Housing and asthma disparities

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The burden of asthma disproportionately affects minority and low-income communities, resulting in racial and socioeconomic disparities in asthma prevalence, asthma exacerbations, and asthma-related death. Social determinants of health are increasingly implicated as root causes of disparities, and healthy housing is perhaps the most critical social determinant in asthma health disparities. In many minority communities, poor housing conditions and value are a legacy of historical policies and practices imbued with structural racism, including redlining, displacement, and exclusionary zoning. As a result, poor-quality, substandard housing is a characteristic feature of many underrepresented minority communities. Consequently, structurally deficient housing stock cultivates home environments rife with indoor asthma triggers. In this review we consider the historical context of urban housing policies and practices and how these policies and practices have contributed to the substandard housing conditions for many minoritized children in the present day. We describe the impact of poor housing quality on asthma and interventions that have attempted to mitigate its influence on asthma symptoms and health care utilization. We discuss the need to promote asthma health equity by reinvesting in these neighborhoods and communities to provide healthy housing. (J Allergy Clin Immunol 2021;148:1121-9.)

Key words: *Asthma, housing, disparities, structural racism, social determinants of health*

Abbreviations used
CAPP: Community Asthma Prevention Program
CHW: Community health worker
ED: Emergency department

In the United States, there are 5.1 million children with asthma, making it the most common chronic physical condition of childhood.[1] Although in recent decades advancements in medical therapy have contributed to an overall reduction in asthma morbidity and mortality, racial, ethnic, and socioeconomic disparities persist for asthma outcomes, including rates of asthma-related death, hospitalization, and emergency room visits.[2] The burden of asthma symptoms— sleep disturbance, activity limitation, and missed days of school and work—is disproportionately represented in underrepresented minority communities.[3-5] To better understand and address asthma disparities, researchers, clinicians, and policymakers have increasingly turned to the role of social determinants of health. Although health care access remains important, other factors account for a substantial portion of health outcomes.[6]

For asthma disparities, perhaps none of these social determinants are as critical as housing. A landmark Institute of Medicine report established that exposure to indoor allergens such as mold, cockroach, mouse, and dust mite allergens is common in substandard housing.[7] The overall level of disrepair in the home, particularly in low-income, urban communities, is an important determinant of the presence of environmental asthma allergens.[8] In this review, we will highlight studies linking indoor aeroallergens, housing conditions, and asthma outcomes, as well as interventions aimed at modifying allergen exposure and the structural housing components that give rise to these exposures, including early results of a major structural repair intervention that we conducted. First, however, we highlight the critical historical context that gave rise to racial and ethnic inequities in housing quality and neighborhood investment, as expectations for solutions to housing-mediated asthma disparities must be bound by a candid understanding of their complex causes.

THE CRITICAL CONTEXT OF HISTORY AND STRUCTURAL RACISM

Racial disparities in housing value and quality are downstream results of systemic and structural racism. There are several detailed accounts of how structural racism became a feature of US housing practices and policy.[9,10] An in-depth discussion of this complex history is beyond the scope of this review; however, several key practices and policies are germane to understanding current racial disparities in housing value and quality in the United States. These include redlining, a real estate practice of ranking non-White neighborhoods as credit unworthy that became codified in the federal housing policy from the

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1930s to 1960s through the Home Owner's Loan Corporation and Federal Housing Authority.[11] These federal organizations were designed to promote home ownership to low-income individuals by providing refinancing assistance and underwriting mortgage risk, but because of the explicit use of race and ethnicity data, only 2% of Federal Housing Authority mortgage insurance was available to non-White families.[12] Another practice, exclusionary land use zoning based on race and ethnicity, was deemed unconstitutional in 1917 but continued through the practice of zoning White, wealthy neighborhoods as exclusively single-family and low-density, thereby preventing the inclusion of multiunit buildings with affordable rent for low-income communities of color.[13] Although the Fair Housing Act of 1968 rendered these practices illegal, they created segregated neighborhoods in which residents were systematically denied mortgages on the basis of race. As a result, entire neighborhoods predominantly occupied by minorities were denied access to home ownership, which is a key component of multigenerational wealth building.[11]

The ongoing effects of exclusionary housing practices and their long-term economic consequences for residents are still felt in neighborhoods characterized by poor-quality, substandard, *unhealthy* housing. Greater housing deprivation leads to poor health, and sustained housing deprivation increases the probability of individuals having poor health as adults.[14] Historical oppressive housing practices have further resulted in limited housing choices for Black and Hispanic families.[11] Homeowners in these neighborhoods often have lower-paying jobs or less opportunity for better-paying jobs, resulting in limited income, which impairs their ability to maintain homes.[15] Black families are twice as likely to experience the burden of housing hardship—the ability of households to afford basic living needs and housing expenses.[11,16] The hardship of maintaining older homes results in defects in the building envelope, leading to conditions in the home that promote problems with pests, a leaking roof or ceilings, plumbing problems, holes or cracks in the walls or ceilings, and large dangerous holes in the floor.[17] Caregivers in low-income neighborhoods struggle to provide healthy housing. Healthy housing, a basic necessity, is a dream for the poor and yet is essential in promoting equitable asthma outcomes.

