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BUILDING-RELATED ILLNESSES

Marian C. Marbury, Sc.D.
James E. Woods, Jr., Ph.D.

Since the early 1970s, outbreaks of work-related health complaints have occurred in large numbers in a wide variety of nonindustrial workplaces such as hospitals, schools, and office buildings. In some cases, careful evaluation of the building or the affected population has revealed an agent responsible for the outbreak. In most cases, however, no specific etiologic agent can be identified as its cause.

The investigation described by Turiel and colleagues (Turiel et al. 1983) of an outbreak of health complaints in an office building exemplifies the type of problem occurring in buildings and the difficulty of investigating such problems. This investigation was initiated because of health complaints, primarily eye, nose, and throat irritation, registered by employees in the building. After documentation showed the prevalence of these health complaints to be significantly higher than in a nearby comparison building, the investigators evaluated the outside airflow rates; the indoor air temperature and relative humidity; the microbial burden and particulate mass; the concentrations of formaldehyde and other organics of carbon dioxide, carbon monoxide, and nitrogen dioxide; and the odor perception. Measurements were made with the ventilation system operating in a mode that brought in outside air exclusively and in a recirculation mode that brought in 15 percent outside air and 85 percent inside air. Although concentrations of all contaminants were lower when the ventilation system used outside air exclusively, concentrations of these contaminants were still well below current health standards when the ventilation system was recirculating 85 percent of the air. The investigators concluded that although contaminant concentrations were low, a synergistic effect of the various contaminants could account for the problems experienced by the building occupants.

This outbreak of work-related health complaints and the resulting investigation exemplify the emerging problem of building-related sickness. Although the number of such episodes nationally is not known, there may be hundreds of occurrences annually. Outside experts, either from private firms or from federal, state, or local agencies, are often consulted by management because of persistent health complaints from employees. Through 1985, the National Institute for Occupational Safety and Health alone conducted 356 health hazard evaluations for building-related complaints, and the number of such investigations increases each year (Samet, Marbury, and Spengler 1988). Typically, symptom questionnaires used in the investigations document a high prevalence of nonspecific symptoms that appear to be work related, and industrial hygiene monitoring reveals the presence of a number of contaminants. The contaminants are at such low concentrations, however, that the reported symptoms cannot plausibly be related to them. In some investigations, a walk-through inspection of the building may suggest one or more specific factors as the cause of the problem, and remedial actions may be advised. However, since the efficacy of the recommended changes is rarely evaluated by follow-up, the relationship between the presumed etiologic factors and the outbreak may not be established.

At present, we understand little about building-related health problems. Research has been hampered by the lack of definitions and standardized terminology for describing the health problems, the failure to evaluate outbreaks according to a comprehensive and standardized protocol, and the intrinsic limitation of the cross-sectional epidemiologic approach that has generally been used to evaluate outbreaks. Investigations have been limited mostly to buildings with identified problems, and evaluation of a random sample of buildings has been performed only rarely. In addition, the results of investigations conducted by private firms are usually maintained in confidence to protect management and building operators; this prevents characterization of the nationwide frequency of building-related problems and the types of outbreak which occur.

The lack of standardized nomenclature merits emphasis as a barrier in understanding building-related problems. In the past, diverse health problems in nonindustrial buildings have frequently been grouped together in spite of the heterogeneity of the specific etiologic agents. Outbreaks were frequently labeled as *sick-building syndrome* or *tight-building syndrome* even though a specific etiologic agent had been identified or the affected building was not "tight."

To clarify the terminology, a committee of the National Research Council (NRC) has proposed two distinct categories of illness associated with problem buildings: building-related illness, and sick building syndrome (NRC 1987). Building-related illness comprises illnesses arising from exposure to indoor contaminants that cause a specific clinical syndrome. The most commonly identified forms of building-related illness include nosocomial infections, humidifier fever, and hypersensitivity pneumonitis, all from exposure to bioaerosols (e.g., fungi and bacteria); Legionnaires' disease from exposure to bacteria; and the symptoms and signs characteristic of exposure to chemical or biologic substances such as carbon monoxide, formaldehyde, chlordane, endotoxins, or mycotoxins. The symptoms of building-related illness frequently do not disappear on exit from the building and often affect only a few workers. Successful mitigation of building-related illness requires identification and removal of the source.

In contrast, sick-building syndrome is characterized by an increased prevalence of certain nonspecific symptoms in more than 20 percent of the work force. The most common symptoms are eye irritation, irritation of the mucous membranes of the nose and throat, and lethargy and headache. Relief of these symptoms usually occurs almost immediately on leaving the building. In outbreaks of sick-building syndrome, conventional industrial hygiene monitoring generally does not show individual pollutants to be at unsafe levels. Modification of the ventilation system often eliminates the symptoms of sick-building syndrome.

This dichotomous classification has potential limitations. Building-related illness and sick-building syndrome may occur simultaneously within a building. Furthermore, some cases of building-related illness may have the characteristics of apparent sick-building syndrome. For example, elevated carbon monoxide levels caused an episode of building-related illness in a school when an exhaust fan was accidently reversed and functioned as an intake fan. The fan was situated only a few feet from a boiler stack (Kreiss and Hodgson 1984). Many of the characteristics of sick-building syndrome were present in this episode: a high percentage of teachers and students experienced the symptoms of headache and nausea, but they experienced relief from symptoms soon after leaving the building, and modification of the ventilation system ended the problem. Nonetheless, since the problem could be traced to a specific source and agent, this episode should be classified as a building-related illness.

