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Asthma and Allergies in the School Environment

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Abstract

The school is a complex microenvironment of indoor allergens, pollutants, and other exposures. The school represents an occupational model for children and exposures in this environment have a significant health effect. Current research establishes an association between school exposure and asthma morbidity in children. This review will focus on common school environmental exposures (cockroach, rodents, cat, dog, classroom pets, dust mite, fungus, and pollution) and their impact on children with allergies and asthma. Understanding and evaluation of school-based environments is needed to help guide school-based interventions. School-based interventions have the potential for substantial benefit to the individual, school, community, and public health. However, there is a paucity data on school-based environmental interventions and health outcomes. The studies performed to date are small and cross-sectional with no control for home exposures. Randomized controlled school-based environmental intervention trials are needed to assess health outcomes and the cost-effectiveness of these interventions. The School Inner-City Asthma Intervention Study (SICAS 2), a NIH/NIAID randomized controlled clinical trial using environmental interventions modeled from successful home-based interventions, is currently underway with health outcome results pending. If efficacious, these interventions could potentially help further guide school-based interventions potentially with policy implications. In the meanwhile, the allergist/immunologist can continue to play a vital role in improving the quality of life in children with allergies and asthma at school through the use of the ADA policy and Section 504 of the Rehabilitation Act as well as encouraging adoption of toolkits to build successful school-based asthma programs and asthma-friendly schools.

Keywords Asthma · Allergen · Environment · Pediatric asthma · Pollutant · School · School exposure · School-based intervention

Abbreviations

SICAS 1	School Inner-City Asthma Study
NIH	National Institutes of Health
NIAID	National Institute of Allergy and Infectious Disease
IPM	Integrated pest management
HEPA	High efficiency particulate arrestance
$PM_{2.5}$	Particulate matter 2.5
BC	Black carbon
NO_2	Nitrogen dioxide
(CO)	Carbon monoxide
O_3	Ozone
SICAS 2	School Inner-City Asthma Intervention Study

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Introduction

Asthma is one of the leading chronic childhood diseases in the USA, affecting 8.4% of children [1]. Pediatric asthma is the most common reason for school absenteeism, accounting for the greatest loss of school days per year [2]. Asthma results in a significant economic burden to patients, families, and collectively, the country. The estimated cost of asthma in the USA is $56 billion per year, with productivity losses accounting for $3.8 billion and productivity losses due to mortality accounting for $2.1 billion [3]. Children with asthma have higher health care utilization due to higher rates of hospitalizations, emergency department visits, and outpatient visits [4]. There is currently no cure for asthma, and it is expected that the burden of asthma will only increase in the future.

Americans spend an average of 87% of their time indoors and about 6% of their time in enclosed vehicles [5]. Furthermore, toddlers and children spend a large proportion of their day (estimated between 7 and 12 h per day) indoors in daycare and school environments. Past research has established an association between environmental exposures at home and pediatric asthma morbidity [6–8]. Researchers have now expanded beyond the home to further understand environmental exposures in the school setting. This research has revealed an overlap in exposures between the home and school environment, including allergens and pollutants [9–14]. Studies have also demonstrated an association with environmental exposure at school and childhood asthma morbidity [13, 15–18]. Home-based strategies to reduce allergen and pollutant exposure have demonstrated improved asthma outcomes [19]. However, the efficacy of environmental interventions outside of the home is not as well understood. There are limited studies on school-based environmental interventions, and the benefits and cost-effectiveness of these interventions are not yet established.

This review will focus on common school environmental exposures and their impact on children with asthma. This review will discuss important exposures in the school setting including cockroach, rodents, cat, dog, classroom pets, dust mite, fungus, and pollution. Other exposures including endotoxin, tobacco, volatile organic compounds, plasticizers, crime, and stress/stressors were beyond the scope of the review and were not included. Additionally, school-based environmental intervention strategies intended to improve asthma morbidity will be reviewed.

