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THE EFFECT OF VARYING LEVELS OF OUTDOOR-AIR SUPPLY ON THE SYMPTOMS OF SICK BUILDING SYNDROME

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Abstract *Background.* The sick building syndrome is the term given to a constellation of symptoms reported by workers in modern office buildings, hypothesized to occur when the supply of outdoor air is reduced, because of the accumulation of contaminants arising from within the building. We undertook this study to determine the effect of changing the supply of outdoor air in four office buildings on the symptoms reported by workers and their perception of the indoor environment.

Methods. Within each of three consecutive two-week blocks, the ventilation systems in each building were manipulated, in random order, to deliver to the indoor environment an intended 20 or 50 ft^3 (0.57 or 1.4 m^3) of outdoor air per minute per person for one week at a time. Each week, the participants, unaware of the experimental intervention, reported symptoms and the indoor environment was thoroughly evaluated.

Results. Of 1838 eligible workers in the four buildings, 1546 (84 percent) participated in the study. The supply of outdoor air averaged 7 percent and 32 percent in the ventilation systems and 30 and 64 ft^3 (0.85 and 1.8 m^3) per minute per person in the work sites at the lower and higher ventilation levels, respectively. These changes in the supply of outdoor air were not associated with changes in the participants' ratings of the office environment or in symptom frequency (crude odds ratio, 1.0; 95 percent confidence interval, 0.9 to 1.1). After work-site measures of ventilation, temperature, humidity, and air velocity were included in the regression analysis, the adjusted odds ratio was also 1.0 (95 percent confidence interval, 0.8 to 1.2).

Conclusions. Increases in the supply of outdoor air did not appear to affect workers' perceptions of their office environment or their reporting of symptoms considered typical of the sick building syndrome. (N Engl J Med 1993;328:821-7.)

THE World Health Organization has defined the sick building syndrome as an excess of work-related irritations of the skin and mucous membranes and other symptoms, including headache, fatigue, and difficulty concentrating, reported by workers in modern office buildings.[1] In 25 percent of the investigations of apparent outbreaks of such symptoms, a specific cause can be identified,[2,3] such as microbial contamination of humidification systems[2] or the accumulation of motor-vehicle exhausts.[3] The remaining 75 percent of outbreaks are unexplained and are considered to be due to the sick building syndrome.[3]

A large number of persons may be potentially affected, since more than half of all workers in industrialized nations work in offices,[4] and 50 to 80 percent of approximately 9000 workers surveyed in Britain,[5] Denmark,[6] and Sweden[7] reported symptoms typical of the sick building syndrome. On the basis of these and other prevalence surveys, it is estimated that at any one time 10 to 25 million workers in 800,000 to 1.2 million commercial buildings in the United States will have symptoms typical of the sick building syndrome.[8] The resultant economic impact is considerable,[8] because symptomatic workers have reduced productivity[9] and increased absence from work.[10]

It has been hypothesized that in mechanically ventilated buildings, symptoms arise because the concentrations of contaminants from indoor sources increase when the supply of outdoor air is reduced.[3,11,12] Despite little supportive evidence, this hypothesis has gained such widespread acceptance that the American Society of Heating, Refrigeration, and Air Conditioning Engineers recommended an increase in the minimal supply of outdoor air from 5 to 10 ft^3 (0.14 to 0.28 m^3) per minute per person in 1981[13] and another increase from 10 to 20 ft^3 (0.57 m^3) per minute per person in 1989.[14] Further increases have been proposed[15,16] that not only would increase energy costs,[8] but could also exceed the capacity of the heating, ventilation, and air-conditioning systems in many buildings to maintain temperature and humidity in the ranges considered ideal for human comfort and well-being.[13,17]

This study was undertaken to test the hypothesis that symptoms of sick building syndrome could be

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reduced in mechanically ventilated office buildings by increasing the supply of outdoor air from 20 to 50 ft^3 (1.4 m^3) per minute per person.