Outbreaks of building-related illness have been more readily recognized and controlled than outbreaks of sick building syndrome. The frank clinical symptoms usually associated with building-related illness demand the attention of building management and may readily indicate the source of the problem. For example, in one outbreak, cases of allergic alveolitis among office workers led to the identification of contaminated humidifiers as the source of the problem (Banaszak, Thiede, and Fink 1970). Many of the etiologic agents that cause building-related illness and the associated illnesses are described in other chapters of this book and in other published papers (Kreiss and Hodgson 1984; Finnegan and Pickering 1986); this chapter concentrates upon a discussion of sick-building syndrome.

THE OFFICE BUILDING ENVIRONMENT

We describe the complex environment of the modern office building because most outbreaks of sick building syndrome have occurred in such structures. Most contaminants in ambient air can be brought indoors; for example, improperly placed air intake vents may entrain vehicle exhaust or vented air from nearby exhaust systems and plumbing vents. Cigarette smoking and unvented combustion emissions may add particles and gases to the air in an office. Volatile organic compounds (VOCs), including formaldehyde, may be released from adhesives, tiles,

vinyl wall coverings, rugs, office furniture, and wet-process copying machines. Ozone and carbon particulates can be emitted from copying machines, and carbonless copy paper has been shown to cause skin and mucous membrane irritation, although the specific etiologic agent has not been identified (Scansetti 1984). Solvents, cleansers, pesticides, and fibers may also contaminate the air in an office. Microbial contaminants, including fungi and bacteria, may be harbored in niches throughout the building, including heating, ventilating, and air-conditioning (HVAC) systems, carpets, books, floors, and ceiling spaces. Bioeffluents such as butyric acid, an odiferous compound, are contributed by building occupants.

In addition to chemical and biologic contaminants, occupant perceptions of indoor air quality may be affected by other aspects of the environment including temperature, humidity, and lighting. Temperature and humidity are closely related. A building's thermal environment depends on the air temperature and also on the radiant temperature of the surrounding environment, determined by the air velocity and the humidity. Since these other factors vary within a building and as there are individual differences in metabolic rate and clothing styles, satisfying the thermal preferences of more than about 80–90 percent of building occupants can be difficult (NRC 1987). An environment that is too warm creates a perception of stuffiness and inadequate airflow; these environmental conditions can lead to lethargy and fatigue whereas an environment that is too cool can lead to discomfort and inattentiveness. Furthermore, elevated temperatures can lead to increased offgasing of VOCs, and insufficient humidity can cause drying and irritation of the mucous membranes.

Complaints about lighting are common. Satisfaction with artificial lighting depends on both its quantity and quality. The quantity of light is related to the strength of the light source and the distance of the source from the work surface. The quality of light refers to the absence of glare, reflections, and flicker. Inadequate lighting may lead to eyestrain, and glare can cause headaches.

Other aspects of the environment can also alter perceptions of environmental acceptability: the quality and comfort of the furniture, the availability of privacy and adequate personal workspace, the degree of control over the environment and the work pace, and the harmony of relationships among management, supervisors, and the work force (NRC 1987).

EPIDEMIOLOGY OF SICK-BUILDING SYNDROME

The descriptive epidemiology of the sick building syndrome has not yet been well characterized. The incidence and prevalence of the syndrome are unknown although more than 20 percent of office workers have been estimated to be affected (Woods, Drewry, and Morey 1987a). Most investigations have been directed toward identifying risk factors for the sick-building syndrome. These investigations have often been cross-sectional studies of the occupants of a number of randomly chosen buildings with health information collected by a standardized questionnaire. Another approach has been to investigate the role of specific factors considered to be plausible etiologic agents.

In England, Finnegan, Pickering, and Burge (1984) performed one of the first comprehensive epidemiologic studies of sick-building syndrome. These investigators administered questionnaires to the occupants of nine buildings, only two of which had been selected because of employee complaints. Of these nine buildings, three had natural ventilation, one had mechanical ventilation but no conditioning (humidification) of the air, two had air conditioning with no air recirculation, and three had air conditioning with air recirculation. The prevalences of nasal and mucous membrane irritation, headache, and lethargy were all markedly elevated in occupants of the buildings without natural ventilation (Table 14.1). Eye irritation, tight chest, and dry and itchy skin were also reported in excess by occupants of buildings with air humidification in comparison with occupants of buildings with natural ventilation.

In a subsequent study, these investigators ascertained symptom prevalence and performed extensive environmental measurements in two buildings, one with natural and one with mechanical ventilation (Robertson et al. 1985). Rhinitis, nasal blockage, dry throat, lethargy, and headache were again significantly elevated among occupants of the building with mechanical ventilation. However, temperature, relative humidity, moisture content, air velocity, positive and negative ions, and carbon monoxide, ozone, and formaldehyde concentrations were similar in the two buildings.

These cross-sectional studies have provided comprehensive descriptions of the symptoms that most commonly occur in sick-building syndrome and have documented the potentially widespread nature of sick-building syndrome. The comparability of the environmental measurements in the two intensively studied buildings (Robertson et al. 1985) suggests that differences in symptom prevalence cannot be attributed to easily identified environmental factors, a finding consistent with other investigations. However, although these studies suggest strongly that sick-building syndrome is a problem of the modern, sealed office building with its environment controlled by a HVAC system, the cause or causes of sick-building syndrome remain elusive.