Cockroach and Rodents

In the USA, epidemiologists and clinical researchers have consistently shown that the burden of asthma is significant in urban areas with high levels of poverty and large minority populations [20, 21]. It follows, therefore, that the inner-city home environment is an important area of study given the disparate burdens of asthma seen in children including increased asthma severity, morbidity, and associated healthcare use [22, 23]. Given the often crowded home environments of low-income families living in the inner-city, it is not surprising that high rates of both cockroach and mouse infestations exist [6, 24–28]. This is noteworthy as both cockroach and mouse allergen exposure in homes are linked to higher asthma morbidity [6, 29, 30].

The major cockroach allergens, Bla g 1 and Bla g 2, have been the primary focus of asthma and allergy research. Newer data suggests that the number of allergens relevant to cockroach allergy may actually be higher with implications for sensitization and clinical disease [31]. In the late 1990s, the National Cooperative Inner-City Asthma Study (NCICAS) showed that urban children with asthma who were both sensitized and exposed to high levels of home cockroach allergen had increased asthma morbidity [6]. In a subsequent study, the Inner-City Asthma Study (ICAS) consortium demonstrated that implementation of an individualized, home-based, multifaceted environmental intervention effectively decreased cockroach and dust mite allergen exposure and improved asthma morbidity for inner-city children [19]. The term "multifaceted" has been used to describe interventions directed toward more than one asthma trigger or interventions with more than one component. Dimango et al. employed the same individualized multifaceted environmental intervention strategy in a randomized controlled trial of New York City homes and concluded that despite a significant reduction of measured allergen levels in the intervention group, it did not result in a reduction in asthma controller therapy [32]. In contrast, a single allergen intervention demonstrated that a single low-cost intervention to reduce cockroach exposure, the strategic placement of insecticidal bait in the homes of children with asthma, resulted in significant cockroach reduction and improved asthma outcomes when compared with the no intervention control group [33].

Similar to cockroach allergen, studies have shown that mouse allergen is prevalent in urban homes and that this exposure is associated with increased childhood asthma morbidity [24, 25, 29, 30]. Major mouse allergenic proteins are Mus m 1 and Mus m 2 and can be found in mouse urine, dander, and hair follicles. Home intervention strategies to reduce mouse allergen levels have incorporated a multidisciplinary approach utilizing a range of pest control methods known as integrated pest management (IPM). Some fundamental principles of IPM include (1) identifying and monitoring pest populations with sticky traps to find out where they are living and hiding (reservoirs); (2) blocking pest access and entryways; (3) preventing pests by eliminating food and water (facilitating factors); (4) controlling pests by selectively applying low-toxicity pesticides. Removing reservoirs such as carpeting, bedding, or other areas containing allergen may also be helpful. The Mouse Allergen and Asthma Intervention Trial (MAAIT) compared a year-long home IPM intervention plus pest management education compared with pest management education alone among mouse-sensitized and exposed children and observed a reduction in mouse allergen levels in both groups but no significant difference in maximal asthma symptom days between the two groups [34]. These and additional studies are highlighted in the recent workshop report, NIAID, NIEHS, NHLBI, and MCAN Workshop Report: The indoor environment and childhood asthma—implications for home environmental intervention in asthma prevention and management [35]. Please refer to this comprehensive workshop report for further details regarding home intervention studies and the implications for asthma prevention and management [35].

Since the majority of children in the USA spend between 7 and 12 h a day in school or daycare settings, researchers are now studying the school environment as an exposure risk for children with asthma. The majority of school-based studies assessing cockroach and mouse allergen exposures have been performed in urban schools [9, 10, 14, 36, 37] and have demonstrated findings similar to the indoor home environment. Chew et al. provided evidence that cockroach and mouse allergens are commonly detected in classroom dust samples of inner-city public high schools [9]. The School Inner-City Asthma Study (SICAS) is a NIH/NIAID-funded comprehensive prospective study of classroom- and school-specific exposures and asthma morbidity among students in the Northeast, adjusting for home exposures [38]. The SICAS findings revealed higher levels of mouse allergen from dust samples obtained in school classrooms linked to enrolled students with asthma when compared with the same students' homes [10]. Moreover, exposure to classroom mouse allergen was associated with increased asthma symptoms and decreased lung function [15]. Another interesting finding was that levels of cockroach allergen were undetectable to very low in SICAS samples from both schools and homes [10, 11]. In contrast, cockroach levels have been detected in schools located in Texas, Baltimore, and England [36, 39, 40]. This highlights the theory that allergen levels may vary by location even within a city, by race/ethnicity, and by shifts in poverty levels [37, 40, 41]. These initial SICAS findings were replicated when the SICAS researchers used another technique for aeroallergen collection and moist table wipes, to examine levels on desktop surfaces of inner-city preschools and elementary schools [14].