Methods

Overall Study Design and Experimental Intervention

A randomized double-blind multiple-crossover trial was conducted to estimate the effect of changes in the outdoor-air supply in four office buildings. During three consecutive two-week blocks of time, building ventilation systems were manipulated to deliver an expected 20 or 50 ft^3 of outdoor air per minute per person to the indoor environment, corresponding to indoor carbon dioxide concentrations of 1000 or 600 ppm.[17] Within each two-week block, the ventilation level was increased for one week and decreased for the other. The order of the increase and decrease in the ventilation level in each block was selected randomly by the study engineers and was not known by the data-collection personnel or the study participants. The dampers supplying outdoor air to the buildings were manipulated each Friday afternoon and then remained in these positions for the following week. Two buildings were studied simultaneously, with opposite ventilation levels in each building, to minimize the potential effect of reduced symptom reporting over time that was found in an earlier pilot study.[18]

Study Population

The study buildings had sealed windows and mechanical ventilation systems and were between 3 and 20 years old. All but one (building 4) had nonsmoking policies. Two buildings were studied in the spring and two in the fall of 1990.

A survey was conducted of all full-time workers in two buildings of 8 and 9 floors (buildings 1 and 3) and of all full-time workers on eight floors in two buildings of 23 and 25 floors (buildings 2 and 4). Eligible workers were considered to be participating if they completed at least two of the six weekly questionnaires, to have dropped out if they completed only one weekly questionnaire, and not to have responded if they completed no questionnaires.

Collection of Environmental Data

The supply of outdoor air at each work site was estimated by measuring the carbon dioxide concentrations at 8 to 12 work sites per floor in midafternoon on the day that the weekly questionnaire was completed. The values for the carbon dioxide concentrations were converted to cubic feet per minute per person with the following accepted formula[14]: carbon dioxide in cubic feet per minute per person = [(0.75) (1,000,000 − indoor carbon dioxide)/60]/(indoor carbon dioxide − outdoor carbon dioxide), where 0.75 ft^3 (0.02 m^3) per minute is the amount of carbon dioxide produced by the office occupant, 1,000,000 ppm is the maximal concentration of pure carbon dioxide, indoor carbon dioxide is the average concentration (in parts per million) of carbon dioxide at each work site on the afternoon of the test day, and outdoor air is the concentration (in parts per million) of outdoor air on the test day.

The outdoor-air supply calculated for each participant was the carbon dioxide value obtained at the nearest work site. The carbon dioxide concentrations in the supply air, return air, and outdoor air of the building's ventilation system were used to verify the level of ventilation in each building[14] (the percentage of outdoor air = 100 − [(supply air − outdoor air)/(return air − outdoor air)] × 100).

The major determinants of human comfort — air velocity, temperature, and relative humidity[13,17] — were measured in the morning and afternoon on the same day and at the same sites as carbon dioxide was measured. The following indoor contaminants were measured with methods previously reported[18,19] once weekly at two to four sites per floor: formaldehyde, nitrogen oxides, carbon monoxide, total volatile organic compounds, total and viable airborne fungal spores, and total airborne dust.

Questionnaires

The workers completed self-administered questionnaires at base line (one to three weeks before the study began) that provided data on their personal, smoking, medical, and work histories and their state of mind, according to the Bradburn index of emotional well-being.[20] To minimize recall bias, in midafternoon on Wednesday or Thursday of each of the six study weeks, they completed a five-minute questionnaire on their environment and the presence or absence of symptoms experienced that day. The symptoms asked about — headache, fatigue, difficulty concentrating, cough, and irritation of the eyes, nose, or throat — were those reported most frequently in our pilot study[18] and in other studies.[6,7,21] The participants' overall impressions of the office environment (good, poor, or variable) were reported, and changes in their impressions from the previous week (better, the same, or worse) were noted. They also rated nine environmental conditions (temperature, humidity, air circulation, lighting, noise, space, dust, smoke, and odors) on an ordinal scale. The scores for the nine items were added and rescaled into a total environmental dissatisfaction score, in which a score of 0 indicated that all conditions were ideal, and a score of 100 that all conditions were terrible.

