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Childhood Asthma and Environmental Interventions

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Abbreviations

EPA	Environmental Protection Agency
ETS	Environmental Tobacco Smoke
HEPA	High Efficiency Particulate Air (Vacuum Cleaner)
IAQ	Indoor Air Quality
IOM	Institute of Medicine
U.S.	United States
VOCs	Volatile Organic Compounds
WTP	Willingness To Pay

Outline of Section Headers

Abstract

BACKGROUND: Contaminants encountered in many households such as environmental tobacco smoke (ETS), house dust mite, cockroach, cat and dog dander, and mold, are risk factors in asthma. Young children are a particularly vulnerable subpopulation for environmentally mediated asthma, and the economic burden associated with this disease is substantial. Certain mechanical interventions are effective both in reducing allergen loads in the home and improving asthmatic children's respiratory health.

RESULTS: Combinations of interventions including the use of dust mite-impermeable bedding covers, improved cleaning practices, high-efficiency particulate air (HEPA) vacuum cleaners, mechanical ventilation, and parental education are associated with both asthma trigger reduction and improved health outcomes for asthmatic children. Compared with valuated health benefits, these combinations of interventions have proven cost-effective in studies that have employed them. Education alone has not proven effective in changing parental behaviors such as smoking in the home.

CONCLUSIONS: Future research should focus on improving the effectiveness of education on home asthma triggers, and understanding long-term children's health effects of the interventions that have proven effective in reducing asthma triggers.

Introduction

People in modern societies spend the vast majority of their time – approximately 90 percent – in indoor environments, including homes, workplaces, schools, and public spaces such as restaurants and malls. Roughly 66 percent of that indoor time is spent in homes (Leech et al. 2002). Hence, indoor environmental quality in the home has a significant impact on public health and well-being. Indeed, indoor pollution has been ranked by both the EPA Science Advisory Board and the Centers for Disease Control as a high environmental risk (Leung et al. 1997).

While globally the greatest health risks are associated with particulate pollution from indoor biomass burning that kills an estimated 1.6 million people per year (WHO 2002), the indoor environmental risks that are the focus of this paper are related specifically to indoor air quality (IAQ) in higher income countries. In this setting, indoor chemical contaminants include environmental tobacco smoke (ETS), nitrogen dioxide from space heaters and poorly ventilated furnaces, carbon monoxide, volatile organic compounds (VOCs), phthalates and pesticides. Biological contaminants include antigens from house dust mites, molds, rodents, cockroaches, and animal dander. Dampness and endotoxins have also been implicated in health risks associated with indoor environments (IOM 2000, 2004, Thorne 2005).

Indoor air pollutants in the home may lead to the development and/or exacerbation of a variety of diseases and symptoms. Some known and postulated adverse health effects that are associated with poor indoor air quality are allergies, asthma, infection, hypersensitivity pneumonitis, inhalation fevers, mucosal irritation, central nervous system effects, psychological effects (including depression), dermatitis, and even some forms of cancer (IOM 2000, 2004).

Asthma and allergic conditions in particular, are believed to be associated primarily with exposure to contaminants common in indoor rather than outdoor environments (IOM 2000). The Institute of Medicine has concluded that there is sufficient evidence of a causal relationship between asthma development and exposure to house dust mite (IOM 2000). There is substantial evidence that children who are exposed to indoor air mold in the first years of their lives have a significantly higher probability of developing asthma (Jaakkola et al. 2005). Also, there is sufficient evidence of a causal relationship between asthma *exacerbation* and exposure to cats, cockroaches, house dust mite, mold, and ETS in preschool-aged children (IOM 2000). There is also increasing evidence that pollutants from vehicle traffic infiltrates indoors adding to the risk of asthma and exacerbations (McConnell et al. 2006).

The number of self-reported asthma cases in the United States rose by 75% between 1980 and 1994 (Mannino et al. 1998). The most dramatic increase, 160%, was seen in children under 4 years of age. From 1975 to 1994, the number of office visits for asthma increased from 4.6 million to 10.4 million. Close to 15 million Americans have asthma today (IOM 2000).

