#5592

EPA's Indoor Air Quality and Work Environment Survey: Relationships of Employees' Self-Reported Health Symptoms with Direct Indoor Air Quality Measurements

C.J. Nelson C.A. Clayton L.A. Wallace, Ph.D. V.R. Highsmith
M. Kollander R. Bascom, M.D. B.P. Leaderer, Ph.D.

ABSTRACT

In recent years, employees at the three headquarters buildings of the U.S. Environmental Protection Agency (EPA) in the Washington, DC, area have expressed concerns about air quality and work environment discomforts. As part of a large-scale study of health and comfort concerns, environmental monitoring was carried out in March 1989 at approximately 100 sites (rooms) within these buildings. Employees in the vicinity of the monitors were administered a brief questionnaire to elicit information regarding their work environment, comfort levels, odors noticed, health symptoms, mood states, and perceptions of overall air quality. Statistical analyses were carried out for the 191 males and the 192 females for whom both questionnaire and monitoring data were available. The analyses entailed estimation of linear regression and logistic regression models aimed at testing for associations between the employees' responses and the environmental measurements, which included temperature, humidity, carbon dioxide, and particulate concentrations (100 sites), and various microbiologic and volatile organic compound concentrations (subset of 56 sites). Principal component analyses were used to develop some of the outcome and explanatory variables used in the models. In this paper, we describe the study design, the study limitations, the statistical models and methods, and the results and implications of the data analysis.

INTRODUCTION

The quality of the air and the work environment in office buildings has become an increasingly important issue. Workers in numerous modern, apparently well-designed office buildings have raised concerns about their health. Concerns of workers in office buildings fall into several categories, including health symptoms associated with indoor air quality, comfort concerns, and ergonomic symptoms. Indoor air quality health symptoms refer to a complex mix of occupant-reported symptoms associated with acute discomfort (e.g., headache, fatigue, stuffy nose, sinus congestion, eye irritation, sore throat) that improve while away from work. Comfort issues include concerns about air movement, temperature, humidity, odors, and other physical comfort considerations (e.g., lighting, noise). Back pain/stiffness or pain/numbness in shoulders or hands are examples of symptoms associated with ergonomic stresses (repetitive motion or awkward postures).

In recent years, employees in the three headquarters building complexes occupied by the U.S. Environmental Protection Agency (EPA) have expressed concerns about indoor air pollution and work environment discomforts. In response to these concerns, EPA undertook a systematic study of the nature and spatial distribution of employees' health symptoms and comfort concerns. One purpose of the study was to determine if associations exist between employee responses and specific workplace conditions (e.g., measured levels of temperature). This is the focus of this paper. Subsequent sections describe the study design, the study limitations, the statistical models and methods, and the results and implications of the data analysis.

BACKGROUND AND STUDY DESIGN

The EPA headquarters is housed in three separate office complexes located within a several mile radius in the Washington, DC, area. Building A is a complex that includes a central 4-story shopping mall and two 12-story towers. Three additional structures were added during the 1980s. At the time of the study, EPA leased 95,096 m^2 (1,004,450 ft^2) of office space, which was assigned to approximately 3,700 EPA personnel. Building B is a nine-story office building. At the time of the study, four floors (11,457 m^2 [121,015 ft^2]) were leased to EPA and were occupied by approximately 850 EPA employees. Building C is a 14-floor office building of which 4 floors (9,753 m^2 [103,019 ft^2]) were

C.J. Nelson is a Statistician, **Lance A. Wallace** is an Environmental Scientist, and **V. Ross Highsmith** is a Chemist with the U.S. Environmental Protection Agency (EPA), Research Triangle Park, NC; **C. Andrew Clayton** is a Statistician with the Research Triangle Institute, Research Triangle Park; **Mel Kollander** is a Survey Statistician with EPA in Washington, DC; **Rebecca Bascom** is with the Department of Medicine, Division of Pulmonary and Critical Care Medicine, University of Maryland, Baltimore, MD; **Brian P. Leaderer** is an Environmental Scientist, John B. Pierce Laboratory, Yale University, Hew Haven, CT.

assigned to approximately 560 EPA employees at the time of the study.

The ventilation systems for these buildings were not evaluated. In Building A, the system was very complex and consisted of more than 100 AHUs. At the time of the study, EPA had a restricted smoking policy that allowed smoking in designated areas only. Environmental tobacco smoke was not a major problem.

An extensive questionnaire, the Employee Survey Questionnaire, was administered to all employees (approximately 5,000) working in the three EPA complexes. Responses were obtained from 3,955 employees. This questionnaire, administered in February 1989, asked about health symptoms present within the previous year and last week and their relationship to time at work. Extensive questions were also asked about demographic and personal factors, as well as descriptions of the work environment.

The responses to the Employee Survey Questionnaire were used in selecting environmental monitoring sites (rooms/areas). An attempt was made to maximize variability in the survey responses by constructing health and discomfort indices from the data and then selecting rooms exhibiting high values of both indices or low values of both indices (U.S. Environmental Protection Agency 1989a). Twice as many rooms were drawn from the high-health/high-discomfort rooms.

During the week of March 6–10, 1989, monitoring was performed for one day in the selected rooms during normal working hours. At the same time environmental monitoring was being conducted, a second survey, called the supplemental or follow-up survey, was administered to EPA employees in the vicinity of the monitoring sites. This follow-up survey asked about health symptoms, comfort concerns, odors noticed, perception of overall air quality, and mood states on the day the questionnaire was administered and the relationship of the symptoms to the work day. The primary intent of the follow-up survey was to estimate the prevalence of work-related health symptoms in areas where environmental monitoring was being performed. Only the health symptom and air quality perception responses are addressed in this paper.

