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The National Institute for Occupational Safety and Health Indoor Environmental Evaluation Experience. Part Three: Associations between Environmental Factors and Self-Reported Health Conditions

W. Karl Sieber [a], Leslie T. Stayner [b], Robert Malkin [a], Martin R. Petersen [a], Mark J. Mendell [a], Kenneth M. Wallingford [a], Michael S. Crandall [a], Thomas G. Wilcox [a] & Laurence Reed [b]

[a] Division of Surveillance, Hazard Evaluations and Field Studies

[b] Education and Information Division , National Institute for Occupational Safety and Health , Cincinnati, Ohio, 45226, USA

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The National Institute for Occupational Safety and Health Indoor Environmental Evaluation Experience. Part Three: Associations Between Environmental Factors and Self-Reported Health Conditions

W. Karl Sieber,[A] *Leslie T. Stayner,*[B] *Robert Malkin,*[A] *Martin R. Petersen,*[A] *Mark J. Mendell,*[A] *Kenneth M. Wallingford,*[A] *Michael S. Crandall,*[A] *Thomas G. Wilcox,*[A] *and Laurence Reed*[B]

[A]Division of Surveillance, Hazard Evaluations and Field Studies, and [B]Education and Information Division, National Institute for Occupational Safety and Health, Cincinnati, Ohio 45226

Associations between environmental factors and work-related health conditions were assessed using regression techniques with environmental and health data for 2435 respondents in 80 office buildings included in the National Institute for Occupational Safety and Health Health Hazard Evaluation program. The health conditions analyzed included two symptom groupings—multiple lower respiratory symptoms and multiple atopic symptoms—and the presence of asthma diagnosed after beginning work in the building. Four categories of environmental variables were included: heating, ventilation, and air conditioning (HVAC) system design; HVAC maintenance; building design; and building maintenance. Female gender and age over 40 years showed increased relative risks (RRs) for each health condition. In regression models adjusted for age and gender, RRs of multiple lower respiratory symptoms were increased for variables in the HVAC design and maintenance categories, with the highest RR for presence of debris inside the air intake [RR = 3.1, confidence interval (CI) = 1.8, 5.2] and for poor or no drainage from drain pans (RR = 3.0, CI = 1.7, 5.2). Elevated RRs of multiple atopic symptoms were found for variables in three of the four environmental categories, with the highest for presence of suspended ceiling panels (RR = 2.3, CI = 1.0, 5.5). The RR of asthma was highest if recent renovation with new drywall had been performed (RR = 2.5, CI = 1.4, 4.5). These data are from office spaces about which there was some level of occupant concern, and thus it may not be appropriate to use them to estimate the magnitude and distribution of symptoms found in all office spaces within U.S. buildings. Furthermore, the high degree of correlation among environmental variables makes it difficult to disentangle which are the most important predictors of work-related health conditions. The analysis is useful, however, for determining factors that may be associated with development of health conditions in the office environment and which might be considered in any building plan to reduce indoor air-related symptoms. © *1996 AIH.*

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In recent years, concerns over the increasing numbers of health complaints among workers in indoor, nonindustrial environments have prompted efforts to identify factors associated with building-related health complaints. Etiologic sources have been identified for some outbreaks of building-related illnesses such as Legionnaire's Disease or hypersensitivity pneumonitis (e.g., cooling towers or humidifiers).[1–3] Another group of health complaints involve nonspecific symptoms, sometimes called building-related symptoms or the sick building syndrome. Nonspecific symptoms reported include irritative symptoms of the eye, nose, or throat; dermal symptoms such as dry skin; and central nervous system symptoms such as headache, fatigue, or dizziness.[4,5] The prevalence of nonspecific symptoms has been estimated between 15 and 40 percent,[4] and it has been estimated that 20 percent of office workers experience lost productivity as a result of such symptoms.[6]

