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The Role of Home Environments in Allergic Disease

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Abstract

Allergic diseases are surprisingly common, chronic health conditions. The primary location where the vast majority of people are exposed to allergens and other substances is in their home. This means it is important to understand home environments and how a home's systems function and interact—and that how we occupy these spaces plays a crucial role in both environmental exposure and management of allergic disease. This review provides an overview of what is understood about home environmental exposure and its impact on our health, and proposes a systematic process for using a patient's environmental history to develop individualized, manageable and cost-effective recommendations. Once occupant-related information has been gathered, a home environmental exposure assessment should be performed focused on identifying the relationships between any identified sources of contaminants and the housing systems, and conditions that may be contributing to exposure. The results and recommendations from this assessment can then be used to guide exposure-reduction efforts by patients and/or their caregivers in an effort to improve disease management. In this review, we'll discuss three different types of home interventions—active, which must be routinely performed by the patient and/or caregiver, passive, which are interventions that work without routine, direct interaction from the homeowner, and behavioral changes in how the home environment is cleaned and maintained for long-term reduction of allergens. In this review, and others evaluated for this discussion, a significant number of home environmental assessment and intervention programs were shown to be cost effective, with the majority of programs showing a net positive return on investment. It is important to recognize that to be cost effective, the level and intensity of services offered through home visit programs need be stratified, based on the estimated health risks of the patient, in order to tailor the assessment and target the interventions to a patient's needs while maximizing cost effectiveness.

Keywords Environment · Asthma · Allergy · Home assessment · Intervention · Allergens

Introduction

Atopic diseases are the most common childhood chronic health condition and present in 75% of children with asthma [1]. Asthma is one of the most common childhood diseases with almost 10% of American children affected [2]. Atopy does not always result in disease and when it does, there can be tremendous heterogeneity of the response [3]. Genetic studies suggest that atopic diseases result from a complex interplay of genetic expression, environmental exposure, and child development [4]. However, these factors can also work together to suppress the allergic response, meaning atopy does not always equal allergy [3]. The home environment represents one of the primary locations where children are exposed leading to different atopic diseases. Children spend 90% of their lives in indoor environments so that almost every breath they take is from indoor air [5]. This means that the composition of indoor spaces in their homes, the mechanical systems that maintain the condition of the indoor air, and the lifestyle and behavior of their parents all play roles in what they are exposed to indoors and what they breathe. Considering previous surveys of settled dust in American homes found more than half of all homes tested (832) had detectable concentrations of at least six allergens while almost half (45.8%) had at least three allergens at significant concentrations known to be associated with symptoms, the home environment represents the primary source exposure to contaminants associated with atopic disease [6]. A recent review of the medical costs and outcomes for asthma patients using data from the years 2000–2009 found across all age groups medical expenditures increased or remained the same, while outcomes did not

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improve [7]. This suggests that more effort is needed to increase the availability and access to home environmental assessment and intervention programs for asthma patients and their families in order to promote more environmental improvements in homes and, perhaps, improve health outcomes.

In this article, we will provide an overview of what the literature indicates about the health impacts of home exposure, the important role a home assessment can play in understanding what exposure risks exist in a home and what can be done to address the risks, and an overview of what the literature says about which home interventions are supported by the research as potentially beneficial to patients. This article focuses on the pediatric population where there is a robust amount of research available. In the last 3 years, there have been several extensive reviews of the literature related to allergic disease and asthma, along with new research associated with the role of microbiomes in the built environment. We will summarize key findings from many of these reviews and use the information to identify best practices. Finally, we will offer a model for identifying which patients with respiratory disease will benefit from a home environmental assessment, some of the basic components of an environmental assessment process, and how to use home assessments and interventions to assist patients and caregivers in reducing environmental exposure in an effort to improve health.

Health Impacts of Home Exposure

It is well-known through more than three decades of research on residential exposure to environmental contaminants that housing plays a significant role in atopic disease [8–13]. The primary environmental allergens found in indoor environments that affect people are from dust mite, pets, rodents, cockroaches, and fungi with many specific antigen proteins identified [11–16]. A recent extensive review of the literature related to home environment exposure and asthma was an update from earlier work by the Institute of Medicine [17]. The review incorporated an additional set of 69 more recent studies and found strong evidence to show causation of asthma exacerbations from exposure to dust mite and cat allergen in sensitized individuals and exposure to cockroach allergen for sensitized individuals, especially adults. The report also found sufficient evidence of a causal association between exposure to dampness or dampness-related agents and exacerbation of asthma in children and between exposure to outdoor culturable fungal exposure and exacerbation in asthmatics sensitized to fungi. They also found sufficient evidence of association but not causation between chronic environmental tobacco smoke (ETS) exposure and exacerbations of asthma in preschool-age children, indoor endotoxin exposure and the exacerbation of asthma, dog allergen exposure and exacerbations of asthma in children sensitized to dogs, brief high-level exposures to nitrogen dioxide, and increased airway responses to nonspecific chemical irritants and inhaled allergens among asthmatic subjects [18]. Other reviews do not support these summary findings for endotoxin and actually indicate that it was among the first microbial byproducts to appear to be protective against atopic asthma and the risk of allergic sensitization [19].

Exposure to many different chemicals, air pollution, environmental tobacco smoke, and other kinds of smoke has been known for many years to increase sensitization to some allergens and exacerbate symptoms in those with existing asthma [20]. Additional research and reviews have expanded the number of chemicals implicated in allergic disease and confirmed what is known about the health impact of the biological agents commonly found in homes [21–23]. Indoor particulate matter (PM) is a significant air pollutant with both outdoor and indoor sources. Some studies have shown that indoor concentrations of PM are much greater than outdoors and are significantly associated with respiratory symptoms and asthma symptoms [24, 25].

A very recent review provides a comprehensive overview of what the current evidence indicates about environmental determinants of allergy and asthma in early life. From their synthesis of the latest evidence, they identify key pre-natal and early-life environmental exposures that likely contribute to the atopy development. They also discuss the increasingly important role of the microbiome of the human and the built environment in promoting or preventing allergic disease. From their summary, vaginal birth, larger number of siblings, exposure to farms, endotoxins, and increased microbial and fungal diversity were all protective against allergic disease, while certain viral infections, environmental allergen exposure, pre-natal/post-natal use of antibiotics, and exposure to tobacco smoke and air pollution are all known promoters of allergic disease [19]. One of the most important underlying factors for how all of these different environmental risks combine, or interact, to promote or prevent allergic disease, is the home environment. This is the primary location where we humans spend time and where exposures are concentrated and magnified, because of the nature of how homes are designed, built, occupied, and maintained.

In recent years, a robust amount of research studying the role of the microbiome in allergic disease, in human health, and in built environments has been published. This has led to the development of a biodiversity hypothesis that suggests exposure to a diverse environmental microbiota is important, especially in early life. There is a growing body of research evidence to demonstrate a relationship between microbiological diversity and an association with allergic disease, asthma, and human immune dysfunction [26, 27]. Exposure to low fungal and bacterial diversity appears to be associated with development of allergies and asthma [27–29]. Many building components are associated with microbial diversity including design, ventilation systems, use of air conditioning, reported water leaks, number of adults and children, single versus multifamily home, and the number and types of pets [30]. Attempts to identify the primary sources of different types of microbiota in homes are under way, but the evidence is limited [31].

The home environment represents the primary location where people spend time and where exposure occurs. One example of an exposure model describes the allergens that lead to symptoms and atopic disease as contaminant sources, the locations in homes where the biological organisms might thrive and lead to allergen accumulation as reservoirs, and certain physical and environmental conditions found in homes (moisture leaks, dirty carpeting, and clutter) as the facilitative factors within homes. When introduced into the home reservoirs, the conditions that result lead to proliferation and accumulation of allergens and other contaminants that the occupants are exposed to [32]. As a different way of illustrating this relationship, figure one is a visual representation of the role the home environment and its impact on disease as represented in a similar fashion to a classic epidemiologic triangle (Fig. 1). In the case of a home, the host remains the same (humans), the agents are the allergens and other contaminants that result in disease or symptoms, and the environment is represented by the home and the reservoirs within the home. The transport mechanisms are the organisms the produce allergens and the fomites are equivalent to the facilitative factors combined with the reservoirs. We have added facilitative factors on the side of the triangle between host and environment because the impact of these factors is often controlled by the human's behavior as they occupy the home. We also included an inner line between home (environment) and contaminant (agent) that represents the interventions that the host can implement within the home to reduce the agents and therefore reduce exposure. The goal of the health provider and the environmental assessor is to get the patient or caregiver to follow certain intervention strategies that will disrupt the relationship shown in this disease triangle in order to avoid and/or eliminate exposure, to reduce symptoms. For many patients, this triangle represents the cycle of exposure that is leading to excessive utilization of health care services, medications, and unnecessary health care costs. Patients and caregivers are often unaware of this triangle of exposure and need the guidance of a home environmental assessor to learn what changes need to be made to improve their health.

Interventions to Reduce Environmental Exposure

In the last 10 years, a wide array of systematic reviews of home environmental intervention research have been completed each taking a different aspect of this research and evaluating the effectiveness of different interventions. In 2010, the Centers for Disease Control and Prevention (CDC) and the National Center for Healthy Housing convened several expert panels to review the evidence up to that time and determine what housing interventions to reduce environmental exposures were supported by the research. One area of focus was biological agents, the allergens they produce, and their impact on asthma and

