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Environmental Control Measures for the Management of Atopy

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Introduction

With the rising prevalence of allergic airway disease in recent years, efforts have focused on the importance of environmental control measures to reduce morbidity and improve quality of life in the allergic population. Once allergy/asthma has been established, allergen abatement is an important aspect of managing the atopic population. We will review current evidence of the role of environmental control and abatement measures for common allergens including furry animals, rodents, cockroach, dust mite, and mold.

The reader should be aware that comprehensive practice parameters for management of allergy to furry animals,¹ rodent,² cockroach,³ and dust mites⁴ have been published from 2012 to 2014. In accordance with these parameters, important terms which will be used throughout the body of the manuscript are *reservoir* and *facilitating factor*. For the purpose of this manuscript, a *reservoir* is a confined area where allergen may concentrate, while a *facilitating factor* is a factor which promotes allergen production.^{1–4} This review will not discuss the role of primary prevention in the development of atopy and wheeze. This review will focus on evidence-based methods of allergen abatement strategies aimed at reducing morbidity in sensitive individuals.

Furry Animals

Sensitization to furry animals has increased in recent years, especially to household pets. Environmental control measures aim to reduce dander in the environment. Pet removal is an effective way to reduce exposure to allergen. In a study of asthmatic pet owners sensitized to

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furry animals, one group opted to remove their pet from the home and the other group opted to keep their pet. Those in the pet removal group had decreased airway hyper-responsiveness and reduced use of asthma controller medication after one year.⁵ Though pet removal from the home is an effective way to reduce exposure, most pet owners will not remove pets due to emotional attachment. Even after pet removal, residual allergen may persist. Further, dog and cat allergen are found in homes without pets.⁶

Cat

Fel d 1 is the major cat allergen; it is primarily found on skin and fur and is produced in sebaceous, anal, and salivary glands. Highly concentrated areas of cat allergen include upholstery, bedding, and carpet.¹ After removal of cats from the home,⁶ the decline of Fel d 1 levels may be slow over time. Therefore, while removal of cat from the environment is important, other methods of allergen elimination are necessary.

Cat immersion washing has been shown to significantly decrease Fel d 1 levels, but only for a short period of time.⁷ Washing must be repeated regularly to maintain effectiveness. Further, there is no proven clinical benefit from washing of cats alone. Cat and dog allergen are present on walls and efficient removal of allergen from walls has been demonstrated through direct washing of walls or through use of dust cloths.^{1, 6} Use of High Efficiency Particulate Arrestance (HEPA) filters in addition to removal of cat from living room and bedroom areas can decrease the level of airborne Fel d 1 allergen, but the clinical benefits of this intervention vary.⁸ As cat allergen is found on settled dust, aggressive interventions including carpet removal can also reduce level of cat allergen.⁹ Therefore, techniques for dust reduction, discussed later, may contribute to reduced cat allergen exposure.

Regular use of high efficiency and standard vacuums can reduce the level of both cat and dog allergen in settled dust and improve lung function, though health effects are variable.⁹ Mattress encasings may prevent passage of both dust and cat allergen; encasings that are woven and have small pore size may be more effective than non-woven encasings.¹¹ In sum, a combination of minimizing exposure to cat allergen (removing reservoirs, cat removal) combined with HEPA filters and frequent cleaning of the cat may reduce allergen exposure.

Dog

Can f 1 is the major dog allergen. Sebaceous glands secrete dog allergen, and Can f 1 is found in canine saliva, fur, and dander, and reservoirs for dog allergen include bedding, furniture, and carpeting.¹ Many dog-allergic patients report better tolerance of certain breeds over others, leading to various breeds being referred to as 'hypo-allergenic.' In a study that examined dust samples taken from homes with various breeds of dogs, those in homes with 'hypo-allergenic' breeds had no difference in Can f 1 levels compared to other breeds.¹² Another study found that Can f 1 levels were actually higher in hair and coat samples in breeds that were touted as hypo-allergenic.¹³ Currently, evidence does not support breed-specific differences in allergenicity.

