

Mechanisms of allergic diseases

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Indoor allergens in school and day-care environments

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Most studies that have examined exposure to indoor allergens have focused on home environments. However, allergen exposures can be encountered in environments other than the home. For example, many children spend a large part of their time in schools and day-care facilities. Over the past 2 decades, a large number of studies have been conducted in school and day-care environments. However, the role of indoor exposures in allergy and asthma development or morbidity in these settings is not well characterized. The purpose of this review is to evaluate the importance of indoor allergen exposures in school and day-care settings. We summarize the key findings from recent scientific literature, describe exposure characteristics, discuss the role of these exposures in relation to asthma and allergy symptoms, and provide information on the effectiveness of published interventions. (*J Allergy Clin Immunol* ■■■■;■■■:■■■-■■■.)

Key words: Allergen, indoor, exposure, asthma, allergy, school, day care

Exposure and sensitization to indoor allergens are important risk factors for asthma and allergic respiratory diseases.¹ Although the role of indoor allergen exposure in the development of allergic sensitization and asthma remains subject to debate, there is strong evidence that indoor allergens play a key role in triggering and exacerbating allergy and asthma symptoms.²

Most studies of indoor allergens have targeted home environments because homes are often considered the primary sites of exposure. Over the past decades, the importance of nonresidential indoor environments has also been recognized.³ For example, in schools and day-care facilities, allergen and other indoor exposures can affect children's health because children spend a large part of their childhood and adolescent years in these environments.

This review focuses on the importance of indoor allergen exposures in day-care and school environments. The purpose of this article is to summarize key findings from the scientific

Abbreviation used

MUP: Mouse urinary protein (mouse allergen)

literature and to identify future research needs. Studies for this review were searched by using the following databases: PubMed, Embase, Web of Science, Scopus, and Education Resources Information Center. Although inhalation of food allergens might induce allergic reactions in sensitive individuals, food allergens, which can constitute an important part of allergen exposures in day-care and school settings, are beyond the scope of this review. Furthermore, the relevance of exposures other than aeroallergens (eg, environmental tobacco smoke, endotoxin, *volatile organic compounds*, and other irritants) will not be discussed, although these exposures might also affect indoor air quality and occupants' health status.

EXPOSURE TO INDOOR ALLERGENS IN DAY-CARE AND SCHOOL ENVIRONMENTS

Study designs and exposure assessment

Indoor allergen exposures in schools and day-care centers have been an area of continuing research interest. Studies have been conducted worldwide,⁴⁻¹⁵ but the research has been most active in the United States and Scandinavian countries.¹⁶⁻³⁵ Although most studies have targeted school environments, the number of studies that have assessed allergen levels in day-care centers has increased over the past decade.^{7,9,11,15,19,22,24,28} To date, studies have mainly been *cross-sectional* in design. Some studies, however, have examined seasonal variation in allergen levels.^{16,20}

Cat (Fel d 1), dog (Can f 1), dust mite (Der f 1 and Der p 1), cockroach (Bla g 1 and Bla g 2), and mouse (Mus m 1 and mouse urinary protein [MUP]) allergens and molds have been the most frequently studied allergens. Although sampling and analytic procedures used in the studies vary considerably, allergen concentrations are usually quantified by using antibody-based *ELISAs*.³⁶ However, methodological differences can contribute to the variability of the findings and complicate comparisons between studies. For example, differences in sampling equipments (eg, flow rate, vacuum power, and collection devices), sampling locations, and used metrics can make comparisons difficult.³⁶ In general, correlations between different sampling methods have been poor.³⁷ In most studies allergen levels have been assessed in settled dust samples collected from various indoor sites. *Air sampling* techniques have been primarily used for pet allergens (eg, Fel d 1), which are carried on aerodynamically smaller-sized particles and remain airborne for longer periods of time. Studies that have assessed allergen levels on the surface of clothing have also used *tape sampling*.³⁸

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Terms in boldface and italics are defined in the glossary on page2.

Allergen levels and exposure characteristics

Tables E1 to E5 in this article's Online Repository at www.jacionline.org summarize the main findings on cat, dog, dust mite, cockroach, and mouse allergen levels from published studies that have examined indoor allergen exposures in day-care and school environments in the past 2 decades.

Exposure to cat and dog allergens. Numerous studies have shown that animal allergens can be present in environments in which no animals reside.^{3,4} In schools and day-care centers, cat (Fel d 1) and dog (Can f 1) allergens are frequently detected, but the levels of exposure vary greatly. In general, these common aeroallergens are found at low levels (see Tables E1 and E2) in these settings. Nonetheless, although the magnitude of exposure tends to be low, studies have demonstrated that allergen levels in educational facilities can be higher than in homes where no pets are present.^{21,29}

Cat and dog allergen levels have generally been found in higher levels in carpeted and upholstered areas.^{4,10,18,19,23,26} Levels in carpeting are often significantly lower than levels in upholstered seats.^{4,27} It is not uncommon that allergen levels in these locations sometimes exceed thresholds that have been associated with allergic sensitization (1.0 µg/g for Fel d 1 and 2.0 µg/g for Can f 1) or asthma symptoms in sensitized individuals (8.0 µg/g for Fel d 1 and 10.0 µg/g for Can f 1).^{39,40} The highest average concentrations have been found in US and Swedish schools; in samples collected from chairs and desks, geometric means reached as high as 11.3 µg/g for Fel d 1 and 15.0 µg/g for Can f 1.²⁹

There is strong evidence that clothing is the primary transfer mechanism and source of pet allergens.^{10,17,41,42} Among schoolchildren, allergen levels have been found to be significantly higher in dust collected from pet owners' clothing than from clothing of non-pet owners.^{10,38,41} Still, allergen levels can be

dependent on clothing type and washing frequency.^{10,42} A recent study has suggested that in addition to clothing, human hair might be a source for transfer and deposition of pet allergens among schoolchildren.⁴³ Several studies worldwide have demonstrated that levels of cat and dog allergens in day cares and schools correlate with the number of children and staff who have either dogs or cats at home or have frequent contacts with these pets.^{10,15,17,24,26,44,45} Increased allergen levels have been detected in both dust and air samples. For example, concentrations of Fel d 1 and Can f 1 in settled dust were significantly lower in Swedish day-care centers in which neither children nor staff owned pets compared with centers in which cat and dog ownership was common (median Fel d 1 levels, 0.64 vs 5.45 µg/g; median Can f 1 levels, 0.39 vs 2.51 µg/g).⁴⁵ In another study there was a 5-fold difference in median levels of airborne Fel d 1 between classes with many (>25%) and few (<10%) cat owners.¹⁷

In summary, published data suggest that schools and day-care centers can be important sites of exposure to cat and dog allergens, particularly for susceptible individuals (eg, sensitized children who do not have pets at home). However, not all studies link these environments to increased exposure levels. The number of pet owners at school or day-care centers is one of the strongest predictors of increased cat and dog allergen levels in these settings.