From a health-economic standpoint, the loss of quality of life and productivity from an early diagnosis of a lifelong chronic disease such as asthma is enormous – both to the individual and to the society. In addition, when a child becomes sick, it is often the case that both a school day and a parent's workday are lost. Thus, educational and productivity losses due to adverse health effects from indoor contaminants could be substantial. Individuals with low incomes, particularly in inner cities, are more likely to be living in sub-standard housing with severe structural problems, with moisture intrusion, poor ventilation and associated mold and pest-related problems. These families are the least likely to have the means (money and education) by which to remediate such problems (Evans and Kantrowitz 2002; IOM 2004). Oftentimes they also lack the access to information regarding the extent of health problems associated with indoor asthma hazards and appropriate remediation responses. Therefore, the group that is most likely to suffer from indoor environment-induced asthma is children in low-income urban families.

Fortunately, many of the interventions that can be taken to reduce asthma triggers in home environments are relatively simple. Recently, a seven-year follow-up of a Canadian birth cohort has confirmed previous suggestions that simple environmental interventions directed at the hazards noted above can prevent asthma all-together in high-risk children (Arshad 2003; Chan-Yeung 2005). Measures such as encasing mattresses and pillows with dust-mite-impermeable cases, removing carpets, and more frequent cleaning of clothes, floors and upholstered furniture can reduce families' exposure to potentially harmful contaminants in home environments. This paper describes costs associated with asthma and sub-optimal indoor environments in the United States, evaluates studies that have investigated links between home environmental interventions and reduction of asthma symptoms in children, and addresses the economic impacts of these interventions and the subsequent health outcomes.

Costs of Asthma

There are heavy economic burdens associated with asthma. In addition to direct medical costs, the symptoms experienced by asthmatics lead to reduced productivity in the workplace, and absenteeism from school and from work. There are also unaccounted costs of pain, suffering, and inconvenience associated with the disease. In 1994, asthma was estimated to cost U.S. society $13.7 billion (all monetary values in the manuscript are given in 2005 USD), through medical costs and the high number of lost workdays (Weiss et al. 2000). Fisk (2000) estimated the cost of asthma, allergic rhinitis, and other associated airway allergic diseases to cost $23 billion, in terms of health care and indirect costs including lost work and lost school days.

There have been several attempts to valuate the economic impact of asthma that can be directly attributed to unhealthy indoor environments. Landrigan et al. (2002) judged that the environmentally attributable factor (EAF) in children's asthma was 30%, with a range of 10-35%. At this EAF value, they estimated the total annual costs from U.S. children's asthma caused by environmental exposures to be $2.3 billion. As much of environmentally mediated asthma is associated with indoor exposures, most of this cost is likely to be due to unhealthy indoor environments. Nguyen et al. (1998) estimated the annual cost of asthma linked with dampness in residential buildings in Finland at $9.40 USD per person, based on direct medical costs and productivity losses. The corresponding per capita cost associated specifically with mold in buildings was $4.96 USD.

Aside from direct medical costs and productivity losses, it is also important to consider losses due to pain and suffering from asthma. In contingent valuation studies assessing people's willingness to pay (WTP) to reduce respiratory symptoms, it was found that individuals were willing to pay between $7 and $341 per additional respiratory symptom day avoided in a year (Berger et al. 1987; Loehman 1979). In another study, asthmatic respondents showed a WTP of an average of $61 for a one-day reduction in bad-asthma days in a year (Rowe and Chestnut 1985).

Table 1 summarizes the literature on costs associated with dampness and related health symptoms, and benefits from relieving symptoms. Although there is uncertainty and variability associated with these estimates, in part due to the differences in adverse effects being measured, these data show that the societal costs of indoor dampness and other indoor asthma hazards and the related respiratory illnesses are very large. With the over-all annual cost of asthma in the U.S. estimated in the tens of billions USD with the costs for asthmatic children specifically is about $2.3 billion in 2002 (Landrigan et al. 2002). In addition, the willingness-to-pay to reduce bad-asthma days among asthma sufferers is substantial on a national scale.

Home Environmental Interventions to Reduce Asthma Triggers

Many studies have assessed the effectiveness of individual or comprehensive strategies to reduce asthma triggers in homes, with subsequent improvement in children's health. Of 32 studies published from 1992 to 2005, 24 reported randomized clinical trials of interventions in homes. Such interventions included increased mechanical ventilation, addition of bedding covers, vacuuming and cleaning, pest control methods, education programs to encourage parents not to smoke inside the home, and various combinations of the above interventions. Several papers had specific targets for allergen removal such as ETS, cockroach, house dust mite, pet dander, and mouse allergens; whereas others sought to remove a combination of potential home allergens. Fourteen studies had the objective of measuring whether children's respiratory health, specifically, improved as a result of interventions to remove asthma triggers in the home. These fall into three categories: those that focused on one or more mechanical methods to reduce home environmental triggers, those that focused on education of asthmatic children and their parents, and those that used a combination of interventions incorporating both of the above. Table 2 summarizes the studies that tested various interventions in home environments to reduce asthma triggers and improve children's health. The intervention type (Mechanical = mechanical home-based environmental intervention to reduce asthma triggers, Education = educating parents and/or asthmatic children, and Combination = a suite of interventions including both mechanical interventions and education) is listed, as well as a brief description of the study and any significant environmental and health effects reported.

