The school environment and asthma in childhood

Marissa Hauptman¹,²,³,⁴,⁵ and Wanda Phipatanakul²,³,⁵,*

¹Division of General Pediatrics, Boston Children’s Hospital, Boston, MA, USA
²Division of Allergy and Immunology, Boston Children’s Hospital, Boston, MA, USA
³Harvard Medical School, Boston, MA, USA
⁴Region 1 New England Pediatric Environmental Health Specialty Unit, Boston, MA, USA
⁵Boston Children’s Hospital, 300 Longwood Ave., Boston, MA 02115, USA

Abstract

In this article, we discuss the relationship between environmental exposures within the school environment and pediatric asthma morbidity. This article will conclude by reviewing novel school based asthma education and therapeutic programs and environmental interventions designed to help mitigate pediatric asthma morbidity.

Keywords

School exposures; School-based environmental intervention; Pediatric asthma; School-based asthma management

Background

Asthma is the most common childhood disease, affecting up to 15% of children in the United States (U.S.) [1, 2]. The burden of asthma is not distributed evenly with urban minority children of low socioeconomic status enduring higher morbidity [3]. In addition to health care utilization, in 2013, pediatric asthma was the leading cause of school absenteeism and accounted for an annual loss of more than 10.5 million school days per year [4]. Data from the U.S. National Interview Survey found that children with asthma missed 3
times more school days and had a 1.7 times increased risk of suffering from a learning disability as compared to children without asthma [3].

It has been well studied that aeroallergen, mold, and airborne pollutant exposure in the inner-city home environment is associated with significant childhood asthma morbidity [5–10]. While the home environment has been extensively studied, the U.S. school environment is less well understood, largely due to the logistical and community hurdles. Despite this, numerous U.S. based and European studies have demonstrated considerable allergen and pollutant levels present in the inner-city school environment, where children spend 7–12 hours per day, which may be contributing to asthma morbidity [11–26]. Additionally, increases in asthma exacerbations and hospitalization have been observed among children 2–3 weeks after return-to-school following holidays, especially summer holidays [27, 28].

In this article, we discuss the relationship between environmental exposures within the school environment and pediatric asthma morbidity. This article will conclude by reviewing novel school based asthma education and therapeutic programs and environmental interventions designed to help mitigate pediatric asthma morbidity. We have focused on inner-city school environments due to the disproportionately high asthma burden in these areas [5–10]. Although, the primary disease of interest in this review article is childhood asthma, environmental exposures and interventions within the school environment may impact morbidity of other allergic and irritant-induced diseases such as eczema and allergic rhinitis [29].

**Review**

**School environmental exposures: allergens**

The school environment is a significant reservoir for allergens, pollutants, and viral respiratory infections [11–26]. In 2009, a comprehensive review of allergen exposures in schools highlights the routine exposure to variable levels of indoor allergens in schools dependent on building characteristics, geographic, climatic and cultural factors [11]. As in home environments, it is unlikely that a single school or classroom based environmental exposure is exclusively responsible for asthma morbidity [30, 31].

The school environment may be an important site of exposure to indoor allergens, including cockroach, cat, dog, mouse, dust-mite, and molds, known to be important in the urban home environment [32]. Higher asthma morbidity in inner-city children has historically been associated with cockroach and mouse allergens more than other commonly encountered allergens in home environments [10, 33–35]. Previous studies found cockroach and mouse allergens highly prevalent in school environments [13, 21]. The School Inner-City Asthma Study (SICAS) is a NIH/NIAID funded, comprehensive, prospective study of inner-city school and classroom specific exposures and asthma morbidity among inner-city students in the Northeast [36]. In SICAS, our study group has reliably detected much higher levels of mouse allergen in schools, compared to the same students’ home environments [22, 24], with levels similar to those seen in occupational lab animal settings [37]. Cat and dog allergen levels in the school environment in SICAS were variable [22], and not at levels previously shown to worsen symptoms [38]. European school-based studies have
demonstrated cat and dog allergens at high levels in schools, likely from passive transfer of students who owned pets in their homes [20, 32]. Consistent with other studies, there was very little cockroach allergen discovered [22, 32]. Dust mite allergen in schools and day care facilities are found in similar or slightly lower levels than in corresponding respective homes, and given their propensity to thrive in humid environments, highest average concentrations were detected in humid regions in the United States and Brazil [11, 39]. Some of the differences between the European and U.S. inner-city cohorts are likely due to climatic, cultural and occupant factors [32].

**School environmental exposures: mold**

Schools are a unique microenvironment of indoor air pollutants and particulates, as well as associated mold and other allergens carried on these particles. An ongoing prospective study evaluating indoor air pollution in Europe, entitled The Health Effects of Indoor Air Pollutants (HITEA), has found high levels of mold in schools, particularly those with moisture damage [29, 40–43]. These mold findings substantiate the results from SICAS, which found elevated levels of mold in settled dust and airborne concentrations [25]. This was further substantiated by a recent national Taiwanese study, which demonstrated that fungal spore levels in classrooms correlated with asthma symptoms and a relief of symptoms on weekends and holidays [44].