Abatement of dog allergen in many ways parallels that of cat allergen. Rooms which dogs inhabit have higher allergen levels, so keeping dogs outdoors or out of specific rooms can lower allergen levels. Repetitive vacuuming has been associated with reduced Fel d 1

levels.⁹ Frequent vacuuming for reduction of allergen in settled dust, use of HEPA air filters, and other techniques to reduce dog allergen in settled dust are recommended to reduce exposure.⁹ In sum, allergy to furry animals is increasingly common, and the clinical benefits of combined intervention measures may be effective in reducing symptoms in sensitized individuals.

Pests

Rodents

The primary source of allergen from pests such as mice and rats is urine,¹⁵ and the major allergens in mice and rats are Mus m 1 and Rat n 1, respectively.² Mouse allergen is prevalent in both inner city and suburban home and schools,¹⁵ while rat allergen is less prevalent than mouse but still common in the inner city setting.¹⁶ Individuals sensitized and exposed to rodents may in turn have higher asthma morbidity, highlighting the importance of abatement tactics in homes and schools.¹⁶

As with cats and dogs, reducing exposure to rodent allergen involves removal of facilitating factors, reservoir elimination, and allergen abatement. Food and shelter are key facilitating factors for rodents, so eliminating any potential rodent food source and blocking route of entry is important. This may involve thorough survey of one's environment.¹⁷ Eliminating rodents once present can be accomplished in several ways. Having a cat may deter or kill rodents, but this may not be a feasible option, especially in those sensitized to cat.² Rodents may also be eliminated through the use of traps.² Rodenticide such as warfarin is also effective way of eliminating rodents, but care must be taken to prevent small children from ingesting the rodenticide or household pets from ingesting the rodenticide or the killed rodents.¹⁸

Abatement of allergen reservoir (carpeting, bedding, etc.) is another key component of minimizing exposure to rodent allergen. Integrated pest management (IPM) combines reduction of facilitative factors and removal of allergen reservoirs.¹⁹ Studies have demonstrated successful reduction of mouse allergen levels with IPM including hole-filling, cleaning, vacuuming, use of traps, and pesticides.²⁰

Cockroach

The major allergens in cockroach are Bla g 1 and 2; Bla g 1 is found in cockroach fecal material, while Bla g 2 is an aspartic protease.³ Asthma morbidity in inner-city children is associated with cockroach allergy,²¹ making cockroach allergen abatement a focus of study in the inner-city asthma population. Further, cockroach exposure in inner city children has been indicated as a risk factor in the development of asthma.²²

Various methods have been investigated to determine the most effective way to remove cockroach from an infested environment. While cockroach allergen levels are reduced with extermination, cockroach extermination alone is not effective in lowering allergen levels below clinically relevant levels.²⁴ The use of sodium hypochlorite has not been shown to aid

in cockroach allergen elimination in homes,²⁴ and the use of boric acid has been shown to paradoxically increase Bla g 1 levels, so is not currently recommended.²⁵

Cockroach allergen abatement has been achieved through IPM including combined use of insecticide, professional cleaning, and occupant education to reduce allergen reservoir and facilitating factors.²³ Removal of cockroach allergen reservoir may include removal of carpeting, bedding, or other areas harboring allergen.³ In a study by Sever et al, cockroach allergen levels were effectively reduced in 12 months when the intervention was performed by a professional entomologist, but not when performed by a commercial pest removal company, indicating that the effectiveness of allergen elimination may depend on who performs the intervention.²⁶ Once an intervention has been performed, sticky traps can be used to monitor effectiveness of the intervention.³

IPM aimed at cockroach elimination has also demonstrated clinical benefit. In a study that used comprehensive pest management (professional cleaning, insecticides, and HEPA filters), results demonstrated reduced cockroach allergen and a reduction in asthma symptoms in the study subjects.²⁹ In another study, reduction of cockroach allergen by IPM combined with occupant education was associated with decreased daytime asthma symptoms compared to the control group.³⁰ In summary, control of cockroach infestation aimed at allergen reduction includes a combination of reservoir elimination, elimination of facilitative factors, and integrated pest management.^{3, 19} Combined tactics, if performed regularly, may lead to reduced allergen level and clinical improvement.