Mechanical Methods to Reduce Home Environmental Asthma Triggers

Four categories of mechanical methods to reduce asthma triggers in the home are discussed here: bedding covers, vacuum cleaners, improved ventilation, and heating. Two projects evaluated the effects of mite-impermeable mattress and pillow covers on dust mite levels and children's respiratory health (Brunekreef et al. 2002; Halken 2004). In both of these studies, house dust mite levels in the bedrooms were significantly reduced. However, the results of the studies on changes in children's respiratory health are mixed. While Halken (2004) found that semi-permeable mattress and pillow encasings significantly reduced house dust mite exposure and the need for inhaled steroids among asthmatic children diagnosed with house dust mite allergy, Brunekreef et al. (2002) showed no important clinical benefits in children up to age two, whose mothers had house dust mite allergy, from the mite-impermeable bedding covers despite a significant reduction in mite-allergen levels in the intervention homes. There may be several reasons for this discrepancy in findings. Brunekreef et al. (2002) evaluated respiratory health up to age two, earlier than most children exhibit asthma. Inhaled steroids use was not described. Also, children whose mothers have dust mite allergy may not have the allergy themselves at such an early age; hence, would not have shown an improvement in respiratory function if house dust mite counts were reduced.

HEPA versus standard vacuum cleaners were tested for effectiveness in removing allergens and improving respiratory health in asthmatic children (Popplewell et al. 2000). It was found that HEPA vacuum cleaners significantly reduced house dust mite, cat and dog allergens throughout the home after 12 months of use, whereas the standard cleaners only reduced cat allergens in mattress dust samples. Clinically, house dust mite-allergic patients in the HEPA group showed improvements in peak respiratory flow rate and bronchodilator usage after 12 months.

HEPA vacuums were also tested in conjunction with mechanical ventilation (Warner et al. 2000) to reduce house dust mite. Specifically, this study tested the efficacy of a whole-house mechanical ventilation system with heat recovery (MVHR) unit; each unit consisted of a heat exchanger and two fans with a manually operated boost switch for the bathroom and a filter on the air supply. It was found that homes with MVHR units achieved significantly lower humidity levels than those without, with an associated reduction of house dust mite counts. Histamine levels in asthmatic patients were seen to improve. The addition of HEPA vacuuming further reduced dust mite concentrations in homes; however, it did not have a significant additional impact on health improvements.

Another ventilation study measured the impact of bedroom and living room air cleaners on asthmatic children's symptoms (van der Heide 1999). It was found that after three months of intervention with active air cleaners, substantial amounts of airborne cat and dog allergen were captured by the cleaners, and airway hyper-responsiveness in the asthmatic children decreased significantly.

Central heating as a prophylactic to indoor dampness and corresponding children's asthma symptoms was the focus of another project (Somerville et al. 2000). The installation of central heating in a number of homes was associated with significantly reduced dampness and improved energy efficiency. Children's adverse respiratory symptoms such as nocturnal cough were significantly reduced, and school-age children lost less time from school for asthma.

In total, these mechanical interventions to improve home environments have largely proven successful in reducing asthma triggers – house dust mite, cat and dog allergen, and dampness - significantly in the home. In many cases, this has led to documented improvements in children's respiratory health.

Education of Asthmatic Children and Their Parents on Healthier Home Environments

Several studies focused on education of parents and children regarding a particular intervention. Two studies (McIntosh et al. 1994; Wakefield et al. 2002) tested the efficacy of educating parents not to smoke in homes, in order to reduce children's exposure to a key asthma exacerbator. Fitzpatrick et al. (1992) tested the efficacy of a weeklong asthma camp for asthmatic children and their parents to decrease hospital visits and sick days from school.

