9 ASTHMA AND NONRESIDENTIAL INDOOR *Environments*

Many cross-sectional epidemiologic studies document an association of asthma diagnoses or asthma symptoms with aspects of the residential environment, such as dampness or mold. In contrast to residences, nonindustrial work buildings often have large numbers of occupants in whom the epidemiology of asthma can be studied in relation to the built environment. Several lines of evidence suggest the efficiency of pursuing indoor environmental factors in relation to asthma among office workers, school staff, and students.

This chapter briefly reviews the scientific literature regarding asthma and nonresidential indoor environments—primarily office buildings and schools. Industrial environments, which may expose workers to a wide variety of allergens and irritants capable of inducing asthma (Chan-Yeung, 1995), are outside the scope of this chapter and report.

BUILDING-RELATED ASTHMA

New-onset asthma caused by specific building environments has been investigated infrequently. Case reports of office building-related asthma with a clear work-related pattern exist, and the causes were related to humidifiers or the biocides used in humidifiers (Finnegan and Pickering, 1986; Robertson and Burge, 1985). Epidemic asthma occurred in a printing factory in association with a contaminated humidifier (Burge et al., 1985). The most compelling description of office building-related asthma found that employees of a county social services agency in Denver had a 2.9-fold rate of physician-diagnosed asthma arising since building occupancy compared to employees of a comparable suburban social service agency (Hoffman et al., 1993). The Denver workers reported excess shortness of breath and chest tightness, and 36% of Denver employees with preexisting asthma reported exacerbation of their asthma in relation to building occupancy, in contrast to none of the preexisting asthma cases in the suburban county agency. Peak expiratory flow measurements of a sentinel case fell markedly over the course of time at work, with recovery within an hour outside the office building. Bronchial reactivity measurements from serial methacholine challenge tests showed improvement to the normal range within two to three months of assignment to another building; recurrence of bronchial hyperreactivity with reassignment to the implicated building; and partial resolution with removal for the second time. In addition to a 4.9-fold excess of asthma with onset or exacerbation since building occupancy, cases of hypersensitivity pneumonitis and other interstitial lung disease occurred among occupants of the implicated building. In this investigation, the suspected cause was bioaerosols associated with below-grade moisture incursion from the posterior wall that was built into an earthen bank.

Although the few publications discussed above document the phenomenology of building-related asthma, little information exists regarding the contribution of building-related asthma to the increasing asthma burden in the United States or elsewhere. Several state health departments solicit physician case reports of occupational asthma for the purpose of state- or federally funded surveillance. Data from four states reported to the National Institute for Occupational Safety and Health (NIOSH) for 1993–1995, documented 86 physician-diagnosed cases attributed to indoor air quality deficiencies, without other specific cause, accounting for 8% of all occupational asthma cases recognized by reporting physicians (Romero Jajosky et al., 1999). Michigan, Massachusetts, and Connecticut supplied data over a longer time, which document increasing proportions of all reported occupational asthma cases attributable to indoor environmental quality, up to 25% (unpublished reports from Carolyn Jean Dupuy, Connecticut Department of Public Health, Respiratory Disease and the Indoor Environment, sent to NIOSH by email on May 13, 1999; from Ruth Vanderwaals, Michigan Department of Public Health sent by email on March 22, 1999; and from Letitia Davis, Massachussetts Department of Health, sent by email on March 6, 1999).

Another source of physician case reporting is the data base of the Association of Occupational and Environmental Health Clinics (AOEC). An unpublished report indicates that from 1991 to 1996, 15% of the 542 occupational asthma cases seen in the reporting members of largely academic clinics were related to indoor air exposures, with the annual proportion increasing from 6% in 1991 to 30% in 1996 (Hunting, 1999). Half of the cases of reported asthma–reactive airways dysfunction syndrome (RADS) from primary and secondary schools and vocational schools in this data base were attributed to indoor air exposures. These data must be interpreted with caution because the number and location of reporting clinics varied from year to year and the numbers are likely influenced by the characteristics of the responding facilities.

This limited information from practitioners reporting to public health agencies or their occupational health association suggests that physicians are seeing patients with work-related patterns of asthma symptoms or objective measurements for which they are unable to identify specific causes apart from alleged poor indoor air quality. Investigations in response to these reports by public health agencies have been limited by lack of knowledge about what agents to measure in evaluating hazards for asthma or for less specific indoor air quality (IAQ) complaints.

Attribution of asthma and asthma symptoms to specific building environments by the lay public far exceeds physician recognition of building-related asthma. One source of data regarding public concerns about building contributions to asthma are the requests from employees or management for Health Hazard Evaluations, a mandated service program of NIOSH. Since the late 1970s, after the energy crisis and changes in ventilation codes, health hazard evaluations coded as "indoor air quality requests" from office and school employees have increased persistently in numbers and proportions of all requests. Of the 100–200 IAQ requests received each year since 1990, the proportion mentioning asthma in the written request increased during the 1990s to 14% in 1998; the proportion mentioning any chest symptom increased to 46% in 1997–98. Among IAQ requests mentioning asthma as a health concern to be investigated in the health hazard evaluation, a substantial minority—43%—come from school staff, management, or unions representing teachers.