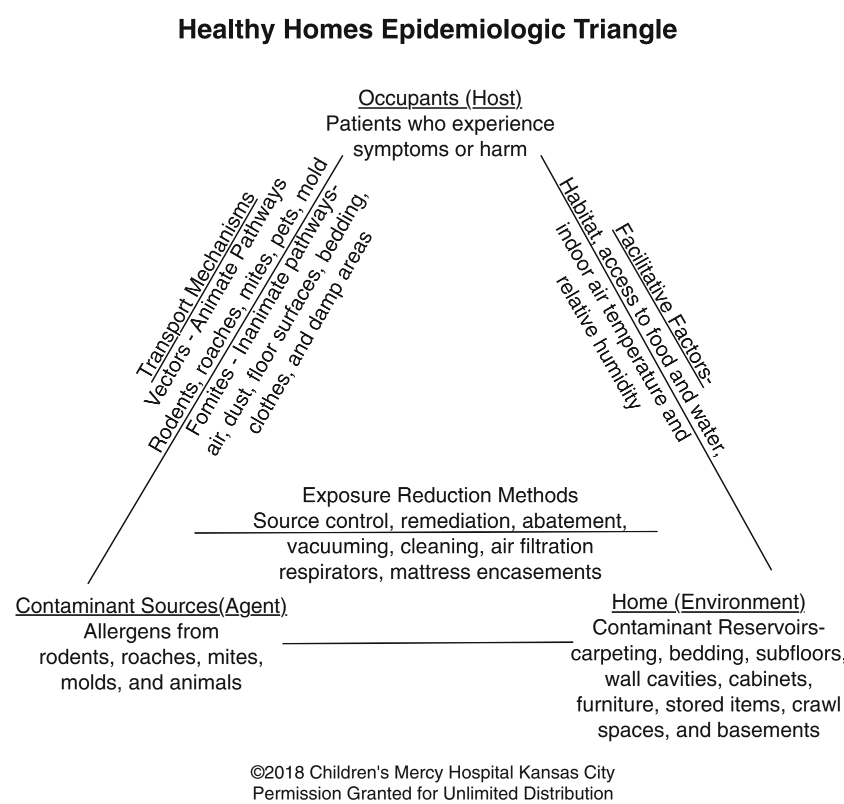

Fig. 1 This figure represents the home environment as an epidemiologic triangle

allergic disease. The expert panel followed a formal review process described previously [33]. The panel identified 11 environmental interventions in the research worth reviewing based on research available. Of the 11 interventions, three had sufficient evidence of effectiveness and were deemed ready to implement by asthma-related home visit programs. Four interventions were considered promising but needed more field research, one needed more formative research and three were determined to be ineffective. The three interventions identified as ready for implementation included multifaceted, in-home tailored interventions, combined elimination of moisture intrusion and removal of moldy materials, and the use of integrated pest management (IPM) for the control of cockroaches [34]. Of particular importance is the application of multifaceted, in-home tailored interventions. These kinds of interventions involve an array of products and services that are implemented together to address multiple environmental triggers.

The results of this review were supported by systematic review of the evidence for environmental interventions completed by the CDC Task Force on Community Preventive Services. This very thorough review used methods developed for the Guide to Community Preventive Services and focused on studies that implemented home-based, multitrigger, and multicomponent interventions, had to include at least one home visit, had to target more than one asthma trigger, had to include more than one intervention component, and one of these had to be focused on the home environment. Thirty-two studies were identified as being home-based, multitrigger, and multicomponent. From these, 23 met the study quality criteria and were used in the evaluation of effectiveness [35]. Eight health outcome measures, as represented by specific outcome categories and measures of effect, were used to assess the impact of home interventions. These included quality of life, health care utilization, productivity, physiologic outcomes, asthma trigger indicators, asthma management behaviors, trigger reduction behaviors, and general asthma control. Their findings indicated strong evidence of effectiveness for the home-based, multitrigger, and multicomponent environmental interventions in reducing symptom days, improving quality of life or symptom scores and in reducing the number of school days missed [35].

Most recently, LeCann (2017) provided a comprehensive review of 26 home environmental intervention and control research studies published between 2004 and 2015. They divided home interventions into three categories: education, physical interventions and a combination of both. The studies chosen were evaluated for the type of home intervention and the impacts of the interventions on the health of subjects and home environment. From this review, they found most programs focused on allergens and molds with very few investigating home chemical pollutants. They found that, in general, home environmental interventions were effective in reducing exposure to allergens and molds. However, they reported lots of variation in the types of interventions, and lots of mixing of the three types of interventions reviewed, so it was difficult to draw conclusions. Studies that were focused on single interventions in particular showed lots of variability and limited effectiveness. An important note in their review was that there were many instances in the studies reviewed where the lack of environmental effects may have been because the actual level of environmental burden in many homes was already low. For this review, they divided health impacts into three categories: clinical outcomes, medication and urgent care use, and quality of life and activity limitations. Here again, the outcomes were mixed and provided a somewhat murky picture of effectiveness, with some studies showing statistically significant health benefit and others showing no real benefit from the interventions implemented. Of the three intervention types the studies evaluated, behavior change appeared to be the most important. They did note that the use of community health workers (CHWs), or similar, for home assessments was shown to have a significant impact on the study subjects and that this was likely because of shared life experience between the caregivers and the home visitors. They further indicated most successful, long-term interventions appear to be those that require little effort by the participants themselves. The authors did note that many of the studies had design problems (lack of significant environmental change, inadequate statistical power, low retention) and this adds to the difficulty of being able to draw conclusions [36••].

Economic Value of Home Environmental Assessment and Interventions

The economics of home environmental assessments and interventions have also been extensively reviewed. Kattan (2005) provided an extensive analysis of the cost-effectiveness of the Inner-City Asthma Study that took place in the early 2000s in seven urban locations in US cities. In each city, they trained environmental counselors to assess the home and provide education and tailored interventions to families of children 5 to 11 years with severe asthma. After participation, they found statistically significant reductions in key health outcomes including unscheduled clinic visits, use of B-agonist inhalers, and symptom days. These reductions were matched with significant health care cost savings when compared to the home-based environmental intervention costs [37]. Since the Inner-City Asthma Study, additional studies and systematic reviews have been performed and found similar results [38, 39]. In particular, Nurmagambetov (2010) used methods developed for the Guide to Community Preventive Services and performed an economic evaluation of home-based assessment and intervention programs. Using 13 studies that met their criteria, their economic evaluation found benefit-to-cost ratios from $5.30 to $14.00 in averted health care costs and productivity losses, for every dollar spent on home environmental assessment and multitrigger, multicomponent interventions [39]. Hsu (2016) provides an extensive analysis and comparative summary of asthma programs from across the country and looks closely at the "return on investment" (ROI) for these programs. They identified nine outpatient programs that focused on asthma self-management education and 17 home-based intervention programs that all reported ROI. In their review, most programs were associated with a positive ROI. However, they found many of these programs observed positive ROIs only among selected populations (e.g., higher health care utilization). They noted that one challenge with their interpretation of these program results was the heterogeneous nature of asthma home visiting program and this variation represents differences in how ROI was calculated [40].

Interventions Used to Reduce Exposure

In this article, we discuss a slightly different approach for understanding the different types of environmental interventions that might be recommended by home environmental assessors. Interventions that are recommended can generally be divided into three categories: passive, active, and behavior change. Passive interventions are those mechanical methods that do not require routine activity by the caregiver in order for the intervention to be effective. Examples of passive interventions are mattress encasements, dehumidifiers, furnace filters, certain types of exhaust fans, and portable room air purifiers. Once installed, these methods perform the mechanical process necessary to reduce the target contaminants. Active interventions are those methods that require caregivers to take an active role in their use in order for these methods to be effective. Examples of active interventions include vacuuming, routine dusting and cleaning, laundering clothes and bedding, bathing and grooming pets, and clearing clutter. Behavior changes involve working with caregivers to learn and use new cleaning and maintenance practices in their routines. Behavioral changes include smoking cessation, stopping the use of fragrances and air fresheners, increasing the amount of cleaning and laundering, expanding the items and areas that are cleaned, and using new or additional supplies and tools that are typically provided by the home assessor or case manager.

To identify the effectiveness of these categories, we performed a literature search to identify home environmental intervention studies for asthma and allergic disease that implemented home-based interventions and evaluated the health impacts. Our goal was to identify how many studies used interventions that fit these categories and what kind of summary information can be drawn from this analysis. We used both Internet search methods and the reviews of home intervention research summarized in other research articles. PubMed was the primary search method used to retrieve relevant articles in the literature published from 2000 to 2017. The following search words were used: (environment, intervention, allergen, education) AND (building, house, home, residence, dwelling) AND (asthma, inflammation, allergy, eczema, wheeze, cough, respiratory, respiratory infection). References identified were selected based on the type of study that was relevant to the purpose for this article. Additional publications were selected from the bibliographies in the articles retrieved. All studies selected for this review had to meet the following criteria: publication in peer-reviewed, scientific journals; publications in English; the study had to involve intervention that took place in the homes of subjects with allergy and asthma; results regarding the effectiveness of the intervention had to be provided. Our limited search identified 41 articles published from early 2000 to 2017 that included a discussion of at least one of the three types of intervention. Most of the studies reviewed involved children. Limited studies involving adults were identified and were included in this review, if relevant.

Table 1 provides a summary of key home environmental intervention research broken down into the three types of interventions and a brief summary of what worked and what did not, if the information was provided.

Active Interventions

Cleaning Practices

Several studies listed in Table 1 included multiple components to the intervention so singling out cleaning was difficult. Vacuums equipped with a high efficiency particulate air (HEPA) filter were provided in seven different studies [43, 45, 47, 49, 50, 62, 74]. Vacuum cleaners were provided to reduce in-home allergens and to determine how their use affected health outcomes. Many studies provided additional cleaning supplies such as all-purpose cleaners, trash bags, mops, brooms, plastic storage bins, and smoke and carbon monoxide alarms [66, 72]. Families were taught how to clean and maintain their homes throughout this comprehensive study. They found reductions in home hazards, moisture leaks and primary care provider visits. Another study worked toward reducing exposures to in-home triggers for children with persistent asthma in 298 homes. They used a multifaceted approach by providing cleaning supplies, a HEPA vacuum, education on asthma management, and additional health and social resources [45]. When families used the HEPA vacuums, they showed a statistically significant difference in certain indoor allergens between the intervention and control groups. Adopting a multifaceted approach appeared to be an effective measure for some health and environmental concerns. None of the studies reviewed indicated if the new cleaning practices taught were continued after the study or if follow-up occurred. After families were provided supplies, they seemed to comply, thus helping reduce allergen exposures for their children [66,

