Title
Indoor Air Flow and Pollutant Removal in a Room with Desk-Top Ventilation

Authors
Faulkner, D.
Fisk, W.J.
Sullivan, D.P.

Publication Date
1993-04-01

LBL-34010
UC-350

Lawrence Berkeley Laboratory

UNIVERSITY OF CALIFORNIA

ENERGY & ENVIRONMENT DIVISION

To be presented at the 1993 Annual Meeting of the American Society of Heating, Refrigerating, and Air Conditioning Engineers, Denver, CO, June 26–30, 1993, and to be published in the Proceedings

Indoor Air Flow and Pollutant Removal in a Room With Desk-Top Ventilation

D. Faulkner, W.J. Fisk, D.P. Sullivan

April 1993

ENERGY & ENVIRONMENT DIVISION

Prepared for the U.S. Department of Energy under Contract Number DE-AC03-76SF00098

To be presented at the 1993 Annual Meeting of the American Society of Heating, Refrigerating, and Air Conditioning Engineers, 26 - 30 June, Denver, CO, and published in the ASHRAE Transactions.

LBL-34010
UC-350

Indoor Air Flow and Pollutant Removal in a Room With Desk-Top Ventilation

David Faulkner, William J. Fisk, Douglas P. Sullivan

Indoor Environment Program
Energy and Environment Division
Lawrence Berkeley Laboratory
University of California
Berkeley, California 94720

April 1993

This work was supported by the Assistant Secretary for Conservation and Renewable Energy, Office of Building and Community Systems, Building Systems Division of the U.S. Department of Energy (DOE) under Contract No. DE-AC03-76SF00098. The research reported here was also funded in part by the California Institute for Energy Efficiency (CIEE), a research unit of the University of California. Publication of research results does not imply CIEE endorsement of or agreement with these findings, nor that of any CIEE sponsor.

Abstract

In a furnished experimental facility with three workstations separated by partitions, we studied indoor air flow patterns and tobacco smoke removal efficiency of a desk-top task ventilation system. The task ventilation system permits occupant control of the temperature, flow rate and direction of air supplied through two desk-mounted supply nozzles. In the configuration evaluated, air exited the ventilated space through a ceiling-mounted return grill. To study indoor air flow patterns, we measured the age of air at multiple indoor locations using the tracer gas step-up procedure. To study the intra-room transport of tobacco smoke particles and the efficiency of particle removal by ventilation, a cigarette was smoked mechanically in one workstation and particle concentrations were measured at multiple indoor locations including the exhaust airstream. Test variables included the direction of air supply from the nozzles, supply nozzle area, supply flow rate and temperature, percent recirculation of chamber air, and internal heat loads.

Our major findings are as follows: (1) In tests with the nozzles pointed toward the occupants, 100% outside air supplied at the desk-top, and air supply rates of approximately 85 cfm (40 L/s) per workstation, the age of air at the breathing level of ventilated workstations was approximately 30% less than the age of air that would occur throughout the test space with perfectly mixed indoor air, (2) with smaller air supply rates and/or air supplied parallel to the edges of the desk, ages of air at breathing locations were not significantly lower than the age with perfect mixing, (3) indoor tobacco smoke particle concentrations at specific locations were generally within 12% of the average measured indoor concentration and concentrations of particles in the exhaust airstream were not significantly different from concentration of particles at breathing locations.
Key words: Air distribution, chamber, control, measurement, office building, tobacco smoke, ventilation

Introduction

A recent field study indicates that a significant percentage of office workers are not satisfied with their thermal environment while at work (Schiller et al. 1988). While some workers prefer to be cooler, other workers in nearby workstations prefer to be warmer. Since a single uniform thermal environment will not satisfy all workers, some manufacturers and researchers have postulated that if workers were given a controllable local supply of air, the workers would be thermally satisfied and, thus, possibly more productive. Task ventilation is a method for providing occupants control of a local supply of air so that they can adjust their individual thermal environment. Controlled variables could be the supply-air temperature, velocity, direction and the ratio of room air to main supply air.

The focus of this paper is the potential benefit of task ventilation, to improve ventilation and indoor air quality in the occupant's breathing zone. Task ventilation systems can provide supply air (which is generally less polluted than room air) near the breathing zone, or direct supply air toward the breathing zone. However, the natural mixing of air within rooms and recirculation of air by the air handler will limit the extent to which breathing-zone air differs from the average room air.

The impact of task ventilation, relative to conventional ventilation, on building energy use is a current subject of study. Task ventilation systems have the potential to decrease or increase the total building-wide energy consumption. An energy saving feature is the use of occupancy sensors to reduce or shut off the system when not needed. An energy consuming feature is the relative inefficiency of a large number of small fans compared to a large central ventilation fan. Because of the multiple factors affecting energy consumption, the influence of task ventilation systems on energy use, relative to the energy use of conventional ventilation systems, will likely depend on the specific application.

