Respiratory Riddles: Untangling How Home Weatherization Impacts Asthma and Respiratory Health

Bruce Tonn, Three[3]
Erin Rose, Three[3]
Michaela Marincic, Three[3]
Laura Humphrey, Three[3]
Justin Sharer, Slipstream
Shannon Stendel, Slipstream

ABSTRACT

This paper presents the results of a four-year study on the relationship between weatherization and respiratory health. Weatherization can reduce dust, draftiness and the infiltration of outdoor air pollution, allergens, and pests, and improve home conditions that improve sleep and mental health. All of these observed non-energy impacts (NEIs) of weatherization have been correlated with improvements in respiratory conditions such as asthma. While four rigorous evaluations of NEIs attributable to weatherization programs showed an improvement in IAQ, the studies did not find strong or consistent improvements in respiratory conditions post-weatherization. This study collected indoor air quality (IAQ) sensor data, conducted in-depth interviews with sufferers of chronic respiratory diseases, administered Asthma Control Tests, conducted whole home environmental assessments, and tested portable air cleaners (PAC) to further explore the relationship between weatherization and occupant respiratory health in single family homes. Weatherized homes have better IAQ post-weatherization than control homes, and environmental conditions of weatherized and control homes were similar. Portable air cleaners can significantly improve IAQ. Largely based on the results from the in-depth interviews, a strong conclusion from this study is that weatherization alone may be insufficient to overcome a lifetime of asthma and other respiratory problems and contributing co-morbidities. Blending weatherization and healthy-homes programs combined with asthma control education is expected to yield improved health outcomes.

Introduction

Energy poverty is a serious issue in the United States (U.S.) (Hernandez 2013) and elsewhere in the world (Boardman 2010). This type of poverty can negatively impact human health (Liddell and Morris 2010). Improving the energy efficiency of homes can improve general health (Willand 2015), mental health (Phillips et al. 2005) and social well-being (Gibson et al. 2011). Other research has found that weatherization can reduce thermal stress (Howden-Chapman et al. 2012; Ahrentzen et al. 2016; Alam et al. 2018), asthma (Howden-Chapman et al. 2008) and improve respiratory conditions (Rose et al., 2015). There is a long history in the U.S. of estimating the non-energy impacts (NEIs) of residential energy efficiency programs (Brown et al. 1993). Recent NEI research has more comprehensively encompassed the health impacts of low-income weatherization (Tonn et al., 2014; Tonn et al. 2023b).

This paper explores the relationship between weatherization and asthma. This is an important topic because asthma is a serious health issue in the U.S. and applicants for weatherization programs have higher rates of asthma than the general population.[1] The second section defines weatherization and presents a theoretical case for why industry experts expect weatherization could have beneficial impacts on asthma. Four weatherization NEI studies are introduced that suggest that at the very least the impacts of weatherization on asthma are mixed. The third section presents four hypotheses for why the data do not support the theory and the components of a research project designed to explore the hypotheses. The fourth section presents the results of the research, which supports only one of the four hypotheses; that weatherization by itself may be insufficient to overcome individuals' history of asthma and co-morbidities. The fifth section offers observations on these and the other findings and recommendations.

Weatherization and Respiratory Health Background

Low-income weatherization broadly refers to programs that install a comprehensive set of energy efficiency measures at no cost to income eligible households. Typical measures installed include air sealing, insulation, heating and cooling system repair and replacement, duct sealing and insulation, window and door repair and replacement, and water heater insulation, repair and replacement. The leading program in the U.S. is the Weatherization Assistance Program (WAP), which is administered by the U.S. Department of Energy (DOE). Utility companies and states across the U.S. also administer weatherization programs, often in conjunction with the local weatherization agencies that administer WAP.

There are several reasons why it is hypothesized that weatherization can decrease asthma symptoms. One is that air sealing can reduce the infiltration of outdoor air pollutants and allergens and intrusion of insects and other pests that could trigger asthma symptoms. Occupants consistently report that weatherization reduces dust and drafts (Tonn et al. 2014; Tonn et al. 2021b; Tonn et al. 2023a; Rose et al. 2022). Weatherization crews clean out heating, and air conditioning filters and dryer vents that may also be sources of airborne asthma triggers. Ventilation improvements can better control indoor humidity, which can result in reductions in mold and mildew. Improving home temperature, comfort, and decreasing the intrusion of outdoor noise by installing insulation and air sealing can reduce asthma symptoms by improving sleep and reducing stress (Tonn et al. 2014). Previous research has found that improving the energy efficiency of low-income homes can improve asthma (Howden-Chapman et al. 2008).

Four previous evaluations of the NEIs of weatherization programs led by the primary authors of this paper provide inconsistent results on the impact of weatherization on asthma symptoms. Each evaluation featured surveys of households living in treatment, control and comparison homes. Treatment homes were surveyed just before and one year after weatherization. Control homes were not weatherized and were surveyed at the same two times that the treatment homes were surveyed. Comparison homes were weatherized before the study period and were surveyed when the treatment homes were surveyed. The phone and paper surveys included questions about changes in home conditions and also changes in asthma flare-ups and the need for asthma-related medical interventions. The same questions were used everytime the survey was administered. Here are brief descriptions of the evaluated programs:

[1] Fourteen to nineteen percent of the main respondents of our NEI evaluation surveys report having asthma, as noted below, versus between eight and nine percent nationally https://aafa.org/asthma/asthma-facts/.