Given the prevalence of pest exposure in the school setting and its association with asthma morbidity, additional research is needed to determine if reducing allergen exposure in children results in improvements in asthma morbidity. The successful home-based interventions serve as the model for school-based interventions. Further research in the area is needed.

Cat and Dog

According to the American Pet Products Association's (APPA) National Pet Owner's survey, 68% of households in the USA owns a pet, which equates to 84.6 million homes [42]. This leads to significant animal exposure inside the home. However, that said, animal exposure occurs outside of the home setting as well in locations where animals are not present including hospitals, schools, public transportation, and/or other public buildings [40, 43, 44]. The major cat allergen is Fel d 1 and the major dog allergen is Can f 1. Cat (Fel d 1) and dog (Can f 1) allergens disperse readily being carried on small airborne particles and can adhere to many things including textiles and carpeting. The transfer of allergens from pet owner to non-pet owner can occur through clothing as well as human hair [45, 46]. Allergen transfer through clothing is dependent on the washing frequency and the type of clothing; for example, woolen sweaters increased personal allergen exposure [45]. Interestingly, a recent study of teenagers revealed that the majority of cat-sensitized individuals did not live in a home with a cat [47]. Previous studies documented threshold levels of dog and cat exposure associated with sensitization and asthma symptoms. The threshold level for sensitization to cat (Fel d 1) is > 1 μg/g, and for asthma symptoms in sensitized individuals is > 8 μg/g [43, 44]. The published threshold level for sensitization to dog (Can f 1) is > 2 μg/g, and the threshold level associated with asthma symptoms in sensitized individuals is > 10 μg/g [43, 44].

Schools and daycares have been identified as sites of exposure to cat and dog allergens. Multiple studies have detected cat and dog allergens in the school setting, with levels exceeding thresholds associated with sensitization [43, 44, 48, 49]. Furthermore, cat and dog allergen levels were demonstrated to be higher in schools than in homes with no animals present [48–50]. In the school environment, the levels of exposure to cat and dog allergens vary extensively within schools and between schools. Past studies have found that the number of pet owners is one of the strongest predictors of elevated cat and dog allergen levels in schools [48, 51]. Additionally, carpeted and upholstered areas are associated with higher levels of exposure [37, 40, 44]. This may be more relevant for elementary school and preschool classrooms as they tend to have more carpeted and upholstered areas for classroom learning and play. Previously published SICAS studies demonstrated that dog and cat allergens were frequently detected in schools; however, these levels were found to be below past published threshold levels associated with asthma symptoms [10, 11, 15]. The researchers hypothesized that the relatively low absolute levels of dog and cat allergens detected in the schools may have been secondary to lower overall prevalence of household pet ownership in the inner-city setting [15]. Ongoing research is needed to assess the health effects of cat and dog allergen exposure in the school setting.

The primary home exposure to cat and dog is through pet ownership. Pet ownership and its role in the pathogenesis of atopic diseases are of considerable interest at this time. There is increasing interest in whether animal exposure can be beneficial or protective to the development of atopic disease. Recent studies suggest a protective association between early life exposure to dogs and cats and asthma [52–54]. This finding may be due to the effect of pets on the home microbiome which may, in turn, affect the gastrointestinal microbiome of the infant [35, 55]. This remains an area of active research. That said, it is evident that in sensitized individuals, exposure to cat and dog allergens are of significant concern and associated with increased asthma morbidity [18, 56].

Classroom Pets (Guinea Pigs, Hamsters, Rabbits, Etc.)