**School environmental exposures: near roadway proximity and indoor air quality**

Schools are typically centrally located within a community and a recent study conducted by Kingsley et al. demonstrated that approximately 3.2 million (6.5 %) children across the United States attended schools located within 100 meters of a major roadway as defined by the United States Census Bureau [45]. In addition, to being in close proximity to heavy traffic routes and commercial or industrial exposures, schools frequently serve as a hub for pick-up, drop-off, and idling of cars and buses, potentially contributing to a site-specific increase in ambient pollution that are not characterized by typical definitions of major roadways or traffic density [46].

Annessi-Maesano et al. [47], as part of the French 6 Cities Study, assessed indoor air quality data in primary schools and investigated the relationships between classroom based air pollutants and asthma and rhinitis in schoolchildren, this study, however, did not comprehensively adjust for home environmental mold and allergen exposure levels. This study demonstrated that overall about one-third of the 6,590 schoolchildren were exposed to high concentrations of air pollutants as defined by the World Health Organization for fine particulate matter with aerodynamic diameter ≤2.5 μm (PM2.5) and nitrogen dioxide (NO₂), levels above 10 μg/m³ and 40 μg/m³, respectively [47]. In multivariate linear mixed regression models, asthma was more common in classrooms with high PM2.5, after adjusting for age, gender, passive smoking, maternal or paternal history of asthma, dampness, gas appliance, ethnicity and socio-economic status [47]. When the population was stratified by skin prick test positivity, significant positive associations were identified among PM2.5 and NO₂ and sensitized asthmatics. Other international studies conducted in urban areas of Taiyuan, China [48] and Barcelona, Spain [49], corroborated these findings.
Further exacerbating indoor air quality, classroom activity re-suspends indoor air particles thereby increasing exposure [50]. Children are frequently physically active in school, increasing their minute ventilation and thus the inhaled dose of pollutant concentrations [50]. Schools also sometimes have poor ventilation [51] and suffer inadequate building maintenance [52]. A review study conducted by Daisy et al. [53], found that classroom ventilation is typically inadequate and may exacerbate children’s exposure to indoor air pollutants. This review article, highlighted a study conducted by Smedje et al. [54, 55], which showed that 41% of carbon dioxide measurements in 38 schools located in the fourth largest city of Sweden were above 1000 parts per million (ppm), the threshold generally regarded as indicative of unacceptable ventilation rates.

**School-based asthma management programs**

Several national, state, and city governmental and nongovernmental organizations including the American Lung Association [56], Allergy and Asthma Foundation of America [57], National Heart, Blood and Lung Institute (NHLBI), the Centers for Disease Control and Prevention’s (CDC) National Asthma Control Program, which includes 36 state and territorial state asthma programs [58], and the Environmental Protection Agency’s Indoor Air Quality Tools for Schools Program have developed a number of school-based asthma programs. These major school-based activities include school-based asthma therapeutic management programs, self-management education for students, indoor air quality and trigger reduction programs, educational trainings for school personnel and administering asthma medication self-carry law [59]. State asthma programs utilize the data from their CDC-funded asthma surveillance systems to focus activities in regions with the most hospitalizations and emergency department visits for asthma. These multidisciplinary programs work with state asthma partnerships to identify areas with high health risk students and to identify evidence-based interventions to implement statewide [58].

A review study published in 2011, demonstrates that school based asthma education programs that teach self-management, knowledge, and skills to children and adolescents with asthma, are effective in decreasing school absenteeism related to asthma with less definitive findings on reduced health care utilization metrics up to the first year post-interventions [3, 60–68]. An example of school based asthma education programs with ongoing success is the American Lung Association’s Open Airways for Schools, which is implemented throughout the United States [62, 69]. It has been sustained through use of undergraduate-level health education students [62, 69] and similar programs have demonstrated success with medical students in Australia [70].

A randomized control trial conducted by Noyes et al. [71, 72], which assessed the effectiveness of administration of a daily dose of preventive asthma medication within the school setting was effective and cost-effective in reducing symptoms in inner-city children with asthma as compared to usual care [64]. This may be especially important for inner-city pediatric populations where inhaled corticosteroids are especially underused, with median usage rates of only 32% among African-Americans compared with 51% among Caucasians [73]. Several small studies of supervised daily control therapy at school have corroborated this randomized control trial with improvements in adherence and health outcomes [3, 74–
There have been documented success, in settings where a consulting physician worked with school nurses, resulting in increases in albuterol treatments at school and subsequent reductions in students being sent home or requiring emergency services for further treatment [3, 77]. Lastly, a larger randomized controlled trial showed marginally significant improvements among students new to controller therapy when treated at school compared to home [3, 78].

Bruzzesse et al., comprehensive review of school based asthma programs, highlighted competing priorities in the education system, which present challenges to the implementation of school-based asthma programs. Among these challenges, is the importance of a school nurse in the success of these management programs. National Association of School Nurses, documents that only 45% of schools had a full time registered nurse or licensed practical nurse [59]. Limited studies [61, 67, 79–81] with mixed results suggest that there is a potential for an innovative intervention targeting school-based personnel beyond school nurses or school based health care settings and further studies are needed to determine their effectiveness.