Data Analysis

The primary outcomes were weekly reports of any symptom, mucosal symptoms (irritation of the nose or throat or a cough), and systemic symptoms (headache, fatigue, or difficulty concentrating).[5,6,22] The primary analysis was a comparison within subjects of the frequency of symptoms under the different ventilation conditions. Combining only discordant responses from the same participants within each two-week block, the crude odds ratio represents the average number of participants who were symptomatic only during the weeks of increased ventilation, divided by the average number of participants who were symptomatic only during the periods of decreased ventilation.[23] The odds of reporting symptoms at different carbon dioxide concentrations, adjusted for other environmental measurements and ratings, were calculated with conditional logistic-regression analysis, in which the symptoms and actual work-site concentrations of carbon dioxide during all six weeks were analyzed.[24] A crude or adjusted odds ratio of less than 1.0 would indicate a reduction in symptom reporting during periods of increased outdoor-air supply.

Additional analyses between subjects were conducted to assess the relation of the participants' characteristics to symptoms, the association of differences between work-site environmental conditions and symptoms (logistic-regression analysis), and the variability of environmental conditions within and between work sites (analysis of components of variance).[25,26]

Results

Study Population

In the four buildings studied, 1838 eligible workers were identified, of whom 182 did not respond to the questionnaires, 110 agreed to participate but subsequently dropped out of the study, and 1546 (84 percent) participated (Table 1). As compared with the participants, the workers who did not respond to the survey were more likely to be men, and those who dropped out were less likely to have a history of atopic illness or to work in clerical positions. All subsequent results refer to the 1546 participants, of whom an average of 82 percent completed questionnaires each week. The 637 who completed all six weekly questionnaires were more likely to be female, younger, and work in open areas in clerical positions, than participants who completed two to five questionnaires.

Achievement and Effect of Experimental Conditions

The average supply of outdoor air at work sites during the study was 64 and 30 ft^3 (1.8 and 0.85 m^3) per minute per person when outdoor-air dampers were open and closed, respectively, and the percentage of outdoor air in the supply air of the ventilation system was 32 percent and 7 percent (i.e., 68 percent

Table 1. Characteristics of Participants and Nonparticipants in the Four Office Buildings Studied.*

CHARACTERISTIC	NONPARTICIPANTS		PARTICIPANTS (N = 1546)
	NONRESPONDERS (N = 182)	DROPOUTS (N = 110)	
Sex (%)			
Male	61	59	53
Female	39	41	47
% French-speaking	60	68	65
Mean (±SD) age (yr)	—	39±8.9	38±10.2
History of atopic illness (%)†	—	18	32
Smoking status (%)			
Never smoked	—	51	48
Current smoker	—	18	25
Exsmoker	—	31	27
Position (%)			
Clerical	—	15	24
Management	—	59	46
Professional	—	17	20
Other	—	10	11
Working in open area (%)	—	51	60
Average daily computer use (%)			
<0.5 hr	—	21	25
0.5–4 hr	—	45	46
>4 hr	—	34	29

*Participants completed at least two weekly questionnaires, nonresponders did not complete any questionnaires, and dropouts completed the base-line questionnaires but fewer than two weekly questionnaires. Because of rounding, not all values total 100 percent.

†Atopic illnesses included eczema, asthma, hay fever, and diagnosed allergies.

and 93 percent of the air was recirculated), respectively (Table 2). In all buildings, reducing the supply of outdoor air resulted in considerably higher concentrations of formaldehyde and volatile organic compounds. The experimental changes in building ventilation conditions were also associated with changes in carbon dioxide concentrations at work sites, as intended, but were not associated with any significant changes in the temperature, air velocity, or humidity of the work sites.

The participants appeared to be unaware of the experimental conditions because their weekly environmental ratings were not associated with the air supply at work sites (Table 3). As shown in Figure 1, however, the total environmental dissatisfaction score was directly associated with the number of symptoms reported. The participants who reported symptoms were also significantly more likely to rate the overall environment as poor ($P<0.001$) or to report that it had changed for the worse as compared with the previous week ($P<0.001$).

Primary Results

On average, a little more than half the participants reported at least one symptom each week, and the proportion reporting symptoms within each two-week block was virtually identical at the two levels of ventilation (Table 4). There was a strong temporal trend in symptom reporting, since the frequency of symptoms declined from 55 percent to 35 percent from the first to the sixth weeks in buildings 1 and 2, and from 66 percent to 55 percent in buildings 3 and 4.