Most office workers do not attribute chest symptoms to their building environments. Preliminary analyses of questionnaire information from occupants of 29 buildings surveyed in the U.S. Environmental Protection Agency's (EPA's) Building Assessment and Evaluation Study (Brightman et al., 1997), revealed that the median prevalence of occupants reporting frequent work-related shortness of breath was 2%. An unpublished NIOSH report evaluating a series of buildings selected without regard to indoor air quality complaints indicated a maximum prevalence of 8% (Sieber and Godwin, 1998). In contrast, one-third of 80 office buildings studied by NIOSH in 1993 in response to health hazard evaluation requests had prevalences of frequent work-related shortness of breath greater than 8%, ranging up to 24% (Malkin et al., 1996). In conclusion, most buildings in which occupants have IAQ complaints probably do not have excesses of respiratory disease, but a substantial subset of "complaint" buildings may have occupants who associate their chest symptoms with building occupancy.

The NIOSH experience with indoor air quality investigations in 1993 gives some epidemiologic leads regarding building-related asthma and its causes (Sieber et al., 1996). Among 2,435 occupants of 80 office buildings classified according to whether moisture was found in the heating, ventilation, and air-conditioning (HVAC) system, the prevalence of physician-diagnosed asthma arising since building occupancy was 61% higher in buildings with HVAC moisture, and the prevalence was doubled of having three of four chest symptoms (cough, shortness of breath, wheezing, and chest tightness) at least once per week in the last month that improved away from work (Table 9-1). In logistic analyses controlled for age and gender, postoccupancy asthma was associated with dirty HVAC filters, debris in the air intake system, and renovation with drywall within the previous three weeks; daily surface cleaning with wet methods appeared protec-

TABLE 9-1 Health Condition Prevalence (%), by Moisture Status of HVAC, Among 2,435 Occupants of 80 Office Buildings with IAQ Complaints

Health Condition	Moisture Present	Moisture Absent	Range
Any physician-diagnosed asthma	11.7	11.6	
Postoccupancy asthma	3.7	2.3	0–33.3
Chest symptoms[a]	4.1	1.8	0–33.3

[a]Three of four (cough, shortness of breath, wheezing, chest tightness) occurring ≥1/week in last month and improving away from work.

SOURCE: W. Karl Sieber, Division of Surveillance, Hazard Evaluations, and Field Studies, National Institute for Occupational Safety and Health, written communication to Kathleen Kreiss, March 8, 1999.

TABLE 9-2 Relative Risks by Health Condition for Environmental Factors

Environmental Variable	Postoccupancy Asthma	Multiple Chest Symptoms
Dirty filters	2.0[a]	1.9[a]
Air intake debris	2.0[a]	3.1[a]
Recent renovation with drywall	2.5[a]	1.1
Ceiling panels	3.2	3.4
Daily surface cleaning	0.5[a]	0.7

[a]$p < .05$.

SOURCE: W. Karl Sieber, Division of Surveillance, Hazard Evaluations, and Field Studies, National Institute for Occupational Safety and Health, written communication to Kathleen Kreiss, March 8, 1999.

tive in logistic regression models (Table 9-2). Similar risk factors existed for the outcome of frequent multiple work-related chest symptoms, which may represent asthma-like conditions for which medical consultation has not been sought or for which an asthma diagnosis was not made. Although these findings do not document specific agents causing asthma in office buildings, they suggest that bioaerosols associated with HVAC moisture, maintenance deficiencies, and water damage requiring renovation are promising hypotheses.

Commercial office building stock and schools are often constructed with flat roofs, which predispose to puddling and moisture incursion; other common sources of moisture problems in nonindustrial building stock are HVAC coils, drain pans, and duct liners; below-grade drainage; inadequate moisture barriers; flashing leaks; flooding; and plumbing mishaps. At present, little information is available regarding the relative health risks of these conditions. Absent risk assessment information, building occupants, tenants, and managers have little leverage to have these conditions fixed.

STUDIES OF SCHOOLS

School is an important indoor environment for many children. The possible influence on health of indoor air in schools and day care centers have been the subject of research. However, very little of this literature specifically addresses indoor air exposures and asthma. Of the available studies on the topic, few have done careful and complete exposure assessments.

Schools are subject to many of the same exposure problems found in homes, although not necessarily at the same levels. The level of some allergens such as cockroach and dust mite is thought to be generally lower in schools because of the relative scarcity of appropriate habitats for infestation (Perzanowski et al., 1999; Sarpong et al., 1997). The absence of a direct source does not, however, necessarily preclude its presence. Cat allergen—which clings to clothing and other belongings—has been measured in schools and other indoor environments where cats have never been (Chan-Yeung et al., 1999). Indeed, schools may be a major source of exposure to cat and dog allergen for individuals who do not have these pets at home (Almqvist et al., 1999; Lonnkvist et al., 1999).

A survey of research on indoor air quality in schools noted that the major building-related problem identified was inadequate outdoor air ventilation (Daisey and Angell, 1998). Water damage and concomitant mold growth constituted the second greatest problem.