- Weatherization Assistance Program (WAP): WAP is a national weatherization program administered by the U.S. Department of Energy. This evaluation administered a national, pre-post weaatherization survey to WAP recipients and a comparison group in 2011 and 2012. The survey was limited to occupants of single-family homes. Over 1,400 households completed the pre-weatherization survey. 14% of the main respondents reported having asthma (Tonn et al. 2014).
- Knoxville Extreme Energy Makeover (KEEM): The Tennessee Valley Authority (TVA) provided funds to the City of Knoxville to weatherize low-income homes. The survey was administered in 2017 and 2018 to treatment, control and comparison homes (n=450). This survey was also limited to occupants of single-family homes. 15% of main respondents reported having asthma (Tonn et al. 2021).
- Low-Income Multi-Family (LIMF): This project focused on assessing the NEIs attributable to weatherizing affordable multi-family buildings of five or more units in the Northeast and Midwest regions of the U.S. The survey was administered to treatment, control and comparison homes in 2018 to 2019 (n=1900). 19% of main respondents reported having asthma (Tonn et al. 2023).
- Home Uplift Program (HUP): TVA provided the funding for this low-income weatherization program that was implemented in the four major cities in Tennessee: Knoxville, Nashville, Chattanooga, and Memphis. All HUP homes are located in a moderate climate zone. The resident survey was administered pre-post weatherization to treatment and control homes in 2018 and 2019 (n=1000). 15% of main respondents reported having asthma (Rose et al. 2022).

Households living in treatment homes receiving weatherization services reported substantial improvements in home conditions pre- to post weatherization. For example, 22% and 28% of HUP treatment households reported reductions in dust and drafts, respectively. The results for LIMF were reductions of 18% and 14% for dust and drafts, respectively. Treatment households surveyed as part of all four evaluations also reported decreases in the intrusion of outdoor noise and the frequency that they kept their homes at unhealthy temperatures. Occupants of treatment homes also reported improvements in physical and mental health and rest/sleep post-weatherization.

In contrast, the results with respect to asthma were mixed. Respondents who reported having asthma provided these results related to the asthma-related questions:

- WAP – The treatment group (n=93) reported reductions in asthma-related hospitalizations and emergency department visits, with the former being statistically significant (Tonn et al. 2014).
- KEEM – The treatment group (n=79) reported an increase in asthma-related medical attention needed pre- to post-weatherization whereas the control group (N=100) reported a decrease, though neither change was statistically significant (Tonn et al. 2021).
- LIMF – The treatment group (n=46) reported a small increase in urgent care visits, no change in hospital visits and a small decrease in emergency department visits whereas the control group (n=96) reported decreases across all three variables, with the change in hospitalizations being statistically significant (Tonn et al. 2023a).
- HUP – The treatment households (n=72) reported an increase in asthma symptoms, decreases in asthma-flare-ups and hospitalizations, and no change in emergency

department visits. The control households (n=57) reported the same results, with the exception being a decrease in emergency department visits. None of the changes were statistically significant (Rose et al 2022).

Given our seemingly strong theory of change and unanimous reported improvements in home conditions and general health, it is not an understatement to say that these results are unexpected.

Hypotheses and Research Design

Hypotheses

We developed four hypotheses that might explain why weatherization may not decrease asthma symptoms in accordance with our theory of change (Tonn et al. 2014) and tested them as described in the Research Design below.

- *Hypothesis 1 (H1): Weatherization worsens indoor air quality (IAQ)* – It could be that air sealing and insulation tighten homes so much that higher levels of air pollutants are trapped indoors in weatherized homes as opposed to unweatherized homes (e.g., particulate matter (i.e.,PM2.5) from cooking and smoking, volatile organic compounds (VOCs) from cleaning products). Both indoor average levels of pollutants and peak levels of pollutants could be higher in treatment homes post-weatherization. The mixture of indoor air pollutants could change from pre- to post-weatherization.
- *Hypothesis 2 (H2): Some unhealthy home environmental conditions are not addressed by weatherization* – Treatment homes could have worse environmental conditions (i.e. mold, mildew, standing water) pre-weatherization than control homes and weatherization may be unable to improve those conditions enough to reduce respiratory symptoms.
- *Hypothesis 3 (H3): Even improved IAQ does not lead to improvements in respiratory health* – Improvements in IAQ, which in this study encompass temperature, humidity, PM2.5, total VOCs (TVOCs) and CO2, may not lead to reducing asthma symptoms.
- *Hypothesis 4 (H4): Weatherization cannot overcome occupant lives and histories* – Weatherization's impact on asthma could be too weak to overcome the influences of individual's health histories, the severity of asthma, and co-morbidities (e.g., COPD).

