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SYMPTOMS AND THE MICRO-ENVIRONMENT IN THE SICK BUILDING SYNDROME: A PILOT STUDY

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ABSTRACT

In a cross-sectional investigation in one building, complaints associated with the "sick building syndrome" were measured on a linear analog scale questionnaire. At the same time, the micro-environment (environmental characteristics in the breathing zone rather than area samples) was characterized by measuring temperature, relative humidity, respirable suspended particulates, carbon dioxide, noise level, lighting intensity, relative humidity, and airflow. No relationship was seen between the degree of symptoms and age, education, or duration of employment at the building or time spent in the building on a daily basis. Statistically, complaints were significantly more frequent among smoking men. Environmental characteristics associated with the increased complaint levels in this group included decreased airflow velocity and increased levels of respirable suspended particulates and dry-bulb temperature. In regression models, there was an association between respirable suspended particulates and the levels of both mucous membrane and systemic complaints. Satisfaction with the thermal environment as predicted by perception of draft did not clearly contribute to the degree of symptoms, although regression models did suggest that complaints were not independent of thermal parameters. Lighting intensity was also associated with complaints. Future studies of the sick building syndrome should examine multiple exposures simultaneously and include psychosocial measures to identify predictors of complaints in indoor spaces.

INTRODUCTION

Complaints termed the "sick building syndrome" have led to numerous investigations in the last 15 years. They are thought to occur primarily in newly constructed office buildings and, at least in the past, were thought to be due to inadequate ventilation (Melius et al. 1984). Nevertheless, a wide variety of causes have been identified in specific settings, including inadequate temperature and relative humidity control, noise, lighting, vibration, volatile organic compounds and formaldehyde, microorganisms, environmental tobacco smoke, pesticides, dust, entrainment of vehicle exhaust or spent and contaminated air and boiler fumes, fibers released from duct linings, and office machine offgases and odors (Kreiss and Hodgson 1984; Hodgson and Kreiss 1986).

A group of investigators from Great Britain (Finnegan et al. 1984) suggested that these complaints were related primarily to mechanical ventilation. The same group of authors (Robertson et al. 1985) was unable to identify differences in wet-bulb globe temperature, dry-bulb temperature (temperature), relative humidity, air velocity, formaldehyde, or positive or negative ions between several rooms in a building with natural and a building with mechanical ventilation, where both sets of rooms had high levels of complaints. Burge et al. (1987) investigated the frequency of complaints in 43 office buildings built over the last 50 years with a validated questionnaire. The symptoms were more common in buildings where the ventilation system also provided cooling and humidification, irrespective of the age of the buildings. A direct relationship between the level of complaints and air quality parameters was not described. Skov et al. (1987) examined indoor air quality symptoms in 14 modern Danish town halls and 14 older control buildings. The level of symptoms was related to a "fleecing" factor (carpets, upholstery, and horizontal surfaces) and the "macro-molecular component" of dust. They also demonstrated a relationship between the number of hours spent photocopying and using carbonless copy paper and the level of complaints. Other studies have demonstrated that ergonomic aspects (Stellman et al. 1985) and psychodynamic factors (Rowland et al. 1984) contribute to indoor air quality complaints.

Several studies have attempted to identify the actual cause of complaints in the sick building syndrome by measuring symptoms and environmental exposures. Robertson et al. (1985) were unable to demonstrate any measurable differences in the concentrations of environmental pollutants between rooms in a mechanically and a naturally ventilated building. They studied the rooms with the highest complaint rates and used area samples. Skov et al. (1987) did demonstrate a relationship between symptoms and both area samples measuring dust and a "macro-molecular" fraction, again in area samples.

Area samples in buildings may not be representative of the exposures in different points in single rooms. Physical characteristics such as windows and partitions, computers, and shelving may influence air currents. Radiant heat may lead to uneven distribution of pollutants. Finally, most pollutants result from point sources, so they will be diluted as a subject is farther removed from the source. The micro-environment around desks and within cubicles may have very different exposure characteristics than the macro-environment of a building. In addition, all applied occupational and environmental health research that attempts to relate dose to health effects suffers from the problem that dose is generally measured at several points in time and then extrapolated to allow development of exposure classifications over decades while most health effects are measured as a single result of these chronic exposures. Where the variability of sampling results is greater than the difference in average samples, and where the level of symptoms may change not merely from day to day but from hour to hour, such a strategy must fail.

No investigations in the peer-reviewed literature have attempted to characterize air-quality parameters in the micro-environment and set these characteristics in relation to the level of individual complaints at a given point in time. This report presents results of a cross-sectional investigation of a problem building using a self-administered, linear analog, self-assessment questionnaire to record short-term symptom

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levels at a given point in time and measures of the indoor air quality in the breathing zone during the completion of the questionnaire in an attempt to use a method to identify the pollutants leading to complaints.