Many classrooms in schools throughout the USA have classroom pets; however, there has been limited research assessing the prevalence of animals in the classrooms. It has previously been reported that of the responding elementary school teachers, 25% reported having a classroom animal, mostly small vertebrates [57]. In 2015, the American Humane Association (AHA) performed an online survey and determined that the most common classroom pet adopted by surveyed teachers was fish (31%), followed by guinea pigs (13.7%) and hamsters (10.5%) [58]. There are no studies assessing exposure to these classroom pets (guinea pigs, hamsters, rabbits) and effects on sensitization and atopic disease. There is ample opportunity for future research in this area.

Dust Mites

Dust mites are a major, ubiquitous allergen source [59]. The most common dust mite species found in the USA are *Dermatophagoides farinae* (Der f 1) and *Dermatophagoides pteronyssinus* (Der p 1) [59]. Dust mites thrive in warm, humid environments. The body of a dust mite is 70–75% water by weight, and this must be maintained in order for the microscopic arthropods to reproduce [60]. Dust mites do not survive in relative humidity levels less than 50% [60]. Dust mite allergens are found in settled dust in bedding, carpeting, upholstered furniture, and less frequently in washed clothing [59]. The major site of dust mite exposure is in the bed; however, more recent studies have suggested significant exposures to dust mite during the day as well [61].

Previous studies have observed an association with dust mite allergen exposure and sensitization [62]. The defined threshold level of dust mite allergen exposure for sensitization is > 2 μg/g (or potentially any level of exposure in a genetically predisposed individual) [62]. The threshold level of dust mite allergen exposure associated with asthma symptoms is > 10 μg/g [63]. For children who are sensitized to dust mites, there is evidence of a causal relationship between exacerbations of asthma and exposure to dust mite allergen [56].

Dust mite allergen is present in the school setting with levels similar to slightly lower than corresponding levels in the home environment [64]. Within the school setting, there is variation in dust mite levels dependent on the location of the classroom. Dust mite levels are found to be higher in carpeted areas [65]. This finding is relevant for classrooms with more carpeted areas for classroom learning and plan (typically elementary and preschool classrooms). Additionally, past studies documented that the highest mite allergen levels in the daycare center were in the carpeted areas during the day when the center was occupied, suggesting that mite allergens become airborne due to disruption of the reservoir with daily activity [66]. Dust mite allergen levels in schools and daycares have been found to be greater than threshold levels associated with sensitization [39, 66]. However, the mean or median concentrations have not exceeded previously determined threshold associated with asthma symptoms (> 10 μg/g) [10, 11, 14, 48, 63]. A direct association of dust mite allergen exposure in the school setting with respiratory health has not yet been identified. Dust mite interventions have been studied in the home environment, and this topic is reviewed in detail in the recently updated practice parameters [59]. Please refer to these practice parameters for further details. That said, there are no studies assessing effect of school-based interventions on dust mite allergen exposure.

Fungus

Fungi are ubiquitous microorganisms that are present in both outdoor and indoor air. These spores and their fragments enter indoor spaces through open windows, open doors, and fresh air intakes in buildings. Once these spores and fragments have entered, they can then accumulate on surfaces. Fungal growth is likely to occur in environments that contain nutrients and moisture adequate for growth. When inhaled, these particles are thought to contribute adverse health effects in sensitized individuals as well as other individuals with respiratory diseases susceptible to irritant effects from exposure. The threshold levels of fungus exposure associated with asthma symptoms in sensitized individuals are not known. It would be assumed that these levels would vary by different fungal species. Multiple studies and meta-analyses have identified an association between exposure to indoor fungus and dampness and the development or worsening of asthma [56, 67–71]. Most of these studies have focused on health effects from household exposures. Few studies have provided an assessment of fungus in the school environment.

