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SICK BUILDING SYNDROME: THE EFFECT OF CHANGES IN VENTILATION RATES ON SYMPTOM PREVALENCE: THE EVALUATION OF A DOUBLE BLIND EXPERIMENTAL APPROACH

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Inadequate ventilation has been identified as the most likely cause of sick building syndrome. In order to determine whether recommended changes in building ventilation would result in a reduction in symptom prevalence, a novel method of evaluating this relationship was developed. A double blind experimental trial of three ventilation ratios; 10,20 and 50 CFMPP was piloted in a 30 storey office building in Montreal. Changes in the symptoms reported by the same individual under the 3 ventilation conditions was used to estimate ventilation effects. Since this approach had never been tried, the pilot study was used to answer questions about the feasibility of this approach along with methodological, environmental and worker characteristics which might influence symptom reporting. The three ventilation conditions were 'set-up' by the study engineers in the pilot building by manipulation of the outdoor dampers and use of the building's heating and cooling apparatus for maintenance of constant temperatures. Each condition was evaluated twice, conditions being changed on a weekly basis. Temperature, humidity, and ventilation were measured in 10 work locations on each of the 4 study floors during each of the 6 study weeks. The response to changes in ventilation conditions was evaluated using 247 employees of one of the building's corporate tenants. One-third of participants completed open-ended questionnaires, while the remainder were given questionnaires with specific symptom probes. Blinding was assessed by weekly ratings of perceived environmental change. Participants were unable to detect the changes in ventilation rate. The prevalence of symptoms was 22% higher when specific probes were used to collect information. Symptom prevalence declined steadily throughout the six weeks; with 55% of workers reporting symptoms in the first week compared to 22% in the last week. 94% of workers indicated that they had experienced at least one of the cardinal symptoms of sick building syndrome on 1-3 occasions a month; the most common being headache (70%). On the weekly questionnaires, 18% never had symptoms and 6% had at least one symptom each week. Nasal problems (12%-31%) and headache (7%-19%) were the two most frequent symptoms reported on the weekly questionnaires. Personal characteristics associated with symptom reporting included gender, allergy history, satisfaction with the work environment, and emotional well-being. Temperature and humidity were the two aspects of the environment which were associated with symptoms, although the estimation of the latter is likely positively biased by time trends in symptom reporting. There was no relationship between the worker's rating of air quality, temperature and humidity and the actual values observed in their work location.

Introduction

"Sick Building Syndrome" (SBS) is the term commonly applied to a constellation of symptoms arising among workers in high rise office buildings in which all indoor ventilation is supplied by mechanical means. This syndrome was first described in the early 1970's coincident with the development of new energy efficient building designs. This problem is the subject of increasing concern on the part of architects, owners, health professionals, regulatory agencies, and the workers themselves. In Canada, in 1988, there were over 1800 separate investigations of problems of indoor environment by consultants from government, university and the private sector (1). In approximately 20% of these cases, a specific causative agent or agents were identified. However, in the majority of instances, no specific etiology could be identified and the problem was labelled as SBS. Inadequate ventilation has been identified as the probable cause of SBS (ventilation, as used throughout this paper, is defined as the proportion of fresh air). This conclusion is based primarily on the observation that this problem emerged at the same time as newer energy efficient building designs. However, scientific evidence for this link is lacking because of the following methodological problems: 1) there is no uniform definition of SBS so different investigators may focus on different symptoms 2) there is no standardized questionnaire so that differences in prevalence in different studies may be a function of questionnaire rather than true population differences 3) comparisons of the prevalence of symptoms among workers in buildings with different forms of ventilation are likely biased by differences in the worker populations 4) comparisons of change in symptoms before and after a change in ventilation conditions may be biased by the Hawthorne effect or time trends in reporting 5) inadequate measurement of the office environment, poor or no control over the confounding effects of temperature and humidity, and inadequate characterization of the operation of the building ventilation systems. To overcome the limitations in previous studies, a research team representing expertise in epidemiology, industrial hygiene and engineering was formed to pilot test a novel double-blind experimental approach to the evaluation of ventilation conditions. The strengths of this approach are that ventilation conditions could be experimentally introduced by the study engineers thereby simulating the conditions which may prevail in the winter and summer months, symptom occurrence could be studied in a situation where both workers and investigators are blind to ventilation condition, and that the effect of improved ventilation could be determined by using the workers as their own control.