A recent large investigation in the United Kingdom demonstrates that the occurrence of sick-building syndrome is not associated directly with the type of ventilation system. Burge and co-workers (Burge et al. 1987) studied 4,373 office workers in forty-two different office buildings with forty-seven different ventilation systems. These systems included natural ventilation (n = eleven), mechanical ventilation without air conditioning (n = seven), local induction units that carried out heating and cooling locally (n = six), central induction/fan coil units (n = ten), and "all air" variable or constant air volume systems that carried out all heating and cooling centrally (n = ten). Similar to previous studies, symptom prevalence was higher in women than in men and, independently of gender, in clerical and secretarial workers than in managers and professionals. As in the study by Finnegan and

Table 14.1 Prevalence (%) of Symptoms in British Workers in Relationship to the Air Supply in Their Office Buildings

	Type of Air Supply			
Symptom	Natural Ventilation (n = 259)	No Humidification or Air Recirculation (n = 73)	Humidification, no Air Recirculation (n = 354)	Humidification, Air Recirculation (n = 477)
Nasal	5.8	13.7	22.4	17.2
Eye	5.8	8.2	28.3	17.6
Mucous membrane	8.1	17.8	37.9	32.6
Tight chest	2.3	1.1	9.6	7.8
Shortness of breath	1.6		4.3	2.9
Wheeze	3.1		5.1	4.4
Headache	15.7	37.0	34.7	39.5
Nosebleed	0.5		1.4	2.2
Dry skin	5.7	5.5	16.2	14.9
Rash	1.9	2.7	3.1	2.9
Itchy skin	2.9	2.7	7.4	7.2
Lethargy	13.8	45.2	49.9	52.5

Source: Adapted from Table II in Finnegan, Pickering, and Burge (1984), with permission.

co-workers (1984), symptom prevalence was highest in buildings with local or centrally supplied induction/fan coil units, which treat air from a room either locally or centrally; intermediate in buildings with all-air variable or constant air volume systems, which treat the air centrally and do not permit local adjustment; and lowest in buildings with natural or mechanical ventilation.

Caution is warranted in interpreting the results of this study. Although Burge and colleagues (1987) reported that their findings are generally consistent with those of Finnegan and Pickering (1986) and Robertson et al. (1985), the symptom prevalences in the report by Burge and colleagues are much higher than in the other studies; for example, in naturally ventilated buildings, the prevalence rates were 40, 50, and 39 percent for blocked nose, headache, and lethargy, respectively. Furthermore, additional analyis showed that the prevalence of symptoms was substantially higher in public sector than in private sector buildings in the study (Hedge et al. 1987). In fact, the prevalence rates of most symptoms in naturally ventilated public sector buildings were comparable to the prevalence rates found in private sector buildings with local or centrally supplied induction/fan coil units. These findings suggest strongly that sick-building syndrome cannot be linked in a simple fashion to the type of ventilation system. In addition, the data demonstrate the need for consideration of potential confounding factors, including gender and job classification, in assessing environmental factors.

The Danish town hall study, a cross-sectional study of more than four thousand workers in fourteen town halls and fourteen affiliated buildings in Copenhagen, represents the largest and most ambitious investigation of sick-building syndrome performed to date (Skov and Valbjørn 1987; Valbjørn and Skov 1987). In addition to the administration of detailed questionnaires concerning work-related symptoms and other factors, the investigators measured environmental factors in one representative office in each of the halls. Preliminary results suggest that a number of work force characteristics are associated with symptom prevalence (Table 14.2) in addition to the "building factor," which appears to represent environmental characteristics (Skov and Valbjørn 1987).

As part of the environmental evaluation in the Danish town hall study, the investigators measured temperature, humidity, air exchange, air velocity, static electricity, airborne particulates, VOCs, formaldehyde, lighting conditions, acoustic conditions, microorganisms, the number of open filled-up shelves, and the amount of fleecy surfaces, including textile floorings, curtains, and seats (Valbjørn and Skov 1987). The investigators calculated a *fleece factor*, the area of all fleecy materials divided by the room volume, and a *shelf factor*, the length of all open shelves and cupboards divided by the room volume. The potentially allergenic part of floor dust, total floor dust weight, the fleece factor, and the shelf factor were found to be associated with both mucosal irritation and headache and fatigue. In addition, the air temperature and the number of workplaces, considered an index of activity, were also associated with headache and fatigue. Although six of the town halls had natural ventilation and eight had varying forms of mechanical ventilation, the type of ventilation system and symptom prevalence were not associated after taking other environmental factors into account.

The investigators hypothesized that the fleece and shelf factors were significantly associated with sick-building syndrome symptoms because both fleecy material and shelves act as sinks for pollutants, which are then released back into the room. This hypothesis is consistent with other Danish data showing a higher prevalence of complaints by occupants of rooms with carpets, which have higher microbial and dust levels, than by occupants of carpetless rooms (Gravesen et al. 1986).

Although the Danish town hall study should provide valuable information on the occurrence and causes of sick-building syndrome, the available reports are too preliminary to allow a complete assessment of either the methods or the data. Although the early results suggest that dust and microbial agents may play an etiologic role, generalization of these results should be cautious. When Harrison and co-workers (1987) studied "clean rooms" in two buildings, that is, rooms with high-efficiency filters, they found that in one room the symptom prevalence was higher than in other parts of the building, whereas in the other room the symptom prevalence was the same as in other parts. In both rooms, however, the levels of particulates, fungi, and bacteria were significantly lower.