Desk-top Task Ventilation System

The task ventilation system discussed in this paper is a desk-top task ventilation system (DTVS). The system contains a mixing box that encloses muffin-type fans, dampers for controlling the percentages of recirculated room air and ventilation system supply air (thus controlling the temperature of air supplied), a white noise generator and electronic controls. This mixing box is installed underneath a desk. Air is supplied to the mixing box from the main air handling unit (AHU) via a flexible duct which is connected directly to supply ducts or to an under-floor supply air plenum. Another stream of air enters the mixing box through an air inlet beneath the desk. After passing through the mixing box, the mixture of AHU supply air and room air exits through two desk-top-mounted nozzles which are located at the back corners of the desk. The DTVS has a control panel from which the following parameters can be changed: air velocity, percent of room air that is mixed in the mixing box with air from the main AHU (which determines the DTVS supply air temperature), volume of a white noise generator, dimming of a task light, and power to a radiant heating panel. The nozzles on top of the desk can be rotated 360° in the horizontal direction and contain movable vanes which can be rotated ± 30° in the vertical direction.

Research Objectives

The primary objectives of the research described in this report were to determine the spatial variability in ventilation and the pollutant removal efficiency in a room ventilated with the DTVS under a variety of operating conditions. More specifically, we desired to compare the rates of ventilation (as indicated by the reciprocals of ages of air) at occupants' breathing zones to the rates of ventilation elsewhere in the room and to the reference ventilation rate that would occur everywhere with perfectly mixed air in the room. An additional objective was to determine the efficiency of removing tobacco smoke particles with this system. Velocity and thermal measurements were taken concurrently by Bauman et al. (in press) with the same DTVS to determine thermal comfort parameters.

Facility, Instrumentation and Procedures

Facility

All experiments were performed in a controlled environment chamber (CEC) with a 18 ft by 18 ft floor and a 8.3 ft high ceiling (5.5 m by 5.5 m and 2.5 m). The CEC resembles a modern office space and has provisions for a high degree of control over the method of ventilation and the indoor thermal environment (Bauman and Arens 1988). As shown in Figure 1, a raised-access floor results in a 2 ft (0.6 m) high sub-floor plenum and the suspended ceiling provides a 1.5 ft (0.5 m) high ceiling plenum. A re-configurable air distribution system permits air supply to and removal from any combination of ceiling and floor locations using ductwork and/or the plenums. Figure 1 illustrates the air-flow configuration for the experiments in which the supply air was ducted, in the sub-floor plenum, to each DTVS. The CEC contained three workstations with furnishings typical of those in offices as shown in Figure 2. Air was exhausted from the chamber through a ducted ceiling-level return grill to the HVAC system, see Figure 1.

The furnished chamber contained sources of heat and air motion typical of real offices, including: overhead lights (with a total power of 500 W of which roughly 100 W directly entered the chamber); 75 W task lights in each workstation (WS); and a personal computer containing a small cooling fan and a monitor in each workstation (90 W each). A seated mannequin was located in both WS2 and WS3 with a DTVS. Electric resistance heating elements wrapped around the mannequin released 75 W (a typical rate of release of sensible heat by an office worker). During a few tests, internal loads were increased by combinations of the following: operation of extra task lights; operation of a 200 W radiant heater beneath a desk; operation of mixing fans within the chamber; and operation of particle sampling and counting instrumentation within the chamber.

The CEC's HVAC system provides a separate stream of conditioned air that is directed through a plenum in the two exterior walls and between the inner two window panes called the annular space. During all tests, this system maintained the temperature of the interior window pane at approximately the average indoor temperature. Consequently, the exterior walls and windows were not a source of strong natural-convection airflow, but affected indoor airflow much like interior walls.

Tracer Gas Measurements

The tracer gas step-up procedure (Sandberg and Sjoberg 1983, Fisk et al. 1988 and 1989), was used to study indoor airflow patterns and the spatial variability of ventilation. In the step-up procedure, the supply air flow rate and the percent outside air in the supply air are held constant. A steady flow of tracer gas is injected into the supply air or the outside air. During the injection of tracer, the concentration of tracer in the room and in ducts is measured over time. Measurement and injection of tracer continues until the tracer concentration, at all measurement locations, have become steady. The age of air at each location is computed from the concentration time history.

The tracer gas was a mixture of 1% sulfur hexafluoride(SF_6) in air. A peristaltic pump drew the tracer/air mixture from a storage bag and directed the mixture through a flow meter and tubing and into the supply duct. Injection rate was monitored using rotameters calibrated with a bubble flow meter and was generally stable within 2%. To ensure thorough mixing of the SF_6 in the supply airstream, an array of small propeller fans was installed inside the supply duct downstream of the injection point. These fans were oriented to cause air flow perpendicular to the general direction of flow in the duct. Mixing was confirmed by collection and analysis of air/tracer samples from the supply duct downstream of the mixing fans.

