IMPACTS OF WEATHERIZATION ON TEMPERATURE, HUMIDITY, AND OCCUPANT WELL-BEING IN THE TENNESSEE VALLEY
FINAL REPORT

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Acronyms and Abbreviations

AC	Air Conditioner
CAC	Knoxville-Knox County Community Action Committee
CARE	Center for Applied Research and Evaluation
COPD	Chronic Obstructive Pulmonary Disease
DOE	U.S. Department of Energy
EPB	Electric Power Board (of Chattanooga)
ETS	Environmental Tobacco Smoke
FPL	Federal Poverty Line
HVAC	Heating, Ventilation and Air Conditioning
IEQ	Indoor Environmental Quality
KUB	Knoxville Utility Board
LPC	Local Power Company
Metro Area	Metropolitan Area
MLGW	Memphis Light, Gas and Water
NEI	Non-Energy Impact
QoL	Quality of Life
SEEED	Socially Equal Energy Efficient Development
SDOH	Social Determinants of Health
SPSS	Statistical Package for the Social Sciences
TN Valley	Tennessee Valley
TVA	Tennessee Valley Authority
UT	University of Tennessee
WAP	Weatherization Assistance Program
Wx	Weatherization
Yr	Year

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Executive Summary

This report contains results from the indoor environmental quality (IEQ) evaluation conducted on the Tennessee Valley Authority's (TVA) Home Uplift weatherization program from 2021-2022. The research team sought to measure the impacts of weatherization on indoor temperature and relative humidity in addition to occupant comfort, health, and well-being. As part of this study, the team conducted both a qualitative phone survey with program participants and in-home IEQ monitoring in the period leading up to and following weatherization. Pre- and post-weatherization surveys captured occupant's subjective feeling of comfort in the home in addition to outcomes such as seeking medical care for exposure to extreme temperatures, asthma, chronic obstructive pulmonary disease (COPD), or arthritis. The survey also explored physical conditions and energy-related hardships in the home, such as whether heating, ventilation and air conditioning (HVAC) equipment functioned properly prior to weatherization, whether mold and moisture were present in the home, and the level of financial burden imposed by energy bills. IEQ monitoring was conducted by placing loggers in program homes to measure indoor temperature and relative humidity one month before and one month after weatherization. The results of this evaluation indicate that weatherization programs could provide meaningful benefits for occupants by reducing indoor exposures to extreme hot and cold temperatures, particularly for those with a chronic health condition that is exacerbated by extreme temperatures, such as asthma, COPD, or arthritis.

Evaluation Objectives

This study sought to measure changes in indoor temperature and relative humidity in homes following weatherization upgrades, as well as the resulting impacts on occupant health and well-being. Previous evaluations of low-income weatherization programs have shown that recipients report that the temperature in their homes is more comfortable following the home upgrades, and they report fewer instances of requiring medical care for exposure to heat and cold inside their homes. However, fewer studies have verified these improvements in indoor environmental quality (IEQ) through direct measurement. Therefore, we sought to fill this gap in the evidence for the beneficial impacts of weatherization on IEQ and human health.

Evaluation Outcomes

Across the three sampling periods, the team recruited 45 participants during the winter heating season and 56 participants across the two summer cooling seasons. Of these, 41 winter participants and 48 summer participants returned complete pre- and post-weatherization logging data due to a combination of nonresponse, technical issues with the loggers, and delays in weatherization work schedules that prevented post-weatherization monitoring during the appropriate season. Similarly, 43 winter participants and 48 summer participants completed both the pre- and post-weatherization health and household surveys.

Key Findings

Survey findings revealed that before entering into the Home Uplift weatherization program household members struggled to maintain healthy indoor temperatures during both cooling and heating seasons. Respondents also reported high levels of chronic illnesses that worsen when it is too hot or cold. Significant reductions in homes being too hot or cold were observed in the post-weatherization survey responses. Improvements in indoor temperature and environmental quality were supported by the logger data from program homes. Analysis of indoor temperatures indicated that homes were 1.1-2.1°F cooler on average in the summer following weatherization, and this result held for all outdoor temperatures between 65 and 95°F (data were insufficient above 95°F). In the winter, homes were 1.0-2.5°F warmer after weatherization when the outdoor temperature was between 15-45°F; results also trended warmer between outdoor temperatures of 45-65°F, but they were not statistically significant. The logger data indicate no consistent changes in moisture levels indoors, though indoor dew point was still responsive to outdoor conditions following weatherization during the heating but not cooling season.

Survey Results Highlights

- Recipients had high rates of health conditions known to be affected by IEQ & many reported improvements following Home Uplift.
- Findings suggest Home Uplift might also prevent severe outcomes associated with extreme indoor temperatures.

IEQ Monitoring Results Highlights

- Home Uplift kept homes cooler in summer and warmer when temperatures were < 45°F.
- Home Uplift had the greatest impact in homes with more extreme indoor temperatures prior to weatherization.

Variation was observed across the metro areas, with Knoxville suggesting the strongest improvements during summer and Chattanooga showing the strongest improvements in winter. These differences are likely due to differences in climate and housing supply quality.

Recommendations for Future Work

This work demonstrated the feasibility of incorporating environmental quality monitoring into standard weatherization program operations with minimal disruption or additional burden for implementers and installers. Building on this successful partnership, the team recommends expanding the scope to incorporate monitoring of other important health hazards such as particulate matter and nitrogen dioxide (NO_2). This monitoring will allow the program to more demonstrably show the underlying mechanism of health benefits associated with weatherization and how the program acts as a protective factor against predicted rises in environmental and air quality hazards associated with climate change.

Additional considerations for future studies or practice:

- **Conduct monitoring in homes near highways & high-traffic roads**, which are exposed to higher levels of pollution resulting from vehicle exhaust.
- **Measure whether weatherization protects against infiltration** of wildfire smoke and other outdoor pollutants, both natural and human made.
- **Incorporate loggers into home upgrade programs** to continue monitoring performance as part of quality assurance and program evaluation.

1. Introduction

It is widely accepted that low-income weatherization programs can reduce households' energy costs and produce multiple household and societal benefits, also referred to as non-energy impacts (NEIs). However, less well studied is the impact weatherization has on indoor environmental quality (IEQ), particularly in warmer and humid climates such as the Southeast. There have been studies to measure changes in indoor temperature attributable to the national Weatherization Assistance Program, but these often pre-date modern ventilation standards and developments in energy efficiency and do not generally include other measures of IEQ or direct monitoring.[1][2][3] Multiple guidelines exist to ensure safe and habitable conditions following weatherization, but it is important to measure real-world results where IEQ can be affected by occupant behavior and extreme weather and outdoor conditions. It is also valuable to learn more about IEQ in homes prior to weatherization in order to more holistically measure the benefits experienced by these households.

Findings from this work could be used to meaningfully engage energy, housing, and health sectors using data resources and findings that illustrate the intersection of energy, housing and health for low-income populations across the TN Valley, the Southeast and the U.S. Outcomes have been shared with participating and non-participating local power companies (LPCs), community partners, philanthropies, and industries as partners and beneficiaries of this work. This evaluation serves to inform future work completed through Home Uplift to successfully fulfill TVA's mission to "make life better for the people of the Tennessee Valley."

Evaluation Overview

Three[3] was contracted by the Tennessee Department of Environment and Conservation to measure changes in IEQ in homes receiving weatherization through the Home Uplift program (see "Background on the Home Uplift Program" below). The team aimed to recruit 40 households during the cooling season and 40 households during the heating season across the four major Tennessee metro areas: Memphis, Nashville, Chattanooga and Knoxville. Each home would complete a survey about perceived IEQ and its impacts on their health and safety, including questions about health conditions that are commonly affected by temperature and humidity: asthma, COPD (Chronic Obstructive Pulmonary Disease), and arthritis. In addition, each home received a data logger approximately four weeks prior to weatherization; the logger recorded the indoor temperature and relative and humidity every 10 minutes, and participants kept the loggers in their homes until 4 weeks after the weatherization work was complete, or until the heating/cooling season ended, if the weatherization work was delayed.

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[1] Ternes, M. P., Boercker, F. D., McCold, L. N., & Gettings, M. B. (1988). (rep.). *Field Test Evaluation of Conservation Retrofits of Low-Income Single-Family Buildings in Wisconsin: Summary Report* (Ser. ORNL/CON-228/P1). Oak Ridge, TN: Oak Ridge National Laboratory.

[2] Ternes, M. P., Hu, P. S., Williams, L. S., & Goewey, P. B. (1991). (rep.). *The National Fuel End-Use Efficiency Field Test: Energy Savings and Performance of an Improved Energy Conservation Measure Selection Technique* (Ser. ORNL/CON-303). Oak Ridge, TN: Oak Ridge National Laboratory.

[3] McCold, L., Goeltz, R., Ternes, M., & Berry, L. (2008). (rep.). *TEXAS FIELD EXPERIMENT: Performance of the Weatherization Assistance Program in Hot-Climate, Low-Income Homes* (Ser. ORNL/CON-499). Oak Ridge, TN: Oak Ridge National Laboratory.

Background on the Home Uplift Program

Home Uplift is a low-income weatherization project funded by TVA and participating LPCs in its jurisdiction. Energy efficiency upgrades through Home Uplift weatherization typically include air sealing and insulation measures, heating and air conditioning equipment maintenance and replacement, heat pump water heater installation, window and door replacement, refrigerator upgrades, LED bulbs, and low-flow showerheads. The four major metro areas in TVA's region participated in the pilot: Knoxville, Nashville, Chattanooga, and Memphis, Tennessee. Other pilot locations included Huntsville, Alabama, 4 County Mississippi and the Western Kentucky Rural Electric Cooperative territory. Home Uplift's eligibility requirements and weatherization procedures were modeled after the U.S. Department of Energy's Weatherization Assistance Program (DOE WAP).

Report Outline

Section 2 of this report contains the methodology underlying the evaluation and monitoring of indoor environmental quality in homes participating in Home Uplift. Section 3 discusses findings from surveys conducted with participants both four weeks prior to weatherization and four weeks after the work was completed. Section 4 reports on the output from the IEQ loggers and analysis of weather-normalized monitoring results. Concluding thoughts are found in Section 5.

2. Methodology

This section explains the research design developed for this project and the objectives for different evaluation activities. Data loggers were placed inside homes to record indoor temperature and relative humidity every ten minutes in the weeks leading up to and after weatherization. A household survey was designed to capture residents' observations about IEQ in their home and collect information on health conditions that may be particularly impacted by poor IEQ. Surveys were administered over the phone pre- and post-weatherization with enough time (> 4 weeks) to allow for household observations of change – if any. Data loggers also recorded indoor temperature and relative humidity every ten minutes in the weeks leading up to and after weatherization. Households participated in either a cooling season or heating season; the same households were not monitored during both seasons.

Survey Design

The survey instrument was designed to capture the following information: household demographics, dwelling quality including thermal comfort and exposure to indoor environmental hazards; general health and well-being; health status, symptoms and healthcare encounters for select health concerns; and energy affordability (Table 1). The majority of survey questions were drawn from pre-existing survey instruments used by the study team in other weatherization evaluation work. As a form of best practice, survey questions from government sponsored research and tracking mechanisms are used for comparability.

Table 1: Survey Categories, Indicators, and Metrics Information

Survey Categories	Indicators and Metrics	Number of Variables
Indoor Temperatures	**Temperature Exposure**: extreme temperatures (2), thermal stress (2); **Housing characteristics**: HVAC use (4), broken heating/cooling equipment (2), **Behavior**: thermostat settings (2) **Adequate Housing**: mold and standing water (2), temporarily moved out due to housing habitability issues (1)	15
Health Status	**General health:** temperature interferes with sleep (1); **Asthma:** prevalence and status (4); **COPD**: prevalence (2), healthcare utilization (1); **Arthritis**: prevalence and status (3), healthcare utilization (2)	13
Hardship	**Financial burden**: difficulty paying for energy (1), utility disconnection (1); **Stressors**: worries about not having heating, cooling, or electricity (1)	3
Demographic Variables	age (1), gender (1), race/ethnicity (2), veteran status (1), household size (1), years lived in home (1)	7
Total Number of Questions in Final Survey Instrument		**38**

On average, the survey took approximately 5-10 minutes to administer over the phone. Households received $40 for their participation in the pre-weatherization tasks including 1.) placement of the data logger inside their home and 2.) completion of the survey. Households received another $40 for completion of post-weatherization tasks that included the return of the data logger (in a pre-paid envelope) and completion of the post-weatherization survey.