Research Design

A three-year research project was launched in December 2022 to further explore the impacts of weatherization on asthma symptoms. The project focused on revisiting HUP treatment and control homes where at least one occupant reported having asthma, COPD or another respiratory issue. All of the homes in this study were single family. The project had two phases. The first phase included installing IAQ sensors, conducting home environmental assessments, and conducting in-depth asthma and respiratory issue interviews as described below:

- IAQ sensors – AWAIR Omni IAQ sensors were installed in 65 homes. The sensors collected data on temperature, humidity, PM2.5, TVOCs, and CO2 every 5 minutes. These data were collected to explicitly explore H1, whether IAQ in weatherized homes was worse than in unweatherized homes. Internet routers were provided to link the IAQ sensors to the cloud. The project paid the monthly internet bills. Data were collected from December 2022 to June 2025.

- Home Environmental Assessments – Research staff revisited homes during the first year of the project to do a walk through to note environmental problems that are not typically addressed during energy audits. Items on the walk-through checklist included signs of mold, moisture, dust, and pests. A short survey was also administered to the main survey respondent to gather more information about the condition of their home. These tasks were aimed at collecting data to explore H2.
- In-depth Asthma and Respiratory Issue Interviews – Main survey respondents who reported having asthma or another respiratory problem were interviewed by phone during the first year to support assessment of H4. Questions explored when they first were told they had asthma and how asthma has affected their lives. They were asked about their housing over their lifetimes and potential exposures to serious sources of outdoor air pollutants. They were asked about co-morbidities. They were also asked about their use of air fresheners and informal remedies for respiratory conditions.

The second phase entailed installing two devices to clean the air in treatment and control homes. One device was a conventional portable air cleaner (PAC). The second device was a DIY box fan with a MERV13 air filter attached, which was cheaper. The IAQ sensors remained in the home throughout data collection in the second phase. Plug load loggers were used to keep track of how often households used the portable air cleaning devices. A shortened and somewhat revised version of our NEI resident survey was administered just before the devices were installed and six to nine months after they were installed to collect data on changes in health and device acceptability. Asthma control tests (ACTs) were also administered regularly during this phase. The second phase of the project was designed to directly assess H3 and to provide insights valuable to weatherization and healthy homes programs about portable air cleaning devices.

Research Results

Table 1 presents demographics for the respondents who completed both the pre- and post-PAC intervention survey and characteristics of their homes. The respondents are overwhelmingly female and black. Consistent with other weatherization programs, the main respondents are older and have lived in their homes for many years. The remainder of this section addresses each of the four hypotheses introduced above.

IAQ – Weatherized Versus Unweatherized Homes

As noted above, IAQ data were collected during both phases of this project from weatherized and unweatherized homes. Figures 1, 2 and 3 present results for three IAQ measurements that can significantly impact respiratory health, PM2.5, TVOC, and CO2, respectively. Each figure presents the average daily maximum for each pollutant by weatherization category and whether smokers were reported living in the home. The background colors indicate thresholds used by AWAIR to indicate good (green), acceptable (yellow), moderate (orange) and poor (red) air quality with respect to each air quality measure.[2]

[2] https://support.getawair.com/hc/en-us/articles/19504367520023-Understanding-Awair-Score-and-Air-Quality-Factors-Measured-By-Awair-Element#h_01HE1QVJ86XD6SN7B20Y8CQH92

Table 1. Demographics and home characteristics

Gender	**Female**	**Male**	**Other**		
	85%	13%	2%		
Race/Ethnicity	**Black**	**White**	**Other**		
	81%	15%	4%		
Education	**GED or Less**	**Some College or Certification**	**College Degree**		
	42%	42%	16%		
Home Ownership	**Own**	**Rent**	**Other**		
	56%	43%	2%		
Home Type	**Single-Family Detached**	**Single-Family Attached**	**Mobile Home**	**Small Multifamily 2-4 units**	**Large Multifamily 5+ units**
	75%	6%	2%	8%	9%
Home Location	**Urban**	**Suburban**	**Rural**		
	65%	24%	11%		
Primary Fuel Types	**Space Heating: Electricity**	**Space Heating: Natural Gas**	**Water Heating: Electricity**	**Water Heating: Natural Gas**	
	69%	12%	83%	14%	
Primary Language	**English**				
	100%*				
Age (Avg.)	65 years				
Household Size (Avg.)	1.8 individuals				
Years in Home (Avg.)	16 years				

* Many respondents declined to answer this question about primary language.

The results presented in the Figures 1, 2, and 3 support the conclusion that IAQ is not worse in weatherized homes than unweatherized homes. In fact, the PM2.5 and TVOC results suggest that IAQ in weatherized homes is better than in unweatherized homes. This means that the air sealing, ventilation, and other measures installed in the weatherized homes improved air quality. The results with respect to CO2 suggest there is no difference between these two groups of homes. The results clearly show the negative impacts of smoking on indoor air quality.

