

Housing Interventions and Control of Asthma-Related Indoor Biologic Agents: A Review of the Evidence

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Subject matter experts systematically reviewed evidence on the effectiveness of housing interventions that affect health outcomes, primarily asthma, associated with exposure to moisture, mold, and allergens. Three of the 11 interventions reviewed had sufficient evidence for implementation: multifaceted, in-home, tailored interventions for reducing asthma morbidity; integrated pest management to reduce cockroach allergen; and combined elimination of moisture intrusion and leaks and removal of moldy items to reduce mold and respiratory symptoms. Four interventions needed more field evaluation, 1 needed formative research, and 3 either had no evidence of effectiveness or were ineffective. The 3 interventions with sufficient evidence all applied multiple, integrated strategies. This evidence review shows that selected interventions that improve housing conditions will reduce morbidity from asthma and respiratory allergies.

KEY WORDS: allergens, asthma, cockroaches, dust, housing, mice, mites, moisture, prevention, rats

Asthma is of great concern because its prevalence and morbidity have increased dramatically in the past 2 decades.¹ Recent basic research suggests that asthma develops as a result of interactions between genes and environments.² The contribution of environmental factors to the observed increase in asthma has been the focus of many investigations.³⁻⁷ Biologic agents figure prominently among environmental factors impli-

cated in asthma morbidity, including allergens from cockroaches, rodents, dust mites, and fungi, in addition to respiratory irritants such as fungal cell wall components.⁴

Housing conditions are associated with exposure to these biologic agents. Excess moisture in a home supports the growth of mold and provides an environment favorable to dust mites, cockroaches, and rodents. Common sources of water and moisture in homes include structural membrane leaks, condensation, damp foundations and crawl spaces, inadequate ventilation, activities such as bathing and cooking,

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and unattended plumbing problems.⁷ Structural and plumbing deficiencies in a home provide entry points for pests, which are attracted by hidden food spills and garbage.⁸ Poorly maintained heating and ventilation can disburse allergen-containing dust throughout the home.

● House Dust Mites

Dust mite allergens are the only class of inhalant allergens for which the National Academy of Sciences found sufficient evidence for a causal association between exposure and the development of asthma.⁴ Exposure to dust mite allergen is also associated with asthma exacerbations. A body of clinical and epidemiologic evidence suggests that exposure to Der p or Der f antigens at levels greater than 2 $\mu\text{g}/\text{mg}$ is associated with sensitization and above 10 $\mu\text{g}/\text{mg}$ with exacerbation of established asthma in mite-sensitized persons.^{9,10} These cut-points are often used to assess exposure risk in field studies. A recent survey found that more than 80% of homes in the United States have detectable levels of house dust mite allergen in the bedroom, 46% have levels above 2 $\mu\text{g}/\text{mg}$, and 24% have levels above 10 $\mu\text{g}/\text{mg}$.¹¹

● Cockroaches

Cockroach allergens are an important cause of asthma exacerbations, particularly in deteriorated homes where cockroach infestation is most common.¹²⁻¹⁴ Heavy infestations in homes may create reservoirs of allergen in carpets, rugs, and beds and in areas that are difficult to reach behind appliances and furniture.¹⁵ A detectable level of cockroach allergen is found in 63% of dwellings in the United States,¹⁶ and 10.2% of all dwellings have cockroach allergen levels above the asthma morbidity cut-point.¹⁷

● Fungi (Mold) and Excessive Moisture

Epidemiologic and laboratory evidence links the presence of mold and moisture to poor health outcomes, such as upper respiratory tract symptoms, cough, wheeze, and other asthma symptoms.¹⁸ Although mold is associated with exacerbation of allergic rhinitis and allergic asthma in those people who are sensitized to mold, some components of mold can also elicit inflammation via nonallergic mechanisms.^{4,18,19} Fungal growth can result from excessive indoor moisture.¹⁷

● Rodents

The contribution of exposure to rodents to allergic conditions was first described in studies of laboratory animal workers caring for mice and rats.^{20,21,22} More recent research has shown that allergens from these rodents are present in homes and are associated with asthma morbidity.²³ Detectable levels of mouse allergen are found in 82% of dwellings in the United States.²⁴ The National Cooperative Inner City Asthma Study found that 95% of all homes assessed had detectable mouse allergen in at least 1 room, suggesting that mouse allergens are widely distributed in inner-city homes.²⁵ Chew et al²⁶ observed that mouse allergens were common in low-income, inner-city apartments even when sightings were not reported.