These cross-sectional studies have been limited by inadequate characterization of the buildings, including age and size, and the maintenance procedures employed for the HVAC system. Although the type of ventilation system has generally been described, published reports rarely document appropriate assessment of the system's design and operation. For example, the difference in symptom prevalence between occupants of public and private sector buildings with the same type of ventilation in the Hedge study (Hedge et al. 1987) might reflect differences in maintenance or in office crowding. This information is needed to understand the contributions of system design and of system maintenance to the sick-building syndrome.

Table 14.2 Adjusted[a] Odds Ratios (OR) and 95% Confidence Limits (CL) of the Associations Between Work-Related Symptoms in Office Workers and Personal and Job-Related Characteristics, Danish Town Hall Study (Skov and Valbjørn 1987)

	Work-Related Symptoms	
Characteristics	Mucous Membrane Irritation OR (95% CL)	Headache, Fatigue, Malaise OR (95% CL)
Female gender	1.6 (1.3–2.1)	1.8 (1.5–2.3)
History of hay fever	1.6 (1.2–2.1)	NS[b]
History of migraines	NS	1.8 (1.4–2.2)
Smoking ≥10 grams/day	NS	1.3 (1.1–1.6)
Residential air quality problems	NS	1.6 (1.3–2.2)
Job category		
Principal	2.5 (1.0–6.1)	1.1 (0.5–2.1)
Head clerk	2.5 (1.1–5.8)	1.2 (0.6–2.3)
Clerk	3.1 (1.4–7.3)	1.6 (0.8–3.0)
Social worker	1.8 (0.7–4.5)	2.1 (1.0–4.3)
Handling carbonless copy paper	1.3 (1.1–1.6)	1.4 (1.1–1.7)
Photocopying >25 sheets per day	1.5 (1.2–2.0)	NS
VDT work >1 h per day	1.5 (1.2–2.0)	NS
Work not varied	NS	1.3 (1.1–1.6)
Dissatisfied with supervisor	1.7 (1.4–2.0)	NS
Dissatisfied with colleagues	NS	2.0 (1.6–2.6)
Job satisfaction inhibited by work quantity	1.4 (1.1–1.7)	1.7 (1.4–2.1)
Little influence, high work speed	NS	1.4 (1.1–1.7)

[a]Odds ratios adjusted for "building factor."
[b]NS, not significant in the final multivariate analysis.

In another set of investigations, the role of specific agents in causing the sick-building syndrome has been assessed. The suspect agents have included VOCs, "photochemical smog," inadequate concentrations of negative ions, excessive or insufficient relative humidity, and psychological factors, including stress. Although the results of these studies have not been definitive, the findings demonstrate the diversity of agents that may play a role in sick-building syndrome.

VOCs have been considered a potential cause of sick-building syndrome. With new analytical methods, hundreds of VOCs have been found in indoor air (Wallace, Pellizzari, and Gordon 1985). A comprehensive investigation of sick-building syndrome in a San Francisco office building documented the presence of more than forty VOCs, with indoor concentrations sixfold higher than outdoor concentrations (Turiel et al. 1983). Although concentrations of individual VOCs measured in buildings are nearly always substantially below workplace standards, the complex mixtures of VOCs found in indoor air may produce effects that would not be anticipated on the basis of individual concentrations. Further, many of the VOCs have irritant effects and could plausibly contribute to the eye, mucous membrane, and respiratory tract irritation common in sick-building syndrome.

Data from experimental investigations lend support to this hypothesized role of VOCs. Ahlstrom and colleagues (Ahlstrom et al. 1984) exposed healthy volunteers to 0.82 ppm formaldehyde in a chamber. Varying percentages of air from a building in which sick-building syndrome had occurred were added to the chamber. Symptoms of mucous membrane irritation were four times more common when the percentage of air from the office building was increased from 10 to 100 percent.

Molhave and co-workers (1984) exposed sixty-two healthy volunteers, all of whom suffered from sick-building syndrome, to a mixture of twenty-two VOCs commonly found in indoor air. The exposure concentrations of 0, 5, and 25 mg/m^3 corresponded to concentrations found in clean air, in air normally present in new houses, and in very contaminated indoor air, respectively. In a double-blind design each subject was exposed to a concentration of 0 mg/m^3 and to a concentration of either 5 or 25 mg/m^3 mixed VOCs. Subjects rated the air quality unacceptable and reported symptoms of nose and throat irritation and inability to concentrate significantly more often when exposed to VOCs at either 5 or 25 mg/m^3. Additionally, the investigators evaluated objectively the participants' responses to different exposure levels using the digit span test, the graphic continuous performance test, and a trigeminal nerve irritation test (Bach, Molhave, and Pedersen 1984). Performance on the digit span test, which measures the ability to concentrate and short-term memory, was impaired at both exposure levels; the results of other tests were normal.

Kjaergaard and colleagues (1987) studied the response of sixty-three healthy volunteers to *n*-decane at concentrations of 1, 10, 35, or 100 ppm in a controlled double-blind study. This VOC is commonly found in residential and workplace environments although concentrations in office buildings are generally below 10 ppm (Wallace et al. 1987). A dose-response relationship was found between *n*-decane and irritation of the mucous membranes with the increase beginning at the lowest concentration. Tear film stability was decreased in all exposure groups in comparison with the control.