Box 1. Patient vignette

Sarah, a single mom and homeowner living in West Philadelphia, balances work, parenting, and homeownership, all in addition to managing the health of a child with a chronic disease—asthma. In the year before enrollment in the CAPP home visiting program, her 4-year-old daughter visited urgent care once and the ED 3 times, all for severe asthma exacerbations. As part of CAPP, she received in-home asthma education from her daughter's home visitor, along with trigger-mitigating supplies, including mattress and pillow covers, asthma-friendly cleaning materials, roach bait and mouse traps, and a new spacer and mask. Still, she had structural issues that the home visitor could not address. Fortunately, because she is a homeowner, she was eligible for the Children's Hospital of Philadelphia's CAPP Plus Home Repairs program, thanks to which substantial structural home repairs were completed to further reduce asthma triggers caused by mold and/or mildew, pests, and dust. Sarah was thrilled by the opportunity to make an even bigger impact on her child's health by having long-overdue repairs completed in her home. She said, "As a homeowner in West Philadelphia, repairs on a home are very, very hard, especially being a single mother."

Despite several months of delays due to the pandemic, since completion of the construction, her daughter's asthma has remained under control and exacerbation-free, not requiring a single ED visit or hospitalization. The repairs to Sarah's home included a new roof; an exhaust fan over the cooktop to remove nitrous oxide; new vinyl plank flooring replacing wall-to-wall carpeting in several rooms, including her daughter's bedroom; and a bathroom fan, clothes dryer vent to outside, and dehumidifier to reduce moisture throughout the house. Sarah is extremely grateful that her daughter's health has benefited so significantly from both the asthma education and the home repairs. She said, "I'm just really excited and really happy about my repairs and am so, so happy about my new house now."

IMPACT OF POOR HOUSING QUALITY ON ASTHMA

In-home asthma triggers

Exposure to indoor allergens is the direct pathway by which poor housing quality may affect asthma.[18] Early childhood exposure and sensitization to allergens found in substandard housing results in increased risk of incident asthma among those who are genetically predisposed.[19] Continued exposure to allergens may exacerbate asthma symptoms and increase ongoing risk of asthma morbidity even after adjustment for age, sex, race, and ethnicity.[20,21] In inner-city children, exposure and sensitization to multiple asthma triggers has been associated with asthma severity.[21,22] By 1 estimate, elimination of all identified residential risk factors for asthma would result in a 39% decrease in asthma in the United States.[23]

Pests such as cockroaches and rodents, which are more likely to be found in substandard housing, present a risk for children with asthma.[24] Children with asthma who have been sensitized to mouse allergen are at increased risk of unscheduled physician visits, emergency department (ED) visits, and hospitalizations when exposed to mouse allergens in the home.[25] Similarly, there is a dose response between exposure to cockroach antigen and asthma exacerbations.[22,26] Dust mites present in house dust can exacerbate asthma symptoms.[27,28] Finally, mold is a common in-home allergen associated with asthma exacerbations. Infants exposed to high concentrations of mold species common among water-damaged buildings were more likely to have asthma when they reached school age.[23]

Housing conditions and asthma triggers

A pooled analysis of 9 studies examined the relationship between housing conditions and the presence of asthma allergens.[29] In homes that have not been actively maintained, common structural issues facilitate allergen exposure. Water intrusion, which can stem from plumbing leaks, roof leaks, and unventilated or damp basements, may lead to mold development and attract pests. Cracks and holes in the walls, below-average housekeeping, and water leaks have been positively associated with cockroach allergen. Housing built before 1951 was associated

