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The Impact of Increased Ventilation on Indoor Air Quality

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ABSTRACT

To assess the impact of increased minimum outside air ventilation on indoor air quality (IAQ), environmental conditions were monitored in a 19-story building in Columbus, Ohio. Nine IAQ parameters were measured during test periods when the HVAC systems were configured to supply outside air at ventilation rates of 20 cfm/person and 5 cfm/person. IAQ did not differ markedly between the test periods, with the exception of carbon monoxide. During the 5 cfm/person test period, the study building was operated under a negative pressure, since the outside air intake was less than the normal building exhaust. A consequence was the infiltration of outdoor pollutants through openings in the building's envelope. These findings suggest that buildings should be operated at a positive pressure to minimize the potential for infiltration of outdoor pollutants.

INTRODUCTION

Research has shown that low outside air ventilation rates are a causal factor of the sick building syndrome (Collett and Sterling 1988). In response to this concern, the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) increased the minimum ventilation rates recommended in the ASHRAE ventilation standard from 5 cubic feet per minute (cfm) per person in 1981 (ASHRAE 1981) to 15 cfm/person in 1989 (ASHRAE 1989).

To evaluate the impact of increased outside air ventilation rates on indoor environmental conditions in office buildings, a case study assessment was undertaken of the Municipal Courthouse building in Columbus, Ohio. The objective of the study was to determine the impact of different ventilation conditions on indoor air quality in a "healthy building," i.e., a building in which occupants are satisfied with indoor environmental conditions and have not reported a high prevalence of complaints typical of the sick building syndrome.

The study building is a 19-story building constructed in 1978, with a total floor area of approximately 354,000 square feet. Windows in the building do not open. The courthouse building is served by three supply air fans and two return air fans located on the 19th floor. Heating is provided to each floor by a perimeter radiant system, and cooling and air conditioning are provided by a ceiling-based variable-air-volume (VAV) system. The HVAC systems are operated continuously (24 hours a day, 7 days a week) to serve the wide range of occupancy requirements, including open-plan and enclosed offices, courtrooms, public waiting areas, and holding facilities. Smoking is permitted throughout the building, with the exception of the courtrooms. Occupancy of the building on a typical day is approximately 1,500 people. It was assumed that occupancy was similar throughout the period of study.

STUDY PROTOCOL

Indoor air quality (IAQ) was monitored under two ventilation conditions in the fall of 1990. In addition, a pilot study was completed in the spring of 1990. For the two test conditions in the fall, the HVAC systems were configured by the building's direct digital control (DDC) system to supply outside air at ventilation rates of 5 cfm/person and 20 cfm/person (the minimum ventilation rate recommended for office space in *ASHRAE Standard 62-1989*). The HVAC systems were initially operated to supply 20 cfm/person for a two-week period. During the second week, nine IAQ parameters were monitored over a three-day period. Following the IAQ monitoring, the HVAC systems were reconfigured using the DDC system to supply 5 cfm/person for a further two weeks. The IAQ monitoring was repeated during this 5 cfm/person test condition.

In the pilot study (referred to as "VMAX"), the HVAC systems were operated on the economizer cycle, with the outside air dampers 100% open. IAQ measurements were taken during one afternoon under the VMAX configuration.

SAMPLING AND ANALYTICAL METHODS

Nine IAQ parameters were monitored during the 20 cfm/person, 5 cfm/person, and VMAX test conditions. Table 1 shows the analytical methods, detection limits, and levels of accuracy. Instantaneous measurements of carbon dioxide (CO_2), carbon monoxide (CO), temperature, relative humidity, and respirable suspended particles (RSP) were taken at 20 indoor sampling locations and 2 outdoor locations during the 20 cfm/person and 5 cfm/person test weeks. Two sets of data were collected on each day, morning and afternoon. In the pilot study, a single set of

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TABLE 1
Sampling and Analytical Methods
Courthouse Building, Columbus, Ohio

PARAMETER	METHOD	DETECTION LIMIT	ACCURACY
Carbon Dioxide	Direct reading non-dispersive infrared.	50 ppm	± 2 %
Carbon Monoxide	Direct reading electrochemical.	1 ppm	± 10 %
Temperature	Direct reading resistance change in sensor.	-	± 0.5°F
Relative Humdity	Direct reading capacitance change in sensor.	-	± 0.2 %
Respirable Suspended Particles	Direct reading piezoelectric microblance.	10 $\mu g/m^3$	± 10 %
Formaldehyde	Passive absorption samplers; colorimetric analysis.	0.03 ppm	± 35 %
Volatile Organic Compounds	Collection on charcoal at flow rate of 300 ml/minute; gas chromatographic analysis.	0.04 ppm	± 10 %
Nicotine	Collection of XAD-4 resin at flow rate of 1 litre/minute; gas chromatographic analysis.	0.4 $\mu g/m^3$	± 1 %
Microbial	Centrifugal impaction on nutrient agar.	1 cfu	-

afternoon data was gathered. The 20 indoor sampling locations were selected to reflect the three HVAC zones in the building and the range of uses of the space.

