EVALUATION OF SMOKING LOUNGE VENTILATION DESIGNS

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ABSTRACT

Two displacement-type and two diffusion-type ventilation configurations were tested in a specially constructed smoking lounge. The four arrangements were tested under worst-case conditions of use to determine the most satisfactory method to ventilate a smoking lounge. Ventilation air was provided to the lounges at rates suggested by ASHRAE Standard 62-1989. Additional tests were performed at reduced ventilation rates. Concentrations of CO and CO_2 were monitored in real time during the tests. Smokers were polled to determine their satisfaction with the air quality in each configuration. Air motion, velocities, and temperatures also were measured in the room. Ventilation at 60 cfm (28 $L \cdot s^{-1}$) per person provided acceptable air quality in the lounge. Under the extreme conditions tested, ventilation at reduced volume resulted in unacceptable air quality. Results of this study indicate that smoking lounge air quality that is acceptable to the occupants can be attained by minor modification of existing conventional air distribution systems.

INTRODUCTION

Where smoking is restricted, smoking lounges provide one method to accommodate individuals who choose to smoke. Presently, little information is available to guide an architect or building manager in the choice of ventilation design for a smoking lounge. ASHRAE (1989) makes specific recommendations on smoking lounge ventilation rates and maximum occupancy and suggests that good indoor air quality is achieved when at least 80% of the people exposed to the indoor environment do not express dissatisfaction. The ASHRAE standard states that ventilation effectiveness is 100% when perfect mixing takes place between ventilation air and air in a space. In this situation, the concentration of contaminants in the air exhausted from the room will be the same as their concentration in the room. In a situation with displacement ventilation flow, concentrations of contaminants can be higher in the exhaust than in a room if they are swept directly to the exhaust by airflow in the room. This should lead to an overall increase in air quality for displacement ventilation relative to diffusional ventilation. However, the standard makes no specific recommendations regarding the best way to distribute air within the room to maximize air quality.

With the above items from the standard as a guide, this study was conceived to test various air distribution systems for smoking lounges. Six variations on the four configurations were tested. They included three diffusional systems, two displacement systems, and one system that might behave as either a diffusional or displacement system. An occupant ballot was used to provide an indicator of air quality as it related to occupant comfort. Air motion and temperature were determined as they are related to people's subjective evaluation of air quality. In addition, a number of air quality indicators were measured in real time during each experiment.

EXPERIMENTAL

Test Facility

A test room, designed to be adaptable to simulate a variety of smoking lounge ventilation conditions, was built in an office/laboratory facility in Richardson, Texas. The room was constructed adjacent to existing offices and laboratories in unconditioned warehouse space. Outer walls were constructed of metal stud and sheetrock. The stud spaces were filled with fiberglass batt insulation. The floor was a standard computer room type with 2 ft × 2 ft (0.61 m × 0.61 m) vinyl-covered floor tile raised 2 ft (0.61 m) to form an underfloor plenum.

A 9-ft (2.7-m) ceiling was constructed of hung inverted tees with drop-in 2 ft × 4 ft (0.61 m × 1.22 m) acoustic tile through which ductwork could be accessed. The room was lit by four 2 ft × 4 ft (0.61 m × 1.22 m) fully recessed, unventilated, four-tube fluorescent fixtures. A plywood roof, covered with 6-in. (0.15-m) fiberglass batt insulation, was constructed approximately 4 ft (1.22 m) above the hung ceiling.

Two partitions were installed within the test room to form the north and south walls of the smoking lounge. The partitions were installed to provide plenum spaces for ducting, to simulate adjacent building spaces for transfer air, and to permit changes for future tests. Leveling screws

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on the bottom of each panel permitted adjustment to seal the top of the partitions against the ceiling after which baseboard strips were installed to seal the panel to the floor. The room was minimally furnished. Metal chairs and vinyl floor tile were used to reduce any effects of contaminant removal by sorption.

A schematic of the air distribution and control system is shown in Figure 1. Supply air and transfer air were taken from adjacent offices and each was separately supplied to the room through fan-powered boxes. Supply air was conditioned by passage over multiple cooling coils. Both supply and transfer air were distributed through regulated dampers equipped with multi-point center averaging sensors and DDC controls. Exhaust air was removed from the room by a fan-powered box equipped with a sensor and vented to the outside.

DDC controls were used to maintain supply, transfer, and exhaust airflows at their respective setpoints. Each controller monitored flow by measuring a differential pressure signal from an inlet sensor. Flow values were transmitted from the controllers to a computer that was used to monitor and program the controllers. These controls were calibrated in situ using a Dahl tube to ensure that the setpoints and airflows were accurate. During the calibration, the airflow rate was varied above and below the required range for the tests. Dampers were calibrated by entering both sensor pressure differentials and airflows into the computer.

Maintaining the correct exhaust airflow rate was critical to these tests. The exhaust sensor pressure differential was monitored with an inclined manometer at all times. Airflows determined using the manometer were regularly compared to the computer readings. In addition, a standard measuring hood was used to check the airflows at all outlet and exhaust openings for comparison against the computer readbacks.

Air motion in the room was examined by releasing concentrated smoke at points throughout the room and recording the air motion with a camcorder. Air movement was tracked near each of the outlet and exhaust points in the room. In addition, smoke was released at regular intervals throughout the room and its path was followed either back into the inlet airstream or to the exhaust. Sufficient smoke could be generated during this procedure to determine whether the air was well mixed or whether pockets of dense smoke tended to remain in various areas of the room.

Test Arrangements

Six variations on four different air distribution arrangements, as shown in Figure 2, were tested. Arrangement 1 was a conventional air distribution system using a pair of four-way blow supply diffusers, which are commonly used in offices, conference rooms, and lounges. A ceiling-mounted exhaust grille was installed near the south wall and connected to an exhaust system to simulate the conversion of such a room to a smoking lounge. Transfer air, to make up the difference between supply and exhaust, was supplied through an eggcrate grille in the ceiling near the north wall. This arrangement was tested at 60 cfm (28 $L \cdot s^{-1}$)/occupant.