Educating asthmatic children and their parents has had mixed results. The weeklong asthma camp intervention to educate children and their families resulted in clinically significant reductions in school absences, emergency room visits, and hospitalizations (Fitzpatrick et al. 1992). However, Wakefield et al. (2002) and McIntosh et al. (1994) found no significant change in parental home-smoking behaviors or asthmatic children's health as a result of educational programs encouraging parents to cease smoking in the home.

Combination of Mechanical and Educational Methods to Remove Home Asthma Triggers

Three series of studies used a combination of interventions, including education and various means of physical remediation, to control asthma triggers in home environments. The Seattle-King County Healthy Homes Project, whose work is summarized in Krieger et al. (2005), employed a community health worker intervention to decrease exposure to indoor asthma triggers in low-income households with asthmatic children. Community health workers provided indoor environmental assessments, education and support for behavior change, and resources to control triggers. Participants were randomly assigned to a high-intensity group receiving a mean of seven home visits and full set of resources or to a low-intensity group receiving a single visit and limited resources. This study demonstrated both significant allergen count reductions (measurements of condensation, roaches, moisture, cleaning behavior, dust weight, dust mite antigen, and total antigens) and improved children's health (reduced symptom days and urgent care visits) as a result of high-intensity interventions (Krieger et al. 2005). The higher-intensity group improved more than the lower-intensity group in its Pediatric Asthma Caregiver Quality of Life score (p=0.005) and asthma-related urgent health services utilization (p=0.026), but not asthma symptom days, after adjustment for baseline differences. Participant actions to reduce asthma triggers increased in the higher-intensity group but not the lower. The higher intensity group showed improvement in measurements of condensation, roaches, moisture, dust weight, dust mite antigen, and total antigens above a clinical effect cut-point, effects not demonstrated in the lower intensity group.

Two multi-center randomized-controlled home intervention trials have been conducted in other inner city U.S. populations, The first, the National Cooperative Inner-City Asthma Study (NCICAS) utilized a social worker implemented home intervention (Evans et al. 1999), while the second used two "Environmental Counselors" to deliver the home intervention (Morgan et al. 2004). The inner-city home environmental interventions were specifically targeted to their allergies and evidence of exposure in the home. The environmental interventions targeted the common allergens of dust mite, cockroach, pet dander, rodents, ETS, and/or mold; and included allergen-impermeable bedding covers, air purifiers with HEPA filters, HEPA vacuum cleaners, professional pest control, and an educational component. These interventions led to significantly lower allergen loads in the home, fewer symptom days in the asthmatic children, reduced albuterol inhaler use, and fewer unscheduled clinic visits.

Two studies (Carter et al. 2001; Hayden et al. 1997) described a project in which asthmatic children in Atlanta were randomized into three groups: two groups with home visits by health professionals, one with active avoidance (including impermeable bedding covers, hot washing of bedding, and cockroach bait) and one with placebo avoidance (permeable bedding covers and cold washing of bedding), and a control with no home visits. The combination of bedding covers, hot water washes of bedding, and removal of carpets resulted in improved respiratory function even among asthmatic children admitted to the hospital (Hayden et al. 1997). Interestingly, when both actual and placebo interventions were employed for allergen reduction in the home (Carter et al. 2001), children's hospitalization rates for asthma dropped in both the actual and placebo intervention groups, but no significant difference in hospitalization was observed between the two groups. As in many of these intervention studies, it was concluded that the home visitation itself influenced asthma management among families.

Economic Impacts of Home Environmental Interventions

Few studies have attempted to assess the cost-effectiveness of various home environmental interventions to reduce children's asthma symptoms. Some data are available as far as how much can be done from an environmental interventional standpoint. Fisk (2000) estimates that improving indoor environments can result in as much as a 10% to 30% reduction in asthma symptoms and their associated costs. This would translate to an annual savings in the U.S. of $2-

$4 billion. However, this includes not just homes, but office buildings, and pertains to both children and adults.

Our analysis above indicates that certain types of interventions are indeed effective in reducing home environmental allergens and improving asthmatic children's health. The question remains how affordable they are, given that many asthmatic children in the U.S. live in low-income urban households. Allergen-impermeable bedding covers have proven effective in reducing allergen exposure; a complete set (for pillows, mattresses, comforters, and box springs) can cost about $150-$450 (for a twin-size to king-size bed; www.allergycontrol.com gives sample costs for these and other interventions). HEPA vacuum cleaners, which have also proven effective in allergen removal and improved children's health, cost about $200-$1000. HEPA air cleaners for a single room range from $100-$500, while single-room dehumidifiers range from $200-$800. Other more intensive interventions, such as installation of a whole-house ventilation system or a central heating system, are likely to be more expensive, though they too have proven effective in improving asthmatic children's health. Educational programs have an enormous range of costs, and applied alone have *not* consistently proven effective in long-term changes in parental behavior.

