Exposure to Varying Levels of Contaminants and Symptoms among Workers in Two Office Buildings

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ABSTRACT

Objectives. We hypothesized that exposure to contaminants would be associated with symptoms reported by office workers.

Methods. In two mechanically ventilated office buildings in Montreal, the outdoor air supply was manipulated for 6 weeks, while symptoms were reported and environmental parameters were measured at multiple sites.

Results. Contaminant concentrations varied considerably, in part related to experimental changes in outdoor air supply. Eye symptoms were reported with higher dust and with higher concentrations of nitrogen dioxide. Mucosal symptoms were increased with higher TVOCs, higher nitrogen dioxide, and higher total contaminant load. Systemic symptoms were associated with higher dust levels.

Conclusions. Symptoms reported by the workers were associated with increased concentrations of several contaminants and a summary measure of all contaminants. (*Am J Public Health.* 1996;86:1629–1633)

Introduction

Cross-sectional surveys of workers in nonindustrial buildings in Europe and North America have reported the common occurrence of work-related symptoms of irritation of the skin and mucous membranes as well as fatigue, headache, and difficulty concentrating.[1–5] There is evidence that temperature and relative humidity may be partially responsible,[6] but apart from descriptions of outbreak situations, there is very little population-based evidence for the role of chemical or biological contaminants.[6,7]

Failure to detect exposure–response relationships between work-related symptoms and chemical or biological contaminants may result from misclassification of exposure, because of spatial[8–10] or temporal variability,[11–13] particularly if exposure for all workers in a building is based on measurement of environmental factors made at a few sites,[3,14–16] at a different time than measurement of symptoms,[16] or over a short period of time.[3,15,16] In addition, symptoms may result from the combined effect of exposure to multiple contaminants, each at low concentrations.[17,18]

We have completed a randomized double-blind study of experimental manipulation of outdoor air supply in office buildings. In this study, workers completed questionnaires each week while environmental parameters were measured; this allowed a within-subject estimate of the association of symptoms and concentrations of individual or multiple contaminants.

Methods

From mid-April to late May 1990, in three consecutive 2-week blocks, building ventilation systems in two office buildings were manipulated in a randomized double-blind, multiple-crossover fashion to deliver, for a week at a time, an intended 20 or 50 cubic ft per min per person of outdoor air to the indoor office environment. The two buildings were studied simultaneously with opposite ventilation levels in each to minimize potential temporal effects[19] and while workers and data collectors were unaware of these levels, so that potential reporting bias would be minimized.

The study buildings were located in downtown Montreal; they had sealed windows and mechanical heating, ventilation, and air conditioning (HVAC) systems; steam humidification in winter; and air supplied with variable air volume systems. Building A was a 10-year-old, 9-story building with 30% efficient pre-filters and 80% to 90% efficient bag-filters. Building B was a 3-year-old, 23-story building with 30% efficient pre-filters. In both buildings, the HVAC systems, dampers, and fresh and supply air plenums were cleaned annually.

On seven floors of Building A and eight floors of Building B, all permanent full-time employees with a fixed, identifiable worksite were asked to sign informed consent to participate. This study was approved by an ethics committee of the Department of Epidemiology of McGill University.

Data Collection

Participants completed a baseline questionnaire on personal, smoking, medical, and work histories, and in each of the 6 study weeks, in midafternoon on Wednesday or Thursday, completed a questionnaire in which they rated the office environment and checked off symptoms experienced that day. The symptoms asked about—headache, fatigue, difficulty concentrating, cough, and irritation of the

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TABLE 1—Mean Contaminant Concentrations at the Two Ventilation Levels in Each Office Building

		Building A		Building B	
Contaminant	Current Norms[a]	Ventilation Increased	Ventilation Decreased	Ventilation Increased	Ventilation Decreased
Temperature, °C[b]		22.0	22.3	22.7	22.7
Relative humidity, %[b]		35	43	44	40
Air velocity, m/sec[b]		.10	.12	.08	.10
Recirculation, %[c]		63	93	63	95
Worksite CO_2, ppm[d]		551	727	567	901
Outdoor air supply, CFMpp[e]		84	37	72	24
CO, ppm	9	4.6	5.5	2.0	3.0
TVOC, mcg/m^3	2000	160	514	737	2353
NO_2, ppm	.05	.025	.030	.034	.018
Dust, mcg/m^3	260	13	22	29	24
Formaldehyde, ppm	0.1	.034	.038	.012	.048
Fungal, cfu/m^3	1000	15	17	15	8

Note. CO_2 = carbon dioxide; CO = carbon monoxide; TVOC = total volatile organic compounds; NO_2 = nitrogen dioxide.

