



CHAPTER 112

Sick Building Syndrome and Building-Related Illness

Kathleen Kreiss

Since the late 1970s, consultants and public health agencies at the local, state, and federal levels have been barraged with requests for investigative assistance to determine the origins of and solutions to complaints of office workers regarding their indoor building environments. The most frequent constellation of building-associated complaints is called *sick building syndrome*. It consists of mucous membrane irritation of eyes, nose, and throat; headache; unusual tiredness or fatigue; and, less frequently, dry or itchy skin. The hallmark of these complaints is their tight temporal association with building occupancy, and their rapid resolution, within minutes to hours, when affected office workers leave implicated buildings. Sick building syndrome is distinguished from more medically serious building-related illness by its subjective nature, reversibility, and high prevalence within implicated buildings and across the nonindustrial building stock in North America and Europe. Building-related illnesses include asthma, hypersensitivity pneumonitis, inhalation fever, and infection. In contrast to sick building syndrome, these building-related illnesses are uncommon and may result in substantial medical morbidity. Building-related asthma and hypersensitivity pneumonitis are usually accompanied by sick building syndrome complaints among co-workers. Whether similar etiologies contribute to sick building syndrome and these building-related illnesses is still speculative.

K. Kreiss: Epidemiology Investigations Branch, Division of Respiratory Disease Studies, National Institute for Occupational Safety and Health, Morgantown, West Virginia 26505.

EPIDEMIOLOGY OF BUILDING-RELATED RISK FACTORS

Despite more than two decades of public health investigation of sick building syndrome, scientific research regarding cause and effective intervention or prevention has been meager. The historical origins of this inattention from the scientific community are of interest for other occupational and environmental problems of uncertain etiology.

The initial approach to building complaints was dominated by an industrial hygiene conceptual framework with applicability to the industrial environment. Since the late 1970s and even currently, building investigators typically measured air concentrations of pollutants of building material origin, such as formaldehyde or volatile organic compounds. Finding individual chemicals in low concentrations, in comparison to permissible exposure limits, frequently led to allegations that building occupants had no verifiable basis for complaint and therefore had mass psychogenic illness. Mass psychogenic illness, however, is not a diagnosis of exclusion and has criteria for diagnosis (1). The endemic nature of sick building syndrome within implicated buildings, its high prevalence in "nonproblem" buildings, and its symptom constellation are not explicable by hysteria resulting from hyperventilation and a visible person-to-person chain of transmission. However, building occupants whose complaints about indoor environmental quality have been ignored or for whom investigation has not resulted in effective remediation are often anxious and turn to nonscientific explanations of their symptoms.

The industrial hygiene conceptual approach to problem building investigation resulted in measurement of carbon dioxide concentration and the guidance that levels should be kept below 1,000 ppm. Of course, CO₂ could not cause the symptoms composing sick building syndrome even at the highest levels found in office buildings. However, CO₂, a product of human metabolism, served as a marker of ventilation rate in relation to occupancy, with increases above the 350 ppm found in outdoor air being typical of indoor environments. The underlying assumption of this ventilation hypothesis for sick building syndrome was that human occupants were the source of the deterioration of indoor environmental quality. Indeed, this assumption was the basis of the earliest ventilation standards, which sought to ameliorate body odor from assembled groups indoors in the decades before current hygiene practices, indoor plumbing, and personal deodorants. The popularity of this approach to problem building investigation derived from the observation that building-related complaints surfaced after the energy crisis in the early 1970s. The American Society of Heating, Refrigeration, and Air-Conditioning Engineers had lowered its consensus standard for ventilation rate in occupied spaces from 20 cubic feet of outdoor air per minute (cfm) per person to 5 cfm per person in 1975. The CO₂ concentration is often still used as an indication of ventilation adequacy for removing nonoccupant produced air pollutants, although scientific data do not support such use, and relationships between CO₂ and actual ventilation rates are complex (2).

