiling supply-and-return air distribution system.

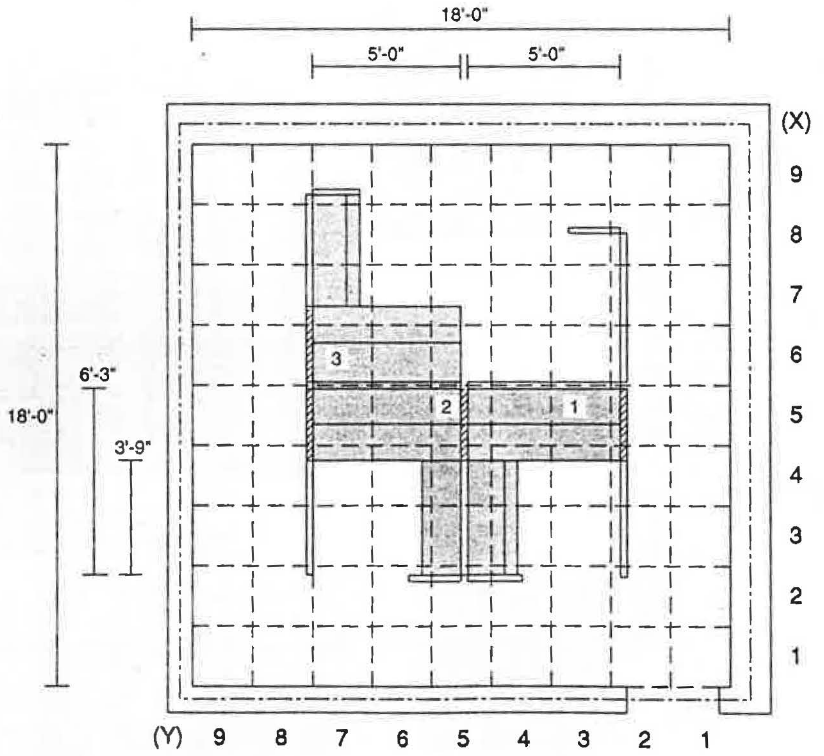

Figure 2. Arrangement of three workstations in the controlled environment chamber. (To change inches to millimeters, multiply by 25.4.)

Continued on page 46

Partitioned workstations

Continued from page 44

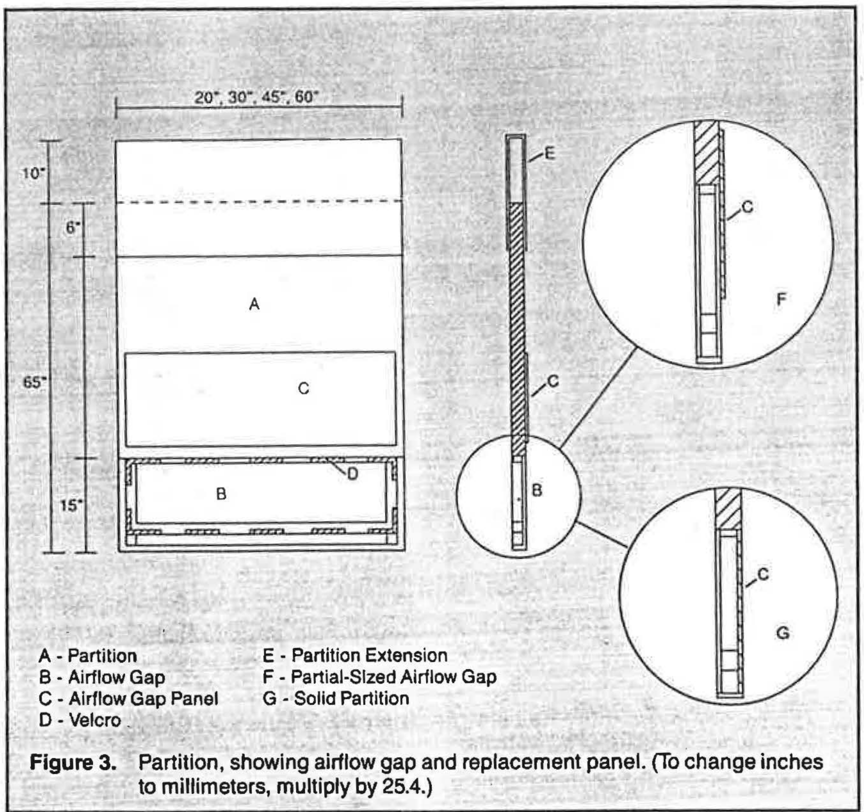

Figure 3. Partition, showing airflow gap and replacement panel. (To change inches to millimeters, multiply by 25.4.)

worker was simulated using a 75 W (260 Btu/h) light bulb near the edge of the desk. During tracer gas measurements of ventilation performances, a heated mannequin seated in front of the desk simulated the occupant load to produce realistic airflow patterns at the breathing level.