[a]Sources for current norms or recommended limits for office environment: carbon monoxide = 9 ppm (US Environmental Protection Agency [EPA] National Ambient Air Quality Standard [NAAQS][30]); total VOCs = 2000 mcg/m^3 (WHO Working Group[31]); nitrogen dioxide = 0.05 ppm (US EPA NAAQS[30]); formaldehyde = 0.1 ppm (US EPA NAAQS and WHO Working Group[30,31]); airborne dust = 260 mcg/m^3 (24-hour exposure limit[21,30]); airborne fungi = 1000 CFU/m^3 (ACGIH[32]).

[b]Mean of morning and afternoon measurements at same sites as CO_2.

[c]Calculated from outdoor, return, and air supply CO_2 measurements: (supply air CO_2 − outdoor air CO_2)/(return air CO_2-outdoor air CO_2) × 100.

[d]Mean of afternoon measurement at 8 to 12 worksites per floor on day of questionnaire completion.

[e]Calculated from worksite CO_2 measurement, using formula suggested by ASHRAE 392: outdoor air in ft^3/min/person = (0.75/60)(1 000 000 − worksite CO_2)/(worksite CO_2 − outdoor air CO_2), where 0.75/60 is the amount of pure CO_2 produced by the average office occupant per minute, 1 000 000 is the concentration (in ppm) of pure CO_2, worksite CO_2 is the concentration in ppm of CO_2 at each worksite on the afternoon of the test day, and outdoor air CO_2 is the concentration in ppm of outdoor air CO_2 on same day.

TABLE 2—Components of Variance of Environmental Parameters

	Variance Attributable to Each Factor				
Contaminant	Building, %	Floor, %	Week, %	Ventilation Level, %	Unexplained, %[a]
Temperature, °C	18	20	12	11	39
Relative humidity, %	7	2	73	11	8
Air velocity, m/sec	1	8	2	25	64
Worksite CO_2, ppm	0	4	0	87	9
CO, ppm	37	3	16	25	20
TVOC, mcg/m^3	24	19	0	12	45
NO_2, ppm	0	1	51	29	19
Dust, mcg/m^3	11	1	17	26	46
Formaldehyde, ppm	0	0	0	96	4
Fungal, cfu/m^3	9	1	0	32	57

Note. CO_2 = carbon dioxide; CO = carbon monoxide; TVOC = total volatile organic compounds; NO_2 = nitrogen dioxide.

[a]Unexplained: percentage of variance of parameter that was unexplained by the factors shown.

eyes, nose, or throat—were those most frequently reported in a pilot study[19] and other studies.[2–4,20]

Environmental data were collected on the same day that the weekly questionnaires were completed in each building. Temperature, relative humidity, air velocity (with the Bruel & Kjaer Indoor climate analyzer, Model 1312), and carbon dioxide (by direct reading, portable infrared analyzer) were measured at 8 to 12 sites per floor in the morning and afternoon. Worksite outdoor air supply was estimated from afternoon concentrations of carbon dioxide[21] at the nearest measurement site, and the percentage of recirculation was estimated from carbon dioxide measured in the HVAC supply air, return air, and outdoor air intake[21] three times during the day.

The following were measured each week at one to three sites per floor in each building:

(1) Carbon monoxide: portable continuous electro chemical detector (with Interscan Model 1142).