Selection of Dependent Variables

The statistical analyses focus on those 384 individuals in the study who responded to both the first questionnaire and the follow-up questionnaire. The dependent (outcome) variables on each individual's data record were developed from the health symptoms and air quality responses in the follow-up questionnaire.

Health Symptoms Reported

The follow-up questionnaire furnished information on 33 individual health symptoms:

a. headache
b. nausea
c. runny nose
d. stuffy nose/sinus congestion
e. sneezing
f. cough
g. wheezing/whistling in chest
h. shortness of breath
i. chest tightness
j. burning lungs
k. dry/itching/tearing eyes
l. sore/strained eyes
m. blurry/double vision
n. burning eyes
o. sore throat
p. hoarseness
q. dry throat
r. unusual fatigue or tiredness
s. sleepiness or drowsiness
t. chills
u. fever
v. aching muscles or joints
w. problems with contact lenses
x. difficulty remembering things
y. dizziness/lightheadedness
z. feeling depressed
aa. tension or nervousness
bb. difficulty concentrating
cc. dry or itchy skin
dd. upper back pain or stiffness
ee. lower back pain or stiffness
ff. shoulder/neck pain/numbness
gg. hand/wrist pain/numbness

A binary variable associated with each symptom was first constructed. If an individual's response was "yes" (they had the symptom) and the symptom began "this morning or afternoon at work," the binary variable was assigned a value of 1 (i.e., a positive work-related response); otherwise, the binary variable was assigned a value of zero. One data analysis option would have been to analyze each of the 33 variables separately. However, for most of the individual items, the prevalence of the symptom was relatively rare, thereby hindering the development of meaningful models. Therefore, a method of grouping or clustering health symptoms was needed.

The health symptoms were grouped into 11 clusters formed on the basis of a principal components analysis (PCA) that was applied to the corresponding health symptom data from the first questionnaire (Q1). In particular, a varimax rotation was used to perform a PCA on the five-point scales (responses were "never," "rarely," "sometimes," "often," and "always") through which respondents indicated the frequency of experiencing the various symptoms during the prior year.[1] All Q1 respondents with nonmissing data were included. A PCA analysis was also performed on the binary responses of the 384 respondents of the follow-up questionnaire and similar results were obtained. The eleven clusters developed from the PCA were as follows:

1. Headache or nausea (symptoms a and b)
2. Nasal and cough symptoms (symptoms c, d, e, and f)
3. Chest-related symptoms (symptoms g, h, and i)
4. Eye-related symptoms (symptoms k, l, m, and n)
5. Throat-related symptoms (symptoms o, p, and q)
6. Tiredness (symptoms r and s)
7. Chills or fever (symptoms t and u)
8. Ergonomic (symptoms v, dd, ee, ff, and gg)
9. Mental or nerve symptoms (symptoms x, z, aa, and bb)
10. Dizziness/lightheadedness (symptom y)
11. Dry or itchy skin (symptom cc)

From responses to the follow-up questionnaire, binary variables associated with health symptom clusters were then formed. The response was considered positive if any symptom in the cluster was reported as beginning "this morning or afternoon at work." The health symptoms were also grouped into five clusters that were consistent with those used by both the EPA and NIOSH (U.S. Environmental Protection Agency, 1989a) and analyzed but are not discussed further here.

Table 1 summarizes the frequency of positive responses to the 11 health symptom cluster variates for males and females. For all symptom clusters, the overall percentage of female employees reporting work-associated health symptoms was greater than the percentage of male employees reporting the same symptom. The largest gender differences (female/male) were seen in headache/nausea (27.6/12.0%), nasal symptoms (44.3/28.3%), fatigue/tiredness (31.8/18.8%), and nervous system symptoms (31.8/17.8). Such health symptom complaints have previously been reported as typically higher for women

[1]The symptoms "problems with contact lenses" and "burning lungs" were omitted. The former symptom applies to a very small subset of individuals; the latter symptom was not asked for in Questionnaire 1.

TABLE 1

Percentage of Employees Reporting Health Symptoms That Began at Work on the Day of Environmental Monitoring (by Gender)

Percentage of Employees Reporting Health Symptoms that Began at Work on the Day of Environmental Monitoring by Gender		
Symptom Cluster	Males	Females
Headache, Nausea	12.0	27.6
Nasal, Cough	28.3	44.3
Chest	7.3	8.3
Eyes	35.6	39.6
Throat	20.9	26.0
Tiredness	18.8	31.8
Chills, Fever	6.8	10.5
Ergonomic	17.3	21.9
Nervous System	17.8	31.8
Dizziness, Light-headedness	4.7	6.8
Dry, Itchy Skin	9.4	14.6
Sample Sizes	191	192

than men (Skov et al. 1989). Chest symptoms, chills/fever, dizziness/lightheadedness, and dry/itchy skin were reported by less than 10% of the sample for males. The presence of headaches for males was also fairly low. The low prevalence of these symptoms limited the development of subsequent models (i.e., developing meaningful models for these symptoms was hindered by the small sample size). These five health symptom clusters were analyzed but are not discussed further.

INDOOR AIR QUALITY PERCEPTIONS

Respondents were asked to report their perception of the overall air quality in the vicinity of their work station on the day of environmental monitoring by choosing one of four possible categories: poor, fair, good, or excellent. Based on the frequency of responses to the question, two binary variables were constructed from the data for use as outcome variables in the modeling analysis:

$A1 = 1$ if a poor or fair rating, $A1 = 0$ otherwise.