Advances in scientific understanding of indoor environmental quality complaints were made by European investigators beginning in the 1980s (3-5). Taking an epidemiologic approach, they showed that building-associated symptoms were common in buildings not recognized as having indoor environmental problems. Complaint rates varied substantially from building to building and were associated with building types and characteristics. Most interesting from the point of view of etiology and prevention was the finding that ventilation system type was important in determining risk of occupant complaints, with mechanical ventilation and/or air-conditioning conferring a severalfold risk in comparison to buildings with natural ventilation (6,7). This finding shifted the research emphasis from affected persons to ventilation engineering and building design concerns. The association of air-conditioning with risk of symptom prevalence also dovetailed nicely with the findings of human panel studies that evaluated subjective air quality, odor, and stuffiness of buildings in relation to ventilation system activity and occupancy (8,9). In some buildings, operation of the ventilation system resulted in deterioration of subjective air quality, suggesting that ventilation systems could be sources of complaints rather than the solution to them.

These findings called into question the simple guidance, now obsolete, that carbon dioxide levels be main-

tained below 1,000 ppm. Today we know that building materials, furnishings, equipment, and ventilation systems produce irritant pollutants that can interact to produce even more irritating chemicals (10). Controlling nonhuman pollutant levels requires ventilation without regard to control of human bioeffluents, as indicated by CO₂ levels. Experimental studies evaluating symptom prevalence rates in relation to ventilation rate have mixed results with regard to level of ventilation. At ventilation rates substantially above the current-standard of 20 cfm per person set by the American Society of Heating, Refrigeration, and Air-Conditioning Engineers, a doubling of ventilation rate had no effect on the symptoms composing sick building syndrome (11). However, starting with low ventilation rates of about 20 cfm per person or less, several experimental studies have documented statistically significant improvement in symptom prevalence with increases in ventilation rate (12,13). In summary, minimum ventilation levels are likely important for dilution of the suspected indoor pollutants resulting in sick building syndrome, as long as the ventilation system is not itself the source of the pollutants (14). In cross-sectional studies, ventilation rates above 30 cfm per person are associated with further reduction of occupant symptoms (15), suggesting that the current ventilation and CO₂ guidelines may not be health protective.

The association of air cooling and or humidification with occupant complaints spawned the hypothesis that moisture in the ventilation system could support microbial amplification and dissemination in the indoor environment. Air cooling may chill the air stream below the dew point within duct work. Humidification obviously increases the moisture available for saprophytic fungi.

Modern duct work is commonly lined with sound-dampening materials, such as fibrous glass, which can support microbial growth when damp and which collect dirt, providing additional carbon sources for microbial proliferation. Despite many attempts to demonstrate associations between microbial burden in indoor air and sick building syndrome symptom prevalences, the evidence is still inconclusive.

Available methods of measuring microbial pollution in buildings are limited. No correlations have been consistently found for total viable bacteria or fungi and complaint rates (12), but sampling times of minutes, used in quantitative sampling methods, may be unrepresentative. A Dutch study reported that gram-negative rods had several times higher concentration in supply air in buildings characterized by higher complaint rates when compared to mechanically ventilated buildings in which occupants had complaint rates typical of naturally ventilated buildings (16). Similarly, gram-negative bacteria in carpet dust have been shown in one study to be related to symptom prevalence (17).

Viability of microbes may not be important for biologic effect of an allergic, toxic, or inflammatory nature.

Endotoxin, a constituent of the cell walls of gram-negative bacteria, has potent biologic effects. Contradictory data exist for the association of endotoxin with complaint prevalence (18); two reports document an association (16,19). Analytical methods for the low levels of endotoxin in the air of nonindustrial environments are problematic, and endotoxin activity was not shown to be correlated with symptoms in one study that showed strong correlations with viable gram-negative organisms in carpet dust (17). Fungal spore counts are independent of viability but may not be representative because of short duration samples. Analytic methods for mycotoxins generally require prior knowledge of the type of mycotoxin sought and relatively large amounts of material, but mycotoxins have been demonstrated in wipe samples of building surfaces with obvious fungal growth. Newer approaches for assessing fungal biomass with ergosterol and β -1,3-glucans, constituents of fungal membranes and cell walls respectively, may be promising as a means of assessing fungal microbial contamination in relation to symptom prevalence (19,20).