Gas chromatography (GC) was used to measure the concentration of tracer in air samples. The GCs were capable of analyzing a sample within one minute of collection using a method described in Fisk et al. (1991).

During tests, air samples were collected via a pump connected to the GCs, and analyzed every three minutes from six locations in the ducting or the chamber. Also, bag samplers directed air/tracer samples at a constant rate into one liter sample bags. Bag sampling commenced at the start of tracer gas injection and continued until tracer gas concentrations were stable, at which time syringe samples were collected manually from the same locations. The bag samplers collected samples from 17 locations within the chamber and one at the return grill, see Figure 2. Bag and syringe samples were analyzed using the GCs immediately after completion of the tests. Equipment and procedures are similar to those used previously and described by Fisk et al. (1985, 1988, 1989, 1991).

The GCs were calibrated after each test using thirteen different calibration concentrations of SF_6 ranging from 0 ppb to 180 ppb. Measurements of tracer gas concentrations were generally repeatable within ± 2 ppb.

Tobacco Smoke Particle Measurements

The efficiency of removing tobacco smoke particles, and intra-room particle transport, were investigated during some of the tests. A cigarette was smoked by a cigarette-smoking machine located on the desk in WS3 and particle concentrations were measured as a function of time during and after the period of smoking at four locations within the CEC identified in Figure 2 and also in the supply duct and at the return grill. An optical particle counter (OPC), measured particle number concentrations in 15 size bins ranging from 3.5×10^{-6} to 1.2×10^{-4} inches (0.09 to 3.00 microns). Air samples were drawn (at a rate of 0.2 cfm (0.08 L/s)) to the optical particle counter through lengths of 0.5 in (1.3 cm) diameter copper tubing connected to electrically actuated ball valves mounted on a copper manifold. The OPC drew an air sample from this manifold at a rate of 1×10^{-4} cfm (3 ml/min).

Test Conditions

Table 1 lists the test conditions. The chamber was divided by 65" (1.65 m) high partitions into two small and one large workstation with the DTVS systems operating in WS 2 and 3, see Figure 2. For all tests, except one, only 100% outside air from the AHU supply ducts entered the DTVS mixing boxes and was supplied to the CEC from the DTVS air supply nozzles. The supply air was always cooler than the chamber air. During test 58, the DTVS mixing boxes drew equal amounts of air from beneath the desk and from the AHU supply ducts. The nozzles were pointed, with the vanes oriented to direct air horizontally, either toward the occupant or straight ahead parallel to the sides of the desk. Two sets of nozzles with different size rectangular openings were used. The small nozzles, supplied by the manufacturer, were 2.28 in wide by 3.86 in high (58 mm by 98 mm). Larger nozzles were fabricated for our tests to reduce the air velocities at the location of the occupants. The manufacturer's nozzles yielded high velocities that could be considered uncomfortable when air is directed toward the occupant and supply flow rates are high (Bauman et al. in press). The large nozzles were 3.07 in wide by 9.06 in high (78 mm by 230 mm).

Data Analysis Methods

Tracer Gas Data

Equations based on age distribution theory are used to calculate the ages of air. The age of air at a location is defined as the elapsed time since that air entered the building. The reciprocal of the age of air at a point is considered to be a local ventilation rate. The age of air exiting the chamber is equal to the nominal time constant which is the volume of air in the ventilated space divided by the flow rate of outside air entering the space. The nominal time constant is the age of air that would exist at all indoor locations with perfect mixing of the indoor air (Sandberg and Sjoberg 1983).
Using tracer gas concentrations as a function of time, the following equation was employed to determine the age of air:

$$A = \int_0^{t_{ss}} \left(1 - \frac{C(t)}{C(t_{ss})}\right) dt \qquad (1)$$

where: A is the age of air, t is the time variable set equal to zero at the start of tracer gas injection, t_{ss} is the time when the concentrations have reached steady state, and $C(t_{ss})$ is the concentration at steady state. The integral is evaluated numerically. Using the tracer gas concentrations in bag and syringe samples, C_{bag} and C_{syr}, respectively, age of air was determined using the equation:

$$A = t_{ss} \left(1 - \frac{C_{bag}}{C_{syr}}\right) \qquad (2)$$

where t_{ss} is the amount of time elapsed to reach steady state concentrations.

To indicate the spatial variability in age of air, we use various ratios based on the ages. For example, the age of air in the return duct divided by the age at breathing level in the "ventilated" workstation (with mannequins and operating DTVS systems) is an indicator of ventilation efficiency--higher values of this ratio indicate more efficient air flow patterns with increased ventilation (lower ages) at the location of the occupant. When ratios contain an average of ages measured at several locations, we use volumeweighted averages assuming that each measurement is representative of a volume that extends half way to adjacent measurement points and/or to the edge of the workstation.