Research Objectives

There were four major objectives for the pilot study. The first was to determine the feasibility of the experimental intervention, whether the ventilation level could be successfully instituted while maintaining temperature and humidity nearly constant. The second was to determine if different ventilation levels could be introduced without the awareness of the building occupants to see if blinding could be maintained. The third was to determine the effect of questionnaire type and repetition in administration on symptom reporting. The final objective was to evaluate the relationship between personal and work characteristics, environmental parameters and symptom reporting.

Methods

Population Selection: A 30 story, 20 year old, office building in Montreal was selected. This building had a single air intake on the 11th floor and was equipped with a variable air volume ventilation system with economizer. This building had no past history of air quality problems or problems with sick building syndrome. A single corporate tenant occupying four floors of the building agreed to participate. With the co-operation of this corporation's personnel department, 320 full-time employees were identified. Fifteen of the employees were excluded because of transfer or maternity leave. Letters of invitation were sent to the remaining 305 employees. Those who agreed to participate were asked to complete baseline and weekly questionnaires.

Experimental Intervention: Three levels of building ventilation were selected: 10 cubic feet per minute per person (CFMPP), the current Montreal standard; 20 CFMPP, the recommended ASHRAE standard; and 50 CFMPP.,the Ontario Department of Labour recommendation. Each level was applied for an entire week in random sequence in a three week block, then a second random sequence was repeated in a second 3 week block. The level for the following week was instituted on late Friday afternoon by adjusting the outside air dampers. Once they were set, they were locked in place for the duration of the study week. The sequence was selected by the study engineer and was known only to him and the building operators.

Data Collection:

a) Environmental Parameters: On Monday and Tuesday of each week, temperature, humidity and ventilation conditions were measured at 5 sites on each floor. On each Wednesday, temperature, humidity, and CO_2 were measured 4 times during the day at 10 workstations on each floor. SF_6 gas decay was used to estimate CFMPP at each of the 10 work locations on each floor for each study week. Total dust, radon,NO, NO_2, VOC's, fungal spores and formaldehyde were measured at 4-5 sites per floor on each week. The results of these measurements are reported elsewhere (6).

b) Worker Demographics, Symptom Reporting and Environmental Rating: Participating workers completed a baseline questionnaire which provided information on the usual conditions of their office environment, experience with cardinal symptoms of SBS, personal and work characteristics, relevant medical and smoking history and the Bradburn index of emotional well-being. Cardinal symptoms included headache, nasal problems, eye problems, difficulty concentrating, fatigue and nausea. On Wednesday of each study week, workers were asked to complete a questionnaire which asked them to rate the quality of their office environment and the symptoms they had experienced on that day. A random third of workers were given an open-ended questionnaire and the remainder were given questionnaires which contained specific probes for cardinal symptoms and the office environment. On both forms of the weekly questionnaire, blinding was evaluated with an open-ended question which asked whether there had been any change noted in the office environment and if so of what nature.

Results

Study Population: 254 of the 305 employees approached agreed to participate. Seven employees dropped out during the study with the result being that data was collected on 79% of eligible participants. The response rate for weekly questionnaires was 85%-90%. Of the participants, 50.4% were female, 48.4% were francophone and the mean age was 38 years. Smoking was reported by 28%, while 27% were ex-smokers and 45% reported that they had never smoked. A history of atopic illness (hayfever, asthma, eczema, allergies) was reported by 25% while other significant illnesses were reported by 9.2%. Clerical jobs were held by 32%, professional jobs by 11%, junior management positions by 31% and senior management positions by 27% of workers. The workers response to the Bradburn Index of emotional well-being was similar to individuals of the same age in the Canada Health Survey and a local survey of Montreal residents (2). On the positive affect scale, 13% were strongly positive and 4% were not positive. On the negative affect scale, 7% were negative and 48% were not negative in their emotional outlook. Two-thirds of the workers had a private office space while the remainder worked in open areas. Approximately half of those in private office space shared this space with one other person. Half of the workers were within 10 feet of an exterior window and one-half were exposed to tobacco smoke in their usual work location. A surprising number, 66%, indicated that they did not enjoy working in their current work location. Most (70%) indicated that one of the reasons was not enough fresh air.

Experimental Intervention: The desired ventilation levels were not achieved precisely as planned (see Table 1) however there was still a significant range of ventilation levels observed (15-63 CFMPP). The failure to achieve the lowest levels of ventilation was due to leakage of outdoor air through the dampers when they were closed. This problem was compounded by the failure of the environmental measurement team, who were blind ventilation level, to provide feedback to the study engineers about the failure to achieve the desired levels. Control of temperature and humidity was not affected by the experimental intervention although humidity rose steadily during the 6 week study period due to external weather conditions. Workers remained blind to the changes in ventilation. Although, 22%-32% indicated that they had noted a change in the environment on one or more of the 6 study weeks, about half each week thought conditions were better and the remainder thought they were worse. The most frequent change noted in the environment was temperature which remained relatively constant throughout the study period.