METHODS

Background

The building was occupied in early 1984 and serves as an academic computing center, with offices and conference rooms for faculty and a large computer terminal hall for students. It is a three-story, "hermetically sealed" building with six ventilation zones through the floors, encompassing approximately 40,000 ft^2 of floor space. The basement (lowest floor) contains storage rooms, mechanical system rooms, and a computer repair shop. The ventilation is provided by variable-air-volume systems in each zone. The maintenance shop on the ground floor has its own ventilation system.

Complaints had begun almost immediately after occupancy and persisted for almost two years by the beginning of this survey. Multiple prior industrial hygiene surveys had failed to provide evidence of concentrations of formaldehyde and other volatile organic compounds in levels that, by themselves, could be expected to cause complaints in a high proportion of occupants. Formaldehyde area samples were in the range of 0.01 to 0.07 parts per million (ppm); carbon monoxide, 3 to 6 ppm; carbon dioxide, 540 to 780 ppm; and relative humidity, 44% to 58%; and part-per-billion (ppb) levels of 1,1,1-trichlorethane and other halogenated hydrocarbons, including freons used in computer maintenance, were found.

Design and Conduct of the Study

The authors designed a cross-sectional study to identify the level of short-term complaints and simultaneously measure indoor air quality characteristics. No attempt was made to measure ergonomic characteristics of the work stations, although building occupants are frequent users of computer terminals. A four-week period was set for this study, and the necessary instruments were rented. The technicians obtained all measurements at each subject's desk in the breathing zone while the study subject was actually completing the questionnaire. All measurements were obtained only once. The time required for completing data collection at each work station was approximately 45 minutes. Completion of the questionnaire required approximately 10 minutes, so measurements were begun while the subject sat at his or her desk and frequently were completed only after the subject had responded to the questionnaire. To ensure blinding, the technicians did not review the questionnaires. Two technicians alternated in obtaining measurements. All measurements were obtained between the hours of 1 p.m. and 5 p.m. on weekdays.

Population

All full-time building occupants were eligible to participate, i.e., staff and faculty. Students were excluded.

Questionnaire

Linear analog questionnaires (Bond and Lader 1974) are well described, with validation studies published in the British psychological literature. This questionnaire was originally used in the investigation of formaldehyde-related complaints in day-care centers (Olsen and Dossing 1982). More recently, it was used to identify complaints (Hodgson et al. 1987) in a building outbreak thought due to inadequate ventilation but subsequently identified as a vibration problem. It collects three kinds of information: 1) demographic data (age, gender, years of education, current smoking status), 2) the magnitude of 10 complaints on a linear analog scale (headache; nose, eye, and throat irritation; chest tightness, etc.), and 3) work characteristics (tenure at the institution and in the building; and hours per day in the building, in individual offices, and at computer screens). A copy is attached as the appendix. No characterization of the physical environment or further description of job tasks was undertaken.

Environmental Characteristics

Nine indoor air-quality characteristics were measured. The instruments and the associated minimum sensitivity are noted in Table 1. Temperature, relative humidity, light intensity, respirable suspended particulates (RSP), air velocity, and volatile organic compounds (VOC) were monitored using direct-reading instruments. The photoionization detector was calibrated to methane, and the manufacturer's correction factor for toluene was applied to all results. Carbon dioxide (CO_2) and formaldehyde levels were measured with direct-reading indicator tubes. Vibration was recorded on a strip chart and subsequent analysis of the chart was made to determine the acceleration. Respirable suspended particulates (RSP) were measured electronically using a meter containing a 3.5 m impactor and piezobalance. Where measurements were below the threshold of detection but registered a value other than zero, the threshold value was entered as a number for purposes of analysis.

The percentage of dissatisfaction attributable to the perception of draft was calculated according to equations developed by Fanger and Christensen (1986). Although this figure was developed to predict a population percentage of dissatisfaction, the authors assumed that the percentage figure might be used as a surrogate variable to explain the amount of dissatisfaction on an individual basis that could be attributed to temperature and airflow. The percentage figure was then used as a continuous variable in regression modeling.

The length of duct work leading to each office was calculated from building floor and engineering drawings. The building was divided into three zones, and the length of ductwork was entered as an ordinal variable (1 to 3), referred to as "duct." This was done by an engineer with no knowledge of the level of complaints in the individual offices.