Analysis of Particle Data

To evaluate the particle data collected at the different sample locations, we compute total particle number concentrations (for all size bins) less the "background" particle concentration (i.e., the concentration before the cigarette is smoked and after an extended period of ventilation). To indicate the spatial variability of particle concentration and the efficiency of particle removal, we compare time-average values of these background-corrected particle concentrations measured at different indoor locations. Concentrations are averaged over the time period between the start of smoking and the time when particle concentrations have returned to the background concentration (i.e., over the period of tobacco smoke exposure). Measurement precision was evaluated during tests in which the chamber air was well mixed.

Results

Data precision

During tests 55, 61 and 66 (see Table 1), the chamber air was well mixed which ideally should produce the same local age of air at every point in the chamber and, consequently, all of the age of air ratios should equal unity. However, due to measurement imprecision and errors (and possible imperfect mixing despite the operation of mixing fans) all of the measured ages of air are not equal. We assume that our measurement of the local age of air at a single point is normally distributed. Thus, for a 95% confidence interval of the measurement of age of air at a single point, we use twice the largest coefficient of variation in the ages of air measured during tests. The resulting coefficient of variation is 6.3% for these tests yielding a 95% confidence interval of ± 13%. Consequently, smaller differences than ± 13% between two ages of air are not considered significant, at the 95% confidence level, from the measurement-precision perspective.

The above estimates for the precision of a single point measurement of age of air are not applicable for the ratios in Table 1. Using propagation of error analysis (Schenck 1979), we combined the precision values to determine the estimated precision of each ratio. The ratios in Table 1 marked with an asterisk are significantly different from unity with 95% confidence.

We believe that at least three factors cause imprecision in the multiple (multi-point) measurements of age of air. First, there is a small bias between ages determined from: (a) numerical integration of real-time data, and (b) the bag and syringe samples. Second, the air in the CEC was probably not perfectly mixed due to the internal partitions. Third, there is undoubtedly some random error in the measured ages due to such factors as instrument imprecision.

Enhancement of Ventilation at Breathing Zone

At certain test conditions, the DTVS systems did provide enhanced ventilation in the breathing zone of a seated occupant. Enhanced ventilation at the breathing level of an occupant was indicated by the air at the occupant's breathing location being younger than the age of air in the return, which is the age of air that would occur everywhere in the room for the reference case of perfectly mixed indoor air. Younger (lower age) air is less likely, as compared to older air, to have accumulated pollutants. This enhancement of ventilation at the breathing locations is comparable to results with other types of task ventilation systems we have tested in the chamber (Fisk et al. 1991). Most of the tests conditions showed that the ratios of the ages of air in the chamber did not deviate from unity by more than ± 40%. Test conditions which consistently provide this enhanced ventilation by 20 to 40%, (see tests 57, 71, 72, with 70 being an

Table 1. Test conditions and results.

Test No.	Nozzle Direction[c]	Nozzle Size[d]	Supply Temp(F)	Room Temp(F)	Internal Loads (W)	Flow rate[e] (cfm)	Archimedes[f] Number	Ratios of Average Ages of Air[g] RET/BLV	BLU/BLV	CLA/BLA	KLA/BLA
66W[a]	S	sm	64.9	77.7	604	48	0.010	0.95	1.03	1.04	0.99
55W	T	sm	66.5	75.6	432	86	0.005	0.95	1.06	1.00	1.03
61W	T	sm	65.4	76.0	1027	179	0.001	0.89	1.02	0.98	0.97
75	S	lg	66.3	77.9	1379	152	0.032	1.27*	1.14*	1.39*	0.93
65	S	lg	63.6	73.9	944	173	0.028	0.91	1.09	1.21*	0.85*
78	S	lg	59.9	66.0	869	173	0.013	0.79*	1.08	1.22*	0.83*
77	S	lg	63.1	73.9	875	174	0.033	0.83*	0.97	1.25*	0.93
76	S	lg	60.4	71.6	955	177	0.031	0.91	1.26*	1.06	0.77*
63	T	sm	69.5	79.4	455	37	0.010	1.01	1.20*	1.02	0.97
54	T	sm	67.5	77.5	372	51	0.016	1.14	1.08	1.14*	0.85*
64	T	sm	64.5	77.2	655	84	0.004	0.94	1.24*	1.11*	0.99
67	T	lg	68.5	78.0	640	39	0.312	1.08	1.19*	1.11*	0.90*
74	T	lg	67.7	79.1	1084	84	0.061	1.00	1.22*	1.08	1.03
57	T	lg	59.7	71.4	865	180	0.004	1.43*	1.38*	1.35*	1.08
71	T	lg	62.4	73.5	832	193	0.035	1.24*	1.24*	1.24*	0.81*
72	T	lg	61.7	76.0	1657	195	0.025	1.36*	1.29*	1.31*	0.93
70	T	lg	61.4	73.1	864	202	0.008	1.11	1.66*	1.12*	0.81*
58[b]	T	lg	70.9	77.6	856	81	0.010	0.99	1.17*	1.01	1.06

a. W indicates a well-mixed test in which fans vigorously mixed the chamber air.