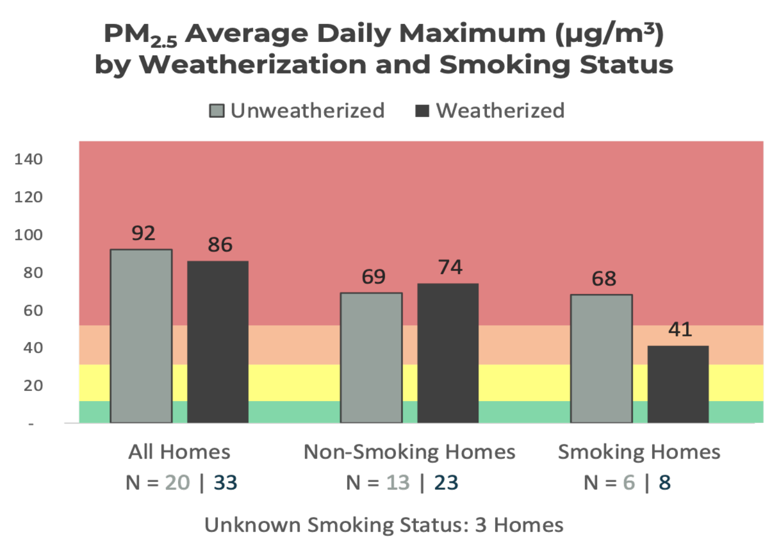

Figure 1. PM2.5 Weatherized and unweatherized homes

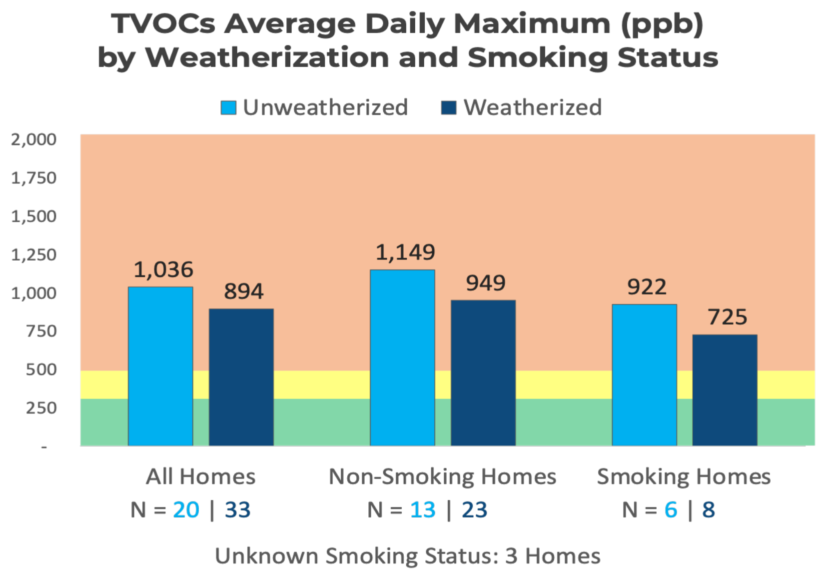

Figure 2. TVOC weatherized and unweatherized homes

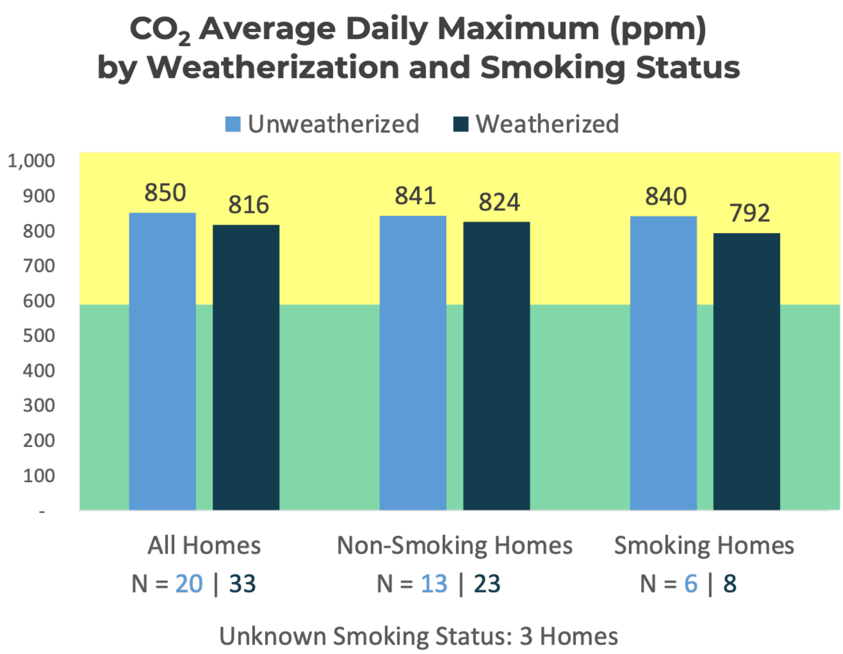

Figure 3. CO2 weatherized and unweatherized homes

Home Indoor Environmental Conditions

All of the homes in our study were revisited two to three years after weatherization but before the PAC intervention to conduct thorough home environmental assessments, which lasted an hour. The goal was to explore if home conditions were different between weatherized and unweatherized homes. Treatment homes in the study are older than the typical home in the state:

almost 70% of the sample was built before 1979 whereas the typical home in Tennessee was built in 1990. Older homes are likely to have more issues with mold, mildew, and standing water. Older housing stock is also more likely to expose residents to hazardous lead, asbestos, and radon (Laquatra, 2023) as aged building materials degrade. While radon and asbestos were not a part of the IAQ testing for this population, 69% of the homes had flaking, and peeling paint, an indicator of lead paint in homes built prior to 1978.

The assessments found that almost all of the mechanical systems were working well. Exceptions were these: one home had no air conditioning, one had only a window AC unit, and one home had no working heating system. However, some mechanical system maintenance issues were observed including leaking water heaters, disconnected or damaged ducts, improper exhausting, or complaints the systems “can’t keep up” with both extreme hot and cold temperatures.