On average, 39 percent of the participants were symptomatic and 33 percent were asymptomatic during both weeks of each block. As shown in Table 5, 14 percent had symptoms only during periods of reduced ventilation, and 14 percent had symptoms only during periods of increased ventilation (odds ratio for increased versus decreased ventilation, 1.0; 95 percent confidence interval, 0.9 to 1.1). The corresponding odds ratio for mucosal irritation was 1.0 (95 percent confidence interval, 0.8 to 1.1), and for systemic symptoms, it was 1.1 (95 percent confidence interval, 0.9 to 1.2).

Conditional logistic-regression analysis showed that the reporting of any symptom was significantly associated with work-site measures of relative humidity, but not with temperature, air velocity, or carbon dioxide concentration (Table 6). Because of the temporal trend and the association of environmental ratings with symptoms, a second regression analysis was carried out that included weekly environmental ratings and the actual environmental measures. Symptoms were independently associated with environmental ratings and the week, but not with the concentration of carbon dioxide, humidity, temperature, or air velocity. When this analysis was repeated for the mucosal and systemic symptoms and for workers within each building, similar associations were found.

Additional Analyses

The following personal and work-site characteristics were significantly associated with the reporting of any symptom: female sex (odds ratio, 1.7; 95 percent confidence interval, 1.5 to 1.9), atopic illness (odds ratio, 1.4; 95 percent confidence interval, 1.3 to 1.6), use of the computer for more than four hours each day (odds ratio, 1.3; 95 percent confidence interval, 1.1 to 1.5), working in an open area (odds ratio, 1.1; 95 percent confidence interval, 1.0 to 1.2), and younger age. These characteristics were also associated with the re-

Table 2. Summary of Experimental Ventilation Conditions and Resultant Concentrations of Contaminants in the Four Office Buildings Studied.

MEASURE	VENTILATION LEVEL*	BUILDING				MEAN VALUE
		1	2	3	4	
% of outdoor air in total air supply†	Increased	37	37	16	36	32
	Decreased	7	5	5	11	7
Work site						
Carbon dioxide (ppm)‡	Increased	551	567	699	666	621
	Decreased	727	901	788	813	807
Outdoor air (ft^3/min/person)§	Increased	84	72	46	53	64
	Decreased	37	24	29	31	30
Volatile organic compounds ($\mu g/m^3$)¶	Increased	161	821	52	112	287
	Decreased	527	2342	93	207	792
Formaldehyde (ppm)‖	Increased	0.033	0.032	0.007	—	0.024
	Decreased	0.046	0.060	0.010	—	0.039

*The increase and decrease in the ventilation level were intended to deliver 50 ft^3 of outdoor air per minute per person and 20 ft^3 of outdoor air per minute per person, respectively.

†Outdoor-air supply was calculated from measurements of carbon dioxide in outdoor air, return air, and supply air in the ventilation system.

‡Carbon dioxide was measured in the afternoon at work sites.

§Values were converted from overall mean carbon dioxide concentration with the formula given in the Methods section. To convert values to cubic meters per minute per person, multiply by 0.02832.

¶Volatile organic compounds were measured at two to three work sites per floor per week, and the mean concentration was determined.

‖Formaldehyde was measured at one to two work sites per floor per week, and the mean concentration was determined. It was not measured in building 4.

Table 3. Assessment of the Likelihood That Participants Were Aware of the Experimental Variations in Air Supply in Office Buildings, According to Their Responses to Questionnaires.*

TRIAL NO.	VENTILATION LEVEL†	OVERALL ENVIRONMENTAL RATINGS			ENVIRONMENTAL DISSATISFACTION SCORE‡	CHANGE FROM PRECEDING WEEK		
		GOOD	POOR	VARIABLE		BETTER	SAME	WORSE
		%				%		
1	Increased	63	8	29	29.6	12	76	12
	Decreased	61	7	32	30.0	14	72	14
2	Increased	64	9	27	28.2	10	74	16
	Decreased	63	10	27	28.5	10	74	17
3	Increased	62	10	28	28.0	9	74	17
	Decreased	64	8	27	27.3	9	77	14

*Because of rounding, not all values total 100 percent.

†The ventilation level was actually increased to 64 ft^3 of outdoor air per minute per person and decreased to 30 ft^3 of outdoor air per minute per person.