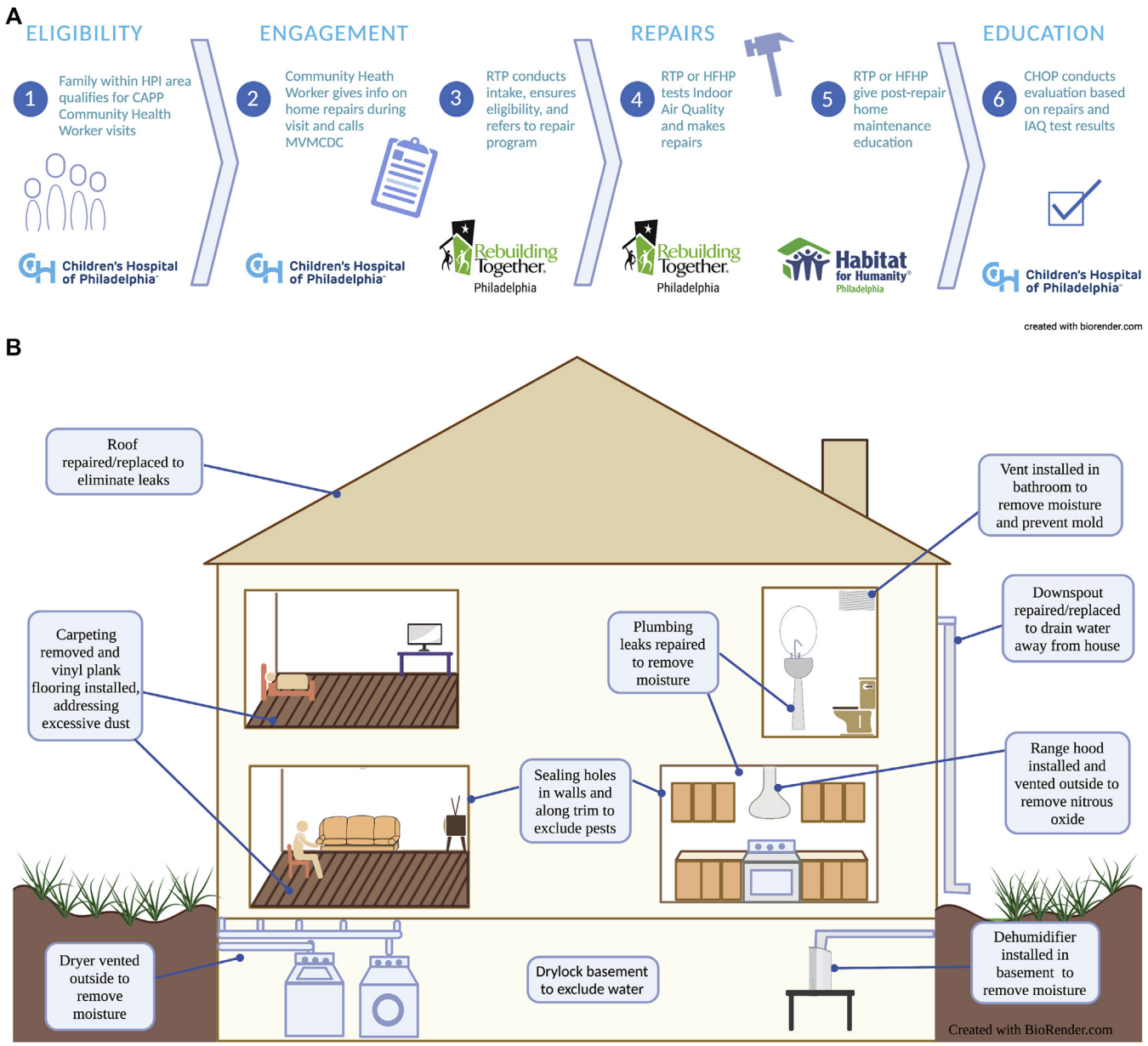

FIG 1. A, Collaboration of partner organizations to support a home repair program for children with asthma. **B,** Examples of home repairs completed. *CHOP*, Children's Hospital of Philadelphia; *HFHP*, Habitat for Humanity Philadelphia; *RTP*, Rebuilding Together Philadelphia; *MVMCDC*, Mt. Vernon Manor Community Development Corporation.

with elevated dust mite levels. Additionally, homes with basements or crawl spaces predicted increased allergens in the home. Carpets in older homes carry a large load of house dust, which can lead to exposures to dust mite, pet dander, and pests.[30]

Low-income households may face differing challenges in eliminating asthma allergens from the home. Although homeowners have autonomy in maintaining their home, the cost burden of improvements may make it difficult for low-income homeowners to complete repairs to address structural deficiencies that facilitate asthma triggers. Renters are less able to control the repairs in their homes, and landlords may not be aware of the impact of housing conditions on residents' asthma control.[31,32] Finally, when public housing is occupied by transient residents, it is more likely to have poorer-quality management and upkeep, resulting in conditions that facilitate the presence of asthma triggers.[33]

LEVELS OF INTERVENTION

Interventions aimed at reducing exposures to asthma triggers occur at 3 levels of intensiveness and investment: (1) multitrigger, multicomponent interventions; (2) single, targeted structural repairs; and (3) major structural repairs.

Multitrigger, multicomponent interventions

The US Centers for Disease Control and Prevention Task Force on Community Preventive Services recommends home-based,

FIG 2. Images of structural repairs done in homes.

multicomponent, multitrigger reduction interventions as an effective way to improve quality of life for children and adolescents with asthma.[34] Except for pests such as cockroaches and mice, targeting a single asthma trigger with environmental mitigation does not appear to be effective in improving asthma outcomes.[35] Therefore, interventions for reducing common triggers such as dust, cockroaches, mice, and mold require a multipronged approach. House dust mites can be reduced through multicomponent intervention, including removal of carpeting and mattress and pillow covers and implementation of targeted cleaning strategies. Cockroach and mouse allergens can be reduced through integrated pest management, which includes cleaning, exclusion practices (filling holes), and traps and nontoxic pest bait.[36] Presence of mold allergen requires better ventilation,

dehumidifiers, and repair of leaks. Studies that use skin testing to target areas of intervention and a more general approach of reducing common asthma triggers in the home with community health workers (CHWs) have been shown to be both efficacious in reducing asthma exacerbations and effective overall.[37-39]