**School-based environmental interventions**

A perspective published in 2014 [29], highlighted the limited nature of school-based environmental intervention studies done to date and proposed feasible school-based environmental interventions to mitigate asthma morbidity. Prior school-based environmental intervention studies have been small, cross-sectional, and did not uniformly control for exposures in the home environment [12–16, 18, 19, 21, 26, 29, 82–86]. To fully understand if school-based environmental interventions improve asthma morbidity, investigators must also collect information on the home environment.

Several small longitudinal studies in Europe have found improvement in asthma symptoms with repair of air filtration systems, repair of moisture damage, and reduction in mold exposure and other building maintenance [55, 87, 88]. A small-randomized trial in Australia found that when controlling for the home environment, replacing school heaters and thus reducing NO$_2$ levels reduced asthma symptoms [29, 83]. Although effective in controlling particle concentrations, these types of heaters are not routinely used in schools in the United States, and most schools do not utilize gas stoves, making indoor sources of NO$_2$ less likely [29]. A study conducted by Beatty et al., assessed the health impact and cost effectiveness of a new localized emissions reduction program that retrofits diesel school buses with aggressive pollution control technologies in the State of Washington [89]. This study was associated with statistically significant and large reductions in respiratory illness incidence among at-risk children and adults with chronic respiratory conditions within the greater Puget Sound region, which includes Seattle [89].

In Sweden, interventions to reduce pet dander in schools have been conducted, although such interventions—including pet avoidance measures or even banning pet ownership—would not be practical in the United States [84–86]. Additionally, given the low level of cat and dog dander found in prior inner city school-based studies, this may not be an effective intervention to reduce asthma exacerbations within the U.S. inner city pediatric populations [22].
Given the scarcity of comprehensive data on school-based environmental interventions and health outcomes, successful home-based strategies currently serve as the model for school-based interventions [29]. A landmark study by Morgan et al., from the Inner-City Asthma Study Group showed that multifaceted removal of multiple allergens and pollutants through allergen-impermeable covers, HEPA filter vacuum cleaners, HEPA air purifiers, and professional pest control could improve asthma outcomes [90]. One potential school-based intervention is the use of air filtration systems to reduce environmental exposures [91, 92]. A recent report on air filtration outlined what is known in this field and called for more rigorous trials and research [91]. With regard to types of air filtration systems, room HEPA air filters may be more practical for study purposes [91, 93], and may be utilized to control classroom-specific exposures. If successful within single classrooms, these results may inform future school-wide policies and practices.

Similarly, a pilot study showed that HEPA filters reduce mold spore counts in daycare centers, which have similar conditions to a school environment [94]. Another example of a feasible school-based environmental intervention is integrated pest management. Given the markedly high levels of mouse allergen in schools compared to levels in children’s individual bedrooms [22, 23], our group piloted strategies toward comprehensive effective school-based environmental reduction techniques and tailored components, such as integrated pest management. These environmental controls were modeled from successful home-based strategies and adapted for tolerance and acceptability in a school and classroom, to collectively reduce allergen and pollutant levels in preparation for a NIH/NIAID funded School Inner-City Asthma Intervention Study [29].

Despite the logistical challenges of implementing comprehensive school-based environmental, educational and therapeutic interventions, evidence provides support towards the contribution of school and classroom exposures and health outcomes [55, 83–88, 94]. School-based interventions have the potential to reduce exposures for many symptomatic children, in contrast to the individual families impacted by home-based interventions. If effective, results from school-based interventional studies could inform public policy change, funding, and initiatives [29]. While establishment and implementation of public policies is an expensive undertaking for cities, preliminary studies suggest that environmental interventions may be cost beneficial [95]. In inner cities where the burden of disease is so great, interventions may reduce the cost to the community even further.

**Conclusions**

The school environment where children and school personnel spend a majority of their day is a significant reservoir for allergens and pollutants [11–26]. There are several domains to which to intervene on school based asthma surveillance, education, optimization of asthma management and adherence to recommendations as well as environmental interventions that all have the potential to mitigate pediatric asthma morbidity. If it can be demonstrated that reduction of classroom-specific exposures and other therapeutic and educational interventions lead to improved asthma outcomes, then findings can be translated into cost-effective strategies to benefit communities of children through improvement of the school environment. In this limited resource environment, it will be critical to determine, which are
most efficient and cost-effective to implement broadly to improve pediatric asthma morbidity.

Acknowledgments

This work was supported in part by grants K24 AI 106822, U10 HL 098102, and U01 AI 110397 (Dr. Phipatanakul) from the National Institutes of Health and was funded (in part) by the cooperative agreement award number FAIN: U61TS000237 (Dr. Hauptman) from the Agency for Toxic Substances and Disease Registry (ATSDR). The U.S. Environmental Protection Agency (EPA) supports the Pediatric Environmental Health Specialty Units (PEHSU) by providing partial funding to the ATSDR under Inter-Agency Agreement number DW-75-92301301.

