VALIDATING A STANDARDIZED PROTOCOL FOR ESTIMATING INDIVIDUALS' EXPOSURES TO CONTAMINANTS IN MECHANICALLY VENTILATED OFFICE BUILDINGS

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ABSTRACT

The detection of exposure response relationships in sick building syndrome requires accurate estimation of exposure of workers in the office environment. However the concentrations of contaminants in this environment show considerable diurnal, seasonal and spatial variation. We wished to develop a standardized environmental measurement protocol that would be practical and feasible, and account for these sources of variation. In ten mechanically ventilated buildings, a number of comfort measures and contaminants were measured at a sample of worksites, outdoor air, and return air. These were measured under conditions of increased and reduced outdoor air supply, to estimate potential seasonal changes. To estimate diurnal variation 24 hours continuous recordings were made. There were significant differences between buildings, and within buildings in levels of contaminants. Changes in outdoor air supply were also associated with significant changes in contaminant concentrations, both at worksites and in return air systems, in mean concentrations and the pattern of diurnal variation. Based on these measurements, an individual's year-round exposure can be estimated. These predictions will be validated by repeated measurements at the same worksites.

INTRODUCTION

One reason for the failure to detect significant associations between contaminants in the office environment and symptoms of Sick Building Syndrome (SBS) may be inaccurate estimation of exposure, due to spatial and temporal variation in concentrations of contaminants. We have previously found that within large office buildings there may be significant variation in a number of environmental parameters between worksites on the same floor or between floors in the same building.[1] This means that in addition to the building "macro-environment", workers' exposures are also determined by their "micro-environments". An additional problem in estimation of exposure is that these exposures may vary over time, related to changes in outdoor conditions,[2] or changes in outdoor air supply.[3] In previous epidemiologic studies of SBS these temporal effects and the within building variation have not been accounted for in measurement of indoor environment.[4,5,6,7] However, measurement of these parameters is complex, time consuming, and expensive, so that sampling strategies must be employed for any environmental measurement protocol.

We have shown that manipulation of outdoor air is feasible and will result in significant changes in indoor concentration of contaminants.[1] We have developed a standardized environmental protocol in which diurnal variation is estimated from 24 hour monitoring of return air systems, seasonal variation from measurement after experimental manipulation of outdoor air supply to the maximum and minimum levels employed throughout the year, and spatial variation from detailed measurement at a sample of worksites. We hypothesize that data from this building characterization, plus a single set of measures at their worksite, could be used to estimate workers' exposure throughout the year at their worksites.

MATERIALS AND METHODS

Buildings

Ten mechanically ventilated buildings, with economizer cycles, located in Montreal, were selected. All had air conditioning systems although these were not operational at the time of the building characterization. One building was characterized each week between October and December of 1992.

Environmental protocol

In each building, the outdoor air supply was reduced to the minimum, usually supplied in mid-winter or mid-summer for that building, beginning Monday morning. This level was continued for two days and changed on Wednesday morning to the maximum outdoor air usually supplied in that building in fall or spring. All environmental measures were made on Tuesdays, and Thursdays.

The following were measured:

1. Return air of HVAC system: A 24 hour recording of CO_2, CO, and TVOCs using a photo-acoustic measuring device with filters for these three substances. Measures were taken every three minutes and recorded in a data logger. As well time weighted 24 hour averages of dust, formaldehyde, fungi, NO_2, and NO, were made using methods described below.
2. Outdoor air: Once weekly dust fungi NO_2, NO, and TVOCs were measured. CO_2, temperature, and humidity were measured three times on Tuesdays and Thursdays.
3. Worksites: At 35-40 worksites per building carbon dioxide, carbon monoxide, temperature, relative humidity, and air-velocity were measured using portable direct-reading instruments, three times per day on Tuesday and Thursday.
4. Worksites: At 5-6 worksites per building the following contaminants were measured on Tuesday and Thursday.

i) Nitrogen oxides: collected on sampling tubes using volumetric air samplers, operating at 100 ml/minute, over the 8 hr workday. Analyzed using NIOSH Method, P and CAM-231.