Many of the home conditions listed in Table 2, such as visible dust, standing water, and signs of mold, were found less often in the weatherized homes (15%, 12%, 21%) compared to unweatherized (30%, 39%, 40%) homes. Weatherized and unweatherized homes had similar results for gutters and downspouts missing or needing repair, and roof leaks. A few conditions were worse in weatherized homes than unweatherized homes, including siding moisture damage and exterior door moisture damage. These results do not support the hypothesis that weatherized homes are in worse condition than unweatherized homes.

Table 2: Conditions observed during the home assessment

Assessed Home Conditions	**Unweatherized** (n=31)	**Weatherized** (n=34)	**Comparison**
Signs of a roof leak	17%	15%	2%
Siding moisture damage	15%	24%	-9%
Window exterior moisture damage	15%	21%	-6%
Exterior door moisture damage	15%	24%	-11%
Foundation moisture damage	19%	12%	7%
Signs of ponding/standing water	39%	12%	27%
Signs of water stains/cracks/flooding	32%	21%	11%
Ceiling cracked or damaged	27%	35%	-8%
Signs of mold or moisture	40%	21%	19%
Foundation drainage towards the house	27%	18%	9%
Gutters and downspouts missing or need repair	30%	27%	3%
Flaking/peeling paint	30%	29%	1%
Clothes dryer not vented to exterior	23%	27%	-4%
Bathroom fan does not vent to outside	13%	18%	-5%
Kitchen fan does not vent to outside	40%	32%	8%
Signs of a plumbing leak	17%	18%	-1%
Visible dust	30%	15%	15%

Residents were interviewed about home conditions while the home environmental assessment was conducted. The home interviews revealed that while the systems were operable, the respiratory health trigger relationship to hot and cold temperatures was still impacting occupants. Weatherized homes (45.5% reported uncomfortable temperature conditions) generally performed better with respect to comfort than the unweatherized homes (61.3% reported uncomfortable temperature conditions), but there were still a significant number of occupants reporting some type of health or comfort issue related to their heating or cooling or with drafts. Occupant responses include not using particular rooms during certain seasons, seeing daylight around the door, and drafts by the windows.

Table 3 presents a list of observations made during the home assessments that can be attributed more to human behavior than to the condition of the home. For example, dirty clothes, dryer ducts, and flooring can be attributable to occupant behavior. There is no pattern in these observations that could explain the lack of weatherization's impact on respiratory health. Overall, the results do not support the hypothesis that the indoor environmental conditions of weatherized homes were worse than the conditions inside control homes.

Table 3: Behavior-Related Conditions Observed During the Home Assessment

Behavior-Related Home Conditions	Control (n=31)	Weatherized (n=34)	Comparison
Dirty clothes dryer duct	37%	17%	20%
Carpet or flooring is noticeably dirty	33%	15%	18%
Signs of rodents indoors	0%	12%	-12%
Signs of bugs indoors	17%	12%	5%
Cluttered floor, surfaces, or debris	37%	32%	5%
Crawlspace/basement clutter debris	13%	24%	-11%
Visible cleaners/chemicals	63%	62%	1%
Signs of indoor smoking/vaping	13%	15%	-2%
Signs of candle, incense or air freshener use	37%	39%	-2%
Open food/drink containers	13%	21%	-8%

Impacts of Portable Air Cleaners on IAQ

Approximately one-year after participating homes received their IAQ sensors, portable air cleaners were installed (N=65). Our study evaluated three different PACs with varying functionality: Coway-AP-1512 Airmega, [3] IQAir Atem Desk Purifier, [4] and Lasko Slim 20" square box fan with a single 4" MERV 13 filter. [5] All devices are designed to clean air in a room, rather than a whole house. Additionally, each home received an Onset HOBO UX120-018 plug load logger to collect power usage data throughout the post-period.

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[3]Coway, Airmega mighty AP-1512HH manual. https://cdn.shopify.com/s/files/1/0351/1864/5383/files/AP-1512HH_AP-1512HH_W__MANUAL_US__COWAY_009__19.07.17.pdf?v=1591305459, (accessed 2 December 2025).

[4]IQAir, Atem desk air purifier: Technical specifications. https://cms.iqair.com/sites/default/files/documents/Atem%20X%20Tech%20Specs.pdf, (accessed 28 January 2026).

[5] CADR/Airflow values for the IQAir and AirMega are from product manuals, and the Box Fan is from research cited in the study. This design was chosen over a more complicated DIY box fan design to save space in smaller low-income homes.

The efficacy of a PAC depends on its usage, the location of deployment, fan airflow, filter effectiveness, and filter cleanliness. The effectiveness is measured by clean air delivery rate (CADR), which is the product of the airflow through the device, measured in CFM, and the percentage of particulate matter of a certain size category successfully removed in air that has passed through the filter, referred to as the fractional removal efficiency percentage (EPA 2018) Table 4 details air cleaner operation by air cleaner type. CADRs contextualize the air cleaning capabilities of the cleaners, runtime metrics provide information on the portion of the time the air cleaners operated during the post-period, cycle metrics provide insight into the usage habits of the residents (i.e. more cycles mean residents were turning the cleaners on and off more frequently), and energy use and cost detail the financial impacts of each air cleaner type and usage behavior.