Table 1 Home interventions summary

Reference	Study design and description	Passive	Active	Behavior	Outcomes: what worked	Outcomes: what had little to no change
Chan-Yeung, 2000 [41]	Test multifaceted interventions and effectiveness as a primary intervention step for children with high-risk asthma ($n = 545$)	Bedding encasements (provided for free), home assessment performed	Education to reduce exposure to mite and pet allergens; weekly laundering of bedding; chemical treatments applied to carpeting and furniture	Breastfeeding and ETS education, removal of pets from home or kept outside	96% of families used encasements; reduced dust mite and cat allergens; approximately 50% of the mom's who smoked a year prior to the study quit prior to third trimester	Little to no success in family members quitting smoking after education
de Blay, 2003 [42]	Randomized prospective study ($n = 378$) sensitized or exposed to dust mite allergens; samples collected from beds and floors	Mattress encasements provided, removing carpeting, changed out mattress	Education on cleaning over longer periods of time; washing bedding, plush animals, and pillows; carpet treatments	None reported	Significant reduction in allergen levels after changing out mattresses; participant compliance with laundering bedding reduced mite allergen up to 88%	Ref. group did not show significant decrease in mite allergens
McConnell, 2005 [43]	Goals to reduce cockroach allergens in homes of Hispanic children living in inner-city. Random control trial (RCT) of children with asthma ($n = 150$)	Mattress and pillow encasements	Used HEPA vacuum, boric acid and bait traps for cockroaches. Education on cleaning	Education on reduction of pest harborage in and around home	Significant difference between groups' compliance using both boric acid and bait traps for cockroaches. Intervention group had 64% lower roach allergen in bedding	None reported
Bryant-Stephens, 2008 [44]	RCT to study asthma symptom reduction through education and avoidance in children's bedrooms ($n = 281$). Samples collected from bed and kitchen for cockroach allergen	Environmental remediation; mattress encasements and pillow covers	Lay educators provided education on asthma triggers and how to avoid them, asthma management; caregivers helping with remediation	None reported	Decreased presence of rodents and removal of carpeting. Intervention groups showed reductions in health utilization; decreased asthma symptoms and clinic visits. Families compliant with encasements use	None reported
Parker, 2008 [45]	CHWs help reduce home asthma triggers in 298 homes of children with asthma (intervention and control groups). Home visits (HV) based on Krieger's HV model; intervention group had 9 HV in 12 months	Used encasements; IPM services provided to 27 families meeting certain criteria	Asthma and allergen triggers education; measured allergen concentration levels in bedrooms and skin prick testing for allergens; HEPA vacuum, cleaning supplies provided	Resources provided regarding health/social services; joint action plans developed between CHWs and family; ETS education	Significant reductions in dog allergens between the intervention and control group ($p < 0.001$). When comparing pre- and post-behavior questionnaire results, significant difference in addressing dust mite reduction v. ETS or mold exposure	No statistically significant reductions in cat, dust mite or roach allergens
Luczynska, 2003 [46]	Randomized into a placebo-controlled trial	Mattress encasements; patient IgE	Diaries kept by participants on medication and	None reported	Decreased dust mite concentrations in the intervention	Encasements least effective when used as single

Table 1 (continued)

Reference	Study design and description	Passive	Active	Behavior	Outcomes: what worked	Outcomes: what had little to no change
	on adult patients with asthma	levels gathered and samples collected mattresses	asthma management regiments		group (25%) compared to the control group (4.5%)	intervention; no effects on asthma symptoms
Francis, 2003 [47]	Air cleaners to reduce exposure to pet allergens for individuals with asthma ($n = 30$). Active group used both HEPA filtered vacuums and air cleaners; the control group used only HEPA vacuums.	Air cleaners installed for 12 month period in bedroom and living rooms	HEPA vacuum cleaners used	None reported	Active group had a 67% clinical benefit response compared to control group (20%)	No statistically significant differences between groups for allergen reservoirs, lung function, or airborne pet allergens
Halken, 2004 [48]	Preventive ways to reduce development of allergic disease in childhood. 2 randomized intervention studies evaluated allergen prevention and specific immunotherapy with asthma; other was double-blind study	Mattress and pillow encasements; mechanical ventilation	None reported	Education on ETS and breast feeding	Reducing mite exposure may help decrease wheezing and allergen sensitization (ages 1 to 4); double-blinded study showed encasements significant reduction in mite exposure and need for dose inhaled steroids (by 50%) compared to placebo	None reported
Popplewell, 2000 [49]	Study looked at HEPA v. non-HEPA vacuuming and potential of removing or reducing allergens in environment and impact on children's health with asthma over a 12 month time period ($n = 60$ homes of mite allergic patients)	Allergen skin testing; baseline dust collection in homes	HEPA v. non-HEPA provided for vacuuming of mattresses, upholstered furniture and carpeting; daily peak flow measurements	None reported	Use of HEPA vacuums significantly reduced cat, dog, and mite allergens; non-HEPA vacs only reduced cat allergens in bedrooms. Children sensitized to dust mites showed some health improvements for peak flow rates after 12 month use of HEPA vacuums	Non-HEPA vacuums did not reduce dust mite or dog allergens
Warner, 2000 [50]	Study used mechanical ventilation [the efficacy of heat recovery units (HRUs)] and HEPA vacuums to reduce dust mites in the environment	Mechanical ventilation	HEPA vacuum cleaners	None reported	Homes with HRUs had lower humidity dust mite levels; histamine levels in children with asthma improved; adding HEPA vacuum cleaning helped reduce mite levels.	No significant health improvements were reported for this study
Somerville, 2000 [51]	This study looked at how installing mechanical ventilation could play a role in indoor dampness and asthma symptoms	Installation of mechanical ventilation	None reported	None reported	Dampness significantly reduced when adding ventilation; improved energy	None reported

Table 1 (continued)

Reference	Study design and description	Passive	Active	Behavior	Outcomes: what worked	Outcomes: what had little to no change
					efficiency; significant reduction in nighttime coughing and less school absenteeism	
Wakefield, 2002 [52]	Intervention ($n = 128$) and control ($n = 136$) study of children (1 to 11 years of age) with asthma and parent(s) that smoke. Urine cotinine levels collected from children	None reported	Educational booklets and phone calls to families on ETS exposure	Feedback and education provided on urine cotinine levels and ETS exposure	After 6 months, 49% of families in intervention group banned smoking in the home compared to 41% in the control group	No significant behavioral changes regarding smoking or clinically significant changes for either group
Krieger, 2005 [53]	CHWs provided in-home education, assessments, and resources to help reduce indoor exposures; high- and low-intensity groups in study; high-intensity group received 7 visits and resources, low intensity received 1 visit and limited resources	Mattress and pillow encasements	Education on cleaning	None reported	Intensity group significant reduced allergens, condensation and moisture; improved cleaning habits; reduced children's health utilization. Statistically significant difference in high and low intensity on quality of life scoring ($p < 0.05$) and urgent health visits ($p < 0.05$). Families' behavior improved in intensity group	There was no clinically significant change in children's asthma symptom days. No behavior changes in the low-intensity group to help decrease in-home asthma triggers.
Carter, 2001 [54]	Three randomized groups in this study. First two groups (active and placebo) had health professionals visit homes, third did not. 100 children with asthma enrolled with 85 completing study	Active group: allergen encasements; Placebo group: non-allergen encasements	Active group: cockroach baits, washing bedding in hot water; placebo group: washing bedding in cold water	None reported	Interventions in active and placebo groups showed decreases in hospitalizations. Only HVs helped improve asthma management and decreases in acute care visits ($p < 0.01$). Decreased mite levels significantly correlated to decreased acute care visits (kids with mite allergies)	No statistical difference in placebo and active group related to implementing interventions for allergen reductions
Schönberger, 2004 [55]	Study of children with high-risk asthma. This study questioned compliance participants taking measures to reduce allergen exposure Pre and post natal (intervention group $n = 222$ and control $n = 221$)	Mattress encasements	Intervention group: received 3 pre- and post-natal visits; control: provided usual care; education on cleaning and allergen reductions	Education on elimination of ETS, pets, and household dust	Statistically significant differences occurred between special and control group in all categories tested—use of bedding encasements,	There was little compliance for keeping areas clean in the home, pre-natal smoking or partner smoking, pet removal

Table 1 (continued)

Reference	Study design and description	Passive	Active	Behavior	Outcomes: what worked	Outcomes: what had little to no change
					keeping pets outside, post-natal smoking, indoor allergen concentrations after 1 year	
Adgate, 2008 [56]	Study involved up to six HVs and two study groups to determine any reductions in allergen concentrations in 47 low-income, inner-city homes	None reported	Education on active cleaning of suspect mold and allergens. Short-term education on home cleaning and allergen avoidance	None reported	Reductions in cat, mite, roach and some fungi occurred post intervention; cleaning regimen significantly reduced dust loading, fungi in all homes and modestly reduced exposure to risk factors related to asthma; significant reductions of indoor fungal spores	No significant reductions in cockroach allergens due to the cleaning intervention
Howden-Chapman, 2007 [57]	Community-based blinded study of 1350 homes with 4407 individual participants. How insulating homes affects indoor temperatures and health of occupants	Mechanical ventilation and insulation	None reported	Self-reporting outcomes and compliance	Increased comfort levels, reduction of moisture and humidity helped decrease mite levels in carpeting; post-intervention decreases by self-reporting of wheezing, school and work absenteeism, fewer PCP visits and hospitalization	Hospital admission records did not show decrease compared to self-reporting by study families
Eggleston, 2005 [58]	Study to decrease pollutant and allergen exposures in home environments of children with asthma ($n = 100$) in inner city	IPM for cockroaches and rodents, HEPA air cleaner and encasements	In-home education	None reported	Significant decrease of PM in bedrooms using HEPA air filter and roach allergens decreased by 51% for treatment group. Improved daytime health symptoms	PM levels and daytime symptoms increased in the control group
Kercsmar, 2006 [59]	Study of asthma morbidity in children ($n = 62$) living in homes with mold; samples collected from children for IgE, cotinine (ETS exposure) and potential exposure to certain mold(s) in control and intervention groups	Household repairs (moisture reduction, removing damaged building materials, adjustments in HVAC)	Education on home cleaning and problem solving, asthma action plan provided	Changes in cleaning habits	Both groups showed asthma symptom improvements. Intervention group showed statistically significant reduction in symptom days ($p < 0.003$) and rate of exacerbation after remediation (1/29	Control group did not show any significant changes in asthma symptoms post intervention

Table 1 (continued)