Survey Analysis

Survey responses were analyzed within each cohort – Summer 2021, Winter 2021/22, and Summer 2022 – as well as across all cohorts as an aggregate. Every question was analyzed in Excel and SPSS according to the number and percent of responses in each answer category; there were no open-ended questions.

IEQ Data Logger Deployment

IEQ monitoring was conducted with HOBO Onset UX100-003 devices, which are rated for indoor use for the purposes of measuring temperature and relative humidity with high accuracy (±0.38°F from 32° to 122°F, ±3.5% from 25% to 85%; ±5% typically below 25% and above 85%). They have an estimated drift of 0.18°F and <1% per year for the temperature and humidity sensors, respectively. Loggers were set to record temperature and humidity every 10 minutes and stored this data locally. Following the informed consent procedure, a logger would be set up to begin data collection and mailed to the participant. Participants were asked to hang the logger from their thermostat, or if they did not have a thermostat, in a centrally located room or hallway away from windows and doors to prevent exposure to direct sunlight or drafts from outdoors. The research team then called participants and recorded the date, time and location where the logger was placed in the home.

Participants were asked to keep the logger in the same place in the four weeks leading up to weatherization and then for four weeks after the work was completed, generally leading to 8-10 weeks of data, though in some cases production delays lead to longer logging periods. There were a limited number of cases in which the first logger never arrived, and a new logger had to be sent, shortening the pre-weatherization logging period. After four weeks of post-weatherization data collection, participants were sent a postage-paid envelope to return the logger.

IEQ Data Analysis

The data were extracted from each logger as a CSV file using HOBOware software by Onset. These data were then restricted to the period between when the participant hung the logger in their home and when the return envelope was mailed to them; the weatherization installation period was also extracted due to IEQ fluctuations that can result from changing out HVAC equipment or workers frequently coming in and out of the home. This data cleaning allowed for valid comparisons between the strictly pre- and post-weatherization periods.

In addition to initial data cleaning, an integral part of the IEQ data analysis involved incorporating weather data to control for differences in outdoor temperature and humidity across the logging period and between study locations. Weather data were acquired from Visual Crossing due to its comprehensiveness, accuracy, and detail. Hourly data on temperature and humidity, among other factors, were downloaded for each town or metro included in the study. The logger data were then averaged at the hourly level and merged with the weather data for that location. A new variable “Outdoor Temperature Bins” was created to bin the data points into 5-degree ranges of outdoor temperatures. An additional variable "Daytime" was created as a binary indicator of whether the observation was recorded during the daytime or nighttime, due to differences in the microclimate from day to night. Daytime was defined as between 6a and 8p during the summer and between 7a and 5p during the winter based on average hours of daylight for Tennessee.

Data analysis and visualization comprised of two main stages. The first stage looked at each home individually, comparing trends in indoor temperature from before weatherization to after under different outdoor weather conditions. This analysis allows us to see how each home “behaved” in the absence of weatherization: whether it was staying at a steady temperature or fluctuating, and whether the temperature was staying within an optimal range for human health, even when the outdoor temperature reached extreme highs or lows. We can then compare this behavior to the post-weatherization period to see if the home temperature is remaining steadier and within a more appropriate range, indicating improved resilience and healthier conditions.

The second stage of analysis then aggregated data across all homes to assess macro trends and the overall effectiveness of the program. In this stage, we took the difference of the pre- and post-weatherization data for each home to measure changes in average temperature, humidity and dew point under different weather conditions. We then calculated the average change and confidence interval across all homes for each measure at different ranges of outdoor temperatures. This indicates how weatherization’s impact varied during moderate versus extreme outdoor temperatures.

Evaluation Limitations

As a pilot study, this research aimed to 1) test the feasibility of incorporating IEQ monitoring and surveying into regular weatherization processes, and 2) evaluate changes in temperature and humidity and accompanying changes in health and comfort following participation in the Home Uplift weatherization program. Due to the relatively short period of evaluation, the study did not include control homes for comparison with the program homes, as instead each participating home was compared against itself, and its pre-weatherization data used as the control. Because the evaluation and monitoring period was limited to a single season (summer or winter), the pre- and post-weatherization periods should be comparable but will still exhibit differences that can only partially be controlled for through weather-normalization. For example, in early summer, the ground itself will be cooler than later in summer after longer exposure to sun and heat; this ground heat then has impacts for maintaining indoor temperatures in the home. There can also be biological differences in the amount and types of pollen in the air over the course of the summer, which may affect the respiratory health measures included in the household survey.

3. Survey Results

The TDEC IEQ study survey findings are presented by season. Findings for specific metro areas are not provided in this report as the objective is to better understand exposures to temperature and humidity pre- and post-weatherization across the TN Valley, not within a targeted geographic area. The survey instrument contained questions related to indoor environmental exposures to extreme temperatures, as well as mold and standing water. Participants were asked to share whether healthcare was utilized as a result from any exposure to extreme temperatures or for worsening symptoms of select illnesses; chronic health conditions related to respiratory illness and arthritis. Finally, participants were asked to share energy affordability issues pre- and post-weatherization. This section first provides sample sizes by metro area and then aims to characterize the household sample by demographics. Housing conditions, heating and cooling affordability, and prevalence of chronic illness are presented at baseline (pre-weatherization) and post-weatherization where appropriate. This report provides statistics generated to measure observable changes in household reported issues related to IEQ, energy insecurity, financial hardships, chronic health conditions, and healthcare encounters.

3.1 Sample and Household Characterization

A total of 101 households participated in the TDEC IEQ Study across all seasons (heating and cooling) and all years between 2021 – 2022 (Table 2). The study was piloted in Nashville, TN during the summer season of 2021 with 22 households. Of those recruited, 20 homes received weatherization and 19 of those returned their data loggers and completed the study; two homes had two loggers each due to unique housing circumstances, so a total of 21 loggers were returned. Based on the outcomes from the Nashville pilot site, the study team agreed to oversample each of the other sites to successfully analyze data from 40 homes monitored during a cooling season and 40 homes monitored during a heating season. A total of 48 households (out of 56 recruited) completed both surveys during a cooling season; 43 households (out of 45 recruited) completed both surveys during a heating season.

Table 2: Study Sample by Location

Participants by site (n = Number of individuals)	% of Sample (n=101)	% of Summer Sample (n=56)	% of Winter Sample (n=45)
Knoxville	19.8% (n=24)	21.4% (n=12)	26.7% (n=12)
Nashville*	33.7% (n=34)	39.3% (n=22)	26.7% (n=12)
Memphis	22.8% (n=23)	21.4% (n=12	24.4% (n=11)
Chattanooga	23.8% (n=20)	17.9% (n=10)	22.2% (n=10)

* Nashville served as the Pilot site (conducted during Summer 2021)

Across all households recruited for the study, the majority of respondents who completed the survey – and participated in the study – identified as female (78%) and Black or African American (55%). Forty-one percent identified as White. Only 2% identified as Hispanic or Latino, or as American Indian or Alaska Native. The average age of respondents was 62 years old. Ten percent of the full sample reported someone in the household had served on active duty in the U.S. Armed Forces, Reserves or National Guard. Respondents reported living in their homes an average of 21 years.

Table 3: Respondent Demographics and Household Information

Variable (n = Number of Individuals in group)	All Participants (n=101)	Summer Participants (n=56)	Winter Participants (n=45)
Gender: Female	78.2%	71.4%	86.7%
Age (mean)	62	60	64
Black or African American	54.5%	57.1%	51.1%
White	40.6%	39.3%	42.2%
American Indian or Alaska Native	2.0%	1.8%	4.4%
Hispanic or Latino Origin	2.0%	1.8%	2.2%
Other Race	1.0%	-	
Anyone in the household ever served on active duty in the US Armed Forces, Reserves, or National Guard	9.9%	14.3%	4.4%
Average number of years lived in the home (mean)	21 years	21 years	21 years
Average number of people living in the home (mean)	2.1	2.4	1.9

3.2 Cooling Season (Summer) Findings

Cooling season findings cover summer months for 2021 and 2022 calendar years combined (Table 4). The majority of households reported being hot or very hot inside their homes the previous summer. Only those households that completed both pre- and post-weatherization surveys (48 households) were included in the analysis to measure changes in self-reported observations. Of those households that completed both surveys, a statistically significant difference in indoor temperature was observed with 55% reporting being hot or very hot inside their homes pre-weatherization to only 4% in the weatherized environment; following feedback from the pilot, the response categories for this question were changed to "Warmer Than I Would Like" rather than "Hot", while the "Comfortable" and "Very Hot" response categories were kept the same. No households in the post-weatherization environment reported their home being kept at unsafe or unhealthy temperatures, down 34% from pre-weatherization. A difference in the percentage of households that had to temporarily move out of their homes because they were too hot was also observed; from 10% pre-weatherization to 0% post-weatherization. Nearly 4% of households reported someone in the home had to seek medical treatment as a result of their home being too hot in the pre-weatherization environment; no households reported a healthcare encounter for this reason in the post-weatherization environment, though the time period for measuring both pre- and post-weatherization occurrences was constrained to between 4-8 weeks to ensure surveys were conducted during the summer season.

Prior to weatherization, nearly half of the participating households reported their cooling equipment was broken and they did not have cooling inside their home, which fell to 6% post-weatherization. The percentage of households that reported waiting to turn on their AC was also reduced by 48% post-weatherization. Table 4 reports these results both for the full pre- and post-weatherization samples (columns 1 & 2) as well as the change in each metric for only those homes that completed both surveys, also called the matched pairs (column 3).

Table 4: Indoor Temperature and Energy Affordability

Variable (n = Number of Individuals in group)	Pre-Wx (n=56)	Post-Wx (n=48)	Matched Pairs Difference (n=48)
Indoor temperature was Hot or Very Hot	55.4%	4.2%	58.3% - 4.2% = **54.1%*****
Home was kept at unsafe or unhealthy temperature	33.9%	0%	**-33.9%*****
Someone in the home had to seek medical treatment because home was too hot	3.6%	0%	**-3.6%**
Had to temporarily move out of home b/c it was too hot	10.7%	0%	**-10%***
Cooling equipment was broken and did not have cooling inside home	49.1%	8.3%	51.1% - 6.4% = **44.7%*****
Utilities were disconnected and did not have cooling inside home	7.4%	0%	-7.4%
Waited to turn on AC b/c worried about cost*	58.2%	10.4%	58.3% - 10.4% = **47.9%*****

The differences within each sample are found to be statistically different at either: * p< .05, ** p< .01, or *** p< .001 in a McNemar test or paired samples t-test (means) comparing responses from within each household and season sample for each survey round (pre-weatherization to post-weatherization).

* Survey respondents were also provided an opportunity to note reasons that they wait to turn on their AC other than worries about cost. Their responses are below.

Pre-Weatherization

- It used to make a bad smell, so I told [them] it might be moldy inside, so I tried to keep it off as much as possible.

- I go as long as I can [without using AC or heat]. On disability. Has congestive heart failure, so I can't handle too much heat at all. Has a defibrillator. "The 76 seems to work for me" Back bedroom stays cooler.
- Even with the AC, it is hot. We just got the AC checked last week. Things are about the same. They just cleaned it; they didn't repair it. The house can get up to 80 degrees inside because of the broken AC.
- Watches when they turn the AC on because it gets really hot upstairs but cool downstairs and that makes it hard to keep the house cool.
- Trying to reduce allergies. I wait to turn it on until the pollen count is down so that it doesn't stir up the pollen that could be in my AC.
- The unit isn't working well, so barely comfortable even with high bill. Use a lot of fans. It's always hotter than what the thermostat is set at (e.g., thermostat at 72 but house is 77)
- Trying to reduce allergies; I wait to turn off until the pollen count is down so that it doesn't stir up the pollen that could be in my AC.
- It gets really hot upstairs but cool downstairs and that makes it hard to keep the house cool.

Post-Weatherization

- Paying loan companies back, trying to budget, will put fan in window instead of AC.
- When weather is cool [will wait to turn on AC].
- Usually turn off at night.

Households were asked about how hot it gets outside before they turn their AC on as well as the average indoor temperature when someone is home during the day and at night (Tables 5-6). Thirteen percent of households reported outdoor temperatures hotter than 90 degrees before they turn their AC on.