In addition to the associations between occupant complaint rates and both air-conditioning and low ventilation rates, epidemiologic approaches have identified a few workspace risk factors for sick building syndrome. Carpets, textile wall materials, and increased numbers of workers in an office space are supported as risk factors in most studies (12,18,21-26). Inconsistent or sparse reports make the associations of sick building syndrome with the following building and workspace factors open to further investigation: humidification, mechanical ventilation without air-conditioning, newer construction, poor ventilation system maintenance, negative ionization, improved office cleaning, proximity of photocopiers, and environmental tobacco smoke (12). In systematic investigations by the National Institute for Occupational Safety and Health (NIOSH) of 2,435 respondents in 80 buildings with perceived problems, the relative risk of having multiple symptoms of sneezing, eye irritation, and other nasal symptoms was increased in the presence of maintenance deficiencies of heating, ventilation, and air-conditioning (HVAC) systems, the presence of suspended ceiling panels, daily surface dusting, and interior pesticide application (27).

Apart from measuring ventilation rates, no measurements of indoor environmental quality have been consistently shown to be associated with some symptom of the sick building syndrome. Measurements consistently shown not to be associated with complaint rates include carbon monoxide, carbon dioxide, formaldehyde, total particles, viable fungi, air velocity, and noise. Measurements remaining open to further investigation because of sparse evidence or inconsistent findings among studies include total volatile organic hydrocarbons, respirable particulates, floor dust, endotoxins, β -1,3-glucan, low negative ions, high temperature, low humidity, and light intensity and glare (12).

Although specific measurements are not available to determine the likelihood that building occupants will avoid the sick building syndrome, the epidemiologic findings to date do lay a foundation for intervention studies (28). The risk factors of air-conditioning, carpet, respirable particulates, carpet or floor dust, and office and HVAC maintenance may all be related as affecting sources or reservoirs of biologically active agents from microorganisms or building fabric. Intervention studies to lower respirable particulates, maintain HVAC systems, and clean office environments are beginning to be conducted with blind and crossover designs (29).

EPIDEMIOLOGY OF PERSONAL AND JOB RISK FACTORS

The study of sick building syndrome is challenging because of the psychosocial milieu in which building complaints arise. Although the body of epidemiologic research clearly documents environmental risk factors for the syndrome, investigators of problem buildings have a common experience of polarization, suspicion, and controversy surrounding their efforts. Job stress or dissatisfaction has been consistently demonstrated to be related to sick building syndrome in investigations of occupants in buildings not known to have indoor air complaints (12). It remains uncertain whether this association is a cause or an effect of sick building syndrome.

Researchers have documented an invariable female gender predisposition to report building-associated symptoms (3,5,11-13,23,25). Whether this female predominance reflects overexposure to unknown etiologic agents in building microenvironments, higher susceptibility, job dissatisfaction, or lower threshold for observation or reporting remains in dispute. Smokers have inconsistently shown increased risk of sick building syndrome (12).

Respondent reports of asthma or allergies are consistently associated with sick building syndrome (11-13,23,25), but no prospective studies exist to establish whether this personal factor is an outcome, a confounder, or a predisposing factor for reports of mucous membrane symptoms in relation to building occupancy. Among occupants of problem buildings, physician diagnosis of asthma since building occupancy was statistically associated with outdoor air intake within 25 feet of vehicular traffic, dirty HVAC filters, debris inside the air intake, the presence of cloth partitions, and renovation (especially the installation of new drywall in the preceding 3 months) (27). These environmental associations with the development of asthma during building occupancy suggest that asthma may be a result of exposures predictive of sick building syndrome.

The job-related risk factor consistently demonstrated to be associated with sick building syndrome has been video display terminal use. Inconsistent associations have

been found with clerical jobs, use of carbonless copy paper, and photocopier use (12).