Reference	Study design and description	Passive	Active	Behavior	Outcomes: what worked	Outcomes: what had little to no change
					compared to 11/33 control)	
Morgan, 2004 [60]	RCT of 937 children from seven different US cities with atopic asthma; 12-month study	Remediation for exposure to allergens and ETS; HEPA air filter provided	Education on avoidance to allergens	ETS education on behavior change	Significant relationship between decreased utilization and decreased roach and mite allergens; intervention group experienced fewer days of asthma symptoms during and after study	No direct quantification of ETS exposure for participants
Schatz, 2012 [61]	Telephone calls to help families of children with asthma to address environmental issues through interventions; stage 1: ($n = 60$) patients called	Survey to determine how willing families were to make changes to home environment	Education/advice given to families regarding home environment	None reported	78% surveyed made changes based on recommendations; 80.6% reported compliance with at least one intervention; home owners more likely to make changes (91%; $p < 0.05$) compared to renters (63.6%)	None reported
DiMango, 2016 [62]	Study looked at how reducing environmental allergens affects use of asthma meds over 40 week period; multifaceted approach for half of subjects; each subj. exposed to at least one indoor allergen	Mattress encasements; HEPA air purifiers provided	Targeted education on indoor allergens and effect on asthma, safety education; HEPA vacuum and cleaning products; replacement of supplies (18 and 32 weeks); follow-up visits	ETS education and remediation plans	All 5 allergens significantly reduced in environmental. Control group: dust mite and roach reduced in kitchen only and mouse in bedrooms. Both groups had similar asthma outcomes no matter whether they had in-home allergen interventions or not	Reductions of pests had no statistically significant effect on any reductions of asthma treatment burden
Arbes, 2003 [63]	6 month study to abate roach issues in inner-city, low-income apartments ($n = 16$ intervention and $n = 15$ controls)	Professional cleaning and IPM provided	Education provided on pest control	None reported	Statistically significant reductions in allergens in all areas tested in home for intervention group	Kitchen allergen concentrations least improved in rooms tested
Breysse, 2014 [64]	Study looked at two groups receiving interventions: 1st group ($n = 34$) received education from CHWs and weatherization-plus--health interventions. 2nd group ($n = 68$) only provided education	Encasements for child's bed; weatherization and safety audit, 2 heating ventilators; allergen sampling; replacement of home items based on audits	Education, low-emission vacuum and cleaning kit provided; family given peak flow meter to monitor child's breathing over time, medication, and action plan	Education on ETS exposure	Statistically significant improvement in poorly controlled asthma, quality of life scores, asthma symptoms, fungi, indoor environment in study group with multifaceted approach	No overall in-home trigger reduction, decrease of rodents or in-home smoking (although families' self-reported decrease)

Table 1 (continued)

Reference	Study design and description	Passive	Active	Behavior	Outcomes: what worked	Outcomes: what had little to no change
Celano 2012 [65]	Study looked at in-home interventions related to asthma education and stress reduction for children ($n = 43$ families). A 2nd group only received one educational session	Mattress and pillow encasements	Developed asthma action plan; targeted education on family-centered goals for asthma management and live stressors	Education on medication delivery and technique	Intervention group saw a reduction in hospitalizations by 30%. Both groups saw decreases in health utilization	Education alone is not sufficient in addressing asthma management due to stresses on the family
Mankikar, 2016 [66]	Study to see if in-home, environmental education could help decrease asthma-related hospital visits, home health and safety issues	Home assessment performed; mattress and pillow encasements	In-home education and healthy home supplies provided (i.e., all-purpose cleaners, trash bags, roach baits, sticky traps, smoke and CO alarms)	Families taught how to clean and maintain home	Reductions in moisture leaks, home hazards, hospitalizations, and doctor's visits through a comprehensive intervention process	None reported
Butz, 2011 [67]	RCT that looked at offering 3 differing combinations of interventions—education and air cleaners, air cleaners alone, and no air cleaners ($n = 41$ children with asthma and $n = 44$ for control)	Installed air cleaners, air quality assessment performed	Health coach provided education	ETS education on exposure	Fine and course PM significantly lower after 6 months compared to the control group. Asthma symptoms decreased with more symptoms-free days when air cleaners were used over this time period	Health coaching did not help reduce PM concentrations. No noted differences in air nicotine and urine cotinine concentrations
Wu F, 2007 [38]	Study of indoor contaminants' role in children's environmental health along with economics associated with asthma disease	Mattress encasements	Education on cleaning and asthma triggers	Behavior changes in cleaning practices; education on ETS exposure	Multifaceted interventions were associated with reductions in asthma triggers and some improved health outcomes	Education alone was not effective in changing ETS behaviors
Chan-Yeung, 2005 [68]	Study of multifaceted interventions related to prevention of high-risk asthma from birth to 7 years of age ($n = 545$ randomized into intervention and control groups)	Allergy skin and breathing tests performed; allergen encasements	Weekly washing of bedding in hot water; chemicals used on carpeting and furniture for allergen reduction and avoidance	Education on removal or reduction of pet exposure; counseling on ETS exposure and cessation	Using simple environmental interventions can help prevent asthma in high-risk children. 7 years after study, the intervention group showed significantly lower rates of diagnosed asthma (14.9%) compared to control (23%)	No difference in allergic rhinitis and atopic dermatitis between groups
Vojta, 2001 [69]	A randomized study conducted in low-income homes to determine effectiveness of physical interventions for dust mite concentrations (39 homes screened, 19 met allergen criteria)	Samples collected; encasements; 1-time professional dry steam cleaning with vacuuming	Weekly professional laundering of non-encased bedding with detergent and hot water; in-home laundering of bedding using	None reported	All groups had significant drops in mite concentrations; steam cleaning and intense vacuuming group had greatest success—	Some families had increase in concentrations after interventions

Table 1 (continued)

Reference	Study design and description	Passive	Active	Behavior	Outcomes: what worked	Outcomes: what had little to no change
			detergents of families choice		concentrations below 10 μg/g	
Causer, 2004 [70]	Study looked at how carpeting affected dust mite concentrations. House dust was placed on different types of carpeting.	Carpeting was dry vacuumed or wet extracted	None reported	None reported	Carpet type made difference on how easily mite allergens were removed. Statistically significant difference observed in worn v. new	None reported
Woodcock, 2003 [71]	A double-blinded randomized control study on allergen covers for beds of adults with asthma ($n = 1122$)	Concentrations measured in mattresses; encasements provided	Peak flow measurements daily for 12 months and inhaled corticosteroid therapy	None reported	At 6 months, intervention group had statistically significant lower mite concentration than the control ($p = 0.01$). At 6 months, both groups improved peak flow rates	At 12 months, no significant difference in concentrations between groups; low compliance of corticosteroid
Levy, 2006 [72]	Study of community health advocate education and interventions to families of children with asthma ($n = 50$)	Skin allergen test, dust and air sampling, visual home assessment; one-time, intensive HEPA vacuum cleaning; replacement of mattress; IPM	Education on routine cleaning; IPM for cockroaches asthma action plans provided through a nurse; provided supplies	Asthma management and control; education on IPM; empowered families to document changes to the home (work orders)	Significant decrease in roach allergens; decreased respiratory symptoms from start to finish of the study (71% reduced symptom scores). Education increased knowledge on allergen triggers; encouraged families to get children allergy tested	No significant changes in other health utilizations such as asthma hospitalizations or asthma attacks
Klinnert, 2007 [73]	Study looked at infants ranging from 9 to 24 months and how environmental interventions played a role in their breathing ($n = 90$ for intervention group and $n = 91$ for controls). Nurses visited these homes for up to 1 year	Samples collected and analyzed for allergens twice during study, urine cotinine levels collected	Education on asthma and allergen triggers, provided pest traps and cleaning materials, provided vacuums	ETS education, reduction of and problem solving for exposures; education on cleaning and removal of pets or keep out of sleeping areas	In the intervention group, fewer homes had cockroach and reductions in dog allergens compared to the control group. The intervention group showed significantly lower levels of cotinine levels compare to the control group at the end	No significant differences between the groups for hospitalizations, ED visits for the year. No significant changes in groups for cat allergen
Woodcock, 2004 [74]	Study looked at environmental control pre-natal to 3 years of age for sensitization affects and lung function ($n = 251$ high-risk children); active and control groups	Encasements for parent and child beds; carpeting to hard surface in child bedroom; IgE and skin testing	HEPA vacuum cleaner; weekly washing of bedding in hot water; lung function testing	None reported	Statistically significant difference at age 3 ($p < 0.003$) in lung function between groups	Environmental control associated with increased dust mite sensitization

Table 1 (continued)

Reference	Study design and description	Passive	Active	Behavior	Outcomes: what worked	Outcomes: what had little to no change
Carrillo, 2017 [75]	Mixed methods study for quality of life, three focused groups of 15 low-income parents, and health survey for asthma of $n = 90$ parents with kids having asthma	Encasements; girt card	None reported	Focus groups identified indoor contaminants	Results from surveys and focused groups found 51% of children had been hospitalized, 53% went to ED and 27% missed schools; families reported asthma self-management behavior changes after focus groups	None reported
Krieger, 2015 [76]	Study to determine if CHW and adults-with-asthma interactions affects health outcomes; study from 2008 to 2011 for low-income adults ($n = 366$; $n = 177$ intervention group, $n = 189$ control)	None reported	Education on asthma management; home visits provided by CHW's (mean 4.9 visits)	None reported	Statistically significant increase in symptom-free days ($p < 0.001$) and quality of life points for intervention; Both had significant decreases in urgent health care (past 12 months)	None reported
Turyk, 2013 [77]	Study used community health educators (CHE) to provide asthma education, interventions and connections to other resources ($n = 218$)	Resources for social and medical agencies; low-cost asthma trigger remediation	Asthma education provided by CHE	Education on asthma management and on home maintenance	Results showed reductions in asthma symptoms and health care utilization, missed school days and work for parents; better asthma management	None reported
Largo, 2011 [78]	Study provided in-home interventions for low-income families between 2005 and 2008, 4 HVs within 6 months ($n = 243$)	Environmental home assessment; interventions to reduce triggers; health and environmental history surveys	Array of products provided to help reduce allergens; tailored one-on-one education on addressing allergen triggers; IPM	Guidance on how to clean and maintain home	Reduced health care utilization and asthma symptoms ($p < 0.0001$ and $p < 0.001$); caregiver frequency of cleaning and maintaining home increased statistically	None reported
Jhun, 2017 [79]	RCT using air cleaners in school setting ($n = 18$ class rooms, $n = 3$ total schools, $n = 25$ children with asthma—$n = 13$ intervention and $n = 12$ control) to effects of PM2.5 and black carbon (BC)	4 HEPA air cleaners and 4 "sham" air cleaners (for control); collected PM and dust; partial IPM for 6 classrooms	Spirometry and in-school air pollutant measurements taken up to 3× during study; asthma symptom surveys completed every 3 months	None reported	Statistically significant reductions ($p < 0.05$) in PM2.5 values and BC compared to control; minimal reduction in peak flow from intervention to control; slight reductions in asthma symptoms for intervention group	Partial IPM did not allergen concentrations; no significant reductions in FEV1 (forced expiratory volume)

72]. When specific asthma education was provided to families on how to clean or how to use their supplies, it helped decrease some health outcomes.