Table 5: Air Conditioning (AC) Usage and Outdoor Temperature

Variable (n = Number of Individuals in group)	Pre-Wx (n=55)
About how hot is it outside before you turn on the AC:	
75 to 80 degrees	18.2%
80 to 85 degrees	36.4%
85 to 90 degrees	30.9%
Hotter than 90 degrees	12.7%

Table 6: Average Indoor Temperature, Cooling Season (Summer)

Variable (n = Number of Individuals in group)	Pre-Wx (n=48-52)	Post-Wx (n=47)
Average indoor temperature when someone is home during the day (mean, °F)	73	73
Average indoor temperature when someone is home at night (mean, °F)	72	73

A statistically significant difference (-49%) was observed in the percentage of households that reported not getting enough rest or sleep because their home was too hot (Table 7). A reduction in households reporting it being hard or very hard to pay bills was also observed (-14%) but not at significant levels. When asked if households noticed any changes in their energy bills, 44% reported costs going down post-weatherization; 19% reported costs going up. Some respondents also expressed feeling that it had not been long enough to know how their bills would change.

Table 7: Sleep and Energy Affordability, Cooling Season (Summer)

Variable (n = Number of Individuals in group)	Pre-Wx (n=56)	Post-Wx (n=48)	Matched Pairs Difference (n=48)
Did not get enough rest or sleep b/c it was too hot inside	46.4%	4.3%	53.2% - 4.3% = **48.9%*** **
Hard or very hard to pay energy bills	69.7%	59.1%	72.7% - 59.1% = **13.6%**
Compared to the previous month's bill, did you notice any change in your energy costs (not including water or sewer)?			
Costs went down		44.2%	
Costs went up		18.6%	

The differences within each sample are found to be statistically different at either: * p< .05, ** p< .01, or *** p< .001 in a McNemar test or paired samples t-test (means) comparing responses from within each household and season sample for each survey round (pre-weatherization to post-weatherization).

3.3 Heating Season (Winter) Findings

During the pre-weatherization phase, household members were asked to reflect on the indoor temperature and energy affordability of the previous winter (approximately one year before). During the post-weatherization phase, these same household members were asked to reflect on these issues for the winter season after the weatherization was completed. These post-weatherization surveys were administered at least 4 weeks after the weatherization was completed to allow for households to observe any changes in the indoor environment or utilities.

Prior to weatherization, 100% of households reported the indoor temperature was colder than they prefer or very cold during the previous winter (Table 8). This percentage went down (significantly) to 12% post-weatherization. Only 2% of households reported keeping their home at unhealthy temperatures post-weatherization. No change was observed in the percentage of households that reported medical encounters for their home being too cold or having to move out temporarily for this reason. Statistically significant differences were observed in the percentage of households that reported broken heating equipment or no heat inside their homes from pre- to post-weatherization from 49% to 2%. The percentage of households that waited to turn on their heat because they were worried about utility costs was also significantly reduced (-38%).

Table 8: Indoor Temperature and Energy Affordability

Variable (n = Number of Individuals in group)	Pre-Wx (n=45)	Post-Wx (n=43)	Matched Pairs Difference (n=43)
Indoor temperature was 'Colder than they would prefer' or Very Cold	100%	11.6%	100% - 11.6% = **88.4%*** **
Home was kept at unsafe or unhealthy temperature	15.6%	2.3%	16.3% - 2.3% = **14%**
Someone in the home had to seek medical treatment because home was too cold	0%	0%	**[No change]**
Had to temporarily move out of home b/c it was too cold	4.4%	2.3%	**[No change]**
Heating equipment was broken and did not have heating inside home	48.9%	2.3%	46.5% - 2.3% = **44.2%*** **
Utilities were disconnected and did not have heating inside home	4.4%	0%	**-4.4%**
Waited to turn on heat b/c worried about cost*	53.3%	16.7%	54.8% - 16.7% = **38.1%*** **

The differences within each sample are found to be statistically different at either: * p< .05, ** p< .01, or *** p< .001 in a McNemar test or paired samples t-test (means) comparing responses from within each household and season sample for each survey round (pre-weatherization to post-weatherization).

* Survey respondents were also provided an opportunity to note reasons that they wait to turn on their AC other than worries about cost. Their responses are below.

Pre-Weatherization

- If it's going to be warm again the next day, won't bother turning it on.
- No, have asthma, so if it gets too cold, will start wheezing.
- Was without heat for three weeks in October/November due to malfunction.
- Wasn't cold enough.

Post-Weatherization

- Don't need it.
- Don't use it overnight.
- When it's hot outside/Turned off when weather was warm enough.

Households were also asked to share whether they used any secondary heating equipment prior to weatherization (Table 9). Only 40% of households reported using no secondary equipment; nearly 40% of households reported using an electric space heater. Several households reported using unvented propane, kerosene, or gas fireplaces. Respondents were also asked about how cold it is outside before they turn their heat on as well as what the average indoor temperature is when someone is home both during the day and at night (Tables 10-11). Forty-four percent of households reported outdoor temperatures colder than 45 degrees before they turn their heat on.

Table 9: Secondary Heating Equipment

Variable (n = Number of Individuals in group)	Pre-Wx (n=45)
Do you use any of the following types of heating equipment in your home?	
Electric space heater	37.8%
Vented gas fireplace	4.4%
Wood Fireplace	2.2%
Unvented propane or kerosene heater	2.2%
Other: Electric Fireplace	6.7%
Other: Electric fireplace or Oven	2.2%
Other: Heating pad at night	2.2%
Other: Oil radiator or ceramic heater	2.2%
Other: Unvented gas fireplace	2.2%
None of the above	40.0%

Table 10: Heating Equipment Usage and Outdoor Temperature

Variable (n = Number of Individuals in group)	Pre-Wx (n=45)
About how cold is it outside before you turn on the heat:	
55 to 60 degrees	26.8%
50 to 55 degrees	22.0%
45 to 50 degrees	7.3%
Colder than 45 degrees	43.9%

Table 11: Average Indoor Temperature, Heating Season (Winter)

Variable (n = Number of Individuals in group)	Pre-Wx (n=45)	Post-Wx (n=43)
Average indoor temperature when someone is inside during the day (mean, degrees)	71	71
Average indoor temperature when someone is inside at night (mean, degrees)	70	70

Pre-weatherization, 20% of households reported not getting enough rest or sleep because their home was too cold; no households reported this issue post-weatherization (Table 12). A statistically significant reduction in households reporting it being hard or very hard to pay bills (-26%) was also observed post-weatherization. When asked if households noticed any changes in energy costs in their bills, 39% reported costs going down post-weatherization; 27% reported costs going up.

Table 12: Sleep and Energy Affordability

Variable (n = Number of Individuals in group)	Pre-Wx (n=45)	Post-Wx (n=43)	Matched Pairs Difference (n=43)
Did not get enough rest or sleep b/c it was too cold inside	20.0%	0%	**-20%****
Hard or very hard to pay energy bills	62.2%	34.9%	60.5% - 34.8% = **25.7%****
Compared to the previous month's bill, did you notice any change in your energy costs (not including water or sewer)?			
Costs went down		39.0%	
Costs went up		26.8%	

The differences within each sample are found to be statistically different at either: * p< .05, ** p< .01, or *** p< .001 in a McNemar test or paired samples t-test (means) comparing responses from within each household and season sample for each survey round (pre-weatherization to post-weatherization).

3.4 Dwelling Quality and Chronic Illness

This section combines the cooling and heating season samples to better characterize the population as a whole, from experiences with exposure to extreme indoor temperatures to prevalence of chronic illness. Chronic health conditions related to respiratory illness (e.g., asthma, COPD) and forms of arthritis were explored. The section also includes findings on reported dwelling quality issues such as exposure to mold.

Upon combining the two samples, a 70% reduction in exposure to cold or hot temperatures inside weatherized homes is observed, with a 26% reduction in homes being kept at unsafe or unhealthy temperatures (Table 13). Reports of homes having broken heating equipment also declined from 49% pre-weatherization to 6% post-weatherization. No households reported utility disconnections in the post-weatherization period of the survey.

Table 13: Indoor Temperature and Energy Affordability (Combined Seasons)

Variable (n = Number of Individuals in group)	Pre-Wx (n=101)	Post-Wx (n=91)	Matched Pairs Difference (n=91)
Indoor temperature was either hot/too hot or cold/very cold	75.2%	7.7%	78.0% - 7.7% = **70.3%*** **
Home was kept at unsafe or unhealthy temperature	25.7%	1.1%	27.5% - 1.1% = **26.4%*** **
Someone in the home had to seek medical treatment because home was too hot or too cold	2.0%	0%	**-2.0%**
Had to temporarily move out of home b/c it was too hot or too cold	7.9%	1.1%	7.7% - 1.1% = **6.6%**
Heating equipment was broken and did not have heating inside home	49.0%	5.5%	48.9% - 4.4% = **44.5%*** **
Utilities were disconnected and did not have cooling or heating inside home	6.1%	0%	**-6.1%***

The differences within each sample are found to be statistically different at either: * p< .05, ** p< .01, or *** p< .001 in a McNemar test or paired samples t-test (means) comparing responses from within each household and season sample for each survey round (pre-weatherization to post-weatherization).

In both the cooling and heating seasons, households reported observations of mold in the pre-weatherization environment (29% and 36%, respectively). A statistically significant reduction in self-reported exposure to mold of 24% was observed for the combined sample (Tables 14-16). Participants also reported observations of standing water inside homes and reductions in these observations post-weatherization by 12% for the combined sample.

Table 14: Mold and Moisture, Cooling Season (Summer)

Variable (n = Number of Individuals in group)	Pre-Wx (n=56)	Post-Wx (n=48)	Matched Pairs Difference (n=47)
Seen mold in the home in the last 12 months	29.1%	6.3%	27.7% - 4.3% = **23.4%*** **
Seen standing water in the home in the last 12 months	16.1%	2.1%	16.7% - 2.1% = **14.6%***

The differences within each sample are found to be statistically different at either: * p< .05, ** p< .01, or *** p< .001 in a McNemar test or paired samples t-test (means) comparing responses from within each household and season sample for each survey round (pre-weatherization to post-weatherization).

Table 15: Mold and Moisture, Heating Season (Winter)

Variable (n = Number of Individuals in group)	Pre-Wx (n=45)	Post-Wx (n=43)	Matched Pairs Difference (n=43)
Seen mold in the home in the last 12 months	35.6%	7.0%	32.6% - 7.0% = **25.6%*** **
Seen standing water in the home in the last 12 months	18.6%	9.3%	18.6% - 9.3% = **9.3%**

The differences within each sample are found to be statistically different at either: * p< .05, ** p< .01, or *** p< .001 in a McNemar test or paired samples t-test (means) comparing responses from within each household and season sample for each survey round (pre-weatherization to post-weatherization).

Table 16: Mold and Moisture, Combined Seasons

Variable (n = Number of Individuals in group)	Pre-Wx (n=101)	Post-Wx (n=91)	Matched Pairs Difference (n=91
Seen mold in the home in the last 12 months	32.0%	6.6%	30.0% - 5.6% = **24.4% *** **
Seen standing water in the home in the last 12 months	16.8%	5.5%	17.6% - 5.5% = **12.1%** **

The differences within each sample are found to be statistically different at either: * p< .05, ** p< .01, or *** p< .001 in a McNemar test or paired samples t-test (means) comparing responses from within each household and season sample for each survey round (pre-weatherization to post-weatherization).

Survey respondents reported whether anyone in the home had ever been diagnosed with asthma and whether that person still has asthma (i.e., active asthma). Approximately one quarter of all participants (across seasons) reported having at least one individual in the home with asthma: 27% in the cooling season and 20% in the heating season samples.

Table 17: Asthma Status for Cooling, Heating, and Combined Seasons

Variable (n = Number of Individuals in group)	Summer Pre-Wx (n=19)	Winter Pre-Wx (n=9)	Combined Pre-Wx (n=28)
Anyone in the home ever been told they have asthma	33.9%	20.0%	27.7%
Does that person still have asthma	84.2%	100%	89.3%
Sample with current asthma:	26.8%	20.0%	24.8%

Respondents reported the severity of asthma symptoms based on when the person in the home with the most uncontrolled asthma last had symptoms (Tables 18-20). Over 42% of respondents reported that the individual with the most uncontrolled asthma last had symptoms within the past week. For those persons with the most uncontrolled asthma in the cooling season sample, 86% reported asthma symptoms seem to worsen when it is hot; in the heating season sample, 75% reported asthma symptoms seem to worsen when it is too cold.