TABLE 1

Instrumentation Characteristics

Parameter	Instrument	Minimum	Variability
Light	Sylvania D-2000	1 foot candle	+/- 5%
Temperature	Solomet MPM	0/60°C	+/- 0.3°C
Relative humidity	Solomat	0–100%	+/- 3%
Particulates	TSI 5500	10 ug/m^3	+/- 1%
Airflow	Alnor Thermo-anemometer	20 feet per minute	+/- 3 fpm
Volatile Organic	Century 128 OVA	0.1 ppm	+/- 0.1 ppm
Compounds Carbon Dioxide	Draeger tubes	300 ppm	+/- 35%
Formaldehyde	Draeger tubes with activator extender tubes	0.04 ppm	+/- 35%
Vibration	Kinematics VM-1 Fotonic MT 1-Sensor	10 Hz	+/- 5%

Statistical Analyses

Data were analyzed using the Statistical Package for the Social Sciences for Microcomputers [SPSS/PC+]. All data were plotted. Where data were distributed lognormally, as suggested by viewing histograms, the transformed number was used in calculations (particulates and relative humidity). Results were accepted as statistically significant when the associated p-value was less than 0.05. Where p-values fell between 0.10 and 0.05, the differences were considered suggestive of an effect and worth closer scrutiny.

Because of several recent investigations (Skov et al. 1987; Hedge et al. 1987) symptoms were summed to two symptom complexes. "Eye irritation," "chest tightness," "pharyngitis," "nose irritation," and "difficulty breathing" were summed to "mucous membrane complaints"; "headache," "irritability," "nausea," "difficulty concentrating," "alertness," and "lethargy" to "systemic symptoms." The logarithm of the sums was used in analyses since variables were lognormally distributed.

The maximum number of available records was used in analyses of variance and in correlations through a standard SPSS/PC+ 2.0 command (missing=pairwise). Only records for which complete data were available were used in regression models. Because of multicollinearity and the number of missing measurements, there were severe restrictions on the number of variables that could be used in developing regression models. The number of variables in each model was restricted so that there were always approximately five times as many complete records available for that analysis as independent variables to avoid overparameterization. Where the zero-order correlation coefficient between two variables was greater than 0.25, only one of the variables was used in any given model.

Environmental measures were examined for their correlation. Zero-order correlation coefficients between symptoms and both demographic variables and exposure measures were obtained. Analyses of variance were then performed using gender and current smoking status as main effects and symptoms and environmental measures as outcome variables to examine the distribution of variables. Finally, multivariable regression models were developed using the symptom categories as dependent variables. For all analyses, first simple and then stepwise models were obtained, using the same structure for mucous membrane and systemic symptoms (dependent symptoms). Only variables that did not demonstrate multicollinearity were used as independent variables in regression models. First, the relationship was explored between the level of symptoms and demographic characteristics (age, education, gender, and current smoking status) and work habits (hours spent at various tasks and in various parts of the building). Second, the same analyses were performed using environmental characteristics (temperature, relative humidity, carbon dioxide, velocity of air, acceleration, noise levels, and lighting). These two sets of models are not presented. Because of the large number of missing values and questionnaire responses, only 13 records had complete records to develop models that included all variables of interest, so that these models could not be viewed as legitimate endeavors.

Finally, models were developed for the factors that have

TABLE 2

Environmental Characterization

		Mean	Median	Standard Deviation	Total # Available	Range
Relative Humidity (%)		35.5	34.8	8.3	90	19.3–65.0
75th, 90th, and 95th percentiles:	40.8, 45.3, 50.0					
% at or below the limit of detection:	0%					
Temperature (°F)		74.5	74.3	2.8	105	62.7–81.3
75th, 90th, and 95th percentiles:	76.4, 77.0, 80.1					
% at or below the limit of detection:	0%					
Airflow velocity (ft/min)		25.0	24.0	5.5	84	nd–43.0
75th, 90th, and 95th percentiles:	27.0, 34.0, 38.0					
% at or below the limit of detection:	20 (24%)					
Carbon dioxide (ppm)		820	800	201	102	300–1250
75th, 90th, and 95th percentiles:	1000, 1070, 1100					
% at or below the limit of detection:	0 (0%)					
Respirable suspended particulates (mcg/m^3)		36	30	15	103	nd–90
75th, 90th, and 95th percentiles:	40, 60, 68					
% at or below the limit of detection:	20 (21%)					
Light (foot-candles)		42.0	38.5	25.1	100	2.0–150
75th, 90th, and 95th percentiles:	52.0, 69.5, 89.5					
% at or below the limit of detection:	0, (0%)					
Noise (decibels on the A-weighted scale)		58.3	55.0	8.9	79	50.0–85.0
75th, 90th, and 95th percentiles:	60.0, 68.0, 85.0					
% at or below the limit of detection:	0 (0%)					
Vibration (Herz)		10.3	10.0	8.9	72	nd–19.9
75th, 90th, and 95th percentiles:	10.0, 10.0, 12.0					
% at or below the limit of detection:	68 (94%)					
Formaldehyde (ppb)		64.4	40.0	131	55	nd–1000
75th, 90th, and 95th percentiles:	40, 64, 152					
% at or below the limit of detection:	40 (73%)					
Volatile organic compounds (ppm)		0.63	0.600	0.30	30	nd–1.00
75th, 90th, and 95th percentiles:	1.0, 1.0, 1.0					
% at or below the limit of detection:	3 (10%)					