Education

The delivery of in-home or over-the-phone education to families was a common practice in several studies [45, 56, 62, 72, 73, 80]. DiMango et al. (2016) used targeted asthma and safety education along with providing cleaning supplies and showed a reduction of allergen levels for dust mites, cockroach, and mouse [62]. Who delivers in-home education, how they are trained and their experience could possibly affect health outcomes [81]. Education by health professionals, health coaches, and/or community health workers (CHWs) or advocates helped families make positive movements toward addressing asthma management and reducing indoor environmental exposures [54, 72, 76, 82]. Kerscmar et al. (2007) showed a statistically significant ($p < 0.003$) decrease in asthma symptoms and exacerbations for the intervention group compared to the control group by using problem solving techniques with families and providing an action plan for health and environmental conditions. Another study looked at in-home interventions related to asthma education and stress reduction for children from 8 to 13 years of age. The intervention group received education, written action plans, targeted goals, and saw significant decreases in hospitalizations a year past initial interventions [65]. For this study, providing education alone was not sufficient in addressing asthma management possibly due to social and other life stresses for families.

From this limited review, the training and knowledge of an educator will make a difference in the quality of the education and overall outcomes. Education on its own, however, does not appear to be as effective in helping address health and environmental outcomes, whereas targeted education about asthma and allergen triggers, and providing hardcopy action plans, helped decrease health utilization by children with asthma, and educators reported better overall asthma management [59, 65, 76].

Pets and Pests

Exposure to pets and pests for children with asthma and/or a sensitization to pet or pest allergens plays a major role in asthma morbidity [83]. Our literature review included 24 studies that tried to address at least one pest allergen and 8 studies included family pets as an environmental trigger. The common active intervention associated with pet allergens involved education, cleaning supplies, and routine cleaning [41, 45, 47, 49, 55, 56, 72, 73]. Parker et al. (2008) reported statistically significant reductions ($p < 0.001$) in dog allergens in the intervention group when compared to a control group. This study also included asthma education and HEPA vacuuming along with visiting families up to nine times. Other studies have provided additional “touches” or visits to the home, which may play an important role in motivation and compliance with interventions related to pests and pets [55, 73].

Sixteen of the reviewed articles contained a specific aim at either reducing or testing for dust mite allergens in the home environment using an active intervention. To reduce dust mite proliferation and increase families’ medical compliance, three studies promoted weekly washing of bedding and clothing in hot water, provided education on long-term cleaning, and used the passive intervention of installing mattress encasements [41, 42, 62]. DiMango et al. (2016) used case managers to provide positive guidance on multifaceted approaches including routine cleaning, HEPA vacuuming, and targeted asthma education that resulted in significant decreases of five specific allergens in the homes studied. Routine vacuuming, when added to other active interventions such as routine cleaning, ongoing health education, and awareness resulted in significant reductions in dust mites and other indoor allergens [46, 49]. Popplewell et al. (2000) found when non-HEPA vacuums were used, there were no significant reductions in dust mite or dog allergens. For many of these studies, the multifaceted approach of providing allergen reduction education, cleaning supplies, and active cleaning using a HEPA vacuum resulted in improved overall awareness of potential exposures and behaviorally, more active cleaning with a vacuum. This combination in several studies resulted in decreased allergen concentrations in homes [41, 45, 62]. Although using multiple intervention components to address pests and pets was effective in reducing allergens, more studies would help clarify which components are most effective.

Health Checks

Some families may need additional “hand holding” when it comes to health guidance for their children (or even their own health, for that matter). Using health professionals and those trained in asthma management or public health may provide this much-needed guidance [72, 73, 81]. One RCT studied the effects of lay educators and the education they provided families on avoiding triggers for their children with asthma [44]. A unique part of this study was the involvement of the caregivers taking an active role in the remediation work in their homes. As a result, families experienced a decrease in health care utilization. An important outcome appears to be the lay educator-caregiver relationship that led to ownership of and empowerment to create change.

In the studies reviewed, education-as-an-intervention was a common theme. Krieger et al. (2005) used CHWs to provide in-home education and resources to families (split into intervention (high-intensity group) and control (low-intensity group)). The high-intensity group received six times as many home visits as the low-intensity group and showed reductions in asthma health utilization and symptoms. There was a statistically significant difference between high intensity and low intensity for quality of life scoring ($p < 0.05$) and health utilization ($p < 0.05$). However, there were no clinically significant changes in children's asthma symptom days [53]. Another study where health professionals visited the homes of children with asthma involved an active group that received interventions and a placebo group that did not showed positive results for the active group with decreased hospitalizations [54]. One explanation for the positive outcome in the active group was that the home visits alone helped improve asthma management and decreased acute care visits ($p < 0.01$) for these children.

One study used in-home education, problem solving with the family and provided an asthma action plan to families. The intervention group showed a statistically significant reduction in symptom days ($p < 0.003$) after the interventions. The intervention group also showed a statistically significant ($p < 0.003$) decreased rate (1 of 29 children) of asthma exacerbations, compared to the control (11 of 33 children) [59]. Another study used a multifaceted approach in a study of 34 participants who received education from a CHW along with weatherization-plus-health interventions, while a second group of 68 families were only provided education. The intervention group also received supplies which included a low-emission vacuum, cleaning supplies, an asthma action plan and instructions for better health monitoring of their child(ren) with asthma. In a years' time, 100% of the children in the intervention group with uncontrolled asthma decreased to only 28% with uncontrolled asthma. Quality of life scores showed a statically significant difference ($p < 0.001$) between the study and control groups post intervention [64]. Continued targeted education, multiple home visits and empowering participants are important and significant steps to improving the overall health and environment and should be considered an integral part of future research on effective asthma management.

Passive Interventions

Many of the articles reviewed included passive interventions as a design component. Some studies supplied families with air purifiers (10 studies), Integrated Pest Management (IPM) services (6 studies), professional cleaning (3 studies), home repairs (4 studies), and mechanical installation or adjustments (4 studies). Using multiple passive intervention approaches also played a role in reductions of health effects, and environmental triggers in many studies..

Home Assessment Activities and Supplies

Eight out of 41 studies included some type of home assessment service. Six of the studies reviewed used CHWs to provide in-home assessments and included multiple interventions such as education, mattress encasements, cleaning, and safety supplies [41, 45, 53, 64, 66, 77]. All of these studies showed significant reductions in health symptoms and negative environmental factors. For example, one study found reductions in hospitalizations, PCP visits and moisture issues when some form of home assessment was performed in conjunction with other interventions [66]. Another study observed similar results when a trained assessor visited the subject's home after having an in-person doctor consultation [42]. Another study involved the services of community health educators (CHE) to provide families with social and medical resources in their communities, low-cost asthma remediation, and education [77]. This study reported similar results to the other studies listed above. They showed reductions in asthma symptoms, health utilization, school and workdays missed, and in-home asthma triggers. Providing simple and effective interventions seemed to play a significant role in these studies health outcomes.

Bedding Encasements and Washing

Many of the articles reviewed had studies that focused attention on dust mites. The most common treatment prescribed was use of bedding encasements (mattress, box springs, and/or pillows). In some cases, this was the only intervention used. Although some studies showed a decrease in the major dust mite allergens (Der f 1 and Der p 2), Matsui and others recommend a multifaceted approach for maximum effect utilizing encasements along with frequent laundering of bedding, removal or at least washing of stuffed toys, removal of carpeting, and, though not always recommended, use of acaricides. Although this single measure is important, it has been shown to be most effective when used in combination with other interventions [2, 13].

In one study, two groups (A and B, $n = 378$), all with either dust mite exposure or sensitization met with an allergist alone (group A) or with an allergist and received a home visit from a Medical Indoor Environment Counselor (MIEC) (group B). Each group received at least education on mite avoidance and bedding encasements free-of-charge. Some went beyond these measures, based on recommendations, and removed the existing mattress, mattress base (box springs), carpeting, curtains, etc. The study showed a statistically significant difference in levels from base to final mite allergen in both groups based on education and employing covers ($p = 10^{-5}$). Group B continued to see a significant decrease in allergens by removing mattresses, box springs, and carpets. The key difference between the groups appears to be the use of multiple interventions in combination with home visits by MIECs [42]. Another study confirmed the conclusion of this study that single interventions (in this case, bedding covers only) had no significant impact on health or environment [84]. Several studies found that providing mattress encasements to families at no cost increased the chance they would install and use them. This intervention, along with washing bedding in hot water, was an effective measure for reducing dust mite allergens in some studies.

Home Weatherization

Of the 40 studies reviewed, only two had clear information indicating they were performing home weatherization. One study observed improvements of indoor environmental conditions and reductions in asthma symptoms when weatherization and healthy home interventions were combined with a home assessment by a CHW [64]. In a second study to determine if simply adding insulation to existing homes would benefit overall occupant well-being, they found surprising evidence of improved secondary outcomes. This robust study, achieving 86% retention over the course of the study (approximately 3300 participants accounting for approximately 1100 households), found that adding insulation to homes improved the energy efficiency of the dwelling, decreased energy costs, and, more importantly, significantly reduced asthma symptoms and absenteeism from school (and work for the children's parents). There was not, however, a notable decrease in primary care visits or hospitalizations (information obtained with permission through participant health records) although subjects reported fewer incidences.

Moisture Control and Mold Environmental Remediation

Controlling moisture in the home environment can improve overall health, especially for an individual or individuals that are vulnerable to fungal allergies [8]. Some of the more basic interventions included simple plumbing repairs, sealing cracks and gaps around the foundation, cleaning out exterior guttering, sloping soil away from the foundation, etc. Unfortunately, many more common moisture-related hazards in homes are costly and difficult for families to get fixed—major plumbing repairs, roof replacement, and foundation issues. Many times, after a water event, building materials are damaged. If the intrusion is extensive, the affected items should be removed. Smaller scale issues can be resolved with cleaning and drying (active intervention). Regardless of scale, the area should be addressed within 48 h to prevent subsequent fungal activity [8, 85]. The Cochrane study reported that removing moldy surfaces decreased asthma-related symptoms and the use of asthma medications [86••].

In one study, Somerville et al. (2000), they wanted to see if improving home environments, specifically updating heating systems (in some cases installing them for the first time) and elimination of moisture and mold issues, would effectively increase health outcomes of the subjects (after initial recruitment, 59 houses accounting for a total of 72 children with asthma remained). The only directive from the local health authority to those performing interventions was to create "as warm, dry and energy-efficient a house as possible." The original objective was met—creating more energy-efficient homes (an increase of 62%), and the secondary benefits were significant with a reported reduction in all respiratory-related symptoms as well as reduced absenteeism from school due to asthma (health outcomes were self-reported) [51].