Table 18: Asthma Morbidity, Cooling Season (Summer)

Variable (n = Number of Individuals in group)	Pre-Wx (n=15)	Post-Wx (n=11)
Last time the person with the most severe or uncontrolled asthma last had symptoms:		
Less than a day ago	22.2%	27.3%
1-6 days ago	22.2%	9.1%
1 week to less than 3 months ago	22.2%	36.4%
3 months to less than a year ago	11.1%	27.3%
1 year to 3 years ago	-	-
More than 3 years ago	22.2%	-
Asthma symptoms worsen when it is hot	85.7%	83.3%

Table 19: Asthma Morbidity, Heating Season (Winter)

Variable (n = Number of Individuals in group)	Pre-Wx (n=9)	Post-Wx (n=5)
Last time the person with the most severe or uncontrolled asthma last had symptoms:		
Less than a day ago	22.2%	20.0%
1-6 days ago	11.1%	-
1 week to less than 3 months ago	33.3%	20.0%
3 months to less than a year ago	22.2%	20.0%
1 year to 3 years ago	11.1%	40.0%
More than 3 years ago	-	-
Asthma symptoms worsen when it is cold	75.0%	100%

Table 20: Asthma Morbidity, Combined Seasons

Variable (n = Number of Individuals in group)	Pre-Wx (n=25)	Post-Wx (n=16)
Last time the person with the most severe or uncontrolled asthma last had symptoms:		
Less than a day ago	26.9%	25.0%
1-6 days ago	15.4%	6.3%
1 week to less than 3 months ago	34.6%	31.1%
3 months to less than a year ago	11.5%	25.0%
1 year to 3 years ago	3.8%	12.5%
More than 3 years ago	7.7%	-
Asthma symptoms worsen when it is (hot / cold)	82.6%	78.6%

Survey respondents reported whether anyone in the home had ever been diagnosed with chronic obstructive pulmonary disease (COPD), emphysema or chronic bronchitis (Tables 21-23). Across both cooling and heating season samples, 20% of respondents reported having at least one individual in the home with one of these respiratory disorders. Of those, 25% had to see treatment for a flare-up. Sixty-three percent of respondents reported respiratory symptoms for these household members seem to worsen when it is hot; compared to 73% that reported symptoms seem to worsen when it is too cold.

Table 21: COPD, Emphysema, or Chronic Bronchitis, Cooling Season (Summer)

Variable (n = Number of Individuals in group)	Pre-Wx (n=8)	Post-Wx (n=5)
Anyone in the home ever been told they have COPD, emphysema or chronic bronchitis	14.3%	
Other than a routine visit, that person had to seek medical treatment for symptoms related to shortness of breath, or other COPD or emphysema flare-ups	25.0%	0%
That person's respiratory symptoms seem to worsen when they are hot	62.5%	60.0%

Table 22: COPD, Emphysema, or Chronic Bronchitis, Heating Season (Winter)

Variable (n = Number of Individuals in group)	Pre-Wx (n=12)	Post-Wx (n=11)
Anyone in the home ever been told they have COPD, emphysema or chronic bronchitis	26.7%	
Other than a routine visit, that person had to seek medical treatment for symptoms related to shortness of breath, or other COPD or emphysema flare-ups	25.0%	9.1%
That person's respiratory symptoms seem to worsen when they are cold	72.7%	40.0%

Table 23: COPD, Emphysema, or Chronic Bronchitis, Combined Seasons

Variable (n = Number of Individuals in group)	Pre-Wx (n=20)	Post-Wx (n=16)
Anyone in the home ever been told they have COPD, emphysema or chronic bronchitis	19.8%	
Other than a routine visit, that person had to seek medical treatment for symptoms related to shortness of breath, or other COPD or emphysema flare-ups	25.0%	6.3%
That person's respiratory symptoms seem to worsen when they are hot or cold	68.4%	46.7%

Survey respondents reported whether anyone in the home had ever been told they have some form of arthritis (Tables 24-26). Across the samples, 66% of households reported at least one person living in the home with arthritis; 67% in the cooling season sample and 63% of in the heating season sample. An overwhelming percentage of respondents reported that, pre-weatherization, the person's arthritis symptoms seem to worsen when it is cold (98%) compared to respondents reporting worsening symptoms when it is hot (47%). However, more households reported that person with arthritis had to see a health professional or received urgent treatment for worsening symptoms in the summer (23%) than in the winter (8%). Nearly 20% of both samples reported visiting a health professional or receiving urgent treatment for worsening arthritis symptoms the previous summer or winter.

Table 24: Arthritis Symptoms and Medical Care, Cooling Season (Summer)

Variable (n = Number of Individuals in group)	Pre-Wx (n=37)	Post-Wx (n=30)
Anyone in the home ever been told they have some form of arthritis	67.3%	
Last time the person with the most severe arthritis had symptoms:		
Less than a day ago	73.0%	76.7%
1-6 days ago	10.8%	3.3%
1 week to less than 3 months ago	10.8%	16.7%
3 months to less than one year ago	5.4%	-
1 year to 3 years ago	-	3.3%
That person's arthritis symptoms seem to worsen when it is hot	46.9%	33.3%
Over the last 30 days, that person saw a health professional for urgent treatment of worsening arthritis symptoms	22.9%	17.2%
Thinking about last summer, that person saw a health professional for urgent treatment of worsening arthritis symptoms	20.0%	

Table 25: Arthritis Symptoms and Medical Care, Heating Season (Winter)

Variable (n = Number of Individuals in group)	Pre-Wx (n=28)	Post-Wx (n=18)
Anyone in the home ever been told they have some form of arthritis	63.3%	
Last time the person with the most severe arthritis had symptoms:		
Less than a day ago	75.0%	59.3%
1-6 days ago	17.9%	14.8%
1 week to less than 3 months ago	3.6%	25.9%
More than 3 years ago	2.2%	-
That person's arthritis symptoms seem to worsen when it is cold	95.8%	92.6%
Over the last 30 days, that person saw a health professional for urgent treatment of worsening arthritis symptoms	7.4%	7.7%
Thinking about last winter, that person saw a health professional for urgent treatment of worsening arthritis symptoms	19.2%	

Table 26: Arthritis Symptoms and Medical Care, Combined Seasons

Variable (n = Number of Individuals in group)	Pre-Wx (n=65)	Post-Wx (n=57)
Anyone in the home ever been told they have some form of arthritis	65.7%	
Last time the person with the most severe arthritis had symptoms:		
Less than a day ago	73.8%	68.4%
1-6 days ago	13.8%	8.8%
1 week to less than 3 months ago	7.7%	21.1%
3 months to less than a year ago	3.1%	-
1 year to 3 years ago	-	1.8%
More than 3 years ago	1.5%	-
That person's arthritis symptoms seem to worsen when it is hot or cold	67.9%	63.0%
Over the last 30 days, that person saw a health professional for urgent treatment of worsening arthritis symptoms	16.1%	12.7%
Thinking about last summer/last winter, that person saw a health professional for urgent treatment of worsening arthritis symptoms	19.7%	

3.5 Key Survey Findings

Overall, the survey findings revealed that the majority of participating households entering into the Home Uplift weatherization program struggled with maintaining healthy indoor temperatures in both cooling and heating seasons. Significant reductions in homes being too hot or cold were observed in the post-weatherization environments. Survey findings suggest that the prevalence of chronic health conditions related to respiratory illnesses and arthritis is perhaps greater in the Home Uplift population (based on this sample) than the general population across the TN Valley. Respondents reported that individuals with these chronic illnesses experience worsening symptoms when it is too hot or cold. Weatherization programs, like Home Uplift, could provide meaningful benefits for these individuals and households by 1.) reducing indoor exposures to extreme hot and cold temperatures, 2.) reducing energy bills, and 3.) improving access to reliable and efficient sources of heating, cooling, and electricity.

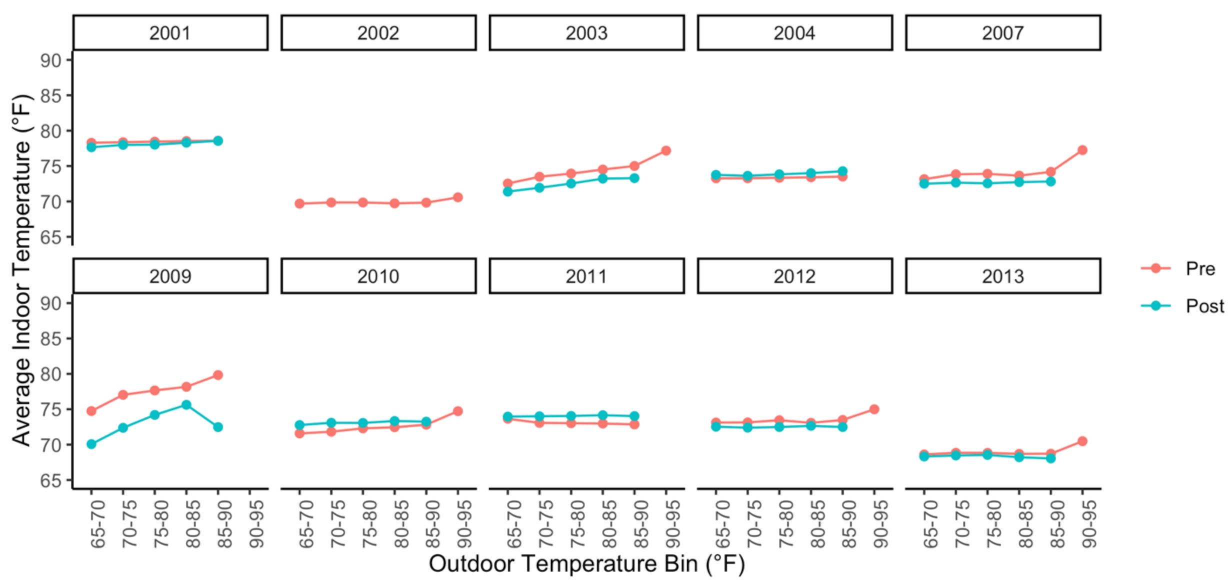
4. IEQ Monitoring Results

After merging the logger data with weather data for the home's location, we took the average of each variable within each outdoor temperature bin. The data were further limited to only include periods where the outdoor temperature was above 65°F in summer or below 65°F in winter, informed by the definition of a heating or cooling degree day. Then for each home, we compared the pre-weatherization and post-weatherization periods for daytime observations. Daytime observations were separated from nighttime due to differences in thermal and environmental dynamics during the day when the sun provides direct radiation versus at night.

4.1 Summer Home Analysis

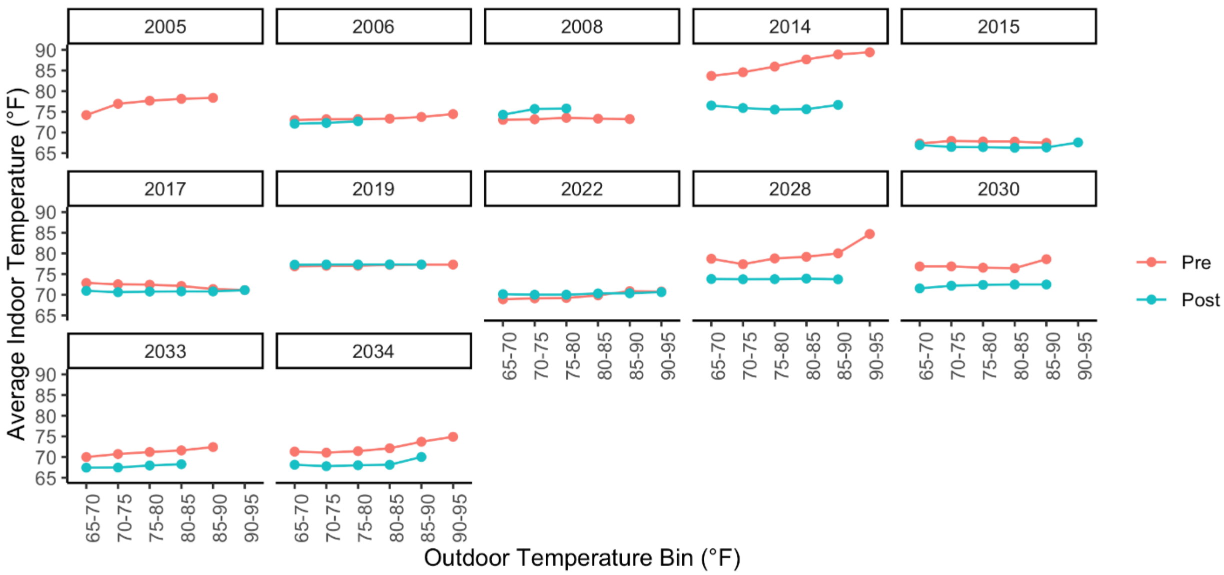
The graphs below show the trend of indoor temperatures prior to weatherization in pink and the post-weatherization trend in blue for Chattanooga participants during the summer; the y-axis indicates the average indoor temperature, while the x-axis shows each outdoor temperature bin. The numbers in rectangular boxes are unique, anonymous identifiers for each home.

