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The Effect of Varying Levels of Outdoor Ventilation on Symptoms of Sick Building Syndrome

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ABSTRACT

Despite numerous and extensive investigations, the cause or causes of sick building syndrome (SBS) remain unknown. This problem has been attributed to inadequate supply of outdoor air to the indoor office space. Although there is little or no scientific evidence to support this hypothesis, there is growing support in Europe and North America to increase the minimum standard for supply of outdoor air to nonindustrial buildings to 50 cubic feet per minute per person (cfmpp).

The objective of this study was to test the hypothesis that the occurrence of symptoms considered typical for SBS would be reduced when outdoor air supply was increased from 20 cfmpp to 50 cfmpp.

The study was designed as a randomized, experimental test, in which building ventilation level was set and maintained for one-week periods at 20 or 50 cfmpp. Over a six-week period, each level was repeated three times in random order. The ventilation level was known only to the study engineers and building operators but not to the building occupants nor other members of the study team, thus reducing the possibility of bias in reporting. Workers were asked to complete questionnaires each week, which provided repeated measures of symptoms in the same individuals under different environmental conditions.

Two buildings were studied in the spring of 1990, and 740 of 840 (88.1%) eligible workers participated. Weekly questionnaires were completed by 79% of the participants on average.

Throughout the study, temperature and humidity in these buildings were well controlled. However, manipulation of the ventilation level was successful in achieving significant changes in concentrations of CO_2 measured in the HVAC system supply air and also of contaminants produced by indoor sources. Despite these changes in environmental conditions, the building occupants remained blinded, i.e., they could not identify changes in ventilation level.

The environmental rating was generally good, although symptoms were frequently reported. The environmental rating improved and symptom frequency diminished steadily over the course of the study. Using a variety of analytic approaches, no association was found between reporting of symptoms and ventilation level. Increasing the amount of outdoor air from 20 to 50 cfmpp did not result in reduction of symptoms considered typical of SBS among office workers. We conclude that this study supports the continued use of 20 cfmpp as the minimum standard for the supply of outdoor air to indoor nonindustrial space.

INTRODUCTION

Outdoor air pollution became a topic of great concern and public interest in the 1960s and the 1970s. However, health problems related to the indoor environment have become of interest only more recently. The first reports of health problems attributable to indoor air pollution appeared in the mid 1970s (Stahl 1974). This was coincident with the construction of buildings with sealed windows in which all indoor air was supplied by mechanical means, and at the same time, because of the energy crisis, the amount of outdoor air was reduced to as little as 10% of the total air supplied to the indoor environment. The prevalence of symptoms was also high among workers in buildings with sealed windows in which all indoor ventilation was supplied by mechanical means (Finnegan et al. 1984; Robertson et al. 1985; Skov and Valbjørn 1987). Based on this evidence, it was hypothesized that these symptoms of workers were due to an inadequate supply of outdoor air in their office environment.

This problem, which has been termed "sick building syndrome," is a constellation of symptoms of headaches, fatigue, difficulty concentrating, and irritation of the mucus membranes of the eyes, nose, and throat. To date, no causative agent or explanation for this problem has been found. Investigations of this problem to date have been flawed by a number of methodological problems, including lack of expertise in epidemiology, industrial hygiene, or HVAC engineering; lack of a standardized approach; and failure to adequately control sources of bias. Differences in the prevalence of symptoms between different populations of workers found in cross-sectional studies may be due to differences in the populations studied rather than differences in exposure.

It has been proposed in Europe, as well as in Canada (Rahjans 1985), that the current ASHRAE standard for mini-

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mum supply of outdoor air to nonindustrial space be increased from the current level of 20 cubic feet per minute per person (cfmpp) to 50 cfmpp, although there is little or no scientific evidence to support this. Adoption of 50 cfmpp as the minimum standard would result in significantly increased energy requirements for heating and cooling of this outdoor air (Tamblyn 1988). Of greater concern is that, stated bluntly, increasing the amount of outdoor air may not improve workers' health or well-being.

Approximately two years ago, the Indoor Environment Research Group was formed to investigate the problem of SBS. A pilot study was conducted in 1989 to resolve a number of methodological issues (Menzies 1990). The current study was designed to test the hypothesis that increasing the amount of outdoor air supplied to the indoor environment from 20 cfmpp to 50 cfmpp would result in reduction of symptoms reported and improvement in well-being among the workers in that environment.

RESEARCH OBJECTIVES

The primary objective was to determine whether increasing the amount of outdoor air supplied to the indoor environment of an office building from 20 to 50 cfmpp would be associated with a reduction in symptoms experienced by workers in that building.