Exposure to dust mite allergens. Studies show that dust mite allergens (Der f 1 and Der p 1) are found in low levels in many schools and day-care facilities (Table E3). Reported levels are often similar or slightly lower than in corresponding local homes.^{5,7} Because *ambient relative humidity* is a key environmental factor that influences mite populations,⁴⁶ dust mite allergen levels are strongly associated with humidity levels. To survive and thrive, dust mites require that the relative humidity

GLOSSARY

AIR SAMPLING: There are multiple methods to sample aeroallergens, including sedimentation/gravity sampling (nonquantitative), rotating arm impactors, suction impactors, centrifugal sampling, and filtration sampling. The selection of the method/device depends on several factors, including the characteristics of the aeroallergen(s) (eg, particle size), sampling conditions and time, and analytical techniques used for quantification.

AMBIENT RELATIVE HUMIDITY: Relative humidity is calculated as the amount of moisture in the air divided by the maximum amount of moisture possible in the air at a specified temperature. Dust mites thrive in environment with temperatures of 70°F to 80°F and greater than 55% relative humidity.

β-1,3 GLUCAN AND ADJUVANT: β-1,3 Glucans are glucose polymers in the cell walls of plants and fungi. Exposure to elevated levels of this glucose polymer has been associated with increased atopy, increased conjunctival/respiratory symptoms, and decreased FEV₁. In addition, β-1,3 glucans can act as adjuvants to increase antigen-specific IgE levels in animal models.

CROSS-SECTIONAL: A cross-sectional analysis examines relationships or associations at a single point in time (as opposed to a cohort study, which looks at a sample population over time). In a cross-sectional study, disease prevalence can be determined, but due to the single time point, a causal relationship between a risk factor and disease cannot be established.

ELISA: An ELISA uses a color detection system to quantify the amount of a protein of interest (antibody or antigen). In a sandwich ELISA a capture antibody is coupled to a solid phase followed by incubation with a biologic fluid (eg, serum, dust extract) and detection of the antigen by a second antibody.

LARGE-SIZED PARTICLE: Only particles of 5 µm or less reach the lower airway. For example, intact pollen grains (15–75 µm) have the greatest effects on the upper airway and conjunctiva because of their size and subsequent trapping before reaching the lower airways.

LOW INCOME: The definition of a low-income family is one in which the income from the preceding year does not exceed 150% of the poverty line income. In 2009, the low-income threshold for the 48 contiguous states was defined as \$33,075 for a family of 4 (poverty level of \$22,050 for a family of 4).

TAPE SAMPLING: A hand-held roller with adhesive tape can be used to collect samples from clothing. Rolled tape samples are immunostained to detect allergen.

VOLATILE ORGANIC COMPOUNDS: VOCs include a variety of organic chemicals that are emitted as gases from certain solids and liquids. Many household products, such as paints, cleaning supplies, pesticides, printers, glues, adhesives, and permanent markers are sources of VOCs in indoor environments. Volatile organic compounds can be up to 10 times more concentrated in indoor air compared with those in outdoor air.

of air is greater than 55% for a sufficient period of time because water vapor in air is their main source of water. Although mite levels tend to exhibit seasonal fluctuations that parallel those in ambient relative humidity, additional factors, including human activities and heating, ventilation, and air conditioning practices, can influence indoor air humidity levels.^{46,47} In the studied facilities the highest average concentrations were detected in Brazil and in some humid regions in the United States (eg, Florida, Texas, Alabama, North Carolina, and Virginia).^{16,22,23,29} In contrast, very low dust mite allergen levels have been found in colder and drier climates (eg, Scandinavia).^{6,21,24-26,29} Levels of Der p 1 were often higher in more humid regions.^{16,22,34} Although concentrations of Der f 1 and Der p 1 tend to be correlated, they can reflect biologic and ecologic differences between the 2 mite species. Furthermore, the presence of other mite species can also influence concentrations of Der p 1 and Der f 1.^{12,46}

As in residential environments, dust mite allergen levels in day-care centers and schools tend to be significantly higher in carpeted areas.^{7,14-16,18,34} Although this is a consistent finding throughout all geographic regions, the highest levels are often detected in humid climates. For example, high average concentrations (geometric mean, 7.0 $\mu\text{g/g}$) in carpeting were reported in rural schools in North Carolina.²³ Furthermore, study sites in which dust mite allergen concentrations exceeded a provisional threshold level representing increased risk of sensitization ($>2 \mu\text{g/g}$) were typically located in humid regions.⁴⁸ In Florida, for example, dust mite allergen levels were greater than 2 $\mu\text{g/g}$ in 40% of the studied day-care centers,²² and in Texas Der p 1 concentrations exceeded the threshold in all types of schoolrooms, particularly in libraries (68%).¹⁶ However, none of the median or mean concentrations exceeded a threshold ($>10 \mu\text{g/g}$) that has been associated with asthma symptoms.⁴⁹ In addition to carpeting, upholstered furnishings (eg, mattresses, pillows, seats, stuffed animals, and toys) can also be important reservoirs for dust mite allergens, particularly in day cares and elementary schools.^{7,11,16} Although dust mite allergens can be transferred passively between environments,⁴² it is not known whether the amounts of passively transferred allergen are clinically relevant.

Given that dust mite allergens are primarily associated with **large-size particles** that settle rapidly, few studies have examined airborne dust mite allergen levels in day-care or school environments. A recent study demonstrated that airborne mite allergens were present in the majority of the studied day-care centers (80%) in which group 1 mite allergen levels in dust exceeded the clinically relevant threshold ($>2 \mu\text{g/g}$).²² Airborne dust mite allergen levels were significantly lower during the nighttime, suggesting that mite allergens can become airborne because of reservoir disturbance during daily activities in day-care settings. The highest airborne levels were recorded in the day-care center with the highest mite allergen level in the carpet (21.8 $\mu\text{g/g}$).

In summary, dust mite allergen levels in schools and day-care centers are associated with climatic, geographic, and building-related factors. Carpeting and upholstered furnishings are important reservoirs and sources of exposure in schools and day-care centers, particularly in humid regions.

