# The indoor environment and inner-city childhood asthma

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## Summary

***Objective:*** **Exposure to indoor pollutants and allergens has been speculated to cause asthma symptoms and exacerbations and influence the risk of developing asthma. The aim of this article is to review the medical literature regarding the role of the indoor environment on inner-city childhood asthma.**

***Data sources:*** **A literature search was performed in PubMed. Studies focusing on inner-city indoor allergen, childhood asthma, and environmental controls were included.**

***Results:*** **The prevalence of asthma in children is increasing especially in inner-city area. Exposure to high levels of indoor allergens and pollutants has been related to asthma development. Studies have shown that mouse, cockroach, pets, dust mite, mold, tobacco smoke, endotoxin and nitrogen dioxide are the important exposures. Recent studies have shown that indoor environmental control is beneficial in reducing asthma morbidity and development.**

***Conclusions:*** **Inner-city children are exposed to various indoor allergens and pollutants that may lead to asthma development and exacerbation of existing asthma. Multifaceted environmental controls are beneficial in improving asthma symptom and maybe a viable prevention strategy. Further prospective studies of environmental intervention are needed to further identify effective strategies to improve and prevent asthma symptoms in inner-city children.** ***(Asian Pac J Allergy Immunol 2014;32:103-10)***


***Keywords:*** *Indoor environment, allergen, children, asthma, inner-city, air pollution*

## Introduction

The prevalence of asthma in the United States has increased over recent decades.[1] Inner city populations have suffered a disproportionately high rate of increasing asthma prevalence compared to other locales.[2] Children living in the inner-cities also have greater asthma severity, based on higher amounts of medication to achieve asthma control, poor response to medication and greater health care use.[3] These conditions account for substantial healthcare cost and morbidity. Since 1991, the National Institute of Allergy and Infectious Diseases (NIAID) have begun the inner-city asthma network program to improve care for children with asthma and to increase understanding of risk factors and evaluate a wide range of interventions, such as educational, behavioral, and environmental. Several published inner-city studies have demonstrated that indoor allergen exposures are important risk factors for asthma development and morbidity in urban children because children spend most of their time in homes and schools. Simon et al. demonstrated in a study of 120 homes of children with asthma that inner-city homes have higher levels of airborne pollutants and home characteristics that predispose to greater asthma morbidity.[4] Mouse, mold, dust mite, dog, cat, cockroach, tobacco smoke, endotoxin and nitrogen dioxide are considered to be important indoor allergens and irritants. Additionally, data from the National Cooperative Inner-City Asthma Study (NCICAS) suggests that most inner city children with asthma are sensitized and exposed to multiple indoor allergens. [5] Therefore, in this article, we will review the role of indoor environmental exposures on asthma symptoms in inner-city children.

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***Mouse***

Mus m 1 and Mus m 2 are the major mouse allergens that are found in mouse urine (only Mus m 1), dander, and hair.[6] The levels of mouse allergen in schools, day care centers and homes have been measured and studied. This allergen is commonly detected in homes and schools that serve inner-city populations. The highest levels of mouse allergen were often found in rooms where food sources were present such as cafeteria or kitchen.[7] Sheehan et al. demonstrated that inner-city school children in the Northeastern US with greater levels of mouse allergen exposure in school had more asthma-related missed school days.[7] Permaul et al. reported that mouse allergen levels in urban school were substantial and were higher as compared to homes.[8] A mean of Mus m1 allergen levels in settled dust from Northeastern US schools was 0.65 ug/g which is greater than previously reported levels associated with more symptom-days, rescue medication use, and a greater risk of asthma-related healthcare use.[8,9] Predictors of mouse allergen in schools included visible mouse droppings which were associated with higher mouse allergen levels in settle dust and air, particularly during the Spring season.[10]

Most homes in the US also have detectable mouse allergen, but the concentrations in inner-city homes are higher than those found in suburban homes.[11] Phipatanakul et al. found in the NCICAS that 95% of homes had detectable mouse allergen levels.[12] Regarding sensitization, inner-city asthmatic children had significantly greater mouse allergen sensitization compared with either suburban or rural children.[13] Exposure to mouse allergen was found to associate with a high rate of allergen sensitization [6] and the development of wheeze in the first year of life and later in childhood.[14,15] Pongracic et al. reported that sensitization and exposure to mouse allergen were associated with increased asthma morbidity in the Inner-City Asthma Study (ICAS).[16] In addition, indoor mouse allergen exposure in Baltimore had been linked to sensitization to mouse, and children who are both sensitized and exposed to high mouse allergen levels were at greater risk for developing asthma symptoms.[17] Recently, Torjusen et al. showed that every tenfold increase in the bed mouse allergen level was associated with an 87% increase in the odds of asthma-related health care use among mouse-sensitized urban children with asthma.[18]