Single targeted structural repairs

Single-intervention home repairs aimed at root causes of moisture damage, poor heating, and poor ventilation for children with asthma show some promise in reducing the presence of asthma triggers, although they generally do not address all asthma triggers in the home. In a pilot study of 72 children with asthma who lived in damp housing, interventions included installation of gas central heating units in 47% of homes, electric heaters in 37%, and solid fuel central heating in 12%. All respiratory symptoms improved, but nocturnal cough improved significantly from 3 nights to 1 night each month.[40] In another study, insulating homes led to self-reported improvement in symptoms and reduced sick visits and missed work and schooldays.[41,42] In a tailored package that combined both ventilation and heating, self-reported physical functioning improved among children with moderate-to-severe asthma.[43] Moisture reduction through targeted home repairs in addition to behavior interventions has also been associated with modestly improved asthma outcomes.[44]

Major structural repairs

Few studies have addressed comprehensive structural interventions aimed at the root causes of a compromised building envelope and internal structural deficiencies, likely on account of the expense of such an approach.[44-46] However, it is the logical next step, given the linkage between poor housing conditions and asthma outcomes. In the Breathe Easy Homes intervention, Takaro et al[46] moved 34 renter families into new homes containing added asthma-friendly elements (including moistureproof exteriors; heat exchange ventilation systems with filtration and continuous fresh air supply; and low-emission, low dust accumulation interior finishes) in addition to being built with both energy-efficient and sustainable products. When they compared the asthma outcomes of children who lived in those homes with those of children who lived elsewhere, they found that the improvement in nighttime symptoms was similar to the improvement in symptom-free days that was achieved as a result of 1 year of inhaled corticosteroid.[45] Gruber et al enrolled 42 families comprising a combination of homeowners and renters.[47] The US Department of Housing and Urban Development Healthy Home assessment (adapted for asthma triggers) was used at baseline to determine need for home structural and behavioral interventions. The repairs, which were prioritized to address mold and pest issues first and then heating, ventilation, and dust, included the repair of heaters and ventilation and creation of vapor barriers and carpet removal. The findings included reduced symptoms, improved quality of life, and reduced costs for hospitalizations.[46]

A NEW PROGRAM MODEL: LINKING MULTITRIGGER INTERVENTIONS WITH MAJOR STRUCTURAL REPAIRS IN PHILADELPHIA

Philadelphia is characterized by older row homes built at the turn of the 20th century. Our program, the Community Asthma Prevention Program (CAPP), utilizes a community-based approach to implement asthma education and asthma trigger remediation interventions in homes. In the past 20 years, we have conducted more than 20,000 home asthma education and trigger remediation visits for children with asthma. Unfortunately, because of the age of the homes and the consequences of historical redlining in Philadelphia, homeowners cannot always maintain their homes, limiting their ability to reduce exposure to asthma triggers. CHWs are often struck by gaping holes in walls and ceilings, improper ventilation, old and worn carpeting, and visible mold, all of which were not addressed by our original interventions (Box 1). For this reason, CAPP sought partners to expand in-home interventions to include structural repairs. With funding provided by our health system and the Build Health Challenge Grant (BUILD) initiative, we partnered with 2 home repair agencies, Rebuilding Together Philadelphia and Habitat for Humanity Philadelphia, to implement major structural repairs for homes to reduce the presence of in-home asthma allergens.

Families meeting the eligibility requirements of being a homeowner living in West Philadelphia and having a child enrolled in CAPP (eligible if the child has 1 asthma-related hospital visit or 2 ED visits in the past year) were offered CAPP Plus home repairs by Rebuilding Together Philadelphia or Habitat for Humanity Philadelphia. Once an eligible homeowner had been identified, the housing repair agency conducted the initial home inspection, created a work scope, reviewed that work scope with the homeowner, and assigned contractors to the job. Fig 1, *A*, illustrates how all partners were connected in implementing home repairs for children with asthma (Fig 1, *B*). The repairs focused on dust, mold, and pests (Fig 2); outcomes were the number of repairs completed and number of repairs needed, reduction in number of triggers, and reduction in asthma symptoms and health care utilization.

TABLE I. Characteristics of the children and households at time of enrollment in CAPP

Characteristic	No.	Percentage
Child characteristic		
Age (y)		
1-4	8	27%
5-9	14	46%
10-17	8	27%
Race		
Black	27	90%
Sex		
Male	15	50%
Female	15	50%
ED visit for asthma in the past 12 months, no. (%)	—	90%
Hospitalization for asthma in the past 12 months, no. (%)	—	86%
Household characteristic*		
General condition of child's bedroom		
Poor	4	14%
Fair	17	61%
Good	7	25%
General assessment of home's condition		
Poor	8	26%
Fair	17	57%
Good	5	17%

*Household characteristics were assessed by CAPP CHWs at the time of enrollment in the program.

