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IMPACT OF INCREASED VENTILATION RATES ON OFFICE BUILDING AIR QUALITY

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To assess the impact of ventilation rate on indoor air quality (IAQ) and comfort, the indoor environment of a 20-story office building was monitored for two weeks during summer 1989. During the second week, the amount of outdoor air introduced into the air-handling system was approximately doubled. Various IAQ and comfort parameters were monitored at 10 primary and 15 secondary locations. Occupant perceptions of IAQ and comfort during monitoring were obtained through questionnaires. The difference in measured air exchange rates between the two weeks was less than twofold, possibly due to natural infiltration/ventilation effects. Neither measured IAQ/comfort nor occupant perceptions thereof were markedly different between the two weeks. Variations across monitoring sites for parameters such as respirable particles and nicotine were more striking than the differences between ventilation settings.

INTRODUCTION

The quality of the indoor environment and potential health consequences thereof have become major concerns for occupants of nonindustrial workplaces such as office buildings. Increasing ventilation rates are often recommended (1) as a potential solution for IAQ problems, whether real or perceived as real by occupants. The recommended amount of outdoor air per person has recently been increased from 5- to 20-cubic-feet per minute (cfm) for office buildings (2). To date, limited quantitative data have been collected to relate increased outdoor-air intake to commonly measured IAQ or comfort parameters. The purpose of this study, which is being conducted for the New York State Energy Research and Development Authority, is to quantitatively assess (a) the effect of ventilation rate on indoor air quality and associated parameters in an occupied office building and (b) the occupants' perceptions of air quality and comfort in the building.

The building studied is a 20-story office tower located in Albany, New York, and having a total floor area of approximately 9,300 m^2 (100,000 ft^2). The building was constructed with an unusual, but aesthetically pleasing, truncated wedge shape (see Figure 1). Offices are located primarily with a northern or southern exposure. The floor plans and types of office vary from floor to floor; there are closed offices with one occupant or multiple occupants, open-office areas with few or no partitions, office areas partitioned extensively, conference rooms, libraries, and photocopy rooms. No special-use areas such as laboratories, cafeterias, or photographic facilities are located in the building.

The air-distribution component of the heating, ventilating, and air conditioning (HVAC) system for the building consists of two air handling units that serve the perimeter of the building through induction supply-air units and two other units that serve the core area of the building through ceiling diffusers. The perimeter system is split to serve northern versus southern sides of the building, whereas the core system is split to serve upper versus lower halves of the building. All but two of the 20 floors are usable for office space--the first floor consists of an elevator/lobby area and a plaza area of open space below the second floor, and the 15th floor is a mechanical room that houses the system serving the perimeter induction units. At the outset of the study, smoking was allowed on all but two of the occupied floors, and there were no lunch rooms or break areas that would be expected to have high densities of smokers.

MATERIALS AND METHODS

A preliminary evaluation of the HVAC system indicated that approximately 30 to 35 cfm/person of outdoor air was provided at existing damper settings, based on a nominal building occupancy of 600 persons. For assessment of differences between high- and low-ventilation rates within the building, a monitoring schedule of four weeks was devised. The HVAC systems were initially set so that the approximate amount of outdoor air per person would be equal to the recommended 20 cfm. After the system was allowed to run at that setting for a week, the first week of monitoring was performed. The HVAC systems were then adjusted to a nominal 35 cfm of outdoor air per person. The system was again allowed to run for a week and the second week of monitoring was performed. The initial HVAC evaluation and the first two weeks of monitoring were completed in the summer of 1989. An identical two weeks of monitoring was performed in January 1990. As the data from the winter measurements have not been completely analyzed, the results and discussion given in this paper concern only the data collected from the two weeks of summer monitoring.

Each of the eighteen occupied floors was divided into five subfloor areas (see Figure 1) for a total of 90 possible monitoring areas. A stratified random sampling design was used for selection of 10 primary and 15 secondary monitoring sites. The building was stratified into upper and lower halves served separately by the two core HVAC systems. Within each stratum, floors were selected at random with probabilities proportional to the number of occupants on each. Sampling was performed with replacement so that any floor could be selected more than once. Subfloor areas (A,B,C,D, or E in Figure 1) were then selected at random for each chosen floor, subject to the constraint that each subfloor area be represented at least once within the 10 primary areas and once within the 15 secondary areas. A representative monitoring site was chosen judgmentally for each subfloor area, with consideration given to maintaining proximity to most workstations while avoiding direct impacts of air diffusers, local heat sources, or occupant activities.