$A2 = 1$ if a poor rating, $A2 = 0$ otherwise.

Distributional results of the responses for these variables are given in Table 2. The air quality was rated poor by about 11% of the 366 respondents (5% of the 180 males and 17.2% of the 186 females). Air quality was rated as fair or poor by about 47% of the males and by about 65% of the females. Modeling results are confined to variable A1 because of the small sample sizes and the low prevalence of those reporting poor air quality ($A2 = 1$).

SELECTION OF INDEPENDENT VARIABLES

Also associated with each individual were various environmental variables that were measured in his/her workstation area on the same day the questionnaire was filled out. All individuals used in the analyses had temporal variables measured (temperature, relative humidity, carbon monoxide, carbon dioxide, and instantaneous respirable suspended particulates [RSP]) in their area three times a day (morning, midday, and afternoon). These data were available for 100 monitoring sites (383 employees). Viable and nonviable microbiologicals, volatile organic compounds (VOC), integrated nine-hour RSP, passive formaldehyde, and passive nicotine were measured at 56 sites (218 employees). Measurement and analytic methods used to collect the environmental data are discussed more fully in Appendix A.

Temporal Variables

For each parameter, averages of the three temporal measurements were first constructed. These daily averages were then used to produce four exposure variables: average temperature, relative humidity, natural logarithm of the average CO_2 concen-

TABLE 2

Percentage of Employees Reporting Air Quality Concerns on the Day of Environmental Monitoring (by Gender)

Percentage of Employees Reporting Air Quality Concerns on the Day of Environmental Monitoring by Gender		
Air Quality Rating	Males	Females
Poor or Fair	47.2	64.5
Poor	5.0	17.2
Sample Size	180	186

tration, and natural logarithm of the average RSP concentration. The CO data were not used because only 55 of the 514 possible values exceeded the limit of detection.

In addition, two other variables were considered. One was a function of temperature squared and the other was temperature change. Temperature change was retained as a candidate exposure variate; temperature squared, however, was dropped from further consideration because of its high correlation (0.94) with average temperature. A PCA performed on the temporal variates indicated a moderate association between CO_2 and temperature (correlation = 0.54), whereas the other measurements were essentially independent factors.

Table 3 shows the overall means of the temporal variables. The average relative humidity was 24%, which is under the ASHRAE recommended minimum of 30%. The outdoor daytime temperature ranged from about 20°F to 40°F. Other indoor temporal measurements were in the normal range, but the variability was very low. The CO_2 and RSP distributions are summarized in terms of geometric means and standard deviations, since the logarithm of these variables is used in subsequent models.

Volatile Organic Compound and Microbiological Data

Many petroleum-based and/or chlorinated organic solvents have been associated with "sick building syndrome" (Molhave 1984; Otto et al. 1990). In particular, headaches, central nervous system (CNS) complaints (difficulty concentrating, loss of memory), and unpleasant odor have been associated with the presence of organic chemicals. At each of the 56 VOC sampling sites (a subset of the 100 monitoring sites), a single integrated air measurement was made covering approximately a nine-hour time frame. Many of the VOC species measured fell below detection limits for all or almost all sample sites. Nine VOCs, however, had a sufficient number of measurable concentrations to warrant further consideration. They were 1,1,1-trichloroethane, benzene, trichloroethylene, toluene, tetrachloroethylene, ethylbenzene, o- and p-xylene (combined), methylene chloride, and n-octane. In addition, total VOCs (in ppmC or ppm carbon) and integrated RSP concentrations were measured at the same subset of sites.[2]

A PCA was applied to the data set consisting of the nine VOC concentrations to determine if a reduced set of variables would be meaningful. The PCA results suggested that the nine specific VOC concentration variates could be reduced to two major components: (1) two solvent-like compounds, total of the concentrations for 1,1,1-trichloroethane and tetrachloroethylene, and (2) six aromatic-like compounds, total of concentrations for benzene, toluene, trichloroethylene, ethylbenzene, o- and p-xylene, and n-octane. Methylene chloride was treated separately because of its chemical and physical properties and its weak association with the other six aromatic compounds. The other two variables were total VOCs (ppm C) and integrated RSP concentration. Table 4 provides geometric means and standard deviations of the VOC variables and the nine-hour RSP values. Aromatics were the most prevalent class of compounds.

At each site with VOC monitoring, a single air sample was also obtained to measure the presence and concentration of various bioaerosols. Air samples were sent to a laboratory, where they were cultured, quantitated, and further identified (i.e., an assay for *viable* organisms). While this is the current standard assay for microbiologicals in the environment, it does not quantitate nonviable bioaerosols that may also cause health effects. The results were adjusted for the volume of air sampled and are expressed in colony-forming units per cubic metre (Table 4). Due to the low numbers for most species, the bioaerosols were grouped into fungi, human source bacteria (HSB), and thermophiles.

In this study, the outdoor concentrations of fungi were 10 to 1,000 times lower than indicated by ACGIH guidelines (1989) and ranged from 1 to 113 cfu/m^3. The weather was extremely cold during the week of sampling and may have lowered the levels of outdoor samples. The fungal concentrations in the indoor samples were low, with most values ranging from 1 to 45 cfu/m^3. A fungi concentration measured in one area was 883 cfu/m^3 (predominantly *penicillium*). Repeat measurements showed lower levels consistent with measurements previously made in other areas. Three sites had fungal concentration of 105–120 cfu/m^3. These three values were several times less than the 500 cfu/m^3 concentration that the ACGIH implies occurs routinely.