Epidemiologic studies of nonspecific health symptoms in office workers have shown the importance of building design characteristics.[7] In studies of the relationship between symptom prevalence and type of ventilation,[4–11] increased prevalence of symptoms has been found in offices with forced ventilation systems, air conditioning, and humidification. Increased nonspecific health symptoms have also been found when interior textile furnishings such as carpets, upholstery, or other fleecy materials with large surface-to-volume ratios are present. It has been suggested that such furnishings may act as depots holding potential irritants which may later be released.[12] The relationship between office cleaning conditions and symptom prevalence has also been suggested.[12] Job category, gender, and age have been found to be associated with symptom prevalence.[10,13] The number of office workers, and office activities such as photocopying and use of video display terminals or carbonless copy paper have been associated with increased prevalence of nonspecific symptoms.[9] Although many general factors associated with the presence of nonspecific symptoms in the indoor nonindustrial working environment have been identified, specific conditions and exposures associated with nonspecific symptom complaints have not necessarily been identified.[1–3,7,9,10]

Following publicity from an October 1992 national television news broadcast, numerous requests for National Institute for Occupational Safety and Health (NIOSH) indoor environmental evaluations were received. Evaluation of a building's indoor working environment may be conducted under the NIOSH Health Hazard Evaluation (HHE) program following formal requests for such evaluations by management, employees, or their union. Such requests resulted in investigations of the indoor working environment in 160 buildings. Standardized environmental and health data were collected during each investigation, and the data were entered into a database. Analyses of data collected from the environmental evaluation and health questionnaire have been reported in companion articles in this journal.[14,15] Analyses of associations between environmental conditions in office buildings and three health conditions (two groupings of nonspecific health symptoms and a diagnosed medical condition) are presented here.

Methods

Data Collection

A full description of methods used in conducting the surveys is presented in Crandall and Sieber[14] and Malkin *et al.*,[15] and are only briefly presented here. All formal HHE requests for indoor evaluations were initially screened to identify specific exposures which might be addressed directly. Due to the large number of requests and limited resources of the HHE program, a sample of buildings for field investigation was then obtained by taking every third request based on those 500 requests which had been received by February 1993. This procedure resulted in the selection of 160 buildings for further investigation. All investigations were conducted between April and July 1993.

As in Malkin *et al.*,[15] we defined a work-related symptom as one that was reported at least once per week in the previous 4 weeks and that improved when the employee was away from the work site. These or similar criteria have, in some studies of indoor air quality, been used to define a work-related symptom.[7–9,11,13]

Two symptom groups were also defined which required a respondent to have more than one work-related symptom as defined above. These symptom groups were defined to correspond with the organ systems involved or to correspond to categorizations used in previous investigations.[7,8,11,13] The multiple lower respiratory group required having at least three of the following symptoms: shortness of breath, cough, chest tightness, and wheezing. The multiple atopic symptom group required all three of the following: sneezing, eye irritation, and stuffy/runny nose/nasal congestion. The presence of asthma diagnosed by a physician after the respondent began work in the building (hereafter referred to as asthma) was also determined.

Much of the symptom data collected from the health questionnaire consisted of incompletely answered questions. When none of the questions about a particular symptom were answered, the symptom was considered not to be present. When some, but not all, information about a symptom was missing in such a way that the symptom status could not be determined, the symptom was treated as a missing value for analysis.

Relationship Between Health Condition, Environmental, and Personal Variables

This analysis was restricted to office buildings, which constituted 105 of the 160 buildings investigated. The remainder were schools, healthcare facilities, and other types of workplaces with limited numbers for analysis. In addition, 25 office buildings were excluded: no symptom data were available for employees in five buildings (investigators had the option of not administering the questionnaire in small workplaces), inappropriate data collection protocols (such as administering the questionnaire to a sample of workers) were used in 14 buildings, and improper identification of the employees to be studied (such as collecting symptom data in an area where no environmental data were collected) was a factor in six of the investigations. This left 80 office buildings for analysis.

Logistic regression[16] was first used in a screening procedure to identify which environmental and demographic variables appeared to be associated with the presence or absence of a health outcome. Each of 67 environmental and demographic variables were tested in models corrected for age (five categories), sex, and smoking status (three categories). For each health outcome, variables that had a significance level of $p \leq 0.10$ were used for further analysis. It was assumed that variables with $p > 0.10$ in the logistic screening procedure would not be significant in subsequent analyses and were therefore not included. All logistic calculations were carried out using Version 6.10 of SAS.[17] Statistical testing was performed using the Wald test.

Estimates of risk were obtained in terms of the relative risk (RR) using the statistical software EPICURE Version 1.8.[18] A multiplicative model was fit, in which the logarithm of the RR was taken as a linear function of the explanatory variables.[19–21] Those variables found in the initial logistic screening to have $p \leq 0.10$ were included, along with gender and age (dichotomized at age 40 years). Smoking status was not strongly associated with any health outcome in the logistic screen, and was not included in further analysis.