Abbreviations

| Abbreviation | Description |
|--------------|-------------|
| CDC          | Centers for Disease Control and Prevention |
| HEPA         | High-efficiency particulate arrestance |
| HITEA        | Health effects of indoor air pollutants |
| NIH          | National Institutes of Health |
| NIAID        | National Institute of Allergy and Infectious Disease |
| NHLBI        | National Heart, Lung, and Blood Institute |
| NO2          | Nitrogen dioxide |
| PM$_{2.5}$   | Particulate matter with diameter ≤2.5 μm |
| ppm          | Parts per million |
| SICAS        | School Inner-City Asthma Study |
| U.S          | United States |

References

1. Silverstein MD, Mair JE, Katusic SK, Wollan PC, O’connell EJ, Yunginger JW. School attendance and school performance: a population-based study of children with asthma. J Pediatr. 2001; 139(2): 278–83. [PubMed: 11487757]
2. Joseph CL, Foxman B, Leickly FE, Peterson E, Ownby D. Prevalence of possible undiagnosed asthma and associated morbidity among urban schoolchildren. J Pediatr. 1996; 129(5):735–42. [PubMed: 8917242]
3. Bruzzese JM, Evans D, Kattan M. School-based asthma programs. J Allergy Clin Immunol. 2009; 124(2):195–200. [PubMed: 19615728]
4. Asthma and Allergy Foundation of America. [Accessed April 30, 2015] Asthma Facts and Figures. [http://www.aafa.org/display.cfm?id=8&sub=42] Updated 2015
5. Call RS, Smith TF, Morris E, Chapman MD, Platts-Mills TA. Risk factors for asthma in inner city children. J Pediatr. 1992; 121(6):862–6. [PubMed: 1447646]
6. Sarpong SB, Hamilton RG, Eggleston PA, Adkinson NF Jr. Socioeconomic status and race as risk factors for cockroach allergen exposure and sensitization in children with asthma. J Allergy Clin Immunol. 1996; 97(6):1393–401. [PubMed: 8648037]
7. Kattan M, Mitchell H, Eggleston P, Gergen P, Crain E, Redline S, et al. Characteristics of inner-city children with asthma: the National Cooperative Inner-City Asthma Study. Pediatr Pulmonol. 1997; 24(4):253–62. [PubMed: 9368259]
8. Eggleston PA, Rosenstreich D, Lynn H, Gergen P, Baker D, Kattan M, et al. Relationship of indoor allergen exposure to skin test sensitivity in inner-city children with asthma. J Allergy Clin Immunol. 1998; 102(4 Pt 1):563–70. [PubMed: 9802363]

9. Crain EF, Walter M, O’Connor GT, Mitchell H, Gruchalla RS, Kattan M, et al. Home and allergic characteristics of children with asthma in seven U.S. urban communities and design of an environmental intervention: the Inner-City Asthma Study. Environ Health Perspect. 2002; 110(9): 939–45. [PubMed: 12204830]

10. Rosenstreich DL, Eggleston P, Kattan M, Baker D, Slavin RG, Gergen P, et al. The role of cockroach allergy and exposure to cockroach allergen in causing morbidity among inner-city children with asthma. N Engl J Med. 1997; 336(19):1356–63. [PubMed: 9134876]

11. Salo PM, Sever ML, Zeldin DC. Indoor allergens in school and day care environments. J Allergy Clin Immunol. 2009; 124(2):185–92. 192.e1–9. quiz 193–4. [PubMed: 19577284]

12. Custovic A, Green R, Taggart SC, Smith A, Pickering CA, Chapman MD, et al. Domestic allergens in public places. II: Dog (Can f 1) and cockroach (Bla g 2) allergens in dust and mite, cat, dog and cockroach allergens in the air in public buildings. Clin Exp Allergy. 1996; 26(11):1246–52. [PubMed: 895573]

13. Sarpong SB, Wood RA, Karrison T, Eggleston PA. Cockroach allergen (Bla g 1) in school dust. J Allergy Clin Immunol. 1997; 99(4):486–92. [PubMed: 9111492]

14. Dungy CI, Kozak PP, Gallup J, Galant SP. Aeroallergen exposure in the elementary school setting. Ann Allergy. 1986; 56(3):218–21. [PubMed: 3954161]

15. Wickens K, Martin I, Pearce N, Fitzharris P, Kent R, Holbrook N, et al. House dust mite allergen levels in public places in New Zealand. J Allergy Clin Immunol. 1997; 99(5):587–93. [PubMed: 9155822]

16. Dybendal T, Elsayed S. Dust from carpeted and smooth floors. V. Cat (Fel d I) and mite (Der p I and Der f I) allergen levels in school dust. Demonstration of the basophil histamine release induced by dust from classrooms. Clin Exp Allergy. 1992; 22(12):1100–6. [PubMed: 1283110]

17. McConnell R, Islam T, Shankardass K, Jerrett M, Lurmann F, Gilliland F, et al. Childhood incident asthma and traffic-related air pollution at home and school. Environ Health Perspect. 2010; 118(7):1021–6. [PubMed: 20371422]