Exposure to cockroach and rodent allergens. Most studies that have examined levels of cockroach (Bla g 1 and Bla g 2) and rodent (MUP) allergens in schools and day-care centers have been conducted in the United States (Tables E4 and E5). Cockroach and mouse allergens are commonly detected in schools that serve **low-income** and inner-city populations, as

well as in rural schools.^{16,18,20,23,28,30,31,34,35} A recent study found detectable levels of cockroach allergen in 71% of the dust samples.²⁰ In another study mouse allergen was found in 100% of the samples.²⁸ Cockroach and mouse allergens have also been present in airborne samples, although the detection frequency has been much lower than in dust samples (21% for Bla g 2 and 5% for MUP).²⁰

Allergen levels show great variability between and within schools.^{18,20,35} For example, geometric mean concentrations for mouse allergen varied from 0.21 to 133 $\mu\text{g/g}$ in a recent study.²⁰ Although increased cockroach allergen levels ($>2 \text{ U/g}$) have been found in many schools,^{16,30,31} low allergen levels are not uncommon in inner-cities.³⁵ Increased cockroach allergen levels have also been reported in rural schools in the United States and some other countries.^{4,11,12,23} However, all median or mean concentrations of cockroach allergen were lower than a threshold of 8 U/g , which has been associated with asthma exacerbation.⁵⁰ Some studies have suggested that exposure to cockroach and mouse allergens in schools and day-care centers might be similar to that which occurs in homes.^{20,22,31} On the other hand, a recent study demonstrated that exposure to mouse allergen can be significantly higher in schools than in homes.³⁵

The highest levels of cockroach and mouse allergens are often found in cafeterias, kitchens, or rooms where food sources are present.^{18,31,35} In an inner-city school kitchen, cockroach allergen concentration was reported to be as high as 591 U/g ;³¹ correspondingly, the highest mouse allergen concentration was found in a school cafeteria (238 $\mu\text{g/g}$).³⁵ Visual evidence of cockroach and rodent infestations in schools is another factor that is strongly associated with cockroach and mouse allergen levels.^{20,31} Therefore indirect exposure to cockroach and rodent allergens in school environments is thought to be less likely.^{31,35} It is important to note, however, that detectable levels of these allergens can be found without visual evidence of infestations.²⁰ In contrast to pet and dust mite allergens, cockroach and mouse allergen levels have often been higher in noncarpeted areas.^{18,20,35} Nonetheless, high allergen levels have also been reported in carpeting in rural schools.²³ It is unknown whether this reflects preferences in floor-covering choices in different locations; carpeting appears to be uncommon in inner-city schools.^{20,35} Studies have shown that cockroach and mouse allergen levels can also vary by season and region.^{16,20,30}

In summary, recent studies suggest that schools might be important sites for exposure to cockroach and mouse allergens, particularly in locations where roach and rodent infestations are common. However, information on the relative importance of cockroach and mouse allergen exposures in schools and day cares is limited.

Exposure to fungal allergens. Several molds produce allergens that can be risk factors for allergic disease, including asthma.⁵¹ However, a major limitation in assessing exposure to fungal allergens has been the difficulty of the accurate quantification of the exposure. Exposure to fungal allergens has usually been estimated by using indirect methods, considering spores as indicators of the presence of allergens.⁵¹ Nonetheless, spore counts might not accurately reflect allergen exposure because allergen content in spores might vary and fungal allergens can be carried by means other than intact spores (eg, hyphal fragments).⁵² Because the availability of fungal immunoassays has been limited, only a few studies have assessed antigenic and allergenic components of fungi with immunoassays. One study that

examined indoor allergen levels in day-care facilities in the United States detected *Alternaria alternata* in 100% of dust samples,¹⁹ whereas in another study in Singapore, Asp f 1 was detected only in 15.4% of the samples.¹⁵

In summary, the complexity of the fungal exposure assessment and the lack of clearly defined threshold levels for fungi and substances derived from fungi (eg, allergens) have limited studies of fungal allergen exposures in day cares and school settings.

INDOOR ALLERGEN EXPOSURES IN DAY-CARE AND SCHOOL ENVIRONMENTS IN RELATION TO ALLERGY AND ASTHMA

Indoor air quality in schools and day-care environments can affect millions of people, including students and staff. In the United States more than 50 million children are enrolled in public and private schools, and more than half of the children ages 3 to 5 years have attended center-based childcare programs over the past decade.⁵³ Asthma and allergies are important public health concerns, not only in terms of health care costs but also in terms of lost productivity and reduced quality of life. For example, asthma and allergies account for more than 16 million missed school days per year in the United States.^{54,55} Among school-aged children, asthma is the leading cause for absenteeism and can influence a child's academic performance and ability to participate in school-related activities.⁵⁶ Importantly, the burden of asthma in schools extends beyond children; a recent report suggests that asthma within the educational services industry is an occupational health problem, particularly among teachers and teacher's aids.⁵⁷

Although people tend to spend the majority of their time at home,⁵⁸ allergen exposures can be encountered in environments other than the home. Schools and day-care centers, where children and teachers spend a large part of their time, can be important sites for indoor allergen exposures. Especially for younger children, the timing of exposure can be critical because IgE-mediated sensitivity to specific aeroallergens develops in early childhood.⁵⁹ In day-care and elementary school classrooms, which often have a variety of potential allergen reservoirs (eg, upholstered furniture, pillows, stuffed animals, and toys), exposure levels might be higher than in middle and high school classrooms.^{16,26} Moreover, the disturbance of allergen reservoirs is more likely because children at younger ages are more physically active.

Remarkably few studies to date have evaluated the relationship between asthma- and allergy-related outcomes and indoor allergen exposures in school and day-care environments. Most studies that assessed allergen exposures in these environments were primarily designed to determine exposure characteristics. Although some studies reported prevalence rates for atopic outcomes, few studies used multivariate analysis to investigate relationships between health outcomes and exposures. Only a small number of the reviewed studies assessed allergen levels simultaneously in school and home environments (see [Tables E1-E5](#)).

In schools and day cares in which occupant density is high, the magnitude of indirect exposure to pet allergens might be sufficient to induce or maintain symptoms. Indeed, several Swedish studies have suggested that indirect exposure to cat and dog allergens in schools might influence asthma morbidity.^{25,60,61} In a recent study asthmatic children who had diagnosed cat allergy but did not report any direct contact with pets were evaluated after they returned to school after summer break. Those children who attended classrooms in which more than 18% of the students

owned 1 or more cats reported significantly decreased peak expiratory flow rates, more asthma symptom days, and increased use of asthma medication than children who attended classes with fewer cat owners ($\leq 18\%$).⁶⁰

Another study demonstrated that asthmatic children with cat and dog sensitivity had significantly increased bronchial reactivity to inhaled methacholine after 1 school week.⁶¹ In this study concentrations of cat and dog allergens were found higher in school dust than in dust collected from children's homes, suggesting greater exposure in school than in home. Among Swedish schoolchildren, cat allergen levels in dust samples have also been associated with the incidence of asthma diagnosis.³²

Recently, a German study examined whether exposure to cat allergen in the school environment was associated with allergic sensitization rates.⁶² Among school-aged children who did not have regular contact with cats, cat-specific sensitization rates increased in a dose-response fashion, depending on the percentages of students in class or school reporting regular contact with cats.