Additional objectives were to determine the relationship between personal, work, and office characteristics and the reporting of symptoms.

STUDY DESIGN

This study was designed as a randomized, experimental, double-blind, cross-over test. The amount of outdoor air was manipulated experimentally to levels of 20 cfmpp or 50 cfmpp. The six-week study was divided into three consecutive two-week tests; in each test, the ventilation level was set for one week at 20 cfmpp and the other week at 50 cfmpp. The order of ventilation levels in each test was selected randomly and known only to the study engineers and building operators. The building occupants, as well as other members of the research group, were unaware of the ventilation level each week, making the study double-blind. The ventilation level was set on Friday afternoon, and the following Wednesday or Thursday afternoon participants completed short questionnaires regarding symptoms suffered *that day*. Participants completed the same questionnaire each week, thereby providing repeated measures of symptoms in the same individual under contrasting environmental conditions.

METHODS

Two buildings were selected for the study, both of which were modern office buildings in which all windows were sealed and ventilation was supplied to the interior office space by mechanical means. These buildings were also selected because they did *not* have a history of excess problems with indoor air quality and were not felt to be problem or "sick" buildings."

In these buildings, the corporate tenants were approached for their consent to participate in the study. Once that was obtained, lists of all potential participants on the selected floors were obtained and updated by an on-site census conducted by the research team. The exact work-site location of all workers was marked on floor plans, after which work sites were identified at which environmental measures were made.

Workers were ineligible if they had no fixed work site, were present in their office less than two full days per week, or were absent for four or more weeks during the study because of vacation, training, or maternity leave. All workers signed informed consent.[1]

A baseline questionnaire was distributed prior to the start of the study regarding personal, smoking, medical, and work history as well as symptoms at work and the usual office environmental conditions. During the study period, participants completed questionnaires each week regarding symptoms and the office environment.

In each study week, temperature, humidity, air velocity, and CO_2 were measured at 8 to 12 work sites on each floor, twice in one day. In addition to CO_2, temperature and humidity were measured in the HVAC system and outdoors, twice in one day of each week. Fungal spores were measured once at approximately 20 sites per floor in each building, and, at two sites per floor on all floors twice daily in three of the study weeks, samples were collected and cultured for quantification and identification of fungal species. Aero-allergens of the house dust mite were collected for 24-hour periods at one site per floor in all weeks. Dust, formaldehyde, nitrogen oxides, total volatile organic compounds (VOCs), noise, and light were measured at a sampling of work sites.

Using floor plans and the building engineers' schema of the ventilation systems, the environmental measures taken at work sites were matched to the workers who were nearest to that site and served by the same ventilation system.

McNemar's test was used to test whether increasing the ventilation level to 50 cfmpp was associated with a reduced number of symptoms in each two-week trial. Also, after combining the subjects' responses and the nearest work site environmental measures for all six weeks, conditional logistic regression was used to estimate the effect on symptom occurrence of local work-site ventilation level (as estimated by CO_2 concentration), temperature, and humidity.

RESULTS

Table 1 shows the overall response rates in the two buildings. Of a total of 840 potential participants, 740 (88%) participated.

TABLE 1
Participation and Questionnaire Completion Rates

	Building A	Building B	Total
Eligible	338	502	840
Refused/drop out (%)	19.8	6.6	11.9
Participated (%)	80.2	93.4	88.1
Questionnaire completion among participants (%)			
Baseline Qst. (%)	91.4	94.2	92.9
Weekly Qst. (%)			
Week			
1	85.6	67.7	74.6
2	79.4	81.2	80.9
3	79.8	79.3	79.9
4	80.5	82.8	82.2
5	83.8	73.1	77.1
6	75.8	76.8	76.6
Average for weeks	80.8	76.8	78.5

[1]This study had been approved by the Ethics Committee of the Department of Epidemiology of McGill University.

Of these, 686 (93%) completed the baseline questionnaires. Nonparticipants were not significantly different from participants, and the rate of participation was high, so that the nonparticipants should not have caused significant bias. However, nonparticipation was higher among those who were older or were males, and because these personal characteristics were associated with reduced symptom reporting, the prevalence of symptoms in the buildings studied may have been slightly overestimated. On average, weekly questionnaires were completed by 81% of the participants in building A and 77% in building B.

In building A, 43% of the participants completed questionnaires in all six weeks, as did 35% of the participants in building B. The participants who completed all six questionnaires were more likely to be younger, female, and to work in open areas. These personal characteristics are associated with increased symptom reporting, meaning that this subgroup with a higher weekly response rate may have resulted in an overestimate of the weekly prevalence of symptoms. However, this group is of particular interest because of greater exposure, having been present in this indoor environment throughout the study period.