The study of sick building syndrome has been complicated by the subjective nature of the complaints. In the face of associations with job stress and dissatisfaction, investigators have feared that classification of cases was unreliable. For eye irritation complaints, however, breakup time of the tear film, eye epithelial damage, and interblink interval have been shown to correlate with subjective complaints and with experimental manipulations of the environment (29,30). Other research methods, such as nasal resistance studies, are being evaluated for their utility in corroborating sick building syndrome complaints. The consistency of building-related complaints across nations and their similar environmental associations make the effort to find objective measures of less concern than formerly, when a substantial portion of the indoor air scientific community wondered whether the complaints were of purely psychosocial origin. Research is proceeding regarding likely mechanisms, such as mediator release associated with inflammatory and toxic effects of microbial constituents expected to be associated with sick building syndrome (31).

MAGNITUDE OF SICK BUILDING SYNDROME

European investigators surveying buildings not known to have indoor environmental complaints found a substantial subset with symptom complaint rates similar to those demonstrable in buildings being investigated for complaints (3-5,7,16). Comparable information for the United States population is meager, with only preliminary information available from studies of nonproblem office buildings (32,33). A random sample telephone survey of the U.S. population documented that about one-fourth of office workers perceived indoor air quality problems to exist in their office environments and 20% of all respondents reported their work performance to be hampered by the air quality (34).

Although sick building syndrome is not considered medically serious by most physicians, the comfort of a substantial sector of nonindustrial workers is compromised by the office building stock. Cost estimates of productivity loss related to discomfort and illness are substantial, in comparison to the energy cost savings of decreasing ventilation or savings on ventilation system capacity and maintenance and housekeeping (35). Solution of this common problem likely depends on many disciplines, including architects, general contractors, ventilation engineers, building operations personnel, physicians, industrial hygienists, epidemiologists, and microbiologists. Although specific etiologies have defied scientific documentation, the epidemiologic findings to date suggest interventions that should be evaluated in experimental studies, such as lowering respirable particu-

lates, maintaining an immaculate ventilation system and duct work, and appropriate housekeeping.

BUILDING-RELATED ILLNESSES

Building-related illnesses, such as hypersensitivity pneumonitis and asthma, often occur against a backdrop of sick building syndrome complaints among other building occupants. Their recognition is important because they are often medically serious, require cessation of exposure to improve prognosis, and serve as sentinel events for others at risk. When building occupants report building-related chest symptoms such as shortness of breath with exertion, cough, and wheezing or chest tightness, asthma or hypersensitivity pneumonitis should be suspected. These chest symptoms are not typical of sick building syndrome, although cough can be of either sinus or chest origin. Profound malaise and sick fatigue are characteristic of granulomatous lung disease, such as hypersensitivity pneumonitis, and are not characteristic of asthma or sick building syndrome. Physician recognition of building-associated asthma and hypersensitivity pneumonitis may be poor, and the building investigator may need to suggest referral of building occupants with building-related chest symptoms to specialists with an interest in early diagnosis of disease from building-associated etiologies. Persons with building-related asthma or hypersensitivity pneumonitis may have symptom exacerbation with reentry into an implicated environment even after environmental remediation (36-39), presumably because of the immunologic potentiation of response to even low levels of antigen exposure.

Outbreaks of building-associated hypersensitivity pneumonitis have been reported in association with contaminated spray water humidification systems and contaminated air-conditioning systems (37,40-43), including duct work (44). Hypersensitivity pneumonitis also can occur endemically in water-damaged buildings (45) in which wet furnishings support microbial growth or in buildings with moisture incursion from below-grade walls (36). In contrast to the frequency of water damage to buildings from roof leaks, plumbing mishaps, and basement flooding, reports of hypersensitivity pneumonitis are infrequent. This may indicate low-risk, reversible disease, or poor recognition of building-related granulomatous or interstitial lung disease by clinicians who seldom inquire about building risk factors for these lung diseases in sporadic cases. In industrial settings, outbreaks of interstitial lung disease are more likely to be recognized in relation to water spray processes, humidification systems, or air-conditioning systems. These have been reported from the stationery industry (46), printing works (47), photographic film industry (48), swimming pools with water spray features (49), and textile industry (50).