Under steady-state conditions, multipoint measurements were made to characterize the thermal environment and ventilation:

• Air velocities and temperatures were measured along with radiant (globe) temperatures to characterize the key environmental variables affecting thermal comfort. A lightweight sensor rig allowed a vertical array of sensors to be positioned at six heights (including those recommended by ASHRAE[10]) and to be moved around the test chamber, mapping out a grid of 26 measurement locations.

• The tracer gas step-up procedure was used to determine the ventilation performance within the test chamber.[11-13] Supply air was labeled with tracer gas (SF_6) and the tracer gas concentration was measured at knee level, breathing level and near the ceiling at up to eight locations in the room, as well as at four locations within the HVAC system.

The test results were analyzed and compared to evaluate the relative performance of each test configuration. Data analysis was performed using the following methods: the ASHRAE Air Diffusion Performance Index (ADPI) method[14] was used to quantify the overall air diffusion performance; the Fobelets and Gagge two-node comfort model[15] was used to predict characteristic comfort indices at typical work locations within each workstation; *ASHRAE Standard 55-1981*[10] was used with the thermal data to determine thermal acceptability; and the age-of-air method[11] was used to evaluate the spatial variability of ventilation. A complete description of the testing methodology is presented in Bauman, *et al.*[7,8]

Results

The major findings from this study are presented below. In discussing the results for different workstations, the reader is referred to *Figure 2*, which depicts the plan view of the test chamber.

As shown, the partitions and furniture were set up to produce two small workstations (WS#1 and WS#2) and one double-sized workstation (WS#3). The overhead position of the nine-by-nine grid of 2 ft by 2 ft (0.6 m by 0.6 m) suspended ceilir panels is also shown with dashed lines i the figure.

For the tests discussed below, air wa supplied through a single perforated lay-i diffuser located near one side of the roor at (x = 5, y = 2), using a three-way blo pattern away from the adjacent wall. Th ceiling return register was located at (x = 5 y = 9) during all tests.

Figure 4 presents average air velocit measurements in the three workstations fo four different solid partition heights: 75 in. (1.9 m); 65 in. (1.65 m); 42 in. (1.1 m); anc 0 in. (no partitions).

The tests were performed under similar thermal conditions: supply air volume of 0.9 to 1.0 cfm/ft² (4.5 to 4.0 L/s·m²); supply air temperature of 62.6° to 65.0°F (17.0° to 18.3°C); average room temperature of 75.7° to 77.4°F (24.3° to 25.2°C); and heat load density of 18 Btu/h·ft² (55 W/m²).

The diffuser manufacturer's specifications indicated that the supply volume used in these tests provided a throw within the acceptable range for good room air diffusion in the test chamber. *Figure 4* shows the average velocity in front of each desk at five of the six measurement heights above the floor, and is organized by workstation.

In *Figure 4*, the largest differences between tests occur in workstation 1 (WS#1), which was the closest workstation to the supply diffuser. Within WS#1, the no-partition test shows the highest velocities at all measurement heights, although the differences are only significant at the 4 in. (0.1 m) and perhaps the 2 ft (0.6 m) levels.

Differences of 6 fpm (0.03 m/s) or less were considered experimentally insignificant. This significance was determined from a combination of anemometer calibrations (±4 fpm; ±0.02 m/s) and empirical repeatability tests under similar test conditions.[7]

The next highest air velocities at these same two heights occurred for 75 in. (1.9 m) partitions and decreased with decreasing partition height to their minimum values for 42 in. (1.1 m) partitions. The upward entrainment of air by the overhead supply diffuser, combined with the buoyancy driven airflow produced by the high heat loads within the partitioned workstation, generated these characteristic velocities.

In WS#2 (further away from the supply diffuser), the no-partition test again shows the highest overall velocities. However, this result is not as significant as it was in WS#1. Velocity differences caused by

Continued on page 48

Partitioned workstations

Continued from page 46

partition height effects are quite small and follow no observable pattern.