Figure 1: Chattanooga Daytime Trend in Indoor Temperature, Cooling Season (Summer)



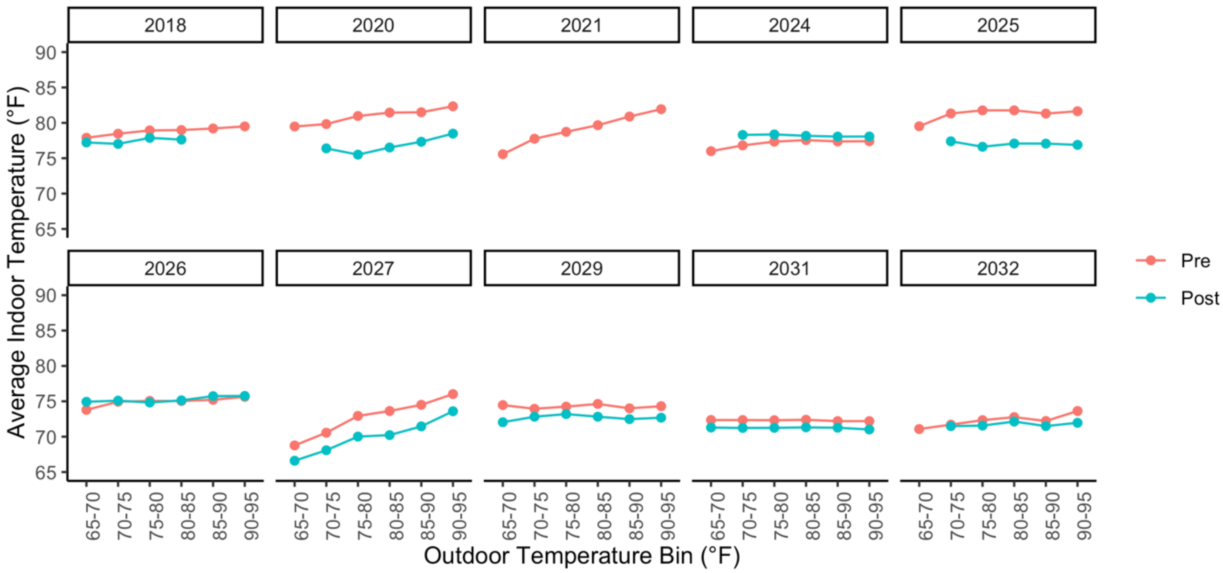
Most homes display a relatively flat trend, where the average indoor temperature is the same regardless of outdoor temperatures. However, in a few cases there is a positive correlation between indoor and outdoor temperature where the indoor temperature got hotter as the temperature increased outside, indicating the home may not have been resilient to heat. For example, prior to weatherization, home 2009 started out keeping the house at an average temperature of 75°F when the outdoor temperature was between 65 and 70°F, but as the outdoor temperature rose, the average indoor temperature also increased, reaching over 80°F. Conversely, following weatherization, the blue line for home 2009 indicates that the indoor temperature was consistently 3-5°F cooler than it would have been before receiving weatherization. The most notable improvement came when the outdoor temperatures were between 85 and 90°F: prior to weatherization the indoor temperature averaged 80°F, but following weatherization, the household was able to keep the indoor temperature down to 72-73°F. Home number 2002 does not have post-weatherization data due to production delays; weatherization on this home was not completed until the end of the year, and therefore a summertime pre/post comparison was not possible.

Figure 2: Knoxville Daytime Trend in Indoor Temperature, Cooling Season (Summer)



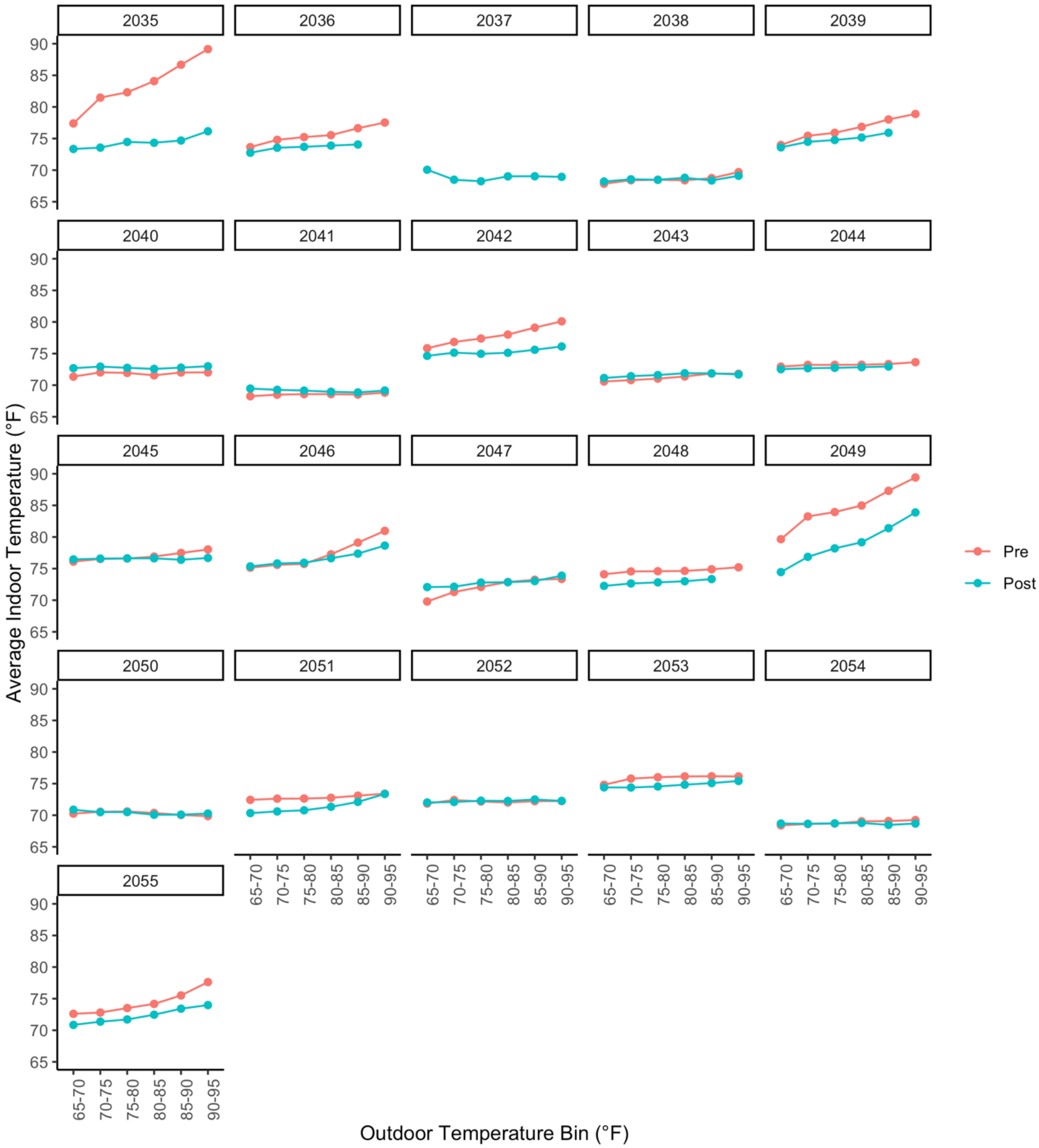
The homes in Knoxville displayed greater variation in temperature trends compared to Chattanooga. We can see a stronger difference between the pre- and post-weatherization periods, particularly in homes 2014, 2028, 2030, 2033, and 2034. Home number 2014 was of particular concern, with indoor temperatures consistently in the 80s prior to weatherization; the resident reported that the home was "Warmer Than I'd Like" but not "Very Hot". Following Home Uplift, the indoor temperature became more consistent and remained closer to 75°F, and the resident reported feeling "Comfortable" in the post-weatherization survey. Home 2005 does not have post-weatherization data due to production delays; the weatherization work was not completed during the study period.

Figure 3: Memphis Daytime Trend in Indoor Temperature, Cooling Season (Summer)



Memphis homes generally showed flatter trends in indoor temperature similar to Chattanooga, but the average temperature being maintained was warmer in many cases. In the top row of the diagram, the households all kept their homes roughly between 75 and 80°F, even after weatherization, though homes 2020 and 2025 both reduce their indoor temperature by 5 degrees or more in many cases. The second row of homes also show slightly lower temperatures following weatherization, though each of these homes generally stayed below 75°F even prior to weatherization. The logger in home 2021 experienced an unexpected mechanical failure and stopped logging prior to weatherization.

Figure 4: Nashville Daytime Trend in Indoor Temperature, Cooling Season (Summer)

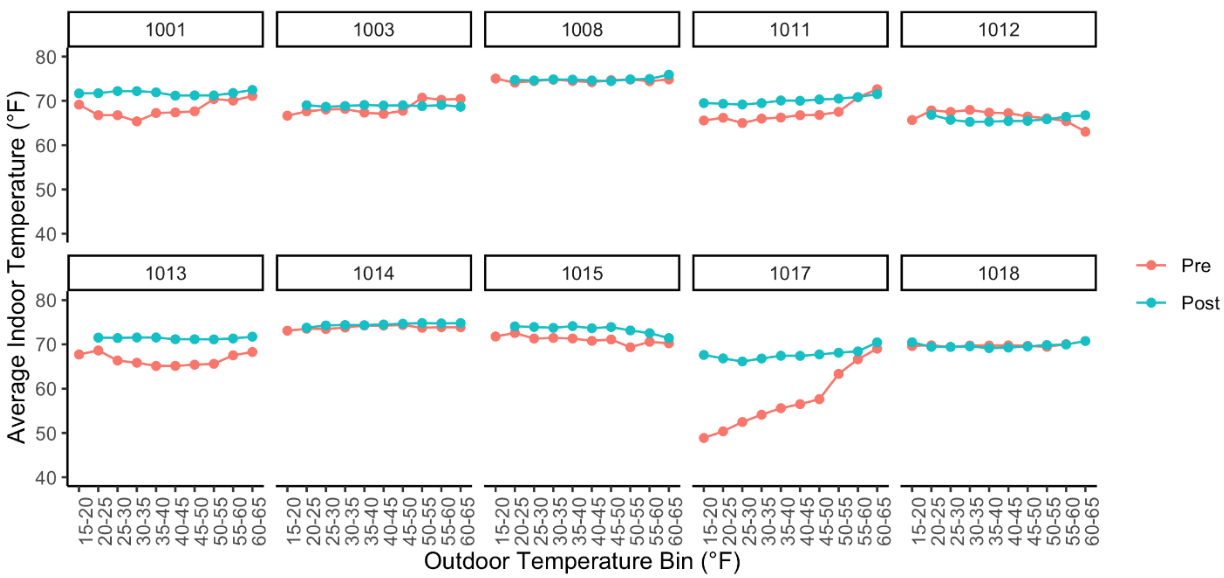


With a few notable exceptions, Nashville homes showed similar temperatures and trends in both the pre- and post-weatherization periods. However, homes 2035 and 2049 showed significant improvement following weatherization, due in part to extreme temperatures prior to Home Uplift. Notably though, the occupant in home 2035 reported in their pre-weatherization survey that the temperature in the home was "Comfortable" and that they typically don't turn on the AC until it reaches 90 degrees outside, yet their usage pattern following weatherization indicates they may have preferred a cooler temperature. The team was not able to reach this household for a follow-up survey, but the resident did return their logger. By comparison, the resident in home 2049 reported that their home was "Hot" prior to weatherization but "Comfortable" afterward, and their ability to pay their utility bills went from "Hard" to "Easy" following Home Uplift. Home 2037 does not have pre-weatherization data because the occupant misplaced the first logger that was sent to them. Homes 2038 and 2041 represent two distinct portions of the same house that each have their own HVAC system; the same is true of 2043 and 2052. These are the only two instances in the study of homes logging two distinct HVAC regions. Loggers 2038 and 2043 were removed in aggregate analyses to avoid representing the same home twice.