Staphylococci and *micrococci* were the dominant bacteria, which implies that environmental bacteria are not being selectively amplified in the building. Human-source bacteria concentrations measured in EPA headquarters (5–240 cfu/m^3) were very low compared to the guidelines, which suggested 4500 cfu/m^3. The ACGIH guidelines do not have a separate section for the interpretation of data on thermophilic actinomycetes. They state that "actinomycetes are unusual in nonfarm, indoor environments, and their presence indicates that contamination

[2] In contrast to the instantaneous temporal measurements, this RSP measurement was an integrated measurement of approximately nine hours' duration.

TABLE 3
Overall Distributions of Temporally Measured Variables

Overall Distributions of Temporally Measured Variables

Variable	Number of Measurements	Mean	Standard Deviation
Temperature (°F)	100	74.1	2.3
Relative Humidity (%)	100	24.4	4.4
CO_2 (ppm)	100	[561.2]*	[1.2]
RSP ($\mu g/m^3$)	97	[9.1]	[2.3]
Temperature Change (°F)	100	1.6	1.4

* [] are geometric means and standard deviations.

is present." Outdoor samples ranged from 1 to 70 cfu/m^3, and indoor samples ranged from 1 to 140 cfu/m^3. The low concentrations of thermophiles is consistent with the air-sampling data showing low humidity, since these organisms can thrive in warm, damp environments. These data suggested that the range of concentrations of thermophilic actinomycetes in the indoor environment was similar to the range of concentrations found outdoors.

CONFOUNDING VARIABLES

Models for relating employee-reported health symptoms or perceived air quality to the exposure measurements can be influenced by a host of confounding factors. Such confounding variables, both personal/medical (age, gender, smoking, asthma, etc.) and workstation (type of office, carpet in office, etc.), were derived from responses on both the first and follow-up questionnaires. The choice of potential confounders was primarily based upon results of prior studies (Burge et al. 1990; Skov and Valbjørn 1987). Seven potential confounding variables were constructed from responses to the first questionnaire: type of office space, type of eye wear, smoking status, asthma diagnosed by physician, age, gender, and pay plan/grade. In addition, items from the first questionnaire were used to develop seven psychosocial scales: job satisfaction, role conflict, job control, work load, utilization of abilities, role clarity, and external stress. Each scale was constructed so that higher values mean "more" and lower values mean "less" of the stated characteristic (e.g., a high score on "job satisfaction" indicates a high degree of satisfaction, a high score for "work load" indicates a perception of heavy work load). Psychosocial factors such as these have been linked to a wide variety of health symptoms (Caplan et al. 1975; Murphy and Hurrell 1987).

From the follow-up questionnaire, four items were regarded as the main potential confounders: (1) How many hours were spent at your workstation today? (2) Have you gone outside today (yes/no)? (3) How many hours did you spend at a video display terminal (VDT) today? and (4) Have you used chemicals at your workstation today (yes/no)?

In addition to the questionnaire information above, two carpet-related variables were included. One identified rooms that had new carpet installed approximately one year prior to this study and the other indicated whether or not glue was used. (A small group of employees began to report severe symptoms shortly after installation of the carpet began in October 1987. Most of these employees were subsequently assigned to other workspaces. Since they were not working in the building at the time the monitoring study was conducted, they are not included in these analyses.)

Binary variables used as potential confounders are presented in Table 5 by gender. Overall, 81% of the male respondents worked in enclosed offices (includes full-height partitioning). Almost all of the others worked in areas separated by mid-height partitions. Thirty-two percent of females worked in areas with mid-height partitions, 22% in open areas, and 46% in enclosed offices. Seventy percent of the males went outside on the day of sampling as compared to 53% of the females. Six percent of the males and 12% of the females used some form of chemicals at their workstation on the day of sampling. About a third of the responding employees worked in areas with new carpet (since 1987); about half of these were cases in which the carpet was glued down. The distribution of persons by pay grade showed more males in the higher pay grades. The percentage of smokers was generally low. Eighty percent of males and 70% of females wore either contact lenses or glasses, at least sometimes, at work. Eleven percent of the males had doctor-diagnosed asthma, compared to 7% for females.

Table 6 presents means of the continuous potential confounding variables by gender. Females were slightly younger, on average, than males. All other continuous variables were very similar for males and females (i.e., the difference between the female and male means was less than one standard deviation).

TABLE 4
Overall Distributions of Other Environmental Measures

Overall Distributions of Other Environmental Measures

Variable	Number of Measurements	Mean	Standard Deviation
Solvents* (μg/m^3)	56	2.40	0.74
Aromatics** (μg/m^3)	56	3.11	0.45
Methylene Chloride (μg/m^3)	56	0.68	0.81
Total VOCs (μg/m^3)	56	-0.16	0.57
Integrated RSP (μg/m^3)	56	2.29	0.75
Total Fungi (cfu)	56	9.5	4.2
Total Human Source Bacteria (cfu)	56	41.7	1.99
Total Thermophiles (cfu)	56	6.9	8.91

* - Solvents = ln [1,1,1-trichloroethane + tetrachloroethylene]

** - Aromatic Compounds = ln [benzene + trichloroethlene + toulene + ethylbenzene + o- and p-xylene + n-octane]

TABLE 5
Distribution of Potential Confounding Dichotomous Variables (by Gender)