Table 4: Annual usage patterns, energy usage, and cost per air cleaner type

Cleaner Model	**Technology CADR/Airflow** (CFM)[1]	**Average Annual Runtime** (Days)	**Range of Annual Runtime** (Days)	**Average Annual Number of Cycles** (On/Off)	**Estimated Annual kWh**	**Estimated Annual Cost**
IQAir (n = 21)	18	180	2-333	82	7.4	$ 0.83
AirMega (n = 4)	248	245	6-304	29	31.0	$ 3.49
Box Fan (n = 12)	150-203	78	0-272	76	77.0	$ 8.67

Figure 4 shows the pre- and post-period particulate matter concentrations per air cleaner type by days recorded by the PACs. The post-period in this figure shows when the device was powered on for more than 12 hours, isolating the IAQ levels to only when the air cleaner was being used for more than half the day. This method removes days when participants chose not to use the cleaner for more than 12 hours, but there still may be consequences of discretionary usage on these averages (i.e. participants may use the cleaners more often on days with higher or lower pollutant levels). These numbers thus do not represent unconditional post-period exposure. A benefit can be observed with both AirMega and box fan usage. There was a particularly notable PM2.5 reduction in the upper quartile of daily average concentrations, which were reduced by a factor of more than five and brought from levels above the EPA guideline threshold to levels below that threshold.

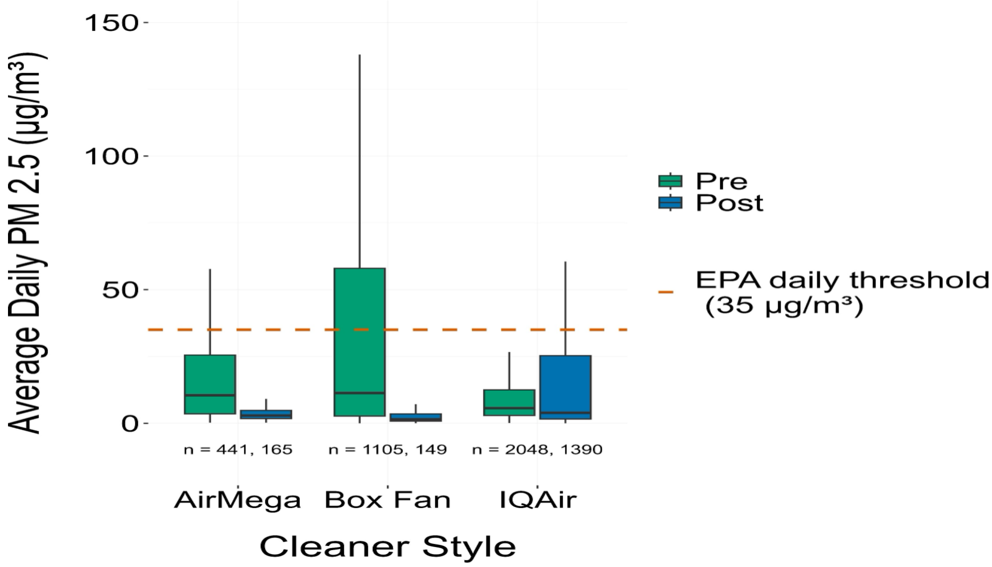

Figure 4: Distribution of daily PM2.5 levels pre- versus post-period per air cleaner type

PACs reduce home PM2.5 most effectively when running for many hours in a day, with CADRs also showing to be a significant factor for performance. Additional analysis showed PACs may accelerate PM removal during episodic pollution events as well. PACs use a small amount of electricity, with all models costing less than an estimated nine dollars a year to operate based on observed usage in the study. Effective air cleaner models therefore can represent a low-cost strategy for improving indoor air quality.

Overall, the PACs were frequently used, with 82% of recipients reporting that they used their PAC everyday whereas only 7% reported hardly ever using their PAC. 83% reported using their PACs while sleeping. Most reported not moving their PACs around the house: 74% did not move their PACs whereas only 4% reported moving their PACs often. A majority, 57%, reported that the noise of their PACs did not bother them whereas only 2% reported that the noise bothered them a great deal. Separately, a majority of users, 54%, checked their air quality monitor a few times a week to everyday, and 83% used their air quality monitor to improve their homes' IAQ. There were notable changes in behavior. Almost 40% kept their windows closed more often, 44% increased their use of ventilation, and 47% used air fresheners less often.

A short survey was administered pre-post PAC installation. The survey results presented in Tables 5 and 6 suggest that the PACs had positive impacts on respondent health. Bad days of physical health and mental health dropped substantially, and the respondents were more able to participate in usual daily activities. Over one-third of respondents reported it being easier to breathe and almost 20% reported a decrease in asthma symptoms. Many respondents reported coughing less, sleeping better, and going to the doctor less often. These results suggest that PACs could be an effective complement to basic weatherization to maximize health benefits for occupants.

Improved IAQ had positive impacts on some aspects of resident health, which does not support H3.