4.2 Winter Home Analysis

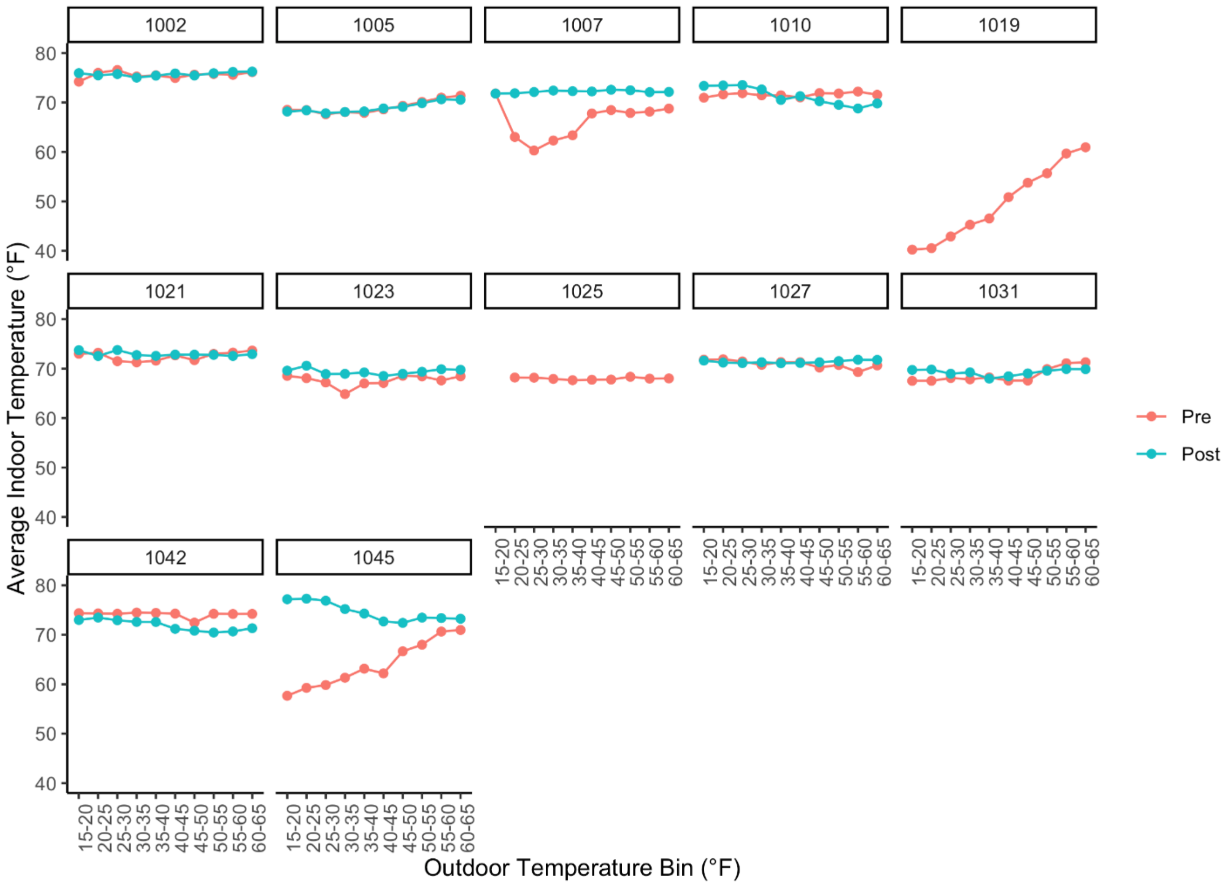
Below we present the same charts as above but for winter results. As before, average indoor temperatures prior to weatherization are shown in pink, while average indoor temperatures after weatherization are shown in blue. The labels along the bottom indicate 5-degree bins of outdoor temperature.

Figure 5: Chattanooga Daytime Trend in Indoor Temperature, Heating Season (Winter)



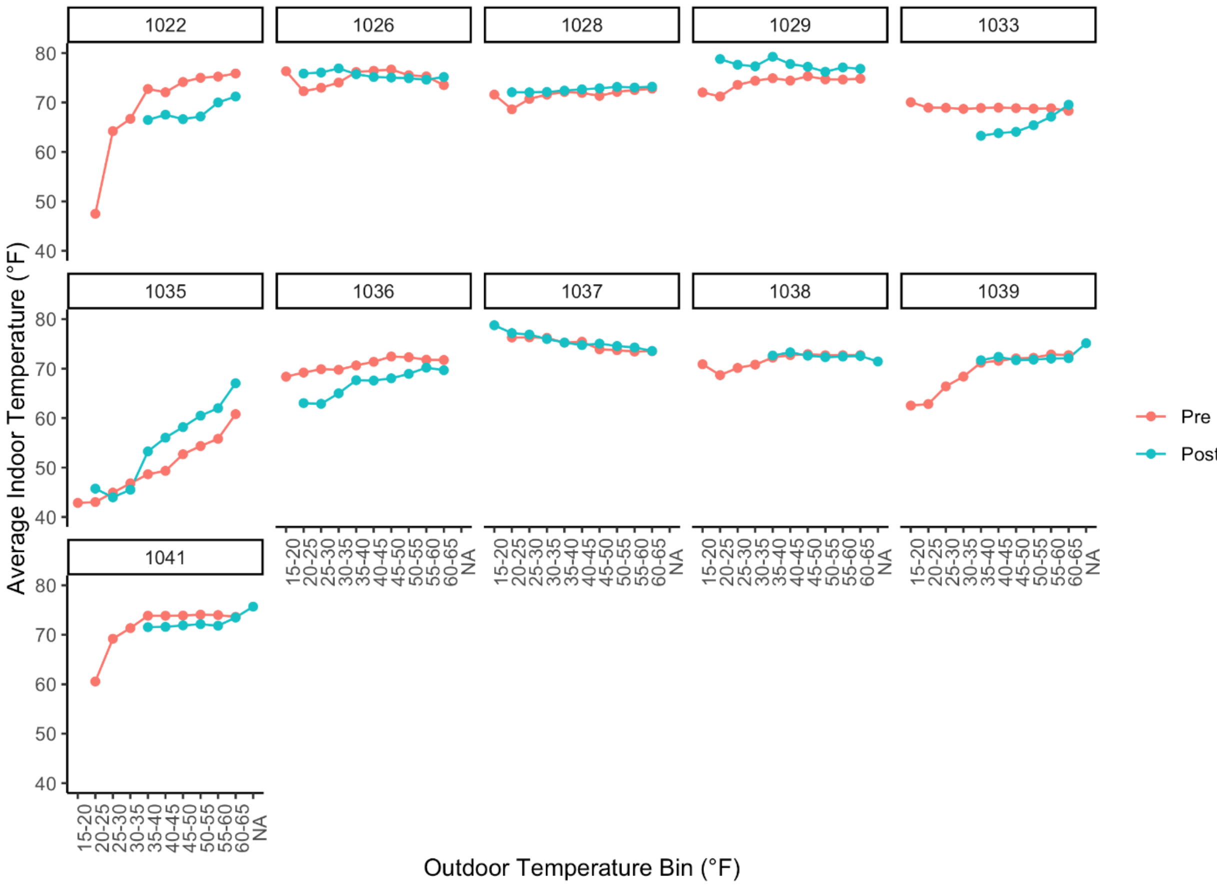
The winter participants in Chattanooga showed primarily flat trend lines similar to the summer participants, with a few exceptions where homes became notably warmer and more stable following weatherization (1001, 1013, and 1017). In their pre-weatherization survey, the resident in home 1017 reported feeling "Very Cold", compared to feeling "Comfortable" after weatherization, and the difficulty of paying their utility bill went from "Hard" to "Easy".

Figure 6: Knoxville Daytime Trend in Indoor Temperature, Heating Season (Winter)



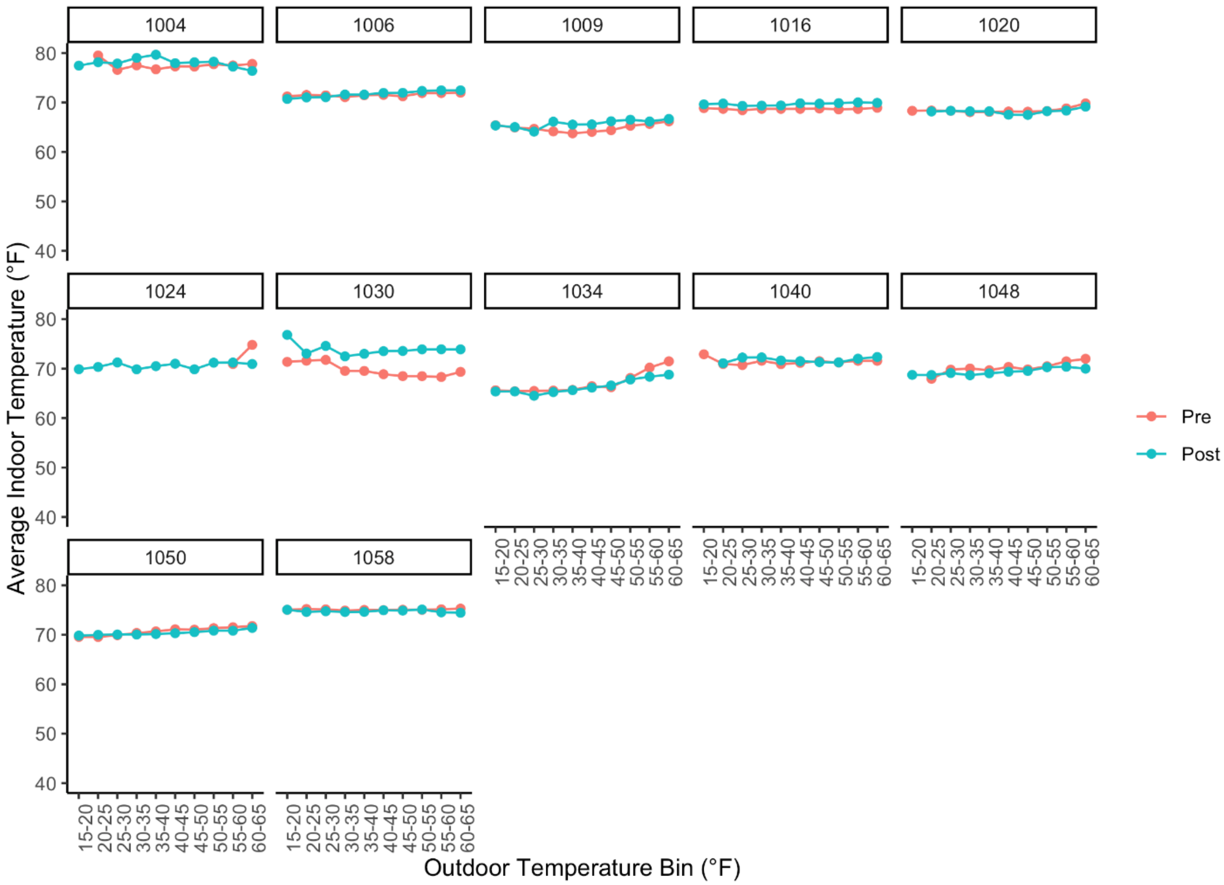
Knoxville residents also saw similar and flat trendlines in both the pre- and post-weatherization periods during winter, with the most notable exceptions in homes 1007 and 1045, which saw 10- to 20-degree improvements in temperature during the coldest outdoor conditions. The resident's perception of the indoor temperature went from "Colder Than I Would Like" to "Comfortable" following weatherization. This home also highlights the importance of weatherization for improving resilience against extreme temperatures, as homes that can remain habitable during mild weather can become dangerously hot or cold when their systems don't keep up with outdoor conditions. Home 1019 does not have post-weatherization data because it was deferred, and the logger in home 1025 had a settings error.