Results

Characteristics of the Office Buildings and Office Respondents

Characteristics of the building and evaluation areas are summarized in Table 1. Table 1 shows that the median area of buildings investigated was 55,000 ft^2, with a median of 215 occupants. The evaluation areas, from which questionnaire data were collected from occupants, had a median area of 7500 ft^2, a median of 32 occupants, and a median of 34 workstations. The evaluation area was typically a floor or section of the building. Between 5 and 108 questionnaires were administered per evaluation area, with a median of 30 questionnaires per area. Response rates varied between 47 and 100 percent, with a median response rate of 93 percent.[22]

Demographic variables for respondents to the health questionnaire in office buildings are shown in Table 2. Of the 2435 respondents in evaluation areas of office buildings, 814 (34%) were male, 1607 (66%) were female, and 1304 (54%) were nonsmokers. Respondents ranged in age from under 20 to over 60 years. Overall, they had worked a median 4 years in the office building, although this time varied from less than a year to 35 years.

TABLE 1. Characteristics of 80 Office Buildings Included in Analysis

	Median	Range
Entire building:		
Area (ft^2)	55,000	3475–6,540,360
Number of occupants	215	10–23,000
Evaluation area:		
Area (ft^2)	7500	1000–81,000
Number of occupants	32	1–461
Number of workstations	34	0–300
Number of questionnaires given	30	5–108
Response rate	93%	47–100%

Prevalence of individual symptoms is discussed in Malkin *et al.*[15] Prevalence of health conditions used in this analysis is shown in Table 3. Both asthma diagnosed after beginning work in the building and the multiple lower respiratory symptom grouping had a mean prevalence near 2.5 percent. Prevalence of the multiple atopic symptom grouping was higher (7.6%). The highest prevalence reported by any building was 33 percent for any health condition.

Regression Results

Results from RR regression models adjusted for age and gender are shown in Table 4 by health condition. Table 4 includes results for all environmental and personal questionnaire variables which were found to be associated with any of the three health conditions at $p \leq 0.10$ in a logistic model adjusted for age, gender, and smoking. Table 4 also contains 95 percent confidence intervals (CIs).

Twenty of the environmental variables presented in Table 4 were associated at $p \leq 0.10$ with multiple lower respiratory symptoms. The RRs of multiple lower respiratory symptoms varied between 0.4 and 3.1 for environmental conditions. RRs were elevated for conditions in the heating, ventilation, and air conditioning (HVAC) design and maintenance categories, which included factors such as outdoor air intake within 25 ft of specific pollutant sources, regularly scheduled air handler inspections, condition and cleanliness of the particulate filtration and HVAC systems, and cleaning of the air ductwork, with the highest RR for presence of debris inside the air intake (RR = 3.1, CI = 1.8, 5.2). An RR of 3.0 (CI = 1.7, 5.2) was found for poor or no drainage from drain pans in the HVAC system. RRs were below 1.0 for variables in the building design and maintenance categories, which included variables for fabric wall covering in the evaluation area, cleaning of the area, application of pesticide, and monthly floor stripping and waxing.

Seven environmental variables were associated with multiple atopic symptoms. Except for having an air intake within 25 ft of a cooling tower, increased RRs were found for all environmental conditions associated with multiple atopic symptoms. These included variables for performance of testing and balancing of the HVAC system, general cleanliness of the HVAC system, and cleaning of the air ductwork in the HVAC maintenance category, and variables for suspended ceiling panels, daily surface dusting, and application of pesticide in the building design and maintenance categories. The highest RR of multiple atopic symptoms was for presence of suspended ceiling panels (RR = 2.3, CI = 1.0, 5.5).

Seven environmental variables were associated with asthma. Elevated RRs were found for each except for cleaning variables for the air ductwork and evaluation area. The highest RR of asthma was for renovation including new drywall performed within the past 3 weeks (RR = 2.5, CI = 1.4, 4.5). Other conditions with elevated RRs included dirty particulate filters, debris inside the HVAC air intake, and cloth partitions in the building. Gender and age were included in each model in Table 4, and showed increased RRs with each health condition. When only gender and age were in the model, the RR of multiple lower respiratory symptoms was 2.8 (CI = 1.3, 5.8) for female gender and RR = 2.2 (CI = 1.5, 3.2) for multiple atopic symptoms. The RR of asthma for female gender was 2.9 (CI = 1.4, 5.9), and was the highest for any variable associated with asthma in Table 4.