A high proportion of workers in both buildings reported having had symptoms considered typical of SBS at work, as shown in Table 2. It can be seen that workers in building A had more symptoms than those in building B. However, when symptom prevalences were adjusted, using multiple regression analysis for differences in personal characteristics of the two populations, no independent effect of building could be found. Symptom prevalence in the two buildings can also be compared with results from other, cross-sectional studies in Table 2. Of interest is that, despite differences in the populations studied and the questionnaires used, symptom prevalence is strikingly similar. Also, symptom prevalence was not different in the Ottawa building, which was considered to have problems with indoor air quality, than in the three buildings our group studied, which were not considered to have such problems.

It was anticipated that peak CO_2 would reach 1,000 parts per million (ppm) when the amount of outdoor air was reduced to 20 cfmpp, and the peak CO_2 was not expected to exceed 500 ppm when the amount of outdoor air was increased to 50 cfmpp (Tamblyn 1988). The actual peak CO_2 levels measured in the HVAC system supply air in the mid-afternoon, for each building, are shown in Table 3, along with the intended outdoor air ventilation level. Substantial changes in peak CO_2 were achieved, although in building A the peak CO_2 levels did not exceed 800 ppm. This was believed to be due to infiltration of outdoor air through the building shell, because of the older age of building A. Mean temperature did not vary substantially over the study period, although humidity was more variable.

Coincident with these changes in CO_2 concentrations, the mean concentrations of total VOCs were significantly different and inversely proportional to the amount of outdoor air, as would be expected with contaminants of indoor sources. Mean concentrations of VOCs were substantially higher in building B, which had been constructed only three years ago, than in building A, which was built more than 20 years ago. These changes in concentrations confirmed that substantial changes in the amount of outdoor air supplied to the indoor office environment were achieved.

Despite these large changes in ventilation conditions, the building occupants were unable to detect the changes, as seen in Table 4. Each week, between one-quarter and one-third of the participants felt there was a change in the environment and, of those who provided specific comments, the majority felt the environment was worse. However, there was no association between the amount of outdoor air and the responses to these questions. When conditions remained the same between weeks 4 and 5, the proportion who felt there was a change, for better or worse, was no different from all other weeks when environmental conditions actually did change. Based on these results and the environmental rating scores (see below), the building occupants appeared to have remained blind to the ventilation conditions.

A high proportion of participants reported symptoms each week, in agreement with their responses on the baseline questionnaires. Nasal problems and other symptoms suggestive of mucosal irritation were reported most commonly. As can be seen in Table 5, symptoms were more commonly reported by workers in building A, but in both buildings, symptoms declined steadily over the six-week study period. Of interest is that the environmental rating score also declined, which means that workers rated the environment closer to ideal as the study continued. This temporal phenomenon was unexplained but was also seen in the pilot study (Menzies 1990). There were no changes in the study population over this time nor changes in the indoor environment as was seen in Table 3. It is possible that this represents response fatigue or an improved sense of well-being coincident with improvement in outdoor conditions, as this was the spring in Montreal!

TABLE 2
Frequency of Symptoms Reported on Baseline Questionnaire in Comparison with Other Studies

Symptoms	Percent Distribution				
	Building A	Building B	Montreal Pilot (1)	Britain (2)	Ottawa (3)
Headache	74.3	54.4	70.0	46.4	36.0
Throat problem	54.0	41.8	—	46.0	40.0
Nose problems	63.6	49.5	59.0	61.5	22.0
Eye problems	50.0	44.1	48.0	38.5	35.0
Poor concentration	56.7	44.4	57.0	63.5	—
Fatigue	68.2	51.9	63.0	57.0	57.0
Cough	40.9	23.8	—	18.0	19.0

Notes:
1. Pilot study in office building in Montreal in 1989 (Menzies 1990)
2. Study of 4,373 office workers in 46 buildings (Burge et al. 1987)
3. Study of a "sick" building in Ottawa (MacDonald et al. 1984)

TABLE 3
Weekly Environmental Parameters in Both Buildings

	Building A				Building B			
Week	Temp (C)	Humidity (RH %)	Ventil. CFMPP	CO_2 ppm	Temp. (°C)	Humidity (RH %)	Ventil. CFMPP	CO_2 ppm
1	22.2	49	20	720	22.7	53	50	505
2	21.8	39	50	689	22.6	43	20	940
3	21.5	37	20	770	22.6	33	50	610
4	21.9	26	50	480	22.5	33	20	910
5	22.3	39	50	490	22.9	44	20	990
6	23.0	43	20	650	22.9	45	50	475

Notes:
1. Temperature and humidity are averages for all work-site measurements.
2. Ventilation level is that planned in study design.
3. CO_2 is the average of peak CO_2 measurements, made in the afternoon in supply air of HVAC system.