(2) Nitrogen oxides: collected on SKC sampling tubes with volumetric air samplers, operating at 100 ml/min, over an 8-hour workday during 2 consecutive days. Analyzed using National Institute for Occupational Safety and Health method 6700.[22]

(3) Formaldehyde: collected with SKC passive samplers over a 24-hour period. Analyzed using American Society for Testing and Materials method D 5014-89.[23]

(4) Total volatile organic compounds: collected on activated charcoal tubes with volumetric air samplers operated at 200 ml/min for 8 hours during 2 consecutive days. Analyzed using flame ionization detection method.

(5) Total airborne particulates: collected with volumetric air pumps operated at 1.5 L/min for 8 hours on 2 consecutive days. Premeasurement and postmeasurement dry weights of filters were compared.

(6) Fungi: sampled with Biotest centrifugal sampler. Cultured on rose bengal culture plates.[24]

Data Analysis

The primary outcomes were the weekly presence or absence of any mucosal symptoms (irritation of the nose or throat as well as cough), systemic symptoms (headache, difficulty concentrating, and fatigue), or eye symptoms. These symptom groupings were based on other reports[2,3,10] as well as on factor analysis of the present data.[25]

Weekly environmental parameters were matched to each participant as follows:

(1) Afternoon carbon dioxide, and mean of morning and afternoon temperature, humidity, and air velocity at the nearest measurement site served by the same ventilation system.

TABLE 3—Average Contaminant Concentrations during Periods in Which Workers (n = 408) Were Symptomatic vs Asymptomatic

	Eye Symptoms			Mucosal Symptoms			Systemic Symptoms		
Contaminant	With	Without	OR[a] (95% CI)	With	Without	OR[a] (95% CI)	With	Without	OR[a] (95% CI)
CO	3.80	3.53	1.17 (0.79, 1.74)	3.63	3.57	1.05 (0.78, 1.41)	3.9	3.6*	1.24 (0.93, 1.66)
TVOC	1167	1055	1.21 (0.91, 1.62)	1310	1024***	1.40 (1.08, 1.82)	1233	1159	1.08 (0.87, 1.35)
NO_2	0.027	0.026*	1.21 (0.96, 1.53)	0.027	0.026*	1.31 (1.08, 1.58)	0.027	0.026	1.09 (0.91, 1.30)
Formaldehyde	0.036	0.043**	0.76 (0.62, 0.93)	0.038	0.042	0.84 (0.73, 0.98)	0.038	0.043*	0.81 (0.69, 0.95)
Dust	26	21*	1.20 (0.96, 1.50)	24	23	1.15 (0.97, 1.36)	25	21***	1.38 (1.14, 1.67)
Fungal	15.5	14.6	0.91 (0.70, 1.20)	15.6	15.0	1.04 (0.85, 1.26)	15.1	15.3	0.73 (0.60, 0.40)
Sum score	1.59	1.56	1.17 (0.89, 1.53)	1.66	1.53***	1.36 (1.07, 1.73)	1.65	1.61	1.10 (0.89, 1.36)

Note. CO = carbon monoxide; TVOC = total volatile organic compounds; NO_2 = nitrogen dioxide; OR = odds ratio; CI = confidence interval.
[a]ORs are adjusted odds ratios for change in1 SD of contaminant, calculated with multivariate logistic regression.
[b]Sum contaminant score = sum of (CO/Norm CO + VOC/Norm VOC + Form/Norm Form + NO_2/Norm NO_2 + Dust/Norm Dust + Fungal/Norm Fungal).
*$P < .05$; **$P < .01$; ***$P < .001$ (comparison by paired *t* test of mean concentrations of contaminants in weeks when symptomatic compared with mean in weeks when asymptomatic).

(2) Averages of all measures on the same floor of carbon monoxide, TVOCs, formaldehyde, nitrogen dioxide, dust, and fungi.
(3) Sum contaminant score calculated as follows:

$$\text{CO/Norm CO} + \text{TVOC/Norm TVOC} + \text{Formaldehyde/Norm Formaldehyde} + NO_2\text{/Norm } NO_2 + \text{Dust/Norm Dust} + \text{Fungi/Norm Fungi},$$

where CO is carbon monoxide, TVOC is total volatile organic compounds, and NO_2 is nitrogen dioxide.