TABLE 2. Demographic Variables for Respondents in 80 Office Buildings

	N	Percent
Number of respondents	2435	
Sex		
Male	814	34
Female	1607	66
Missing	14	
Smoking status		
Nonsmoker	1304	54
Ex-smoker	670	27
Current smoker	450	19
Missing	11	
Age categories		
<20	10	
20–29	383	16
30–39	734	30
40–49	826	34
50–59	364	15
60+	97	4
Missing	21	
	Median	Range
Years worked in building	4	0–35

TABLE 3. Prevalence of Health Conditions Across 80 Office Buildings

Health Condition	Mean Prevalence	Range
Diagnosed condition		
Asthma diagnosed after beginning work in building	2.6%	0–33.3%
Symptom groupings*		
Multiple lower respiratory (at least three of the following: shortness of breath, cough, chest tightness, wheezing)	2.5%	0–33.3%
Multiple atopic (all three symptoms: sneezing, nasal congestion, eye irritation)	7.6%	0–33.3%

*Symptoms are experienced at least once per week in the last 4 weeks, and improve away from work.

TABLE 4. Relative Risks by Health Condition

Variable Category	Analysis Variable	Health Condition: Multiple Lower Respiratory Symptoms RR	CI[A]	Multiple Atopic Symptoms RR	CI[A]	Asthma Diagnosed After Beginning Work in Building RR	CI[A]
I. Environmental							
HVAC design	Outdoor air intake within 25 ft of:						
	Standing water	2.3[B]	(1.2, 4.3)	1.0	(0.7, 1.6)	0.6	(0.2, 1.7)
	Exhaust vents	2.4[B]	(1.3, 4.3)	1.1	(0.8, 1.7)	1.1	(0.5, 2.3)
	Sanitary vents	2.2[B]	(1.2, 4.1)	1.0	(0.6, 1.5)	0.7	(0.3, 1.8)
	Cooling tower	0.6	(0.1, 2.8)	0.3[B]	(0.1, 0.8)	1.4	(0.5, 3.8)
	Vehicle traffic	1.8[B]	(1.0, 3.5)	1.1	(0.7, 1.7)	1.2	(0.6, 2.6)
	Trash dumpster	2.1[B]	(1.0, 4.6)	0.9	(0.5, 1.8)	1.6	(0.6, 3.8)
HVAC maintenance	No scheduled air handler inspection	2.0[B]	(1.2, 3.6)	1.3	(1.0, 1.8)	1.5	(0.8, 2.6)
	No testing and balancing report available	1.6	(0.9, 3.0)	1.8[B]	(1.3, 2.5)	0.8	(0.4, 1.5)
	Particulate filtration system:						
	Filters not secure in place	2.2[B]	(1.0, 4.6)	0.8	(0.4, 1.5)	0.5	(0.1, 2.2)
	Dirty filters	1.9[B]	(1.1, 3.2)	0.8	(0.5, 1.1)	2.0[B]	(1.2, 3.4)
	HVAC cleanliness[C]	1.8[B]	(1.0, 3.3)	1.3[B]	(0.9, 1.7)	1.4	(0.8, 2.3)
	HVAC condition:						
	Debris inside air intake	3.1[B]	(1.8, 5.2)	1.1	(0.8, 1.5)	2.0[B]	(1.2, 3.5)
	Residue/dirt in drain pans	1.6[B]	(1.0, 2.8)	1.1	(0.8, 1.5)	1.5	(0.9, 2.6)
	Poor or no drainage from pans	3.0[B]	(1.7, 5.2)	1.2	(0.8, 1.7)	1.2	(0.6, 2.3)
	Dirty ductwork	2.1[B]	(1.2, 3.7)	1.2	(0.9, 1.7)	0.6	(0.3, 1.4)
	Presence of moisture in HVAC system	2.2[B]	(1.3, 3.9)	1.2	(0.8, 1.6)	1.1	(0.6, 2.0)
	Air ductwork never cleaned	2.8[B]	(0.9, 9.1)	1.8[B]	(1.0, 3.0)	0.6[B]	(0.3, 1.1)
Building design	Presence of fabric wall covering	0.4[B]	(0.1, 1.0)	0.8	(0.5, 1.2)	1.0	(0.5, 2.0)
	Presence of cloth partitions	1.2	(0.7, 2.1)	0.9	(0.7, 1.2)	1.7[B]	(0.9, 3.1)
	Presence of suspended ceiling panels	3.4	(0.4, 27.2)	2.3[B]	(1.0, 5.5)	3.2	(0.5, 23.5)
Building maintenance	Daily surface cleaning with solution	0.7	(0.4, 1.3)	1.0	(0.7, 1.4)	0.5[B]	(0.2, 1.0)
	Daily vacuuming	0.5[B]	(0.3, 0.9)	1.1	(0.8, 1.5)	0.7	(0.4, 1.2)
	Daily surface dusting	0.6[B]	(0.4, 1.1)	1.3[B]	(1.0, 1.8)	0.5[B]	(0.3, 0.9)
	Interior pesticides have been applied	0.5[B]	(0.3, 0.9)	1.5[B]	(1.0, 2.3)	1.2	(0.6, 2.4)
	Floor stripping and waxing done monthly	0.4[B]	(0.2, 1.2)	1.1	(0.8, 1.6)	0.5	(0.2, 1.4)
	Renovation including installation of new drywall within last 3 weeks	1.1	(0.5, 2.3)	0.8	(0.5, 1.3)	2.5[B]	(1.4, 4.5)
II. Personal and questionnaire data							
Demographic	Female gender	2.8[B]	(1.3, 5.8)	2.2[B]	(1.5, 3.2)	2.9[B]	(1.4, 5.9)
	Age over 40 years old	2.4[B]	(1.3, 4.5)	1.2[B]	(0.9, 1.6)	2.0[B]	(1.2, 3.6)
Work organizational factors	Conflict at job	1.2[B]	(1.1, 1.3)	1.1[B]	(1.0, 1.2)	1.1[B]	(1.0, 1.2)
	Sufficient time to do things on job	1.1[B]	(1.0, 1.2)	1.1[B]	(1.0, 1.1)	1.0	(1.0, 1.1)
	Job category (compared to managerial)						
	Professional	0.8	(0.4, 1.6)	1.0	(0.7, 1.4)	1.6[B]	(0.7, 3.4)
	Technical	0.8	(0.3, 2.0)	1.2	(0.7, 2.0)	2.2[B]	(0.9, 5.3)
	Secretarial/clerical	0.7	(0.4, 1.5)	1.1	(0.7, 1.6)	1.4[B]	(0.7, 3.2)