Arrangement 2 differed from the first only in that the four-way blow diffusers were replaced with one-way blow

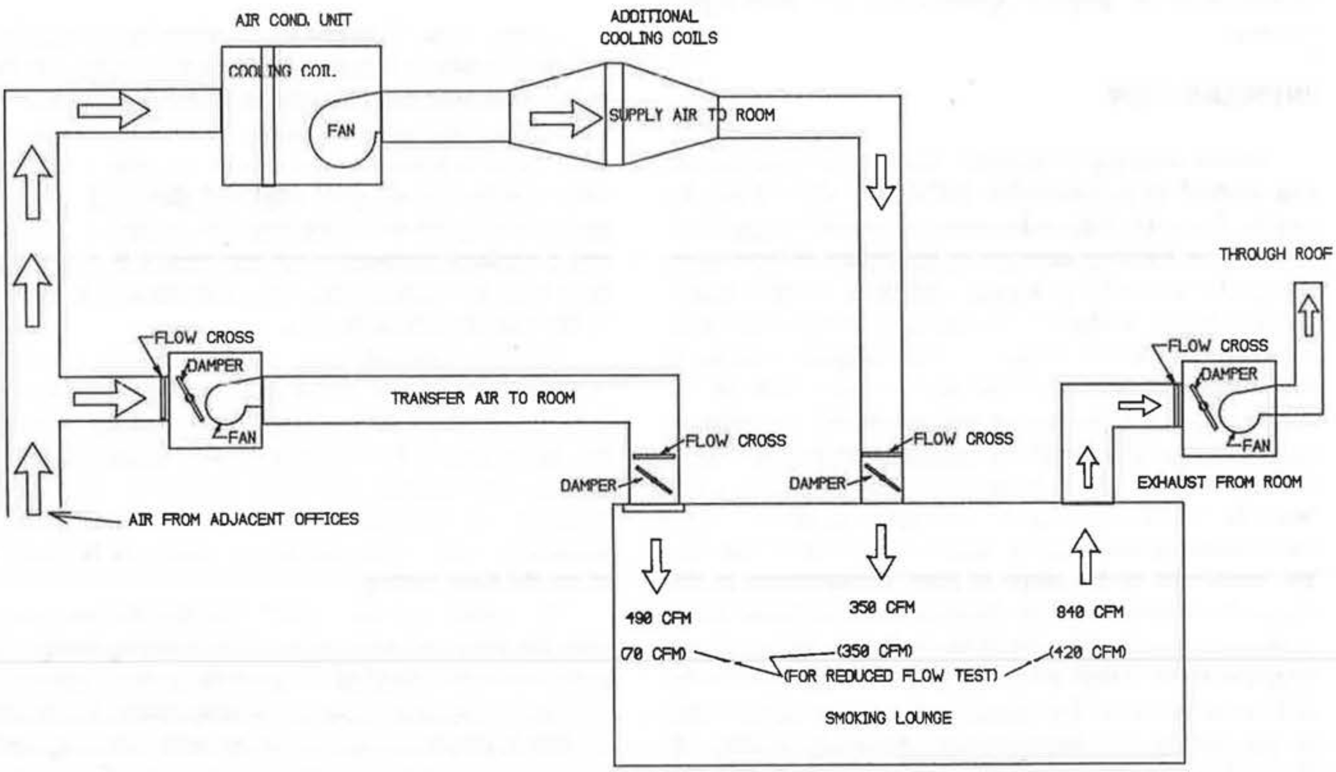

Figure 1 *Schematic drawing showing duct arrangement and airflows to the test room used for the smoking lounge study.*