Distribution of Potential Confounding Dichotomous Variables by Gender		
Potential Confounding Variables	Males	Females
Office space:		
Partioned	19.4	31.6
Open Area	None	21.6
Went Outside Today	70.5	52.9
Used Chemicals at Work	6.3	12.5
New Carpet:		
Tacked or Glued	27.7	39.1
Glued	12.6	18.2
Pay Grade:		
Medium	22.5	34.2
High	70.1	33.2
Smoking Status:		
Light	4.7	9.6
Heavy	6.8	5.9
Eye Wear At Work:		
Contacts or Glasses	79.3	69.6
Contacts Only	17.6	25.1
Doctor Diagnosed Asthma	11.1	6.9
Range of Sample Sizes	187-191	187-192

STATISTICAL ANALYSIS METHODS

A series of logistic regression analyses were performed to determine whether reported health symptoms and air quality perceptions were associated with the environmental monitoring results. Thus the dependent variables are those shown in Tables 1 and 2, while the candidate independent variables are those given in Tables 3, 4, 5, and 6. Since there were large gender differences for some of the outcome clusters and different male and female distributions for other variables (e.g., type of workstation), a decision was made to develop separate models for males and females. This is equivalent to an overall model in which gender is included and in which gender is allowed to interact with each of the other independent variables appearing in the model. The decision to use separate gender models was supported by the modeling results, in that gender interactions were often apparent (i.e., only rarely were similar significant effects evidenced for both males and females). The modeling strategy involved four basic steps.

First, stepwise linear regression was used to determine which of the confounding variates (workstation characteristics and personal/medical characteristics) were pertinent. The paired variates associated with workstation, pay grade, and

TABLE 6
Mean Values for Potential Confounding Continuous Variables (by Gender)

Mean Values for Potential Confounding Continuous Variables by Gender		
Potential Confounding Variable	Male	Female
Hours at Workstation	4.4	4.2
Hours at VDT	1.2	1.3
Age in Years	41.9	37.9
Psychosocial Index:		
Job Satisfaction	2.64	2.63
Role Conflict	1.74	1.70
Job Control	3.19	3.08
Work Load	3.61	3.68
Use of Skills	3.26	3.49
Role Clarity	3.60	3.77
External Stress	1.65	1.93
Range of Sample Sizes	184-191	179-192

smoking status were treated simultaneously in the stepwise procedure, so that both members of the pair either entered or failed to enter the model. The temporal variables were included in the model and were not allowed to be dropped at this stage, because testing hypotheses concerning these variables was a primary objective. For each health symptom measure (e.g., nasal, cough), the stepwise procedure was used to arrive at a model for males and a model for females. Because the VOC and microbiological data were available at only a subset of the sites, they were not included at this stage.

The next step involved estimation of a logistic regression model that contained as independent variables the five temporal variables plus those workstation and personal variables that were identified by the stepwise regression procedure as statistically significant at the 0.10 level of significance in either the male or the female model. This model is designated as Model A. Its purpose was to test for the effects of the temporal variables on the reported health symptoms. Appendix B gives a more detailed discussion of logistic regression.

Next a more parsimonious model, upon which subsequent models could be based, was built. This model, Model B, contained the subset of the temporal, workstation, and personal variables in Model A that were found to be statistically significant in either the male or female model. This model was also fit via logistic regression methods.

Finally, Model C[3] was obtained by augmenting the VOC and microbiological variables onto the terms in Model B. Model C tested for the effects of the VOC and microbiological measures on the health outcomes. As previously mentioned, a significant reduction in sample size occurred for Model C estimation as contrasted with the other types of models.

[3]Model C was referred to as Model D′ in Volume III.

RESULTS AND DISCUSSION

Model A was used to test the temporal variables (temperature, relative humidity, carbon dioxide concentration, integrated RSP concentration, and temperature change) for significant associations with the employee-reported health and perceived air quality variables. The sample size for males ranged from 175 to 183 and the sample size for females ranged from 163 to 175. Statistically significant results are summarized in Table 7. In areas that had higher measured CO_2 levels, males reported a significantly higher (0.01 level) prevalence of nasal/cough symptoms. However, in this same model, temperature showed a negative association (0.05 level) with the nasal/cough symptom prevalence. Because the CO_2 and temperature variables were correlated ($r = 0.54$) with one another, it is unclear how to interpret these associations. These counteracting effects may be spurious. Other significant relationships at the 0.05 level included central nervous system (CNS) symptoms with nine-hour RSP (males), fatigue with temperature change (females), and ergonomic symptoms with temperature (females). The sparseness of significant relationships between the outcome measures and the temporal measurements may be due to the

TABLE 7
Summary of Hypothesis Test Results for Model A and Model C

Summary of Hypothesis Test Results for Model A and Model C

INDEPENDENT VARIABLES	DEPENDENT VARIABLES						
	Nasal Cough	Eyes	Throat	Fatigue	Ergo-nomic	Nervous System	Poor/ Fair IAQ
MODEL A:							
Temporal							
Temperature	-m				f		
Relative Humidity							
Log CO_2	M						
Log RSP						m	
Temperature Change				f			
MODEL C:							
VOCs							
Log Solvents					f		
Log Aromatics							
Log Methylene Chloride						f	
Log Total VOC	-m				f		
Log Integrated RSP							-F
Microbiologicals							
Log Fungi	-f		-m, -f				
Log Human Source Bacteria							
Log Thermophiles		-f					

Key: M - Statistically significant at 0.01 level, for males. m - 0.05 level.
F - Statistically significant at 0.01 level, for females. f - 0.05 level.
The negative sign indicates a negative association between the independent and dependent variable.

limited degree of variability in the latter; for example, the humidity ranged from only 18% to 38%.