Integrated sampling for formaldehyde, total volatile organic compounds (TVOC), and nicotine was conducted at six indoor locations. Airborne microbial samples were collected at all 20 indoor locations on two days during the 20 cfm/person and 5 cfm/person test weeks and on the afternoon of the pilot study.

RESULTS

The results of the IAQ monitoring are summarized in Table 2, which shows mean data for all sampling locations and all sampling periods within each test condition combined. Differences in the results between the 20 cfm/person and 5 cfm/person test conditions were analyzed using multiple regression analysis. Analyses were performed separately for each IAQ parameter, with the IAQ parameter as the dependent variable and test condition (20 cfm and 5 cfm), time of day (a.m. or p.m.), day of the week, and sampling location as the independent variables. Application of the multiple regression technique allowed analysis of spatial and temporal variations within the data set.

For each IAQ parameter, differences between sampling locations were found to be significant. These intra-locational variations relate to different occupancy levels and uses of the space (e.g., enclosed offices, open plan, waiting areas, etc.). The pattern of differences is being further analyzed.

Carbon dioxide concentrations were similar during the 20 cfm/person and 5 cfm/person weeks. Mean concentrations were 680 parts per million (ppm) and 695 ppm, respectively. CO_2 concentrations were substantially lower during VMAX (mean 501 ppm) when the HVAC economizer was operating. Multiple regression analysis comparing the 20-cfm and 5-cfm test weeks shows that CO_2 concentrations varied significantly by time of day ($p < 0.01$), but differences between the two test weeks were not significant.

The similarity in CO_2 concentrations between the test weeks despite the reduced mechanical supply of outside air during the 5-cfm week suggests that outside air was entering the building through paths other than the HVAC system. The building's normal exhaust is equivalent to a ventilation rate of 15 cfm/person. During the 20 cfm/person test week, the building was, therefore, operating properly under a slight positive pressure. However, during the 5 cfm/person test week, the building was operating improperly under a negative pressure, since the outside air intake was not sufficient to balance the exhaust of 15 cfm/person. A consequence was the infiltration of unconditioned outside air through openings in the building's envelope.

TABLE 2
Mean Results of IAQ Monitoring
Courthouse Building, Columbus, Ohio
(Standard deviations shown in parentheses)

	VMAX	NOMINAL VENT. RATE 20 CFM/PERSON (Estimated Rate) 32.5 CFM/PERSON			NOMINAL VENT. RATE 5 CFM/PERSON (Estimated Rate) 30.6 CFM/PERSON		
	PM	AM	PM	AM & PM	AM	PM	AM & PM
CO_2 (ppm)	501 (104)	704 (125)	655 (93)	680 (113)	721 (134)	670 (86)	695 (115)
CO (ppm)	1.5 (0.7)	1.3 (0.5)	1.3 (0.6)	1.3 (0.3)	2.7 (1.6)	1.8 (0.7)	2.3 (1.3)
Temperature (°F)	74.2 (1.4)	72.7 (2.5)	73.0 (2.1)	72.9 (2.3)	72.6 (2.9)	72.5 (2.5)	72.5 (2.7)
Relative Humidity (%)	34.0 (1.0)	48.0 (7.5)	47.4 (7.4)	47.7 (7.4)	39.8 (4.4)	38.8 (5.5)	39.3 (5.0)
RSP ($\mu g/m^3$)	23 (12)	73 (75)	36 (31)	55 (61)	73 (80)	34 (37)	54 (65)
Formaldehyde (ppb) *	32 (11)		38 (6)				40 (9)
Formaldehyde (ppb) **			25 (13)				21 (8)
VOC (ppm)	<1		0.28 (0.11)				0.09 (0.04)
Microbial (cfu/m^3)	418 (222)		504 (446)				400 (265)
Nicotine ($\mu g/m^3$)	6.0 (3.2)		3.9 (3.4)				4.6 (4.0)

* Eight hour samples.
** Twenty-four hour samples.