Symptom Prevalence: On the baseline questionnaire, 94% indicated that they had experienced at least one of the cardinal symptoms of sick building syndrome at work, the average frequency being 1-3 times a month. Headache was the most commonly reported symptom (70% of respondents) followed by fatigue (63%), nasal problems (59%), poor concentration (57%), and eye problems (48%). About half of those reporting symptoms indicated that they only occurred at work, the majority attributing the cause of their symptoms to the quality of the office environment. Headache, poor concentration and fatigue had the greatest reported impact on work with one-third of those having these symptoms indicating that they could not work as well as usual and 1% finding that they could not work at all when the symptom was present.

Table 1 Symptom Prevalence by Study Week, Questionnaire Type, and Average Level of Temperature, Humidity and CFMPP

Week	Planned CFMPP	Observed CFMPP	Temperature	Humidity	Symptom Prevalence Probes	Open-ended
1	50	45.0	23.7 C.	36.2	65%	34%
2	20	31.3	23.4 C.	33.2	52%	29%
3	10	22.9	23.0 C.	37.1	50%	14%
4	50	30.8	22.9 C.	44.6	39%	25%
5	20	23.2	22.5 C.	48.8	36%	17%
6	10	20.6	22.9 C.	54.6	29%	18%

Notes:
1. The CFMPP reported was estimated using SF6 tracer gas decay
2. Symptom Prevalence refers to the percent of respondents reporting any one of the cardinal symptoms

On the weekly questionnaires, 18% never reported a symptom and 6% reported at least one symptom on each study week. Headache and nasal problems were the two symptoms most frequently reported by 7%-19% and 4%-18% respectively during the 6 study weeks. As depicted in Table 1, the prevalence of symptoms was on average 22% higher with the specific probe versus the open-ended questionnaire format. In addition, for both forms of the weekly questionnaire, the prevalence of symptoms steadily diminished with each study week.

Environmental Rating: In the baseline questionnaire, office conditions rated as being usually terrible included humidity (20% of respondents), air quality (16%), temperature (12%) and dust (12%). In the weekly questionnaire, there was no relationship between the respondent's weekly rating of these three aspects of their environment and actual values observed in their work location on the day of the rating.

The Association of Personal, Office and Environmental Characteristics with Symptom Occurrence: We investigated the relationship between factors which were associated with the occurrence of 1) any symptom 2) total number of symptoms reported and 3) the combination of number of symptoms reported and rated work impact (symptom burden). We also examined the factors which influenced environmental rating. Factors which were significantly associated with these outcomes in bivariate analysis were entered into a logistic regression model for dichotomous outcomes and a repeated measures regression model for continuous outcomes (outcomes 2&3). Conditional logistic regression was used to examine the association between environmental parameters and symptom occurrence. To examine the relative contribution of environmental, personal and work characteristics, logistic regression was used. Estimated coefficients for environmental parameters were similar for both conditional and unconditional logistic regression. The results of this latter analysis are displayed in Table 2.

Table 2 Logistic Regression Estimates of the Relative Odds of Symptom Occurrence in Relation to Humidity, CFMPP, PPM CO2, Temperature and Personal and Work Characteristics

Independent Variable	Relative Odds of Symptom Occurrence			
	Any	Headache	Systemic	Mucosal
Personal Characteristics				
Age (relative to people a year younger)	.99	1.0	.98	.99
Gender (relative to males)	1.38*	1.34*	1.24*	1.32*
Atopic History (relative to no atopic history)	1.09	1.45*	1.12	1.00
Positive Affect Score (relative to strongly positive affect score)	5.31*	9.5*	6.28*	3.6*
Negative Affect Score (relative to not negative affect score)	1.59	13.3*	15.5*	.02
Work Characteristics				
Office Type (relative to closed offices)	1.03	1.1	.66	1.1
Office Sharing				
(sharing with 1 relative to private)	1.1	5.4	.48	6.7*
(sharing with 2+ relative to private)	1.1	8.2	.76	5.0*
Satisfaction Work Locale (relative to satisfied)	1.38*	1.09	1.57*	1.28*
Weekly Environment Score (ratings of terrible relative to those rating all aspects of the environment as very good)	141.5*	17.4*	42.5*	136.5*
Environmental Values				
Temperature (relative to one degree lower)	1.09	1.17	1.1	1.1
Humidity (relative to one unit lower)	.96*	.99	.97*	.97*
CFMPP (relative to one unit cfmpp lower)	1.00	1.00	1.00	1.00
PPM of CO2 (relative to 1 ppm CO2 lower)	1.00	1.00	1.00	.99