Dust Mites

The common household dust mites (HDM) in the United States are *Dermatophagoides farinae* and *Dermatophagoides pteronyssinus*, and the major allergenic proteins are Der p 1 and Der f 1.⁴ Abatement of dust is multi-faceted. Dust mites require adequate moisture and a feeding source for survival, so abatement tactics should focus on these factors. HDM feed off of dead skin cells and microorganisms, so minimizing the food source as a facilitating factor can reduce HDM in the environment. HDM thrive in humid environments, so maintaining humidity <50% limits dust mite growth.⁴

Key reservoirs for dust mites include carpets/rugs, upholstered furniture, mattresses, bedding, and clothing. As complete removal of these reservoirs is often not feasible, frequent washing and other reduction techniques are needed. Use of chemical killing devices such as acaricides has been studied extensively. While acaricides may effectively kill mites, other methods such as mattress encasings are more effective and have less risk of chemical side effects.³¹

Use of encasings for pillows, mattresses and box springs are an effective means of containing dust mite allergen.³² Also, washing bedding and clothing in hot water and drying may effectively kill a majority of HDM.³³ While numerous studies have tested the effectiveness of varying water temperatures, washing bedding at temperature greater than 25° C (77° F) with detergent can remove most HDM.³³

Regular vacuuming of carpets and mattresses with HEPA filtration can remove dust allergen, though may not eliminate live mite.³⁴ Trials examining the clinical benefit of air filtration have had varied results. In a review of 10 trials, HEPA filtration was found to be associated with decreased symptom reporting.³⁵ Use of HEPA air filters is likely not effective as a stand-alone intervention, but may be especially helpful when placed in the room where an individual sleeps.³⁶

Efforts to reduce dust mite exposure have shown to have clinical benefit. One study demonstrated that use of intensive dust mite control was associated with decreased asthma symptoms.³⁷ When home visit and dust avoidance measures (dust mite covers, hot water to wash bedding) were employed in an at-risk inner city asthma population, there was a decrease in acute visits.³⁸ In sum, there is evidence to support the efficacy of interventions targeted at dust elimination, and these interventions should be combined and repeated often for the greatest impact.⁴

Mold

An estimated 5–20% of atopic individuals are sensitized to mold.³⁹ Mold depends on moisture for growth, and individual molds thrive on varying levels of moisture to support growth. Common indoor molds include *Fusarium*, *Penicillium*, and *Aspergillus*; common outdoor molds include *Cladosporium*, *Alternaria*, and *Epicoccum*. Many outdoor molds contaminate indoor areas by way of open windows, clothing, or pet fur.⁴⁰ A mold's propensity to thrive in certain environments depends on the moisture level needed for optimal growth. In particular, *Alternaria* and *Cladosporium* grow outdoors in a damp or humid environment.⁴¹ Other molds require higher moisture level including *Penicillium*, *Aspergillus*, *Stachybotrys*, and *Chaetomium*, so these molds may be found indoors in the setting of sustained water intrusion.⁴¹

Exposure to mold has been linked to asthma morbidity, and mold exposure is prevalent both indoors and outdoors.⁴² Outdoor molds thrive in humid climates, especially during summer months, and spore counts often decrease significantly during cold, winter months.⁴³ In one study, asthmatic patients sensitized to *Alternaria* reported increased symptoms in the late spring and summer months compared to winter months.⁴⁴ Thus clinical symptoms in those sensitized to molds may correlate with fungal spore counts. Immunotherapy with standardized fungal extracts for *Alternaria* and *Cladosporium* has shown to improve symptom reporting in European studies, so immunotherapy may be considered in mold-sensitized individuals.³⁹

Indoor mold thrives in damp areas with high humidity, so eliminating the source of dampness should be a focus of mold reduction efforts.⁴⁵ Methods of reducing moisture include maintaining humidity below 50%, sealing leaks, using fans in areas prone to dampness, and use of air conditioning during humid, summer months.⁴⁵ Cleaning and maintenance of contaminated air conditioning units can also be helpful in reducing indoor mold, especially since heating, ventilation, and air conditioning (HVAC) systems may recirculate contaminated air.⁴⁶