TABLE 3

Environmental Characteristics: correlation matrix[1]

	RSP[1]	Temperature	Airflow Velocity	Relative Humidity	Carbon Dioxide	Volatile organic compounds	Formaldehyde	Lighting	Sound	Acceleration
Temperature	.029 90									
Airflow velocity	−.113 84	−.310** 84								
Relative humidity	.366** 90	.018 90	.310** 77							
Carbon dioxide	.330** 102	.352** 102	.045 84	.481** 98						
Volatile organic Compounds	−.515** 29	−.700** 30	−.116 11	−.594** 21	−.627** 28					
Formaldehyde	.109 55	.303* 55	−.024 45	.031 52	.140 55	−.094 15				
Light intensity	−.002 99	−.198* 100	−.041 80	−.050 86	.137 98	−.155 29	.637** 55			
Sound level	−.102 77	−.552** 79	.639** 59	.114 71	−.013 76	−.597** 25	−.092 48	−.025 78		
Acceleration	.236* 72	−.096 61	.227 72	.022 64	−.083 72	.068 17	.002 35	−.091 71	−.091 51	
Draft[3]	−.218* 84	−.338* 84	.937** 84	.230* 77	.058 84	−.088 11	−.029 45	−.028 80	.662** 59	.063 64

1: Each cell contains the coefficient and the number of records from which that coefficient was calculated.
2: RSP = log (respirable suspended particulates)
3: draft calculated from Fanger and Christensen (1986)
*: $p < 0.01$
**: $p < 0.001$

been considered of greatest interest, again for both systemic and mucous membrane symptoms. Only these models are presented in the tables. Because of the interrelationship of temperature, airflow velocity, and relative humidity and the non-random distribution of these parameters in the analyses of variance, and their contribution to some of the regression models using only environmental parameters, the "perception of draft" was used in the final models.

Simple and backward-stepping models (p(out) = 0.1) were developed using all variables. In forward-stepping models (p(in) = .05), gender and smoking status were forced as indicator variables; subsequently the other variables were allowed to enter. All models were developed both with and a second time without the duct variable.

RESULTS

Measurements of volatile organic compounds and formaldehyde were discontinued after two weeks, since the instruments had been rented only for that period, and initial review of the data revealed levels only in the range of 0.5 to 1.5 ppm for VOC (n = 30) and consistently less than 0.04 ppm for formaldehyde (n = 55). Because of travel, illness, and mobility of the population, questionnaires were available only on 105 (67.75%) of all eligible individuals. Because of instrumentation difficulties and incomplete questionnaire responses, not all records could be used in each comparison. Only 13 had complete records for all questionnaire responses and all measured variables. Only 73 (68.9%) had complete questionnaires and measurements of RSP, thermal parameters, lighting, and noise.

Table 2 summarizes the distribution of environmental characteristics. Relative humidity, temperature, and airflow were generally in the acceptable range for office work. No carbon dioxide levels exceeded 1250 ppm. RSP concentrations were all less than 100 μm/m³. Only one measurement of light intensity exceeded 100 fc at the desk level. Noise was generally acceptable for office work. No levels of VOC exceeded 1 ppm. Plotting the data revealed that particulates and relative humidity were lognormally distributed, so that those variables were transformed and the transformed values used in further calculations. Table 3 presents the correlation matrix for environmental measures. The levels of many of the variables were related. The associations were generally complex, but generally expected. There was a meaningful relationship between levels of RSP, VOC, and CO_2: as effective local ventilation increased, RSP and VOC concentrations decreased. Temperature was directly related to both VOC and CO_2 concentrations, implying again that as local ventilation effectiveness increased, temperature was controlled better and VOC concentrations decreased. Nevertheless, several relationships imply surprising effects: a significant relationship between the noise level and temperature, airflow velocity, and VOC concentrations clearly demonstrates the entanglement of the individual parameters. The duct variable was not associated with any variables.

No correlation was seen between the level of symptoms and age, years of education, duration of employment at the institution or the building, time spent in offices, or time spent at computers. Similarly there were no statistically significant relationships between either symptom grouping and any of the environmental measures. The only non-randomly distributed factor detected was that women tended to sit farther downstream along the ventilation ducts (chi-square = 9.68; 2° of freedom: $p < 0.01$). There was no overall relationship between the length of duct work leading to an office and symptoms.