18. Dotterud LK, Van TD, Kvammen B, Dybendal T, Elsayed S, Falk ES. Allergen content in dust from homes and schools in northern Norway in relation to sensitization and allergy symptoms in schoolchildren. Clin Exp Allergy. 1997; 27(3):252–61. [PubMed: 9088651]

19. Munir AK, Einasarson R, Schou C, Dreborg SK. Allergens in school dust. I. The amount of the major cat (Fel d 1) and dog (Can f 1) allergens in dust from Swedish schools is high enough to probably cause perennial symptoms in most children with asthma who are sensitized to cat and dog. J Allergy Clin Immunol. 1993; 91(5):1067–74. [PubMed: 8491399]

20. Perzanowski MS, Ronmark E, Nold B, Lundback B, Platts-Mills TA. Relevance of allergens from cats and dogs to asthma in the northernmost province of Sweden: schools as a major site of exposure. J Allergy Clin Immunol. 1999; 103(6):1018–24. [PubMed: 10359880]

21. Chew GL, Correa JC, Perzanowski MS. Mouse and cockroach allergens in the dust and air in northeastern United States inner-city public high schools. Indoor Air. 2005; 15(4):228–34. [PubMed: 15982269]

22. Permaul P, Hoffman E, Fu C, Sheehan W, Baxi S, Gaffin J, et al. Allergens in urban schools and homes of children with asthma. Pediatr Allergy Immunol. 2012; 23(6):543–9. [PubMed: 22672325]

23. Sheehan WJ, Rangisithichai PA, Muilenberg ML, Rogers CA, Lane JP, Ghaemghami J, et al. Mouse allergens in urban elementary schools and homes of children with asthma. Ann Allergy Asthma Immunol. 2009; 102(2):125–30. [PubMed: 19230463]

24. Sheehan WJ, Hoffman EB, Fu C, Baxi SN, Bailey A, King EM, et al. Endotoxin exposure in inner-city schools and homes of children with asthma. Ann Allergy Asthma Immunol. 2012; 108(6): 418–22. [PubMed: 22626594]

25. Baxi SN, Muilenberg ML, Rogers CA, Sheehan WJ, Gaffin J, Permaul P, et al. Exposures to molds in school classrooms of children with asthma. Pediatr Allergy Immunol. 2013; 24(7):697–703. [PubMed: 24112429]
26. Amr S, Bollinger ME, Myers M, Hamilton RG, Weiss SR, Rossman M, et al. Environmental allergens and asthma in urban elementary schools. Ann Allergy Asthma Immunol. 2003; 90(1):34–40. [PubMed: 12546335]

27. Lincoln D, Morgan G, Sheppeard V, Jalaludin B, Corbett S, Beard J. Childhood asthma and return to school in Sydney, Australia. Public Health. 2006; 120(9):854–62. [PubMed: 16904142]

28. Tovey ER, Rawlinson WD. A modern miasma hypothesis and back-to-school asthma exacerbations. Med Hypotheses. 2011; 76(1):113–6. [PubMed: 20869177]

29. Huffaker M, Phipatanakul W. Introducing an environmental assessment and intervention program in inner-city schools. J Allergy Clin Immunol. 2014; 134(6):1232–7. [PubMed: 25441649]

30. Owenby DR. Will the real inner-city allergen please stand up? J Allergy Clin Immunol. 2013; 132(4):836–7. [PubMed: 23978444]

31. Gruchalla RS, Pongracic J, Plaut M, Evans R 3rd, Visness CM, Walter M, et al. Inner City Asthma Study: relationships among sensitivity, allergen exposure, and asthma morbidity. J Allergy Clin Immunol. 2005; 115(3):478–85. [PubMed: 15753892]

32. Tranter DC. Indoor allergens in settled school dust: a review of findings and significant factors. Clin Exp Allergy. 2005; 35(2):126–36. [PubMed: 15725182]

33. Ahluwalia SK, Peng RD, Breysse PN, Diette GB, Curtin-Brosnan J, Aloe C, et al. Mouse allergen is the major allergen of public health relevance in Baltimore City. J Allergy Clin Immunol. 2013; 132(4):830–5. e1–2. [PubMed: 23810154]

34. Phipatanakul W, Eggleston PA, Wright EC, Wood RA. Mouse allergen. I. The prevalence of mouse allergen in inner-city homes. The National Cooperative Inner-City Asthma Study. J Allergy Clin Immunol. 2000; 106(6):1070–4. [PubMed: 11112888]

35. Phipatanakul W, Eggleston PA, Wright EC, Wood RA. National Cooperative Inner-City Asthma Study: Mouse allergen. II. The relationship of mouse allergen exposure to mouse sensitization and asthma morbidity in inner-city children with asthma. J Allergy Clin Immunol. 2000; 106(6):1075–80. [PubMed: 11112889]

36. Phipatanakul W, Bailey A, Hoffman EB, Sheehan WJ, Lane JP, Baxi S, et al. The school inner-city asthma study: design, methods, and lessons learned. J Asthma. 2011; 48(10):1007–14. [PubMed: 22010992]