Field investigations of the relationship of VOCs to sick-building syndrome have not confirmed these experimental studies. VOCs were measured in the Danish town hall study (Valbjørn and Skov 1987). Indoor VOC concentrations were low (mean = 1.56 mg/m^3) and not related to symptom prevalence. In another study, Sterling and co-workers (1987) investigated areas with and without complaining workers in an eight-story office building. The two sets of work areas did not differ in the presence of detectable odor, formaldehyde concentrations, temperature, or relative humidity. Although the air changes per hour were lower in the affected as compared with the control areas (0.4 versus 0.1 air exchanges per hour), the concentrations of VOCs were higher on average in the control areas.

These findings do not rule out a causative role for VOCs in some cases of sick-

building syndrome, but they suggest that the role of VOCs may be limited. In new buildings, where VOC concentrations tend to be higher, these compounds may produce sick-building syndrome more often. Wallace and co-workers (1987) found that the concentrations of most VOCs were an order of magnitude higher in three newly constructed buildings when compared with seven buildings that were one to thirteen years in age.

Sterling and Sterling (1983) suggested that the action of ultraviolet radiation from fluorescent lights on VOCs may produce a photochemical smog that is responsible for the symptoms found in sick-building syndrome. To test this hypothesis, the investigators studied the occupants of two buildings, one mechanically ventilated and the other naturally ventilated. On the initial survey of symptoms, the investigators documented a higher prevalence of eye irritation, headaches, dizziness, nausea, sleepiness, and poor concentration in workers in the mechanically ventilated building. Subsequently, the employees completed a questionnaire on symptoms and environmental quality twice a week during the ten-week study period.

Without the employees' knowledge, the investigators varied the percentage of fresh air entering the mechanically ventilated building and replaced the lights with standard cool white fluorescent lights. During the period that a greater percentage of fresh air was circulated, the employees reported an improvement in environmental quality, including better air movement, decreased stuffiness, and more comfortable temperatures. Symptoms of eye irritation decreased 6.8 percent when the ventilation was changed, 8 percent when the lighting was changed, and 31.2 percent when both were changed simultaneously. Reporting of other symptoms also decreased although the changes were not statistically significant. Negative perceptions of environmental quality and reports of eye irritation rose to the levels documented at the start of the experiment when the ventilation and lighting were restored to their original state.

A deficiency of negative air ions has also been postulated to cause sick-building syndrome (Hawkins and Morris 1984). Clinical studies have suggested that excess negative ions can improve concentration and reaction times whereas a deficiency of negative ions (or an excess of positive ions) can cause upper respiratory tract and eye irritation, dizziness, and headaches (Hawkins and Barker 1978; Tom et al. 1981). To evaluate this hypothesis, Hawkins (1981) studied 106 workers over a twelve week period in a double-blind study. He found that increasing the negative ion concentration led to an increased feeling of alertness and reduced complaints of headache, nausea, and dizziness. However, a subsequent study by the same investigators, using a similar design, was not confirmatory (Hawkins and Morris 1984).

Studies by other investigators have also failed to find a beneficial effect of excess negative ions. Finnegan and colleagues (1987) studied twenty-six workers in five different rooms in a building in which occupants had a high prevalence of typical complaints of sick-building syndrome. A negative ion generator was placed in each room for twelve weeks. An on/off switch on the generator indicated that the generator was on for the entire twelve weeks whereas in actuality the generator was turned on in three rooms after four weeks and in the other two rooms after six weeks. The study subjects filled out a daily questionnaire on the environment and their symptoms. Symptom rates did not drop when the generator was on. These investigators also measured the positive and negative ion concentrations in two buildings, one with workers affected by sick-building syndrome and one with unaffected workers, and found no differences in concentrations of ions (Robertson et al. 1985).

Low relative humidity, which has been reported to increase the incidence of upper respiratory infections and to cause dryness and irritation of the eyes and mucous membranes (Arundel et al. 1986), could also plausibly cause sick-building syndrome. Prevalence studies of sick-building syndrome have suggested that occupants of buildings with humidification systems have higher symptom prevalence rates than those in buildings with mechanical ventilation without humidification (Hedge et al. 1987). However, several studies that measured the relative humidity in buildings with and without sick-building syndrome did not show any difference in the humidity level between the two groups of buildings (Robertson et al. 1985; Sterling, Moschandreas, and Relwani 1987).

Several investigators have also suggested that high stress levels, precipitated by the inability to control environmental conditions in a sealed building, poor labor-management relationships, or other human factors may contribute to sick-building syndrome (Breysse 1984; Waller, Atkins, and Partners 1984; Morris and Hawkins 1987). For example, Morris and Hawkins (1987) administered questionnaires concerning symptoms and perceptions of the environment to workers in three buildings in which occupants had previously had high complaint rates. Questionnaires were administered daily to occupants in two buildings for a period of two to four weeks and on one occasion only to occupants of the third building. Little correlation was shown between symptoms and reported environmental conditions that might cause those symptoms (e.g., nasal congestion and low humidity). In addition, daily fluctuations in the prevalence of symptoms were not correlated with temperature and humidity. However, in all three buildings, a higher percentage of people with health complaints complained of stress than did people without complaints.

The studies on psychological factors and sick-building syndrome are inherently limited by use of the cross-sectional design. The temporal relationship between the occurrence of stress and the onset of sick-building syndrome must be described but cannot be addressed in a cross-sectional study. A report of psychological stress could plausibly antedate or follow the occurrence of sick-building syndrome. Longitudinal studies will be needed to investigate the relationship between stress and sick-building syndrome.