Model C tested whether levels of VOCs, nine-hour RSP, or microbiologicals were associated with the health symptoms and the general perceptions of air quality reported by the participants. Results are summarized in Table 7. The sample sizes were approximately half those of Models A and B—males ranged from 86 to 99 and females ranged from 100 to 122—because environmental measurements were made at 56 of the 100 possible monitoring sites. The power for detecting associations was further hampered by the fact that the observed levels of the VOCs, integrated RSP, and microbiologicals were uniformly low across the monitoring sites compared to guidelines published by the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE 1989) and the 10 public-access building study (Wallace et al. 1987). In fact, no associations between the VOC, RSP, or microbiological levels with any of the health symptom outcomes occurred simultaneously for both men and women at $p < 0.01$. At the 0.05 level of significance, ergonomic symptoms were associated with increased levels of solvents and total carbon for females. CNS symptoms were associated with increased levels of methylene chloride for females. Nasal symptoms among males increased with decreasing levels of total carbon. Women who reported experiencing nose or throat symptoms had a negative association with fungi levels and a negative association between eye irritation and thermophiles ($p < 0.05$). Males who had throat irritation also had a negative association with fungi. The relationship between the microbiological concentrations and mucous membrane irritation may be an indirect measure of long-term local humidity. Thermophiles are known to increase in warm, moist conditions. While the humidity measured during the study was uniformly low and varied very little, it is possible that greater variation occurs in the building over time. If so, the concentration of thermophiles may reflect variations in average local humidity. Areas that have consistently lower humidity may have lower thermophile concentrations.

This study was unable to establish consistent relationships between measured environmental parameters and self-reported health symptoms among the sampled employees. This inability to find relationships does not preclude the possibility that such relationships might, in general, exist. It should be remembered, for example, that measurements at a given office were made on only one day and may have been atypical (for a number of reasons).

For women, indoor air quality was more often perceived as fair or poor in areas with lower levels of nine-hour RSP. This result may be spurious, since the observed levels of RSP were extremely low. An effect would not be expected because the direction of the effect is counterintuitive.

In developing the above-described models, a number of personal and workstation variables were found to be significantly related to the health symptoms and the perceived IAQ rating. Hundreds of tests were performed and those that were significant at the 0.05 level (Model B) are reported in Table 8. The sample sizes in model B ranged from 180 to 187 for males and from 167 to 184 for females.

Among the workstation variables, three were significant at the 0.01 level: women working in open areas reported fewer eye and ergonomic symptoms and men exhibited a positive association between nasal symptoms and hours spent at a VDT. At the 0.05 level, mid-height partitions showed a positive association with air quality perception for males but a negative association for females. Time spent at work was associated with eye irritation symptoms and fatigue for males at the 0.05 level. Females who used chemicals at their workstation had a positive association with CNS symptoms, but there was a negative association between ergonomic symptoms and the installation of new carpet.

There were no associations significant at the 0.01 level for the personal variables and only a few at the 0.05 level. Age was negatively associated with fatigue for females, and medium pay grade was negatively associated with nasal symptoms for males. Women who wore contacts reported more eye irritation.

For the psychosocial scales, three associations with the dependent variables were found at the 0.01 level and five at the 0.05 level. Males who reported higher external stress also reported higher nasal and eye symptoms. Females who reported fair/poor air quality also reported that they had higher role clarity. Job satisfaction was negatively associated with eye symptoms for females. Males who reported higher throat and CNS symptoms had higher role conflict. Women with a higher work load reported more CNS symptoms, and those who reported that their skills were utilized more reported fewer nasal symptoms.

CONCLUSIONS AND RECOMMENDATIONS

This study was unable to establish consistent relationships between measured environmental parameters and self-reported health symptoms among the sampled employees.

We conclude that in future studies of this type, a pilot study to determine the range of environmental measurement would be helpful. If the low levels and the low variability of these measures had been detected, long-term measurement of the environmental parameters would have been indicated. A larger sample size might also have been drawn to increase the likelihood of finding significant associations between the health symptoms and environmental measures.

Based on the results of the statistical tests summarized here and the study results reported in Volumes I, II, and III (U.S. Environmental Protection Agency 1989a,b, 1990a,b), the following general recommendations can be made. An attempt to maintain the indoor environment in accordance with the ASHRAE guidelines should be made. Dryness of mucous membranes in several analyses and the low humidity indicate that mechanisms for humidifying the indoor air, at least during the winter heating season, should be considered. The environmental measurements in this paper were made only in the winter while the humidity was low. However, humidification should be carefully studied prior to implementation, since it can also increase the potential for additional airborne microbiological agents, which might increase the risk of injury to employees.

REFERENCES

ASHRAE. 1989. *ASHRAE Standard 62-1989, Ventilation for acceptable indoor air quality*. Atlanta: American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc.

ACGIH. 1989. "Guidelines for the assessment of bioaerosols in the indoor environment." Cincinnati, OH: American Conference of Governmental Industrial Hygienists.

Burge, P.S., A.S. Robertson, and A. Hedge. 1990. "Validation of self-administered questionnaire in the diagnosis of sick building syndrome." In Walkinshaw (ed.), *Indoor Air '90: Proceedings of the 5th International Conference on Indoor Air Quality and Climate*, Toronto, Canada, Vol. 1, pp. 575-580.

Caplan, R.D., S. Cobb, J.R.P. French, R.V. Harrison, and S.R. Pinneau. 1975. *Job demands and worker health*. HEW Publication No. (NIOSH)75-105.