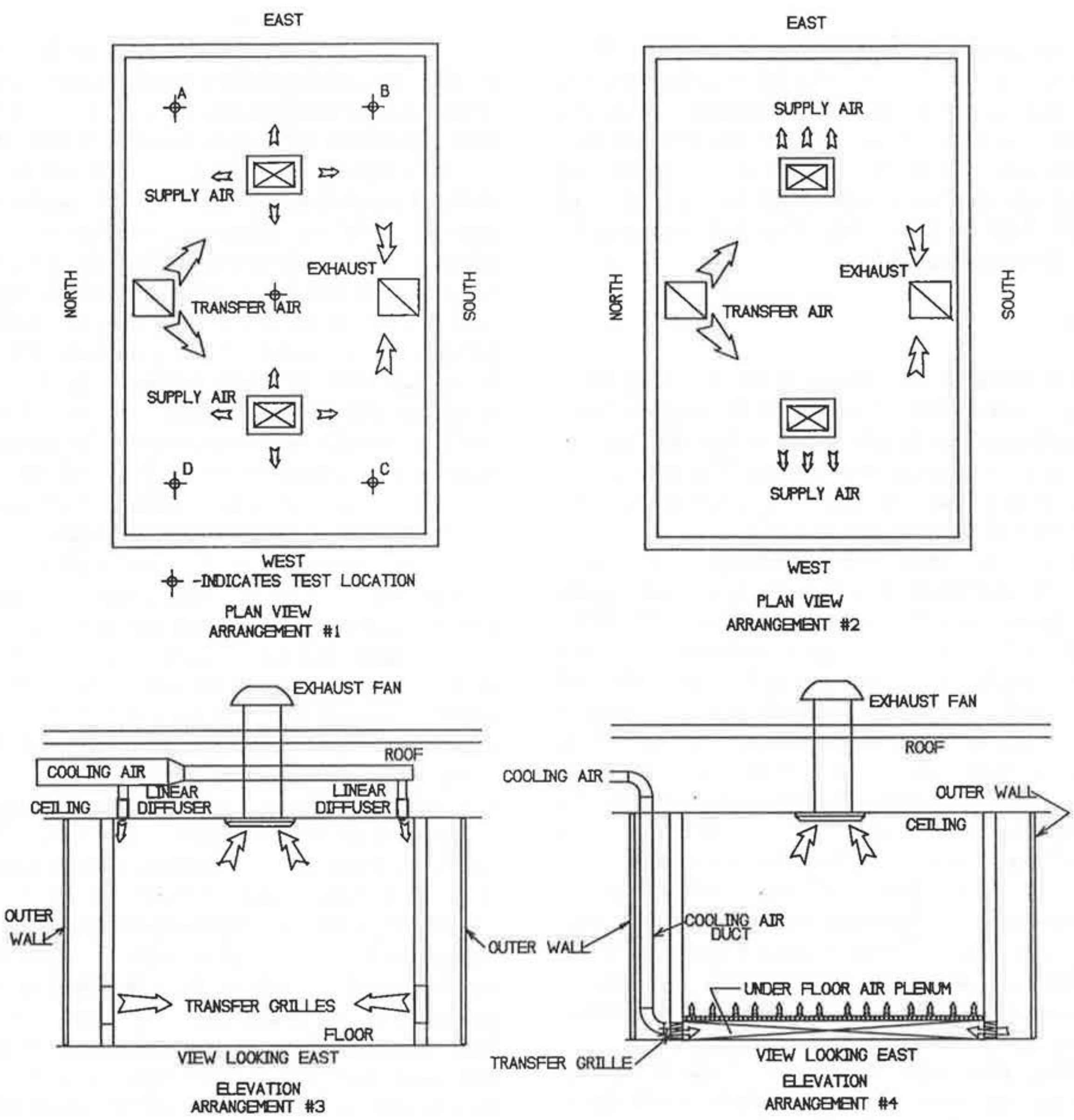

Figure 2 *Schematic views of the four ventilation arrangements used for the smoking lounge air distribution tests.*

diffusers discharging toward the east and west walls. This arrangement was tested at normal as well as at reduced ventilation rates. For arrangement 2R, the exhaust volume was reduced to 30 cfm (14 $L \cdot s^{-1}$)/occupant. Supply air volume was unchanged; as a result, transfer air volume was reduced accordingly.

For arrangement 3, four 4-ft (1.22-m) linear diffusers were located in the ceiling at the center of each wall and set to discharge supply air at low velocity down each wall. A total of four grilles, located near the floor in the north and south walls, supplied transfer air to the room. This arrangement was designed to approach a displacement system.

Two arrangements were tested that were expected to provide a true displacement system. In arrangement 4, a perforated computer floor was installed in the room. Supply and transfer air were supplied to the plenum space beneath the floor; the exhaust was located in the ceiling in the center of the room. In arrangement 4, 45 (75%) of the tiles were replaced with perforated tiles. In arrangement 4R, the number of perforated floor tiles was reduced to 18 (30% of the floor area).

Analytical Measurements

Carbon dioxide concentrations were monitored in real time with a nondispersive infrared CO_2 monitor. Prior to each experiment, the analyzer was calibrated with ultra-zero nitrogen and 1,000 ppm CO_2 in air standards. Carbon monoxide (CO) was monitored in real time with a nondispersive infrared CO analyzer. Prior to each experiment, the CO analyzer was calibrated with ultra-zero nitrogen and 20 ppm CO in air standards. Analog output from the real-time analyzers was digitized, then recorded using a data analysis program. Concentrations of other ETS components were also measured, and those results have been described elsewhere (Nelson et al. 1992).

Air was sampled through two lengths of ½-in. (12.7-mm) tubing. The sample lines extended from the analyzers to the transfer air supply duct and to the center of the test room. The sample line in the test room was mounted on a pole in the center of the room at the 4-ft (1.22-m) level (breathing zone of a seated individual). Air from either of the sample lines could be directed to both analyzers by turning a three-way ball valve.

Smokers

Sixteen smokers were recruited for the study by a marketing research firm. Fourteen of the smokers were used in each experiment, and the other two remained on hand in case an alternate was needed. The recruitment criteria were as follows: the smokers must be between the ages of 18 and 55, they must smoke at least 10 cigarettes a day, and they must inhale when smoking. The smokers were not informed of the study's sponsor, and each signed a consent form prior to his or her participation in the study. Eight male and six female smokers were used in each test session to closely approximate the gender distribution of American smokers. The smokers in the test room smoked cigarettes with a market representative distribution of FTC "tar" yields. In each test session, six subjects smoked full-flavor cigarettes (> 13.5 mg FTC "tar" per cigarette), six smoked full-flavor low-"tar" (13.5 > FFLT > 7.5 mg FTC "tar" per cigarette), and two smoked ultra-low-"tar" cigarettes (< 7.5 mg FTC "tar" per cigarette). During each experimental run, the smokers sat in chairs around the perimeter of the room. For entertainment, a television was installed behind a window in the north wall. This led to a disproportionate number of smokers being located along the south wall.

Smoking rates were determined in the lounge by counting the total number of cigarette butts in ashtrays at the end of the experiment (partially smoked cigarettes were counted as being completely smoked) then dividing that total by the length of the smoking period. An average of 3.3 (sd = 0.2) cigarettes per hour were smoked in the lounge by each smoker.

Testing Procedure

All the air supplied to the test room was drawn from an adjacent nonsmoking office area; no outside air was supplied to the lounge. Occupancy of the room—7 people per 100 ft² (9.3 m²) of net usable space—was based on ASHRAE Standard 62-1989 (ASHRAE 1989). The room was 13 ft, 11 in. by 19 ft, 4 in. (4.24 m by 5.9 m), an area of 269 ft² (25 m²). The net usable area was assumed to be 200 ft² (18.6 m²); thus, the test population was 14 and the exhaust rate 840 cfm (396 $L \cdot s^{-1}$). Cooling required 350 cfm (165 $L \cdot s^{-1}$) at temperatures down to 52°F (11°C). A room thermostat regulated supply air temperature. Neither the supply nor the transfer air was filtered during the tests. Three replicate runs were performed for each of the six test arrangements.

In order to separate the effects of background air, people, and smoking on the air quality within the test room, several distinct sampling periods were used. At the start of each experiment, air from the transfer air duct was sampled for 10 minutes as the smokers who entered the test room received instructions. In this way, the quality of the air supplied to the test room was evaluated and found to be adequate. Air was then sampled from the test room for 10 minutes. This sample was obtained to determine whether, in the absence of smoking, CO or CO_2 increased due to the presence of the smokers. Twenty minutes into the experiment, the smokers were instructed to begin smoking simultaneously. After smoking the first cigarette, the smokers were allowed to smoke at will for the remainder of a 50-minute smoking period. At the 70-minute time point, the smokers were instructed to extinguish all cigarettes and exit the test room. At this time, an additional 10-minute sample was obtained from the transfer air duct. This was done to determine whether background concentrations of CO or CO_2 had changed during the experiment.