37. Curtin-Brosnan J, Paigen B, Hagberg KA, Langley S, O’Neil EA, Krevans M, et al. Occupational mouse allergen exposure among non-mouse handlers. J Occup Environ Hyg. 2010; 7(12):726–34. [PubMed: 21058157]

38. Platts-Mills TA. Allergen avoidance in the treatment of asthma: problems with the meta-analyses. J Allergy Clin Immunol. 2008; 122(4):694–6. [PubMed: 19014759]

39. Tovey ER, Willenborg CM, Crisafulli DA, Rimmer J, Marks GB. Most personal exposure to house dust mite Aeroallergen occurs during the day. PLoS One. 2013; 8(7):e69900. [PubMed: 23894558]

40. Peitzsch M, Sulyok M, Taubel M, Vishwanath V, Krop E, Borras-Santos A, et al. Microbial secondary metabolites in school buildings inspected for moisture damage in Finland, The Netherlands and Spain. J Environ Monit. 2012; 14(8):2044–53. [PubMed: 22714101]

41. Jacobs JH, Krop EJ, Borras-Santos A, Zock JP, Taubel M, Hyvarinnen A, et al. HITEA schools study consortium: Endotoxin levels in settled airborne dust in European schools: the HITEA school study. Indoor Air. 2014; 24(2):148–57. [PubMed: 23927557]

42. Jacobs J, Borras-Santos A, Krop E, Taubel M, Leppanen H, Haverinen-Shaughnessy U, et al. Dampness, bacterial and fungal components in dust in primary schools and respiratory health in schoolchildren across Europe. Occup Environ Med. 2014; 71(10):704–12. [PubMed: 25035116]

43. Borras-Santos A, Jacobs JH, Taubel M, Haverinen-Shaughnessy U, Krop EJ, Huttunen K, et al. Dampness and mould in schools and respiratory symptoms in children: the HITEA study. Occup Environ Med. 2013; 70(10):681–7. [PubMed: 23775866]

44. Chen CH, Chao HJ, Chan CC, Chen BY, Guo YL. Current asthma in schoolchildren is related to fungal spores in classrooms. Chest. 2014; 146(1):123–34. [PubMed: 24676386]

45. Kingsley SL, Eliot MN, Carlson L, Finn J, MacIntosh DL, Suh HH, et al. Proximity of US schools to major roadways: a nationwide assessment. J Expo Sci Environ Epidemiol. 2014; 24(3):253–9. [PubMed: 24496217]
46. Hochstetler HA, Yermakov M, Reponen T, Ryan PH, Grinshpun SA. Aerosol particles generated by diesel-powered school buses at urban schools as a source of children’s exposure. Atmos Environ (1994). 2011; 45(7):1444–53. [PubMed: 25904818]

47. Annesi-Maesano I, Hulin M, Lavaud F, Raherison C, Kopferschmitt C, de Blay F, et al. Poor air quality in classrooms related to asthma and rhinitis in primary schoolchildren of the French 6 Cities Study. Thorax. 2012; 67(8):682–8. [PubMed: 22436169]

48. Zhao Z, Zhang Z, Wang Z, Ferm M, Liang Y, Norback D. Asthmatic symptoms among pupils in relation to winter indoor and outdoor air pollution in schools in Taiyuan, China. Environ Health Perspect. 2008; 116(1):90–7. [PubMed: 18197305]

49. Rivas I, Viana M, Moreno T, Pandolfi M, Amato F, Reche C, et al. Child exposure to indoor and outdoor air pollutants in schools in Barcelona, Spain. Environ Int. 2014; 69:200–12. [PubMed: 24875803]

50. Stranger M, Potgieter-Vermaak SS, Van Grieken R. Characterization of indoor air quality in primary schools in Antwerp, Belgium. Indoor Air. 2008; 18(6):454–63. [PubMed: 18823343]

51. Godwin C, Batterman S. Indoor air quality in Michigan schools. Indoor Air. 2007; 17(2):109–21. [PubMed: 17391233]

52. Mendell MJ, Heath GA. Do indoor pollutants and thermal conditions in schools influence student performance? A critical review of the literature. Indoor Air. 2005; 15(1):27–52. [PubMed: 15660567]

53. Daisey JM, Angell WJ, Apte MG. Indoor air quality, ventilation and health symptoms in schools: an analysis of existing information. Indoor Air. 2003; 13(1):53–64. [PubMed: 12608926]

54. Smedje G, Norback D, Edling C. Asthma among secondary school children in relation to the school environment. Clin Exp Allergy. 1997; 27(11):1270–8. [PubMed: 9420130]

55. Smedje G, Norback D. New ventilation systems at select schools in Sweden--effects on asthma and exposure. Arch Environ Health. 2000; 55(1):18–25. [PubMed: 10735515]

56. American Lung Association. A National Asthma Public Policy Agenda. Washington: American Lung Association; 2009. Available at: http://www.lung.org/lung-disease/asthma/becoming-an-advocate/national-asthma-public-policy-agenda/National-Asthma-Public-Policy-Agenda-January-2009.pdf [Accessed on May 15, 2015]