To assess the extent of infiltration, a gross estimate of total outside air ventilation (mechanical plus infiltration) can be calculated from the indoor and outdoor CO_2 concentrations using Appendix D from *ASHRAE Standard 62-1989* (ASHRAE 1989). Assuming that (1) the mean CO_2 data are representative of steady-state conditions and (2) occupancy remained constant during the test weeks, the estimated outside air ventilation rates were 32.5 cfm/person for the 20-cfm test week and 30.6 cfm/person during the 5-cfm test week. The estimated ventilation rate during VMAX was 71 cfm/person. These estimates show the high degree of infiltration of outside air through openings in the envelope during the 5-cfm week resulting from the building operating under a negative pressure.

Carbon monoxide concentrations were higher during the 5-cfm test week (mean concentrations 1.8 to 2.7 ppm) compared to the 20-cfm and VMAX conditions (1.3 to 1.5 ppm). Multiple regression analysis shows that differences in CO levels between the two test weeks were significant ($p < 0.01$). The significantly higher CO levels in the 5-cfm week confirms the infiltration of outdoor air resulting from the operation of the building under negative pressure. There were street-level sources of CO from street traffic and construction activity adjacent to the study building.

Temperature levels were not significantly different between the 20-cfm and 5-cfm test weeks. Mean levels ranged from 72.5°F to 73°F. The similarity in temperatures between the 20-cfm and 5-cfm weeks suggests that the HVAC systems were able to control indoor thermal conditions despite the infiltration of untempered outside air during the 5-cfm week.

Relative humidity levels differed between the 20-cfm, 5-cfm, and VMAX test weeks, ranging from 34% during VMAX to 48%

during the 20-cfm test week. The differences were a function of variations in outdoor humidity levels rather than building-related concerns. Multiple regression analysis shows significant differences in humidity levels between the test weeks ($p < 0.01$).

Respirable suspended particle concentrations did not vary significantly between the 20-cfm and 5-cfm test weeks, with mean concentrations of 55 and 54 micrograms per cubic meter (g/m^3). However, RSP concentrations varied significantly by sampling location within the building ($p < 0.01$). This significant variation relates to the level of occupancy and human activities (including smoking) at different sampling locations in the building. For example, the highest RSP concentrations were measured in courtroom waiting areas during the morning sampling periods, when people were waiting to enter the courtrooms.

Formaldehyde concentrations did not vary significantly between the 20-cfm and 5-cfm test weeks and were also similar during VMAX. Mean concentrations ranged from 32 to 40 parts per billion (ppb). There was significant variation by sampling location ($p < 0.01$), indicating variation in source strengths of formaldehyde within the building, such as furnishing and finishing materials.

Total volatile organic compound concentrations (expressed as hexane) were significantly higher ($p < 0.01$) during the 20-cfm week. This difference was the result of markedly elevated VOC concentrations on the first day of sampling in the 20-cfm week (0.3 to 0.4 ppm) compared to concentrations ranging from 0.05 to 0.2 ppm during the other days of sampling. The cause of the elevated VOC concentrations may have been carpet-cleaning solvents that had been used in the building on the previous day.

Nicotine concentrations did not differ significantly between the test weeks and were similar during VMAX. Mean concentrations ranged from 3.9 to 6.0 μg/m^3.

Microbial concentrations did not vary significantly between the test weeks and were similar during VMAX, with mean concentrations ranging from 400 to 504 colony-forming units per cubic meter (cfu/m^3). There was significant variation by day of measurement ($p < 0.05$). In both test weeks, microbial concentrations were higher on the first day. On all sampling days, indoor concentrations were lower than outdoors, suggesting that the primary source of indoor fungi and bacteria was the outdoor environment.

CONCLUSIONS

The measured IAQ parameters were not markedly different between the two test weeks and the pilot survey. There were observable variations in IAQ levels between sampling locations within the building and time of day that data were collected. During all sampling periods, the measured IAQ parameters were at low concentrations, showing that there were not excessive sources of indoor pollution in the building. These findings are consistent with a recent study in Albany, New York (Nagda et al. 1990).

The similarity in CO_2 concentrations when the HVAC system was configured to supply outside air ventilation rates of 20 cfm/person and 5 cfm/person shows that outside air was infiltrating though paths other than the outside air intakes during the 5 cfm week, as a consequence of the building operating under a negative pressure. This led to the infiltration of CO into the building from adjacent street-level sources. While this infiltration did not create excessively poor air quality in the study building, the uncontrolled entry of unfiltered and untempered outside air could cause more severe indoor pollution and thermal control problems in some buildings, particularly in times of extreme outdoor temperatures or if the building is adjacent to specific sources of contamination.

These findings suggest that "healthy buildings" should be operated at a positive pressure to minimize the possible infiltration of outdoor pollutants.

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