Table 4 summarizes demographic characteristics, work habits, level of symptoms, and air quality parameters for smoking and non-smoking women and men. There was no difference in age or education between gender or smoking categories. Men complained of increased levels of mucous membrane symptoms ($p < 0.10$), sat closer to air-conditioning units ($p < .02$), and were subjected to higher levels of RSP ($p < 0.1$) and noise ($p < .1$) than women. Women worked longer hours elsewhere in the building outside of their own offices ($p < .1$) and were exposed to higher concentrations of volatile organic compounds ($p < .02$) than men. Smokers did not complain of higher levels of mucous membrane symptoms ($p > 0.10$) but were exposed to higher concentrations of RSP ($p < .01$) and lower air velocity ($p < .1$) than non-smokers, who in turn were subjected to higher levels of noise pollution ($p < .1$). Male smokers had begun working more recently at the institution ($p < .1$) but not at the building, worked more hours at computers ($p < .02$), and had less airflow at their workstations ($p < .02$). They had the highest levels of RSP ($p < 0.01$). They also complained of more mucous membrane symptoms than did any other subgroups ($p < .03$). Although VOC were not randomly distributed, their pattern did not fit that of the complaint levels, so no simple relationship between them and complaints may be construed.

Regression models demonstrated significant relationships between environmental exposures but not demographics. Gender, age, years of schooling, length of employment at the institution and in the building, and duration of time spent at their own desk and at computers were unrelated to the level of complaints. In models with exposure measures alone, using only non-collinear variables, RSP, temperature, and relative humidity generally contributed to the models. The coefficient for light intensity often approached statistical significance, but never at the .05 level.

Table 5 presents the results of four models for mucous membrane symptoms as dependent and known factors of interest as independent variables. Because air velocity, relative humidity, and temperature showed some relationship to the level of complaints in models developed using each one separately, regression models for environmental characteristics were developed using the "prediction of draft" variable. Additionally, because of the uneven distribution of males and females along the duct distance, all models were run with and without the "duct" variable. In the simple models, the only variable to consistently and spontaneously enter all four equations was the concentration of RSP. When the sex variable was forced into the forward-stepping model, the duct variable no longer contributed any significant information, although in unforced models the duct variable was a stronger predictor. Smoking status was never clearly associated with the development of symptoms, although associated p-values were generally between .1 and .05. Lighting intensity contributed to two of the models.

In models examining systemic symptoms, RSP were again the strongest predictor of complaints. Smoking status was consistently unrelated, in contrast to mucous membrane symptoms, where there was at least an association. The distance from the air-handling unit, i.e., the duct variable, was also consistently unrelated to symptoms. In two models, light intensity contributed significantly. Interestingly, the sex variable approached statistical significance in all four models, although there was no clear gender effect visible in the analyses of variance.

Most interestingly, carbon dioxide levels failed to demonstrate a consistent significant relationship to either symptom category in any of the equations. When the models were run substituting CO_2 for the ordinal "duct" variable, no substantial difference was noted in the other variable coefficients.

DISCUSSION

The results seen in this cross-sectional study in a single building are consistent with results recently presented elsewhere, namely that complaints attributed to indoor air may in fact be related to specific environmental exposures. On the other hand, carbon dioxide alone was not an indictor of the level of complaints, either across buildings or within a single building.

First, RSP were the strongest predictors of complaints in this data set. Three large cross-sectional studies, without personal sampling, have suggested that IAQ complaints may have a cause. Two (Finnegan et al. 1985; Burge et al. 1987) suggest that they may be related to mechanical ventilation and, specifically, chilling. The third (Skov et al. 1987) suggests that dust aspects may contribute substantially. Fanger et al. (1988) demonstrated that indoor air quality complaints in a series of 20 buildings in Copenhagen were related to several parameters. They attributed approximately 40% of the pollutant load to the ventilation system, approximately 20% to office furnishings, and only 15% to the building occupants. A recent study (Sterling et al. 1987) suggested that indoor air quality is independent of environmental tobacco smoke (ETS). Several subsequent contributions (Repace and Lowrey 1987; McCunney and Caskins 1988) suggest the answer may not be as firm as the authors would like, since anecdotal reports do support a possible connection. In fact, Fanger et al. (1988) have demonstrated that approximately 20% of the pollutant load as perceived by panels of arbiters may be related to ETS. There was no clear evidence that complaints were related to smoking status, although in a data set of this size, failure to demonstrate a significant relationship may well be due to a type-two error.