‡These values reflect the participants' ratings of nine environmental items on a 100-point scale in which a score of 0 indicates that all conditions were ideal and a score of 100 that all conditions were terrible.

porting of mucosal or systemic symptoms. No extra-binomial variation was found in the frequency distribution of discordant responses within trials, and symptoms were not associated with the level of ventilation in more susceptible groups, such as female participants or those with a history of atopic illness (i.e., no subgroup could be identified in whom responses were associated with the level of ventilation).

The variation in temperature and air velocity during the six-week study period was minimal within the work sites, but substantial between work sites, even those located on the same floor. These differences in temperature and air velocity between sites were associated with differences between subjects in symptom reporting, as shown in Figure 1.

Discussion

In this study, increasing the supply of outdoor air in mechanically ventilated office buildings was not associated with either improved environmental ratings or a reduction in the number of symptoms reported by the participants. Key features of the design were that three randomized crossover trials of experimental manipulation of outdoor-air supply were conducted, during which the participants, who were unaware of the study intervention, completed standard questionnaires under different environmental conditions. The occurrence of reporting bias[28] should have been reduced by keeping the participants unaware of the ventilation conditions, and the effect of reduced reporting over time, noted in our pilot study,[18] should have been reduced by counterbalancing the experimental sequence in pairs of buildings studied simultaneously. The estimate of the effect within subjects should have reduced the effect on symptoms of differences in personal and work-site characteristics[5-7] and the effect of nonparticipation bias (which was already minimized by the participation rate of 84 percent). The likelihood of potentially misclassifying participants' exposures[22] to outdoor-air supply was reduced by measuring carbon dioxide at more than 250 work sites (i.e., that of every sixth participant).

The failure to detect a significant association between the level of ventilation and the number of symptoms reported may have occurred for several reasons. The participants may not have had the sick building syndrome. On average, however, over 50 percent of the participants reported at least one symptom each week, comparable to the frequency of symptoms reported in other studies of sick buildings.[5-7] In addition, the symptomatic participants had the same personal and work-site characteristics that have been associated with the reporting of symptoms in other studies.[5-7]

The buildings studied may not have been sick. The World Health Organization has defined a sick building as one with an "excess" frequency of symptoms among occupants,[1] but there are no established norms for the frequency of these symptoms among office

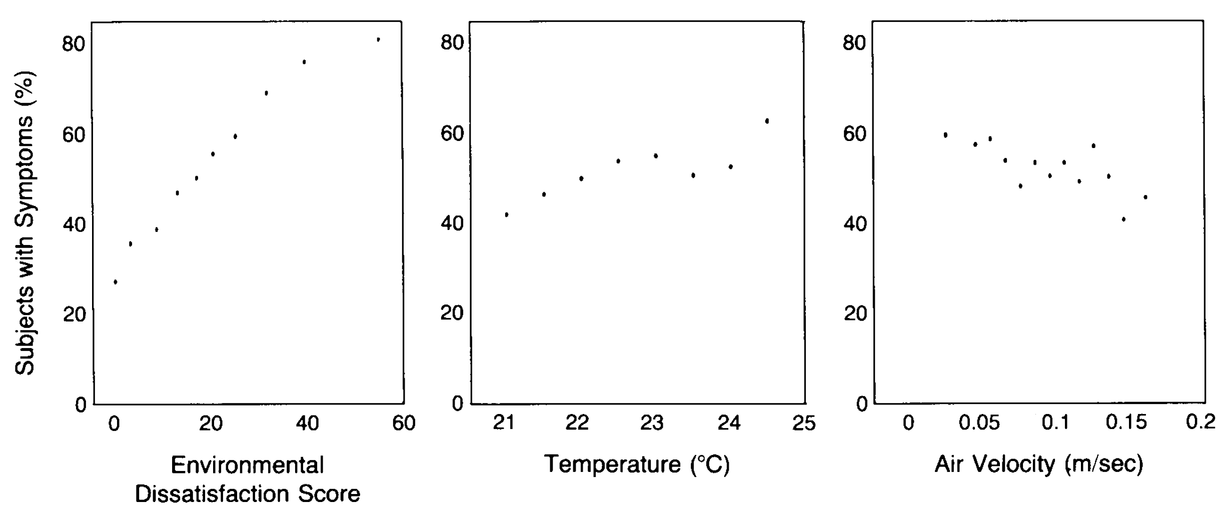

Figure 1. Association of Symptoms with the Environmental Dissatisfaction Score, Work-Site Temperature, and Air Velocity in Four Office Buildings.