● Interventions Reviewed

The literature search and review methods are described in more detail in a companion article in this series by Jacobs et al.²⁷ In brief, the panel sought to identify interventions that are effective in improving asthma outcomes by reducing exposure to indoor biologic asthma triggers. The panel searched the literature for publications describing interventions as well as the Web for guidelines. Titles and abstracts of all retrieved articles were read and each relevant articles was reviewed and abstracted into standard study summary templates by 2 panel members and scored as to the degree of impact and study quality. Panel members as a group reviewed the scoring and agreed-upon classification of each intervention as having sufficient evidence effectiveness and ready for implementation, needing more field testing but promising, promising but needing formative research, and ineffective.

An effective intervention results in improvements in health or leads to changes in behaviors or other factors that have been previously shown to result in better health.²⁸ The definition of “sufficient evidence” of effectiveness is based on the Centers for Disease Control and Prevention Community Guide, which bases its ratings on intervention studies.²⁸ In addition, we deemed an intervention to have sufficient evidence if the combination of intervention studies (on their own insufficient for meeting the guide criteria), other expert panel recommendations, and strong epidemiologic evidence of association between exposure and health outcomes was convincing. We did not limit the studies reviewed to randomized controlled trials, because the likelihood of harm from the types of interventions under consideration is low, suggesting that the level of evidence need not be as rigorous, and because this is an emerging and rapidly developing field. In short, the

recommendations are based on existing evidence and not the best possible evidence.

For this topic, a panel of subject matter experts reviewed the following 11 interventions:

- multifaceted, tailored asthma interventions;
- integrated pest management (IPM) to reduce pest exposure;
- elimination of moisture intrusion and leaks and removal of moldy items;
- improved insulation;
- HEPA air filtration;
- carpet cleaning and vacuuming;
- ventilation and dehumidification;
- one-time professional cleaning;
- bedding encasement and/or sheet and/or upholstery cleaning alone;
- acaricides as a single intervention; and
- air cleaners releasing ozone.

● Results

Of the 11 interventions reviewed, 3 have sufficient evidence of effectiveness and are ready for implementation, 4 need more field testing but are promising, 1 is

promising but needs formative research, and 3 are ineffective.