TABLE II. Need for and completion of asthma-related structural repairs in the homes of children with asthma

Structural home repairs	Homes eligible for repair at initial walkthrough		Homes with repairs completed at final walkthrough	
	No.	Percentage of all homes	No.	Percentage of eligible homes that received the repair
Pest-related repairs				
Seal all accessible plumbing penetrations to exclude mice	22	81%	19	86%
Eliminate pests during demonstratoin: vacuum cockroaches, clean rodent sebum (rub marks), etc, cockroach frass (feces), and grease buildup, etc	19	70%	18	95%
Fill rodent holes with copper mesh and finish with spackle or patching cement	17	63%	15	88%
Repair subfloor and seal along walls to exclude rodents. Ensure that there are no gaps behind cabinets, etc	14	52%	12	86%
Seal cabinets to walls, floor, etc, with silicone caulk to deny pest access. Apply boric acid dust (cockroach prevention) into voids before sealing	14	52%	11	79%
Seal gaps and open joints in accessible HVAC ducts to reduce pest entry	13	48%	10	77%
Install wall or base cabinets in kitchen when they are badly damaged or missing, leading to insufficient storage for food	9	33%	7	78%
Mold-related repairs				
Ensure that the roof and building shell are watertight and properly shed water away from the home	23	85%	23	100%
Repair plumbing leaks in sinks, showers/tubs, toilets, supply lines, and/or drain lines	19	70%	18	95%
Correct improperly vented exhaust fan to exhaust outside	11	41%	10	91%
Install dehumidifier if humidity in the home is higher than 60% and homeowner understands the maintenance requirements and electricity costs	9	33%	7	78%
Dust-related repairs				
Paint with low–volatile organic compouind paint areas of the home where interior paint covering is chipped or peeling	16	59%	11	69%
Remove carpeting in living areas such as living rooms, dining rooms, and hallways and install smooth, cleanable flooring	13	48%	13	100%
Vacuum and clean grates and termination points in duct systems	12	44%	10	83%
Remove carpeting in the bedroom of the person with asthma and install smooth, cleanable flooring	11	41%	11	100%
Replace air filters on the heating/cooling system; install filter seals if the slot for the furnace filter allows air to bypass the filter	10	37%	8	80%

HVAC, Heating, ventilation, and air conditioning.
Homes were assessed for structural deficiencies at the time of enrollment in the home repair program and then again at the final walkthrough to ascertain whether each repair had been completed.

Demographics and living conditions

We enrolled 30 homeowners in the first cohort. Homeowners were primarily African Americans who were living with children between 2 and 17 years of age (Table I). According to the CHWs' observations at the initial home visit, only 25% of the children's bedrooms were in good condition and less than 20% of the general living conditions were rated as good.

Home repairs for asthma triggers

Most repairs identified at baseline were targeted to reduce pests, moisture, and dust (Table II). Repairs made to eliminate pests were primarily exclusionary in focus. For mold, repairs were made to eliminate sources of water intrusion and provide adequate ventilation. For dust, removing sources of dust in the living area and child's bedroom were the most common repairs (Figs 1 and 2). Parents reported a reduction in cockroaches, mice, and evidence of mold (Table III) at the 12- to 18-month postrepair survey.

TABLE III. Parental report of in-home asthma triggers before and after repair

Environmental asthma trigger	Before repair	After repair	*P* value*
Cockroaches	43%	13%	<.01
Rodents	57%	26%	<.01
Evidence of mold	53%	43%	.41

Before repairs, the presence of environmental triggers was indicated if either the parent or the CHW reported evidence of the trigger. Following repairs, all triggers were assessed by parental self-report.
*The McNemar test was used to examine changes in the number of households with each outcome between the prerepair and postrepair periods.

Asthma symptoms and health care utilization

Self-reported symptoms were used as a proxy for asthma control (Tables IV and V). The 12-month postrepair questionnaire revealed a nearly 50% reduction in nighttime symptoms, 40% reduction in use of rescue medication, and 60% reduction in missed school days, all of which indicate improved asthma control. Approximately 90% had an inpatient and/or ED visit in the year before enrollment in CAPP home visits. At 12 months, ED and hospital visits decreased by approximately 90%.

TABLE IV. Parental report of asthma symptoms before and after home repairs*

	Before repairs		After repairs	
Asthma symptoms	Mean	Percentage reporting any	Mean	Percentage reporting any
During the past 4 weeks, how many days did [child's name] have any daytime asthma symptoms (eg, wheezing, shortness of breath, tightness in the chest, or cough)?	1.9	70%	1.2	61%
During the past 4 weeks, how many nights did [child's name] wake up during the night because of asthma?	1.9	43%	0.5	22%
During the past 14 days, how many days did [child's name] use [his/her] quick-relief or rescue medicine (by pump or machine) to help stop asthma symptoms such as wheezing, shortness of breath, tightness in the chest, or cough?	1.7	62%	0.8	39%
In the past 4 weeks, on how many days did [child's name] have to slow down or stop [his/her] play or activities because of asthma symptoms such as shortness of breath, wheezing, tightness in chest, or cough?	1.7	60%	1.2	39%
There are many reasons why children sometimes stay home from school. During the past 12 months, how many days did [child's name] miss school because of asthma?	4.6	71%	0.8	30%
In the past 12 months, on how many days did you [or other caregivers] have to miss work to care for [child's name]'s asthma?	4.3	46%	0.4	17%

Asthma symptoms were assessed by parental self-report at the time of enrollment in CAPP, as well as at 12 months following completion of the home repair.