Building-related asthma is recognized even less frequently than hypersensitivity pneumonitis. Outbreak

investigations and case reports document water incursion (36), cool mist vaporizers (51), and humidifiers (52,53) as factors in etiology. As with hypersensitivity pneumonitis, recognition of possible cause by clinicians may be lacking. There are population-based studies of asthma that implicate residential dampness as a risk factor for asthma (54–57).

Building-related illness includes inhalation fevers. Pontiac fever is a self-limited illness with high attack rate associated with serologic immunity to *Legionella* antigen (58). Humidifier fever has been attributed to endotoxins (59), *Bacillus subtilis* (60), and amoebae (61–64).

INFECTION

From a public health viewpoint, the most important condition influenced by buildings is communicable respiratory infection, such as influenza and tuberculosis. Compelling evidence exists that infection transmission for respiratory disease is affected by ventilation characteristics. A landmark study in this regard was the observation that military recruits housed in energy-efficient barracks had a 51% increase in incidence of febrile respiratory disease when compared to recruits housed in old barracks, presumably with greater air infiltration (65). Higher increases to 250% were documented in epidemic years when trainees were not immunized against adenovirus. Military troops housed in air-conditioned buildings in Saudi Arabia had excess symptoms of sore throat and cough compared to troops housed in outdoor environments, and this was attributed to increased infection transmission indoors (66). Similarly, epidemic pneumococcal disease has been documented in an overcrowded jail, in which median ventilation was only 6.1 cfm per inmate (67). In office worker populations, a Swiss investigator found that absenteeism due to respiratory illness was greater in a fully air-conditioned building than in a naturally ventilated building with a similar population (68). Tuberculosis transmission has long been known to be affected by ventilation patterns and rates (69). Despite the considerable burden of preventable infection associated with building environments, insufficient research exists in this area to support educational efforts for architects and ventilation engineers. Our understanding of microbial etiology in the case of infection has put this set of diseases in the purview of infectious disease specialists, with scant consideration by the many disciplines required to pursue preventive strategies of an environmental nature.

Apart from building ventilation characteristics enhancing transmission of communicable disease, building structures have been implicated as sources of noncommunicable infections. The classic example of building-related infection is *Legionella* pneumonia, and there is increasing evidence that potable water supplies in buildings, rather than aerosols, may be the ultimate reservoir

and means of transmission of the organism (70–72). Infection of immunocompromised patients with *Mycobacterium avium* complex has also been shown to be associated with this organism in potable water supplies (73) and indoor swimming pools (74). Systemic fungal infections in immunocompromised hosts have occurred in hospital settings with saprophytic fungi colonizing ventilation duct work or disseminated in renovation dusts (75–79). Laboratory techniques and molecular epidemiology are allowing us to understand the implications of building environments as risk factors for both common and new agents of infection (67,73).

SUMMARY

Occupational and environmental health professionals have a unique contribution to make in the assessment of indoor environmental problems. We do not yet know enough to recommend specific measurements of office building air concentrations to assure occupant health prospectively or in response to intervention in a problem building. Nevertheless, we have promising leads from the epidemiology of building-related symptoms to pursue research using new methods of assessment of environment and microbial burden. We also have promising leads for intervention studies without knowing specific etiologies. The science of indoor environmental quality does not support the uncritical application of either recommended ventilation rates or carbon dioxide measurements as assessment of whether the building is acceptable to occupants.

Careful assessment of the nature of health complaints can result in the recognition of building-related asthma or hypersensitivity pneumonitis. These diseases require a different clinical management and public health investigation than does sick building syndrome alone. Finally, the study of indoor environmental quality points toward potential opportunities to lower morbidity from infections that are impacted by ventilation rates and building operation practices.

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