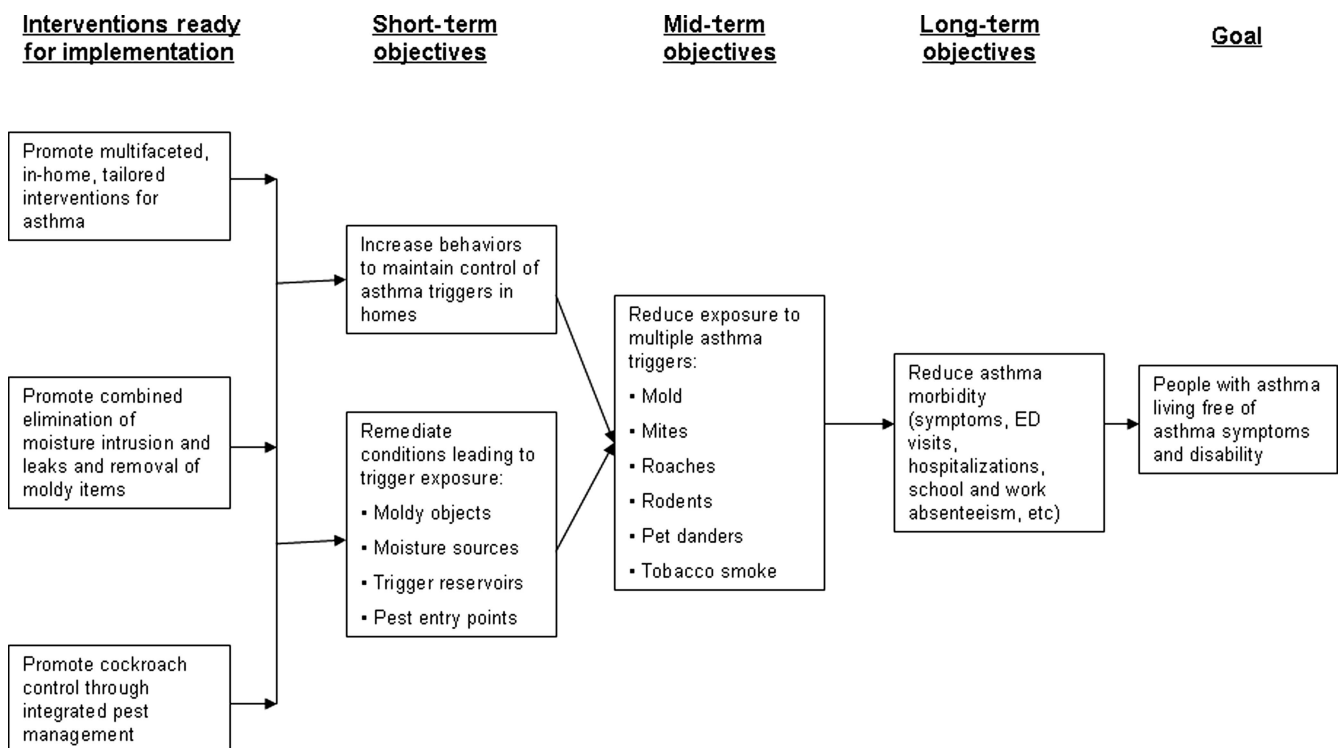
Sufficient evidence

Three interventions were supported by sufficient evidence to warrant widespread implementation. The Figure depicts the relationships between these interventions and health outcomes.

Multifaceted, in-home, tailored interventions for asthma

Home-based interventions that use a multifaceted approach to help residents decrease exposure to multiple asthma triggers are effective in reducing exposure to triggers, decreasing asthma symptoms and short-term health care use, and improving quality of life. These interventions tailor activities to triggers found in an individual's home and/or to which the individual is sensitized. Interventions include home environmental assessment, education, use of mattress and pillow covers, use of HEPA (or equivalent) vacuums and HEPA air filters, smoking cessation and reduced environmental tobacco smoke exposure, cockroach and rodent management, minor repairs, and intensified household cleaning. The panel found that evaluations of this approach were well designed, had many subjects from

FIGURE 1 ● Housing Interventions to Control Indoor Biologic Agents: Interventions Ready for Implementation^a



^aED indicates emergency department.

appropriate populations, and identified statistically significant improvements.

The strongest evidence comes from studies examining the impact of interventions on control of existing asthma.^{5, 29-31} The Inner City Asthma Study was a large, multisite randomized trial that targeted interventions to reduce exposure to asthma triggers to which a child was sensitized. It showed a large and clinically significant reduction in asthma symptoms days and a modest and significant reduction in emergency department and urgent clinic use.²⁹ Eggleston et al³⁰ found that their in-home intervention reduced concentrations of airborne particulate matter and dustborne cockroach allergen and decreased daytime asthma symptoms but not other measures of morbidity. Krieger et al⁵ showed that home visits by community health workers to support families in decreasing exposure to asthma triggers led to significantly reduced use of urgent health services and to improved quality of life for caretakers. Carter and colleagues²⁹ found that home visits also decreased short-term visits for asthma among children with dust mite allergy.

Other studies with important methodological limitations (such as large attrition rates and small sample size) did not find significant benefits from home interventions.^{32,33} Additional studies of the benefit of such interventions for reducing incidence of asthma among infants at high risk for it have yielded mixed but generally modest positive results.³⁴⁻³⁶

The panel conclusion that multifaceted, in-home interventions are effective is consistent with a recent high-quality systematic review of the evidence completed for the Centers for Disease Control and Prevention Task Force on Community Preventive Services. On the basis of strong evidence of effectiveness for these interventions, the task force now recommends home-based, multicomponent, multitrigger interventions with an environmental focus for children with asthma.³⁷ The conclusion is also supported by recent studies that were not available when this panel convened.^{38,39}

Cockroach control through IPM

Integrated pest management is effective in reducing cockroach allergen and pesticides.^{30,40} It includes carefully assessing the presence and location of roaches, removing food sources through proper food storage and cleaning (in some cases, professional cleaning), educating residents, repairing structural defects that allow roaches to gain access, applying low-toxicity gel-bait pesticides as needed, and monitoring and continuing intervention until roaches are eliminated.