Figure 7: Memphis Daytime Trend in Indoor Temperature, Heating Season (Winter)



Memphis homes experienced the most severe drop-offs in indoor temperature as the weather got colder, evidenced by the two sickle-shaped graphs at 1022 and 1041 and to a lesser degree in 1039, as well as the extremely low temperatures in 1035, where the resident reported being "Colder Than I Would Like" prior to weatherization and "Comfortable" afterward. Household 1041 moved from "Very Cold" to "Colder Than I Would Prefer", though they also reported setting the thermostat at 68°F and the logger indicates the home was even slightly warmer at closer to 71°F (they also report using an electric space heater). All of these factors indicate the complexity at the intersection of energy consumption, energy burden, and resident comfort and the need for multifaceted measurements and research. One can even see that four homes (1022, 1033, 1036, 1041) were generally cooler after weatherization, contrary to expectations; it may be that these homes experienced higher temperature variation from room to room, and residents were setting the thermostat higher than necessary in order to keep colder rooms from getting too cold. For example, one resident described having a bedroom above the garage that was exposed to cold air coming up from below; the bedroom was therefore consistently colder than the rest of the house.

Figure 8: Nashville Daytime Trend in Indoor Temperature, Heating Season (Winter)

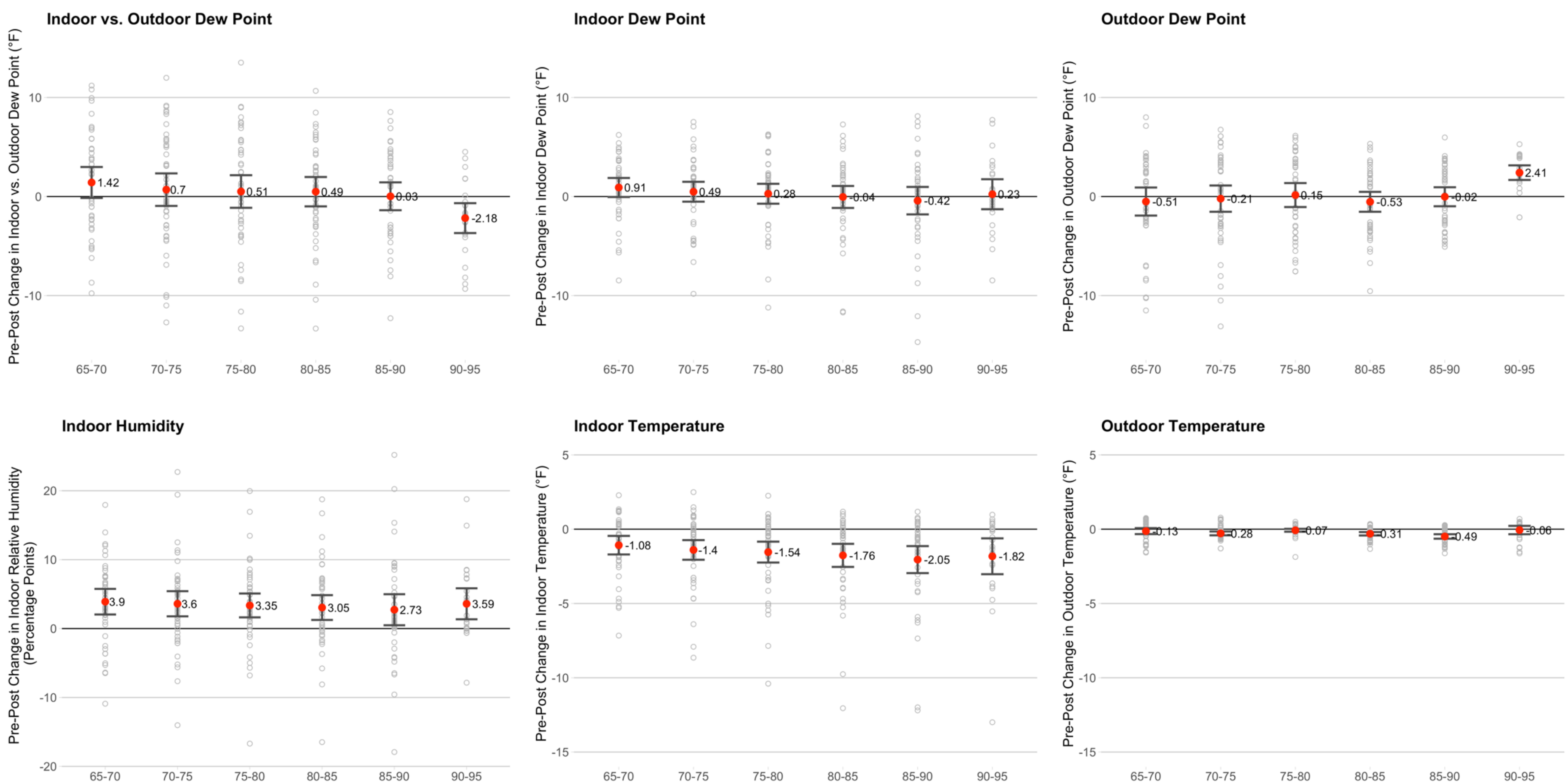


As in summer, the Nashville homes showed some of the most consistency between pre- and post-weatherization trends, with the majority of the graphs having nearly overlapping lines and all hovering near 70°F. Only homes 1004 and 1030 show a temperature increase, indicating the residents may not have been able to keep their homes as warm as they would like prior to weatherization. Home 1024 lacks most pre-weatherization due to an unexpected mechanical failure in the logger.

4.3 Combined Measures

The team next aggregated the logger data across all homes in each season to identify overall trends and impacts of weatherization across geographies and individual homes. Still using the same temperature bins as before, we calculated the difference in average temperature before versus after weatherization for each home, then plotted the average and confidence interval. In each of the plots below, the red dot indicates the average change across all homes, with black bars to indicate a 95% confidence interval (CI). Each light grey dot represents an individual participant home.

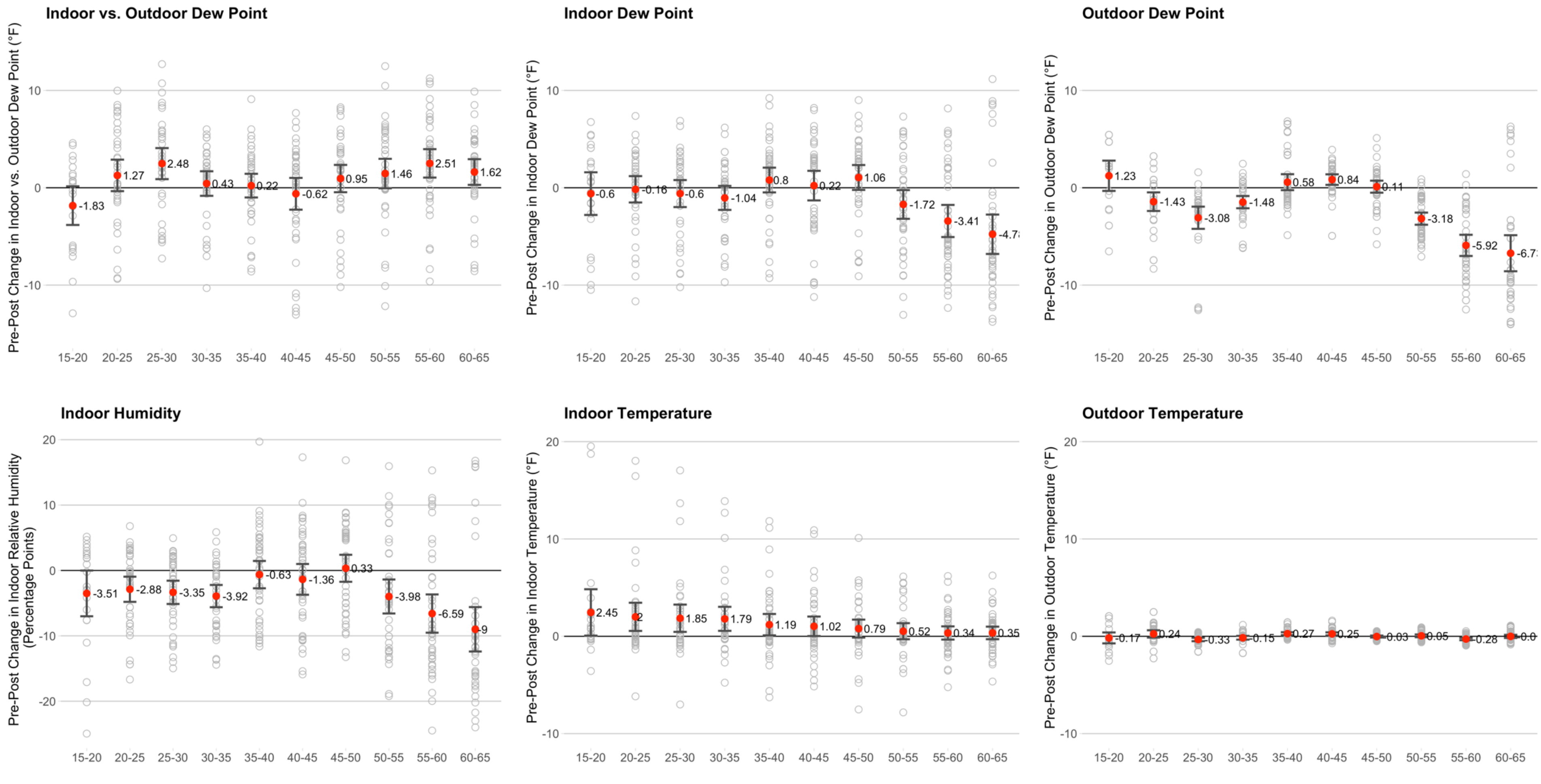
Figure 9: Changes in Summer Daytime Indoor Environmental Quality Indicators for All Metro Areas



Looking again at temperature to start, the average indoor temperature across all summer participants ranged from 1.1-2.1°F cooler after weatherization compared to before, and this result was statistically significant at all outdoor temperatures, as the line representing zero change is not included in any of the confidence intervals. To verify that observed changes in indoor temperatures can't be explained by shifts in outdoor temperature, we also plotted change in outdoor temperature against the outdoor temperature bins (bottom right). Because the temperature bins encompass 5-degree intervals, it is possible that the average outdoor temperature within each bin could be lower later in the summer compared to earlier (e.g., within the 65-70°F bin, the temperature could average closer to either 65 or to 70). While we do see some slight downward shift, it is not enough to independently explain the temperature decreases seen following weatherization, and so we conclude that weatherization still had a measurable impact.

Moving to the bottom lefthand side of the plots, we see that indoor relative humidity did increase across all temperature bins following weatherization. However, this may be explained largely by lower indoor temperatures, as relative humidity is affected by indoor temperature, even if the amount of moisture in the air does not change. When examining indoor dew point (top center), which is a measure of the absolute amount of moisture in the air and does not depend on indoor temperature, we see that none of the changes were statistically significant. The outdoor dew point was similarly stable throughout this period excepting when the outdoor temperature reached 90-95°F. Despite this increase in outdoor dew point, the indoor dew point remained steady. Despite some initial concerns based on humidity increases in the raw logger data, weatherization does not appear to be having strong impacts on moisture levels inside the homes of summer participants.

Figure 10: Changes in Winter Daytime Indoor Environmental Quality Indicators for All Metro Areas



Indoor temperatures across the winter participants were slightly warmer after weatherization, though the change was statistically significant only when the outdoor temperature was between 20-35°F and marginally significant between 35-40°F. Residents may have been more able to keep their homes at a comfortable temperature during the more moderate weather between 40-65°F prior to weatherization compared to other outdoor temperatures. Once again, we examine potential temporal changes in outdoor temperatures and find minimal movement with no particular pattern. Indoor humidity decreased at both ends of the temperature range, with decreases of 3-4.5 percentage points at the lower end of outdoor temperatures and decreases of 5-7% at the upper end; for comparison, the loggers advertise a margin of error of ±3.5%. The variation in indoor humidity tracks a similar pattern in the outdoor dew point, though the indoor dew point is less volatile, indicating that homes are at least partially protected against changes in outdoor moisture levels.