Notes: 1. Age, positive and negative affect scores were treated as continuous variables in the analysis.
2. Only main effects were estimated using a linear model.
3. * values were significant at $p<.05$
4. Systemic symptoms=fatigue, nausea and poor concentration; Mucosal Symptoms=eye & nasal irritation
5. In order to analyse the relative contribution of all factors to symtpom occurrence, logistic regression was used, ignoring the repeated measures aspect of the design. As a result signifigance may be overestimated.

Factors associated with the occurrence of any symptom included gender, atopic history, emotional well-being, dissatisfaction with work location, environmental rating, temperature and humidity. Females were 28%-32% more likely to report a symptom, experience more symptoms than males and report a e prevalence of symptoms steadily

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15.5*	.02
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.48	6.7*
.76	5.0*
1.57*	1.28*
42.5*	136.5*
1.1	1.1
.97*	.97*
1.00	1.00
1.00	.99

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greater impact of these symptoms on their ability to work. Those with a history of atopy were 45% more likely to experience headache but not any other symptom. They were also apt to rate the usual quality of their work environment more poorly. Bradburn Index ratings of emotional well-being were strongly associated with symptom occurrence as well as the burden of these symptoms on work ability. The odds of reporting a symptom were 3-15 times higher among those who were more negative compared to those who were not. Ratings of emotional well-being were also significantly associated with the total number of symptoms reported and the impact of those symptoms on work. Those who were dissatisfied with their work location were apt to rate the quality of their environment as poor and were also more apt to experience symptoms. However these two factors were not related to the total number of symptoms reported or their work impact. The only aspect of the office environment which was significantly associated with symptom occurrence was office sharing arrangements. Those in private offices were less apt to experience symptoms while those sharing with one other person were most apt to experience symptoms. The risk of symptom occurrence for those sharing their work space with more than one other person was in between these two extremes. The same pattern was observed for environmental rating, those in private offices rating the environment as better than those sharing office space. Although those exposed to tobacco smoke at work rated their environment more poorly than those not exposed, this factor was not associated with symptom reporting. The strongest predictor of symptom occurrence was weekly rating of the office environment. Those who rated their enviornment as poor were more apt to have symptoms than those who rated it as good even though environmental ratings bore no relationship to actual values observed. Ventilation conditions had no relationship to symptom occurrence, in fact with higher values for CFMPP, the risk of symptoms was slightly greater. Higher values of humidity were associated with a reduction in symptom occurrence on individual weeks as well as over all weeks. This relationship is probably positively biased by time trends in symptom reporting and may not be found in subsequent investigations. Higher values of temperature were associated with an increased risk of symptoms, particularly for headache although these findings were of marginal significance.

Discussion and Conclusions

Double-blind experimental manipulation of ventilation conditions proved to be feasible. Temperature and humidity were maintained within the comfort range for the duration of the study period. There were technical problems in instituting the desired study levels, problems which can be identified and resolved by pre-testing study building and unblinding at least one member of the environmental team so that feedback can be provided to the engineers during the study period. In addition, future studies could be improved by limiting evaluation to the two extreme levels of ventilation. This would permit more replications of the ventilation conditions within the same study period. Since there were only two replications in this study, it was difficult to adjust for time trends in symptom reporting, a problem which may be partially resolved by more frequent replications. Time trends in symptom reporting have not been reported elsewhere although this is the first study to use a design requiring repeated administrations of the same questionnaire. Nevertheless, the possible presence of this phenomenon in symptom reporting is of importance to those involved in the evaluation of building interventions. Reduction in symptom prevalence in pre-test, post-test designs may be partly attributable to this phenomenon

The prevalence of symptoms reported in this study was high, particularly considering that this was not identified as a problem building, the work force was young and had few other medical problems which could account for symptoms. Between 50%-70% of workers reported experiencing most of the cardinal symptoms. These prevalences are similar to those found by investigators who have studied workers in 'sick buildings'(3-5). These findings would, at minimum, suggest that prevalence of symptoms should not be used as the sole criteria for identifying sick buildings. The reported prevalence of symptoms proved to be extremely sensitive to the type of questionnaire used with prevalence rates being on average 22% higher when the workers' experience with symptoms was queried with specific probes. These findings reinforce the need for a standardized questionnaire which would permit comparisons to be made across studies.