Resources limited the number of possible sampling points to one. It was decided that the most representative sampling location would be the center of the room. In the case of well-mixed arrangements, ETS concentrations at all points within the room should be similar. For displacement ventilation arrangements, a sampling point in the center of the room would be representative of a smoker's exposure to ETS generated by other smokers. Analyte concentrations in configurations 1 and 2 were consistent with those predicted by modeling ETS concentrations in the room, thus confirming good mixing of air in the test room and validating the sampling location. True displacement ventilation was not achieved in configurations 3 and 4, as discussed later, and visual observation of airflow patterns in the room confirmed that the central sampling point adequately represented the ETS exposure of smokers throughout the room.

RESULTS AND DISCUSSION

Ballots

ASHRAE recommends the use of a subjective ballot, such as a visitor ballot, for assessing air quality (ASHRAE 1989). However, in an appendix, the standard also warns that "the use of this method [visitor ballot] is only a test for odors." For this investigation, an occupant ballot was used to rate the air quality in the smoking lounge. There were several reasons for this approach. Perceptions of indoor air quality are affected by a number of factors including, but not limited to, drafts, odors, irritation (either perceptual or cellular), temperature, humidity, and light level. The primary occupants of smoking lounges are smokers who will typically remain in a lounge long enough to be influenced by all of these factors; therefore, their satisfaction with the air quality should be based on occupant standards, not just odor strength. Further, the use of visitors would have been disruptive to the experiment; their use may have led to alterations of air distribution patterns and smoking rates. The smokers indicated their satisfaction with air quality in the test room by marking a simple ballot right after they exited the test room at the end of each experiment. The ballot consisted of a single statement, "The air quality in the smoking lounge was acceptable to me," followed by the two choices: "true" and "false." Three replicate experiments (14 ballots) were performed for each condition, which resulted in a total of 42 ballots being collected.

The percentages of occupants who indicated satisfaction with the air quality in each smoking lounge arrangement have been tabulated and are presented in Table 1. The highest ratings of air quality satisfaction were obtained for arrangements 1 and 2. If one takes 80% satisfaction as a minimum level of acceptability, then the two conventional air distribution systems, arrangements 1 and 2, and arrangement 4R will provide acceptable air quality for smoking lounges. Under maximum conditions, reducing the ventilation to 30 cfm (14 $L \cdot s^{-1}$) per smoker had a detrimental impact on air quality in a smoking lounge, as indicated by reduced occupant satisfaction.

Real-Time Measurements

Real-time CO_2 concentrations for the measurements made in arrangement 2 are illustrated in Figure 3. Three runs were performed in this arrangement, and the individual real-time results are shown by the run 1, run 2, and run 3 lines in the figure. The average concentration is shown by the thick line. Each of the sampling regions described in the analytical measurements section are separated by vertical lines. Concentrations measured in the A region were sampled from the transfer air duct leading to the testing room. The B region represents sampling from the test room with people inside. No smoking took place during this period. The C region represents samples taken from the test room with smoke present in the air. All 14 smokers were smoking during the 20- to 28-minute time period at the start of the C section.

Initial CO_2 concentrations in the air supplied to the test room were slightly greater than 600 ppm. When the room was ventilated at 60 cfm (28 $L \cdot s^{-1}$) per occupant, the presence of 14 people in the room increased the CO_2 concentration by 110 ppm. In the reduced ventilation arrangement, CO_2 concentrations were somewhat higher, with an average concentration of 868 ppm. The maximum CO_2 concentration never exceeded 1,000 ppm during any of the experiments reported here, which indicates that ventilation should be sufficient to control occupant odor. ANOVA of data corrected for the presence of smokers in the room revealed no significant differences between the CO_2 concentrations in any of the arrangements. The background air and the room's occupants were the only significant sources of CO_2 in the test.

CO concentrations were measured to provide a surrogate for ETS exposure to the occupants of the room. CO concentrations in the test room are also indicative of the smoking activity that is taking place at any given point. The average ambient CO concentration during the experiments was 0.7 ppm. Smoking did have a detectable, although minor, impact on CO concentration in the room. Figures 4 through 6 show background subtracted CO concentrations in the test room during the smoking period. The background has been subtracted so that the change in concentration due to the smoking of cigarettes is more visible.

From Figure 4, several observations are noteworthy. CO generation during the initial light-up period of each experiment was very reproducible. The peak increase in CO maximized at 2.5 ppm with 14 cigarettes being smoked simultaneously. Following the initial smoking period, the smoke generation in the room was more variable. This illustrates the temporal changes in smoking patterns in a smoking lounge. Overall, the average ETS contribution to CO concentration during the ad libitum smoking period remained fairly steady around 1 ppm.

Figure 5 shows the CO concentration in arrangement 4. Overall, CO concentrations were lower in this arrangement than in arrangement 2. However, it is interesting to note that the CO profile in this arrangement is characterized by spikes of relatively high concentration with low CO levels between the spikes. In this arrangement, a stratification layer was present near the sampling tube. Small movements of the smokers may have resulted in disturbances in this layer. The irregular pattern observed in Figure 2 may have been caused as a result of these disturbances, i.e., fresh and stagnant air may have alternately been sampled through the tube.

The effect of reduced ventilation is shown in Figure 6 (arrangement 2R). Halving the amount of air supplied to the room led to an approximate doubling of CO concentration within the room relative to the 60 cfm/occupant condition.

TABLE 1
Percent of Respondents Who Found AirQuality Acceptable for Each Test Room Arrangement (Standard Errors Are in Parentheses)

	Arr. 1	Arr. 2	Arr. 4R	Arr. 3	Arr. 2R	Arr. 4
Ballots % Acceptance	93 (0)	88 (6)	81 (12)	79 (11)	69 (6)	45 (5)