Other sources of RSP exist in the indoor environment. A case of palpable purpura from a photoactive copy machine has been reported (Tencati 1982). At a northeastern university a case of allergic rhinitis has recently been attributed to printed laser jet printer paper (Skoner, personal communication). Although no published reports are available to demonstrate contamination of duct linings as a major contributor to indoor air quality problems, the idea has been discussed for several years at conferences. The possible relationship of complaints to the distance from the air-handling units may be interpreted as suggesting that the length of ventilation ducts (in this case unlined) contributed to complaints. On the other hand, given the unequal distribution of males and females along the length of ducts, we cannot address the issue with certainty. RSP in buildings may accumulate from ETS, from office machines such as laser jet printers and photocopying machines, and from contaminated duct linings. We are not certain of the source of the dust in this study. Electron microscopic analysis of several dust samples suggested it was a collection of fibers from insulation, environmental tobacco smoke, and spores. Thermal parameters were also related to symptoms, although draft was not. One possible interpretation is that the thermal conditions are not important for humans but, for example, for microorganisms. In any case, future investigations of indoor air quality should focus on respirable and total suspended particulates as serious contributors to indoor air quality complaints.

Interestingly, female gender and educational level failed to predict complaints clearly. Skov et al. (1987) and Burge et al. (1987) both demonstrated a mildly increased rate of complaints among women. This also is consistent with prior studies (Gamble et al. 1986) presented at this meeting. Never-

TABLE 4

Demographics, Symptom Levels, and Environmental Parameters by Smoking and Gender Groups

NS = non-smoker
S = smoker

	WOMEN[1] NS	WOMEN[1] S	MEN[1] NS	MEN[1] S	F-Value Gender[2]	Smoking[2]	Interaction[2]	Explained[2]
Number available	53	12	29	12				
DEMOGRAPHICS								
Age (years)	30.2 (1.0)	29.7 (2.2)	31.9 (1.7)	35.5 (6.4)	1.544 (0.217)	0.347 (0.55)	0.683 (0.410)	0.926 (0.431)
Education (years of school)	16.4 (0.4)	15.0 (0.5)	15.2 (0.6)	15.6 (0.8)	1.747 (0.188)	0.647 (0.423)	0.730 (0.191)	1.463 (0.229)
Duration of employment at the:								
institution (years)	3.2 (0.3)	4.9 (1.3)	3.1 (0.4)	2.4 (0.5)	1.305 (0.256)	0.865 (0.355)	3.086 (0.082)	1.684 (0.175)
building (months)	20.2 (1.6)	22.4 (3.7)	17.0 (2.8)	17.3 (3.0)	2.430 (0.122)	0.231 (0.632)	0.135 (0.714)	0.882 (0.453)
Hours in:								
office	4.9 (0.3)	5.0 (0.5)	5.6 (0.4)	5.3 (0.9)	1.289 (0.259)	0.017 (0.895)	0.067 (0.797)	0.452 (0.716)
Duration of employment at the:								
building	2.8 (0.4)	3.2 (0.5)	1.9 (0.7	1.6 (0.2)	2.430 (0.122)	0.231 (0.632)	0.135 (0.714)	0.882 (0.453)
at a computer	4.2 (0.3)	3.5 (0.5)	2.8 (0.4)	5.0 (1.1)	1.882 (0.173)	1.041 (0.310)	5.999 (0.016)	2.885 (0.039)
SYMPTOM SCORES								
Mucous Membrane Symptoms								
log (sum of mucous membrane symptoms)	1.86 (0.06)	1.73 (0.16)	1.90 (0.09)	2.31 (0.14)	2.817 (0.096)	0.892 (0.347)	5.397 (0.022)	3.163 (0.028)
DIFFUSE SYMPTOMS								
log (sum of diffuse symptoms)	1.91 (0.07)	1.86 (0.16)	1.97 (0.11)	2.25 (0.15)	1.599 (0.299)	0.606 (0.438)	1.756 (0.188)	1.399 (0.248)
ENVIRONMENTAL PARAMETERS								
relative humidity (%)	34.1 (1.3)	34.8 (1.8)	36.3 (1.7)	40.4 (2.6)	2.964 (0.089)	1.200 (0.276)	0.726 (0.397)	1.709 (0.159)
temperature (° Fahrenheit)	74.6 (0.4)	74.8 (0.9)	73.9 (0.5)	75.1 (0.6)	0.702 (0.404)	1.008 (0.318)	0.547 (0.461)	0.698 (0.555)
velocity (feet/minute)	23.5 (1.4)	23.9 (1.4)	25.6 (1.4)	15.6 (3.6)	0.066 (0.798)	3.278 (6.074)	6.327 (0.014)	3.326 (0.026)
carbon dioxide (parts per million)	787 (30)	875 (46)	851 (38)	827 (49)	0.843 (0.361)	0.596 (0.442)	1.357 (0.247)	0.981 (0.405)
particulates (ug/m^3)	31 (0.1)	36 (0.5)	34 (0.2)	50 (0.8)	3.227 (0.075)	8.303 (0.005)	2.339 (0.129)	5.006 (0.003)
formaldehyde (parts per billion)	90 (38)	60 (20)	40[7] —	40[7] —	1.548 (0.219)	0.114 (0.737)	0.092 (0.763)	0.582 (0.629)
volatile organic compounds (parts per million)	0.75 (0.06)	0.60* —	0.40 (0.15)	0.57 (0.01)	6.962 (0.014)	0.437 (0.515)	0.949 (0.339)	2.743 (0.063)
lighting (footcandles)	46 (4)	38 (6)	38 (3)	36 (2)	1.300 (0.257)	0.861 (0.357)	0.172 (0.679)	0.834 (0.47)
noise level (dBA)	58 (1)	55 (1)	62 (2)	56 (2)	3.324 (0.072)	3.063 (0.084)	0.479 (0.491)	2.145 (0.102)
acceleration (Herz)	4.09 (0.70)	3.21 (0.69)	3.13 (0.36)	3.48 (1.35)	0.476 (0.493)	0.166 (0.685)	0.437 (0.511)	0.384 (0.765)