All models corrected for age and gender.
[A]95 percent confidence interval.
[B]Variable statistically significant at $p \leq 0.10$ for this health condition.
[C]Any one of ten conditions in the HVAC system: dusty air handler, dirty sound liner, presence of debris inside air intake, moist sound liner, dirty coils, residue/dirt in drain pans, poor/no drainage from drain pans, dirty or moist ductwork, or dirty duct liner.

Conflict on the job was associated with all three health conditions; sufficient time to do things on the job was associated with only the two symptom groupings; and job category was associated only with asthma. The highest RR among job categories was for the technical category (RR = 2.2, CI = 0.9, 5.3).

Discussion

In this analysis, RRs for health conditions generally increased for variables in the HVAC maintenance category. In models adjusted for age and gender, increased RRs of multiple lower respiratory symptoms were found for most of the HVAC maintenance variables considered. The availability of a testing and balancing report, cleanliness of the HVAC system, and cleanliness of the air ductwork were associated with multiple atopic symptoms, while the presence of dirty particulate filters, debris inside the air intake, and cleaning of the air ductwork were associated with asthma. Whether the air ductwork was ever cleaned was associated with each health condition. Not cleaning the ductwork resulted in increased RRs for multiple lower respiratory symptoms and multiple atopic symptoms, but a decreased RR for asthma. HVAC design variables for air intake within 25 ft of sources of irritants such as standing water, exhaust vents, sanitary vents, vehicle traffic, or trash dumpsters showed generally increased RRs, especially for multiple lower respiratory symptoms.

Guidelines for maintenance and design of HVAC systems have been developed.[23,24] These guidelines include inspections of many of the conditions included in this analysis. Critical components requiring maintenance include the air intake, air filters, and drain pans. Poor maintenance practices may also result in the introduction of other conditions associated with health conditions in this analysis. For example, dirty air filters may become clogged, or may cause dirt to build up in air ducts, resulting in the need for air duct cleaning.