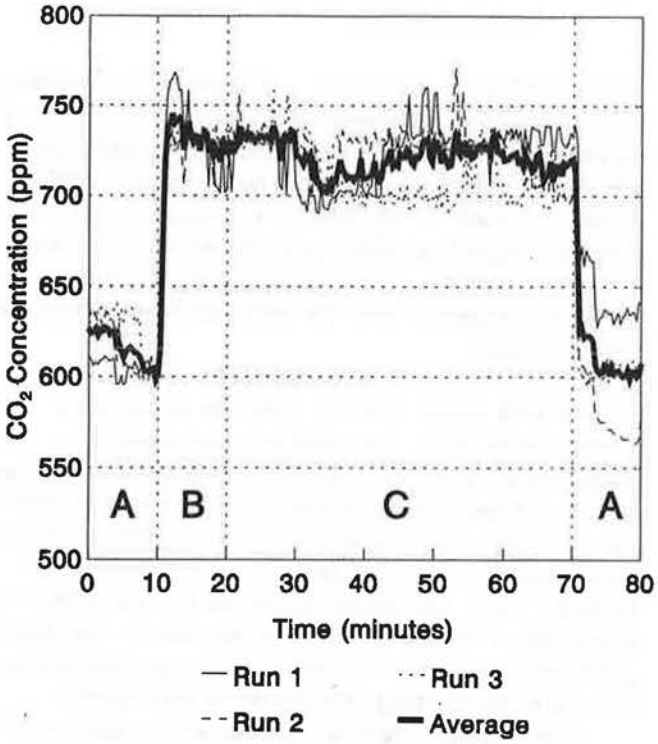

Figure 3 *Real-time CO_2 concentration in the test room operated in arrangement 2. The segments identified by letter are: A, air sampling from transfer air duct; B, air sampling from the test room with the smokers in place before the smoking period; C, air sampling from the test room during the smoking period.*

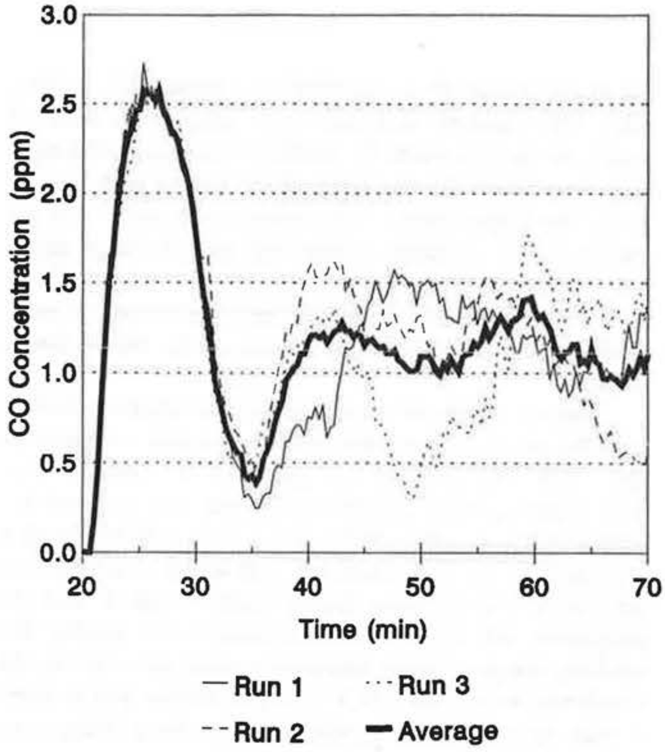

Figure 4 *Real-time CO concentration measured during the smoking period for test room operation using arrangement 2. Individual replicates are indicated by run 1, run 2, and run 3. The average real-time CO concentration is represented by the thick line.*

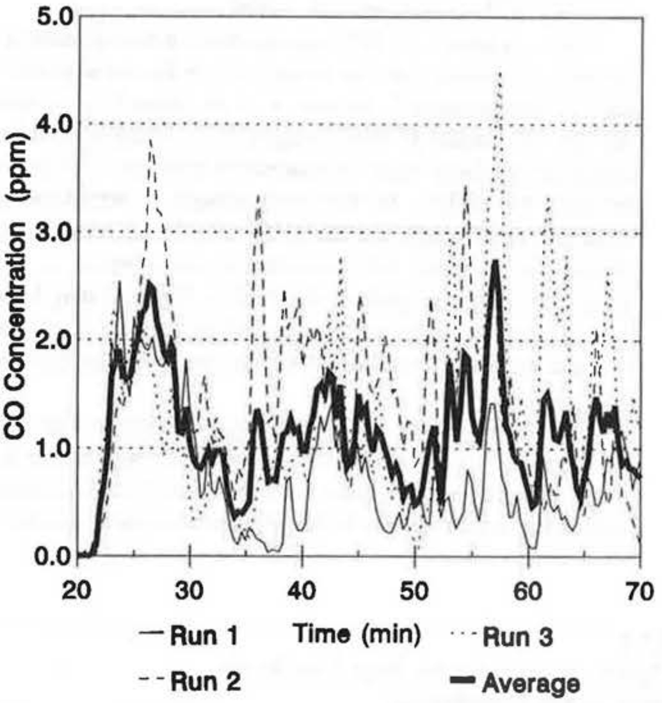

Figure 5 *Real-time CO concentration measured during the smoking period for test room operation using arrangement 4. Individual replicates are indicated by run 1, run 2, and run 3. The average real-time CO concentration is represented by the thick line.*

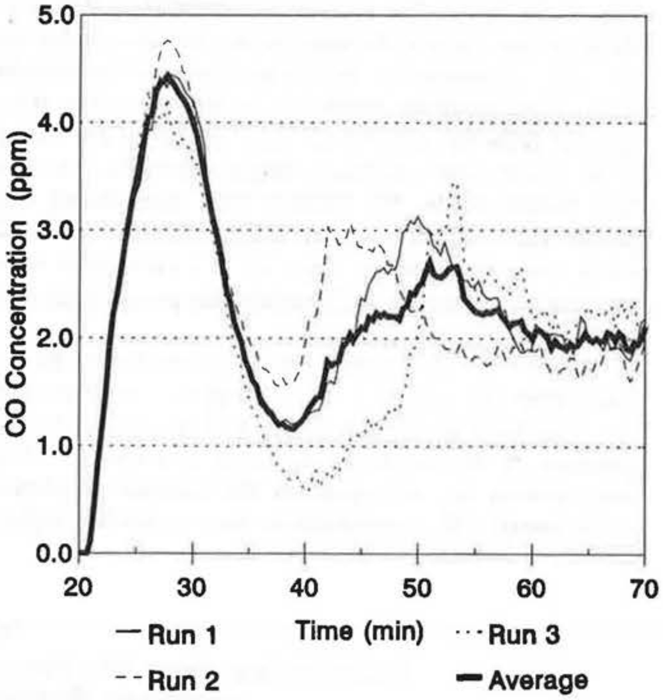

Figure 6 *Real-time CO concentration measured during the smoking period for test room operation using arrangement 2R. Individual replicates are indicated by run 1, run 2, and run 3. The average real-time CO concentration is represented by the thick line.*