1: Numbers in parentheses are standard errors
2: Numbers in parentheses are p-values
1, 2: One way analysis of variance for groups main effects with interactions (gender smoking)
*: only one value available for calculation

TABLE 5

Results of regression models for mucous membrane symptoms as the dependent variable

Variable	simple	simple (without duct variable)	stepwise backward	stepwise forward (forcing sex and smoking)
	Model			
Adjusted R-squared	.256	.115	.266	.113
p-value	.02	.15	< .01	< .1
Variables				
Sex	−1.38	.486	—	.43
Smoking	1.771+	1.34	1.78+	1.01
Duct length	3.001**		2.35*	—
Log RSP	−3.145**	−2.31*	−3.28**	−2.76**
Draft	0.610	−.82	—	—
Formaldehyde	0.912	.21	—	—
Lighting	2.250*	.94	2.04*	—
Sound	0.391	1.10	—	—

+ $p < 0.100$
* $p < 0.050$
** $p < 0.010$

Draft = 13800 {[(airflow velocity − 0.04)/(temperature − 13.7) + 0.0293]^2 − 0.000857};
RSP = respirable suspended particulates (microgram/m^3);
Duct = an ordinal variable (1, 2, 3) for distance from the central air-handling unit that served that individual room;
RH = relative humidity;
form = formaldehyde concentrations (in ppm);
light = light intensity (foot-candles);
sound = sound pressure level (decibel on the dBA scale)

TABLE 6

Regression models using systemic symptoms as dependent variables

	Simple	Simple (without duct variable)	Stepwise backward	Stepwise forward (forcing sex and smoking)
	Model			
Adjusted R-square	.233	0.259	.286	.318
	<.04	<.02	<.01	<.01
Sex	1.77+	1.85+	1.70+	1.94+
Smoking	1.50	1.56	—	1.60
Duct length	−.09		—	—
Log RSP	−3.53**	−3.64**	−3.93**	−4.32**
Draft	.52	.52	—	—
Formaldehyde	0.22	.20	—	—
Lighting	1.46	1.64	2.22**	2.64*
Sound	−.13	−.15	—	—

+ $p < 0.100$
* $p < 0.050$
** $p < 0.010$

Draft = 13800 {[(airflow velocity − 0.04)/(temperature − 13.7) + 0.0293]^2 − 0.000857};
RSP = respirable suspended particulates (in microgram/m^3);
Duct = an ordinal variable (1, 2, 3) for distance from the central air-handling unit that served that individual room;
RH = relative humidity (in %);
form = formaldehyde (in ppm);
light = light intensity (in foot-candles);
sound = sound pressure level (decibels on the dBA scale)

theless, those studies merely requested information on the presence and frequency of complaints, not on their intensity. Assumptions that women or less educated "pink-collar" workers complain more than traditional "white-collar" workers or those with higher education could not be substantiated in this study, since the authors did not ask about the presence but merely about the intensity of complaints. It is not implied that women complain less than men or that psychodynamic and ergonomic factors are uninvolved. Well-designed studies have demonstrated their importance, and the topic is discussed elsewhere in this symposium. The authors simply wish to point out that the level of indoor air quality complaints may in fact be associated with specific environmental characteristics (elevated RSP, lighting, and possibly thermal parameters). Video display terminal (VDT) operators may have similar exposures to air pollutants as their colleagues. Nevertheless, until specific sampling is done to demonstrate that the exposures of women in offices (who are much more frequently VDT operators than their male colleagues) are the same as those of males, the excess complaint rate among women may be attributed to other factors in addition to their gender.

Carbon dioxide, the parameter most often cited as an indicator of poor ventilation and, at least in the past, used as an indicator of inadequate fresh air provision, did not seem related to complaint levels. This has been pointed out by others (Berglund et al. 1987). This result was elegantly explained by Fanger et al. (1988), who demonstrated that humans and ETS, the primary sources of CO_2, contribute less than 40% of the perceived pollution load in buildings. It is therefore not surprising that no relationship was found.