TABLE 4
Blinding to the Experimental Intervention

	Building A						Building B					
	Wk1	Wk2	Wk3	Wk4	Wk5	Wk6	Wk1	Wk2	Wk3	Wk4	Wk5	Wk6
Intended ventilation (cfmpp)	20	50	20	50	50	20	50	20	50	20	20	50
Peak CO_2 in supply air (ppm)	720	689	770	480	490	650	505	940	610	910	990	475
Number of Respondents/wk	240	222	223	224	233	211	327	392	384	401	352	370
Respondents noting change (%)	41	37	38	31	37	25	29	33	30	29	25	23
"Changed for the better" (%)	15	10	4	5	6	8	10	11	7	5	5	5
"Changed for the worse" (%)	26	27	34	26	31	17	13	15	14	18	15	12
"Overall conditions good" (%)	58	62	52	67	64	72	70	70	75	78	74	73
"Overall conditions bad" (%)	5	9	16	8	10	5	6	7	6	5	6	6

TABLE 5
Mean Environmental Ratings and Percent with Symptoms Each Week

	Building A			Building B		
Week	Ventilation Level (cfmpp)	Environmental Rating (Mean)	% with Symptoms (%)	Ventilation Level (cfmpp)	Environmental Rating (Mean)	% with Symptoms (%)
1	20	9	58	50	8	53
2	50	8	54	20	7	43
3	20	8	48	50	6	39
4	50	7	50	20	6	40
5	50	7	47	20	6	40
6	20	5	43	50	6	30

Notes:
1. Ventilation level is that planned in study design
2. Environmental rating was scored from 0 = "all conditions ideal" to 40 = "all conditions terrible"

To estimate the effect of increasing outdoor air supplied to the indoor environment, symptom prevalence under the two ventilation conditions was first compared. The results of this analysis are shown in Table 6. Symptoms have been grouped as (1) any of the seven symptoms elicited; (2) irritation of the mucous membranes of the eyes, nose, or throat and/or cough; (3) systemic, meaning headache and/or poor concentration and/or fatigue; and (4) headache alone. There was no difference in symptom occurrence under different ventilation conditions in each of the three trials.

As shown in Table 7, 12% to 14.9% of the workers had symptoms only at 20 cfmpp of outdoor air. On the other hand, 11% to 14.5% were symptomatic only when the amount of outdoor air was increased to 50 cfmpp. Twenty-seven to forty-three percent of workers were asymptomatic under both conditions, while 28% to 47% were symptomatic under both conditions. The odds of reporting symptoms when exposed to 20 cfmpp compared to 50 cfmpp of outdoor air were calculated for each symptom group in each of the three tests. The odds ratios range from 0.7 (meaning more symptomatic at 50 cfmpp) to 1.6,

TABLE 6
Percent of Workers Reporting Symptoms in Each Experimental Test

Test	Ventilation Level (cfmpp)	Number Reporting	Percent Reporting Symptoms			
			Any	Nasal/Throat	Fatigue	Headache
1	20	622	44	36	19	10
	50	543	54	43	25	11
2	20	615	43	35	17	9
	50	599	43	35	17	9
3	20	560	41	35	17	8
	50	602	36	30	15	9

TABLE 7
The Odds of Reporting Symptoms When Ventilation Level Decreased from 50 CFMPP to 20 CFMPP

Test	N	Symptomatic at 20 cfmpp only (%)	Symptomatic at 50 ccfmpp only (%)	Asymptomatic at both vent levels (%)	Symptomatic at both vent levels (%)	Odds Ratio
(i) Any Symptom						
1	427	12.0	14.5	34.7	38.8	.8
2	530	14.7	13.6	43.4	28.3	1.1
3	489	14.9	10.8	27.1	47.3	1.4
(ii) Mucosal Irritation						
1	427	14.8	17.3	36.3	31.6	.9
2	530	12.8	12.3	52.1	22.8	1.1
3	489	13.9	8.6	55.2	22.3	1.6
(iii) Systemic						
1	482	11.8	15.1	63.4	9.8	.8
2	527	9.9	9.1	73.6	7.4	1.1
3	489	12.3	10.2	71.6	5.9	1.2
(iv) Headache						
1	480	9.4	8.8	79.4	2.5	1.1
2	527	5.9	6.5	85.2	2.5	.9
3	488	5.7	7.8	84.4	1.0	.7

Notes:
1. Odds Ratio = Respondents symptomatic at 20 cfmpp but not at 50 cfmpp/ Respondents symptomatic at 50 cfmpp, but not at 20 cfmpp.
2. A test consisted of two consecutive weeks in which both ventilation levels (20 cfmpp and 50 cfmpp) were applied.

although in all instances the 95% confidence intervals included 1.0, meaning there was no significant association between ventilation level and symptoms.