Among workers who had symptoms in some but not all weeks, the mean concentration of contaminants and the mean sum contaminant score were calculated for weeks when workers were symptomatic and weeks when the same workers were asymptomatic. Significance of differences was tested with paired *t* tests, and conditional logistic regression provided within-subject estimates of the effect of contaminant levels on symptoms, adjusted for temperature, humidity, air velocity, and carbon dioxide.

Results

Of 840 eligible workers in the two buildings, 702 (84%) participated. Compared with the participants, nonparticipants were more likely to be male, older, and in nonclerical positions. Workers in Building A were more likely to be female, in clerical positions, and in enclosed offices. On average, 83.5% of participants, or 70% of the total eligible population, completed questionnaires each week; this did not change over the 6 study weeks. In Building A, 50% of workers reported at least one symptom each week, compared with 40% of workers in Building B.

As can be seen in Table 1, the percentage of recirculation in the HVAC supply air was varied substantially in both buildings. In Building B, worksite carbon dioxide levels were close to those intended, but in Building A, which was older and less "tight," carbon dioxide levels were not as precisely controlled because of significant infiltration of air through the building shell. Worksite air velocity was similar at the two ventilation levels; it increased at higher temperatures because the variable air volume systems controlled local air delivery on the basis of local temperature.

The mean concentrations of carbon monoxide, volatile organic compounds, and formaldehyde were higher in both buildings when the outdoor air supply was reduced (Table 1). Overall carbon monoxide and nitrogen dioxide levels were higher in Building A; this was traced to entrainment of automobile exhausts from an underground garage. Nitrogen dioxide, dust, and fungi levels were higher with increased outdoor air supply in Building B because the major sources were outdoors, and the filtration systems were ineffective for all three.

As is shown in Table 2, the experimental manipulation in outdoor air supply was responsible for the great majority of variance of carbon dioxide and formaldehyde, but for less than one third of the variance of all other parameters. After we accounted for the ventilation level, week was the primary source of variation for nitrogen dioxide and humidity, as a result of fluctuations in outdoor nitrogen dioxide, temperature, and relative humidity. TVOC levels were affected by building and floor factors—a reflection of local sources, particularly in Building B where wet photocopiers and printing devices were located on certain study floors.

In univariate and multivariate analyses, changes in symptom status were associated with changes in contaminant concentrations (Table 3), notably nitrogen dioxide and TVOCs for mucosal symptoms, carbon monoxide and dust for systemic symptoms, and dust and nitrogen dioxide for eye symptoms. The sum contaminant score was significantly associated with mucosal symptoms, but when the ratios of each contaminant/norm were log transformed and then added, this log-transformed score was less strongly associated with all outcomes tested.

Discussion

In this study, office workers completed symptom questionnaires in 6 consecutive weeks during which the concentration of several contaminants varied substantially. Changes in the occurrence of symptoms at work were associated with changes in these parameters and with a summary measure of all contaminants.

Strengths of the study include the repeated-measures design, which allowed a within-subject estimate of effect to control the potential confounding effect of personal, medical, worksite, or job-related factors.[2-4,14] Workers were unable to detect whether ventilation levels (or contaminants) were increased or decreased;[25] this reduced potential reporting bias. Some symptoms may not have been work related. However, these should have occurred independently of the environmental conditions, creating random misclassification and reducing the likelihood of detecting exposure–response relationships.

A multidisciplinary team was involved in this study. The engineer enabled successful experimental manipulation of the HVAC system, and an industrial hygienist provided the necessary expertise and specialized equipment for environmental measurement, while the epidemiologists and biostatistician ensured proper study design and outcome measurements. Potential misclassification of exposure should have been reduced by measuring the chemical and microbial parameters each week at one to three sites on each study floor on the same day as questionnaire completion. Nevertheless, some exposure misclassification occurred because environmental parameters were not measured at the worksites of all participants because of prohibitive costs.

These two buildings were selected because they were similar to buildings where problems of sick building syndrome have been described[2–4,14,20] and not because they were known to be "sick buildings," a poorly defined term.[7] Reporting of symptoms among participants in this study was very similar to the prevalence of symptoms in other studies of "sick buildings."[2–4,20] The size of the study population (704 workers) was large, enhancing the generalizability of the findings to other office workers. However, only two buildings were studied; findings of a similar study in other buildings could vary because of differences in the relative proportion or types of contaminants found.