Cost data are available from three of the comprehensive intervention projects: the Seattle – King County Healthy Homes project (Krieger et al. 2005) the NCICAS (Sullivan et al. 2002) and ICAS Study groups (Kattan et al. 2005; Morgan et al. 2004). Krieger et al. (2005) made certain assumptions about the costs of hospital admissions, emergency department visits, and clinic visits; and compared these costs with benefits seen in the asthmatic children that participated in their study in terms of reduced number of visits. Within the high-intensity group, the estimated net decrease in two-month urgent care costs between baseline and exit ranged from $22,084 to $36,700 ($201 to $334 per child), and within the lower-intensity group, from $19,246 to $32,756 ($185 to $315 per child). Although this study did not collect follow-up data on both groups, a six-month follow-up of a randomized sample of the higher-intensity group demonstrated that urgent health care utilization continued to decline after the active intervention ceased.

Both multi-center inner-city one-year interventions were also cost-effective at reducing morbidity in inner-city children with atopic asthma. Cost-effectiveness analyses have done on both by Sullivan et al. (2002) and Kattan et al. (2005). Both interventions were cost effective based-upon symptom free days (SFD) The NCICAS intervention cost was $9.20 per SFD (95%CI $12.56-$55.29). The ICAS Study estimated the costs of the tailored, home-based environmental intervention to be $1469 per family (Kattan et al. 2005). The children who received this intervention had 19% fewer unscheduled clinic visits, a 13% reduction in the use of albuterol inhalers, and 38 more symptom-free days over the two-year course of the study than those in the control group. This translated into an estimated intervention cost of $27.57 per symptom-free day (95%CI $7.46-$67.42). Given that one day of symptoms for an asthmatic child could include an unscheduled clinic visit ($49.34), an emergency department visit ($390), or an inpatient hospital day ($1134), this type of intervention is indeed cost-effective (Kattan et al. 2005).

Discussion

Indoor environmental quality in homes is an important health concern, particularly for infants and small children who are more susceptible to the adverse health effects that can result from exposures to hazards encountered in homes. In particular, pediatric asthma, a disease whose incidence has been increasing dramatically over the last three decades, is associated with pollutants found indoors. The medical and societal costs of asthma are significant. These costs are multiplied when lifetime medical and productivity and other less direct costs are considered. Since children can develop asthma from allergens encountered indoors, and these allergens exacerbate existing asthma, home environmental interventions take on great health as well as economic importance.

Simple mechanical home interventions are effective, both in the reduction of allergen loads in the home, in reducing symptoms and urgent care associated with asthma and in preventing the emergence of the disease. Use of bedding covers, HEPA vacuum cleaners and air cleaners, increased ventilation, and central heating in the home can reduce indoor air allergens and often improve children's respiratory health. A combination of interventions, involving both mechanical methods for allergen reduction and educational efforts of asthmatic children and their parents, has proven effective in asthma prevention, asthma trigger reduction and improved health outcomes for asthmatic children.

Education and information dissemination alone have generally not proven effective in reducing indoor asthma triggers and the resulting asthma symptoms. Pilot projects in which educational interventions encouraged parents not to smoke in the home showed no significant effect on parental smoking behaviors, indicating that for this addictive behavior more effort is necessary to deliver effective messages. Even when parents are able to identify asthma triggers in children's environments, they may not always know proper interventions to control the triggers. Cabana et al. (2004) found that though 80% of parents of asthmatic children in a nationwide survey were able to identify at least one environmental asthma trigger, and though 82% of these parents attempted to control such triggers, less than half of the control actions were thought to be useful by the authors. Hence, better education for parents about effective control methods for home asthma triggers is needed. Clark and Valerio (2003) and Clark and Partridge (2002) provide guidelines for improving patient and parental education on asthma, describing the potential usefulness of health behavior theories and improving the educational role and skills of clinicians.

