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SBS in the USA -- BUILDING EPIDEMIOLOGY AND INVESTIGATIONS; APPROACHES AND RESULTS

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ABSTRACT. Most epidemiology studies and investigations of Sick Building Syndrome in the United States are conducted in complaint buildings in contrast to Europe where researchers have conducted several important studies in "non-complaint" buildings. Many investigations have been conducted by indoor air experts in relation to litigation, though few of these have been published in the open literature. There is a sizeable body of literature on U.S. investigations of "problem buildings" including two major recent studies of federal government facilities in Washington, D.C. Additionally, the National Institute for Occupational Health and Safety (NIOSH) has published individual reports and several summaries of more than 500 investigations it has conducted into complaint buildings. A lack of standardized protocols, measurement methods, and standards or guidelines for interpretation of results impedes comparison of study results and more rapid improvement in understanding the causes of "problem buildings" and effective action to prevent the problems from occurring. The federal government is now embarking on a program to address these lacks, although funding is rather small to meet the need.

Introduction

While European researchers have conducted many building epidemiology and survey studies in "non-complaint" buildings, relatively few such studies have been conducted in the United States. Most U.S. investigations and studies have involved "complaint" buildings (also variously called "problem buildings," "sick buildings," among other names). Many investigations, some of them quite extensive, have been conducted by indoor air experts in relation to litigation, though few of these have been published in the open literature. In many instances, the law suits are settled before being tried in court, and a condition of the settlement often is that the case not be discussed by the experts who have conducted the investigations.

On the other hand, there is a very large body of literature on U.S. investigations of "problem buildings." These include two major recent studies of federal government facilities in Washington, D.C., the headquarters of the Environmental Protection Agency and an office building of the Library of Congress. Additionally, the National Institute for Occupational Health and Safety (NIOSH) has published individual reports and several overall summaries of 535 investigations it has conducted into complaint buildings.

There are two distinct approaches to understanding the effects of indoor air quality on occupant health and comfort. One is to intensively study one or more "problem buildings," buildings where abundant occupant complaints and reported health effects suggest that there are environmental factors that may be responsible. Here, it is assumed, it should be reasonably easy to find abonormalities in the environment, at least when compared with non-problem buildings. Investigators called in to resolve problems usually do not study a similar population in a non-complaint building as an experimental "control." Epidemiologists sometimes refer to other sutides or do a study of a control building in order to develop a baseline or comparison for the frequency of occupant complaints and health effects reports.

The second basic approach is to investigate a large number of occupants in many buildings, usually buildings not known to have an excessive or unusually high rate of complaints. Here researchers try to find the potential causal environmental factors by identifying the environmental conditions associated with elevated complaint rates where they do occur. There is a very large body of literature on problem building

investigations. Therefore, this review is necessarily selective and incomplete.

SFSSB San Francisco Social Services Building (SFSSB)

The investigation of this building was the first published comprehensive problem building investigation in the United States (Turiel et al, 1983). The office building was subject to occupant complaints from the time it was first occupied. A more recent study by Mendell et al (1991) indicates that the building remains a "problem building" after more than a decade.

An employees' union questionnaire showed a high rate of complaints. An epidemiologic study was conducted by Molly Coye, then of NIOSH, comparing complaint rate prevalence to that of an older building with workers from the same agency. The symptom prevalence was clearly elevated at SFSSB as shown in Table 1. The results are not unlike those from many other studies.

Table 1. Comparison of health-related complaints at SFSS and control buildings.

Symptom Or Complaint	% Positive Responses At SFSS Building	% Positive Responses At Control Building	"p Value"
Eye irritation/itching	54.9	36.1	0.0493
Frequent irritation of nose or throat	52.5	23.5	0.0024
Increased shortness of breath	18.9	3.0	0.0405
Chest tightness	20.6	3.0	0.0268
Eye inflammation/infection	19.5	3.4	0.0586
Skin dryness	35.1	22.4	0.0625

Scientists from Lawrence Berkeley Laboratory conducted extensive environmental measurements and found levels well within established industrial exposure limits. Their measurements were made nearly nine months after the outbreak of complaints, and the exposure levels used for evaluating the results of their monitoring efforts were not established to protect the non-industrial worker. Considerably more sophisticated monitoring methods are now available, and industrial or outdoor air quality standards are no longer considered appropriate for interpretation of indoor air quality monitoring. But more relevant guidance for interpretation of results is still needed. And less obtrusive, less costly monitoring devices are still needed as well.