Molhave, L. 1984. "Volatile organic compounds as indoor air pollutants." Indoor Air and Human Health, *Proceedings of the Seventh Life Sciences Symposium*, Knoxville, TN, pp. 403-414.

Murphy, L.R., and J.J. Hurrell, Jr. 1987. "Stress measurement and management." In A.W. Riley and S.J. Zaccaro (eds.), *Occupational Stress and Organizational Development*. New York: Prager.

Otto, D., L. Molhave, G. Rose, H.K. Hudnell, and D. House. 1990. "Neurobehavioral and sensory irritant effects of controlled exposure to a complex mixture of volatile organic compounds." *Neurotoxicology & Teratology*, Vol. 12, Nov.-Dec.

Skov, P., and O. Valbjørn. 1987. "The 'sick' building syndrome in the office environment: The Danish town hall study." *Indoor Air '87 Proceedings of the 4th International Conference on Air Quality and Climate* (Seifert et al., eds.). Berlin: Institute of Air, Water, and Soil Hygiene.

Skov, P., O. Valbjørn, and B.V. Pedersen. The Danish Indoor Climate Study Group. 1989. "Influence of personal characteristics, job-related factors and psychosocial factors on the sick building syndrome." *Scand. J. Work Environ. Health*, Vol. 15, pp. 286-295.

TABLE 8
Summary of Hypothesis Test Results for Potential Confounders in Model B

SUMMARY OF HYPOTHESIS TEST RESULTS FOR POTENTIAL CONFOUNDERS IN MODEL B

INDEPENDENT VARIBLES	DEPENDENT VARIABLES						
	Nasal Cough	Eyes	Throat	Fatigue	Ergo-nomic	Nervous System	Poor/ Fair IAQ
WORKSTATION:							
Office Space:							
Mid-Height		i			i		m, -f
Open Area		-F			-F		i
Hours at Work	i	m		m			i
Went Outside							
Used Chemicals						f	
Hours at VDT	M						
New Carpet:							
Tacked or Glued					-f		
Glued	i	i					
PERSONAL:							
Age				-f			
Pay Grade:							
Medium	-m						
High	i						
Smoking History:							
Light	i						
Heavy	i						
Doctor Diagnosed Asthma				i			
PSYCHOSOCIAL SCALES:							
Job Satisfaction		-f					
Role Conflict			m			m	
Job Control					i		
Work Load					i	f	
Use of Skills	-f						
Role Clarity							-F
External Stress	M	M					
EYE WEAR:							
Glasses or Contacts							
Contacts Only		f					

Key:
M - Statistically significant at 0.01 level, for males. m - 0.05 level.
F - Statistically significant at 0.01 level, for females. f - 0.05 level.
i - The term was significant at the 0.10 level in the linear regression model but was not significant at the 0.05 level in this model.
A negative sign indicates a negative association between the dependent and independent variable.

U.S. Environmental Protection Agency, Atmospheric Research and Exposure Assessment Laboratory. 1989a. *Indoor air quality and work environment study: EPA headquarters buildings—Volume I: Employee survey.* Research Triangle Park, NC: U.S. Environmental Protection Agency.

U.S. Environmental Protection Agency, Atmospheric Research and Exposure Assessment Laboratory. 1989b. *Indoor air quality and work environment study: EPA headquarters buildings—Supplement to volume I: Additional employee adverse health effects information.* Research Triangle Park, NC: U.S. Environmental Protection Agency.

U.S. Environmental Protection Agency, Atmospheric Research and Exposure Assessment Laboratory. 1990a. *Indoor air quality and work environment study: EPA headquarters buildings—Volume II: Results of indoor air environmental monitoring study.* Research Triangle Park, NC: U.S. Environmental Protection Agency.

U.S. Environmental Protection Agency, Atmospheric Research and Exposure Assessment Laboratory. 1990b. *Indoor air quality and work environment study: EPA headquarters buildings—Volume III: Relating employee responses to the follow-up questionnaire with environmental measurements of indoor air quality.* Research Triangle Park, NC: U.S. Environmental Protection Agency.

Wallace, L., R. Jungers, L. Sheldon, and E. Pellizzari. 1987. "Volatile organic chemicals in 10 public-access buildings." In *Indoor Air '87, Proceedings of the 4th International Conference on Indoor Air Quality and Climate*, Berlin, Germany, pp. 188–192.

APPENDIX A

MEASUREMENT AND ANALYTIC METHODS USED FOR ENVIRONMENTAL DATA

Real-time temperature and relative humidity measurements were made using a battery-operated psychrometer. Dry- and wet-bulb temperature readings were monitored, and the corresponding relative humidity was determined via the manufacturer-supplied curve.

Real-time CO_2 levels were determined by using portable CO_2 indicators. The battery-operated instruments monitored CO_2 (range 0 to 4,975 ppm) via nondispersive infrared absorption with a sensitivity of 25 ppm. Instrument zeroing and calibration were performed daily prior to use with zero air and a known CO_2 span gas (800 ppm). Confirmations were conducted throughout the period of instrument use.

Real-time RSP concentrations were measured by using a portable, battery-operated instrument that assessed changes in particle concentrations via an infrared detector, centered on a wavelength of 940 nm. Indoor air is sampled (2 L/min) first through a cyclone preselector, which restricts the penetration of particles greater than 9 μm. The air sample then passes through the detection cell. Operating on the 0 to 2 mg/m^3 range with a 32-second time constant yields a resolution of 0.001 mg/m^3.