The monitoring strategy (Table 1) included continuous monitoring together with integrated and grab samples. Continuous sampling was performed using a mobile cart configured with air quality/comfort instrumentation and a data logger programmed to scan each sensor and record 1-minute averages. The cart was "parked" at each primary and secondary site for about 5 minutes to adequately characterize each location while allowing time for transport between locations and instrument rise time at any location. Primary sites were monitored once each morning and once each afternoon on Monday, Wednesday, and Friday, and secondary sites were monitored in the same manner on Tuesday and Thursday. The specific sequence of monitoring sites was determined randomly. The comfort parameters--dry-bulb and mean radiant temperature, relative humidity, and air velocity--were used to calculate the predicted percentage of dissatisfied (PPD) occupants with the thermal environment, based on equations developed by the International Organization for Standardization (3). Outdoor levels of carbon dioxide (CO_2), carbon monoxide (CO), temperature, and relative humidity were monitored continuously in an intake duct for the HVAC system on the 15th floor.

In addition to continuous measurement of CO_2, CO, and respirable particles (RSP) with the mobile cart, 8-hour integrated samples for formaldehyde, nicotine, and RSP were collected at the primary monitoring sites on Monday, Wednesday, and Friday. Due to greater resource requirements, integrated sampling of volatile organic compounds (VOCs) was restricted to two primary sites in addition to a site in one of the HVAC return ducts and the outdoor site; grab samples for microbial aerosols (bacteria and fungi) were also taken at these sites. Building-wide air exchange rates were determined through periodic injections of sulfur hexafluoride (SF_6) directly into the primary air supply ducts followed by sequential syringe samples over a period of several hours at each of three HVAC return sites(4).

In addition to monitoring of physical parameters, a questionnaire was designed for assessment of the building occupants' perceptions of temperature, humidity, air movement, stuffiness, thermal environment, odors, tobacco smoke, and dust. The survey was administered each morning and afternoon to all building occupants whose primary workstation was near a primary monitoring location, or approximately 60 occupants in total. Prior to monitoring, a baseline questionnaire was administered to identify potentially sensitive individuals and general opinions relating to air quality and the thermal environment.

RESULTS AND DISCUSSION

Measured intake rates of outdoor air were slightly lower than targeted at the low-ventilation setting and slightly higher than targeted at the high-ventilation setting, resulting in a greater than twofold difference between settings (Table 2). However, measured air exchange rates differed by only 25 to 30 percent. Natural infiltration/ventilation may account for the lower-than-expected difference in air exchange; some balcony doors were observed to be open during the monitoring periods.

Measured air quality and comfort parameters shown in Table 2 were not markedly different for the two ventilation settings. Differences among monitoring sites were typically greater than differences between the two settings. In particular, two monitoring sites impacted by local smoking had substantially higher RSP/nicotine concentrations than the other sites monitored. CO_2 levels were lower than existing criteria (2) by nearly 50 percent during both weeks. Monitored VOC levels, not shown on the table, were generally lower during the high-ventilation week at the monitoring site in the lower half of the building but higher at the site in the upper half and at the HVAC-return site; however, outdoor VOC levels were also higher during the high-ventilation week. Bacteria levels varied widely across sampling sites and monitoring days, having no apparent relationship with ventilation rate. Fungi levels were consistently lower during the high-ventilation week.

Predicted occupant dissatisfaction with the thermal environment, based on temperature, humidity and air velocity measurements, was near the minimum possible (5 percent) during both weeks but was slightly higher for the high-ventilation setting. The actual percentage of occupants indicating that the thermal environment was unacceptable was higher than predicted in both cases and also was slightly higher for the high-ventilation setting. Acceptability levels were quite high for odors and tobacco smoke and were somewhat higher during the low-ventilation week. Nearly a third of the occupants indicated that dust levels were unacceptable, with a somewhat higher percentage during the high-ventilation week.