Air Distribution

Room air motion characteristics (visually determined from smoke movement), temperatures, outlet air pattern, and outlet and inlet jet velocities are shown in Table 2 and Figures 7 through 11. Generalizations about comfort and air quality can be drawn from this information. Temperature and air velocity were measured in the test rooms at various heights in five locations. Four of the locations are marked on Figure 2 as A, B, C, and D. The remaining measurement was obtained in the center of the room. ASHRAE Standard 62-1989 (ASHRAE 1989) refers to ANSI/ASHRAE Standard 55-1981 (ASHRAE 1981a) for acceptable environmental conditions. All temperature measurements taken at the 4-ft (1.22-m) level fell within the recommended range of 72.5° to 76.5°F (22.5° to 24.7°C). Within a few minutes after the smokers entered the room, the temperature started to increase. The cooling system was able to control the room temperature during the test within 1°F (0.5°C). The exceptions to this were the tests performed with arrangements 4 and 4R. In these tests, the supply and transfer air was introduced under the floor and the thermostat was unable to attain the same level of control. Between the 4-in. (0.1-m) and 4-ft (1.22-m) level, the temperature variation did not stray beyond the recommended value of 5°F (3°C) in any configuration.

The air diffusion performance index (ADPI) provides another method for evaluating comfort based upon local air velocities and temperature differences from the reference room temperature (ASHRAE 1981). Substituting temperatures and air velocities into the calculations to determine ADPI yields results over 80 for each arrangement tested with the exception of arrangement 2. This value corresponds to an expected 80% of the room occupants rating the air as comfortable. The arrangement 2 data contain a large number of points with velocities of more than 70 fpm (0.36 $m \cdot s^{-1}$), which are greater than the comfort limit for calculating ADPI.

TABLE 2
Airflows (±25 cfm), Temperatures (±1°F),Velocities (±5 fpm), and ADPI Determined for Each Ventilation Arrangement Tested

CFM, TEMPERATURE, AND VELOCITY READINGS

Arr.	Run	Exhaust		Supply		Transfer		Room	Elev.	Measurement Location: Center		A		B		C		D		ADPI
		CFM	Temp.	CFM	Temp.	CFM	Temp.	Temp.		V	T	V	T	V	T	V	T	V	T	
1	1	866	78.3	175	55.2	500	77.2	73.1	8'	NA	73.2	25	72.3	35	72.7	40	71.6	45	71.9	
									6'	NA	72.6	35	72.4	35	72.9	30	71.4	65	71.5	
	2	850	78.2	175	54.1	500	77.5	72.4	4'	NA	73.1	35	72.4	25	72.6	30	72.0	50	71.1	94
									2'	NA	73.4	40	72.7	30	73.0	25	72.5	40	71.6	
	3	866	77.2	175	58.9	500	77	73.2	4"	NA	74.4	55	72.9	40	72.7	40	72.3	60	72.6	
2	1	849	77.5	172	57.9	514	77.4	74.1	8'	NA	74.0	25	73.7	60	73.5	40	73.5	25	73.1	
									6'	NA	73.8	25	74.0	30	74.1	40	73.5	30	73.0	
	2	849	75.2	175	56.8	514	75.2	73.1	4'	NA	74.1	60	73.5	25	73.7	30	73.1	65	72.1	56
									2'	NA	74.4	100	73.5	25	73.5	40	73.1	100	72.4	
	3	849	76.1	177	57.7	514	76.1	73.1	4"	NA	75.1	75	73.1	75	72.3	85	72.9	120	71.2	
2R	1	433	76.6	170	59.2	76	82.9	73.4	8'	NA	74.7	25	74.0	20	73.6	25	73.7	25	74.0	
									6'	NA	74.1	25	73.7	20	73.2	30	73.4	30	73.4	
	2	433	78.4	177	59.4	76	84.4	74.4	4'	NA	74.4	20	72.9	30	73.0	30	72.9	25	72.9	82
									2'	NA	74.0	80	72.4	45	72.5	50	72.7	30	72.4	
	3	433	79.8	175	60	76	85	75.4	4"	NA	74.3	75	72.2	25	72.0	30	72.4	25	72.2	
3	1	857	76.4	86	58.4	487	79.4	76.1	8'	60	76.0	25	75.6	20	74.8	25	75.0	20	75.4	
									6'	25	75.7	24	74.3	20	74.3	30	74.3	25	74.8	
	2	857	72.9	89	56.8	492	77.1	73.3	4'	30	76.0	30	73.7	25	73.7	35	73.6	25	74.3	100
									2'	30	75.4	30	73.5	30	72.9	30	74.0	25	73.4	
	3	857	74	88	57.4	496	78.1	74.2	4"	25	75.8	30	71.6	30	72.9	35	72.2	30	73.3	
4	1	839	74	349	55.5	492	79.1	74.3	8'	65	74.5	20	73.8	<10	74.2	<10	73.9	<10	74.5	
									6'	20	74.4	<10	73.7	<10	74.0	<10	74.0	<10	74.0	
	2	839	75.1	349	55.1	492	78.9	75	4'	<10	74.3	<10	73.2	<10	73.5	<10	73.6	<10	73.6	100
									2'	<10	72.9	<10	72.8	<10	72.7	<10	73.2	<10	73.1	
	3	839	74.4	354	55.5	492	78.8	74.4	4"	<10	73.0	<10	71.1	<10	71.9	<10	71.7	<10	72.1	
4R	1	857	76.5	352	52.9	492	80.9	74.8	8'	65	75.7	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	
									6'	<10	75.0	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	
	2	840	74.6	349	50.2	489	79.5	74.8	4'	<10	74.8	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	100
									2'	<10	73.0	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	
	3	857	75.2	349	51.3	482	81.1	75.2	4"	<10	72.9	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	