Four randomized controlled studies have demonstrated the effectiveness of IPM in reducing exposure

to cockroaches.^{30, 41-43} Arbes et al⁴³ conducted a 6-month study and found that roach allergen levels were significantly reduced in beds and kitchens. The levels in the beds dropped below the thresholds for both sensitization and exacerbation. Wang and Bennett⁴¹ showed a significantly greater decrease in roach counts with IPM than with gel bait alone. Miller and Meek⁴² found that IPM was initially more costly but also much more effective in reducing cockroaches than with traditional pesticide treatment. These 3 studies did not report on health outcomes. A study by Eggleston et al³⁰ showed a modest benefit on clinical outcomes but was a multifaceted intervention that addressed other allergens besides cockroaches.

Additional research, using less rigorous methods, has also found IPM to be effective. For example, Levy and colleagues³² showed reduced cockroach allergen and improved clinical outcomes in a single-group prepost study. McConnell and colleagues⁴⁴ conducted a randomized trial of IPM methods that showed decreased cockroach counts and dust allergen levels in the IPM group relative to the control group. This trial also showed that intensive cleaning can significantly reduce allergen levels in homes with initially high levels. Clinical outcomes were not reported. Other studies^{45,46} have also demonstrated improvements, but their conclusions were weakened by small sample sizes, inclusion of multiple interventions in addition to IPM, lack of control groups, use of nonstandard, self-reported measures of cockroach exposure, or interventions that would be difficult to replicate.

Evidence of the effectiveness of IPM for reducing exposure to rodent allergens is less well developed. A small study showed no significant improvement in asthma symptoms or forced expiratory volume but did show a significant decline in mouse allergen levels.⁴⁷ In conclusion, the evidence that IPM is effective in reducing exposure to cockroach allergens is quite strong, but further evaluation of its role in reducing exposure to other pests is needed.

Combined elimination of moisture intrusion and leaks and removal of moldy items

The panel believes there is enough evidence to begin implementation of interventions that combine elimination of moisture intrusion and leaks and removal of moldy items to reduce mold exposure and respiratory symptoms. The panel took into consideration the Institute of Medicine report,¹⁸ local (New York City)⁴⁸ and international guidelines (World Health Organization,⁴⁹ Finland,⁵⁰ Canada¹⁹), and the studies evaluated in the following text. The recent World Health Organization report states that “although few intervention studies

were available, their results show that remediation of dampness can reduce adverse health outcomes.⁴⁹ It is important to recognize that these interventions may not produce improvements in health in all individuals who are exposed to dampness and mold.

The panel reviewed several intervention studies, many of which were limited by small sample size, lack of control groups, or implementation in nonresidential settings. The largest study (164 homes) was a randomized controlled trial of visible mold eradication (with removal, fungicide application, and ventilation fan installation) among people with asthma. It reduced symptoms and medication use, although not peak flow variability.⁵¹ Another randomized trial⁵² had only 29 participants in the experimental group and 33 in the control group. Despite the small sample size, this housing remediation intervention showed improved asthma clinical outcomes. While it is not clear how much mold was in the homes of these studies before the intervention, both studies listed presence of mold as an inclusion criterion.

Several smaller studies have also suggested that interventions can decrease exposure to mold. One study examined the effect of prompt remediation after water intrusion in a single home and found decreased spore counts and resolution of allergic symptoms.⁵³ A time-series study compared mold exposure and symptoms at a mold-contaminated school before and after remediation with a comparison school. The investigators found that prior to remediation, the contaminated school had higher mold levels and the children had more allergic and respiratory symptoms than the comparison school. These differences disappeared after intervention.⁵⁴ A small uncontrolled study of moisture and mold control in 3 flood-damaged homes showed that mold (eg, spore and colony counts) and endotoxin increased significantly during renovation work and declined significantly following the removal of moldy items and a multistep cleanup process.⁵⁵

Promising interventions that need more field evaluation

The panel identified 4 interventions—improved insulation, repeated dry-steam cleaning of carpets and upholstered furniture and repeated vacuuming, use of air cleaning devices, and moisture control through dehumidification (including improved general and local exhaust ventilation)—as promising interventions that need more field testing. Each of these interventions has been evaluated, but the evidence of effectiveness is not sufficient to recommend widespread implementation. Further evaluation in real-world settings is needed to determine generalizability and feasibility of replication.