The primary study outcomes were self-reported symptoms. Physical examination of subjects was impractical, given that more than 3500 measurements of symptoms were made. Most large-scale epidemiologic surveys published to date have utilized self-reported symptoms,[1–4,14,20] which have also been linked to sickness absence,[26] impaired performance of computer-based neurobehavioral tests,[27] and other measures of productivity.[28]

The variation in environmental parameters was substantial; this was in part attributable to the changes in outdoor air supply, but in large part it was related to other factors, such as local, or floor, effects, temporal factors (effects of the week, independent of ventilation level), and unexplained factors that were perhaps related to human activities or other unmeasured factors. In Building B, the changes in concentrations of dust, fungi, and nitrogen dioxide were opposite to the changes in formaldehyde, carbon dioxide, and TVOCs (Table 1). These findings may explain the apparent paradox of finding no association between symptoms and the changes in outdoor air supply,[25] yet finding associations with concentrations of certain contaminants.

The combined contaminant score was significantly associated with symptoms, but this score was not a better predictor of symptoms than individual contaminants. The derivation of the sum contaminant score was arbitrary; that is, it was calculated from ratios with certain values as norms. The use of norms suggested by other authorities, different methods of calculation, or other contaminants could alter the sum scores and possibly the relationships found. However, there is some supportive evidence from outbreak reports[29] and chamber studies[17,18] of an additive effect of combined exposure to multiple contaminants. This concept should be explored further, because it would have important implications for current concepts of the health effects of indoor air quality.

We conclude that symptoms considered typical of sick building syndrome were associated with higher concentrations of nitrogen dioxide, total volatile organic compounds, and airborne dust, as well as a high combined contaminant score. We have shown that it is feasible to characterize workers' responses and indoor environmental conditions in large office buildings in a repeated-measures design. This methodology may be used in further studies to improve our understanding of sick building syndrome and to provide a scientific basis for standards for indoor air quality in the office environment. □

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Preventing Recurring Injuries from Violence: The Risk of Assault among Cleveland Youth after Hospitalization

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ABSTRACT

Objectives. Although interpersonal violence has increased among urban youth, its epidemiology remains unclear. To prevent such violence, identifying the susceptible population is important.

Methods. Medical records for 998 patients aged 5 to 25 years at an urban hospital were reviewed to compare data for patients admitted for assault-related injuries, those admitted for unintentional injuries, and those for problems other than injuries.

Results. Those initially admitted for treatment of assault were found to be at greater risk of subsequent treatment for assault than those admitted for noninjuries.

Conclusions. Admission for injuries caused by violence may increase risk for future assaults; hospitalization may offer an opportunity to interrupt these patterns. (*Am J Public Health.* 1996;86:1633–1636)

Introduction

It is widely recognized that injuries are responsible for more deaths and years of life lost among individuals younger than 44 years than any other cause of death in the United States.[1–6] While many studies document relatively constant rates for several injury types over the last 15 years,[1–4] rates for intentional injuries are rising.[5,7–10] Injury inflicted with intent to cause harm represents a health problem that has become the second leading cause of death for Americans aged 15 to 24[1,6] and the leading cause of death for young African Americans.[6]

Descriptive studies have contributed significantly to our understanding of the mortality trends associated with violence.[11–17] As with unintentional injuries, however, the absence of injury surveillance limits an appreciation of the scope of nonfatal violence and slows public health efforts toward developing and evaluating prevention and intervention strategies.[18]

The focus of intentional injury control efforts has been the development of strategies aimed at altering known risk factors and identifying new ones and their interactions. Intentional injury recurrence, which is recognized as part of the rationale for admitting individuals attempting suicide for intensive treatment to prevent future efforts at self-harm, should be considered a potential focus for these strategies.[19] Recent studies suggest, for example, that assaults frequently reoccur among those previously assaulted[4] and are observed more commonly among individuals who are unemployed, are of lower socioeconomic status, and use drugs

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