Integrated RSP samples were collected at the primary sites by passing representative air samples (1.67 L/min) through a preweighed 37 mm filter medium loaded in a millipore cassette. The cassette flow orifices prevent the collection of large particles.

VOCs were collected in precleaned, evacuated (29 in. Hg), polished canisters by using standard EPA monitoring procedures. Randomly selected precleaned canisters were analyzed for the target VOC compounds prior to canister shipment and sample collection. Evacuated canisters were loaded into a sampler downstream of a flow controller calibrated for an inlet flow of 8 to 10 cm^3/min). At the beginning of the sampling period, the canister valve was opened, the canister vacuum recorded, and the indoor air was sampled over the nine-hour monitoring period (approximately a 5 L sample). At the completion of sampling, the final vacuum reading of the canister and time were recorded, and the valve was closed. Sampled canisters were returned to the laboratory for analysis. Representative aliquots of each canister were analyzed for targeted compounds via GC/MS. Additional aliquots were drawn and analyzed by GC/FID without a separation column for total nonmethane VOCs. For the nine VOCs that were used in the analyses, "not detected" values were set equal to 0.5 times the limit of detection (LOD), "trace" values were set equal to 0.5 (limit of quantitation ' LOD), and "not calculated" values were treated as missing values. For integrated RSP concentrations, all missing values and all values less than 10 μg/m^3 were set equal to 5 μg/m^3.

Viable microbiological samples were collected at each primary site, the fixed indoor and outdoor sites, selected locations in the HVAC system, as well as other sites where biological growth was suspected. Samples were collected, using a duplicate sampling protocol, on appropriate growth media by using viable air samplers modified to employ only the sixth stage. The samplers employed inertial impaction at a flow of 1.0 cfm for organism collection into standard 100 cm^3 plastic petri dishes filled with 45 cc of the appropriate agar to ensure adequate plate-to-agar distance. Mesophilic fungi, human-source bacteria, and thermophilic bacteria were collected on malt extract agar (MEA), trypticase-soy agar (TSA), and TSA, respectively. Samples were collected over a five-minute time period. Fungal samples were stored at room temperature. Bacterial and thermophilic samples were refrigerated. Samples were shipped to the laboratory within two days following collection. The mesophilic, human-source bacteria, and thermophilic samples were incubated (25 °C, 37 °C, and 56 °C, respectively). Fungal spores were counted after three to five days of incubation, whereas the bacteria samples were counted after one or two days of incubation. Colony types were identified initially by number, and the most common were identified by genus.

Nonviable samples (fungal spores) were collected using a recording air sampler. Samples were collected for a 24-hour period at four sites per day, Monday through Thursday. The indoor air passes through the sampler (10 L/min) with particles impacting on a greased tape attached to a rotating drum turning at a constant speed. Upon completion of the monitoring study, the samples were returned to the laboratory for spore counting and the determination of eight-hour averaged values.

Measurement and method of analysis of carbon monoxide, passive formaldehyde badges, other aldehyde analysis, pesticides, and passive sodium bisulfate-coated nicotine badges are described in Volume II.

APPENDIX B

DISCUSSION OF LOGISTIC REGRESSION

The logistic regression model offers a way of relating a binary outcome variate to a given set of independent variables. Let Y be a variable taking on values of 0 and 1 only (e.g., one of the health or air quality variables previously defined). Then the logistic model assumes that p, the (true) probability that Y takes on a value of 1, can be modeled as

$$\begin{aligned} p &\equiv \Pr[Y=1] \\ &= 1/\{1+\exp[-(\beta_0+\beta_1X_1+\beta_2X_2+\ldots+\beta_rX_r)]\}, \end{aligned}$$

or, equivalently, that the expected value of the (natural) logarithm of the odds, $\ln[p/1-p)]$, can be represented as

$$\beta_0+\beta_1X_1+\beta_2X_2+\ldots+\beta_rX_r.$$

Maximum likelihood estimation is usually invoked to estimate the βs in the model. Hypothesis tests regarding the βs can be used to address questions such as, "Are different levels of the X variate associated with different proportions, p?" Since such tests rely on the assumption that the estimated parameters are asymptotically normally distributed, they should be regarded as approximate. Predictions of incremental changes in odds can be obtained by exponentiating the estimated βs. If the β is associated with a continuous X variate such as age, then $\exp[\beta]$ is interpreted as the factor by which the odds are estimated to change when a change of one unit in X occurs. If X is a binary variable, then $\exp[\beta]$ is the odds ratio for category 1 vs. category 0. To represent the effect of tertiary variables, two binary variables (e.g., pay grade) are employed in a model. For example, suppose the pay-grade categories are used to form two binary variables as follows:

Low Pay	= 1 = => X1	= 0 and X2 = 0
Medium Pay	= 2 = => X1	= 1 and X2 = 0
High Pay	= 3 = => X1	= 0 and X2 = 1.

The coefficient on $X1$ is then the incremental difference between the low-pay and medium-pay categories, and the coefficient on $X2$ is the incremental difference between the low-pay and high-pay categories. That is, the low-pay category is the baseline category, and the odds ratios are relative to that group. Other variables that had more than two categories were office space and smoking history.

Estimated standard errors for the estimated βs can be used to provide approximate confidence intervals for the βs. Exponentiation of the end points of the 99% confidence interval—that is, $\exp\{\text{est}(\beta_i) \pm 2.576[\text{standard error of est}(\beta_i)]\}$—provides an interval that covers, with approximately 99% confidence, the true odds ratio (in the case of a dichotomous X variable) or the per-unit increment in the odds (in the case of a continuous X variate).