***Cockroach***

German cockroach and American cockroach are common cockroaches that cause sensitization. Bla g 1 and Bla g 2 are the major cockroach allergens found in secretions and fecal material.[19] Cockroach infestation is associated with living in densely populated areas, urban environments, inner-city communities, and low socioeconomic status.[20] High population areas, such as multifamily homes have also been associated with higher levels of cockroach allergen, particularly in older cities.[21]

The NCICAS measured cockroach allergen from dust obtained from 476 children's bedrooms. This comprehensive study by Rosenstreich et al. found that 85.3% of samples had detectable levels of cockroach allergen.[22] A study of homes in Gary, Indiana showed 98% had detectable cockroach allergen.[23] Chew et al. found that 77% of public housing residences in New York City had evidence of cockroaches.[24] Moreover, a study among New Orleans children with asthma found that 56.6% of households had moderate to high levels of cockroach allergen. These findings demonstrate the prevalence of cockroach allergen across geographic regions in continental U.S. cities. Regarding schools, study of elementary schools in Birmingham, Detroit, and Houston showed that schools in these cities had levels of cockroach allergen greater than the proposed sensitization thresholds.[25] However, in the Northeastern US, Permaul et al. found that there were undetectable to very low levels of cockroach allergens in both homes and schools.[8]

Cockroach allergen exposure is considered to be an important influence on the high rates of asthma among inner-city children. Sensitization to cockroach allergens is correlated with presence and severity asthma. Studies have exhibited a consistent association between sensitized individuals' exposure to cockroach allergens and asthma exacerbation or severity. Rosenstreich et al. found that inner-city children with asthma who were sensitized to cockroach and exposed to cockroach allergen in high level (>8 U/g) had higher asthma morbidity, including hospitalizations, medical visits, and symptoms.[22] A study in 61 homes of low-income Chicago children by Turyk et al. also found that exposure to cockroach allergen in bedroom was associated asthma morbidity by increasing number of asthma symptoms.[26]

***Dust mite***

Der f 1 and Der p 1, the major allergens identified from house dust mite species Dermatophagoides farrinae and Dermatophagoides pteronyssinus, are concentrated in particles of mite feces. Cysteine proteases found in the dust mite's gut and fecal particles are the potent inducers of allergic disease.[19] Because mite allergens are found on large particles (mostly ≥10 μm), they become airborne relatively briefly when disturbed.

The home and school environment of children with asthma has been characterized for the presence of dust mite allergen. Allergen levels are strongly associated with level of humidity. Rabito et al. found that, in New Orleans, asthmatic children living indoors with average humidity levels >50% were three times more likely to have elevated dust mite levels.[27] But in Northeastern US, where the climate is drier, there were undetectable to very low levels of dust mite allergens in both homes and schools.[8] High percentages of dust mite allergen can be found in bedding. In a study in homes of 120 asthmatic children in central Taiwan, Wu et al. reported that greater than 80% of pillows and mattress had detectable level of Der p 1 and Der f 1.[28]

Studies have demonstrated that there is a dose response relationship between dust mite exposure and allergen sensitization. Dust mite allergen sensitization in asthmatics is associated with an increased risk of medication use and health care utilization, including asthma-related unscheduled visits and hospitalizations.[29] The risk of developing asthma has also been shown to be increased in infants with early exposure to high levels of dust mite allergen (≥10 ug/g).[30] To lower the levels of dust mite allergen, a systematic review of 54 trials from 1955 to 2007 demonstrated that interventions including acaricides, mattress covers, cleaning, washing, air filtration, and ionizers were not successful in reducing dust mite levels or asthma symptoms compared with no treatment.[31] However, many factors such as sample size, multiple sensitizations, and other exposures might account for the negative results of this analysis. Nevertheless, a recent study in 2013 by Ghitany et al. conducted a randomized control trial to control dust mite level in Egypt with 160 asthmatic children who were sensitized to dust mite. Children were randomized into four groups: physical, chemical, both physical and chemical interventions, and no intervention. In the physical intervention group, there was an improvement in lung function and decreased hospitalizations in a 16 week period.[32] Thus, further study on dust mite allergen control measures is required.