Table 5. During the past 30 days, how many days did you...(N=47)

	Not Enough Rest or Sleep	Physical Health Not Good	Mental Health Not Good	Physical or Mental Health Kept from Doing Usual Activities
Pre-Air Cleaner	9.3	9.7	12.5	9.4
Post-Air Cleaner	9.5	7.4	5.6	5.1

Table 6. Changes in health-related variables (N=47)

	Asthma Symptoms Decreased	Easier to Breathe	Sleep Better	Cough Less	Go to Doctor Less
Yes	19%	38%	30%	32%	13%
No	81%	62%	70%	68%	87%

Asthma Interview Results

In-depth semi-structured interviews were completed with 76 participants – in both treatment and control groups – to document and better understand impacts of environmental exposure and unique experiences with asthma across the lifespan. This examination of lifetime exposure and individual responses to those exposures helps to explain why we observe differences and inconsistencies in asthma and other respiratory health outcomes within and across weatherized and unweatherized study groups.

Although only 19% stated they were diagnosed with asthma as a child, the majority of study participants reported being exposed to a number of indoor and outdoor environmental hazards during childhood that are known to contribute to respiratory health challenges and asthma morbidity (Table 7). Exposure to environmental triggers included using wood and coal in the home for heating, exposure to smoke from parents or caregivers or from burning materials inside the home, and structural issues associated with older housing such as lead paint, poor insulation and unfinished basements. The conditions likely contributed to poor indoor air quality and increased exposure to respiratory irritants.

Environmental exposures were also present in the surrounding outdoor neighborhood environments for some participants (Table 8). They described both their homes and schools being near industrial areas, railroads or buildings later identified as containing hazards like lead and burning of plastics.

Table 7. Childhood exposures to indoor evidence-based asthma triggers

Survey Question	Response (n=66)
Heating fuel in childhood home	
Wood	27.3%
Coal	19.7%
Kerosene	6.1%
Childhood home had gas cooking stove	33.3%
Childhood home was dusty or dirty	19.4%
Exposed to burning of materials in childhood home	25.8%
Exposure to environmental tobacco smoke as child	69.6%

Table 8. Childhood exposures to outdoor evidence-based asthma triggers

Survey Question	Response (n=66)
Childhood home located in industrial area	10.1%
Childhood home near to industrial or chemical plants	42.4%
Childhood home near to highway, railway or airport	12.1%
Childhood home near to contaminated water or soil	9.1%

Conclusions, Recommendations and Limitations

Weatherized homes' IAQ and environmental conditions are similar to unweatherized homes. Observations about occupant behaviors provided no suggestions for any differences in respiratory health in the two groups of homes. PACs can improve IAQ and respondents report improved health post-PAC installation. The results refute three of the four hypotheses that guided this research. With respect to the fourth hypothesis, an important conclusion of this research is that weatherization alone may not be sufficient to overcome lifetimes of chronic respiratory problems and other co-morbidities to yield statistically significant respiratory health benefits. However, weatherization alone can lead to improvements in physical and mental health, sleep, and arthritis and can improve households' financial situations.

To consistently achieve respiratory benefits from weatherization, weatherization needs to be augmented. Blending weatherization with healthy homes programs can produce synergistic benefits for those with chronic respiratory diseases. Weatherization plus health programs are being tested across the U.S. but these programs have not been institutionalized nor supported with stable long-term funding. These programs could include resources for education around "Keep it Clean" and "Keep it Smoke-Free" principles and funding for PACs and IAQ monitors. The research indicates PACs were frequently used and, anecdotally, the IAQ monitors were frequently viewed and influenced behavior. Provisions should be made to revisit homes post-weatherization to help low-income households address severe deterioration of their homes that could adversely impact their health. These programs can cooperate with healthcare providers to provide asthma and other respiratory education at appropriate times during the weatherization process. These programs could also establish procedures to directly refer patients who could best benefit from weatherization plus health programs to those programs. Lastly, funding should continue to increase to improve weatherization of homes that would have been deferred for weatherization. This is because it is most likely that deferred homes are in worse condition and occupants could be suffering from worse health.

There are several limitations to this research worth noting. The sample size is limited in number and limited to single family homes in Tennessee, which is located in a moderate climate zone. The results could differ in hotter or colder climate zones, in areas with different levels of pollutants and allergens and for weatherization conducted in multifamily buildings. The project used commercially available IAQ sensors to reduce costs, but the sensors were limited in the number of pollutants that could be measured (e.g., radon, carbon monoxide and nitrogen oxides were not measured) and in the specificity of pollutants that could be measured (e.g., it was not possible to determine the composition of PM2.5 particles or the VOCs).

This project faced many in-field challenges. Internet routers replaced the original hotspots because the hotspots worked inconsistently. Many of the commercial IAQ sensors needed to be replaced due to a hardware update malfunction. Households frequently unplugged the sensors and routers. Cockroaches infested both devices, attracted to the warmth of the devices.

This project had a goal of contracting community-based organizations (CBO) to assist with the field work. This commitment proved challenging. One CBO went out of business. Another lost most of its staff. It was challenging to train CBO staff and for the CBOs to retain staff. Many lessons were learned that will benefit future in-field projects.

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References

Ahrentzen S, Erickson J, Fonseca E. 2016. "Thermal and health outcomes of energy efficiency retrofits of homes of older adults." *Indoor Air*. 26 (4): 582-593. doi:10.1111/ina.12239.