b. In test 58, each DTVS supplied a mixture of 50% outside air from the AHU supply duct and 50% room air from beneath the desk. In all other tests, each DTVS supplied 100% outside air from the AHU supply duct.

c. T = toward occupant ; S = straight ahead parallel to the sides of the desk.

d. sm = small (2.28 in x 3.86 in) ; lg = large (3.07 in x 9.06 in).

e. total rate of air supply from the two operating DTVS systems, each supplied approximately equal amounts of air.

f. Archimedes number is the ratio of buoyant forces to inertial forces.

g. RET = age of air in the return duct; BLV = average age of air at breathing level in the ventilated workstations with operating DTVS and mannequin; BLU = average age of air at breathing level in the unventilated (without DTVS) workstation ; CLA = average age of air at ceiling level above all workstations ; BLA = average age of air the breathing level in all workstations; KLA = average age of air at the knee level in all workstations.

* Ratio statistically different from unity with 95% confidence.

exception) are high, supply flow rates (about 89 cfm (42 L/s) per occupant) with the nozzles pointed toward the occupant., see Table 1. These flow rates are high compared to the minimum flow rate suggested by ASHRAE (20 cfm (10 L/s) per occupant). With the nozzles pointed straight ahead, the only test with significantly enhanced ventilation in the breathing zone, was test 75, with high loads. We can not explain the results of this one test.

Another indicator of enhanced ventilation at the location of occupants is the ratio of the average age of air in the unventilated workstation (without a DTVS) to the average age of air in the DTVS-equipped workstations. In all tests with the nozzles pointed toward the occupant, except one, this ratio was significantly greater than 1.00 by 20 to 30%. This was often but not consistently true for the configuration with the nozzles pointed straight ahead (parallel to the sides of the desk).

In tests with the nozzles pointed straight ahead (parallel to the sides of the desk) the ratio of the age of air in the return to the average age of air at the breathing height in the ventilated workstations is less than 1.00 for four of five tests and significantly less for two tests. This is in contrast to this ratio usually being greater than 1.00 for tests with the nozzles pointed toward the occupant. This ratio being less than 1.00 can indicate that the flow has short-circuited from the supply nozzles directly to the return grill (the opposite of enhanced ventilation). The extent of short-circuiting is small, but the existence of any short-circuiting is surprising.

The effect of nozzle size on enhanced ventilation was not a primary objective in our tests, thus only three tests were performed with the small nozzles. Bauman et al. (in press) did find improved comfort with the large nozzles as compared to the small nozzles all else being equal.

Age of Air versus Height above Floor

In many tests, the age of air increased with height, based on the measurements at three heights. The ratio of the average age of air at the ceiling level to the average age of air at the breathing level in the ventilated workstations is often greater than 1.00 and the ratio of the average age of air at the knee level to the average age of air at the breathing level in the ventilated workstations is often less than 1.00 (see Table 1). This age of air pattern could possibly indicate a displacement-type flow pattern. A displacement flow pattern is a horizontally separated two zone flow. The lower region is characterized by an upward piston-like flow of cool and low-age air, while the upper zone is well-mixed, warm and potentially more contaminated older air. Displacement flow typically occurs with cool air supplied with a low velocity at or near the floor. Since the DTVS nozzles are at the desk-top level, and not near the floor, displacement flow is unlikely.

To further determine if displacement flow is likely to have occurred during the tests, the Archimedes number was computed, (see Table 1). This number is the ratio of buoyancy forces to inertial forces of the jet emanating from the nozzles. The Archimedes number was calculated using the equation:

$$Ar = \frac{g \Delta T H}{T_r v^2} \qquad (3)$$

where: g is the gravitational constant, ΔT is the temperature difference between the chamber air and the supply air, H is the height of the nozzle opening, T_r is the average chamber air temperature, and v is the air velocity from the nozzle.

We found no correlation between the Archimedes number and the trend of age of air with height. Displacement flow does not appear to explain the increased age of air with height. This trend may result from the forced convective air flow patterns associated with this type of task ventilation system.

Particle Concentration Distribution and Removal Efficiency

The data from the particle measurements (see Table 2), consistent with the age of air data, indicated only moderate deviations from perfect mixing. The particle concentrations at each indoor location varied from the mean of all locations, excluding the supply airstream, by less than ± 12%. In a limited number of tests, the particle data indicate that the DTVS systems reduce the particle exposure to the occupant seated next to the cigarette, as indicated by the concentration at location 3B being lower than the room-average particle concentration. However, the DTVS system does not greatly reduce concentrations in the non-smoking adjacent workstations with a DTVS, relative to the room-average concentration. The highest average particle concentration was at the ceiling level of the workstation with the cigarette but the increase in concentration at this location is small. The higher particle concentrations at this location are possibly due to the buoyancy of the hot tobacco smoke rising to the ceiling. Concentrations of particles at the return grill (i.e., in the air that exits the chamber) were not substantially different from concentrations at breathing locations. Consequently, particle removal efficiencies were essentially equivalent to those of a conventional ventilation system with thoroughly mixed indoor air.