ii) Formaldehyde: collected over 24 hours with passive samplers. Analyzed using NIOSH Method 3500.

iii) Total volatile organic compounds: collection on activated charcoal tubes using volumetric air samplers, at 200 ml/minute, for 8 hrs Analyzed using: flame ionization detection method.

iv) Total airborne particulates: collection by volumetric air pumps, at 1.5 litres/minute, for 8 hrs. Pre and post dry weights of filters compared.

v) Fungi: airborne colony-forming units sampled with volumetric air samplers, on adhesive coated glass slides for spore counts, and on Sabhourad containing petri dishes for culture.

Validation

5-6 worksites per building will be remeasured in detail on 2 additional occasions between February and June 1993. All environmental parameters above will be remeasured. At the same time outdoor conditions and outdoor air supply will also be measured.

Analysis

1. Prediction of the workers' likely exposure will be based on the percent recirculation and time of day for instantaneous measures. For contaminants measured over 8 or 24 hour periods, prediction will be based on the percent recirculation and outdoor levels of the same contaminants.
2. The predicted values will be correlated with actual values measured on visits 2 and 3. The predicted values will be based on visit 1.
3. Sensitivity and specificity of prediction will be calculated, as to whether the worker will be above the building averages on visits 2 and 3. Sensitivity and specificity will also be calculated for whether the worker will be exposed to levels above norms, on these visits.

RESULTS

In Table 1 are shown the means of environmental parameters and contaminants in the 10 buildings characterized. In each building, the average of all measures taken at worksites are shown. There was considerable variation between buildings in the levels of contaminants. For example, building 8 had the highest CO_2 levels and also the highest TVOC concentrations; this was because the HVAC system remained at 80% recirculation, even when operating at maximal outdoor air supply. In building 2, both TVOC's and formaldehyde were high; this was related to the large workshop located in part of this building -- the fumes from which appeared to reach most worksites in the building. In other buildings such as buildings 3 and 5, CO was relatively high; this was attributed to cigarette smoking in the former and entrainment of vehicular exhaust fumes in the latter building. Fungal levels were generally low as was dust although in 3 buildings -- 1, 6 and 10 -- average dust levels exceeded the US Environmental Protection Agency national ambient air quality standards of 75 micrograms/m³ for one year exposures.

Table 1. Means of environmental measures in 10 study buildings.

	Measures and Units							
Bldg No.	Temp °C	Air Vel m/sec	CO_2 ppm	CO ppm	TVOC mcg/m³	Form. ppm	Dust mcg/m³	Fungi cfu/m³
1	23.1	.027	531	0.08	---	.009	95	20
2	23.5	.123	548	0.40	3712	.037	--	49
3	23.1	.013	679	1.60	---	.015	41	98
4	23.9	.017	491	1.00	160	.016	42	40
5	23.9	.017	625	0.20	74	.008	41	14
6	24.0	.116	506	0.00	---	.090	133	13
7	23.6	.019	542	1.50	154	.017	45	11
8	21.9	.024	826	1.20	1815	.021	--	46
9	23.6	.015	652	0.30	331	.014	--	64
10	22.3	.061	476	0.40	135	.014	117	80

As seen in Table 2, the changes in ventilation level were associated with significant changes in the contaminant concentrations. The temperature was significantly higher when outdoor air supply was reduced. This was because the building characterizations were done in the fall at a time of "free cooling" when outdoor air is usually used for cooling in Montreal. The chillers for the air conditioning systems had been turned off and an administrative decision was made not to turn them back on for the 2 days of reduced outdoor air supply needed for the characterization. Decreased outdoor air supply was associated with significantly increased CO_2 levels, formaldehyde, CO and fungal CFU concentrations. Additionally TVOCs and dust were increased but not significantly. Increased outdoor air was associated with significantly increased NO_2 and somewhat but not significantly increased NO. Air velocity was also somewhat increased with increased outdoor air supply. Increased CO_2 was positively correlated with increased CO (r=.41), TVOCs (r=.12), and NO (r=.28); while increased TVOCs were positively correlated with formaldehyde (r=.34), and NO (r=.50).