The use and effectiveness of chemical cleaning products has been assessed in various studies. Use of soap and water alone can remove mold, but it has been shown to grow back after a few weeks.⁴⁷ Cleaning agents containing hypochlorite can effectively kill and denature mold protein⁴⁸ and can kill mold on contaminated building materials.⁴⁹ Tannic acid was studied more extensively in the past. While it has shown to be effective in reducing allergen level (especially cat and dust) over a short time period, reduction of allergen level is not sustained.⁵⁰ In one study, various cleaners were compared based on ability to remove *Stachybotrys* from contaminated walls; the most effective cleaners included Borax, Lysol All-Purpose Cleaner (Orange Breeze), Orange Glo Multipurpose Degreaser, and Fantastik Orange Action.⁵¹

Killing mold does not remove allergenic particles completely, so attention must be paid to removal of mold particles and spores. For mold remediation of non-porous areas such as walls or flooring, surface cleaning can be applied. However, mold particles may be more difficult to remove from carpeting and upholstered furniture.⁴⁵ When such porous surfaces have been contaminated with mold, complete removal is advisable. Even papers and books may harbor mold and should be examined carefully for contamination. Dust is a key reservoir for mold in the indoor environment, and dust aerosolization can lead to increased mold exposure.⁵² Therefore, dust abatement techniques may also reduce mold exposure. As carpet harbors dust, carpet removal or use of frequent vacuuming may reduce mold exposure.³⁴

While numerous methods are available to test for presence of mold, there are no standardized methods for gathering data or analyzing the results. Importantly, results of an environmental assessment for mold may not correlate with actual health outcomes.⁵⁴ Practitioners must be familiar with the techniques for identifying and measuring mold in the environment and also understand the usefulness and the limitations of the various methods, highlighted below:

- a. Petri dish mold counts are inexpensive, but biased toward heavier spores and spore clumping. Spores which prevail in the petri dish may not represent true air samples. They may also overestimate species tolerant to culture media.^{54, 55}
- b. Areas with visible mold or elevated surface mold counts typically indicate water leakage and may not be representative of airborne mold counts.⁵⁴
- c. Indoor air mold counts must be compared to concurrent outdoor counts from around the same area and should only be considered significant if greater than outdoor counts. An outdoor count taken from a shaded area with an aggregate of vegetation near an open window might indicate a mold source if compared to a representative sample from freely moving outdoor air. However, such a source should be obvious through observation alone, without needing to use time or resources on a mold count. Pruning of vegetation is recommended in such cases^{54, 55}
- d. During winter freeze, mold sources are frozen over and less likely to yield fungal spores. In patients with suspected environmental allergies in cold/wet weather who clinically improve during the winter, mold allergy is likely.

Outcomes related to mold intervention efforts have shown promise. Extensive interventions including cleaning of damaged areas and other moisture sources has also been shown to reduce asthma-related morbidity.⁴² In a population of asthmatics with in-home mold exposures, interventions combining education with in-home remediation efforts aimed at moisture reduction led to decreased symptom reporting and fewer health care visits.⁴²

Home and School-Based Interventions

In patients with one or more allergic sensitizations, the importance of a multi-faceted approach to allergen abatement is vital. The effectiveness of comprehensive home-based intervention in improving allergy and asthma-related morbidity has been a focus of research in recent years (Table 1).^{29, 42, 58–64} Combining disease-based education along with interventions (weatherization, home interventions including carpet replacement, moisture/mold reduction) may be beneficial in reducing asthma morbidity.^{29, 42}

As children spend a large percentage of their time in schools, attention has also been placed on allergen exposure in the school. Studies have found significant exposure to mouse and rat in schools but also exposure to cat, dog, cockroach, mold, and dust.^{15, 16, 21, 22} Beyond identifying exposures in the school, current research is underway to determine the impact of environmental interventions in the school on asthma morbidity in affected individuals. Based on knowledge of exposures in schools and the impact on student health, the United States Environmental Protection Agency's Indoor Air Quality Tools for Schools Program was created with the aim of improving environmental conditions in schools. This program provides schools with means to both assess and improve the school environment for the benefit of children's health. A key focus of this program is to improve conditions for children with allergies and asthma.⁶⁵ Study of the effect of comprehensive school-based intervention on asthma outcomes is underway in the School Inner City Asthma Intervention Study 2 (SICAS2), which will determine the health effects of a comprehensive intervention in Boston inner-city public schools (Clinical Trial: NCT02291302).