The cost of effective interventions is important to consider, as well as the extent to which an asthmatic child's parent is able to achieve the home interventions independently without external aid. It is important to remember that children's asthma disproportionately affects low-income urban households (IOM 2000), who may find it difficult to achieve some of the more costly or complicated interventions described in the studies above. Typically, the costs for bedding covers, HEPA vacuum cleaners and air cleaners, and dehumidifiers range from $100 to several hundreds of dollars. These types of interventions can be useful for removing multiple allergens. In the few studies that have evaluated the economic impacts of a combination of home environmental interventions to reduce children's asthma symptoms, the interventions have proven cost-effective in terms of improved respiratory health outcomes. This indicates that investments in providing low-cost interventions and educating the public about improving their home environments are likely to reap significant and lasting benefits for asthmatic children and prevent asthma in families with children at risk.

Future work may focus on understanding long-term effects of the interventions that have proven effective in reducing home environmental asthma triggers and improving symptoms and quality of life in children with asthma. Improvements in educational design may be needed to motivate parents to change behaviors such as smoking and more frequent cleaning in the home. It is important to consider potential risks of synthetic bedding, plasticizers, new paint, and other indoor emissions as subjects for future intervention research on children's asthma. Also, future research could ascertain whether such forms of intervention and education are effective in reducing the adverse effects of other environmentally-mediated diseases from hazards inside the home and how genes and these environmental exposures interact.

References

Allergy control products. www.allergycontrol.com Accessed 23 June 2006

Arshad SH, Bateman B, Mathews SM. 2003. Primary prevention of asthma and atopy during childhood by allergen avoidance in infancy: a randomized controlled study. Thorax 58:489-493.

Berger MC, Blomquist GC, Kenkel D, Tolley GS. 1987. Valuing Changes in Health Risks: A Comparison of Alternative Measures. Southern Econ J. 53:977-984.

Brunekreef B, Smit J, de Jongste J, Neijens H, Gerritsen J, Postma D et al. 2002. The prevention and incidence of asthma and mite allergy (PIAMA) birth cohort study: design and first results. Pediatr Allergy Immunol 13 Suppl 15:55-60.

Cabana MD, Slish KK, Lewis TC, Brown RW, Nan B, Lin X et al. 2004. Parental management of asthma triggers within a child's environment. J Allergy Clin Immunol 114:352-357.

Carter MC, Perzanowski MS, Raymond A, Platts-Mills TA. 2001. Home intervention in the treatment of asthma among inner-city children. J Allergy Clin Immunol 108:732-7.

Chan-Yeung M, Ferguson A, Watson W, Dimich-Ward H, Rousseau R, Lilley M et al. 2005. The Canadian Childhood Asthma Primary Prevention Study: outcomes at 7 years of age. J Allergy Clin Immunol. 116:49-55.

Clark NM, Partridge MR. 2002. Strengthening asthma education to enhance disease control. Chest 121:1661-1669.

Clark NM, Valerio MA. 2003. The role of behavioural theories in educational interventions for paediatric asthma. Paediatr Respir Rev. 4:325-333.

Evans R III, Gergen PJ, Mitchell H, et al. 1999. A randomized clinical trial to reduce asthma morbidity among inner-city children: results of the National Cooperative Inner-City Asthma Study. J Pediatr 135:332-8.

Evans, G.W., Kantrowitz, E. 2002. Socioeconomic status and health: the potential role of environmental risk exposure. Ann Rev Publ Health 23:303-331.

Fisk WJ. 2000. Estimates of potential nationwide productivity and health benefits from better indoor environments: an update. Indoor Air Quality Handbook, Spengler J, Samet JM, McCarthy JF (Eds). New York, McGraw Hill 4.1-4.36.

Fitzpatrick SB, Coughlin SS, Chamberlin J. 1992. A novel asthma camp intervention for childhood asthma among urban blacks. The Pediatric Lung Committee of the American Lung Association of the District of Columbia (ALADC) Washington, DC. J Natl Med Assoc 84:233-7.

Halken S. 2004. Prevention of allergic disease in childhood: clinical and epidemiological aspects of primary and secondary allergy prevention. Pediatr Allergy Immunol Suppl 16:4-5, 9-32.

Hayden ML, Perzanowski M, Matheson L, Scott P, Call RS, Platts-Mills TA. 1997. Dust mite allergen avoidance in the treatment of hospitalized children with asthma. Ann Allergy Asthma Immunol 79:437-42.

IOM (Institute of Medicine) 2000. Clearing the Air: Asthma and Indoor Air Exposures. National Academy Press, Washington, D.C.