57. Asthma and Allergy Foundation of America. State Honor Roll 2015: Asthma and Allergy Policies for Schools. Landover, MD: Asthma and Allergy Foundation of America; 2015. Available at: www.statehonorroll.org [Accessed on September 27, 2015]

58. Centers for Disease Control and Prevention. Strategies for Addressing Asthma Within a Coordinated School Health Program, With Updated Resources. Atlanta, Georgia: Centers for Disease Control and Prevention, National Center for Chronic Disease Prevention and Health Promotion; 2006. Available at: www.cdc.gov/HealthyYouth/asthma/pdf/strategies.pdf [Accessed on August 15, 2015]

59. Lynn J, Oppenheimer S, Zimmer L. Using public policy to improve outcomes for asthmatic children in schools. J Allergy Clin Immunol. 2014; 134(6):1238–44. [PubMed: 25482868]

60. Ahmad E, Grimes DE. The effects of self-management education for school-age children on asthma morbidity: a systematic review. J Sch Nurs. 2011; 27(4):282–92. [PubMed: 21478414]

61. Clark NM, Brown R, Joseph CL, Anderson EW, Liu M, Valerio MA. Effects of a comprehensive school-based asthma program on symptoms, parent management, grades, and absenteeism. Chest. 2004; 125(5):1674–9. [PubMed: 15136375]

62. Bruzzese JM, Markman LB, Appel D, Webber M. An evaluation of Open Airways for Schools: using college students as instructors. J Asthma. 2001; 38(4):337–42. [PubMed: 11456387]

63. Bruzzese JM, Bonner S, Vincent EJ, Sheares BJ, Mellins RB, Levison MJ, et al. Asthma education: the adolescent experience. Patient Educ Couns. 2004; 55(3):396–406. [PubMed: 15582346]

64. Joseph CL, Peterson E, Havstad S, Johnson CC, Hoerauf S, Stringer S, et al. Asthma in Adolescents Research Team: A web-based, tailored asthma management program for urban African-American high school students. Am J Respir Crit Care Med. 2007; 175(9):888–95. [PubMed: 17290041]
65. Shah S, Peat JK, Mazurski EJ, Wang H, Sindhusake D, Bruce C, et al. Effect of peer led programme for asthma education in adolescents: cluster randomised controlled trial. BMJ. 2001; 322(7286):583–5. [PubMed: 11238152]

66. Bruzzese JM, Unikel L, Gallagher R, Evans D, Colland V. Feasibility and impact of a school-based intervention for families of urban adolescents with asthma: results from a randomized pilot trial. Fam Process. 2008; 47(1):95–113. [PubMed: 18411832]

67. Clark NM, Mitchell HE, Rand CS. Effectiveness of educational and behavioral asthma interventions. Pediatrics. 2009; 123(Suppl 3):S185–92. [PubMed: 19221162]

68. Gerald LB, Redden D, Wittich AR, Hains C, Turner-Henson A, Hemstreet MP, et al. Outcomes for a comprehensive school-based asthma management program. J Sch Health. 2006; 76(6):291–6. [PubMed: 16918857]

69. Greenberg C, Luna P, Simmons G, Huhman M, Merkle S, Robin L, et al. Follow-up of an elementary school intervention for asthma management: do gains last into middle school? J Asthma. 2010; 47(5):587–93. [PubMed: 20560833]

70. Shah S, Roydhouse JK, Sawyer SM. Medical students go back to school—the Triple A journey. Aust Fam Physician. 2008; 37(11):952–4. [PubMed: 19037472]

71. Noyes K, Bajorska A, Fisher S, Sauer J, Fagnano M, Halterman JS. Cost-effectiveness of the School-Based Asthma Therapy (SBAT) program. Pediatrics. 2013; 131(3):e709–17. [PubMed: 23400614]

72. Bhaumik U. School-based asthma controller medication administration is associated with cost savings. J Pediatr. 2013; 163(1):304. [PubMed: 23796345]

73. Wheeler LS, Merkle SL, Gerald LB, Taggart VS. Managing asthma in schools: lessons learned and recommendations. J Sch Health. 2006; 76(6):340–4. [PubMed: 16918868]

74. McEwen M, Johnson P, Neatherlin J, Millard MW, Lawrence G. School-based management of chronic asthma among inner-city African-American schoolchildren in Dallas, Texas. J Sch Health. 1998; 68(5):196–201. [PubMed: 9672858]

75. Millard MW, Johnson PT, McEwen M, Neatherlin J, Lawrence G, Kennerly DK, et al. A randomized controlled trial using the school for anti-inflammatory therapy in asthma. J Asthma. 2003; 40(7):769–76. [PubMed: 14626333]

76. Halterman JS, Szilagyi PG, Yoos HL, Conn KM, Kaczorowski JM, Holzhauer RJ, et al. Benefits of a school-based asthma treatment program in the absence of secondhand smoke exposure: results of a randomized clinical trial. Arch Pediatr Adolesc Med. 2004; 158(5):460–7. [PubMed: 15123479]