Carpet Shampoo

Kreiss et al (1982) investigated reported respiratory irritation among most employees in an office building. Symptom prevalence in cases (individuals whose symptoms abated when they left the building) was as high as 10 times the rate reported by other employees. Symptoms persisted for many weeks and even as long as three months, and did not abate until carpets were wet extracted. Three shampoo products implicated in the office building and two similar outbreaks contained sodium dodecyl sulfate, a respiratory irritant in mice. Symptom prevalence was high -- 80 to 100% of the exposed individuals. The authors found

unpublished evidence that soap dust exposure may be associated with abnormal pulmonary function in exposed workers.

National Institute for Occupational Health and Safety (NIOSH)

Melius et al (1984) and later Seitz (1990) have reported on investigations by the Hazard Evaluations and Technical Assistance Branch of the National Institute for Occupational Safety and Health (NIOSH). Since 1971, NIOSH conducted more than 500 investigations presumed related to indoor air quality in various business and government office environments. In addition, it investigated schools and health care facilities. These investigations were initiated after reported complaints and illnesses among occupants.

NIOSH investigators have been presenting the results from their investigations at conferences and in publications since 1984. The presentation has been updated periodically to include more recent results. It usually includes the numbers and types of buildings investigated by year and building type and the "problem type" by number and percent.

Table 2 is from the most recent published version of the data by Teresa Seitz of NIOSH's Cincinnati office. Seitz originally presented the paper at the Indoor Air Quality International Symposium at the American Industrial Hygiene Association's 50th Annual Meeting in St. Louis, May 23, 1989. Nearly everyone who attends an indoor air quality course, seminar, or conference in the United States has seen these data at least once.

Table 2. NIOSH Indoor Air Quality Investigations by Problem Type (Seitz, 1990)

Problem Type	Number Completed*	%
Contamination (inside)	80	15
Contamination (outside)	53	10
Contamination (building fabric)	21	4
Contamination (microbial)	27	5
Inadequate ventilation	280	53
Unkown	68	13
TOTAL	529	100

* Investigations completed through 1988.

WHAT DO THE NIOSH NUMBERS MEAN?

NIOSH officials acknowledge privately and publicly that the numbers in their table do not necessarily define the causes of the problems they investigate. Often NIOSH investigators (like many others) recommend improved ventilation when they are unable to define the etiology of the occupants' complaints. This, the investigators admit, does not necessarily mean that they have demonstrated the presence of a ventilation problem. Indeed, pollutant sources may have caused or contributed to the problem.

Although NIOSH data have been interpreted to mean that ventilation problems caused 53% of the cases they investigated, but in most cases NIOSH investigators made no systematic effort to prove that poor ventilation caused the problems, and identifying the causes is not necessarily the focus of their efforts. Like most investigators of problem buildings, NIOSH teams attempt to alleviate complaints. The NIOSH teams did not follow a standardized protocol, nor did they conduct any routine follow-up to verify that their recommendations worked or were implemented.

Wallingford (1991) says that NIOSH investigators generally have used ASHRAE standards as a basis for comparison. According to Wallingford, of those cases attributed to "inadequate ventilation," roughly

half did not meet ASHRAE Standard 62-1981 for outside air supply rates; about one-quarter did not meet ASHRAE Standard 55-1981 criteria for thermal control and relative humdity. And about a quarter involved other ventilation problems such as poor space air distribution, inadequate filtration, or other ventilation problems observed by the investigators and deemed inadequate according to their professional judgment.

Improving ventilation usually costs less and is more productive than conducting the kind of study necessary to demonstrate the causal relationships between contaminants and occupant responses. Furthermore, in most problem buildings, both owners and occupants are more interested in reducing the effects than in finding the causes. Since it is possible to improve ventilation in nearly every building, whether it has an air quality problem or not, it is almost *de riguer* to recommend improved ventilation. And for nearly every type of indoor air pollutant, increasing ventilation rates and improving ventilation system performance are likely to reduce indoor airborne concentrations. This, in turn, will mitigate the causes of many complaints.