In the United States only 1 study has examined asthma prevalence in relation to the presence of common indoor allergens in the school environment. This study found a positive correlation between asthma prevalence rates and levels of cockroach allergen in schools.¹⁸

Over the past decades, numerous studies have reported positive associations between respiratory morbidity (eg, asthma) and exposure to fungi in indoor environments,^{63,64} including schools and day-care centers.⁶⁵⁻⁶⁸ However, the underlying mechanisms for the observed health effects are not well characterized. Although fungal allergens can induce IgE-mediated hypersensitivity,⁶⁹ exposure to fungi might also induce non-IgE-mediated inflammatory and immunologic processes; particulates derived from fungi not only contain allergens but also contain a variety of biologically active molecules (eg, β -1,3-glucans).^{3,70} It has also been suggested that fungal exposure might promote adjuvant effects on allergic immune responses.⁷¹

In summary, although published studies demonstrate the importance of the school environment, the relationship between allergic respiratory diseases and indoor allergen exposures in schools and day cares is not well characterized. Although studies suggest that exposure to pet allergens in schools might influence asthma morbidity, studies provide limited information on whether exposures to indoor allergens in schools and day cares contribute to the development of allergic sensitization and asthma.

ENVIRONMENTAL CONTROL, REMEDIATION, AND INTERVENTIONS IN SCHOOL ENVIRONMENTS

Most studies designed to evaluate methods for reducing indoor allergen exposures in schools and day-care facilities have been conducted in Sweden and have primarily focused on reducing cat and dog allergen exposures. Swedish researchers found that cat allergen levels were significantly reduced in classrooms that required the use of special school clothing compared with control classrooms.³⁸ Intervention measures, however, were rigorous; children with and without pets changed clothes separately, school clothes were worn and laundered only at the school, staff changed their clothes before entering the classroom, a separate entrance was used for allergic children, and no other children were allowed in the area of the school where the special school clothing classrooms were located. The study also showed that similar reductions in cat allergen levels were achieved by implementing a pet

TABLE I. Summary of the key findings

Exposure to indoor allergens in day-care and school environments
Exposure to indoor allergens is common in day cares and schools.
Allergen levels can vary by time, location, and type of room within the building.
The relative importance of different allergens can vary in different parts of the world depending on a variety of geographic, climatic, and cultural factors.
Schools and day-care facilities might be important sites of allergen exposures. Studies have demonstrated that allergen levels in these environments can sometimes be significantly higher than in the home environment.
Carpeting, upholstered furnishings, and clothing are important reservoirs for allergens.
Exposure to allergens can occur directly or indirectly. For example, clothing is the primary transfer mechanism and source of exposure for pet allergens.
Indoor allergen exposures in relation to allergy and asthma
The relationship between allergic respiratory diseases and indoor allergen exposures in schools and day cares is not well characterized.
Exposure to pet allergens in schools might influence asthma morbidity.
Published data provide limited information on whether exposures to indoor allergens in schools and day cares contribute to the development of allergic sensitization and asthma.
Environmental control, remediation, and interventions
Multifaceted approaches might be needed to decrease indoor allergen levels in schools and day-care facilities.
Information on cost-effective intervention strategies is limited.
Little is known about the extent to which reductions in allergen exposures in these environments influence allergy and asthma morbidity.

ownership ban in which parents agreed not to keep furred pets or birds at home.

Another intervention study examined whether increased cleaning and reduction of potential reservoirs were efficient measures to reduce cat allergen levels in classrooms.⁷² In the intervention classrooms open shelves, upholstery, carpets, curtains, and plants were removed, and cleaning was increased. Children were asked to avoid contact with pets in the mornings before school. The intervention classrooms were compared with control classrooms and allergy-prevention classrooms that had been established before the start of the study. The allergy-prevention classrooms, which were located in a separate school building, had implemented extensive allergen avoidance measures for several years. No differences in cat allergen levels were found in the intervention classrooms before and after the intervention. The allergy-prevention classrooms had a trend toward lower levels of cat allergen than both the intervention and control classrooms.

An earlier Swedish study also evaluated whether extensive renovation, installation of a new ventilation system, ventilated floors, cleaning habits, and pet-avoidance measures (ie, families and personnel avoiding direct and indirect contacts with pets) influence cat and dog allergen levels.⁷³ The intervention measures reduced cat and dog allergen levels substantially (6-fold reduction for Fel d 1 and 10-fold reduction for Can f 1) in a day-care facility.

In Australia a “low-allergen” school was designed to reduce exposure to dust and hazardous chemicals.⁷⁴ In the low-allergen school several measures were implemented. These included reducing potential dust reservoirs, improving ventilation, introducing materials with lower emissions of volatile organic compounds and dust particles, and using central vacuuming and radiant heating systems. Allergen concentrations and other environmental end points were measured in the low-allergen school and 3 other schools to evaluate the effectiveness of this intervention. The levels of dust mite and cat allergens tended to be lower in the low-allergen school, but differences between schools did not reach statistical significance.

One US study investigated the effectiveness of measures to reduce cockroach allergen levels.⁷⁵ In an urban dormitory, which was chronically infested with cockroaches, successful abatement was accomplished by using routine extermination and vacuuming.

A number of interventions have been conducted to reduce exposure to molds and moisture in schools and day-care facilities. Most of the studies have been conducted in Nordic countries.⁷⁶⁻⁸⁰ Renovations and repairs of moisture-damaged classrooms and buildings were found to be effective at reducing mold exposure in schools and day-care facilities and were associated with improvement in building occupants’ symptoms. Improvements in ventilation (eg, increased air-exchange rates) might also affect relative humidity and concentrations of airborne viable molds. In a recent study new ventilation systems improved indoor air quality and reduced asthma symptoms among students in intervened schools.⁸¹ In the United States a small pilot study that combined dehumidification with high-efficiency particulate air filtration reported reductions in airborne fungal spore counts.⁸² Because of the increased concern about indoor mold exposures in school and home environments, a variety of programs and guidelines have been launched over the past decades. For example, in the United States the US Environmental Protection Agency has provided guidance and tools for schools in addressing mold and remediation-related issues.⁸³

In summary, multifaceted approaches might be needed to decrease indoor allergen levels in school and day-care settings. Combined allergen-avoidance measures, such as improvements in ventilation systems, control of excess moisture, reductions in potential dust reservoirs, regular and thorough cleaning and maintenance, pest control, and use of special school clothing, might help to decrease exposure to indoor allergens in school and day-care environments. However, there is limited information on how to choose and implement the most cost-effective intervention approach and the extent to which reductions in allergen exposures in these environments influence allergy- and asthma-related morbidity.