The available evidence suggests the improbability of a single cause of sick-building syndrome; instead, the symptoms commonly found in sick-building syndrome are most likely to represent a nonspecific response to an array of environmental stimuli, the particular components of which vary from office to office. For example, in one office, nose and throat irritation might be caused by exposure to irritant chemicals such as VOCs whereas in another these same symptoms might be

due to low relative humidity. By the same token, a ventilation system alone does not cause sick-building syndrome, but when the ventilation is inadequate, regardless of cause, the concentration of pollutants may exceed threshold levels and so produce symptoms. Future research must be directed toward a more complete characterization of the pollutants and environmental conditions most likely to cause sick-building syndrome if the syndrome is to be prevented.

THE ROLE OF HEATING, VENTILATION, AND AIR-CONDITIONING SYSTEMS

HVAC systems probably contribute to the onset of sick-building syndrome by allowing a buildup of pollutants when the capacity of the HVAC system is inadequate. Although an understanding of the pollutants or conditions directly responsible for sick-building syndrome is essential to developing strategies for prevention, a thorough analysis of the HVAC system is often the key to mitigating the problem in a particular problem building.

In a recent paper, Woods (1988) summarized the experience of more than thirty investigations of problem buildings. Although these buildings are probably not representative of all office buildings, the types of problems found are illustrative and will be described in some detail. Woods classified HVAC deficiencies as reflecting operational problems, inadequate system design, or both.

Operational problems can occur even though the system was adequately designed at installation. For example, failure to maintain the HVAC system adequately, exceeding the original design load, and changes in the original control strategies may all render the HVAC's functioning inadequate. Inadequate maintenance may result in the removal or inadequate servicing of air filters, dirty makeup air intakes, fouled and contaminated heating and cooling coils, and contaminated supply air ducts.

The characteristics of a building and the patterns of building use often change during the lifetime of a building. Occupant density frequently becomes higher than initially planned; unanticipated thermal loads, such as lighting and computers, may be added; and new sources of contaminants, such as copy machines and printers, may be installed. The interior of the building may be redesigned, with, for example, partitions erected in an open bay or the sizes of private offices altered. Because of such changes, the total system capacity may no longer be sufficient to meet demands, or the total system capacity may remain adequate for the whole building but with a load imbalance in certain areas which causes locally inadequate ventilation.

Deviations from the original control strategies are probably one of the most common problems. As energy costs increased over the last decade, many building managers sought to economize by reducing the amount of ventilation with outdoor air and increasing the amount of air that was recirculated; by reducing the temperature differentials between supply and return air systems; and by reducing airflow rates to occupied spaces. This approach to energy management was encouraged by a standard promulgated by the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE). This standard, originally known as ASHRAE 90-75, suggested that the previous standard, set in 1973, for the minimum acceptable ventilation rate (ASHRAE 62-73, 5 cubic feet per minute (cfm) per person), should now be used for design purposes (NRC 1981). The subsequent decrease in air quality in buildings prompted a revision of the ventilation standard, ASHRAE 62–1981, which specified the required outdoor air ventilation rate for smoking and nonsmoking spaces (20–30 cfm and 10 cfm/per person, respectively) (ASHRAE 1981).

Inadequate design of HVAC systems has been implicated in many investigations of sick-building syndrome. Some systems lack adequate makeup air for ventilation, particularly those designed to use fixed minimum amounts of outdoor air. HVAC systems may also be supplied with contaminated makeup air from an intake located at ground level, where it may entrain soil or vehicle exhaust, or from a roof intake that entrains air that is cross-contaminated with discharges from cooling towers, plumbing vents, and toilet or other exhaust fans. Poor air distribution may also result from inadequate design, particularly in unducted ceiling return systems, variable air volume systems, and distributed heat pump systems. In addition, inadequate design may result in unbalanced exhaust air, particularly if a central exhaust air system is not in place. Airflow imbalances result from short-circuiting of the supply air.

Many of these problems can be identified during a walk-through investigation involving the gathering of complaint information from office managers, affected employees, and facility engineers, and an examination of the HVAC system and the control strategies in use. A smoke pencil, a complete set of mechanical plans and specifications, and the availability of the facility engineer along with direct-reading instruments for measuring temperature, humidity, and CO_2 levels are usually essential for the initial assessment. More detailed aspects of HVAC system analysis, system performance simulations, air sampling, and questionnaire assessment should be deferred until a later stage of evaluation, which is frequently not necessary.

FUTURE DIRECTIONS

In the past five years, the concept of sick-building syndrome as a distinct phenomenon, albeit one with diverse and poorly understood etiologies, has received increasing scientific and lay acceptance. Growing understanding that sick-building syndrome and building-related illness are related but fundamentally different problems has also helped focus scientific effort. We anticipate better understanding of the causes and prevention of sick-building syndrome in the next decade from more refined epidemiologic approaches and the use of multidisciplinary investigative teams. To be more informative, the new epidemiologic studies must assess a sample of buildings, and not only buildings with identified problems. The new studies must incorporate objective measures of health outcomes rather than relying solely on questionnaire assessments of symptoms. High response rates must be achieved to reduce selection bias, and confounding variables must be considered and their effects controlled. Appropriate control populations must be selected.