Schools and classrooms provide unique environments that are susceptible to fungus exposure. In a SICAS study, Baxi et al. demonstrated that schools located in the Northeastern United States are a source of fungus exposure and that visible fungus may be a predictor for higher fungal spore counts [12]. In this study, the authors evaluated 180 classrooms in 12 schools for fungal spores using Burkard air samplers and found that all classrooms had varying amounts of fungal spores present [12]. Interestingly, classrooms within the same school had substantial variability in quantity of spores and species [12]. Studies from other countries have also identified fungal exposure in the classroom and found an association of fungal exposure and asthma morbidity. Simoni et al. evaluated 46 classrooms in 21 European schools and found viable mold and fungal DNA in all classrooms [72]. Furthermore, they found that *Aspergillus/Penicillium* was significantly associated with wheeze and children exposed to high levels of viable mold had a higher risk for night cough [72]. In a nationwide school survey in Taiwan, Chen et al. investigated the correlation between fungal spores in classrooms and asthma in school children using Burkard personal air samplers to collect fungal spores [16]. They demonstrated that classroom *Aspergillus/Penicillium* and basidiospores were associated with current asthma and asthma with symptoms reduced on holidays [16]. In Portugal, investigators evaluated 71 classrooms in 20 schools using single-stage microbiologic impactors to determine fungal diversity [73]. Higher concentrations of *Penicillium* were found in classrooms with a higher number of children with atopic sensitization [73]. In contrast, investigators found that exposure to higher fungal diversity was protective against allergic sensitization but this was not seen for asthma [73].

Reducing indoor exposure, using a variety of interventions largely aimed at reducing moisture, killing fungi, and removing contaminated materials, has been shown to decrease the risk of asthma morbidity [74]. However, there are still many unknowns including (1) whether there are threshold levels that cause disease, (2) whether there is a dose-response relationship, (3) whether specific fungal genera are responsible for the effect, or (4) whether interventions to reduce exposure prevent asthma morbidity. Further research is necessary to determine whether efforts to decrease fungus exposure in schools can be effective at reducing adverse health effects.

Indoor Pollution and Air Quality

Exposures to ambient air pollution have been associated with adverse health effects including increased asthma symptoms, decreased lung function, increased medication use, increased hospitalizations, and increased mortality [75–79] [75–78, 80, 81]. In the school environment, some of the common exposures to pollution include particulate matter (PM), black carbon (BC), nitrogen dioxide (NO_2), carbon monoxide (CO), and ozone (O_3). PM is a complex mixture of microscopic particles and liquid droplets that are aerosolized and once inhaled can affect the heart and lungs [82]. BC is a sooty black substance emitted from diesel and gas engines, burning of wood and coal, and other sources that burn fossil fuel [82]. BC is released directly into the atmosphere in the form of particulate matter. NO_2 is one of the group of gases called nitrogen oxides and is used as the indicator for the larger group of nitrogen oxide gases [82]. High concentrations of these gases can irritate the airways and even short exposures can aggravate respiratory diseases. CO is a colorless and odorless gas released through combustion, such as the burning of fossil fuels, that can be harmful when inhaled in large amounts [82]. Breathing high concentrations of CO reduces the amount of oxygen that is transported to vital organs [82]. O_3 is a gas composed of three oxygen atoms [82]. Harmful ozone is found at the ground level and is created by chemical reactions between nitrogen oxides and volatile organic compounds, and reaction can occur when emissions from vehicles or factories interact with sunlight [82]. The federal Clean Air Act requires the Environmental Protection Agency to set National Ambient Air Quality standards for pollutants like PM, NO_2, CO, and O_3.