***Cat and Dog***

Cats and dogs are common domestic animals. The primary cat and dog allergen are Fel d 1 and Can f 1, respectively, which are found in saliva, skin and hair follicles.[19] High levels of Fel d 1 and Can f 1 are found in the air and dust of homes with cats and dogs, but are also found in many buildings without resident cats and dogs.[33] These allergens have been found in high levels in upholstered and carpeted areas.[34] In schools, cat and dog allergen are frequently detected but the levels vary greatly.[8] In these locations, they are likely brought into schools on clothing and shoes of students and staff with pets at their homes. Among school children, these allergen levels have been found to be higher in dust from pet owners's clothing,[35] whereas cat and dog allergen levels were significantly lower in Swedish day cares in which children and staff had no pet at homes.[36]

The findings in studies of pet allergens, atopy, and asthma have been complex, possibly suggesting different effects depending on age at exposure, level of exposure, and sensitization status. Some studies suggest that cat and dog exposure may be protective against allergy.[37] Wegienka et al. reported that indoor pet exposure for children was associated with lower IgE level at age of 18 years.[38] Gaffin et al. demonstrated that cat and daycare exposure in children with atopic dermatitis might reduce the risk of developing early childhood asthma.[39] However, a retrospective study by McHugh et al. found that cats and dogs were associated with diagnosis of both asthma and eczema.[40] Two additional studies showed that exposure to cat and dog allergens significantly increased asthma severity, rescue medication use, frequency of asthma symptoms and fractional exhaled nitric oxide (FENO) in sensitized children.[41-43] More recently, issues regarding hypoallergenic pets were addressed. Many pet companies have marketed so called "hypoallergenic" pets. However, there is no scientific evidence to support the existence of "hypoallergenic" pets.[44]

***Mold***

Several common molds such as, *Alternaria, Cladosporium, Aspergillus,* and *Penicillium* have allergens that can be risk factors for asthma.[19]

O'connor et al. showed that the concentrations of molds were higher in homes with dampness problems, cockroach infestation, and cats.[45] A study of 506 inner-city children with asthma by Wang et al. demonstrated that *Alternaria* sensitization was associated with an increased risk of asthma-related hospitalization.[29] Apart from *Alternaria*, Pongracic et al. found that an increase in total molds exposure and indoor Penicillium species exposure were associated with increases in symptom days and asthma-related unscheduled visits. [46] In the homes of 61 low-income Chicago children with asthma, Turyk et al. also found that children exposed to higher levels of Penicillium in the bedroom had more frequent asthma symptoms.[26] In Harlem communities with high prevalence of children with asthma, self-reported presence of moisture or mildew on ceilings, walls, or windows was associated with higher frequency of hospitalizations for breathing-related problems, frequent episodes of wheezing, and higher frequency of night symptoms due to asthma.[47] Similarly, a study in Montreal, found that the presence of visible mold or mold odor in homes associated with poor asthma control in children.[48]

Baxi et al. found that there molds were present in all 180 classrooms air samples collected from 12 inner-city schools in the School Inner City Asthma Study (SICAS). The amount of mold varied from classroom to classroom within the same school. The most commonly found species, at high concentrations, were *Cladosporium* (29.3 ± 4.2 spores/$m^3$), *Penicillium/Aspergillus* (15.0 ± 5.4 spores/ $m^3$), smut spores (12.6 ± 4.0 spores/$m^3$), and basidiospores (6.6 ± 7.1 spores/ $m^3$).[49] This implies that, not only homes but also schools have high level of molds that could affect asthma morbidity in children. Reduction of mold levels have shown to be beneficial in controlling asthma symptoms. A previous study in homes of 62 inner-city asthmatic children showed that the intervention group, which had aggressive mold remediation including repair of leaks, removal of water-damaged materials, ventilation alteration, and decreasing the humidity in damp basements, had fewer emergency room visits and hospitalizations compared to the control group.[50]

***Tobacco***

Tobacco smoke contains solid particles, semi-volatile, and volatile organic compounds. These compounds are known or suspected eye and respiratory irritants, toxicants, mutagens, and carcinogens.[51] Several studies have shown that more than 50% of inner-city children with asthma are exposed to Environmental Tobacco Smoke (ETS), and more than 60% of those children have a mother or caregiver who smokes.[52-54] Kumar et al. demonstrated that caregiver smoking was strongly associated with child exposure and also was associated with lower socioeconomic status, non-Hispanic ethnicity, and dpression symptoms.[55] However, all parents and caregivers had good knowledge regarding the harmful effects of ETS. Parents described the use of various strategies tokeep ETS away from children.[56] Nevertheless, a Cochrane review found that most intervention studies aimed at reducing children's ETS exposure were ineffective.[57]