Among the epidemiologic studies identified by the committee, Smedje and colleagues (1997) investigated air quality, environmental characteristics, and asthma outcomes in 762 students in 39 schools in Uppsala County, Sweden. They used a self-administered questionnaire for health status information and employed trained occupational hygienists to gather building information and measurements in the schools. Data gathered included air exchange rate, temperature, and relative humidity; airborne levels of volatile organic compounds (VOCs), NO_2, molds, and bacteria; and levels of endotoxin, and cat, dog and mite allergen in settled dust. They found that self-reported current asthma was more common in schools that were larger, and had more open shelves (a repository of settled dust), lower room temperature, higher relative humidity, higher concentrations of formaldehyde or other VOCs, viable mold or bacteria, and more cat allergen. The observations were drawn on the basis of 40 asthma cases.

Haverinen and colleagues (1999) investigated three school buildings that were suspected of causing occupant health problems. The buildings were subjected to extensive structural and microbial contamination surveys; questionnaires were used to collect data on health problems. Widespread moisture damage was observed. Fungi identified (*Aspergillus, Eurotium*) were typical of buildings with mold problems. The prevalence of self-identified asthma among upper secondary school students, but not elementary or high school students, was reported to be higher than typical for the age group.

Hunting (1999) noted that half (14 of 28) of the cases of reported "occupational asthma" or RADS from primary and secondary schools and vocational schools in AOEC's Occupational and Environmental Disease Surveillance Database over the years 1991–1996 were attributed to indoor air exposures. The specific exposures were not identified.

Nafsted and colleagues (1999) investigated the respiratory health of 3,853 children in Oslo, Norway. Parents completed a questionnaire concerning day care arrangements, the child's health, environmental conditions, and family characteristics. The study found that the lifetime risk of doctor-diagnosed asthma was higher in children who started attending day care centers during the first two years of life. The authors speculated that this was a consequence of the higher rate of early respiratory infections in children in day care. There were no data reported on other environmental exposures.

Two studies addressed respiratory outcomes in children in the United States. A study of 1,268 children in Minnesota by Marbury and colleagues (1997) found that day care attendance was associated with an increased risk of recurrent wheezing illnesses and lower-respiratory infections. Celedon and colleagues (1999) examined respiratory tract illnesses in 498 Boston-area children who had at least one parent with a history of allergy or asthma. Researchers found that day care attendance increased the risk of upper and lower respiratory tract illnesses in the first year of life for these children. (Chapter 5 includes a discussion of the state of the literature regarding exposure to infectious agents and asthma.)

Such findings are not, however, uniform. McCutcheon and Woodward (1996) studied the respiratory health of 445 Adelaide, South Australia, school children, using data from questionnaires completed by parents and school records. They found that children who had attended child care prior to commencing school experienced half as many episodes of asthma as children who had never attended child care. Among the explanations for the findings offered was protection against later respiratory illness as a result of early exposure, although selection of illness-prone children into home care might also have had an influence.

School exposures are an area of continuing research interest. One ongoing study of schools in the Chicago area is monitoring levels of a wide variety of potentially problematic agents—including molds, dust mites, animal and insect allergens, particulates and various chemicals—and other environmental characteristics such as ventilation and humidity. The study is also evaluating the effect of interventions including educational initiatives and integrated pest management. An interesting observation from this effort is the importance of involving engineering and janitorial staff, along with school management, in the planning and implementation of interventions (Persky, 1999).

CONCLUSION

Published case reports, public health surveillance of physician reporting, and cross-sectional studies of building occupants with indoor air quality complaints provide limited or suggestive evidence of an association between aspects of the nonindustrial indoor environment and the development of asthma with a building occupancy-related pattern of symptoms and, in some instances, objective abnormalities. What is lacking for the most part, however, is knowledge of specific etiologic agents in these nonindustrial indoor environments that might be responsible for these new work-related asthma cases. Epidemiologic data suggest that moisture and ventilation system problems are markers for the problematic agents when work-related asthma arises in particular office and school buildings. Similarly, one cross-sectional study comparing two building populations (with comparable IAQ discomfort complaints) provides evidence that one particular office environment caused exacerbation of asthma among more than a third of occupants with preoccupancy physician diagnoses of asthma, and the other office environment did not. However, the proportion of building environments that precipitate exacerbation of asthma and the specific etiologies of asthma exacerbation are unstudied.

RESEARCH NEEDS

The few available studies suggest the importance of building factors in relation to asthma, but further research is critical to assessing the attributable risks, remediable risk factors, and means of hazard assessment. Development of methods for representative quantitative assessment of bioaerosols of fungal and bacterial origin is a high priority for health outcome studies and hazard assessment. In addition, knowledge of the epidemiology of building-related asthma in problem buildings where there are excess chest complaints among occupants, in comparison to buildings where there are no complaints, can advance our understanding of specific bioaerosols in relation to asthma. Research should focus on exposure–response studies of many building environments and populations; clinical investigation of patients with building-related asthma; and intervention studies, even without knowing the specific etiology involved. This research agenda requires new partnerships among academic investigators, clinicians, public health agencies, industrial hygienists, and building scientists.

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