Indoor Air Diagnostics

Woods (1987) conducted numerous investigations while he directed an interdisciplinary investigatory team at Honeywell's Indoor Air Diagnostic Program. Woods, a mechanical engineer as well as a physiologist, indicates that there are usually multiple problems that *could* be causing the occupant symptoms. The results of his work are presented in Table 3. The numbers (given in percent) add up to more than 100 because he includes each type of identified problem that his team defines as potentially contributing to the complaints. Woods says there is usually more than one thing wrong with a problem building.

Table 3. Types of Predominant Environmental Stressors (Woods, 1987)

Type of environmental stressor	Prevalence in problem buildings (percent)
Chemical and particulate contaminants	75
(With odor discomfort)	70
Thermal discomfort	55
Microbiological contaminants	45
Non-thermal humidity problems (With eye irritation and mold growth from low and high relative humidities respectively)	30

Woods says that of all the buildings he investigated, about two-thirds contained SBS and one-third contained Building-related illness (BRI). Like many other authorities, Woods classifies SBS and BRI as distinct types of of building problems. Woods says that you can find SBS without BRI but that you are unlikely to find BRI without SBS. He says he has never seen BRI without SBS. "If BRI is found, you must identify the source and absolutely must mitigate it. A good example of that is Legionnaire's Disease."

Table 4. Frequencies of Occurrence of Physical Causes of Problem Buildings

PROBLEM CATEGORY	PHYSICAL CAUSE	FREQUENCY (%)
Design		
System problems		
	Inadequate outdoor air	75
	Inadequate supply air distribution to occupied spaces	65
	Inadequate return/exhaust air	75
Equipment problems		
	Inadequate filtration of supply air	65
	Inadequate drain lines and drain pans	60
	Contaminated ductwork or duct linings	45
	Malfunctioning humidifiers	20
	Inadequate access panels to equipment	60
Operations		
	Inappropriate control strategies	90
	Inadequate maintenance	75
	Thermal and contaminant load changes	60

Woods' investigation method focuses on the ventilation system, so it may exagerrate the contribution of ventilation by describing its many defects. The ventilation bias reinforces the notion of Lars Molhave that diagnosis of problem buildings usually reflect the disciplinary bias of the lead investigator (Molhave, 1987). Woods' data support the notion that ventilation problems often exist in problems buildings, but the ventilation problem data do not demonstrate the nature of the contaminant sources.

Army Barracks Febrile Acute Respiratory Disease Study

One of the most valuable epidemiological studies in the United States is that of Brundage *et al* (1988) involving comparison of respiratory disease rates among army trainees housed in old and in modern army barracks. The study shows a significantly higher risk of febrile acute respiratory disease (ARD) among trainees housed in the modern barracks. The overall trainee hospital admission adjusted relative risk ratio for the modern barracks was 50% higher than for old barracks.

Old Barracks. The old barracks were single- to three-story structures generally constructed during the 1940s or 1950s of various designs and construction materials. Ventilation was routinely provided by opening windows and running ceiling exhaust fans. Typical heating and air conditioning systems (if present) recirculated more than 50% of previously conditioned air and used approximately 40% outdoor make-up air. Generally, old barracks were divided into open bays housing 20 to 55 trainees per bay.

New Barracks. The new barracks were three-story concrete structures constructed in the late 1970s or 1980s, were nearly identical, and were designed, built and operated to be energy efficient. Mechanical HVAC systems typically recirculated approximately 95% of conditioned air with total circulated air supply of 17 L/s per person [36 ft^3 per minute per person (cfm/p)] -- about three air changes per hour. Although not so stated in the published report, those figures calculate to slightly less than 1 L/s per person (1.8 cfm/p). Dampers for outside air intake were closed except when outside temperatures were within 2.8 °C (5 °F) of inside temperatures. New barracks were divided into platoon-sized open bays housing up to 55

trainees. Although windows were present on two sides of each bay, they were not generally opened in accordance with energy conservation guidelines.