The environmental dissatisfaction score was derived by asking the participants to rate nine items on a 100-point scale on which a score of 0 indicated that all conditions were ideal and a score of 100 that all conditions were terrible.

Table 4. Proportion of Participants Reporting Symptoms in Each Trial of Variation of Air Supply in Office Buildings.

Trial No.	Ventilation Level*	Symptoms			
		Any	Mucosal†	Systemic‡	Ocular
		%			
1	Increased	60	44	37	22
	Decreased	56	42	31	21
2	Increased	51	38	28	18
	Decreased	52	39	30	15
3	Increased	47	36	26	15
	Decreased	48	36	26	17
Overall results	Increased	53	39	30	18
	Decreased	52	39	29	18

*The ventilation level was actually increased to 64 ft^3 of outdoor air per minute per person and decreased to 30 ft^3 of outdoor air per minute per person.

†Mucosal symptoms consisted of nasal or pharyngeal irritation and cough.

‡Systemic symptoms consisted of headache, fatigue, and difficulty concentrating.

workers. In studies in Britain,[5] Denmark,[6] and Sweden,[7] the reported frequency of symptoms among workers in "problem" buildings was similar to that among workers in "non-problem" buildings. In the absence of any clear definition, the buildings used in this study were not selected on the basis of a previous identification of the building as sick, but rather because the characteristics of the buildings were similar to those of buildings in which the sick building syndrome has been described.[5-7,21] Some buildings, but not the four we studied, may have increased concentrations of certain contaminants that lead to symptoms among workers. In such buildings, increasing the supply of outdoor air could potentially reduce the frequency of symptoms. We studied buildings constructed 3 to 20 years ago, typical of the majority of existing office buildings in North America. In new buildings, which have increased concentrations of contaminants released from construction materials and new furnishings,[29] increasing the supply of outdoor air may be beneficial.

The supply of outdoor air in the work sites may have been poorly estimated from measurements of carbon dioxide. Current ventilation standards for buildings in North America are expressed in terms of cubic feet per minute per person, calculated from carbon dioxide concentrations,[14] which can be measured rapidly and directly with portable instruments. As a result, the carbon dioxide concentration is the most widely used, commonly reported, and easily understood measure for estimating the level of ventilation in a building, although it is produced only by the human occupants, who contribute just 13 percent of the total indoor load of other contaminants.[15] Estimating the outdoor-air supply with tracer gas decay is more accurate, but is also complex and time consuming[30] and could not have been done at many sites. The practice of basing the key exposure variable — the change in ventilation conditions from week to week — on measurements of carbon dioxide should have been valid, because the buildings' occupants did not change and other sources of contaminants should have remained constant.

The reduction in the supply of outdoor air may have been insufficient to produce symptoms. Although outdoor air composed an average of only 7 percent of the total air supply in the ventilation system (i.e., 93 percent was recirculated air) during the weeks in which the level of ventilation was reduced, it proved impossible in the three older buildings to reduce average work-site levels of outdoor air to less than 30 ft^3 per minute per person, because of the infiltration of outdoor air through the buildings' shells. However, all participants were exposed to substantial changes in the supply of outdoor air, which resulted in significant changes in the concentrations of formaldehyde and volatile organic compounds — contaminants that are produced almost entirely from indoor sources[15,29] and removed by the exchange of indoor air with outdoor air.[11,12,29]

The experimental intervention may have been con-

Table 5. Percentages of Participants Reporting Symptoms during Periods of Increased and of Decreased Ventilation in Office Buildings.*

Type of Symptom and Trial No.	No. of Participants	Symptomatic Only during Decreased Ventilation	Symptomatic Only during Increased Ventilation	Asymptomatic during Both Ventilation Levels	Symptomatic during Both Ventilation Levels	Odds Ratio†
Any symptom						
1	1032	122	169	285	456	1.4
2	1129	178	148	388	415	0.8
3	1101	152	134	422	393	0.9
Average (%)		14	14	33	39	1.0
95% confidence interval‡						0.9–1.1
Mucosal irritation						
1	1032	139	161	439	293	1.2
2	1129	155	128	559	287	0.8
3	1101	136	129	563	273	1.0
Average (%)		13	13	48	26	1.0
95% confidence interval‡						0.8–1.1
Systemic symptoms						
1	1032	150	210	500	172	1.4
2	1129	174	151	644	160	0.9
3	1101	152	146	657	146	1.0
Average (%)		15	15	55	15	1.1
95% confidence interval‡						0.9–1.2

*Values are the number of subjects except where stated otherwise.