Table 2. Effect of changes in outdoor air supply on environmental measures.

	Decreased	Increased	(P-value)
Temperature (°C)	23.7	22.8	$p < .0001$
Humidity (RH%)	27.9	29.3	NS
Air velocity (m/sec)	.031	.051	NS
CO_2 (ppm)	682	532	$p < .0001$
CO (ppm)	1.0	0.7	$p < .05$
TVOC (mcg/m^3)	823	740	NS
NO_2 (mcg/m^3)	7.2	15.3	$p < .05$
NO (mcg/m^3)	10.9	13.1	NS
Formaldehyde (ppm)	.023	.016	$p < .05$
Dust (mcg/m^3)	78	66	NS
Fungi - CFU (/m^3)	64	39	$p < .05$
- spores (/m^3)	54	53	NS

The diurnal variation, and effect of changes in outdoor air supply on concentration of contaminants in the return air system is shown in Figure 1, taken from a single building. CO_2 increased and then diminished over the course of the day as might be expected with occupancy of an office building. Somewhat surprisingly, in parallel with CO_2, CO also increased substantially over the course of the day, which can only be explained by cigarette smoking, as there were no other sources of combustion, and no enclosed or underground garage attached to this building. Based on this figure, one could venture the opinion that compliance with the official non-smoking policy of this building appears to be low! The pattern of TVOCs was very similar to CO and CO_2 and showed a rapid rise during working hours particularly when outdoor air was diminished. The sources of TVOCs have not yet been identified. These figures emphasize that instantaneous measurements of contaminants using direct reading instruments may seriously misclassify exposures if there is significant diurnal variation. As well they demonstrate that 24 hour, or even 8 hour average concentrations may underestimate peak exposures.