RESULTS

The study reported results in terms of hospital admissions rates for febrile acute respiratory disease (ARD) per 100 trainee-weeks. Overall there were 14,731 admissions during 2,633,916 trainee-weeks, or 0.56 admissions per 100 trainee-weeks. Table 5 shows the results. The overall admission rate per trainee-week in modern barracks was 0.67 (8,028/1,189,433) compared with an admission rate of 0.46 (6,073/1,444,483) in old barracks. The overall rate difference was 0.21 admissions per 100 trainee-weeks with and adjusted relative risk estimate of 1.51 (95% confidence interval, 1.46 to 1.56).

After an initial increase during the second week, the incidence of febrile acute respiratory disease (ARD) stabilized overall during the seven week progress of training in the old barracks while it increased steadily through the fifth of the seven weeks in the modern barracks. It was higher in the modern barracks in each week, and substantially higher during periods when adenovirus vaccines were administered only seasonally rather than year-round. The administration of adenovirus vaccine appears more effective in limiting the incidence of febrile ARD in old barracks than in modern ones.

CONCLUSIONS

The study's authors concluded that "...the increased risk attributable to residence in modern barracks was epidemiologically important, statistically significant, and consistent among the [various training] centers." They also concluded that several of the study's findings "...suggest modern barracks increased ARD risk by facilitating the transmission of respiratory pathogens among immunologically susceptible trainees. Relative risks were consistently and most significantly increased during the period when adenovirus immunizations were not administered."

Table 5. Admission Rate Ratios and Estimated Excess Admissions for Acute Respiratory Disease.

YEAR	MODERN BARRACKS	OLD BARRACKS	RATE RATIO (95% confidence interval)	NO. OF EXCESS ADMISSIONS
		POST JACKSON		
1982	151/34 360	134/40 148	1.32 (1.05-1.66)	41
1983	1998/136 565	1354/184 737	2.00 (1.87-2.14)	1028
1984	416/120 623	651/171 186	0.91 (0.80-1.03)	-33
1985	439/103 063	609/146 541	1.02 (0.91-1.16)	-5
1986	351/56 683	564/104 444	1.15 (1.00-1.31)	48
Subtotal	3355/451 294	3312/647 056	1.45 (1.39-1.52)	1078
		POST SILL		
1982	79/11 048	75/14 428	1.38 (1.01-1.88)	21
1983	674/51 902	489/63 760	1.69 (1.15-1.90)	279
1984	404/52 077	426/58 195	1.06 (0.93-1.21)	-1
1985	245/48 115	205/62 246	1.55 (1.29-1.86)	86
1986	45/14 014	85/29 299	1.03 (0.72-1.48)	-5
Subtotal	1447/178 156	1280/227 928	1.45 (1.34-1.56)	379
		POST McCLELLAN		
1982	110/15 109	79/14 543	1.34 (1.01-1.79)	31
1983	562/62 526	300/53 818	1.61 (1.40-1.85)	213
1984	687/62 338	564/65 596	1.28 (1.15-1.43)	192
1985	216/41 485	162/59 595	1.92 (1.57-2.34)	91
1986	52/10 289	159/36 058	1.15 (0.84-1.57)	14
Subtotal	1627/191 747	1264/229 610	1.54 (1.43-1.66)	542
		POST BENNING		
1982	225/24 348	113/20 990	1.72 (1.37-2.14)	90
1983	705/97 187	279/96 099	2.50 (2.19-2.86)	415
1984	238/102 341	144/95 938	1.55 (1.26-1.90)	84
1985	236/95 537	197/77 400	0.97 (0.80-1.17)	4
1986	195/48 823	114/49 462	1.73 (1.38-2.18)	72
Subtotal	1599/368 236	847/339 889	1.74 (1.61-1.89)	664
		ALL POSTS		
1982	565/84 865	401/90 109	1.46 (1.28-1.65)	183
1983	3939/348 180	2422/398 414	1.94 (1.85-2.04)	1935
1984	1745/337 379	1785/390 915	1.13 (1.06-1.21)	242
1985	1136/288 200	1173/345 782	1.22 (1.12-1.32)	175
1986	643/130 809	922/219 263	1.24 (1.12-1.38)	128
Subtotal	8028/1 189 433	6703/1 444 483	1.51 (1.46-1.56)	2663