Schools have a unique indoor environment with fewer sources of indoor pollutants, as most schools do not have fuel-burning kitchens and smoking is prohibited. However, indoor air quality in the classroom is an important issue, and traffic emissions are a source of pollutant exposure in the schools. Kingsley et al. examined the proximity of public and private schools in the USA and the nearest major roadway and demonstrated that 3.2 million students attended schools located within 100 m of a major roadway [83]. These students are potentially exposed to very high levels of traffic-related air pollution on a daily basis [83]. Additionally, there are often cars and buses idling for pick up and drop off [84]. The French 6-Cities Study assessed air quality in schools in six metropolitan French cities and found that air quality in the classroom was poor, with 30% of school children exposed to high levels of pollutants [85]. Madureira et al. assessed the indoor air quality of 73 classrooms in 20 schools in Porto, Portugal, and found frequent high levels of CO2, $PM_{2.5}$, and PM_{10}, and low rates of ventilation [86]. From SICAS, Gaffin et al. described the relationship between indoor and outdoor levels of $PM_{2.5}$ and BC in inner-city schools in 136 classrooms over 30 schools in the Northeastern United States [87]. They demonstrated a strong relationship between measured indoor classroom levels of $PM_{2.5}$ and BC with matching outdoor levels [87]. Furthermore, they demonstrated that indoor sources of $PM_{2.5}$ and BC within the school contributed significantly to indoor levels despite the absence of smoking and cooking at the locations [87]. In a similar cohort, Gaffin et al. described NO_2 levels in 218 classrooms within 37 schools and found that levels were relatively low compared with the US Environmental Protection Agency's air quality standards with a mean level of 11.1 ppb and mean of 10.4 ppb [13]. This study demonstrated that NO_2 levels greater than 8 ppb were significantly associated with airflow obstruction but not with asthma symptoms [13].

There have been few studies that have evaluated the impact of a school-based intervention on indoor air quality and health effects (Table 1). Pilotto et al. in a randomized control trial of 19 schools, an intervention replacing unflued gas heaters with electric heaters resulted in significant reduction in NO_2 levels and asthma symptoms in the intervention group [88]. Jhun et al. performed a small randomized control trial using an intervention of classroom-based air cleaners using high efficiency particulate air (HEPA) filters vs. a control of sham air cleaners [89]. In the intervention classrooms, $PM_{2.5}$ and BC

Table 1 School-based Environmental Intervention Studies

Study	Design	Population	Intervention	Effectiveness of Intervention
Pilotto et al. [88] (2004)	Randomized control trial	Children (aged 8-9 y; Australia)	Replacement flued gas or electric heaters in schools	• Reduction in NO_2 exposure • Reduction in asthma symptoms
Jhun et al. [89] (2017)	Randomized control trial (Pilot Study)	Children (aged 6-10 y; USA)	Classroom based HEPA air cleaner intervention	• Reductions in $PM_{2.5}$ and BC • No significant changes in FEV_1 and asthma symptoms • Modest improvement in peak flow
Bernstein et al. [90] (2005)	Randomized control trial (Pilot Study)	Children (aged newborn-5 y; USA)	Dehumidification plus day care room based HEPA air cleaner	• Lower average dew point from baseline for both day care A and B • Reduction in fungal spore counts for day care A only • No health outcomes assessed
Lignell et al. [91] (2007)	Longitudinal intervention study	Children (aged 7-12 y; Finland)	Damaged school renovated for all identified problems, mechanical exhaust and supply air ventilation system installed	• 50% reduction in fungal concentrations • Modest reduction in respiratory symptoms
Meklin et al. [92] (2005)	Longitudinal intervention study	Children (aged 6-17 y; Finland)	Damaged schools thoroughly cleaned, repaired, renovated, and mechanical exhaust and supply ventilation system installed	• Normalization of indoor air fungal concentrations • Reduction in respiratory and other symptoms
Karlsson et al. [93] (2004)	Intervention study	Children (aged 6-12 y; Sweden)	School clothing or pet-free classes. Two classes of children with special school clothing, one class of children with no pets, and three control classes.	• 4-6 fold lower airborne cat allergen levels in intervention classes compared with controls. • No health outcomes assessed
Nalyanya et al. [94] (2009)	Longitudinal intervention study	Children (USA)	Integrated pest management (IPM) or conventional pest control	• Reduction in Bla g 1 concentrations in IPM-treated schools than in schools treated with conventional approaches. • No health outcomes assessed

Abbreviations: NO_2: nitrogen dioxide; US: United States; HEPA: high efficiency particulate arrestance; $PM_{2.5}$: particulate matter 2.5; BC: black carbon; FEV_1: forced expiratory volume in 1 second; Bla g 1: Blattella germanica, German cockroach levels were significantly reduced compared with the control classrooms [89]. The air cleaner intervention reduced $PM_{2.5}$ and BC levels during the follow-up periods, demonstrated modest improvement in peak flow, but did not demonstrate significant changes in FEV_1 or asthma symptoms [89]. Further large-scale studies are needed to evaluate the effectiveness in reducing pollutant levels in schools and whether this has a resultant effect on asthma morbidity.