Future Directions

Newer technology and research for air purification has important implications for allergic and asthmatic patients. The temperature-controlled laminar airflow device is a new device that can be used at night to displace aeroallergens from the breathing zone of the allergic individual.³⁶ Use of this device is associated with improved quality of life and reduced airway inflammation.³⁶ In another study, installation of non-polluting, improved heating systems in the homes of asthmatic children led to decreased asthma symptom reporting in the intervention group vs. the control group, though there was no significant change in lung function in the study.⁶²

Beyond home-based interventions for exposure minimization, the concept of green housing has also been studied as a method to improve health outcomes in the allergic population. Green housing uses low-impact materials with the goal of energy efficiency and improved health effects.⁶³ In one study of a low income population, those in green vs. conventional housing had lower concentration of particulate matter 2.5 (PM_{2.5}), NO₂, and nicotine as

well as reduced mold and pest infestation.⁶³ After green housing was implemented into Chicago housing developments, self-reported asthma symptoms, quality of life, and other self-reported health measures were significantly improved.⁶⁴ In a study done in South Bronx, implementation of green housing led to decreased daytime and nighttime asthma symptoms and fewer urgent visits for asthma.⁶⁶ These interventions highlight important avenues for needed ongoing research, which may improve symptom control and create a cleaner environment in sensitive individuals.

The microbiome has gained attention in recent years as an important factor in the development of allergies and asthma. Early life microbial gut dysbiosis has been indicated in the development of atopy in humans.⁶⁷ Variations in the environmental microbiome have also been implicated in the development of atopic disease. In a study of children raised in inner-city environments, exposure to specific allergens and bacteria early in life were negatively associated with the development of atopy and wheeze.⁶⁸ In another study, children living on farms were exposed to greater environmental microbial diversity, which was associated with lower prevalence of asthma.⁶⁹ Future work is needed to further characterize the association between the gut and environmental microbiomes in the development of atopy and how knowledge of the complex interactions between the developing immune system and the microbiome may be used to guide future preventive measures.

Conclusion

Ultimately the goal of environmental intervention measures in the atopic patient should be aimed at reducing symptoms and improving quality of life. In the sensitized individual, a multifaceted approach to reducing exposure and abatement of the allergen reservoir may improve overall symptom control and quality of life. Future efforts should focus on effective ways of implementing more sophisticated home and school interventions as well as a greater understanding of the impact of clean air interventions on allergy and asthma. Finally, efforts should focus on advancing our understanding of the impact of the gut and environmental microbiomes on the development of atopy, as this may highlight new avenues for prevention and intervention.

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Abbreviations

HVAC	heating, ventilation, and air conditioning
HDM	household dust mites
HEPA	High Efficiency Particulate Arrestance
IPM	Integrated pest management

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Table 1

Home Intervention Studies

Author	Population	Design	Population Size	Intervention	Effectiveness of Intervention
Morgan et al. (2004)	Children with asthma (5–11y) (US)	Randomized Control Trial	937 total Intervention group: 468 Control group: 469	• Education and remediation for exposure allergens and smoke	<ul style="list-style-type: none"> • At each 2-week interval, the intervention group had fewer symptoms than control throughout the intervention year. • In the year following intervention, there were declines in allergen levels in homes (dust, cockroach). • Reduced allergen levels were significantly correlated with reduced asthma symptoms.
Kercsmar et al. (2006)	Children with asthma (2–17y) living in homes with mold (US)	Randomized Control Trial	62 total Intervention group: 29 Control group: 33	<ul style="list-style-type: none"> • Household repairs and modifications • Asthma education 	<ul style="list-style-type: none"> • At 6-months, intervention group showed reduction in mold scores; at 12 months both groups had significant reductions. • Remediation group had a significant decrease in symptom days ($p = 0.003$, as randomized; $p = 0.004$, intent to treat) after remodeling; control group did not significantly change. • Remediation group had a lower prevalence of exacerbations compared with control asthmatics (as treated, $p = 0.003$; intent to treat, $p = 0.11$).
Breyse et al. (2014)	Families with 1 or more children with asthma (3–17y) (US)	Quasi-experimental design	102 total Intervention group: 34 Control group: 68	• Weatherization-plus-health intervention and education compared to education alone	<ul style="list-style-type: none"> • Percentage subjects in the intervention group with not-well-controlled or very poorly controlled asthma decreased more than the comparison group ($P = .04$). • Intervention group caregiver quality-of-life improvements exceeded comparison group ($p = .002$) by 0.7 units. • Decrease in study home asthma triggers (evidence of mold, water damage, pests, smoking) was marginally greater than the comparison group decrease ($P = .089$). • The percentage allergen floor dust samples at or above the detection limit decreased (except mouse) decreased in the intervention group. Most reductions were not statistically significant.
Turcott et al. (2014)	Children with asthma (1–15y) (US)	Intervention design	170 total Intervention group: 116 households (170) Control: none	• Targeted household interventions and asthma education	<ul style="list-style-type: none"> • The study population had significant health improvements from baseline to follow-up related to asthma. • The cost of the interventions (not including personnel) was \$36,240, while the estimated medical savings over 4-weeks was \$71,162. The estimated annual savings was \$821,304.