Table 2. Total (for all size bins) time-average particle concentration (particles/cm^3) at various locations in the chamber with cigarette smoked in workstation 3 (WS3).

Test No.	2C	2B	3C	3B	RET	SUP	AVG[c]
	LOCATIONS[b]						
61W[a]	1506	1412	1691	1619	1788	145	1603
66W	2117	2106	2076	2028	2113	213	2088
63	3835	3620	4105	3289	3722	179	3714
64	2453	2620	2655	2501	2574	175	2560
67	1982	1886	2354	NA	2186	130	2102

a. W indicates a well-mixed test in which fans vigorously mixed the chamber air.
b. Locations: 2C = ceiling level, WS2; 2B = breathing level, WS2; 3C = ceiling level, 3B = breathing level, WS3; RET = return duct; SUP = supply duct.
c. AVG = average concentration, excluding concentration in supply duct.

Conclusions

When a relatively high supply flow rate of 100% outside air was directed at the breathing zone, the DTVS systems consistently provided enhanced ventilation (i.e., a decreased local age of air) at the breathing zone of ventilated workstations, compared to the age that would result with perfectly mixed indoor air. With lower supply flow rates or supply air directed parallel to the sides of the desk (rather than at the occupants), there was generally no significant enhancement of ventilation at the breathing zone.

The high supply flow rates of 100% outside air that resulted in enhanced ventilation at the breathing zone (approximately 85 cfm (40 L/s) per occupant) substantially exceed the minimum outside air supply rates specified in ASHRAE Standard 62--1989 (20 cfm (10 L/s) per occupant). Consequently, these high rates of outside air supply may be atypical operating conditions except during periods of economizer operation when large volumes of outside air are used for cooling. During economizer operation, enhancement of ventilation is less important because of the high ventilation rates. Supplying a mixture of room air and outside air through the DTVS systems (evaluated in only one test) would be a more common operating condition, but would increase air mixing and reduce the enhancement of ventilation at the breathing zone.

The tobacco smoke data were consistent with the measurements of local ventilation rates--both sets of data indicate that the indoor air is relatively well mixed. Time-average tobacco smoke particle concentrations at individual locations generally varied by less than ± 12% from the mean of concentrations measured within the chamber.

Our findings, which need to be confirmed in field studies, suggest that the use of DTVS systems leads to only marginal improvements in the spatial patterns of air delivery to occupants, compared to an air delivery system that yields thoroughly mixed indoor air. However, this paper describes only one aspect of DTVS performance. The use of DTVS systems may have other significant advantages such as improved thermal comfort (Bauman et al. in press), improved occupant satisfaction with the indoor environment (Drake 1990), and possibly even improved occupant productivity (Kroner et al. 1992).

References

Bauman, F.S. and Arens, E.A. (1988) "The Development of a Controlled Environment Chamber for Physical and Subjective Assessment of Human Comfort in Office Buildings" In: A New Frontier: Environments for Innovation, Proceedings of the International Symposium on Advanced Comfort Systems for the Work Environment, Kroner, W. Ed., Troy, NY: Center for Architectural Research.

Bauman, F.S., Arens, E.A., Benton, C.C., and Zhang, H. (in press) "Localized Comfort Control with a Desk-top Task Conditioning System: Laboratory and Field Measurements" Center for Environmental Design Research, University of California-Berkeley, Berkeley, CA. Draft paper to be submitted for presentation at the Symposium "Innovative Diffuser Performance Characteristics", ASHRAE Annual Meeting, June 26-30, 1993, Denver CO.

Drake, P. (1990) "Summary of Findings from the Advanced Office Design Impact Assessments" Center of Building Diagnostics (CANTECH) Ltd., Ottawa, Ontario (draft report)

Fisk, W.J.; Binenboym, J.; Kaboli, H.; Grimsrud, D.; Robb, A.W.; and Weber, B. (1985). A Multi-Tracer System for Measuring Ventilation Rates and Ventilation Efficiencies in Large Mechanically-Ventilated Buildings. *Supplement to the Proceedings of the 6th AIVC Conference Ventilation Strategies and Measurement Techniques*, pp. 69-92. Published by the Air Infiltration and Ventilation Centre, Coventry, Great Britain.