IOM 2004. Damp Indoor Spaces and Health. National Academy Press, Washington, D.C.

Jaakkola JJK, Hwang BF, Jaakkola N. 2005. Home dampness and molds, parental atopy, and asthma in childhood: a six-year population-based cohort study. Env Health Perspect 113:357-361.

Kattan M, Stearns S, Crain E, Stout J, Gergen P, Evans R, et al. 2005. Cost-effectiveness of a home-based environmental intervention for inner-city children with asthma. J Allergy Clin Immunol 116(5):1058-1063.

Krieger JW, Takaro TK, Song L, Weaver M. 2005. The Seattle-King County Healthy Homes Project: a randomized, controlled trial of a community health worker intervention to decrease exposure to indoor asthma triggers. Am J Public Health 95:652-9.

Landrigan PJ, Schecter CB, Lipton JM, Fahs MC, Schwartz J. 2002. Environmental pollutants and disease in American children: estimates of morbidity, mortality, and costs for lead poisoning, asthma, cancer and developmental disabilities, Environ Health Perspect 110:721-728.

Leech JA, Nelson WC, Burnett RT, Aaron S, Raizenne ME. 2002. It's about time: a comparison of Canadian and American time-activity patterns. J Expos Anal Environ Epidemiol 12:427-432.

Leung R, Koenig JQ, Simcox N, van Belle G, Fenske R, Gilbert SG. 1997. Behavioral changes following participation in a home health promotional program in King County, Washington. Environ Health Perspect 105:1132-5.

Loehman ET. 1979. Distributional analysis of regional benefits and cost of air quality control. J Env Econ & Management 6:222-243.

Mannino DM, Homa DM, Pertowski CA, Ashizawa A, Nixon LL, Johnson CA et al. 1998. Centers for Disease Control and Prevention. Surveillance for Asthma Prevalence – United States, 1960-1995. Morbidity and Mortality Weekly Report 47:1-28.

McConnell R, Berhane K, Yao L, Jerrett M, Lurmann F, Gilliland F et al. 2006. Traffic, susceptibility, and childhood asthma. Environ Health Perspect 114:766-772.

McIntosh NA, Clark NM, Howatt WF. 1994. Reducing tobacco smoke in the environment of the child with asthma: a cotinine-assisted, minimal-contact intervention. J Asthma 31:453-62.

Mendell MJ, Fisk WJ, Kreiss K, Levin H, Alexander D, Cain WS et al. 2002. Improving the health of workers in indoor environments. Am J Pub Health 92:1430-1440.

Morgan WJ, Crain EF, Gruchalla RS, O'Connor GT, Kattan M, Evans R 3rd et al. 2004. Results of a home-based environmental intervention among urban children with asthma. N Engl J Med 351:1068-80.

Nguyen TT, Pentikainen T, Rissanen P, Vahteristo M, Husman T, Nevalainen A. 1998. Health related costs of moisture and mold in dwellings. National Public Health Institute, B13, Kuopio University Printing Office, Finland.

Peleg R, Gehtman P, Blancovich I, Aburabia R, Allush R, Hazut S et al. 2002. Outcomes of an intervention programme for treatment of asthma in a primary care clinic for Bedouins in southern Israel. Fam Pract 19:448-51.

Popplewell EJ, Innes VA, Lloyd-Hughes S, Jenkins EL, Khdir K, Bryant TN et al. 2000. The effect of high-efficiency and standard vacuum-cleaners on mite, cat and dog allergen levels and clinical progress. Pediatr Allergy Immunol 11:142-8.

Rowe RD, Chestnut LG. 1985. Oxidants and Asthmatics in Los Angeles: A Benefits Analysis. Report to the Office of Policy Analysis, U.S. Environmental Protection Agency. Energy and Resource Consultants, Inc., Boulder, CO

Somerville M, Mackenzie I, Owen P, Miles D. 2000. Housing and health: does installing heating in their homes improve the health of children with asthma? Public Health 114: 434-9.

Stroupe KT, Gaskins D, Murray MD. 1999. Health-care costs of inner-city patients with asthma. J Asthma 36:645-655.

Sullivan SD, Weiss KB, Lynn H, Mitchell H, Kattan M, Gergen PJ, Evans R 2002. National Cooperative Inner-City Asthma Study (NCICAS) Investigators. The cost-effectiveness of an inner-city asthma intervention for children. J Allergy Clin Immunol 110:576-581.

van der Heide S, van Aalderen WM, Kauffman HF, Dubois AE, de Monchy JG. 1999. Clinical effects of air cleaners in homes of asthmatic children sensitized to pet allergens. J Allergy Clin Immunol 104:447-51.