Evidence for the higher risk of efficient transmission of pathogens in modern barracks comes from the data acquired during an epidemic in 1983. "Rates increased as training progressed in modern, but not in old, barracks. Contrasts in patterns of progression, supported by virus isolation findings, suggest that pathogenic microorganisms ... were efficiently transmitted, and cycles of infection and clinical disease were propagated primarily among trainees in modern barracks." Rate differences between old and modern barracks were neglible during low overall ARD incidence, after year-round adenovirus immunizations were commenced, and during the early weeks of training. Thus, it does not appear that factors intrinsic to modern buildings were responsible for ARD excesses; and "...reporting or ascertainment biases were not likely explanations for observed differences." The authors did qualify their conclusions by stating that "...potentially significant confounding factors, [such as crowding factors,] precludes a definitive judgment regarding causality."

IMPORTANCE OF THE STUDY

The study is fairly unique among building epidemiologic investigations. Most such studies have been conducted in office or school environments where environmental exposures and other factors outside the study building(s) and population variability can weaken the strength of the findings. Even those done in residential environments have been limited in scope or subject to confounding variation in population or exposure outside the study environments.

The military training population and environmental exposures make them ideal study subjects for several reasons. No geographic or demographic factors are used to assign trainees to training centers or barracks types; all trainees receive identical immunizations; there is minimal contact between members of different barracks-defined groups; activities outside the barracks are rigidly standardized; and all groups at a given training center are exposed to the same outdoor environmental conditions. The training environment is extremely uniform by regulation and intent.

Outbreaks of several important diseases are believed likely or certain to be transmitted by the aerosol route. These include rhinovirus infections, a significant cause of the common cold, rubella, measles, influenza, legionellosis, tuberculosis, and other viral and bacterial diseases. Outbreaks of these diseases "...have been documented among office workers, hospital patients and staff, outpatients, nursing home residents, hotel guests, prison inmates, elementary and secondary school students, and college students. The greatest potential threat is presented during influenza epidemics...[when] it is estimated that 10,000 or more excess deaths occurred in each of 19 different [epidemics] in the United States between 1957 and 1986." The impact is greatest in terms of morbidity and mortality among elderly but also for previously healthy children, adolescents, and young adults. Therefore, during influenze epidemics, indoor airborne-transmitted infections may contribute to thousands of disabling illnesses, and billions of dollars of financial, social, and health costs in a broad segment of the population over an extended period of time." So, if the characteristics of modern buildings of other types impart risks of similar magnitude to those imparted by modern barracks, then modifiable building design characteristics may be significant contributors to morbidity and mortality risk on a nationwide basis.

Investigation of EPA Headquarters Buildings, Washington, D.C.

The environment at the EPA Washington, D.C. headquarters facility at Waterside Mall has received considerable publicity ever since numerous employees complained of health problems following the installation of new carpeting in late 1987 and early 1988. Actually, health and comfort complaints have been reported there for many years. In fact, complaints about the building environment were reported on a National Public Radio broadcast as long ago as 1981 (Zwerdling National Public Radio). When employees publicly protested the building environment in the spring of 1988 the building received national press coverage as a result.

BACKGROUND OF THE STUDY

In March of 1990 EPA conducted a study of its Waterside Mall facility and two other Washington area buildings it occupies. The investigators used a questionnaire survey of building occupants and extensive environmental measurements. The study was one of the most comprehensive building environment studies conducted in the United States to date. EPA conducted the study with the assistance of the National Institute for Occupational Safety and Health (NIOSH), Yale University, and private consultants. The manpower and financial resources expended on it were considerable.

Until recently most of the reported results of the study have been disappointing in light of the investigators' and occupants' expectations and the expense and effort expended. EPA has released the complete results in a four-volume series of reports (EPA, 1991). Earlier volumes reported the results of the questionnaire survey and the environmental measurements. Selected study methods, results, and data analyses of the questionnaire responses were reported by the investigators (Wallace, 1991; Nelson, 1991) at "IAQ '91 - Healthy Buildings."

METHODOLOGY

An important element of Wallace's report was the use of principal component analysis as a statistical method. If building-associated illness is truly a result of multifactorial causes, then effective analysis of investigation results requires methods capable of managing multivariate data. Such data can provide information about the relationships between the variables and about the subjects in the study.