TABLE V. Parental report of health care utilization before and after repairs

	Before repairs		After repairs	
Health care utilization				
In the past 12 months, how many times has [child's name] made unscheduled visits to the doctor's office or clinic for urgent asthma care?	1.3	57%	0.5	22%
In the past 12 months, how many times has [child's name] been treated in the ED or emergency room for asthma?	1.3	90%	0.2	17%
In the past 12 months, how many times has [child's name] had to stay overnight for ≥1 night(s) in a hospital because of asthma?	1.0	86%	0.1	4%

Asthma morbidity was assessed by parental self-report at the time of enrollment in CAPP, as well as at 12 months following completion of home repairs.

Box 2. Qualitative feedback from homeowners

"Everything is really good. They just completed the basement steps. One person has to come out and change the address sign on the front. A lot of back and forth toward the end. But everybody was friendly, in and out, kept areas clean. Other than that, totally happy with the bathroom. Likes to just sit in the bathroom. I thank you for referring to the program, can focus on other little things. [She can focus on smaller repairs because the biggest repairs were taken care of]. We love Courtney [a CHW]."

"No more wheezing now. Everything is feeling good. Every month I'd go to the hospital. But now, everything is perfect. No more. They are taking their medications. They are doing good. Not like before. They helped me a lot for my kids."

"A lot of things on the list they did not get to because of the cost of other repairs. My expectations were high and I was excited for things to get done, but my home is a fixer upper. I am greatly appreciative, but I wish the homeowner had a say in what repairs were prioritized."

"Some contractors did not seem to be on the same page. The gentleman who did the work seemed to have a different vision than the project manager, and some things did not get done that the contractor said because the project manager did not agree."

"Best advice I would give is to be patient with the process and definitely use your voice even though ultimately the decision is not yours on what repairs are completed. I think this is a great opportunity. Thank you."

"I felt like my brothers and my father were working in my house. Let me tell you, everybody you sent to my house was so respectable, so down to earth, friendly, and did nothing but their job. To the point that I trust them. To the point where I could walk out my house and leave them."

Homeowner feedback

In general, homeowners were grateful for the repairs offered (Box 2), although some were disappointed that other major home repairs (not asthma trigger–related) could not be completed on account of budget restraints.

Pilot program summary

This pilot feasibility study combined an evidence-based CHW-led intervention with major structural housing repairs. We demonstrated the feasibility of health care organizations partnering with home repair agencies, with a signal for improved asthma control. Lessons learned include the importance of the following: setting expectations for homeowners at the beginning of the repair process, allowing homeowners to prioritize which repairs are made when possible, and having the CHW serve as the liaison between the homeowner and the contractor. Although we showed a decrease in symptoms and health care utilization, this was a pilot feasibility study in which follow-up data were collected during the COVID-19 pandemic. The early evidence shows that hospitalizations and ED visits for asthma decreased for all children with asthma during the pandemic, so future evaluations

including a control group will be necessary to expand on our findings.[48]

This demonstration of feasibility and signal for improved outcomes prompted an expansion of this program (CAPP Plus) funded by the Children's Hospital of Philadelphia, which is now approaching 100 completed homes. Our hope is to serve as a model for other health care organizations to leverage expertise across different sectors to improve children's lives.

DISCUSSION AND FUTURE DIRECTIONS

Although we have highlighted the results of several interventions with at least a signal of effectiveness, there is currently a paucity of rigorous research or evaluation of programs that complete targeted or major structural repairs to improve asthma morbidity. As stated earlier, this is likely due to the large financial investment necessary to complete such repairs at the scale necessary to show impacts on health outcomes. Other barriers beyond cost include the cross-sector collaboration and time-intensiveness of intervention planning and repairs, both of which require committed stakeholders, relationship building, and a shared vision of the goals. Given these barriers, a common critique of this intensive and expensive approach is the concern about return on investment, especially if funding for such interventions comes solely from the health sector. This critique may be appropriate if the only goal is improving narrow asthma-specific metrics such as symptom control or ED visits. But if the goal is to decrease or eliminate broader health disparities by investing time and effort to address their fundamental causes, including inhumane housing conditions and wealth inequality from centuries of policies imbued with varying degrees of structural racist practices such as redlining and exclusion, perhaps the return on investment critique is shortsighted in both time horizon and its underlying motivation. If we are to achieve health equity, we first must correct the wrongs of disinvestment in these communities by achieving adequate housing for all children, especially children with asthma.