School Environmental Intervention Strategies

School-based studies examining environmental interventions and health outcomes are lacking in the USA. The few published European studies are small and not adequately powered to comprehensively assess asthma morbidity outcomes [88–93]. Studies evaluating school-based environmental interventions are highlighted in Table 1. In addition to indoor air quality interventions previously discussed above [88, 89], other studies have assessed interventions targeted at fungi, pet allergens, and cockroach [90-94]. One study showed that banning pet ownership in Swedish schools and having dedicated school clothing resulted in four to six times lower airborne cat allergen levels in the intervention groups (classes with school clothing or pet ownership ban) compared with the control classes, thereby, reducing pet dander in schools [93]. Despite its efficacy in Sweden, this school-based environmental intervention is unlikely to find favor in the USA. In another Swedish study, other allergen prevention measures such as dedicated cleaning, removal of upholstery and curtains, and replacement of bookshelves with cupboards to lessen allergen load offered no significant change in cat allergen levels in school classrooms [95]. Two longitudinal Finnish studies, limited by the small number of schools assessed, demonstrated improvement in asthma symptoms through reparation of air filtration systems and moisture damage in schools, reduction in mold exposure, and other building maintenance [91, 92]. In one Australian school study, as previously mentioned, an intervention replacing unflued gas heaters with electric heaters effectively reduced NO_2 levels and improved asthma symptoms [88]. The use of air filtration systems to reduce environmental exposures is a potential effective school-based intervention [96]. One pilot study showed that HEPA air filters reduced mold spore counts in daycare centers by 50% [90]. Lastly, Nalyanya et al. demonstrated that IPM implementation in North Carolina schools was not only more effective at controlling cockroaches than conventional pest control but lead to long-term reductions in allergen concentrations [94]. Ongoing research is needed to better understand the health outcome effects of school-based IPM interventions.

Well-designed randomized, double-blinded, controlled school-based environmental intervention trials are needed. The majority of school-based intervention studies to date have been cross-sectional with small sample sizes and with no control for home exposures [36, 37, 40, 41, 49, 97, 98] [99]. The School Inner-City Asthma Intervention Study (SICAS 2), is an NIH/NIAID-funded (ClinicalTrials.gov NCT02291302) randomized controlled clinical trial using an environmental intervention of classroom HEPA filters and school wide IPM to comprehensively determine health benefits on reducing asthma morbidity, adjusting for exposure in the home [100]. Pilot data from this SICAS 2 study revealed that a classroom-based air cleaner intervention led to significant reductions in $PM_{2.5}$ and BC, compared with sham filters [89]. This study demonstrated modest improvement in peak flow but no significant changes in FEV_1 and asthma symptoms [89]. The SICAS 2 research group is working to better understand the benefits of school-based interventions and associated health outcomes.

Challenges of School Environmental Intervention Studies

We know that the school environment contains a large reservoir of exposures such as indoor allergens and pollutants, and like homes, should also be considered for interventions. In schools throughout the country, there will be variation in exposures secondary to multiple factors including differing geographic, climate, socioeconomic conditions, distance from major highways and roadways, and the built environment, as well as many other factors. Given this, a single school-based environmental intervention strategy may not be realistic or generalizable for all schools. This is similar to the fact that an intervention strategy for one home may not be generalizable to all homes. This makes implementation of school-based environmental intervention strategies complicated. Additionally, to adequately study and demonstrate improved asthma outcomes in school based-intervention studies, multiple exposures must be taken into consideration. Although challenging, school-based environmental interventions have the potential to benefit a community of children. Past research in the state of Maryland demonstrated that single- and multi-component environmental strategies in the home were cost-saving relative to the standard of care [101]. Given that school-based interventions have the potential to impact a large number of children, if effective, these programs could be even more cost-effective.