Wakefield M, Banham D, McCaul K, Martin J, Ruffin R, Badcock N et al. 2002. Effect of feedback regarding urinary cotinine and brief tailored advice on home smoking restrictions among low-income parents of children with asthma: a controlled trial. Prev Med 34:58-65.

Warner JA, Frederick JM, Bryant TN, Weich C, Raw GJ, Hunter C et al. 2000. Mechanical ventilation and high-efficiency vacuum cleaning: A combined strategy of mite and mite allergen reduction in the control of mite-sensitive asthma. J Allergy Clin Immunol 105:75-82.

Weiss KG, Sullivan SD, Lyttle CS. 2000. Trends in the cost of illness for asthma in the United States. J Allergy Clin Immunol 106:493-499.

WHO. 2002. World Health Report: Reducing Risks, Promoting Healthy Life, Geneva.

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Table 1. Costs Associated with Respiratory Illnesses Attributable to Poor Indoor Environments, and Benefits from Relieving Symptoms

Cost or Benefit to Society	Value ($US 2005)	Reference
Costs of asthma across US population, medical and productivity costs (annual, US)	$13.7 billion	Weiss et al. 2000
Costs in US of asthma, allergic rhinitis and other associated allergic airway diseases	$23 billion	Fisk 2000
Cost of environmentally attributable children's asthma in US	$2.3 billion	Landrigan et al. 2002
Direct and indirect costs of asthma due to damp residences (annual, Finland, per capita)	$9.40	Nguyen et al. 1998
Direct and indirect costs of asthma due to mold (annual, Finland, per capita)	$4.96	Nguyen et al. 1998
WTP per additional respiratory symptom day avoided per year (per capita)	$7 - $341	Berger et al. 1987 Loehman 1979
WTP per additional bad asthma day avoided per year (per capita)	$61	Rowe & Chestnut 1985

Study	Intervention Type	Description of Intervention	Home Environmental Effects	Health Effects
Brunekreef et al. 2002	Mechanical	Mite-impermeable bedding covers	Lower house dust mite count	No important clinical benefits in children <2
Halken 2004	Mechanical	Mite-impermeable bedding covers	Lower house dust mite count	Reduced need for inhaled steroids in asthmatic children
Popplewell et al. 2000	Mechanical	HEPA and standard vacuum cleaners	Reduced house dust mite, cat & dog allergens with HEPA	Improved peak respiratory flow rate, bronchodilator usage
Warner et al. 2002	Mechanical	HEPA vacuum cleaners and whole-house mechanical ventilation system	Reduced dampness and house dust mite count	Improved histamine levels with whole-house ventilation; no significant added benefit from HEPA
Van der Heide 1999	Mechanical	Bedroom and living room air cleaners	Reduced airborne cat & dog allergen	Improved peak expiratory flow rate; reduced airway hyper-responsiveness
Somerville et al. 2000	Mechanical	Central heating systems	Reduced dampness; improved energy efficiency	Improved asthma outcome measures; fewer sick school days
Wakefield et al. 2002	Education	Parents refraining from smoking in the home	No significant difference in parental behavior	No significant improvement in children's health
McIntosh et al. 1994	Education	Parents refraining from smoking in the home	No significant difference in parental behavior	No significant improvement in children's health
Fitzpatrick et al. 1992	Education	Asthma camp for asthmatic children and their parents	Improved use of medication and breathing exercises	Reduced school absences, ER visits, and hospitalizations

Krieger et al. 2005	Combination	Community health workers deployed to Seattle homes: high-intensity, low-intensity interventions	Reduction in numerous home allergens	Reduced children's asthma symptom days and use of urgent health services
NCICAS Kattan et al. 2005 Morgan et al. 2004 Sullivan et al. 2002	Combination	Seven cities: compre-hensive home environmental interventions and education targeted to children's allergies	Reduction in numerous home allergens	Reduction in asthma symptom days in children, use of albuterol inhalers, and unscheduled clinic visits
Carter et al. 2001 Hayden et al. 1997	Combination	Interventions in homes of hospitalized asthmatic children with home visits : active, placebo & control	Reduction in house dust mite	Reduced children's acute asthma hospital visits ; no difference in active vs. placebo groups

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