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REFERENCES

1. Most recent national asthma data. US Centers for Disease Control and Prevention. Atlanta, GA: US Centers for Disease Control and Prevention; 2021. Available from: https://www.cdc.gov/asthma/most_recent_national_asthma_data.htm. Accessed June 29, 2021.
2. Akinbami L, Moorman J, Simon A, Schoendorf K. Trends in racial disparities for asthma outcomes among children 0 to 17 years, 2001-2010. J Allergy Clin Immunol 2014;134:547-53.e5.
3. Schwartz J, Gold D, Dockery DW, Weiss ST, Speizer FE. Predictors of asthma and persistent wheeze in a national sample of children in the United States: association with social class, perinatal events, and race. Am Rev Respir Dis 1990;142:555-62.
4. Gold DR, Wright R. Population disparities in asthma. Annu Rev Public Health 2005;26:89-113.
5. Gupta R. The widening Black/White gap in asthma hospitalizations and mortality. J Allergy Clin Immunol 2006;117:351-8.
6. McGovern L, Miller G, Hughes-Cromwick P. The relative contribution of multiple determinants to health outcomes. Bethesda, MD: Health Affairs Health Policy Brief; 2014. Available at: https://www.healthaffairs.org/do/10.1377/hpb20140821.404487/full/. Accessed June 20, 2021.
7. Institute of Medicine. Clearing the air: asthma and indoor exposures. Washington, DC: Institute of Medicine; 2000:105-221.
8. Rauh VA, Landrigan PJ, Claudio L. Housing and health: intersection of poverty and environmental exposures. Ann N Y Acad Sci 2008;1136:276-88.
9. Massey D, Denton N. American apartheid. Cambridge, MA: Harvard University Press; 1993.
10. Rothstein R. The color of law: a forgotten history of how our government segregated America. New York NY: Liveright Publishing; 2017.
11. Swope CB, Hernández D. Housing as a determinant of health equity: a conceptual model. Soc Sci Med 2019;243:112571.
12. Woods L, Shaw-Ridley M, Woods C. Can health equity coexist with housing inequalities? A contemporary issue in historical context. Health Promot Pract 2014;15:476-82.
13. Hirt, S. The rules of residential segregation: US housing taxonomies and their precedents. PP 2015 Mar; 30(3):367-395.
14. Desmond M. Heavy is the house: rent burden among the American urban poor. Int J Urban Reg 2018;42:160-70.
15. Carr JH, Kutty NK. Segregation: the rising costs for America. New York, NY: Routledge; 2008.
16. Rodems R, Shaefer HL. Many of the kids are not alright: material hardship among children in the United States. Children and Youth Serv Rev 2020;112:7.
17. Blake KS, Kellerson RL, Simic A. Measuring overcrowding in housing. Washington, DC: US Department of Housing and Urban Development, Office of Policy Development and Research; 2007. Available at: https://www.huduser.gov/publications/pdf/Measuring_Overcrowding_in_Hsg.pdf. Accessed June 23, 2021.
18. Institute of Medicine, Committee on the Assessment of Asthma and Indoor Air. Indoor biological exposures: cockroach. In: Clearing the air: asthma and indoor air exposures. Washington, DC: National Academy Press; 2000.
19. Burrows B, Martinez FD, Halonen M, Barbee RA, Cline MG. Association of asthma with serum IgE levels and skin-test reactivity to allergens. N Engl J Med 1989;320:271-7.
20. Poowuttikul P, Saini S, Seth D. Inner-city asthma in children. Clin Rev Allergy Immunol 2019;56:248-68.
21. Matsui EC. Environmental exposures and asthma morbidity in children living in urban neighborhoods. Allergy 2014;69:553-8.
22. Rosenstreich DL, Eggleston P, Kattan M, Baker D, Slavin RG, Gergen P, et al. The role of cockroach allergy and exposure to cockroach allergen in causing morbidity among inner-city children with asthma. N Engl J Med 1997;336:1356-63.
23. Reponen T, Lockey J, Bernstein DI, Vesper SJ, Levin L, Khurana Hershey GK, et al. Infant origins of childhood asthma associated with specific molds. J Allergy Clin Immunol 2012;130:639-44.e5.
24. Wang J, Visness CM, Calatroni A, Gergen PJ, Mitchell HE, Sampson HA. Effect of environmental allergen sensitization on asthma morbidity in inner-city asthmatic children. Clin Exp Allergy 2009 Sep;39:1381-9.
25. Matsui EC, Eggleston PA, Buckley TJ, Krishnan JA, Breysse PN, Rand CS, Diette GB. Household mouse allergen exposure and asthma morbidity in inner-city preschool children. Ann Allergy Asthma Immunol 2006;97:514-20.
26. Matsui EC, Perzanowski M, Peng RD, Wise RA, Balcer-Whaley S, Newman M, Cunningham A, Divjan A, Bollinger ME, Zhai S, Chew G, Miller RL, Phipatanakul W. Effect of an integrated pest management intervention on asthma symptoms among mouse-sensitized children and adolescents with asthma: a randomized clinical trial. JAMA 2017;317:1027-36.
27. Perzanowski MS, Chew GL, Divjan A, Jung KH, Ridder R, Tang D, et al. Early-life cockroach allergen and polycyclic aromatic hydrocarbon exposures predict cockroach sensitization among inner-city children. J Allergy Clin Immunol 2013;131:886-93.
28. Wilson JM, Platts-Mills TAE. Home environmental interventions for house dust mite. J Allergy Clin Immunol Pract 2018;6:1-7.
29. Morgan WJ, Crain EF, Gruchalla RS, O'Connor GT, Kattan M, Evans R 3rd, et al. Results of a home-based environmental intervention among urban children with asthma. N Engl J Med 2004;351:1068-80.
30. Wilson J, Dixon SL, Breysse P, Jacobs D, Adamkiewicz G, Chew GL, et al. Housing and allergens: a pooled analysis of nine US studies. Environmental Res 2010;110:189-98.
31. Elliott L, Arbes SJ, Harvey ES, Lee RC, Salo PM, Cohn RD, London SJ, Zeldin DC. Dust weight and asthma prevalence in the National Survey of Lead and Allergens in Housing (NSLAH). Environ Health Perspect 2007;115:215-20.
32. Grineski SE, Hernández AA. Landlords, fear, and children's respiratory health: an untold story of environmental injustice in the central city. Local Environ 2010;15:199-216.
33. Peters JL, Levy JI, Rogers CA, Burge HA, Spengler JD. Determinants of allergen concentrations in apartments of asthmatic children living in public housing. J Urban Health 2007;84:185-97.
34. Northridge J, Ramirez OF, Stingone JA, Claudio L. The role of housing type and housing quality in urban children with asthma. J Urban Health 2010;87:211-24.
35. Crocker DD, Kinyota S, Dumitru GG, Ligon CB, Herman EJ, Ferdinands JM, et al. Effectiveness of home-based, multi-trigger, multicomponent interventions with an