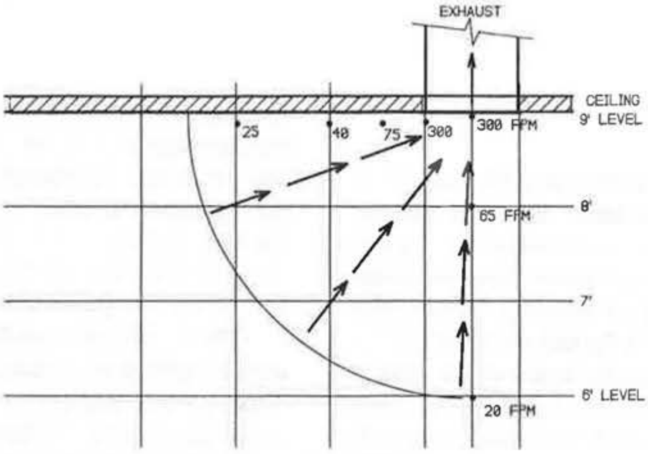

Figure 7 *Airflow velocities measured in the vicinity of the test room exhaust.*

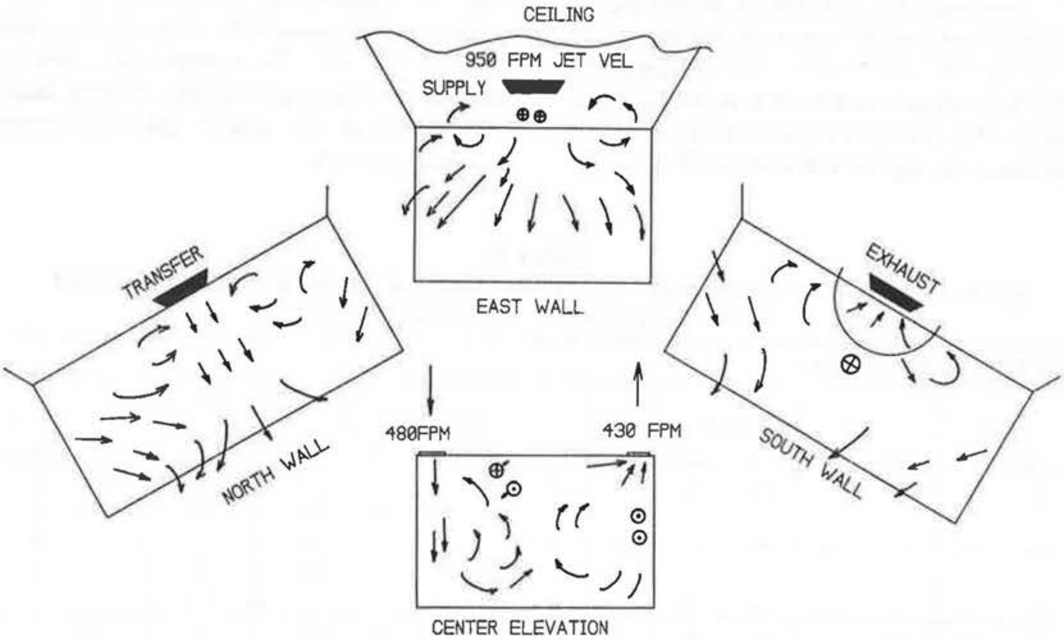

Figure 8 *Airflow patterns in the test room operated in arrangement 2.*

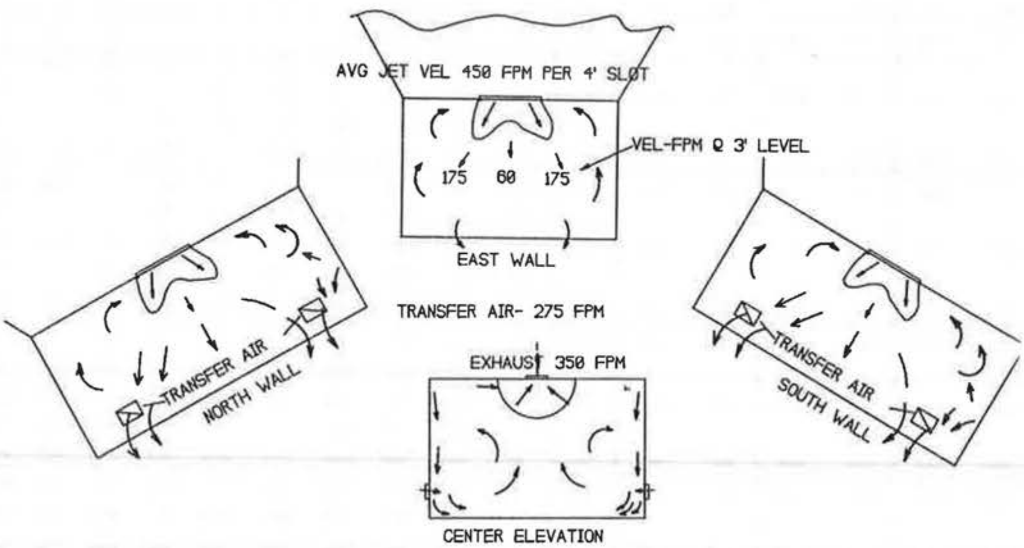

Figure 9 *Airflow patterns in the test room operated in arrangement 3.*

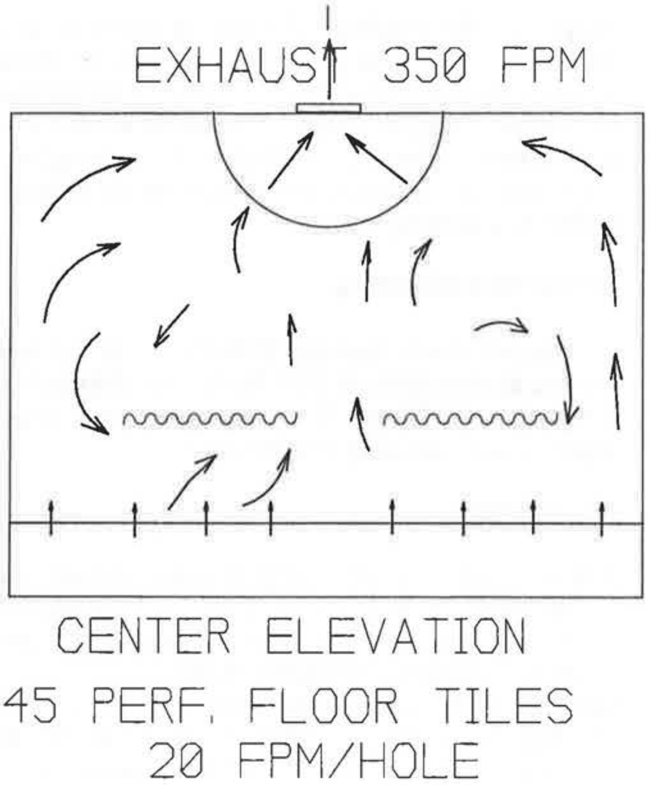

Figure 10 *Airflow patterns in the test room operated in arrangement 4.*

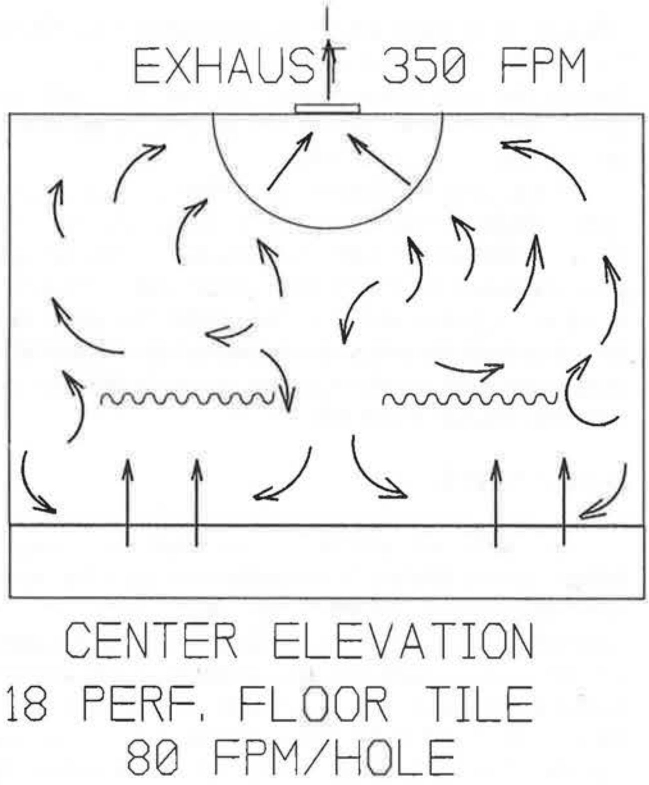

Figure 11 *Airflow patterns in the test room operated in arrangement 4R.*

Comfort must have influenced the votes on air quality, but there is some conflict between the ADPI and ballot ratings of air quality. A review of the air patterns in Figures 7 through 11 helps to clarify the conflicts. The velocity approach to the exhaust in Figure 7 shows a portion of a hemispherical air pattern to the exhaust inlet. This is a typical pattern around an exhaust or return intake. When the outer circle of air velocity is only about 20 fpm, airstreams of slightly higher velocity can move past this circle without being drawn into it.

Figure 8 shows that in arrangement 2, the air thrown toward the east wall fanned out on the wall and moved toward the floor and the north and south walls. Air throughout the room, and especially at the ceiling, was moving to be induced into the supply and transfer air jets. In this pattern, the transfer air jet was a major factor in the results. Transfer air was supplied at 514 cfm (243 $L \cdot s^{-1}$), and a 480-fpm (2.4-$m \cdot s^{-1}$) jet velocity was projected straight down to the floor. Air near the ceiling is induced into the jet and produced a well-mixed air pattern in the room. The south wall air pattern shows that the jets from the one-way diffusers followed along the wall downward toward the floor. The majority of smokers sat along the south wall to watch the television located behind the north wall partition. This allowed a clear movement of their smoke up toward the exhaust and may have helped to maintain their satisfaction with the air quality.

In arrangement 2R, the transfer airflow was reduced to 76 cfm (36 $L \cdot s^{-1}$). At this lower flow, mixing was not as effective. The combination of higher analyte concentrations and poorer mixing may have led to the low acceptance ratings shown in Table 1. These results demonstrate that a relatively high-velocity jet with high induction projected down to the floor would be desirable.

The airflow patterns in arrangement 1 were similar to those in arrangement 2. An exception was that air was projected directly across the ceiling toward the north and south walls and toward the center of the room. The airflow down the south wall passed by the smokers along this wall and carried contaminants to the center of the room. This movement of smoke away from the smokers may have helped to increase the acceptability rating.