The logistics of implementing these interventions in a classroom setting in an unobtrusive way should also be considered. HEPA filters need to be both obscure and noiseless so as not to disturb students in the classrooms. While it is possible for some school-based interventions to be blinded, such as sham versus active filters in the classrooms, large-scale interventions might be more difficult to blind. In addition, certain interventions such as IPM cannot be randomized from classroom to classroom but could be randomized between schools. Of utmost importance to the success of these school-based environmental intervention studies is the involvement and commitment from the school systems as well as community buy-in. Support for school-based interventions must be attained from many sponsors including senior school administrators, principals, teachers, school nurses, facilities management, and the students and their families.

Policy and Policy Implications

It is evident that there is a relationship between school exposure and pediatric asthma morbidity and thus, policy changes could provide an important supplement to clinical care to improve the quality of life and health of students. Abramson's recent review [102] discussed potential policies to help reduce allergic triggers and improve care for patients with allergic rhinitis and allergic asthma. In this review, Abramson discussed occupational exposure policies with the school environment, as the school represents the occupational environment for many children [102]. We remain hopeful that SICAS 2, a prospective randomized, blinded, sham-controlled school environmental intervention trial currently underway, will help determine the efficacy of a school-based intervention to improve asthma control. If efficacious, these interventions could then further guide policy change.

The allergist/immunologist plays an important role in improving the quality of life at school. The allergist/immunologist can aid families through the ADA policy and Section 504 of the Rehabilitation Act that require schools to accommodate children with disabilities, including allergies. The allergist/immunologist can help facilitate a 504 plan and communicate with the school administrators and nurses to develop an action plan for the school [102]. The developed action plan for the school is variable patient to patient dependent on the allergens, issues in the school, and identifiable exposures.

External to the role of the allergist/immunologist, multiple toolkits have been developed to educate schools with the goal to build successful school-based asthma programs and asthma-friendly schools. The EPA has created the Indoor Air Quality Tools for Schools Program that provides recommendations to improve the quality of environmental conditions in the school setting [103]. These tools are available to all schools and the program recognizes effective implementation of these policies along with innovations in environmental control with EPA awards to schools [102, 104]. Additionally, the Centers for Disease Control and Prevention (CDC) Healthy Schools Program [105] and the School-Based Asthma Management Program (SAMPRO™) [106] offer toolkits to schools. These toolkit and reward programs are valuable and should continue; however, there remains a need for continued identifications of best practices for reducing allergenic exposures. This emphasizes the need for ongoing environmental health research to assess the efficacy of school interventions.

Conclusion

The home and school environments are both rich sources of allergen and pollutant exposures, and these exposures are associated with increased asthma morbidity. Past research has assessed the efficacy of environmental interventions in the home setting, but there is limited data on interventions in the school setting. Successful environmental interventions in the home serve as the model for interventions in the school. Through school-based interventions, the goal is to decrease exposure to multiple allergens and pollutants in the school and thereby improve health outcomes, including atopic diseases. However, there are many additional challenges and costs associated with school-based interventions and further research is necessary to assess the impacts of school-based interventions and the cost-effectiveness of these interventions. SICAS 2 is currently underway as a randomized controlled trial to determine the efficacy of a school-based intervention to improve asthma control.

The potential benefit of successful school-based interventions is substantial as many students, teachers, and staff are impacted by a school-based intervention. From a public health perspective, interventions in the schools have the potential to improve the health of a community instead of the focus on individual homes and families. Ongoing research is needed to determine the effectiveness of these interventions, but we remain optimistic in hopes to improve the health and lives of those attending schools. In the meanwhile, the allergist/immunologist can continue to play a vital role in improving the quality of life in children with allergies and asthma at school through the use of the ADA policy and Section 504 of the Rehabilitation Act as well as encouraging adoption of toolkits to build successful school-based asthma programs and asthma-friendly schools.

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Compliance with Ethical Standards

Conflict of Interest The authors declare that they have no conflict of interest.

Ethical Approval This article does not contain any studies with human participants or animals performed by any of the authors.

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