Improved insulation

The panel found that a large, well-designed, randomized controlled trial of home insulation in New Zealand showed decreased moisture and mold exposure and improved general and respiratory health status.⁵⁶ This promising finding should be replicated in different climate zones and settings as the next step toward wider implementation.

Repeated dry-steam cleaning and repeated vacuuming

The panel found that several studies of repeated cleaning and/or vacuuming showed these interventions to be promising but in need of more field testing. For example, a small study (11 homes) of intensive vacuuming and steam cleaning of carpeting and furnishings showed sustained reductions in concentration and load of mite allergen in dust relative to vacuuming alone. Both approaches decreased allergen levels, but a control group was not included in the study and clinical outcomes were not reported.⁵⁷ These findings are consistent with those from a small laboratory study showing benefits from steam cleaning.⁵⁸ British investigators found that high-efficiency vacuums reduced cat and dog allergen concentrations but not dust mite allergen concentrations. Patients showed improved pulmonary function and decreased β -agonist use.⁵⁹ Several studies have demonstrated that repeated vacuuming can decrease mite levels, although these studies were of short duration and did not report clinical outcomes.^{60,61} A small study that compared 5 HEPA vacuums with 1 regular vacuum did not find any difference in exposure to mite allergen during vacuuming.⁶² Laboratory studies that examined the effect of 1-time vacuuming of carpet samples have yielded both positive and negative results.^{63,64} The vacuuming procedure may not have been intensive enough to show a benefit in the negative study.

Use of air cleaning devices

Evaluation of HEPA air filtration has yielded mixed results. A review by Wood⁶⁵ concluded that HEPA filters may be effective for removing pet allergens, although studies were mixed and more evidence is needed. HEPA filters do not appear to be effective for reducing exposure to mites and mold. When used in uncarpeted rooms or in conjunction with HEPA vacuuming of carpeted rooms, HEPA air filters were effective in decreasing cat and dog allergens.⁶⁶⁻⁶⁸

Evidence for improvements in clinical outcomes is less convincing. For example, a small, randomized, controlled trial examining the reduction of cat allergen by using HEPA air filtration, along with bedding

encasements and cat exclusion, did not show a significant clinical effect.⁶⁹ However, another small (n = 40), randomized trial of HEPA air filters showed a decline in airborne particulates and possible improvement in rhinitis or asthma symptoms and medication use among patients with sensitivity to dust mites.⁷⁰ A study by van der Heide⁷¹ found that HEPA filters improved airways hyperresponsiveness but not symptoms among 20 children allergic to cats or dogs. Another study showed modest clinical benefits but no reduction in pet allergens.⁷² A comparison of vacuuming with vacuuming plus air filters found modest clinical benefits from the filters but no improvement in allergen exposure.⁶⁶ A Cochrane review concluded that the evidence is insufficient to support or refute the effectiveness of air filters among people with pet allergies and exposure to pets.⁷³

Moisture control through dehumidification

Ventilation and dehumidification to reduce humidity levels and exposure to mites have yielded mixed but generally positive results. In a national survey, the use of a dehumidifier was an independent predictor of lower levels of some asthma triggers and mold.⁷⁴ Installation of whole-house mechanical ventilation can decrease humidity, decrease the number of mites, decrease mite allergen levels, and improve clinical outcomes.⁷⁵⁻⁷⁷ Dehumidification in temperate climates with air-conditioners and dehumidifiers is effective in reducing mite levels.⁷⁸ Ventilation and moisture control are typically related. Also, ventilation can decrease indoor contaminants, assuming that the outdoor air has lower levels of contaminants than the indoor air, which is not always the case if housing is located near point sources such as industrial emissions or near high-traffic roadways. In high-humidity climates, whole-house ventilation has been less effective.⁷⁹⁻⁸¹ Ventilation and air cleaners are considered further by Sandel et al⁸² in a companion article in this series.