environmental focus for reducing asthma morbidity: a community guide systematic review. Am J Prev Med 2011;41(2 suppl 1):S5-32.

36. Cloutier MM, Baptist AP, Blake KV, Brooks EG, Bryant-Stephens T, DiMango, et al. 2020 focused updates to the asthma management guidelines: a report from the National Asthma Education and Prevention Program Coordinating Committee Expert Panel Working Group. J Allergy Clin Immunol 2020;146:1217-70.
37. Phipatanakul W, Cronin B, Wood RA, Eggleston PA, Shih MC, Song L, et al. Effect of environmental intervention on mouse allergen levels in homes of inner-city Boston children with asthma. Ann Allergy Asthma and Immunol 2004;92:420-5.
38. Leas BF, D'Anci KE, Apter AJ, Bryant-Stephens T, Lynch MP, Kaczmarek JL, Umscheid CA. Effectiveness of indoor allergen reduction in asthma management: a systematic review. J Allergy Clin Immunol 2018;141:1854-69.
39. Nurmagambetov TA, Barnett SB, Verughese J, Chattopadhyay SK, Hopkins DP, Crocker DD, et al. Economic value of home-based, multi-trigger, multicomponent interventions with an environmental focus for reducing asthma morbidity: a community guide systematic review. Am J Prev Med 2011;41:S33-47.
40. Turcotte DA, Alker H, Chaves E, Gore R, Woskie S. Healthy homes: in-home environmental asthma intervention in a diverse urban community. Am J Public Health 2014;104:665-71.
41. Somerville M, Mackenzie I, Owen P, Miles D. Housing and health: does installing heating in their homes improve the health of children with asthma? Public Health 2000;114:434-9.
42. Howden-Chapman P, Matheson A, Crane J, Viggers H, Cunningham M, Blakely T, Cunningham C, et al. Effect of insulating existing houses on health inequality: cluster randomized study in the community. BMJ 2007; 334:460.
43. Howden-Chapman P, Pierse N, Nicholls S, Gillespie-Bennett J, Viggers H, Cunningham M, et al. BMJ 2008;337:a1411.
44. Woodfine L, Neal RD, Bruce N, Edwards RT, Linck P, Mullock L, et al. Enhancing ventilation in homes of children with asthma: pragmatic randomised controlled trial. Br J Gen Pract 2011;61:724-32.
45. Kercsmar CM, Dearborn DG, Schluchter M, et al. Reduction in asthma morbidity in children as a result of home remediation aimed at moisture sources. Environ Health Perspect 2006;114:1574-80.
46. Takaro TK, Krieger J, Song L, Sharify D, Beaudet N. The breathe-easy home: the impact of asthma-friendly home construction on clinical outcomes and trigger exposure. Am J Public Health 2011;101:55-62.
47. Gruber KJ, McKee-Huger B, Richard A, Byerly B, Raczkowski JL, Wall TC. Removing asthma triggers and improving children's health: the Asthma Partnership Demonstration project. Ann Allergy Asthma Immunol 2016 May; 116:408-14.
48. Ulrich L, Macias C, George A, Bai S, Allen E. Unexpected decline in pediatric asthma morbidity during the coronavirus pandemic. Pediatr Pulmonol 2021;56: 1951-6.