The presence of multiple indoor air-related problems found in investigations of any single building is not unusual.[25,26] Indeed, many of the environmental conditions in this analysis were found in combination with other conditions. For example, in the 19 buildings with no scheduled air handler inspections, testing and balancing reports were also not available in 7 buildings, particulate filtration system problems were noted in 14 buildings, the lack of cleanliness of the HVAC system was noted in 17 buildings, and the air ductwork had never been cleaned in 6 buildings. Because multiple factors associated with symptoms may exist simultaneously, it is difficult to implicate a specific environmental condition associated with a health condition. A plan to minimize indoor air-related symptoms should include maintenance of, at the least, components indicated in this analysis.

The RRs for multiple atopic symptoms and asthma are increased for building design factors. Of all environmental conditions associated with multiple atopic symptoms, the presence of suspended ceiling panels resulted in the highest RR. Ventilation ductwork may run above ceiling panels, or dust may accumulate there. The materials used to insulate such ventilation systems may provide a substrate for microbial growth, which may in turn cause symptoms in susceptible individuals.[27] The RR for asthma was elevated in the presence of cloth partitions. Cloth partitions may collect irritants which may later be released.[12] Contrary to results from another study,[9] the RR for multiple lower respiratory symptoms was reduced for fabric-covered walls.

Building maintenance practices, including cleaning activities and pest management practices, are included in most air quality guidelines. Although the RRs of multiple lower respiratory symptoms and asthma were reduced when daily housekeeping practices were followed, the RR of multiple atopic symptoms was elevated for daily surface dusting. Daily dusting may serve to release irritants. Renovation, redecorating, and remodeling activities may produce dust, odors, or microbiological exposures.[24] An increased RR of asthma was found for recent renovation including new drywall. The isolation of work areas involving renovation and drywall installation might be prudent.

The RRs for female gender and age over 40 years are elevated for each health condition. Female gender has been found to be associated with indoor air symptoms in other studies.[1,2,7] Although smoking status was included initially in this analysis, it was not strongly associated with any health condition. This may be consistent with smoking being related to chronic symptoms rather than the reversible symptoms temporally related to work conditions, which were analyzed here. Other studies have not shown consistent findings for smoking status.[7]

Limitations in the procedures by which data were collected and in the interpretation and generalizations of the findings here are discussed in Malkin *et al.*[15] Also, in this study, a building was chosen for investigation, and then a questionnaire was given to all occupants in the study space of the building. Correlation between occupants' symptoms in a given building was possible due to common environmental exposures and working conditions. The low RR of multiple atopic symptoms in the presence of an air intake near a cooling tower (RR = 0.3, CI = 0.1, 0.8) may be a result of such correlation. Future analyses of health symptom data in the indoor environment should take correlation between exposures into account.

Further work to characterize indoor exposures which may be associated with indoor air-related health complaints is warranted. Most problems analyzed here involved environmental problems. Problems involving occupant comfort, ergonomic or physical agents, or job-related factors were also noted in these investigations,[14] and associations between such factors and symptom prevalence have been found.[7] Multivariate analytic strategies such as factor analysis or path analysis might be employed to investigate the multifactorial nature of nonspecific health complaints.

Conclusion

The ultimate goal of these analyses is to identify causal factors for health symptoms in indoor environments, which will allow the prevention or reduction of these symptoms. The results presented here do not describe causal relationships between specific factors and health conditions, nor exonerate factors not discussed. These findings may perhaps best be interpreted as identifying indicators of inappropriate building or work space design or maintenance which may represent exposures causing increased health symptoms within office buildings. Since this is a cross-sectional study of nonindustrial office buildings where

environmental evaluations have been requested and performed, the buildings may not accurately represent office buildings as a whole. The analysis is useful, however, for identifying factors, both in the HVAC system and building and work space environment, which may be associated with development of health outcomes in the office environment. As such, the results also indicate the appropriateness of HVAC and building design and maintenance procedures in accordance with existing guidelines. Further analysis of the relationship of health symptoms and building, workplace, and demographic characteristics in both problem and nonproblem buildings would add to our understanding of the causes of work-related symptoms in office buildings.

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