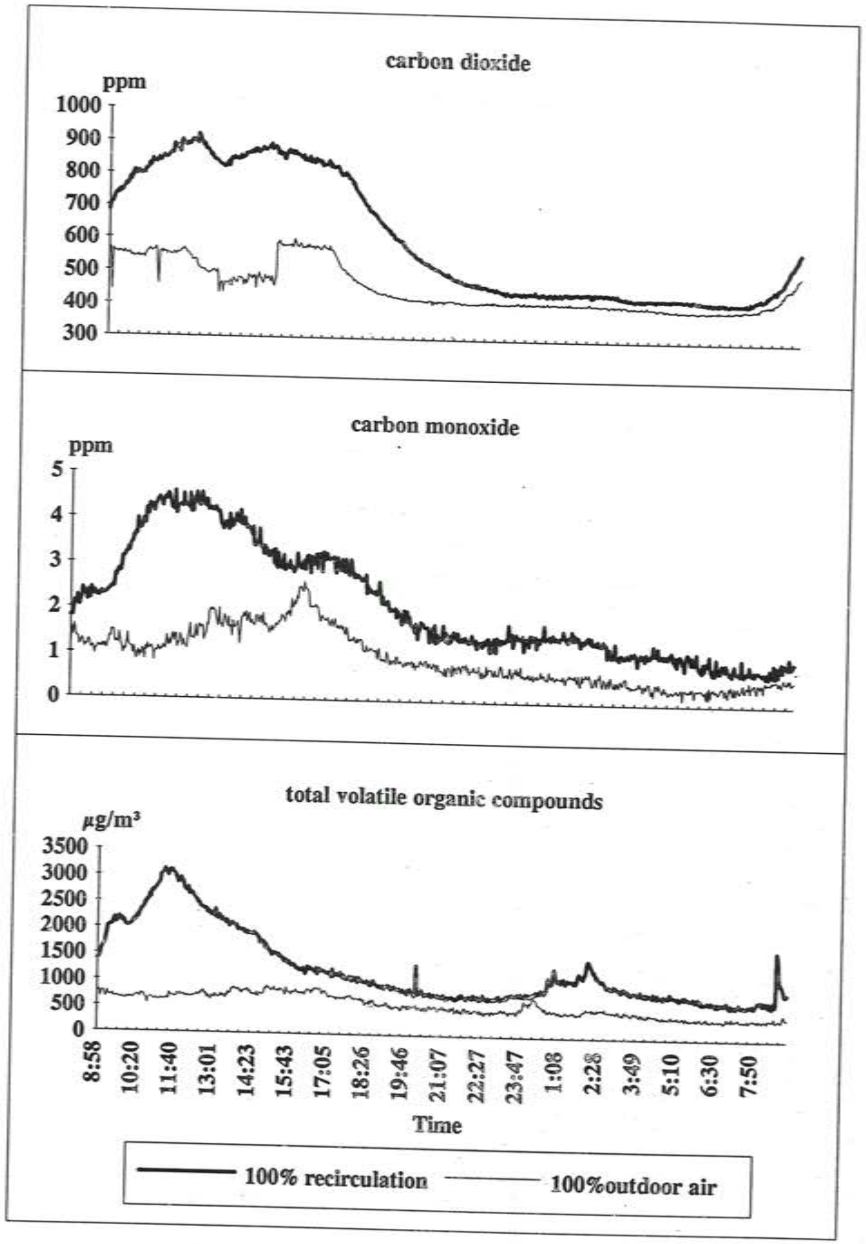

Figure 1. 24 hour monitoring of 3 contaminants at 2 ventilation levels.

DISCUSSION

In this study we have found that commonly measured environmental contaminants va considerably between buildings, but also between sites within buildings, and at the same sites over the course of the day. As well changes in outdoor air supply resulted in significant differences in contaminant concentrations.

The degree and different sources of variability may help to explain the failure of man studies to find any association between environmental measures. If short exposures to hig concentrations are critical in the pathogenesis of SBS symptoms, then failure to account fo diurnal variation may mean that peak exposures are not detected. Failure to account for differences between sites within buildings may result in significant mis-classification of workers' exposures. Finally failure to account for changes in indoor contaminant concentrations related to varying outdoor air supply may mean that conditions present at the time of symptoms may not be present as little as one week later because of changes in outdoor temperatures, and building cooling needs.

We have shown that experimental manipulation of outdoor air supply is feasible, and can be accomplished without awareness of building occupants.[1] As shown in this study these changes will result in changes in mean contaminants mean concentrations, as well as their diurnal patterns. This information can sometimes be used to identify building or HVAC problems (I93hvac), but also can be used to provide an estimate of the likely range of exposures that a worker should experience over the course of the year.

A major difficulty in comparing results from different investigations of SBS is the lack of a standardized environmental protocol. We believe that this approach, although intensive, may provide accurate information to characterize workers' long term exposures in the microenvironment of their worksites, and allow exposure response relationships to be analyzed and identified.

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REFERENCES

(1) Menzies R, Tamblyn R, Farant JP, Hanley J, Nunes F, Tamblyn RT. The effect of varying levels of outdoor air supply on symptoms of sick building syndrome. New Eng J Med 1993. (in press)

(2) Morey PR. What are typical concentrations of fungi, total volatile organic compounds, and nitrogen dioxide in an office environment? ASHRAE (?) Indoor Air Quality 1989:67-71.

(3) Turiel I, Hollowell CD, Miksch RR, Rudy JV, Young RA. The effects of reduced ventilation on indoor air quality in an office building. Atmos Envir 1983;17:51-64.

(4) Burge PS, Hedge A, Wilson S, Bass JH, Robertson A. Sick building syndrome: a study of 4373 office workers. Ann Occup Hyg 1987;31,4A:493-504.

(5) Skov P, Valbjorn O, DISG. The "sick" building syndrome in the office environment: the Danish Town Hall study. Envir Intl 1987;13:339-349.

(6) Robertson AS, Burge PS, Hedge A, et al. Comparison of health problems related to work and environmental measurements in two office buildings with different ventilation systems. British Med J 1985;291:373-376.

(7) Norback D, Michel I, Widstrom J. Indoor air quality and personal factors related to the sick building syndrome. Scand J Work Environ Health 1990;16:121-8.