In a randomized controlled trial (RCT), they identified homes with active mold colonization (confirmed by a sanitarian's inspection v. self-reporting of families). Sixty-two subjects with asthma were enrolled, 29 selected to receive remediation, and 33 to receive only education. Construction activities were conducted, mainly in basements to address the root cause of the moisture source(s). Together with education, the remediation group had a statistically significant reduction in symptomatic days and acute care utilization compared to the control group [59].

Dehumidification

Though closely related to moisture interventions, dehumidification pulls excess humidity out of the air and condensed moisture off surfaces, not typically the result of a moisture intrusion event. Cooking and bathing are known to be the big contributors to excess moisture in homes [87]. Installing a stand-alone dehumidifier or one within the HVAC system is known to be beneficial in homes that struggle to maintain relative humidity levels under 50%. In homes lacking central air conditioning, installing a stand-alone dehumidifier may be the quickest and cheapest method. Preferably one can be placed near an existing floor drain so that it will both operate and drain continuously. Dehumidifying the air also removes an essential facilitative factor for dust mite and fungi growth [13, 85].

Studies found on the subject of dehumidification were limited and dated (late 1990s and early 2000s). Two of the studies examined found neither consensus nor significant reduction in mite allergen concentrations between study groups (those receiving education and employing a dehumidifier and those only receiving education) [88, 89]. Further, Singh et al. (2013) could not definitively conclude that such interventions helped in controlling asthma and that more research is needed [89].

Integrated Pest Management

Effective IPM involves targeted steps to address and removal of the facilitative factors that enable the infestation(s) such as identification of pest(s); plugging and sealing interior and exterior cracks, gaps, and holes; removing and/or cleaning up food and water sources; and using baits and gels [14]. For example, one study found that applying IPM to treat a cockroach infestation significantly reduced the population (depending on severity) in as little as 2 weeks. They determined that it could take 1 to 2 months to fully eliminate. Maintaining IPM for at least 1 month and longer provided a continual reduction in cockroach allergen [58]. The temptation for many families may be to stop IPM after they see a decrease in population. However, cockroach allergen remains in settled dust, on dead roaches and their waste (frass). Failure to effectively remove these allergen reservoirs can result in continued exposure and exacerbation in sensitized individuals. Continual effort by families to deep clean the affected areas around the home is required (see "Pets and Pests" in the "Active Intervention" section above). Another important part of IPM is the use of an environmental professional trained in recognizing and/or able to identify the facilitative factors to determine where to effectively target treatment [12].

Air Filtration

In our review, we found that the studies using air filtration as an intervention referred to and/or provided stand-alone air filtration units, also known as portable room air cleaners [PRACs] (versus whole house filtration). In general, there are two types of PRACs—those with HEPA filtration and those that rely on electrostatic precipitation. Studies have shown better reduction in PM and respiratory inflammation when a HEPA-filtered PRAC was used [90]. Another benefit of using a PRAC is in its name—"portable." These units can be used to target certain rooms, especially the bedroom of the vulnerable subject. At the same time, they are usually meant for smaller spaces and should be used in accordance with the manufacturer's recommendations and instructions when deciding where to place within the home. Previous reviews found they were not effective as a single intervention. If used, it is important to know the subject's allergies prior to installing a filtration unit. PRACs have been shown to be effective for removal of cat, dog, and rodent allergens, but not for dust mite or other indoor allergens [91]. Little research has been done to determine their effect on reducing fungal allergens. According to some of the review literature, the results are mixed—some show improvement while others do not. However, like the other interventions, when air filtration was used within a suite of activities, the results were positive [90].

In a RCT study they divided subjects into three groups—(1) asthma education with delayed air filtration (not installed until last education home visit), (2) air filtration and education (from first visit), and (3) asthma education, a health coach, and air filtration. The group that had the most significant improvement was group 3. They installed PRACs in homes of children with asthma, specifically in their bedroom. They found that PM concentrations were significantly reduced while symptom-free days increased. Though seemingly successful, the authors point out that although PM levels decreased, they did not fall below the EPA's requirements for outdoor air quality. And, like the review articles mentioned above, there were still questions regarding the overall effectiveness of their use as a single intervention. An important conclusion made by the team is that "it is a tenet of public health practice that eliminating a source of contaminant is better than reducing it through an engineering control" [67]. Another study also showed mixed results for the use of air filtration as an intervention. Although they provided HEPA-PRACs as part of a whole package of indoor allergen defense (i.e., encasements, cleaning supplies, a vacuum), their outcomes were inconclusive as both the control and intervention groups experienced a reduction in allergens, but not enough to really distinguish between the two. They believe one explanation may have the Hawthorn effect—where subjects of a study change behavior based on the fact of being observed. Looking at school-aged children with asthma, one study that took place in schools attempted to measure the effect of air cleaners on PM2.5 and black carbon (BC) in the buildings. They tested HEPA filtered air cleaners against "sham" air cleaners in several classrooms. Like others, their research found statistically significant reductions in PM2.5 values and BC as compared to the control group, but only slight reductions in asthma symptoms again creating questions as to the overall effect for the targeted children [79].

Behavior Interventions

Environmental Tobacco Smoke Education

Changing or adjusting one's behavior can be quite challenging especially when dealing with adults with varying and diverse backgrounds, cultures, and lifestyles. Promoting certain behavioral changes whether for medical (disease management, compliance) or environmental reasons can create tensions within the family and/or between the family and the provider. One study used the "stages of change" to look at how a patient's compliance, motivation, readiness to make change(s), and/or possible barriers may all play a role in which direction a family will choose to go when faced with behavioral modifications. They looked at different interview techniques related to smoking and alcohol cessation and realized that one size does not always fit all. Although there are general techniques that can be used and have proven to work over time, it is important to tailor interventions to individuals and their current stage in the behavior change process [92]. One study looked at the caregiver's perception of asthma management of children, and found that ignoring psychosocial issues as it relates to health management could play a negative role in efficacy with inner-city families [93, 94]. By better understanding family psychosocial needs and their stresses, burdens, and challenges, more specific and family-centered interventions can be tailored to better assist them with asthma management.

The six studies reviewed that included environmental tobacco smoke (ETS) had difficulty reducing exposure to children enrolled. In one study, the intervention group included 128 children and the control had 136 children (1 to 11 years of age) that had asthma and parents that smoked. Urinary cotinine (nicotine metabolite) levels were collected from children at the beginning of the study. After 6 months, 49% of families in the intervention group banned smoking in the home compared to 41% in the control group. However, there were no significant behavior changes for smoking in the car, smoking in front of the child in general, smoking cessation, or clinically significant changes or either group [52]. Other studies reviewed provided education on how to reduce ETS exposure for their children [38, 41, 55, 64, 67]. Some found education alone was not effective in changing family's behaviors [41, 67]. Others did not comply pre-natal for smoking or partner still smoked [55]. Another study did find family's reporting lower smoking activity (7%) were still smoking indoors and 0% at the very end of the study [64]. A study looking at infants breathing and how environmental interventions play a role had nurses provide ETS education, helped family's problem solve to decrease such exposures, provided cessation resources, and found the intervention group showed significantly lower levels of cotinine compared to the control group at the end of the study [73]. However, there were no statistical significant difference between the two groups for hospitalizations and ED visits.

Addressing ETS behaviors is a challenging task where, in many cases, the family member(s) motivation to avoid exposing their child plays a key role. In-home education in written and verbal forms about health concerns and the risk of child exposure were helpful in the studies reviewed [52, 64]. Others have found education alone was not effective in addressing this significant exposure [41, 67]. Continued efforts should be made to provide face to face education on smoking cessation and developing an action plan for the family that works with their timeline on trying to comply.

Cleaning Practices

The word clean or cluttered means something different to each of us. The level of cleanliness in a family's home may reflect on other aspects of their lives such as personal hygiene, health management, or life stresses. In one study, the families of asthmatic children did have some challenges related to self-management behaviors, which included adjustments in behavior for cleaning and using safer products, reducing exposure to pets, and not smoking inside their homes [75]. Previous reviews have shown that pet removal is the best strategy for reducing both cat and dog allergen in homes, although allergen concentration in settled dust may take months before it is reduced [10]. Rarely will families give up a pet and keeping pets outside or away from certain areas of a home can be a difficult task since many feel like they are part of the family. Thus, education and effective cleaning become the preferred intervention strategies, if they work.

In a study for children with high-risk asthma during pre- and post-natal, education on adjusting cleaning behavior was provided along with trying to reduce the child's exposure to pets. This study found that families complied for keeping pests outside in the special group at 51% compared to 19% for the control [55]. There were reductions in allergen concentrations for pets (cat and dog) and dust mites, but it is unclear if that is from passive interventions (mattress encasements) or overall better cleaning habits, or both. Another study that combined education on cleaning practices and active cleaning found the combination resulted in significant reduction of cat allergen in homes with cats and the cleaning intervention alone led to only a moderate decrease in cat, cockroach and fungal allergen in dust from subsequent homes visits [56]. Unfortunately, in a different study of infants and how environmental interventions affected their breathing, they did not find significant reductions in dog or cat allergens after education was provided on cleaning behaviors and keeping pets outside or away from child's bedrooms [73]. One study looked at in-home interventions related to asthma education and stress reduction for children from ages 8 to 13 years ($n = 43$ families). A second group in this study received only one educational session. Education was provided on how to best deliver medication and technique. The results showed a reduction in hospitalizations from 35 to 5% a year after interventions for the intervention group. For both groups, they saw decreases in health utilizations. However, providing only education may not be effective in addressing asthma management [65]. It is thought that through multiple approaches of continued education either in person or over the phone, primary care physician (PCP) involvement, and developing specific strategies, this may help improve family behavioral adherence.

Another study describing similar multifaceted approaches for in-home interventions for low-income families provided specific guidance in order to address allergen triggers and to show participating families how to effectively clean and maintain their homes. These families experienced statistically ($p < 0.001$) significant reductions in their health affects for their asthma and for unscheduled health care visits (e.g., ED visits, hospitalizations). Through ongoing education from four home visits, families increased their frequency for cleaning and maintenance of their homes. With the variety of cleaning products, education, and some minor home repair, it is unknown to what extent all of these interventions role played in affecting the health and environments of these families [78]. The more in-home visits and follow-ups with families on cleaning and maintaining their homes, the more environmental assessors can help continue to provide motivation and compliance for reducing in-home environmental exposures.