In WS#3 (also further away from the supply diffuser and twice the size of WS#1 and WS#2), velocity differences between all four tests are insignificant. This result is not surprising, as the magnitude of partition effects should diminish with distance from the diffuser as well as with increasing workstation size; approaching, in the limiting case, air movement conditions found with no partitions present.

In all other test results, only small differences were detected in air velocity between solid and airflow partitions (solid partitions versus partitions with gaps near the floor). Also, in most cases, the measured differences were experimentally insignificant. Even in the instances where the velocity increases with airflow partitions were the highest, comfort model predictions indicated no improvement in comfort conditions.

Except for a few isolated data points, measured velocities at all locations within the occupied zone (4 to 67 in.; 0.1 to 1.7 m; height) for all tests were within the acceptable summer limits specified by *ASHRAE Standard 55-1981* (50 fpm; 0.25 m/s).[10] It is not surprising that changes in velocity at this relatively low range have little effect on overall comfort conditions.

The ASHRAE ADPI range for acceptable air diffusion is 80% or higher.[14] The air diffusion performance for 17 tests covering the full range of test conditions exceeded that standard because all calculated ADPI values fell between 89% and 99%.

Heat loads in partitioned workstations had a significant impact on air temperatures, mean radiant temperatures and overall comfort conditions. As the heat load density increased or the workstation size decreased, thermal conditions became less comfortable.

Figure 5 presents results from six representative tracer gas tests. The figure shows the average measured age of air at the return grill and at different heights in and above partitioned workstations: knee level, 16 in. (0.4 m); breathing level, 43 in. (1.1 m); and near the ceiling, 83 in. (2.1 m). The age of air is the time elapsed since the air entered the building from outside.

The error bars extend two standard deviations above (shown) and below (not shown) the measured values. The error bars are based on tests of precision and the number of values of age of air used for each average.

Results are shown for 65 and 75 in. (1.65 and 1.9 m) partitions, both solid and airflow (open gap) partitions, supply volumes from 0.17 to 0.62 cfm/ft² (0.8: 3.1 L/s·m²) and for an equal number cooling mode and heating mode tests.

In the cooling tests, the age of air the return is not significantly different frc the age of air at the breathing level. Bas on these and other results, the partitions c not produce preferential ventilation insi or outside the partitioned workstations.

In the heating tests, the age of air the return grill is slightly less than the age air at the breathing zone in the workst tions. This indicates a small amount c short-circuiting of air from the suppl diffuser to the return grill. This effect i most likely because of the buoyancy of th warm supply air and not because of th partitions.

A complete analysis of all tracer ga measurement data led to the conclusior that neither the height of the partitions no an airflow gap at the bottom of the partitions had any significant impact on the variation of age of air with height, short-circuiting or uniformity of workstation ventilation.

Conclusions

Although members of the building engineering community continue to express concern over the potentially detrimental effects of office partitions on air movement, comfort and air quality, the results of this study based on an extensive series of experiments in a controlled environment chamber do not support this contention.

A ceiling-mounted supply-and-return air distribution system supplying air to the test chamber over the range of 0.2 to 1.0 cfm/ft² (1 to 5 L/s·m²) was able to provide uniform ventilation rates into all three partitioned workstations. The range of tested air supply volumes represented rates that were both below and above the manufacturer's recommended minimum levels for acceptable diffuser performance. Variations in solid partition height produced only small differences in overall thermal performance and had no measurable impact on ventilation performance.

While the existence of an airflow opening at the bottom of office partitions can, in some cases, produce slight increases in air velocities near the floor, there are no significant improvements in comfort conditions or deviations from uniform ventilation within the workstations compared to results obtained for solid partitions.