The use of multidisciplinary teams to investigate outbreaks should also improve our understanding of sick-building syndrome. Typically, the protocol for the evaluation of a building varies with the expertise of the lead investigator. Building engineers focus on the HVAC system; industrial hygienists measure chemical contaminants; ergonomic specialists address lighting, acoustics, and furniture design; architects evaluate workplace design; and physicians are generally concerned with microbial agents. Consequently, understanding of what sick-building syndrome is and what causes it has varied with the investigator. It is clear, however, that sick-building syndrome is multifactorial in nature, and the physical, psychological, and biologic factors must all be considered.

SUMMARY

Although scientific uncertainties remain, the cost of sick-building syndrome has become increasingly apparent. Sick-building syndrome was initially considered to be a comfort problem that was perhaps less important than the money saved by

Table 14.3 Criteria for Characterization of Healthy Buildings

Human responses Criteria must be met for building to be characterized as healthy	No known clinical signs of building-related illness among any building occupants Frequency of reported sick-building syndrome symptoms and complaints of discomfort should be below 20 percent
System performance Criteria must be met for building to be characterized as healthy	Compliance with environmental criteria Ventilation efficiencies for each space should exceed 80% Energy management strategies should not compromise environmental acceptability Outdoor air for ventilation should not be contaminated by exogenous or endogenous sources (e.g., combustion products or cross-contamination for exhaust air) Supply and return air ductwork should not be conducive to contaminant accumulation Exhaust air systems should be balanced with makeup air systems to assure acceptable ventilation in all occupied spaces Systems should be designed for ease of maintenance
Service factors Criteria should be met to assure continued acceptable building performance	Records should be established to document occupant complaints and symptoms; structured preventive maintenance should be instituted to include: • Periodic inspections and routine procedures for all components comprising the HVAC system • Scheduled filter changing or cleaning • Scheduled control calibration • Scheduled air and hydronic balancing of systems

emphasizing energy efficiency. More recently, however, the high dollar costs of sick-building syndrome in terms of employee productivity and morale have been recognized (Woods et al. 1987).

Recognition of the cost of sick-building syndrome has prompted attention to the conditions necessary to keep buildings "healthy," that is, free of problems. Woods (1988) suggested recently that healthy buildings can be characterized in terms of three sets of criteria: human responses, system performance, and service factors (Table 14.3). Although the proposed criteria will undoubtedly undergo refinement and expansion, they nonetheless provide guidance to the individuals responsible for the design, construction, and maintenance of buildings. This new emphasis on the conditions necessary to create an acceptable environment should help to prevent future cases of sick-building syndrome.

REFERENCES

Ahlstrom, R., et al. 1984. Odor interaction between formaldehyde and indoor air of a sick building. In *Proceedings of the third international conference on indoor air quality and climate*. Ed. B. Berglund, T. Lindvall, and J. Sundell, Vol. 3, 349–53. Stockholm: Swedish Council for Building Research.

American Society of Heating, Refrigerating, and Air-Conditioning Engineers, and American National Standards Institute. 1981. *ASHRAE/ANSI standard 62-1981: Ventilation for acceptable indoor air quality.* Atlanta, Ga.: ASHRAE.

Arundel, A. V., et al. 1986. Indirect health effects of relative humidity in indoor environments. *Environ. Health Perspect.* 65:351–61.

Bach, B.; Molhave, L.; and Pedersen, O. F. 1984. Human reactions during controlled exposures to low concentrations of organic gases and vapors known as normal indoor air pollutants: Performance tests. In *Proceedings of the third international conference on indoor air quality and climate*. Ed. B. Berglund, T. Lindvall, and J. Sundell, Vol. 3, 397–402. Stockholm: Swedish Council for Building Research.

Banaszak, E. F.; Thiede, W. H.; and Fink, J. N. 1970. Hypersensitivity pneumonitis due to contamination of an air conditioner. *N. Engl. J. Med.* 283:271–76.

Breysse, P. A. 1984. The Office environment: How dangerous? In *Proceedings of the third international conference on indoor air quality and climate*. Ed. B. Berglund, T. Lindvall, and J. Sundell, Vol. 3, 315–20. Stockholm: Swedish Council for Building Research.

Burge, S., et al. 1987. Sick-building syndrome: A study of 4373 office workers. *Ann. Occup. Hyg.* 31:493–504.

Finnegan, M. J., and Pickering, C. A. C. 1986. Building-related illness. *Clin. Allergy* 6:389–405.

Finnegan, M. J.; Pickering, C. A.; and Burge, P. S. 1984. The sick-building syndrome: Prevalence studies. *Br. Med. J.* 289:1573–75.

Finnegan, M. J., et al. 1987. Effect of negative ion generators in a sick building. *Br. Med. J.* 295:1195–96.

Gravesen, S., et al. 1986. Demonstration of microorganisms and dust in schools and offices. *Allergy* 41:520–25.

Harrison, J., et al. 1987. The sick-building syndrome: Further prevalence studies and investigations of possible causes. In *Proceedings of the fourth international conference on indoor air quality and climate*. Ed. B. Seifert et al., Vol. 2, 487–91. Berlin: Institute for Water, Soil, and Air Hygiene.

Hawkins, L. H. 1981. The influence of air ions, temperature and humidity on subjective well-being and comfort. *J. Environ. Psychol.* 1:279–92.

Hawkins, L. H., and Barker, T. 1978. Air ions and human performance. *Ergonomics* 21:273–78.

Hawkins, L. H., and Morris, L. 1984. Air ions and the sick-building syndrome. In *Proceedings of the third international conference on indoor air quality and climate*. Ed. B. Berglund, T. Lindvall, and J. Sundell, Vol. 3, 197–200. Stockholm: Swedish Council for Building Research.