Author	Population	Design	Population Size	Intervention	Effectiveness of Intervention
Lamphear et al. (2011)	Children with asthma (6–12y) living in homes with smokers (US)	Double-blind Randomized Control Trial	215 total Intervention group: 110 Control group: 115	• HEPA filters	<ul style="list-style-type: none"> • 25% reduction in particles counts > 0.3 µm in intervention group relative to 5% reduction in control group (statistically significant). • No statistically significant reductions in particle counts > 0.5 µm or in airborne nicotine. • In the intervention group, there were 42 fewer unscheduled asthma visits $P=0.043$ compared with control group, after adjustment for baseline differences.
Howden-Chapman et al. (2008)	Children with asthma (6–12y) (New Zealand)	Randomized Control Trial	409 total Intervention group: 200 Control group: 209	• Installation of a non-polluting heater (heat pump, wood pellet burner, or flued gas).	<ul style="list-style-type: none"> • Improvements in lung function were not significant. • Intervention group children had 1.80 fewer days off school (95% CI: 0.11 to 3.13), 0.40 fewer visits to a doctor for asthma (0.11 to 0.62), and 0.25 fewer visits to a pharmacist for asthma (0.09 to 0.32) than controls. • Children in the intervention group had fewer reports of poor health (adj. OR=0.48, 95% CI: 0.31 to 0.74), less sleep disturbed by wheezing (0.55, 0.35 to 0.85), less dry cough at night (0.52, 0.32 to 0.83), and reduced scores for lower respiratory tract symptoms (0.77, 0.73 to 0.81) than control children. • Lower NO₂ levels were measured in intervention living rooms than in those of the controls (geometric mean 8.5 µg/m³ v 15.7 µg/m³, $P<0.001$). A similar effect was found in children's bedrooms (7.3 µg/m³ v 10.9 µg/m³, $P<0.001$).
Colton et al. (2014)	Families living in public housing (U.S.)	Observational cohort	24 total Conventional: 6 in year 1; 13 in year 2 Green: 18	• Environmental sampling, home inspections, and health questionnaires in conventional vs. green housing	<ul style="list-style-type: none"> • There was 57% 65%, and 93% lower concentrations of PM2.5, NO₂, and nicotine (respectively) in green vs control homes ($p = 0.032$, $p < 0.001$, $p = 0.003$, respectively) • In green vs. conventional housing, there were fewer reports of mold, pests, inadequate ventilation, and stuffiness. • Differences in formaldehyde and CO₂ were not statistically significant. • Participants in green homes had 47% fewer sick building syndrome symptoms ($p < 0.010$).
Jacobs et al. (2015)	Public housing and low income subsidized housing (U.S.)	Mixed methods study	325 apartments total 803 individuals	• Green vs. control (dilapidated housing)	<ul style="list-style-type: none"> • Housing conditions and self-reported physical and mental health improved significantly in the green healthy housing study group compared with both the control group and the dilapidated public housing from which the residents moved • Symptoms including hay fever, headaches, sinusitis, angina, and respiratory allergy.

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Author	Population	Design	Population Size	Intervention	Effectiveness of Intervention
					<ul style="list-style-type: none">• Asthma severity measured by self-reported lost school/work days, disturbed sleep, and symptoms improved significantly• Sadness, nervousness, restlessness, and child behavior improved significantly.• Medicaid data in this exploratory study were inconclusive and inconsistent with self-reported health outcomes and visual assessment data on housing quality.