Test parameters that were found to have a more substantial impact on air

Continued on page 50

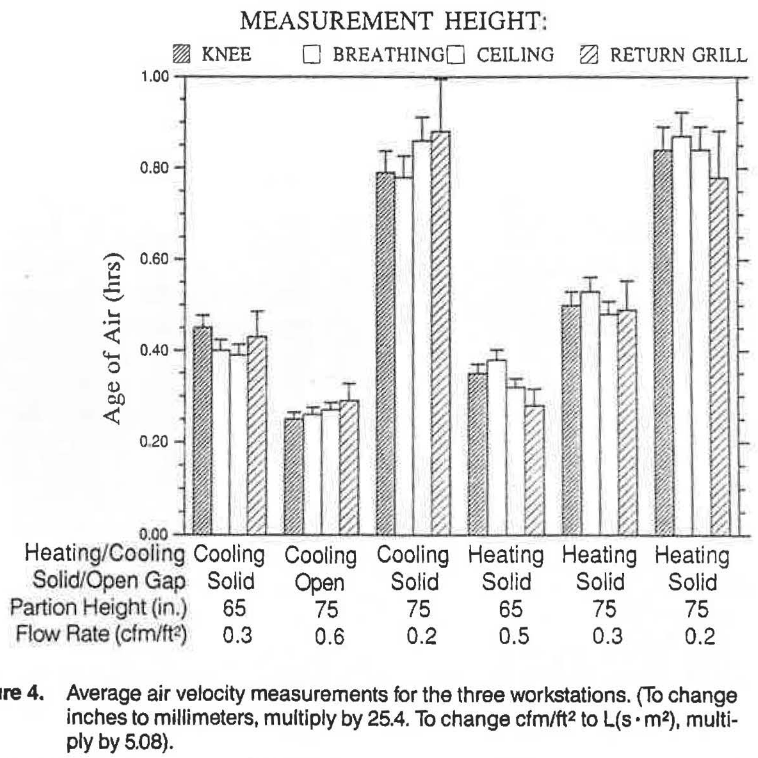

Figure 4. Average air velocity measurements for the three workstations. (To change inches to millimeters, multiply by 25.4. To change cfm/ft² to L(s·m²), multiply by 5.08).

Partitioned workstations

Continued from page 48

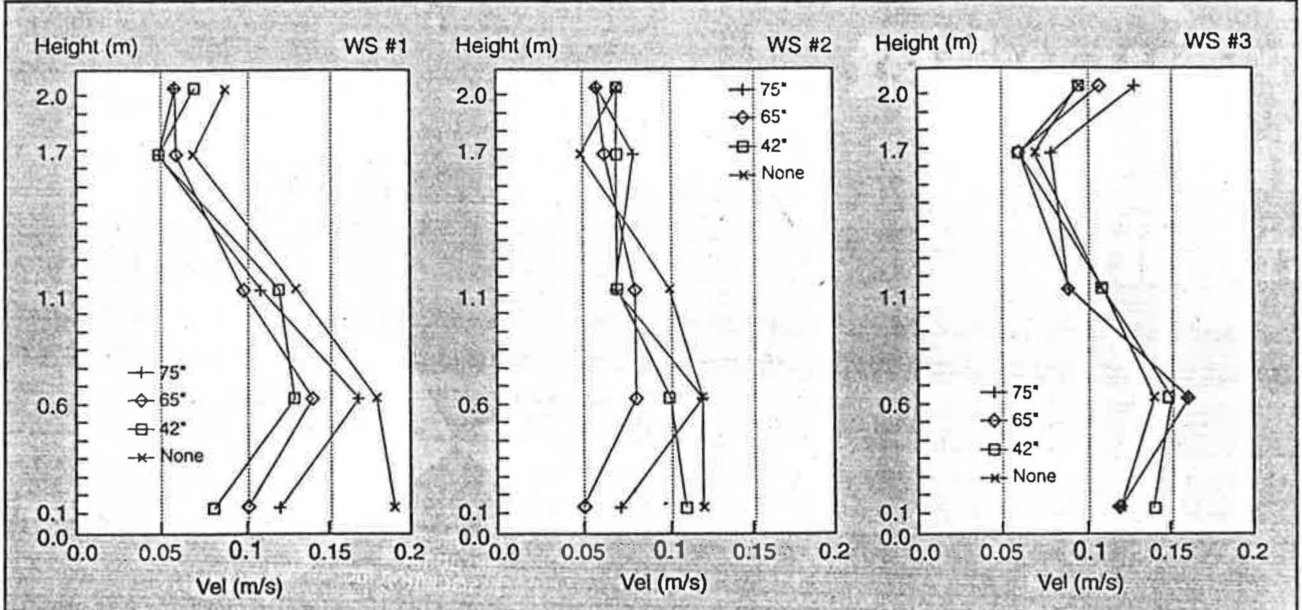

Figure 5. Results of six representative tracer gas tests. (To convert meters to feet, divide by 0.3048. To convert m/s to fpm, divide by 0.00508.)

movement and comfort included heat load density and distribution, supply air temperature and supply diffuser location.