Interventions in need of formative research

One-time professional cleaning

The panel identified 1-time professional cleaning as an intervention needing more formative efficacy research. Professional cleaning included removing clutter, washing hard surfaces, and vacuuming porous surfaces. Such cleaning is largely ineffective for lead hazard control purposes and has very short-lived effects.⁸³ However, this cleaning may be more effective for biological contaminants if key elements of the cleaning process can be identified. For example, evidence shows that cleaning reduces cockroach allergen levels.^{44,84}

No evidence/ineffective/harmful interventions

The panel found that 3 interventions—air cleaners that generate high levels of ozone, bedding encasement and/or sheet and/or upholstery cleaning alone, and acaricides (chemicals that reduce mite allergen levels) as single interventions—either had no evidence of effectiveness or were ineffective—and should not be used.

Air cleaners generating high levels of ozone

The panel found that air cleaners that generate high levels of ozone should not be used because of the association between ozone and asthma morbidity⁸⁵ and because of the unknown benefits such devices have on removing indoor airborne particulate matter.⁶

Bedding encasement and/or sheet and/or upholstery cleaning alone

Studies that used single interventions—such as bedding encasements and/or sheet and/or upholstery cleaning—to control specific asthma triggers without the multifaceted approach described earlier either did not find benefit or tended to suffer from methodological deficiencies. The use of bedding encasements as isolated interventions to reduce exposure to mite allergen and improve asthma and allergy outcomes has been well studied. Two well-designed, large, randomized studies did not find improvements in clinical measures.^{86,87} Other earlier, smaller studies of bedding covers also did not find symptom benefits,^{88,89} although the study by van den Bemt et al⁸⁸ observed improvement in morning peak flow. A study that evaluated efficacy of mattress covers, but had limited covariate data, showed no effect on clinical status.⁹⁰

Studies that have attempted to prevent asthma incidence by reducing exposure to a single allergen (dust mite) have generally not been successful. For example, 2 studies employed multiple mite control measures among high-risk children. The Child Asthma Prevention Study, a well-designed trial that assessed the impact of bedding encasements and bed linen washing with acaricide solution, did not show reduced asthma, wheeze, or atopy incidence.^{91,92} Another multicomponent study using allergen-impermeable covers for the maternal and child beds, an allergen-impermeable cot/carrycot mattress, a high-filtration vacuum cleaner, vinyl flooring in the child's bedroom, bed linen that was hot-washed weekly, and a washable soft toy showed increased mite sensitization in the intervention group but better lung function (specific airway resistance) at age 3 years.⁹³ A study that employed aggressive and multiple interventions for mites (tannic acid, bedding encasements, and laundry service) showed decreased

exposure and improved airways hyperresponsiveness but did not affect forced expiratory volume in the first second of expiration (a measure of lung function), symptoms, or quality of life.⁹⁴

Acaricides as a single intervention

The panel found that acaricides used as a single intervention do not appear to be effective. A study of treating carpets with chemicals (tannic acid and benzyl benzoate) showed reduced mite allergen concentration, but effects were not seen in all treated carpets and were not long-lasting.⁹⁵ In addition, certain carpet treatments can interfere with immunoassay measurement of allergens, which questions the validity of studies that used this outcome measure.^{95,96} A meta-analysis of 23 studies that focused on dust mite control with acaricides found no effect.⁹⁷

● Conclusions

The panel concluded that some interventions are effective in reducing exposure to indoor biologic agents that can cause asthma symptoms among people with asthma. In particular, sufficient evidence supports the widespread dissemination of multifaceted, in-home, tailored interventions for asthma; IPM for reducing cockroach allergen; and combined elimination of moisture intrusion and leaks and removal of moldy items to reduce respiratory symptoms. An important limitation of these conclusions is that the effectiveness of interventions may vary by region (due to variability in climate and predominant types of housing) and tailoring to local conditions may be important. Another caveat is that even the strongest housing interventions will be hampered in their ability to reduce asthma morbidity if individuals residing in those houses are exposed to other indoor and outdoor pollutants, such as environmental tobacco smoke and ozone.

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