ETS exposure is known to exacerbate asthma. A study in 705 public school students in Chicago found that maternal smoking during pregnancy was significantly associated with children's asthma with odds ratio 1.9.[58] Morkjaroenpong et al. reported that among elementary school inner-city children with asthma, exposure to higher levels of ETS was associated with increased frequency of nocturnal symptoms.[59] A birth cohort study in 4,089 newborn infants exhibited an association between in-utero smoke exposure and increased incidence of asthma in infants up to two years of age.[60] Additionally, postnatal ETS exposure in infants has been associated with difficulty breathing and probable asthma in children exposed to aromatic hydrocarbon by 24 months of age.[61]

Recently, there was a published study on the potential health hazards of third-hand smoke (THS) in children. THS is smoke pollutants remaining in the indoor environment and on surfaces after active tobacco smoking has stopped. Smoke pollutants include nicotine, formaldehyde, phenol, 3-ethenylpryidine, cresols, naphthalene, and tobacco-specific nitrosamines which can undergo physical and chemical transformations.[62] These smoke pollutants can persist for weeks to months on surfaces and in settled dust. With the behavioral habit of young children including crawling and ingesting non-food items, these make children highly susceptible to have more potential hazardous effects of THS than adults.[62]

***Endotoxin***

Endotoxin is a component found in the outer membranes of Gram-negative bacteria. This bacteria is associated with the presence of pets, rodents, and dampness or mold in homes. Toxic effects are

considered to come from its lipopolysaccharide which carries the lipid A. Sheehan et al. demonstrated that inner-city children with asthma were exposed to higher concentrations of endotoxin in their school classrooms as compared to their home bedrooms. One hundred percent of school settled dust samples had detectable levels of endotoxin with a median concentration of 13.4 EU/mg whereas 96.6% of home dust samples had detectable endotoxin levels with a median concentration of 7.0 EU/mg.[63]

The evidence of an association between endotoxin exposure and asthma exacerbations has been observed. Monitoring endotoxin exposure in asthmatic schoolchildren by using portable monitors over 24-hour period showed that personal endotoxin exposure were associated with decrease $FEV_1$ and increase asthma symptoms.[64] A study by Perzanowski et al. showed that an endotoxin exposure in the inner-city community was inversely associated with eczema at age 1 year, but positively associated with wheeze at the age of 2 years. Therefore, endotoxin exposure might relate to wheeze in early life. However, given the inverse association seen with eczema, the long-term development of allergic disease is still in question.[65] Recently, Matsui et al. reported that effects of household airborne endotoxin exposureon asthma are modified by co-exposure to air nicotine and $NO_2$. Among children and adolescents with persistent asthma living in homes with detectable air nicotine, higher endotoxin level was associated with acute visits and oral corticosteroid bursts. Whereas, living in homes with higher $NO_2$ concentrations (<20 ppb), higher endotoxin was inversely associated with acute visits.[66]

More studies are needed to further determine the effect of endotoxin exposure on asthma and the role of endotoxin remediation on asthma morbidity.

***Nitrogen dioxide***

Nitrogen dioxide ($NO_2$) is a pollutant gas produced from high-temperature combustion. Indoor combustion sources including gas stoves, heaters, and poorly vented furnaces and fireplaces, produce high indoor $NO_2$ concentrations. Diette et al. found that inner-city homes of children with asthma in Baltimore had higher levels of indoor $NO_2$.[67] The authors speculated that poorly ventilated gas stoves serve as the source of indoor $NO_2$. A year-long prospective study by Belanger et al. showed that 1,342 asthmatic children age 5-10 years exposed to $NO_2$ indoors, at levels well below the U.S. Environmental Protection Agency outdoor standard (53 ppb), were at risk for increased frequency of wheeze, night symptoms, and use of rescue medication. These risks are not confined only to inner-city children, but also to children in suburban homes.[68] A study in 150 preschool inner-city asthmatic children by Hansel et al. demonstrated that each 20-ppb increase in $NO_2$ exposure was significantly associated with an increase in the number of days with limited speech, cough, and nocturnal symptoms.[69] In a double blind crossover trial conducted by Marks et al., exposure to $NO_2$ via unflued gas heaters in school classrooms was associated with increased respiratory symptoms in atopic children compared to the use of non-indoor-air-emitting flued gas heaters.[70]

***Interventions to improve indoor environment***

Environmental control has an established role in asthma management. Most children are sensitized to more than one allergen[5] and an environmental intervention approach that targets multiple allergens is likely to be an appropriate strategy. Additionally, multifaceted interventions are the most promising to produce a long term benefit from reducing indoor allergens and triggers. A systematic review of 23 multifaceted home environmental intervention studies, in sensitized asthmatics, showed that these interventions in children were associated with decreased asthma morbidity as measured by asthma symptom days, asthma-related missed school days, and healthcare utilization.[71] In the ICAS, Morgan et al. reported that among inner-city children with atopic asthma, a comprehensive environmental intervention was able to decrease exposure to indoor allergens including cockroach and dust mite allergens, resulting in reduced asthma-associated morbidity.[72] Even though a multifaceted approach is preferred in the management of asthma, many studies have focused on single allergen.