Hedge, A., et al. 1987. Indoor climate and employee health in offices. In *Proceedings of the fourth international conference on indoor air quality and climate*. Ed. B. Seifert et al., Vol. 2, 492–96. Berlin: Institute for Water, Soil, and Air Hygiene.

Kjaergaard, S.; Molhave, L.; and Pedersen, O. F. 1987. Human reactions to indoor air pollution: *n*-Decane. In *Proceedings of the fourth international conference on indoor air quality and climate*. Ed. B. Seifert et al., Vol. 1, 97–101. Berlin: Institute for Water, Soil, and Air Hygiene.

Kreiss, K., and Hodgson, M. J. 1984. Building-associated epidemics. In *Indoor air quality.* Ed. P. J. Walsh et al., 87–106. Boca Raton, Fla.: CRC Press.

Molhave, L.; Bach, B.; and Pedersen, O. F. 1984. Human reactions during controlled exposures to low concentrations of organic gases and vapors known as normal indoor air pollutants. In *Proceedings of the third international conference on indoor air quality and climate*. Ed. B. Berglund, T. Lindvall, and J. Sundell, Vol. 3, 431–36. Stockholm: Swedish Council for Building Research.

Morris, L., and Hawkins, L. 1987. The role of stress in the sick-building syndrome. In *Proceedings of the fourth international conference on indoor air quality and climate*. Ed. B. Seifert et al., Vol. 2, 566–71. Berlin: Institute for Water, Soil, and Air Hygiene.

National Research Council (committee on indoor pollutants). 1981. *Indoor pollutants.* Washington, D.C.: National Academy Press.

National Research Council (committee on indoor air quality). 1987. *Policies and procedures for control of indoor air quality.* Washington, D.C.: National Academy Press.

Robertson, A. S., et al. 1985. Comparison of health problems related to work and environmental measurements in two office buildings with different ventilation systems. *Br. Med. J.* 291:373–76.

Samet, J. M.; Marbury, M. C.; and Spengler, J. D. 1988. Health effects and sources of indoor air pollution, part 2. *Am. Rev. Respir. Dis.* 137:221–42.

Scansetti, G. 1984. Toxic agents emitted from office machines and materials. In *Ergonomics and health in modern offices.* Ed. E. Grandjean, 1–18. London: Taylor and Francis.

Skov, P., and Valbjørn, O. 1987. The sick-building syndrome in the office environment: The Danish town hall study. In *Proceedings of the fourth international conference on indoor air quality and climate*. Ed. B. Seifert et al., Vol. 2, 439–43. Berlin: Institute for Water, Soil, and Air Hygiene.

Sterling, D. A.; Moschandreas, D. J.; and Relwani, S. M. 1987. Office building investigation. In *Proceedings of the fourth international conference on indoor air quality and climate*. Ed. B. Seifert et al., Vol. 2, 444–48. Berlin: Institute for Water, Soil, and Air Hygiene.

Sterling, E., and Sterling, T. 1983. The impact of different ventilation levels and fluorescent

lighting types on building illness: An experimental study. *Can. J. Public Health* 74:385–92.
Tom, G., et al. 1981. The influence of negative air ions on human performance and mood. *Hum. Factors* 23:633–36.
Turiel, I., et al. 1983. The effects of reduced ventilation on indoor air quality in an office building. *Atmos. Environ.* 17:51–64.
Valbjørn, O., and Skov, P. 1987. Influence of indoor climate on the sick-building syndrome prevalence. In *Proceedings of the fourth international conference on indoor air quality and climate*. Ed. B. Seifert et al., Vol. 2, 593–97. Berlin: Institute for Water, Soil, and Air Hygiene.
Wallace, L. A.; Pellizzari, E. D.; and Gordon, S. M. 1985. Organic chemicals in indoor air: A review of human exposure studies and indoor air quality studies. In *Indoor air and human health*. Ed. R. B. Gammage and S. V. Kaye, 361–78. Chelsea, Mich.: Lewis Publishers.
Wallace, L. A., et al. 1987. The influence of personal activities on exposure to volatile organic compounds. In *Proceedings of the fourth international conference on indoor air quality and climate*. Ed. B. Seifert et al., Vol. 1, 117–21. Berlin: Institute for Water, Soil, and Air Hygiene.
Waller, R. A.; Atkins, W. S.; and Partners, U. K. 1984. Case study of a sick building. In *Proceedings of the third international conference on indoor air quality and climate*. Ed. B. Berglund, T. Lindvall, and J. Sundell, Vol. 3, 349–53. Stockholm: Swedish Council for Building Research.
Woods, J. E. 1988. Recent developments for heating, cooling, and ventilating buildings: Trends for assuring healthy buildings. In *Proceedings of the CIB conference "healthy buildings '88."* Stockholm, Sweden.
Woods, J. E.; Drewry, G. M.; and Morey, P. R. 1987a. Office worker perceptions of indoor air quality effects on discomfort and performance. In *Proceedings of the fourth international conference on indoor air quality and climate*. Ed. B. Seifert et al., Vol. 2, 464–68. Berlin: Institute for Water, Soil, and Air Hygiene.
Woods, J. E., et al. 1987b. Relationships between building energy management and indoor air quality: Perceptions of conflict and opportunity in the United States and Europe. In *Proceedings of the third international conference on building energy management*, 49–70. Lausanne, Switzerland: Presses Polytechniques Romandes.