5. Conclusion

Survey findings and IEQ monitoring both indicated that homes going through the Home Uplift weatherization program experienced measurable improvements in indoor temperature and reduced exposure to temperature extremes. Following weatherization, indoor temperatures were 1.1-2.1°F cooler on average in the summer and 1.0-2.5°F warmer when winter temperatures reached below 45°F outside. In the summer, 5 of 47 homes (10.6%) with pre- and post-weatherization logger data experienced average temperature reductions of over 5 degrees Fahrenheit. In the winter, 3 of 43 home (7.0%) with pre- and post-weatherization logger data experienced average temperature increase of over 5 degrees Fahrenheit. Overall, the survey findings revealed that the majority of participating households entering into the Home Uplift weatherization program struggled with maintaining healthy indoor temperatures in both cooling and heating seasons. Significant reductions in homes being too hot or cold were observed in the post-weatherization environments.

Survey findings suggest that the prevalence of chronic health conditions related to respiratory illnesses and arthritis is perhaps greater in the Home Uplift population (based on this sample) than the general population across the TN Valley. Respondents reported that individuals with these chronic illnesses experience worsening symptoms when it is too hot or cold. In light of the high rates of chronic illness among weatherization-eligible participants, these findings illuminate the ways in which income-eligible programs meet a unique and particularly strong need in the community by alleviating issues that disproportionately fall on lower income residents. This work leads to broader questions about the role weatherization can serve in a changing climate, where extreme heat will intensify and sources of outdoor air pollutants, such as wildfires and ozone, will be exacerbated by rising temperatures. Exploring the ability of weatherization to protect against outdoor air pollution would expand upon this work and the field of indoor environmental quality monitoring to better understand the health risks and protective factors inside our homes.

Appendix A: Survey Instruments

Summer Survey Questions	Response Categories
About how long have you lived in your current home, in years and months?	Numeric
How many people currently live in your home?	Numeric
Thinking about last summer, which of the following statements best describes the indoor temperature of your home that summer?	Comfortable
	Warmer Than I Would Prefer
	Very Hot
During the summer, what is the average temperature when someone is inside your home DURING THE DAY?	Numeric
	Not Applicable
During the summer, what is the average temperature when someone is inside your home AT NIGHT?	Numeric
	Not sure
	Not Applicable
Thinking about last summer, was your home ever kept at a temperature that you felt was unsafe or unhealthy?	Yes
	No
Thinking about when you first turn your AC on for the summer, about how hot is it usually OUTSIDE before you turn the AC on?	70 to 75 degrees
	75 to 80 degrees
	80 to 85 degrees
	85 to 90 degrees
	Hotter than 90 degrees
Now, thinking about this summer, did you wait to turn your air conditioning on because you worried about the cost of your energy bill, even though it got hot inside your home?	Yes
	No
	Don't Know
Are there other reasons you might wait to turn your air conditioning on, even when it gets hot inside your home?	Yes
	No
What are the reasons you might wait to turn your air conditioning on, even when it gets hot inside your home?	String
Thinking about last summer, did anyone in the household have to seek medical treatment because your home was too HOT?	Yes
	No

[SKIP IF NO OR DON'T KNOW to previous question] What type(s) of medical attention did they seek?	String
Thinking about last summer, did you have to temporarily move out of your home because your home was too hot?	Yes
	No
Thinking about last summer, was there ever a time your cooling equipment was broken, and you did not have cooling inside your home?	Yes
	No
Thinking about last summer, was there ever a time your utilities were disconnected, and you did not have cooling inside your home?	Yes
	No
	Don't Know
In the last 12 months, have you seen mold inside your home?	Yes
	No
	Don't Know
In the last 12 months, have you seen standing water inside your home?	Yes
	No
Was there ever a time living in this home that you did not get enough rest or sleep because it was too hot inside?	Yes
	No
Have you or anyone in the home ever been told by a doctor or other health professional that you or they have asthma?	Yes
	No
Does this person still have asthma?	Yes
	No
Thinking about the person with asthma in the home with the most severe or uncontrolled asthma, how long has it been since that person last had any symptoms of asthma?	Less than one day ago
	1-6 days ago
	1 week to less than 3 months ago
	3 months to less than 1 year ago
	1 year to less than 3 years ago
	3 years ago or more
Do that person’s asthma symptoms seem to worsen when they are hot?	Yes
	No

Have you or anyone in the home ever been told by a doctor or health professional that you have COPD, emphysema, or chronic bronchitis?	Yes
	No
Last summer, other than a routine visit, did that person have to seek medical treatment for symptoms related to shortness of breath, bronchitis, or other COPD or emphysema flare-ups?	Yes
	No
Do that person's respiratory illness symptoms seem to worsen when they are hot?	Yes
	No
Have you or anyone else in the home ever been told by a doctor or other health professional that you have a form of arthritis?	Yes
	No
	Don't Know
	Less than one day ago
	1-6 days ago
	1 week to less than 3 months ago
	3 months to less than 1 year ago
	1 year to less than 3 years ago
	3 years ago or more
Do that person's arthritis symptoms seem to worsen when they are hot?	Yes
	No
	Don't Know
Over the LAST 30 DAYS, did that person see a doctor, nurse, or other health professional for urgent treatment of worsening arthritis symptoms?	Yes
	No
And then thinking about last summer, did that person have to see a doctor, nurse, or other health professional for urgent treatment of worsening arthritis symptoms?	Yes
	No
How hard is it to pay for your energy bills? Would you say...	Very Hard
	Hard
	Neither hard nor easy
	Easy
	Very Easy

Has anyone in the household ever served on active duty in the U.S. Armed Forces, Reserves, or National Guard?	Yes
	No
Do you consider yourself to be of Hispanic, Latino/a, or Spanish origin, such as Mexican, Puerto Rican, or Cuban?	Yes
	No
	Black or African American
	White
	American Indian or Alaska Native
	Asian
	Native Hawaiian or Other Pacific Islander
	A race not listed
	Prefer not to answer
If you selected more than one race, which one of these groups BEST represents your race? You can only choose one.	Black or African American
	White
	American Indian or Alaska Native
	Asian
	Native Hawaiian or Other Pacific Islander
	A race not listed
	Prefer not to answer
What is your age?	Numeric
What is your gender?	Woman
	Man
	String

Winter Survey Questions	Response Categories
About how long have you lived in your current home, in years and months? (years)	Numeric
About how long have you lived in your current home, in years and months? (months)	Numeric
How many people currently live in your home?	Numeric
Thinking about last winter, which of the following statements best describes the indoor temperature of your home that winter?	Comfortable
	Colder Than I Would Prefer
	Very Cold
	Numeric
	Not sure
	Not Applicable
	Numeric
	Not sure
	Not Applicable
Thinking about last winter, was your home ever kept at a temperature that you felt was unsafe or unhealthy?	Yes
	No
Thinking about when you first turn your AC on for the winter, about how cold is it usually OUTSIDE before you turn the AC on?	Colder than 45 degrees
	45 to 50 degrees
	50 to 55 degrees
	55 to 60 degrees
	Don't Know
Now, thinking about this winter, did you wait to turn your air conditioning on because you worried about the cost of your energy bill, even though it got cold inside your home?	Yes
	No
	Don't Know
Are there other reasons you might wait to turn your air conditioning on, even when it gets cold inside your home?	Yes
	No
What are the reasons you might wait to turn your air conditioning on, even when it gets cold inside your home?	String
Do you use any of the following types of extra heating equipment in your home? Check all that apply.	Electric space heater
	Vented gas fireplace

	Wood fireplace
	Unvented propane or kerosene heater
	Other
	None of the above
Do you use any of the following types of extra heating equipment in your home? Check all that apply.	Electric space heater
	Vented gas fireplace
	Wood fireplace
	Unvented propane or kerosene heater
	Other
	None of the above
Do you use any of the following types of extra heating equipment in your home? Check all that apply.	Unvented gas fireplace
	Heating pad at night
	Oven
	Ceramic heater
	Oil radiator heater
	Electric fireplace
Thinking about last winter, did anyone in the household have to seek medical treatment because your home was too COLD?	Yes
	No
[SKIP IF NO OR DON'T KNOW to previous question] What type(s) of medical attention did they seek?	String
Thinking about last winter, did you have to temporarily move out of your home because your home was too cold?	Yes
	No
Thinking about last winter, was there ever a time your heating equipment was broken and you did not have heating inside your home?	Yes
	No
Thinking about last winter, was there ever a time your utilities were disconnected and you did not have heating inside your home?	Yes
	No
	Don't Know
In the last 12 months, have you seen mold inside your home?	Yes
	No
	Don't Know
In the last 12 months, have you seen standing water inside your home?	Yes
	No

Was there ever a time living in this home that you did not get enough rest or sleep because it was too cold inside?	Yes
	No
Have you or anyone in the home ever been told by a doctor or other health professional that you or they have asthma?	Yes
	No
Does this person still have asthma?	Yes
	No
Thinking about the person with asthma in the home with the most severe or uncontrolled asthma, how long has it been since that person last had any symptoms of asthma?	Less than one day ago
	1-6 days ago
	1 week to less than 3 months ago
	3 months to less than 1 year ago
	1 year to less than 3 years ago
	3 years ago or more
Do that person's asthma symptoms seem to worsen when they are cold?	Yes
	No
Have you or anyone in the home ever been told by a doctor or health professional that you have COPD, emphysema, or chronic bronchitis?	Yes
	No
Last winter, other than a routine visit, did that person have to seek medical treatment for symptoms related to shortness of breath, bronchitis, or other COPD or emphysema flare-ups?	Yes
	No
Do that person's respiratory illness symptoms seem to worsen when they are cold?	Yes
	No
Have you or anyone else in the home ever been told by a doctor or other health professional that you have a form of arthritis?	Yes
	No
	Don't Know
Thinking about the person with Arthritis who has the most severe symptoms… How long has it been since that person last had any symptoms of arthritis?	Less than one day ago
	1-6 days ago
	1 week to less than 3 months ago

	3 months to less than 1 year ago
	1 year to less than 3 years ago
	3 years ago or more
Do that person's arthritis symptoms seem to worsen when they are cold?	Yes
	No
	Don't Know
Over the LAST 30 DAYS, did that person see a doctor, nurse, or other health professional for urgent treatment of worsening arthritis symptoms?	Yes
	No
And then thinking about last winter, did that person have to see a doctor, nurse, or other health professional for urgent treatment of worsening arthritis symptoms?	Yes
	No
How hard is it to pay for your energy bills? Would you say...	Very Hard
	Hard
	Neither hard nor easy
	Easy
	Very Easy
Has anyone in the household ever served on active duty in the U.S. Armed Forces, Reserves, or National Guard?	Yes
	No
Do you consider yourself to be of Hispanic, Latino/a, or Spanish origin, such as Mexican, Puerto Rican, or Cuban?	Yes
	No
Which of these categories describe your race? You can select more than one category.	Black or African American
	White
	American Indian or Alaska Native
	Asian
	Native Hawaiian or Other Pacific Islander
	A race not listed
	Prefer not to answer
If you selected more than one race, which one of these groups BEST represents your race? You can only choose one.	Black or African American
	White

	American Indian or Alaska Native
	Asian
	Native Hawaiian or Other Pacific Islander
	A race not listed
	Prefer not to answer
What is your age?	Numeric
What is your gender?	Woman
	Man
	String

Appendix B: Participant Selection Criteria

Question	Eligibility Implications
Is your home currently vacant?	**YES: Not eligible** **NO: Go to next question**
Are your utilities currently active?	**YES: Go to next question** **NO: Not eligible**
Have you noticed any roof leaks in the past 12 months?	**YES: Not eligible (likely to be deferred)** **NO: Go to next question**
Have you had any mold or moisture problems in the past 12 months? If Yes, is the mold less than 10 square feet?	**YES to both: Not eligible (likely to be deferred)** **NO: Go to next question**
Is your house currently being remodeled or are there any areas of the home that are not finished?	**YES: Not eligible (would interfere with ability to measure Home Uplift solely)** **NO: Go to next question**
Are you currently enrolled and approved in any other weatherization program offering similar services? If Yes, when work is scheduled to begin?	**YES: Not eligible (would interfere with ability to measure Home Uplift solely)** **NO: Go to next question**
Are there areas of the home that are difficult to heat or cool?	**YES: Prioritize for inclusion** **NO: Go to next question**
Thinking about last winter, do you remember it being cold inside your home?	**YES: Go to next question** **NO: Not eligible**
Do you have a central heating system? If Yes, is it currently working?	**IF WORKING: Go to next question** **IF NOT WORKING: Prioritize for inclusion**
What temperature do you keep your thermostat set on in the (winter/summer)?	**IF VERY LOW/HIGH: Prioritize for inclusion** **ELSE: Eligible if meets all criteria above**