Energy and Weatherization Interventions and Asthma

Since this article focuses on the home environment and its role in allergic disease, it should be noted that two reports came out last year that reviewed the role of interventions focused on home energy efficiency improvement in improving the health of occupants where these home-related services have been utilized. Both reports originate from the Department of Energy (DOE) but one report focuses on the health and safety impacts of state weatherization programs and the energy efficiency work performed on low to moderate income housing. Typical weatherization work performed by these programs include air sealing of the building enclosure, installing insulation, heating and air conditioning system repair/replacement, exhaust ventilation, mechanical ventilation, clothes dryer ducting, and ground vapor barriers in crawl spaces. These interventions result in reductions of indoor environmental contaminants (particulate matter, allergens, pollutants, tobacco smoke, volatile chemicals, etc.) and were found to be associated with allergic disease and can result in improvement in symptoms of occupants [95]. In another report, weatherization work was associated with fewer ED visits and hospitalizations due to asthma after controlling for race, ethnicity, city geographic location, building style, stove type, housing quality, rodent or roach infestation, and self-reported psychosocial stress. Participants also reported the energy dollars saved post-weatherization could be used to pay for items like controller medications needed for disease management [96].

Environmental Assessment

The research reviewed here clearly supports the benefit of providing in-home asthma and allergy education services as well as environmental assessment services to help identify potential environmental triggers and any contaminants or other exposure concerns in the home. This concept has actually been well supported for more than 10 years [35]. The National Heart, Blood and Lung Institute (NHBLI) asthma guidelines recommend a home assessment by a trained professional to help guide caregivers in the management of environmental triggers of a patient's disease [97]. A previous model for the principles of environmental assessments has been described and provides a good overview of the comprehensive nature of home environmental assessment [32]. The goal of any home environmental assessment should be to reduce exposure to hazards and contaminants in homes. The primary concern is the contaminant sources that may be present in a building since these are what lead to health impacts. In order to effectively address contaminant sources (example, allergens), the home assessor must also evaluate the role of reservoirs (carpeting, walls, floors, furniture, beds, etc.), facilitative factors (water, food, clutter, trash, dust, filth), and their contribution to the proliferation of the contaminant sources. When guiding caregivers in how to address contaminant sources, the education and home intervention must treat all three of these components in one comprehensive and simultaneous intervention process. This should reduce exposure, and sustain the reduction over a much longer period, ultimately leading to improvement in health [32]. More evaluations of home assessment programs continue to support the benefit of this service [45, 98]. Much of the research also shows that all asthma patients do not need nor will they all benefit from a home assessment. The research on the economic value of asthma home visit programs suggest that the strongest ROI is from programs (or part of programs) that focused resources on the higher utilizers of expensive health care services when they are longer able to control the health impact of their disease. By focusing on these higher utilizers, significant cost savings can be achieved [40]. Different approaches have been developed in an attempt to identify high-risk patients who may show greater benefit from a home assessment because their disease is poorly controlled, their economic resources are small, and their knowledge of home environmental conditions that can lead to exposure is limited leading them to use excessive utilization of health care resources.

Some studies have used past utilization of services as a method of stratifying patients into different levels of risk. These studies use large population health data sets from either health plans or hospitals systems. Data sets are run through models to stratify patients into risk categories based on health care utilization. One example developed a model using health plan data for 8789 asthma patients for acute care visits, quantity of dispensed medication, number of different prescribers, and number of routine visits for asthma, to develop a three-level risk stratification (low, medium, high) using logistic regression to assign risk points. High-risk patients were defined as those who have had any emergency hospital care in the previous 12 months or use greater than 14 b-agonist canisters or oral corticosteroid use [99]. Another study used 5 years of utilization data from 10,785 patients representing over 28,000 outpatient visits. For each patient they evaluated how predictive acute care visits 12 months prior to a given visit were of a future acute care visit for the same patient in the next 12 months. They found that the probability of future acute care visit for asthma increased from 30% with one historical acute care visit to 87% with 5 or more prior acute care visits. The analysis showed that future acute care risk could be stratified based on prior visits. That analysis also showed that a small group of patients accounted for a significantly disproportionate number of future acute care visits [100]. More advanced models have been described and are under development using larger data sets and predictive analytic methods as well as machine learning [101, 102]. Part of the justification for this use of patient data to analyze utilization patterns is based on the recognition that proper use of the appropriate health care case management for a particular health condition, for example asthma and home environmental control, has been shown to significantly reduce excessive health care utilization [40].

For patients with asthma, the asthma control test (ACT) has become a well-established tool for understanding how well controlled a patience asthma is at the time it is administered [103]. The ACT score can be used to determine if their disease is currently well-controlled as well as thresholds indicating moderate control and very poorly controlled [103–105]. This information, combined with the risk stratification developed from past utilization further identifies the high-risk patients that have poorly controlled asthma as well as a likelihood of future acute care visits. In order to break this cycle of poor control and high utilization, these patients should benefit from in-home self-management education and a home environmental assessment.

As part of identifying which asthma and allergy patients would benefit from a home environmental assessment and interventions, it is essential to understand the kind of environmental exposures that a patient and/or their caregiver are trying to manage and whether any kind of environmental exposure risks are present in their home. An environmental history is a formal information collection process that includes questions about the physical conditions of the home including age, location, type of mechanical systems, appliances, reported moisture intrusion and plumbing leaks, number of rooms, single-occupied or multifamily, presence of pets or evidence of pests, presence of smokers, and other risk factors. A variety of these types of questionnaires or checklists are available from both government and private organizations. Links to some examples are available at the end of this document. Additionally, very specific environmental history questions based on research evidence have been published as guidance for health providers to use in relation to specific environmental allergens for dust mites [13] and moisture and mold [87]. Based on the answers to a series of specific questions, a provider can make specific recommendations for home interventions and determine whether a home environmental assessment is recommended.

Once a patient's level of risk has been determined, and the environmental history for the patient and their home has been collected, this information can be used to determine what type and level of investigation may be necessary for the environmental assessment. For example, if a patient's risk is determined to be low to medium based on low utilization (from their historic health record), have moderate control (from their ACT score), and their environmental history results indicate they are not currently dealing with significant environmental health risks at their home, one might recommend a home environmental assessment with a focus on reviewing self-management education and a visual assessment of the home for education about environmental trigger reduction. If however, a patient's risk is determined to be high, based on high utilization and poor control (from their ACT score) and their environmental history results indicate there are ongoing significant environmental health risks at their home, for example, active moisture intrusion, a pest infestation or reported housing structural or mechanical deficiencies, then one might recommend a more comprehensive home environmental assessment. Asthma self-management education is still a primary part of the home visit process, but the home environmental assessment may need to be a more comprehensive, detailed investigation of the home's physical, mechanical, and environmental conditions. This type of assessment often requires a professional with specific knowledge and expertise related to building, environmental science, and diagnostics. It is not uncommon for caregivers to have a lack of understanding of the basic components of their home and how they are designed and operate. When reporting information about their home, there may be inaccuracies in what they report. In a report from the World Health Organization (WHO), they indicated home occupants can either underestimate or overestimate the extent of home moisture and mold problems when compared to an assessment of the same conditions by a building or environmental professional [8].

Figure 2 is an algorithm representing the general home environmental assessment process. It begins at the initial contact with the patient's health care provider office. This individual collects information about the health status of the patient and makes the determination about the severity and risk of their disease. With this information, they make a referral for an environmental assessment either within their organization or agency, or to another organization that provides this type of service. If it is determined that a home environmental assessment is warranted, the case manager/environmental assessor determines the level of home assessment based on the health risks determined by the provider (often in collaboration with the case manager) following the process described above. Then, the case manager/environmental assessor works with the patient or caregiver to collect additional information and arrange for the home visit. For the majority of patients, a home environmental assessment can be successfully provided by a CHW. Many programs use CHWs and several reviews have shown their impact and economic value. Studies show generally consistent positive outcomes including reduced asthma symptoms, reduced utilization, improved quality of life, and improved adherence to recommended environmental control measures. In particular, CHWs are more cost-effective and more readily accepted by the at-risk communities they serve [76, 106–109]. However, these individuals are not housing or environmental exposure experts. In some instances, the reported environmental and/or physical conditions reported by the caregiver suggest that a higher-level or advanced environmental assessment is warranted. Indoor environmental professionals with advanced knowledge and skills should perform

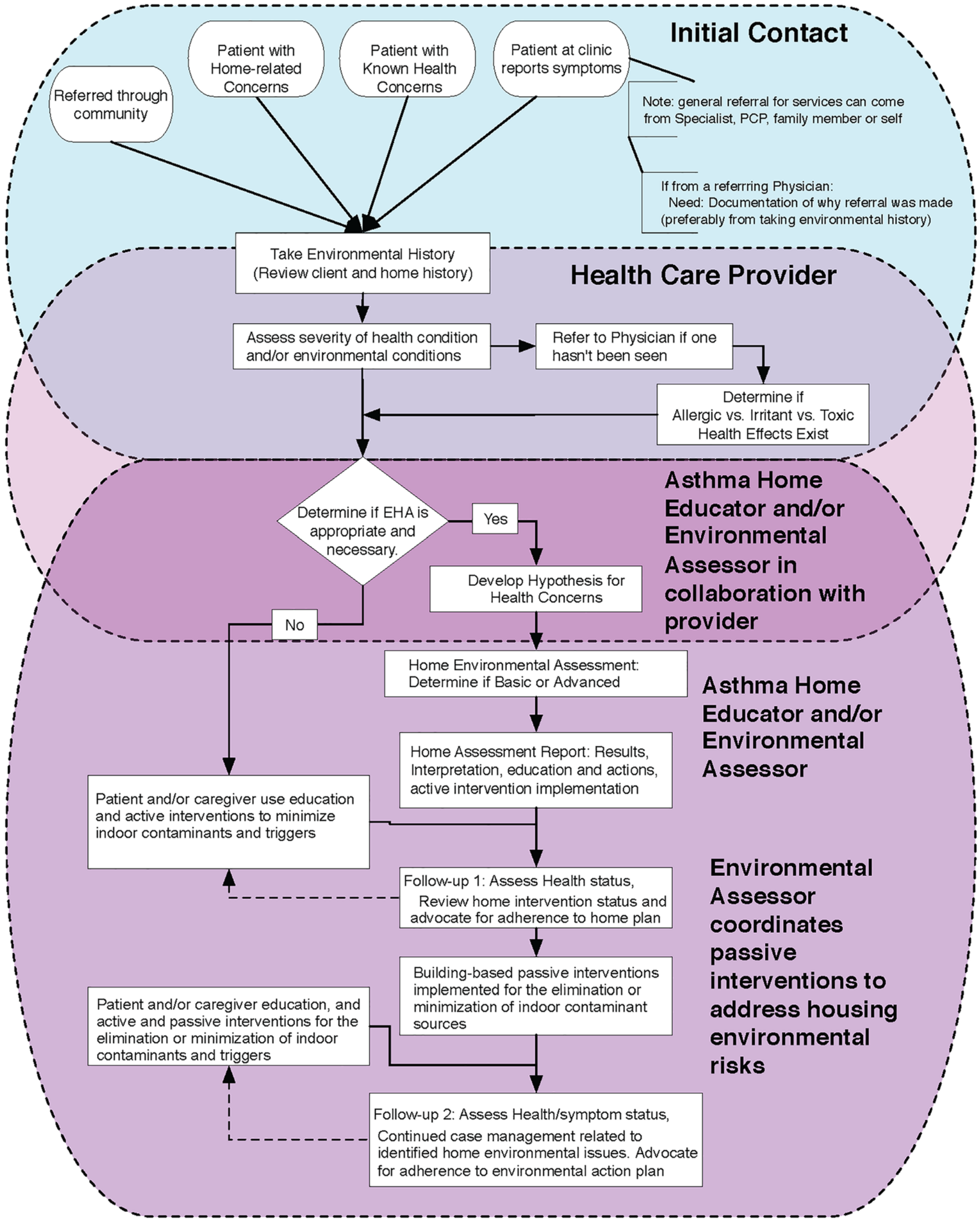

Fig. 2 Healthy home health assessment algorithm

these types of home assessments and can serve as excellent partners and collaborators with case managers and CHWs.