SUMMARY AND CONCLUSIONS

We have summarized the key findings of the review in [Table I](#). Exposure to indoor allergens in school and day-care environments is common. However, published data show that levels of allergens are highly variable. Allergen levels can vary by time, location, and type of room within the building. This is not surprising because variety of physical (eg, humidity, temperature),

structural (eg, age and type of building/room/surface), and behavioral (eg, pet ownership among children and staff, cleaning, and maintenance practices) factors can influence indoor allergen levels. The relative importance of different allergens can vary in different parts of the world depending on a variety of geographic, climatic, and cultural factors. Allergen levels in schools and day-care facilities are often lower than levels that have been reported in homes. Nonetheless, it is not unusual that allergen levels in these settings exceed thresholds that have been associated with allergic sensitization and asthma morbidity. It has also been demonstrated that allergen levels in schools can be significantly higher than in the home environment. Carpeting, upholstered furnishings, and clothing are important reservoirs for allergens, particularly for pet and dust mite allergens. Because allergens are also transported passively to school and day-care environments, exposure to allergens can occur either directly or indirectly. Schools and day-care facilities might be important sources of allergen exposures, but there are limited data available to evaluate to what extent these exposures contribute to allergic sensitization and exacerbation of allergic symptoms. Information on cost-effective intervention strategies is also limited; in published studies the effectiveness of the interventions varied substantially.

RESEARCH NEEDS AND RECOMMENDATIONS

Over the past 2 decades, a considerable amount of research has been conducted on indoor allergen exposures in school and day-care environments. Although several guidelines have been developed and a variety of programs have been initiated to sustain asthma- and allergy-friendly schools in the United States and abroad,⁸⁴⁻⁸⁶ further research is warranted. Studies are needed to assess the extent to which school and day-care environments contribute to allergic sensitization and asthma morbidity. Published data provide limited information on the potential additive effects of school or day-care exposures in relation to allergy and asthma outcomes. For instance, few studies have collected information on health outcomes and exposure levels in schools/day cares and homes simultaneously; further studies addressing this issue are needed. Although schools and day-care environments might not be primary sites for exposure, sensitization, or both to the dominant local allergen or allergens, it is essential to establish cost-effective approaches to reduce allergen levels in these indoor environments. Allergen exposures in school and day-care settings might compromise the effectiveness of allergen avoidance measures used at home. From a public health perspective, it would be important to examine the extent to which various interventions are able to influence exposure levels and building occupants', children's, and staff members' allergy- and asthma-related morbidity. Economic analysis would help to evaluate the cost-effectiveness and clinical benefits of future interventions.

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TABLE E1. Studies assessing cat allergen (Fel d 1) levels in schools and day-care facilities

Country	Study design	Sampling methods and surface†	Allergen levels (μg/g unless otherwise noted)	Health outcomes assessed?	Reference
United States	Cross-sectional (spring and fall), 41 elementary schools in 3 cities	Dust, hard	Range of median levels for all sites: 0.02-0.4	No	E16
United States	Cross-sectional, 12 elementary schools	Dust, soft Dust, hard	Mean (range) for all samples: 1.66 (0.2-12)	Yes	E18
United States	Cross-sectional, 89 day-care centers	Dust, soft Dust, hard	Geometric mean (SE): 0.39 (0.21) Geometric mean (SE): 2.28 (1.45)	No	E19
United States	Cross-sectional, 20 day-care centers	Dust	Mean (SE): 16.6-31.7 U/g	No	E22
United States	Cross-sectional, 1 middle school (tiled) and 1 elementary school (carpeted)	Dust, tiled	Geometric mean (GSD): 4.8 (0.0035)	No	E23
		Dust, carpeted	Geometric mean (GSD): 6.0 (0.0017)		
		Air, tiled	Geometric mean (GSD): 0.097 ng/m ³ (0.0061 ng/m ³)		
		air-carpeted	Geometric mean (GSD): 0.064 ng/m ³ (0.0054 ng/m ³)		
United States	Cross-sectional, 33 preschools	Dust	Median (range): 0.4 (<0.02-4.3)	No	E28
United States	Cross-sectional, 2 middle schools*	Dust	Geometric mean (range) floor: 0.9 (<0.2-2.4), 1.5 (1-4.4) Geometric mean (range) desk/chair: 11.3 (0.1-90), 4.8 (<0.4-185) Geometric mean (range) combined: 2.7 (<0.4-90), 2.3 (<0.4-185)	Yes	E29
United States	Cross-sectional in winter, spring, and fall; 2 elementary schools	Dust, soft	Range: <0.015-4.67	No	E30
United States	Cross-sectional, 4 elementary schools*	Dust	Geometric mean: 0.56	Yes	E35
United States	Cross-sectional, 20 elementary schools	Dust, hard	Median (range): 0.031 (0.0048-0.28)	No	E34
		Dust, soft	Median (range): 0.091 (0.008-1.44)		
Brazil	Cross-sectional, 15 day cares, 15 preschools, 15 kindergartens, and 15 elementary schools	Dust	Range: undetectable–1.1	No	E11
China	Cross-sectional, 10 junior high schools	Dust	Median (range): <0.10 (<0.10-0.18)	Yes	E13
France	Cross-sectional, 30 day-care centers	Dust, hard Dust, soft	Range: <0.1-2.4 Range: <0.1-4.5, <0.1-4.1, <0.1-3.7	No	E5
Korea	Cross-sectional, 12 schools	Dust, hard	Median (range): <0.2 (<0.2-1.4)	Yes	E8
New Zealand	Cross-sectional, 18 day-care centers and 18 kindergartens	Dust	Geometric mean (range): 1.24 (0.06-13.9)	No	E9
New Zealand	Cross-sectional, 9 schools	Dust, clothes	Range of mean (95% CI): 1.49 (1.02-2.17)–13.17 (6.24-27.8) per garment	No	E10
		Dust, hard dust-soft	Mean (95% CI): 0.33 (0.10-1.14) Mean (95% CI): 2.21 (1.28-3.84)		
Norway	Cross-sectional, 10 schools*	Dust, hard Dust, soft	Mean: 283 ng/m ² Mean: 3275 ng/m ²	No	E21
Norway	Cross-sectional, 81 schools, 24 day-care centers	Dust, hard	Median: 0.2	No	E24
		Dust, soft	Median: 1.5 (day care), 1.7 (school)		
Singapore	Cross-sectional, 10 schools and 10 day-care centers*	Dust	Geometric mean (maximum) Childcare centers: 0.03 (0.2) Geometric mean (maximum) Schools: 0.03 (1.8)	No	E12
Singapore	Cross-sectional, 104 day-care centers	Dust	Geometric mean (range): 0.025 (0.01-0.41)	No	E15
Sweden	Cross-sectional, 7 elementary schools (air) and 3 elementary classrooms (dust, clothes)*	Air	Median (IQR): 2.94 ng/m ³ (2.37-4.77 ng/m ³), 0.59 ng/m ³ (0.45-0.81 ng/m ³)	No	E17