†The odds ratios were calculated with the following equation: the average number of respondents symptomatic only during periods of increased ventilation (64 ft^3 of outdoor air per minute per person) divided by the average number of respondents symptomatic only during periods of reduced ventilation (30 ft^3 of outdoor air per minute per person).

‡The 95 percent confidence intervals were based on the total number of discordant responses in all three trials and on the variability in the calculated odds ratios when the sets of trials contributed by individual participants were deleted, according to the method of jackknifing.[27]

Table 6. Effects of Environmental Measures and Ratings on the Reporting of Any Symptom among Participants in the Four Buildings.

Model	Change in Measure	Odds Ratio	95% Confidence Interval
Model 1: environmental measures only			
Air velocity	Decrease of 0.1 m/sec	1.1*	0.9–1.2
Temperature	Increase of 1°C	1.0	1.0–1.1
Humidity	Decrease from 40% to 30%	1.1	1.0–1.1
Carbon dioxide	Decrease from 1000 to 600 ppm	1.0†	0.8–1.0
Model 2: environmental ratings and measures			
Week	Current week vs. following week	1.1	1.0–1.1
Air velocity	Decrease of 0.1 m/sec	1.0	1.0–1.1
Temperature	Increase of 1°C	1.1	0.9–1.2
Humidity	Decrease from ±40% to 30%	1.0	0.9–1.1
Carbon dioxide	Decrease from 1000 to 600 ppm	1.0‡	0.8–1.2
Overall environmental rating	Poor vs. good	1.8	1.4–2.2
	Variable vs. good	1.6	1.4–1.8
Change in rating	Worse vs. better	1.1	1.0–1.4
Environmental dissatisfaction score§	+16 (1 SD)	1.3	1.2–1.4

*For example, the odds of reporting any symptom were 5 percent greater if air velocity was decreased by 0.1 m per second.

†For example, the odds of reporting any symptom were 4 percent lower when the carbon dioxide concentration decreased from 1000 to 600 ppm.

‡For example, the odds of reporting any symptom were 1 percent lower when the carbon dioxide concentration decreased from 1000 to 600 ppm.

§The participants were asked to rate nine environmental items on a 100-point scale in which a score of 0 indicates that all conditions were ideal and a score of 100 that all conditions were terrible. The odds ratio was calculated for the mean score as compared with the mean score −1 SD.

founded by the effects of temperature, relative humidity, and air velocity, all of which have important effects on workers' perceptions of indoor-air quality[17,31] and on symptoms.[13,17,31] We measured the temperature, air velocity, and relative humidity at the work site of every sixth worker twice daily each week and used multivariable analysis to adjust for any potential effect of these variables. These measurements also varied independently of the experimental changes in ventilation conditions. Finally, temperature and air velocity should not have contributed to differences in symptoms within subjects, because they varied little at the same work sites throughout the study.

In this study, temperature, humidity, and air velocity varied significantly between work sites and contributed to differences between subjects in the number of symptoms reported. This finding and the findings of others[22] suggest that the microenvironmental conditions of individual employees' work sites may be important determinants of exposure.

In conclusion, the supply of outdoor air was experimentally increased, from an average of 7 percent of the total air supply in the ventilation system and 30 ft^3 of outdoor air per minute per person at work sites to an average of 32 percent and 64 ft^3 of outdoor air per minute per person, respectively, and these increases were associated with significant changes in the concentrations of contaminants at different work sites. These changes were not associated with the participants' ratings of the environment or with the number of symptoms reported that were considered typical of the sick building syndrome. We believe that this research method can be used in further studies to establish a scientific basis for ventilation and contaminant standards to ensure the health and safety of the majority of North American workers.

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