The home environmental assessment and intervention process involves visiting the home to provide in-home education, as well as, to perform a visual assessment of the indoor environment. Part of the visual assessment is to confirm information provided by the caregiver during the collection of the environmental history and part of the assessment is to directly observe conditions in the home in order to assess and characterize the health and safety risks that may be present. This information is then summarized in a report that should include educational information and recommendations for environmental mitigation and management. This information can then be used as a guide for the caregiver to address the environmental conditions himself or herself, or if needed, to refer them to outside resources and contractors to address the housing deficiencies. Different algorithms have been developed and published elsewhere to summarize how to address certain home conditions related to exposure to a specific allergen [12, 13, 85]. Guidance has also been provided about what might be included in certain types of home assessments and assessment reports depending on the nature of the environmental risks present in a home [12, 85].

Figure 3 is a representation of the general timeline for the process of interacting with patients and caregivers as case management for home environmental assessment services

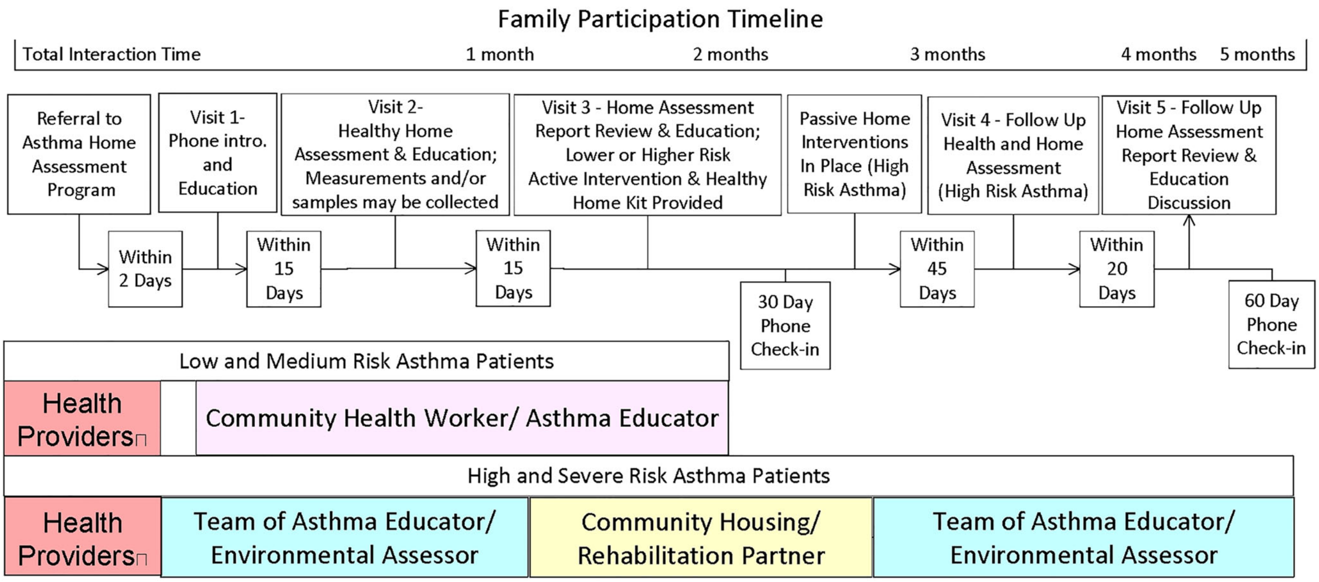

Fig. 3 Home environmental assessment/intervention timeline

provided. Many programs use similar visit models and may involve less contact or more contact with caregivers. The number of visits (caregiver interactions) can vary greatly, from 1 to 17, and it is not clear how many visits are recommended [35, 36••]. The total number of visits varies from program to program and many use each visit as part of a step-wise process often following a model for behavior change [106]. Visits include asthma self-management and medications, allergen education, household hazard and pollutant education, and intervention education. Programs that use a multivisit model work well for maintaining communication, reinforcing education and supporting adherence to recommended active interventions. One important goal is to change home cleaning and maintenance practices in order to reduce environmental exposures. For those patients who are considered low to medium risk with a small number of environmental risks reported or observed, fewer visits are usually required. For those patients who are considered high or severe risk, more visits and interaction with their caregivers is necessary, a more careful environmental assessment is typically warranted, and additional interaction is needed to address any identified physical, mechanical, and/or environmental deficiencies in the home. As mentioned previously, additional home visits to check in with the caregiver and address needs may be added. For families that do not have the financial resources to make repairs, this work often involves working with local community housing organizations or other programs that have resources to address home physical and environmental concerns. For this reason, it is not uncommon for participation in a program working to resolve significant home environmental issues in their home, to be involved in the program for several months. This means routine communication with the family is essential.

Conclusions

From what we now understand about the physical and environmental condition(s) of homes and its role in allergic disease, the quality of the indoor environment in a person's home is essential to one's long-term health and well-being. When a person has an allergic disease or chronic respiratory condition, they are particularly vulnerable. And yet, most people understand little about the basic components of a home, how they operate, and ultimately how they can impact health. The most recent American Housing Survey has for the first time statistics on the number of homes reporting environmental problems as well as basic health and safety concerns. More than 6 million homes have reported significant physical deficiencies like roof leaks, missing steps, inadequate heating equipment and plumbing. Over 15 million homes report musty smells with 4 million homes reporting smelling musty odors on a weekly basis. Over 13 million homes reported signs of mice or rats and over 14 million reported sign roaches. Over 4 million homes report second-hand smoke entering the home on a weekly or daily basis [110]. Millions more homes likely have indoor environmental problems that are often not identified or addressed, either because people do not understand how their home can impact health or because they do not have the financial resources to eliminate the problem. Even though this review indicates many passive and active interventions are effective, far too many homes have poor indoor environments that people with chronic disease like asthma and allergies are exposed to because this is where they spend 90% of their time. The vast majority of caregivers need assistance in how to best manage their home to facilitate health improvement.

Home assessments have been shown to effective at identifying home environmental risks and providing a way to communicate about how to reduce indoor environmental burden to avoid exposure and the resulting health impact [35, 36••]. A recent report from the American Academy of Pediatrics indicated home environmental control is as important as medication in controlling asthma symptoms [2]. Although home intervention studies paint a murky picture, there is enough evidence to suggest both passive and active interventions are effective in improving indoor environmental conditions and health. However, both need the support of education and routine communication to be successful. Effective and efficient identification of patients who are likely to benefit from home physical and environmental improvement often requires a system for stratifying their health status and environmental risk. Identifying higher risk patients is a cost-effective way to target assessment and intervention services. Once identified, this system can be used to provide home assessment services focused on a particular patient's health and home environmental needs. These stratified home assessment and intervention services should be a more cost-effective way to provide home environment-focused case management and support. Many programs around the country have shown positive ROI for asthma home visiting programs [40]. Using community health workers can help keep costs of service low while enhancing the quality and value of the health care experience. New health care rules are allowing reimbursement for home assessments. New models of support for home assessments and interventions are under development and represent real opportunities to improve health while working to keep health care costs low through home environmental assessments.

A critical component of the home assessment model that both Figs. 2 and 3 represent is the regular communication with the caregivers through a case management process. For caregivers to adhere to recommendations from their provider about best practices in home environmental management, a provider cannot always depend on what the caregiver indicates they are willing to do. For example, in one study, people were provided asthma education and home intervention options that they could do in their home to reduce allergens. Then, they were asked what they were willing to do using a questionnaire with a likelihood Likert scale. Six months later, the same people received a follow-up call and were asked, of the interventions you indicated you were willing to do which ones did you complete. The results indicated even though people indicated they were very likely to implement an intervention to reduce their likely exposure to certain allergens, they generally did not do what they said they would. [111] One possibility that might improve adherence to recommendations from the home assessor is to provide additional information in a home assessment report that includes actual measurement and sample results that can be used to show exactly what type of contaminant sources are present and at what concentration in a home. By showing caregivers this information, it might improve their adherence and compliance with recommendations. One recent study did just that. For the intervention group, they provided educational materials and the results of dust mite test results from their home at 1, 2, 5, and 8 months into the study. To a control group, they only provided the education. They visited all homes on repeat visits at baseline, 6 months, and 12 months and evaluated cleaning behaviors and collected samples from three locations in the home. At the end of the study, they found the allergen concentrations from samples collected from the floors in the child's bedroom and living room were significantly lower when compare to the control homes. Unfortunately, the study was small and the investigators were not able to study the health outcomes of these interventions [112••]. But, this work suggests that if more patients received home assessments and interventions that included measurement data indicating the progress of the interventions in reducing potential exposure, they might be much more compliant with recommended home environmental management practices.

Additional studies are needed that expand on the use of home-based, multitrigger, and multicomponent environmental assessments that are stratified to the asthma and allergy risk of the patient. The studies should evaluate more carefully the use of home assessment data and measurements that help encourage adherence and compliance with the prescribed environmental management practices. A large amount to research already shows the value of home assessments and interventions in management of allergic disease. This additional research will provide more support for the continued integration of home assessment services into the routine care of asthma and allergy patients.

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Compliance with Ethical Standards

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

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

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Links to sample environmental history questionnaires

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