(Continued)

TABLE E1. (Continued)

Country	Study design	Sampling methods and surface†	Allergen levels (µg/g unless otherwise noted)	Health outcomes assessed?	Reference
		dust-clothes	Median (IQR): 3030 ng/garment (900-15,620 ng/garment), 146 ng/garment (86-234 ng/garment)		
Sweden	Cross-sectional, 8 schools	Dust, hard	Median (IQR): 0.86 (0.45-1.4)	Yes	E25
Sweden	Cross-sectional, 7 day-care centers	Dust	Median (range): 1.6 (<0.02-22.8)	No	E26
Sweden	Cross-sectional, 4 schools	Dust	Geometric mean (range) chairs: 0.95 (0.63-1.63), Geometric mean (range) tables: 0.53 (0.03-1.58), Geometric mean (range) floors: 0.13 (<0.02-0.57)	No	E27
Sweden	Cross-sectional, 22 elementary schools*	Dust	Geometric mean (range) floor: 0.3 (<0.2-8.8), Geometric mean (range) chair: 2.6 (<0.2-13), Geometric mean (range) combined: 0.8 (<0.1-13)	Yes	E29
Sweden	Cross-sectional, 48 schools	Dust	Geometric mean (range): 0.11 (<0.015-0.39)	No	E32
Sweden	Cross-sectional, 11 schools	Dust	Mean (range): 0.13 (<0.016-0.39)	Yes	E33
United Kingdom	Cross-sectional, 5 schools*	Air	Only 1 of 9 samples detectable (0.79 ng/m ³)	No	E4

GSD, Geometric SD; IQR, interquartile range.

*Additional samples collected in homes.

†Soft refers to carpeting, rugs and upholstered furniture, or other types of soft/porous sampling surfaces (eg, clothing). Hard generally refers to hard floors and other nonporous surfaces types (eg, tile, desks, and nonupholstered furniture).

TABLE E2. Studies assessing dog allergen (Can f 1) levels in schools and day-care facilities

Country	Study design	Sampling methods and surface†	Allergen levels (µg/g unless otherwise noted)	Health outcomes assessed?	Reference
United States	Cross-sectional, 12 elementary schools	Dust, hard	Mean (range) for all samples: 1.44 (0.1-9.6)	Yes	E18
		Dust, soft			
United States	Cross-sectional, 89 day-care centers	Dust, hard	Geometric mean (SE): 0.29 (0.13)	No	E19
		Dust, soft	Geometric mean (SE): 2.13 (1.05)		
United States	Cross-sectional, 33 preschools	Dust	Median (range): 1.7 (0.1-33.6)	No	E28
United States	Cross-sectional, 2 middle schools*	Dust	Geometric mean (range) floor: 1.2 (<0.5-4.8), 1.4 (<0.5-9.9) Geometric mean (range) desk/chair: 1.7 (0.6-7.9), 2.3 (<0.5-37) Geometric mean (range) combined: 1.4 (<0.5-7.9), 1.7 (<0.5-37)	Yes	E29
United States	Cross-sectional, 4 elementary schools*	Dust	Geometric mean: 0.2	Yes	E35
Brazil	Cross-sectional, 15 day cares, 15 preschools, 15 kindergartens, and 15 elementary schools	Dust	Range: undetectable–3.3	No	E11
China	Cross-sectional, 10 junior high schools	Dust	Median (range): <0.20 (<0.20-0.53)	Yes	E13
France	Cross-sectional, 30 day-care centers	Dust, hard	Range: <0.2-1.2	No	E5
		Dust, soft	Range: <0.2-4.5		
Korea	Cross-sectional, 12 schools	Dust, hard	Median (range): 0.7 (<0.2-4.7)	Yes	E8
New Zealand	Cross-sectional, 18 day-care centers and 18 kindergartens	Dust	Geometric mean (range): 0.43 (0.01-4.09)	No	E9
Norway	Cross-sectional, 81 schools, 24 day-care centers	Dust, hard	Median: 1.7	No	E24
		Dust, soft	Median: 10.0 (day care), 7.0 (school)		
Singapore	Cross-sectional, 10 schools and 10 day-care centers*	Dust	Geometric mean (max) childcare centers: 0.1 (8.0) Geometric mean (max) schools: 0.1 (0.2)	No	E12
Singapore	Cross-sectional, 104 day-care centers	Dust	Geometric mean (range): 0.11 (0.04-2.86)	No	E15
Sweden	Cross-sectional, 8 schools	Dust, hard	Median (IQR): 0.75 (0.44-3.0)	Yes	E25
Sweden	Cross-sectional, 7 day-care centers	Dust	Median (range): 4.3 (<0.06-21.0)	No	E26
Sweden	Cross-sectional, 4 schools	dust	Geometric mean (range) chairs: 5.3 (1.7-28.2), Geometric mean (range) floors: 0.20 (0.06-0.51)	No	E27
Sweden	Cross-sectional, 22 elementary schools*	Dust	Geometric mean (range) floor: 1.1 (<0.5-60), Geometric mean (range) hair: 15 (0.45-176), Geometric mean (range) combined: 3.3 (<0.5-176)	Yes	E29
Sweden	Cross-sectional, 48 schools	Dust	Geometric mean (range): 0.38 (<0.10-3.99)	No	E32
Sweden	Cross-sectional, 11 schools	Dust	Mean (range): 0.92 (<0.06-3.99)	Yes	E33

IQR, Interquartile range.

*Additional samples collected in homes.

†*Soft* refers to carpeting, rugs and upholstered furniture, or other types of soft/porous sampling surfaces (eg, clothing). *Hard* generally refers to hard floors and other nonporous surfaces types (eg, tile, desks, and nonupholstered furniture).