Regarding dust mite, the evidence suggested that the most effective long term strategy for control is a comprehensive plan which includes cleaning regularly, washing and drying bedding weekly in high heat, using dust mite impermeable encasings, maintaining indoor humidity below 50%, and avoiding the use of carpet, upholstered furniture, and stuffed animals.[19] In Australia, school interventions improving ventilation, reducing potential dust reservoirs, using materials with lower emission of volatiles organic compounds, and using central radiant heating system, defined as “low-

allergen schools", was shown to have lower levels of dust mite and cat allergens.[73]

For furry pet, the American Academy of Allergy and Immunology (AAAAI) practice parameter for furry animals states that hypoallergenic cats and dogs should not be recommended for sensitized individuals.[44] The most effective long term strategy for environmental remediation in pet sensitized individuals is to remove the pet from the home. However, HEPA filter may be beneficial in pet sensitized individuals who want to keep their pets at homes because pet allergen may be airborne in these homes.[74]

Although pests and pest allergens are quite difficult to eliminate, Pongracic et al. found that a controlled environmental intervention to remove mouse allergens from homes of inner-city sensitized children with asthma significantly reduced school absenteeism, nights of child and caretaker wakening, and number of days on which caretakers had to change plans, but not asthma symptoms or health care utilization.[16] Intensive cleaning and use of bait traps can produce significant reductions in cockroach allergen in homes with heavy initial cockroach infestations.[75] Phipatanakul et al. used integrated pest management (IPM) to reduce mouse allergen in Boston homes. This study used a combination of hole filling with mesh, vacuuming, cleaning, the use of baited traps with low-toxicity pesticides and education. These were able to decrease mouse allergen levels by more than 75% in kitchens and bedrooms.[76] Thus, IPM might be an effective and sustainable intervention to control pest for long term effects. Rodenticides can be used if other interventions are ineffective; however, it should be applied by professional exterminators. [77]

A comprehensive removal of dampness sources and visible mold may cause asthma exacerbations in susceptible individuals. Evidence from two intervention trials, by cleaning or radiation to reduce dampness and mold, demonstrated a causal association between indoor dampness or mold and asthma exacerbations in children.[50,78] Another randomized control trial in 1,350 households by Howden-Chapman et al. found that insulating the house made the indoor environment warmer and drier and led to improvement in wheezing, school absence, and hospital visits due to respiratory conditions.[79] Additionally, installing an effective heating system in the home of children with asthma could raise indoor temperature and reduce asthmatic symptoms.[80] The use of HEPA filters in an air filter review conducted by Sublett et al. concluded that air filtration decreased allergic respiratory disease progression.[74] Bernstein et al. demonstrated that a combined dehumidification with HEPA filter could reduce in airborne fungal spore counts in daycare centers.[81]

Regarding $NO_2$, there was a recently three-armed randomized trial by Paulin et al.[82] evaluating the efficacy of interventions aimed at reducing indoor $NO_2$ concentrations in homes with unvented gas stoves. This study found that replacement of existing gas stove with electric stoves, installation of a ventilation hood over existing gas stoves, and placement of air purifiers with HEPA and carbon filters could significantly reduce $NO_2$ levels within 1 week and up to 3 months. Additionally, a randomized controlled trail in New Zealand by Howden-Chapman et al. reported that effective heating in homes of children with asthma significantly reduced the level of $NO_2$ as well as symptoms of asthma, days off school, healthcare utilization and visits to a pharmacist.[83]

## Conclusion

Inner-city children with asthma are exposed to various indoor allergens and irritants in their homes and schools. Pets, pests, mouse, dust mite, tobacco smoke, endotoxin and $NO_2$ are common indoor exposures in the inner-city. These potential exposures can influence the development of asthma and asthma morbidity in children known to have asthma. Multifaceted environmental control programs have shown promise in reducing these exposure levels and improving asthma symptoms. Nevertheless, strategies for reducing indoor allergen or pollution with reducing penetration of outdoor pollutants into the indoor environment need to be further explored and refined. Additional prospective studies of environmental interventions are needed to demonstrate consistently effective environmental remediation and improvement of asthma symptoms in inner-city children.

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