According to S.S. Cohen in his book, *Practical Statistics*, variables can be clustered or searched for combinations of them that as a single measurement account for a large proportion of the total variability in the sample. The linear combination that corresponds to the largest amount of variability is called the "first principal component." After removing the effect of the first principal component, the factor accounting for the most remaining variability is called the "second principal component," and so forth. There are as many principal components as there are variables, but the first few usually explain a significant portion of the total variance and the rest are ignored.

The principal component analysis tries to combine the variables in the data set into a smaller set of "derived measurements" that describe the most salient features of the sample. Each component assembles correlated variables and provides a single value to express their information content.

The Statistical Analyses. The investigators analyzed separately 25 personal and psychological factors and 29 workplace factors included in the questionnaire. They also factored in new carpet and ventilation. They examined the effect of "coarse-grained" location (by building or major building sector) and "fine-grained" location (by 66 air handling unit/floor locations) in the three buildings. They ran numerous statistical analyses on each of 22 health, comfort, and odor factors. The 32 health symptoms clustered into 12 factors, "largely by single body systems such as eye, nose, throat, chest, central nervous system, etc."

They ran all of their regression analyses separately for men and women. In all, then, they ran 68 separate regressions within each set of three linear regressions and one set of logistic regressions. Each regression contained between 20 and 120 personal and workplace characteristics, so thousands of asssociations were investigated. Since this approach increases the likelihood of "false positives," they considered effects significant only if there was no more than one chance in 100 ($p \leq 0.01$) that the association was due to chance.

RESULTS OF THE STUDY

The authors noted an important finding of their study was that headache is the single most common reported cause of absenteeism and lost work time. They also noted that glare appeared associated with headaches, and other ergonomic factors were associated with neck and shoulder pain. They suggested that improvement of the ergonomic design of work stations could be an effective means to improve productivity.

QUESTIONNAIRE RESULTS

About 5,000 EPA employees received the questionnaire, 3,955 (81%) returned it. The results were organized in terms of either comfort and odor factors or in terms of health factors. Wallace concluded that

"...the workplace variable affecting the largest number of health symptoms and comfort/odor concerns was dust. Perceptions of hot, stuffy air and the odor of paint and carpet cleaning and other chemicals were also associated with a number of health symptoms." Glare, noise, and nearby water leaks were also associated with comfort and odor. Seven variables were associated with at least three comfort and odor factors. These are shown in Table 6.

Table 6. Variables Associated[a] with at Least 3 of the 10 Comfort and Odor Factors.

WORKPLACE CHARACTERISTICS	
Dust:	All four comfort concerns and all six odor factors.
Glare:	Hot air; Dry air; Odors of paint; Cosmetics; Dampness.
Noise:	Hot air; Dry air; Cold air Odors of paint and cosmetics.
Use fan:	Hot air; Humid air; Cold air (negative); Odors of cosmetics.
Water leaks:	Odors of dampness; Cosmetics; Tobacco smoke.
PERSONAL CHARACTERISTICS	
Sensitivity to chemical fumes:	Humid air; Odors of paint; Photocopying; New carpet; Tobacco smoke.
Conflicting: demands:	Dry air; Cold air; odors of cosmetics; Photocopying; Dampness; Tobacco smoke.

[a] Significant ($p<0.01$) in at least two (of four) linear and logistic regressions.

The eleven variables associated with at least four of the 12 health factors are shown in Table 7.

Table 7. Variables Associated[a] with at Least 4 of the 12 Health Factors.

WORKPLACE CHARACTERISTICS	
Dust:	Headache; Nasal, chest, eye, throat symptoms; Fatigue; Chills and fever; Difficulty concentrating[b]; Dizziness; Dry skin; Contact lens problems.
Glare:	Headache; Eye Symptoms; Fatigue; Difficulty concentrating; Pain[c].
PERSONAL CHARACTERISTICS	
Sensitivity to chemical fumes:	Headache; Nasal, chest, eye, throat symptoms; Fatigue; Pain; Chills and fever; Difficulty concentrating; Dizziness.
Mold allergies:	Headache; Nasal, eye, throat symptoms; Fatigue; Pain; Dry skin.
No college:	Headache; Chest symptoms; Fatigue; Chills and fever; Dizziness.
PSYCHOSOCIAL CHARACTERISTICS	
Workload:	Headache; Eye symptoms; Pain; Difficulty concentrating; Dizziness.
Conflicting demands:	Nasal, chest symptoms; Chills and fever; Pain; Difficulty concentrating; Dizziness.
COMFORT AND ODOR CHARACTERISTICS	
Hot stuffy air:	Headache; Nasal eye, chest symptoms; Fatigue; Difficulty concentrating; Dizziness.
Dry air:	Headache; Nasal, eye, throat symptoms; Dry skin.
Odor of paint, chemicals:	Headache; Nasal, chest, throat symptoms; Fatigue; Chills; Difficulty concentrating; Dizziness.
Odor of cosmetics:	Eye symptoms; Chills and fever; Pain; Difficulty concentrating.