Fisk, W.J., Prill, R.J., and Seppanen, O. (1988) "Commercial Building Ventilation Measurements Using Multiple Tracer Gases" In *Proceedings of the 9th AIVC Conference, "Effective Ventilation,"* Vol. 1, pp. 161-182. Published by the Air Infiltration and Ventilation Centre, Coventry, Great Britain.

Fisk, W.J., Prill, R.J., and Seppanen, O. (1989) "A Multi-Tracer Technique for Studying Rates of Ventilation, Air Distribution Patterns, and Air Exchange Efficiencies" In *Proceedings of Building Systems: Room Air and Air Contaminant Distribution*, pp. 237-240. Published by ASHRAE, Atlanta.

Fisk, W.J., Faulkner, D., Pih D., McNeel, P.J., Bauman, F.S., and Arens, E.A. (1991) "Indoor Air Flow and Pollutant Removal in a Room with Task Ventilation." *Indoor Air* 3, pp. 247 - 262.

Kroner, W.M., Stark-Martin, J., and Willemain, T. (1992) "The West Bend Mutual Study" Press Release, Center for Architectural Research, Rensselaer Polytechnic Institute, Troy, NY

Sandberg, M. and Sjoberg, M. (1983) "The Use of Moments for Assessing Air Quality in Ventilated Rooms" *Building and Environment* 18, pp. 181-197.

Schenck, J. (1979) *Theories of Engineering Experimentation*, 3rd ed. McGraw-Hill, New York.

Schiller, G.E., Arens, E.A., Bauman, F.S., Benton, C. (1988) "A Field Study of Thermal Environments and Comfort in Office Buildings" *ASHRAE Transactions* 94, Part 2.

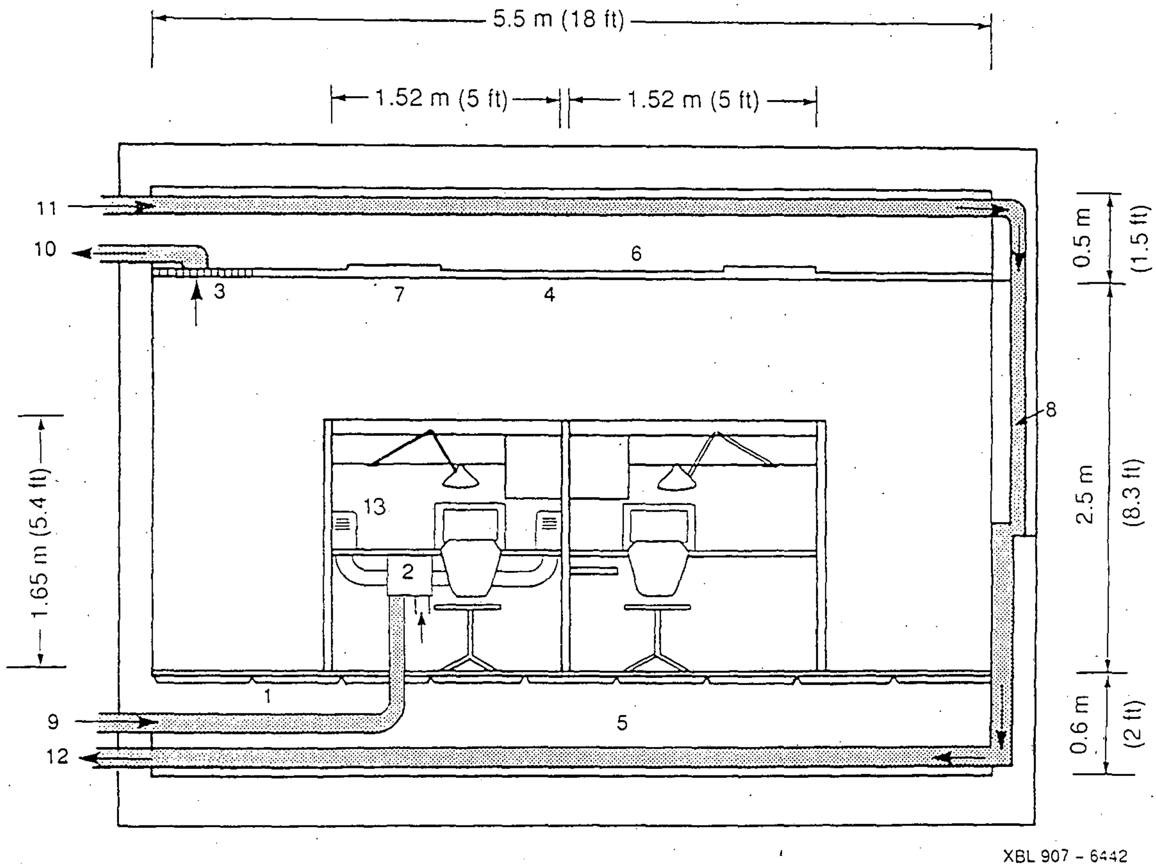

Figure 1. Cross sectional view of the Controlled Environment Chamber. Numbered items are: 1 = floor panel; 2 = DTVS mixing box; 3 = return grill; 4 = suspended ceiling; 5 = subfloor plenum; 6 = ceiling plenum; 7 = light fixture; 8 = conditioned annular space between windows; 9 = supply air from air handler; 10 = return/exhaust air; 11 = conditioned air to annular space; 12 = air return from annular space; 13 = DTVS desk top supply nozzle. The return air grill is centered between the front and back walls.