CONCLUSIONS

Based on summer monitoring, measured IAQ and comfort parameters and occupant perceptions of IAQ/comfort were not markedly different for the two ventilation settings. Variations across monitoring sites for parameters such as integrated RSP and nicotine were more striking than differences between ventilation settings. During both weeks, the percentage of occupants indicating that the thermal environment was unacceptable was higher than predicted from measurements of comfort parameters. Although there was a twofold difference in mechanical ventilation rates for the two weeks of monitoring, measured air exchange rates (which also include natural infiltration/ventilation components) differed by only 25 to 30 percent.

For the recently completed winter monitoring exercise, differences in measured air exchange rates were more consistent with differences in mechanical ventilation rates and, thus, may provide a better indication of the effects of increased ventilation. Because the building studied has not been characterized by a high degree of occupant complaints, the monitoring results should provide a good benchmark for future comparison with "sick" or high-complaint buildings.

ACKNOWLEDGEMENTS

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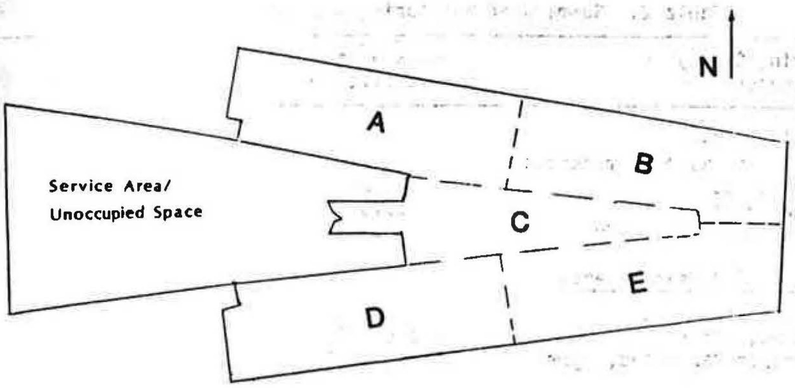

——— indicates walls --------- indicates nominal subfloor divisions

Figure 1. State Agency Building No. 2 Floor Plan.

Table 1. Monitoring Strategy for Air Quality, Comfort and Air Exchange Parameters

	Number of Monitoring Sites			
Measurement Methods/Parameters	Primary	Secondary	HVAC Return	Outdoors
Continous Monitoring[1]				
Carbon Dioxide/Monoxide, Temperature, Humidity	10	15	--	1
Respirable particles, Air Velocity	10	15	--	--
Integrated Monitoring[2]				
Formaldehyde, Nicotine Respirable Particles	10	--	--	--
Volatile Organic Compounds	2	--	1	1
Grab Samples				
Microbial Aerosols	2	--	1	1
Sulfur Hexafluoride (air exchange)	--	--	3	--

[1]A mobile cart was "parked" at each indoor site for about 5 minutes each morning and afternoon
[2]Sampling duration of 8 hours (8:00 a.m. to 4:00 p.m.)

Table 2. Summary of Monitoring and Survey Results

Monitoring/Survey Parameter	Week with Low Ventilation	Week with High Ventilation
Fresh-Air Supply		
Ventilation Rate, cfm/person		
- targeted	20.0	35.0
- measured	16.5	38.0
Air Exchange Rate, ACH	0.84	1.08
Integrated IAQ Measurements[1]		
Formaldehyde, nL/L	9.4 ± 8.1	11.7 ± 5.5
Nicotine, µg/m^3	1.1 ± 3.3	1.0 ± 2.3
Respirable Particles, µg/m^3	30.4 ± 60.0	27.3 ± 20.0
Continuous IAQ/Comfort Measurements[1]		
Respirable Particles, µg/m^3	54.5 ± 4.7	60.0 ± 11.3
Carbon Dioxide, µL/L	550 ± 8	526 ± 7
Carbon Monoxide, µL/L	1.1 ± 0.05	0.7 ± 0.03
Comfort, PPD (see text)	5.8 ± 0.2	6.5 ± 0.3
Occupant Surveys[2]		
Thermal Environment, Percent	15.5	17.3
Odors, Percent	1.0	4.6
Tobacco Smoke, Percent	0.9	4.6
Dust, Percent	27.2	32.0

[1]Average ± standard deviation across primary monitoring sites
[2]Percent of occupants indicating "unacceptable" for each parameter