[a] Significant ($p < 0.01$) in at least two (of eight) linear and logistic regressions.
[b] Includes difficulty concentrating, difficulty remembering, depression, tension.
[c] Includes aching muscles, back pain, shoulder/neck pain, had/wrist pain.l
[d] Significant at $p < 0.01$ in at least two (of four) linear and logistic regressions.

The results did not implicate individual air-handling units. This is not surprising since the number of air handlers serving EPA's portion of Waterside Mall is believed upwards of 50; some sources have said that there are more than 100 serving the entire building complex. Areas with new carpet did have higher incidences of reported throat problems. This is also not surprising, since so much has been made of the problems occurring after new carpet installations at the Waterside Mall facility.

The investigators concluded that "improved maintenance, better recirculation and filtration of air, and glare screens" could improve employee health and productivity. Again, the focus on maintenance problems is a frequent theme in reports of problem building investigations. In fact, it was probably the most common single theme at the ASHRAE "IAQ 91 - Healthy Buildings" conference.

SIGNIFICANCE OF THE STUDY

According to Wallace, "[t]his is the first large-scale building study to employ an objective measure (PCA)

[principal component analysis] to assess the way in which health symptoms cluster together." Wallace writes that authors of "[p]revious studies have subjectively grouped symptoms into clusters, which sometimes contain symptoms belonging to different factors as identified by the more objective PCA. The effect of lumping different factors would likely be to make it more difficult to detect associations."

Another important aspect of the study was that it attempted a census rather than a sample of all the occupants of all three buildings studied. The 81% coverage achieved allowed analysis of the effects of spatial variation including the effects of ventilation and carpet installation. According to Wallace, "These analyses have not been possible in most preceding studies because they typically have involved only a sample of employees from multiple buildings. The Danish [Town Hall] study was also a census, but measurements were made in only one room per building."

Finally, reported health complaints and indoor air quality problems at the EPA facility at Waterside Mall in Washington, DC, have been the subject of so much attention during the past four years, it is valuable to have the results of a fairly comprehensive study. We think that the most surprising study result is that the complaint rates at Waterside Mall were not terribly different from those at the other two facilities in the area.

DISCUSSION OF FINDINGS

Dust. Dust was the strongest contributor to reported effects based on the questionnaire study. These included a wide variety of health, comfort, and odor concerns. The cause is not known, but it could be physical irritation, allergens, or endotoxins. This finding is similar to one from the Danish Town Hall Study (DTHS) where dust was the most highly correlated variable to self-reported health symptoms. Another study, conducted in Sweden by Norback and Torgen, found reduced health symptoms in an office environment following intensive cleaning of carpet and wet dusting. Hedge (1991) reported that increasing recirculation and filtration employing HEPA filters and charcoal reduced occupant symptoms on two floors compared with occupants of two untreated floors.

Perception of dust also contributed most strongly to comfort and odor factors, based on the questionnaire results. Since dust particles may be generated by processes that create odors such as tobacco smoking, printing, or painting, the relatioship between odors and particles may have physical causes, according to the authors. The main odor factor with health associations was composed of the odors of paints, carpet cleaning, pesticides, and other chemicals such as glues and cleansers. Most of these odors are associated with maintenance activities in the building.

Health Symptoms Cluster. The 32 health symptoms clustered into 12 factors, "largely by single body systems such as eye, nose, throat, chest, central nervous system, etc." The authors thought this finding should be useful in designing questionnaires for future studies. This is an important issue not only in questionnaire design but also in analysis of the results. Other investigators have found that the way symptoms or complaints are clustered can affect the results of the studies. A notable example is the Northern Sweden Office Environment Study (Sundell et al, 1991).