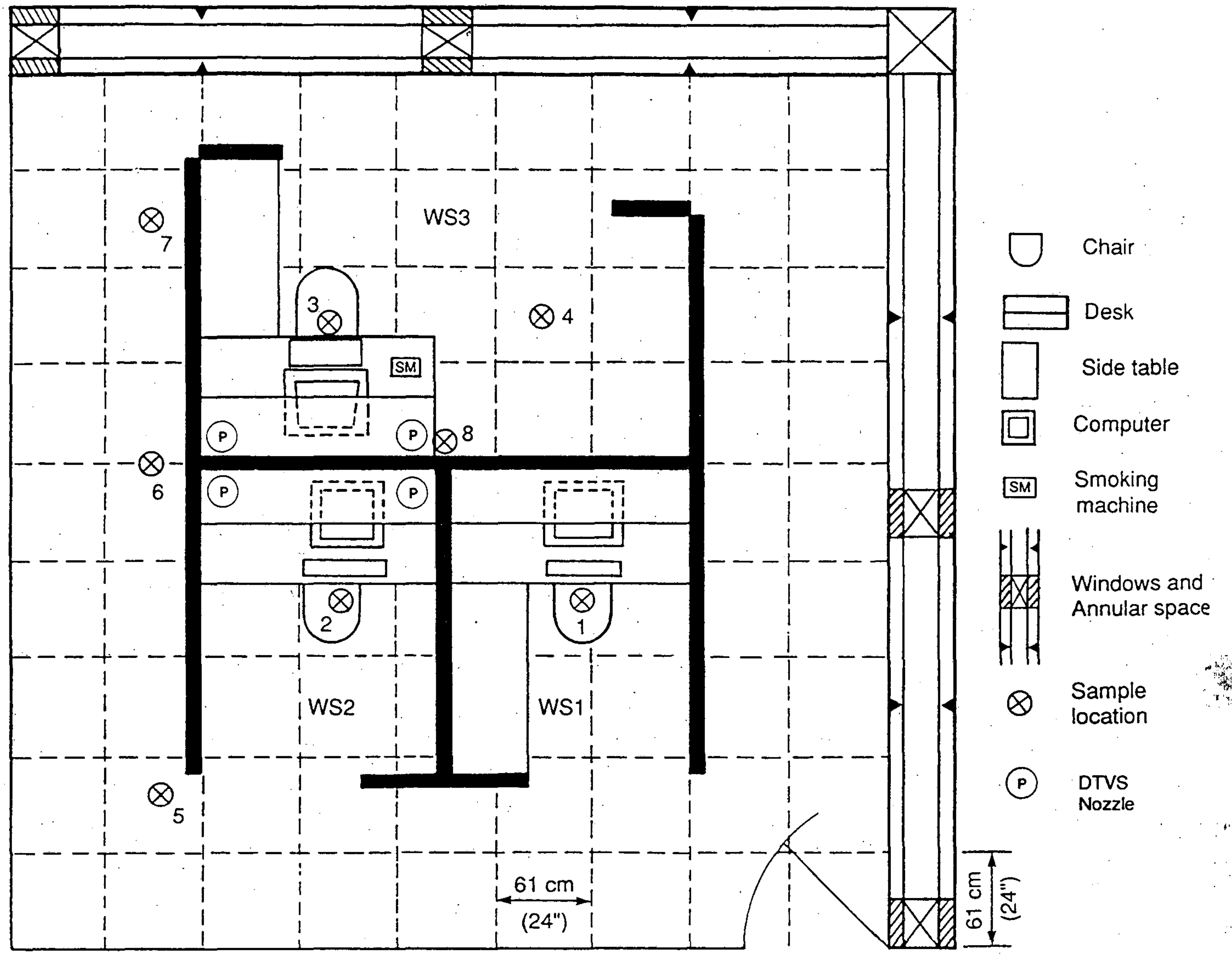

Figure 2. Plan view of the CEC with workstations denoted WS1, WS2, and WS3. Tracer gas was sampled at points 1-4 (16 in, 43 in, and 84 in above the floor), at points 5 and 7 (43 in above the floor), and at point 8 (84 in above the floor).

LAWRENCE BERKELEY LABORATORY
UNIVERSITY OF CALIFORNIA
TECHNICAL INFORMATION DEPARTMENT
BERKELEY, CALIFORNIA 94720