Conditions very similar to those observed for arrangement 1 were noted for arrangement 3 (Figure 9). The four linear diffusers swept the smoke away from the smokers toward the center of the room. The linear diffusers were selected to produce a relatively low velocity with the intent of discharging the air to the floor and letting it react like a displacement ventilation system. It is not clear whether displacement ventilation took place with this system, but air quality just short of 80% acceptability and concentrations of analytes measured in real time were higher for this arrangement than they were for more acceptable ventilation arrangements.

The arrangement 4 (Figure 10) air pattern resulted in a stratification layer—a dense layer of smoke that hovered between 2 and 3 ft (0.61 and 0.92 m) from the floor, which was bounded on the top and bottom by relatively clear air.

This resulted in nearly all of the contaminants remaining in the vicinity of the smokers. The cooling effect was lost because the main cooling remained near the floor. Air quality as assessed by ballots was poor in comparison to arrangements 1, 2, 3, and 4R.

Arrangement 4R (Figure 11) resulted in a stratification layer at about the same level as the sampling tube. A smoke check of this airflow showed a solid layer of smoke that gradually moved toward the walls. At the walls, the stratification layer joined with air from under the layer then moved up the walls toward the ceiling and the exhaust inlet. Despite this airflow pattern, the air quality in this arrangement was rated as acceptable.

CONCLUSIONS

Acceptable air quality, as described by occupant ratings, can be attained in a smoking lounge at the ASHRAE-recommended ventilation rate. The results shown here demonstrate that ventilation configurations that maximize the mixing of air within the lounge and move smoke away from occupants result in high (> 80%) acceptability. Under the occupancy and airflows used for this test, the vertical velocity of air in the displacement configurations was not great enough to rapidly move smoke away from the occupants. At higher velocities, such a system may still be practical.

A major concern with the implementation of smoking lounges is the potential for high construction and operating costs. Results obtained in this study demonstrate that acceptable air quality can easily be attained in a smoking lounge with minimal modification to an existing room. The major variable in the construction cost would be the expense of running an exhaust duct from the lounge to the exterior of the building. The use of conventional air distribution is preferable and will minimize the construction cost of a smoking lounge. Furthermore, it is not necessary to ventilate a smoking lounge with outside air; the use of transfer air to augment the ventilation of a smoking lounge can provide an acceptable, cost-effective means to increase airflow to a smoking lounge.

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