Building Maintenance. In the conclusion, the authors wrote: "The importance of dust, mold allergies, the odor of paints and other chemicals, and nearby water leaks in affecting multiple health symptoms and comfort/odor factors points to building maintenance or renovation as a possible factor in the complaints at the three buildings. Therefore, it is recommended that attention be given to ways of improving building maintenance, particularly to reduce dust, clutter, and conditions conducive to growth of mold.... The design of new buildings should allow for adequate building maintenance and should reduce the likelihood of dust buildup. This could include decisions on the optimum extent of carpeting and fabric-covered partitions vs. other, more easily cleaned surfaces; the use of walk-off mats to reduce track-in dust and dirt; and techniques to allow for easy replacement of water-soaked carpet or cleaning and disinfecting water-stained surfaces."

Air cleaning and filtration. The authors note that many office tasks are associated with dust production. Therefore, they recommend consideration of "supplemental air cleaning and filtration." They note that this

would require additional ventilation which might also reduce complaints associated with hot, stuffy air. Some means to achieve reduced dust levels include more frequent, more effective housekeeping, more efficient filters in HVAC systems, increased air circulation, or the use of local fans and filtration systems. We note that there are many vendors available to provide all of these, but it is essential to obtain competent professional assessment of equipment and evaluation of the options.

Library of Congress Study

NIOSH and EPA investigators involved in the EPA Headquarters study have conducted a parallel study on an office building at the Library of Congress (NIOSH, 1991). The results have not provided significant insights into the causes of the problems that have been present there for many years. Some observers believe that although the investigation was costly and extensive, the investigation did not address the problems in an effective manner. Either things were not measured in a useful way, or the wrong things were measured.

Re-Analysis of the European Studies

Mendell and Smith performed a re-analysis of data from British and Danish large-scale building surveys and found a positive association between type of ventilation system and SBS complaint rates. (Mendell and Smith, 1990). Their analysis showed a consistent association between air conditioning and prevalence rates for work-related headache, lethargy, and upper respiratory/mucus membrane symptoms. Humidificaiton was not associated with higher symptom prevalence rates in air conditioned buildings; neither was mechanical ventilation without air conditioning.

California Healthy Buildings Pilot Study

Mendell and colleagues at the California Department of Health Services and Lawrence Berkeley Laboratory have initiated a multi-building investigation intended to elucidate the differences between mechanically ventilated and naturally ventilated buildings. The work reported to date is from a pilot study involving ten buildings. Further work is contemplated for a much larger building population. As of September 1992, the results have not been published.

Microenvironmental Studies

Michael Hodgson of the University of Connecticut School of Medicine has conducted studies in which questionnaires were administered in the same time frame as microenvironmental measurements were made in the subjects' immediate work area. These studies have found positive associations between VOCs or airborne dust concentrations and symptom intensity (Hodgson and Collopy, 1989).

Hodgson and Olesen (1992) more recently reported preliminary results of a pilot study comparing the performance of various questionnaires together with microenvironmental measurements (Hodgson and Olesen, 1992). The results indicate that some of the results from the use of various questionnaires will differ significantly when evaluated in this manner. Further analysis is currently underway.

EPA Large Building Study

The U.S. Environmental Protection Agency (EPA) has initiated a process that will lead to funding of

portions or all of several field studies of large buildings. The basic purpose of the study is to gather normative data and distributions of important environmental factors and occupant responses in a wide range of U.S. office buildings. No field work has commenced as yet, but the program promises to provide a much-needed injection of funding for building investigations in the United States.

Conclusion

It is difficult to identify the causes of health and comfort complaints due to the multitude of factors that separately or in concert affect building occupants. These factors include the building environment and the psychosocial environment. The building environment factors are physical, chemical, biological; the psychosocial environmental factors are personal, interpersonal, and institutional. Most factors are difficult to measure, vary over time, vary from space to space within buildings, and vary regarding their effect on different individuals. To date, U.S. researchers and investigators have had limited success in determining the causes of comfort and health complaints in many problem buildings. New efforts undertaken in California and at the EPA are likely to provide more opportunities for productive investigations and studies in the early 1990s.

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