We are unable to discuss the relationship of our results with those presented by Molhave et al. (1986) for two reasons. First, there were few records in this data set that contained both VOC and RSP. Even in the small sample obtained, there was a statistically significant relationship between VOC and RSP, so that it would not have been legitimate to develop regression models containing both variables. Second, some authors feel that the method used here to measure RSP may in fact be sensitive to the concentrations of VOC where the RSP concentration is low. VOC may simulate the presence of particles through a site-specific "particle production" effect, which occurs locally on the piezobalance itself. This pilot study should therefore not be interpreted as evidence against the VOC hypothesis. On the other hand, no relationship between formaldehyde exposures and the level of symptoms was seen, either in zero-order correlations or in regression models. Only five records contained values that exceeded the minimum detectable levels. This study alone therefore may not be used to discount the importance of formaldehyde and other VOC, specifically since recent studies (Ritchie and Lehnen 1987; Horvath et al. 1988) have demonstrated a higher prevalence of mucous membrane symptoms at formaldehyde concentrations of less than 0.5 ppm and there is some literature suggesting neuropsychological deficits in laboratory technicians and mattress workers may arise from as yet unspecified concentrations.

At least one prior study has suggested that complaints attributed to indoor air quality are indistinguishable from and may be attributed to lighting. Sterling and Sterling (1983) demonstrated that a change in fluorescent lighting may reduce the level of complaints among office workers in the same way as increased provision of outside air. There was a high degree of collinearity between the individual symptoms so that it may not be possible to attribute symptoms of one category solely to an exposure that could be expected to lead to the symptoms. Such a spillover effect has been documented previously (Stellman et al. 1985). Other additional factors such as the thermal parameters that could not be adequately examined in this study, ergonomic issues, and psychosocial measures may interact with RSP and lighting to contribute to the overall comfort in indoor environments.

No pilot study will provide results that may be generalized to the population of sick buildings or to the problem of any air quality-related complaints as a whole. Several results are not inconsistent with prior literature, i.e., the relationship of RSP and lighting with complaints, but should not be overinterpreted at the present time, although they should be clearly considered when designing further studies. Other findings, e.g., the lack of excess symptoms in women or the possible association of duct work with symptoms, have not been seen in the past and must be replicated before they are discussed seriously. This pilot study does suggest, as have prior studies, that the sick building syndrome is not due solely to "inadequate ventilation." It presents a method that may be useful for relating the level of complaints to levels of specific air quality parameters that may prove useful in identifying the actual cause of the rampant complaints among office workers. This method may in fact allow the development of dose-response relationships between exposures and effects. Obviously the study design must be replicated in a larger series of buildings, unselected for the presence of complaints, before the results may be considered important. Until others have replicated the results, one may not assume a true, generalizable relationship. A study using the same methodology in five buildings unselected for the presence of complaints is currently in progress (Hodgson et al. 1989).

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DISCUSSION

Carl N. Lawson, LRW Engineering Inc., Tampa, FL: Were there any stress problems that were related to the project?

M.J. Hodgson, University of Pittsburgh School of Medicine, Pittsburgh, PA: This was an extraordinary building and the occupants were computer scientists in industry consulting jobs, i.e., "soft money" positions, administrative staff (managers, secretaries), and some computer technicians. I have no reason to believe that they were completely happy with their work—they had had complaints for almost two years.

Ed Light, Biospherics, Beltsville, MD: Was the broader study associating occupant complaints with the building completed?

Hodgson: Several engineering studies were conducted in the building. Rebalancing of the system and modifications were undertaken. No attempts have been made to investigate symptoms after these modifications.

William A. Turner, Harriman Associates, Auburn, ME: Back calculating based on present CO_2 levels of 1000 ppm, 140 people, and 50,000 ft^2 suggests low occupant density (three people per 1000 ft^2) less than 7 cfm O.A. per person, and less than .3 ach O.A. Would you characterize this building as a poorly ventilated building with cooling load problems, though meeting suggested ASHRAE 62-1981 ventilation guidelines?

Hodgson: Yes, that is a reasonably apt characterization, although the CO_2 levels were on average lower than 1000. At times, substantially more individuals (up to 100 students using computer labs) occupied the building. There were major problems with ventilation effectiveness.

Lee Hathon, Rocky Mountain Center for Occupational and Environmental Health, University of Utah, Salt Lake City: When designing a questionnaire, should the investigator attempt to uncover if any of the symptoms may be behaviorally induced by workplace stress?

Hodgson: "Workplace stress" is a poorly defined term in this context. Most outbreaks of occupational disease have some contribution of emotional distress. The purpose of identifying organizational stressors and psychological distress varies. In research settings, both are important. When attempting to identify causes of complaints in buildings, those factors must also be identified because if they contribute to the problem, they must be dealt with appropriately if the problem is to be resolved.