In a third analysis, all weekly responses were combined with weekly work-site measurements for each participant to provide a more precise estimate of individual exposure to temperature, humidity, and ventilation as estimated by CO_2 concentration. To take advantage of the repeated-measures design, conditional logistic regression was used on symptoms to provide an estimate of the independent effects of environmental conditions and personal characteristics. Again, no association was found between symptoms and amount of outdoor air, as estimated by work-site CO_2 measurements.

Personal characteristics (such as gender, psychological effect score, atopic history), as well as work characteristics (such as work in an open area or use of a computer for more than five hours per day), were significantly associated with symptoms. The most important predictor of symptoms was the workers' perception of the environment as measured by the weekly environmental rating score.

The concentrations of certain contaminants, such as VOCs or formaldehyde, despite significant changes from week to week, were not associated with any, or groups of, symptoms. The association of symptoms with fungal spore levels has been reported elsewhere (Tamblyn 1991).

DISCUSSION

This study is notable because it is the first of its kind to manipulate the amount of outdoor air experimentally and in a double-blind, randomized fashion in entire office buildings. A large population was studied, with a high participation rate. The indoor environment was measured in detail, providing an accurate estimate of the actual conditions experienced by the workers at their work sites. In particular, temperature and humidity, which could have confounded the estimate of effect of ventilation level, were demonstrated to have been well controlled throughout the study. The estimate of effect of ventilation is strengthened because of the within-subject analysis made possible by the repeated-measures design. This eliminates the potential biases introduced by comparisons between different populations. Of note and of particular importance is that the building occupants remained blind to the amount of outdoor air, thereby eliminating the possibility of bias in the reporting of symptoms.

In this study, only acute symptoms occurring on the day of questionnaire administration were measured. The ventilation conditions were changed every week, so that any long-term effect would have been missed. However, SBS is currently defined as an acute problem occurring at work and resolving after leaving work. Also, if the study duration had been longer in order to measure more chronic changes, the confounding effects of seasonal changes would have been greater, and more participants would have dropped out due to vacation, leave, etc.

No objective measures were taken in this study. To date, no investigators have been able to demonstrate any objective health effect of SBS (McDonald et al. 1984; Robertson et al. 1985; Skov and Valbjørn 1987). Temperatures above 30 °C have been shown to adversely affect performance (Macworth 1946), but such extreme temperatures are unlikely in office buildings. Relative humidity below 25% has been associated with greater complaints of eye irritation (Reineken et al. 1990), and some objective signs of eye irritation have been reported when low humidity is combined with exposure to environmental tobacco smoke (Kay et al. 1990). Army recruits housed in barracks with mechanical ventilation had higher incidence of upper respiratory tract infections than those housed in barracks with natural ventilation (Brundage et al. 1988). However, this population is susceptible to a number of epidemics of infectious diseases due to the unusual crowding, so these findings cannot be generalized to workers in office buildings.

The study demonstrates quite conclusively that increasing the amount of outdoor air supplied to the indoor office environment above 20 cfmpp is not associated with a reduction of symptoms considered typical of SBS.

The factors associated with the high prevalence of symptoms appear to be characteristics of the person, the work, and the work location rather than the actual environment. In particular, the workers' perception of their environment appears to be one of the most important determinants of their sense of well-being. This was found in a number of other studies (Woods 1987; Menzies 1990; Broder et al. 1990), although the determinants of the workers' perceptions of their environment remain unknown.

The importance of the workers' symptoms should not be underestimated, because there is a strong relationship between workers' complaints of ill health and absence due to sickness (Preller et al. 1990). This means that a worker's perception that the work environment is bad or unhealthy has economic costs, because it may lead to diminished productivity (Zyla-Wisensale and Stolwijk 1990). Further work is needed to better understand this phenomenon.

CONCLUSIONS

1. Symptoms suggestive of SBS are common even in non-problem buildings.
2. These symptoms are not reduced by increasing the amount of outdoor air supplied to the indoor office environment.
3. The major determinants of symptom reporting were personal, work, and office characteristics.
4. The single most important determinant of symptom reporting among office workers in this study was the worker's perception of the office environment.
5. This study does not support the adoption of 50 cfmpp of outdoor air as the new minimum standard for indoor ventilation of nonindustrial buildings.

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