Comparison of the results of this study with future field-based research in large partitioned offices is necessary before general conclusions can be drawn. However, it is important to know, based on the research presented here, that office partitions do not necessarily present a significant barrier to effective circulation or ventilation efficiency.

Acknowledgments

This work was supported by: Steelcase Inc., Grand Rapids, Michigan; the Assistant Secretary for Conservation and Renewable Energy, Office of Building Technologies, Building Systems and Materials Division of the U.S. Department of Energy; and by the Universitywide Energy Research Group, University of California, Berkeley.

We gratefully acknowledge the efforts of other members of the project team: Gail Brager, Lucy Johnston and Zhang Hui of the Center for Environmental Design Research, University of California, Berkeley; and Pleas McNeel and David Pih of the Indoor Environment Program, Lawrence Berkeley Laboratory.

We appreciate the technical advice received from Dan Int-Hout, Carrier Corp., Savannah, Georgia, and the equipment donations received from Environmental Technologies, Largo, Florida, and Flexible Technologies, La Mirada, California. ■

References

1. Brill, M., *et al.* 1984. *Using Office Design to Increase Productivity.* Buffalo, New York: Workplace Design and Productivity Inc. Vol. 1.

2. Woods, J., *et al.* 1987. "Office worker perceptions of indoor air quality effects on discomfort and performance." *Proceedings of the 4th International Conference on Indoor Air Quality and Climate.* Berlin, Germany: Institute for Water, Soil and Air Hygiene. August 17-21. pp. 464-68.

3. Dillon, R., Vischer, J. 1987. *Derivation of the Tenant Questionnaire Survey Assessment Method: Office Building Occupant Survey Data Analysis.* Ottawa, Ontario: Public Works Canada. AES/SAG 1-4:87-9.

4. Baillie, A., *et al.* 1987. *Thermal Comfort Assessment: A New Approach to Comfort Criteria in Buildings.* Final report ETSU 5-1177. Guildford, United Kingdom: University of Surrey, Department of Psychology.

5. Schiller, G., *et al.* 1988. "A field study of thermal environments and comfort in office buildings." *ASHRAE Transactions.* Vol. 94, Pt. 2.

6. EPA. 1989. *Indoor Air Quality and Work Environment Study: EPA Headquarters Buildings Employee Survey.* Washington, D.C.: U.S. Environmental Protection Agency. November.

7. Bauman, F., *et al.* 1992. "Air movement, ventilation and comfort in a partitioned office space." *ASHRAE Transactions.* Vol. 98, No. 1.

8. Bauman, F., *et al.* 1991. *Air Movement, Comfort and Ventilation in Workstations.* Berkeley, California: Center for Environmental Design Research, University of California. April.

9. Bauman, F., Arens, E. 1988. "The development of a controlled environment chamber for the physical and subjective assessment of human comfort in office buildings." *A New Frontier: Environments for Innovation. Proceedings of the International Symposium on Advanced Comfort Systems for the Work Environments.* W. Kroner, ed. Troy, New York: Center for Architectural Research.

10. ASHRAE. 1981. *ANSI/ASHRAE Standard 55-1981, Thermal Environmental Conditions for Human Occupancy.* Atlanta, Georgia: ASHRAE.

11. Sandberg, M., Sjoberg, M. 1983. "The use of moments for assessing air quality in ventilated rooms." *Building and Environment.* Vol. 18, pp. 181-197.

12. Fisk, W., *et al.* 1988. "Commercial building ventilation measurements using multiple tracer gases." *Proceedings of the 9th AIVC Conference on Effective Ventilation.* Coventry, Great Britain: Air Infiltration and Ventilation Centre. Vol. 1, pp. 161-182.

13. Fisk, W., *et al.* 1989. "A multi-tracer technique for studying rates of ventilation, air distribution patterns and air exchange efficiencies." *Building Systems: Room Air and Air Contaminant Distribution.* Atlanta, Georgia: ASHRAE. pp. 237-240.

14. ASHRAE. 1990. *ANSI/ASHRAE Standard 113-1990, Method of Testing for Room Air Diffusion.* Atlanta, Georgia: ASHRAE.

15. Fobelets, A., Gagge, A. 1988. "Rationalization of the effective temperature ET*, as a measure of the enthalpy of the human indoor environment." *ASHRAE Transactions.* Vol. 94, Pt. 1, pp. 12-31.