TABLE E3. Studies assessing dust mite allergen levels in schools and day-care facilities

Country	Study design	Sampling Methods and surface	Allergen levels (µg/g unless otherwise noted)	Health outcomes assessed?	Reference
United States	Cross-sectional in spring and fall, 41 elementary schools in 3 cities	Dust, hard	Median range†: 0.01-2.8 Median range‡: 0.01-0.5	No	E16
		Dust, soft	Median range†: 0.01-7.0 Median range‡: 0.01-1.3		
United States	Cross-sectional, 12 elementary schools	Dust, hard	Mean (range) for all samples: 0.38 (0-11.9)	Yes	E18
United States	Cross-sectional, 89 day-care centers	Dust, hard	Geometric mean (SE)†: 0.02 (0.01)	No	E19
		Dust, soft	Geometric mean (SE)‡: 0.02 (0.01) Geometric mean (SE)†: 0.16 (0.08) Geometric mean (SE)‡: 0.04 (0.02)		
United States	Cross-sectional, 20 day-care centers	Dust	Mean (SE)†: 1.3 (0.9)	No	E22
		Air	Mean (SE)†: 5.4 (6.9) Mean(SE)†: 0.2 AU/m ³ (0.6 AU/m ³)		
United States	Cross-sectional, 1 middle school (tiled) and 1 elementary school (carpeted)	Dust, tiled	Geometric mean (GSD): 3.4 (0.0035)	No	E23
		Dust, carpeted	Geometric mean (GSD): 7.0 (0.0025)		
		Air, tiled	Geometric mean (GSD): 0.074 ng/m ³ (0.0044 ng/m ³)		
		Air, carpeted	Geometric mean (GSD): ≤0.032 ng/m ³ (0.0023) ng/m ³)		
United States	Cross-sectional, 33 preschools	Dust	Median (range)†‡: 0.6 (<0.02-22.0)	No	E28
United States	Cross-sectional, 2 middle schools*	Dust	Geometric mean (range) floor†‡: 0.6 (<0.4-1.7), 0.8 (<0.4-2.4)	Yes	E29
			Geometric mean (range) desk/chair†‡: 2.0 (<0.4-19), 2.4 (1-8.4)		
			Geometric mean (range) combined†‡: 0.9 (<0.2-18), 1.3 (<0.2-7.9)		
United States	Cross-sectional in winter, spring, and fall; 2 elementary schools	Dust, soft	Range†‡: <0.01-0.12	No	E30
United States	Cross-sectional, 4 elementary schools*	Dust	Geometric mean†: 0.04 Geometric mean‡: 0.05	Yes	E35
United States	Cross-sectional, 20 elementary schools	Dust, hard	Median (range)†: 0.093 (0.007-18.3) Median (range)‡: 0.035 (0.007-0.13)	No	E34
		Dust, soft	Median (range)†: 0.580 (0.042-50.9) Median (range)‡: 0.057 (0.010-4.0)		
Brazil	Cross-sectional, 15 day-care centers, 15 preschools, 15 kindergartens, and 15 elementary schools	Dust, hard	Geometric mean (range)†‡: 1.3 (<0.02-10.5), 1.9 (0.35-5.5), 0.07 (<0.02-0.25), 0.5 (0.06-4.7)	No	E11
		Dust, soft	Geometric mean (range)†‡: 2.6 (<0.02-16.2), 6.3 (1.3-30.7)		
China	Cross-sectional, 10 junior high schools	Dust	Only detected in 1 sample (0.32‡)	Yes	E13
France	Cross-sectional, 30 day-care centers	Dust, hard	Range†‡: <0.1-1.4	No	E5
		Dust, soft	Range†‡: <0.1-5.3, <0.1-0.4, <0.1-2.3		
Germany	Cross-sectional, 41 day-care centers*	Dust	Median (IQR)†‡: 0.6 (0.2-1.5)	No	E7
Korea	Cross-sectional, 12 schools	Dust, hard	Median (range): 0.25 (<0.2-0.9)‡, <0.2 (<0.2-0.3)†	Yes	E8
Netherlands	Cross-sectional, 49 schools	Dust, hard	Geometric mean (range)†: 0.023 (<0.005-0.193)	No	E14
		Dust, soft	Geometric mean (range)†: 0.044 (<0.005-18.7)		
New Zealand	Cross-sectional, 18 day-care centers and 18 kindergartens	Dust	Geometric mean (range)†: 0.25 (0.01-103.8)	No	E9
Norway	Cross-sectional, 10 schools*	Dust	Range†: <1-5 ng/g	No	E21
		Dust, soft	Mean†: <3 ng/g		
Norway	Cross-sectional, 81 schools, 24 day-care centers	Dust	Detected in 6 samples, maximum†: 0.2	No	E24

(Continued)

TABLE E3. (Continued)

Country	Study design	Sampling Methods and surface	Allergen levels (μg/g unless otherwise noted)	Health outcomes assessed?	Reference
Singapore	Cross-sectional, 10 schools and 10 day-care centers*	Dust	Geometric mean (maximum) child-care centers: 0.3 AU/g (2.7 AU/g)†, 0.2 AU/g (2.8 AU/g)‡, 564 AU/g (11,230 AU/g)§ Geometric mean (maximum) schools: 0.1 AU/g (3.7 AU/g)†, 0.2 AU/g (3.3 AU/g)‡, 632 AU/g (14,200 AU/g)§	No	E12
Singapore	Cross-sectional, 104 day-care centers	Dust	Geometric mean (range): 0.05 (0.01-8.77)†, 0.21 (0.01-1.83)§	No	E15
Sweden	Cross-sectional, 8 schools	Dust, hard	None detected†‡	Yes	E25
Sweden	Cross-sectional, 7 day-care centers	Dust	Median (range)†‡: <0.02 (<0.02-0.11)	No	E26
Sweden	Cross-sectional, 22 elementary schools*	Dust	None detected†‡	Yes	E29
Sweden	Cross-sectional, 4 schools	Dust	Geometric mean (range) tables†‡: 0.258 (0.016-0.790) Geometric mean (range) chairs†‡: 0.044 (0.016-0.358), Geometric mean (range) floors†‡: 0.041 (0.016-0.087)	No	E6

GSD, Geometric SD; IQR, interquartile range.

*Additional samples collected in homes.

†Der p 1 allergen measured.

‡Der f 1 allergen measured.

§Blo t 5 allergen measured.

||*Soft* refers to carpeting, rugs and upholstered furniture, or other types of soft/porous sampling surfaces (eg, clothing). *Hard* generally refers to hard floors and other nonporous surfaces types (eg, tile, desks, and nonupholstered furniture).