The most important determinant of symptom occurrence was weekly environmental rating.. This implies that the worker's perceptions of their environment strongly influenced their reporting of symptoms. This finding underlines the importance of using a double blind approach so as to reduce the possibility of bias in symptom reporting. In addition it suggests that more research is needed to understand the factors which influence how workers perceive their environment. The results from this type of research may provide guidelines for building design and construction. This avenue of pursuit would likely provide more effective means of symptom reduction than modification of ventilation standards. The finding that females and those with an atopic history are more apt to experience symptoms has been found in other studies (3). In this study, females were more apt to be in clerical positions and work in shared, open office areas. The size of our sample may not have permitted us to adequately adjust for these factors, both of which were strongly associated with symptom reporting in the bivariate analysis. Measures of emotional well-being have not been reported in other studies. The direction of this relationship is unclear; those experiencing more symptoms may develop a more negative outlook or vice-versa. In future studies, variation in mood and its association with symptom reporting should be evaluated.

The levels of all the contaminants measured were significantly less than levels previously associated with toxic effects. The levels of these contaminants were associated with ventilation level (6). Symptom occurrence was not associated with ventilation level, in fact the more workers experienced symptoms during the week where ventilation levels were highest. This paradoxical finding may be partly attributable to the time trends in symptom reporting, however in this study it did not appear that better ventilation conditions were associated with a significant reduction in symptom experience. It may be that ventilation levels are of importance in reducing symptoms for a select subset of sensitive workers. The size of our sample in this pilot study did not permit us to explore this possibility but it will be investigated in future studies. Temperature and humidity were the two factors associated with symptom occurrence. however no relationship could be demonstrate between better ventilation and symptom reduction. In fact, symptom prevalence was greatest in the week with highest ventilation levels and no association between these contaminants and symptoms could be demonstrated. Temperature and humidity were associated with symptom occurrence. The range of temperature studied was limited as a result of efficient building control. In buildings with poorer temperature control, stronger associations would likely be found. In view of the time trends in symptom reporting, we cannot be confident that humidity is significantly associated with symptom occurrence. Although, on a week by week basis, workers who were exposed to lower levels of humidity were more apt to experience symptoms, these between subject comparisons may not be adequately adjusted for worker differences. Furthermore, in contradiction to these findings, workers who found the humidity to be terrible were systematically exposed to higher levels of humidity than those who found it to be good. Although these differences were not significant, the trend is the opposite of expected.

We conclude that this type of study design answers many of the methodological problems that have hampered past studies of SBS. Building ventilation levels can be manipulated experimentally while maintaining temperature and humidity constant and without the awareness of the building occupants. Weekly questionnaires, completed by the same individual, allows a within subject estimate of ventilation effect. This design is not subject to the potential biases of between subject comparisions. However, in view of the susceptibility of within subject estimates to temporal trends, a hybrid design which permits both between and within subject estimates of ventilation effect would be the preferred approach in future studies.

References

1. Fárant,J.P. (1987) Report on the Need for Additional Sick Building Syndrome Research in Canada Report to the Federal-Provincial Working Group in Indoor Air Quality Guidelines for the Office Environment. Ottawa: Health & Welfare Canada
2. Health & Welfare Canada (1988) Canada's Health Promotion Survey Ottawa: author.
3. Jaakhola,J. (1987) Sick Building Syndrome in an Office Tower Complex in Helsinki Doctoral Thesis, university of Helsinki, Finland.
4. Samet,J.M., Marbury,M.C. & Spengler,J.D. (1988) Health Effects and Sources of Indoor Air Pollution Part II Am. Rev. Resp. Dis. 137:221-242.
5. Skov,P., Valbjorn,O.(1987) The Sick Building Syndrome in the Office Environment-The Danish Town Hall Study Proc. 4th Ann. Conf. Indoor Air Quality:252-255
6. Farant,J.P.,Menzies,R.I., Tamblyn,R.M., Tamblyn,R.T., Hanley,J.P., Spitzer,W.O. (1990) "The Effect of Changes in the Operation of a Building's Ventilation System at Individual Workstations inan Office Complex" Proc. 5th Ann.Conf. Indoor Air Quality & Climate, Toronto.