77. Richmond CM, Sterling D, Huang X, Wilson K, Pike E. Asthma 411—addition of a consulting physician to enhance school health. J Sch Health. 2006; 76(6):333–5. [PubMed: 16918866]

78. Gerald LB, Gerald JK, McClure LA, Harrington K, Erwin S, Bailey WC. Redesigning a large school-based clinical trial in response to changes in community practice. Clin Trials. 2011; 8(3): 311–9. [PubMed: 21730079]

79. Jaramillo Y, Reznik M. Do United States' teachers know and adhere to the national guidelines on asthma management in the classroom? A systematic review. Scientific World Journal. 2015; 2015:624828. [PubMed: 25729770]

80. Reznik M, Bauman LJ, Okelo SO, Halterman JS. Asthma identification and medication administration forms in New York City schools. Ann Allergy Asthma Immunol. 2015; 114(1):67–8. e1. [PubMed: 25454012]

81. Bruzzese JM, Unikel LH, Evans D, Bornstein L, Surrence K, Mellins RB. Asthma knowledge and asthma management behavior in urban elementary school teachers. J Asthma. 2010; 47(2):185–91. [PubMed: 20170327]

82. Oeder S, Dietrich S, Weichenmeier I, Schober W, Pusch G, Jorres RA, et al. Toxicity and elemental composition of particulate matter from outdoor and indoor air of elementary schools in Munich, Germany. Indoor Air. 2012; 22(2):148–58. [PubMed: 21913995]

83. Pilotto LS, Nitschke M, Smith BJ, Pisanelli D, Ruffin RE, McElroy HJ, et al. Randomized controlled trial of unflued gas heater replacement on respiratory health of asthmatic schoolchildren. Int J Epidemiol. 2004; 33(1):208–14. [PubMed: 15075170]
84. Karlsson AS, Andersson B, Renstrom A, Svedmyr J, Larsson K, Borres MP. Airborne cat allergen reduction in classrooms that use special school clothing or ban pet ownership. J Allergy Clin Immunol. 2004; 113(6):1172–7. [PubMed: 15208601]

85. Karlsson AS, Renstrom A, Hedren M, Larsson K. Allergen avoidance does not alter airborne cat allergen levels in classrooms. Allergy. 2004; 59(6):661–7. [PubMed: 15147452]

86. Munir AK, Einarsson R, Dreborg S. Allergen avoidance in a day-care center. Allergy. 1996; 51(1): 36–41. [PubMed: 8721526]

87. Lignell U, Meklin T, Putus T, Rintala H, Vepsalainen A, Kalliokoski P, et al. Effects of moisture damage and renovation on microbial conditions and pupils’ health in two schools—a longitudinal analysis of five years. J Environ Monit. 2007; 9(3):225–33. [PubMed: 17344947]

88. Meklin T, Putus T, Pekkanen J, Hyvarinen A, Hirvonen MR, Nevalainen A. Effects of moisture-damage repairs on microbial exposure and symptoms in schoolchildren. Indoor Air. 2005; 15(Suppl 10):40–7. [PubMed: 15926943]

89. Beatty TK, Shimshack JP. School buses, diesel emissions, and respiratory health. J Health Econ. 2011; 30(5):987–99. [PubMed: 21741102]

90. Morgan WJ, Crain EF, Gruchalla RS, O’Connor GT, Kattan M, Evans R 3rd, et al. Inner-City Asthma Study Group: Results of a home-based environmental intervention among urban children with asthma. N Engl J Med. 2004; 351(11):1068–80. [PubMed: 15356304]

91. Sublett JL, Seltzer J, Burkhead R, Williams PB, Wedner HJ, Phipatanakul W. American Academy of Allergy, Asthma & Immunology Indoor Allergen Committee: Air filters and air cleaners: rostrum by the American Academy of Allergy, Asthma & Immunology Indoor Allergen Committee. J Allergy Clin Immunol. 2010; 125(1):32–8. [PubMed: 19910039]

92. Sublett JL. Effectiveness of air filters and air cleaners in allergic respiratory diseases: a review of the recent literature. Curr Allergy Asthma Rep. 2011; 11(5):395–402. [PubMed: 21773748]

93. Du L, Batterman S, Parker E, Godwin C, Chin JY, O’Toole A, et al. Particle Concentrations and Effectiveness of Free-Standing Air Filters in Bedrooms of Children with Asthma in Detroit, Michigan. Build Environ. 2011; 46(11):2303–13. [PubMed: 21874085]

94. Bernstein JA, Levin L, Crandall MS, Perez A, Lanphear B. A pilot study to investigate the effects of combined dehumidification and HEPA filtration on dew point and airborne mold spore counts in day care centers. Indoor Air. 2005; 15(6):402–7. [PubMed: 16268830]

95. Jassal MS, Diette GB, Dowdy DW. Cost-consequence analysis of multimodal interventions with environmental components for pediatric asthma in the state of Maryland. J Asthma. 2013; 50(6): 672–80. [PubMed: 23614791]