TABLE E4. Studies assessing cockroach allergen levels in schools and day-care facilities

Country	Study design	Sampling Methods and surface¶	Allergen levels (µg/g unless otherwise noted)	Health outcomes assessed?	Reference
United States	Cross-sectional in spring and fall, 41 elementary schools in 3 cities	Dust, hard	All sites and classrooms had detectable levels‡	No	E16
United States	Cross-sectional, 12 elementary schools	Dust, soft Dust, hard	Mean (range) for all samples†‡: 1.49 (0-8)	Yes	E18
United States	Cross-sectional, 89 day-care centers	Dust, soft Dust, hard	Geometric mean (SE)†: 0.21 (0.07) Geometric mean (SE)†: 0.29 (0.10)	No	E19
United States	Cross-sectional in winter, spring and fall, 11 high schools*	Dust, hard	Range‡: <0.003-1.1	No	E20
United States	Cross-sectional, 20 day-care centers	Air	Range§: 0.058–3.8	No	E22
United States	Cross-sectional, 33 preschools	Dust	Mean (SE) : 0.26 (0.45) Median (range)†: <0.4 U/g (<0.4-5.4 U/g)	No	E28
			Median (range)‡: <1.0 U/g (<1.0-1.4 U/g)		
United States	Cross-sectional, 2 middle schools*	Dust	Geometric mean (range) floor‡: <0.2, <0.2 Geometric mean (range) desk/chair‡: <0.2, <0.2 Geometric mean (range) combined‡: <0.2, <0.2	Yes	E29
United States	Cross-sectional in winter, spring, and fall; 2 elementary schools	Dust, soft	Range†: <0.01-12.3	No	E30
United States	Cross-sectional, 4 elementary schools	Dust, hard	Classrooms median (range)†: 2.4 (0-186) All samples median (range)†: 2.6 (0-591)	No	E31
United States	Cross-sectional, 20 elementary schools	Dust, hard	Median (range)‡: 0.0052 (0.0015-0.140)	No	E34
		Dust, soft	Median (range)‡: 0.0057 (0.0016-0.015)		
United States	Cross-sectional, 1 middle school (tiled) and 1 elementary school (carpeted)	Dust, tiled	Geometric mean (GSD): 1.6 (0.0035)	No	E23
		Dust, carpeted	Geometric mean (GSD): 4.6 (0.0027)		
		Air, tiled	Geometric mean (GSD): 0.049 µg/m³ (0.0030 µg/m³)		
		Air, carpeted	Geometric mean (GSD): 0.087 µg/m³ (0.0042 µg/m³)		
United States	Cross-sectional, 4 elementary schools*	Dust	Geometric mean‡: 0.02	Yes	E35
Brazil	Cross-sectional, 15 day-care centers, 15 preschools, 15 kindergartens, and 15 elementary schools	Dust, hard	Range of geometric mean† floor: 0.9-4.7 Range of geometric mean† chair/table: 3.6-5.2	No	E11
China	Cross-sectional, 10 junior high schools	Dust	None detected†	Yes	E13
France	Cross-sectional, 30 day-care centers	Dust, hard Dust, soft	Range: 2-14 U/mL†, 2-4 U/g‡ Range: <0.6-2 U/mL†, <0.6-6 U/g‡	No	E5
Korea	Cross-sectional, 12 schools	Dust, hard	None detected†	Yes	E8
New Zealand	Cross-sectional, 18 day-care centers and 18 kindergartens	Dust	Geometric mean (range)‡: 0.028 (0.006-0.203)	No	E9
Singapore	Cross-sectional, 10 schools and 10 day-care centers*	Dust	Geometric mean (maximum) childcare centers†: 0.7 (15.1) Geometric mean (maximum) schools†: 5.9 (26.3)	No	E12
Singapore	Cross-sectional, 104 day-care centers	Dust	Geometric mean (range)†: 0.19 (0.02-5.21)	No	E15
Sweden	Cross-sectional, 8 schools	Dust, hard	None detected†	Yes	E25

(Continued)

TABLE E4. (Continued)

Country	Study design	Sampling Methods and surface¶	Allergen levels (µg/g unless otherwise noted)	Health outcomes assessed?	Reference
Sweden	Cross-sectional, 22 elementary schools*	Dust	Geometric mean (range)‡ floor: 0.2 (<0.2-0.25), Geometric mean (range)‡c hair: 0.2 (<0.2-0.56), Geometric mean (range)‡ combined: 0.2 (<0.2-0.56)	Yes	E29
United Kingdom	Cross-sectional, 5 schools*	Dust	Geometric mean (range)‡: 2.4 U/g (0.8-4.4 U/g)	No	E4

*Additional samples collected in homes.

†Bla g 1 allergen measured in units per gram unless otherwise noted.

‡Bla g 2 allergen measured in micrograms per gram unless otherwise noted.

§Bla g 2 allergen measured in nanograms per cubic meter.

||Per a 1 allergen measured in micrograms per gram unless otherwise noted.

¶*Soft* refers to carpeting, rugs and upholstered furniture, or other types of soft/porous sampling surfaces (eg, clothing). *Hard* generally refers to hard floors and other nonporous surfaces types (eg, tile, desks, and nonupholstered furniture).

TABLE E5. Studies assessing mouse allergen levels in schools and day-care facilities

Country	Study design	Sampling Methods and surface	Allergen levels (μg/g unless otherwise noted)	Health outcomes assessed?	Reference
United States	Cross-sectional, 12 elementary schools	Dust, hard	Mean (range) for all samples†: 1.44 (0.1-9.6)	Yes	E18
United States	Cross-sectional, 89 day-care centers	Dust, soft Dust, hard	Geometric mean (SE)†: 0.004 (0.002) Geometric mean (SE)†: 0.008 (0.004)	No	E19
United States	Cross-sectional in winter, spring, and fall; 11 high schools*	Dust, hard	Range‡: <0.2-1125	No	E20
United States	Cross-sectional, 33 preschools	Air Dust	Range§: 0.09-0.25 Median (range)†: 0.18 (0.02-1.7)	No	E28
United States	Cross-sectional, 4 elementary schools*	Dust	Geometric mean (range)‡: 1.66 (<0.25-238)	Yes	E35
Singapore	Cross-sectional, 104 day-care centers	Dust	Geometric mean (range): 0.007 (0.001-0.57)	No	E15

*Additional samples collected in homes.

†Mus m 1 allergen measured in micrograms per gram.

‡MUP allergen measured in micrograms per gram.

§Mus m 1 allergen measured in nanograms per cubic meter.

||*Soft* refers to carpeting, rugs and upholstered furniture, or other types of soft/porous sampling surfaces (eg, clothing). *Hard* generally refers to hard floors and other nonporous surfaces types (eg, tile, desks, and nonupholstered furniture).