Boardman, B. 2010. *Fixing Fuel Poverty: Challenges and Solutions*. London: Earthscan.

Alam, M., Rajeev, P., Sanjayan, J., Zou, P., and Wilson, J. 2018. "Mitigation of heat stress risks though building energy efficiency upgrade: a case study of Melborne, Australia." *Aust. J. Civ. Eng.* 16 (1): 64–78, https://doi.org/10.1080/ 14488353.2018.1453331.

Brown, M., Berry, L., Balzer, R., and Faby, R. 1993. *National impacts of the weatherization assistance program in single-family and small multifamily dwellings*. in: ORNL/CON-326, Oak Ridge National Lab., TN (United States).

Building Performance Institute. 2015. *Building Science Principles Reference Guide*. 2nd Edition. Saratoga Springs, NY.

Gibson, M. Thomson, H. et al. 2011. "Understanding the psychosocial impacts of housing type: qualitative evidence from a housing and regeneration intervention." *Hous. Stud*. 26 (4) 555e573.

Hernandez, D. 2013. "Energy insecurity: a framework for understanding energy, the built environment, and health among vulnerable populations in the context of climate change." *Am. J. Public Health* 103 (4) e32–e34, https://doi.org/10.2105/ AJPH.2012.301179.

Howden-Chapman, P., Pierse, N. et al. 2008. "Effects of improved home heating on asthma in community dwelling children: randomised controlled trial." *Br. Med. J*. 337 1411a.

Howden-Chapman, P., Viggers, H., Chapman, R., O'Sullivan, K., Bernard, L., and Lloyd, B. 2012. "Tackling cold housing and fuel poverty in New Zealand: A review of policies, research, and health impacts" *Energy Policy*. 49 134–142, https://doi.org/10.1016/j.enpol.2011.09.044.

Laquatra, J. 2023. "Indoor Air Quality in Homes." *Journal Engineering, Technologies, and Informatics* 4, (3).

Liddell, C. and Morris, C. 2010. "Fuel poverty and human health: a review of recent evidence." *Energy Policy* 38 (6) 2987–2997, https://doi.org/10.1016/j. enpol.2010.01.037.

Phillips, D., Siu, O., Yeh, A., and Cheng, K. 2005. "The impacts of dwelling conditions on older persons' _psychological well-being in Hong Kong: the mediating role of residential satisfaction." *Soc. Sci. Med*. 60 2785–2797.

ROCIS 2022. *Reducing Outdoor Contaminants in Indoor Spaces (ROCIS), Insights from the Low Cost Monitoring Project (LCMP).* https://rocis.org/wp-content/uploads/2022_01-26_SW-PA-IPL.pdf, 2022 (accessed 12 December 2025).

Rose, E., Hawkins, B., Tonn, B., Paton, D., and Shah, L. 2015. *Exploring the Potential of Weatherization Plus Health Interventions on Asthma-related Medicaid Claims and Costs in Washington State*. ORNL/TM-2015/213, Oak Ridge National Laboratory, Oak Ridge, TN, September.

Rose, E., Marincic, M., Tonn, B., and Hawkins, B. 2022. *TVA Home Uplift Metro Areas: Final Report on Non-Energy Impacts*. Three[3], Inc., Knoxville, Tennessee, March.

Sussman, R. 2025. *Need for Repairs Is Blocking Weatherization in a Fifth of Eligible Homes*. American Council for an Energy Efficient Economy (ACEEE), Washington, DC.

Tonn, B., Rose, E., Hawkins, B., and Conlon, B. 2014. *Health and Household-Related Benefits Attributable to the Weatherization Assistance Program.* ORNL/TM-2014/345, Oak Ridge National Laboratory, Oak Ridge, TN, September.

Tonn, B., Hawkins, B., Rose, E., and Marincic, M. 2021a. "Income, Housing and Health: Poverty in the United States Through the Prism of Residential Energy Efficiency Programs." *Energy Research & Social Science* 73, 101945.

Tonn, B., Rose, E., Hawkins, B., and Marincic, M. 2021b. "Health and financial benefits of weatherizing low-income homes in the southeastern United States." *Build. Environ*. 197 #107847.

Tonn, B., Hawkins, B., Rose, E., Marincic, M., Pigg, S., and Cowan, C., 2023a. "Saving lives by saving energy: examining the health benefits of energy efficiency in multifamily buildings in the United States." *Build. Environ* 228 109716.

Tonn, B., Marincic, M., and Rose, E. 2023b. "A Dollar Well Spent: Monetizing the Societal Benefits of Low-Income Weatherization Programs in the United States." *Energy Research & Social Science* 107, 103341.

U.S. Environmental Protection Agency 2018. *Indoor Environments Division, Residential air cleaners - A technical summary (3rd Edition)*. Office of Radiation and Indoor Air, https://www.epa.gov/sites/default/files/2018-07/documents/residential_air_cleaners_-_a_technical_summary_3rd_edition.pdf, (accessed 2 December 2025).

Willand, N., Ridley, I., and Maller, C. 2015. "Towards Explaining the health impacts of residential energy efficiency interventions – _a realist review. Part 1: pathways." *Soc. Sci. Med*. 133 191–201.