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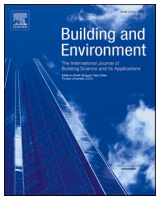

# Cascading benefits of low-income weatherization upon health and household well-being

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A B S T R A C T

This paper presents research that shows how home environmental conditions are part of a larger household-centric system that contains nodes related to household finances, occupants' general health, life satisfaction, and serious health-related life events. Data were collected to assess the non-energy impacts of a utility-driven low-income energy efficiency (i.e., weatherization) program implemented in the Southeastern United States. A household survey was administered by phone to a treatment group just prior to weatherization and one year after weatherization and to a control group during the same timeframes. The survey posed questions that were used to create five aggregate variables that compose the household system: 1) home conditions; 2) household financial problems; 3) general health and well-being; 4) life satisfaction; and 5) major health-related life events. The results show that all five aggregate variables are highly correlated with each other with the expected signs both pre- and post-weatherization. A five-equation simultaneous equation model was estimated using three-stage least squares, where the endogenous variables were the post-weatherization values for the aggregate variables. A weatherization treatment dummy variable was added to each equation. The results indicate that home conditions and general health were the most statistically significant endogenous variables. The treatment dummy was statistically significant in three of five equations, including home conditions. Age and income were the most influential demographic variables. Overall, the results suggest energy efficiency improvements in low-income homes can have a cascading positive influence on financial issues, general health, life satisfaction, and major life events.

## 1. Introduction

This paper presents a framework for studying the relationships between home environmental conditions and other important components of a household-centric system that includes household finances, general occupant health, life satisfaction, and serious health-related life events. A substantial literature exists that demonstrates the impact of poor housing conditions on occupant general health (e.g., mental health, physical health) but not, for example, on how general health may impact housing conditions, if at all. Additionally, many studies have been conducted to assess the impacts of improving energy efficiency on these types of household variables but do not then go on to assess how these impacts may cascade through a household-centric system.

The research reported below is driven, in part, to better understand how the impacts of weatherization may provide cascading benefits to households. Weatherization is a term of art used in the United States to describe comprehensive low-income home energy retrofit programs that install these types of measures: air sealing, insulation, heating and cooling system repair and replacement, CO monitors, window and door repair and replacement, duct sealing, ventilation, water heater wraps, moisture barriers in crawlspaces, and energy efficient lights and refrigerators. The research presented herein makes use of survey data collected as part of an evaluation of a low-income weatherization program administered in the Southeastern United States.

The largest barrier to weatherization in the U.S. is lack of funding. The combined resources for weatherization provided by the U.S. energy efficiency sector, which includes the federal and state governments, utility companies, and non-profits, is far outweighed by demand. In response, efforts have been made to assess the benefits of weatherization to other sectors of the economy, such as health care and public health. For example, improving the comfort of homes can reduce thermal stress, which in extreme cases can reduce emergency department and hospital visits. Making the case for weatherization to non-energy efficiency entities requires building theory of change models that explain the non-energy benefits of weatherization.

This paper contributes to the literature because it is the first to situate weatherization specifically, and home conditions more generally, in a household-centric model. It is hypothesized that not only do home conditions impact the health of occupants, for instance, but also that the health of occupants could also affect home conditions. In fact, it is hypothesized that these five components of a household-centric model – home conditions, financial problems, general health, life satisfaction, and life events – are all strongly correlated with each other. It is further hypothesized that changes in one component, in this case home

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conditions through weatherization, can positively cascade through the system. Building evidence for this model and the cascading benefits of weatherization will be important for weatherization program managers to make the case to healthcare, public health, and housing program managers across the U.S. to work together to improve home conditions through weatherization.

The literature reviewed for this paper is presented in Section 2. The research approach, study area, and survey are discussed in Section 3. Section 4 presents descriptive statistics that characterize the survey sample, which includes treatment homes that received weatherization and control homes that did not. Also presented in this section are results of correlations between the system's five aggregate variables and the estimation of a simultaneous equation model that provides more systemic insights into the relationships between home conditions, weatherization, and the other important aspects of the household system. Our observations about the results of this research are presented in Section 5.

## 2. Literature review

Numerous studies report on the relationships between poor housing conditions and the quality of life of occupants and how improvements in housing conditions can improve quality of life. For example, recent research has continued to link poor housing and poor mental health and to find that improvements in housing can improve mental health and well-being [1–10]. Kang [11] found that housing instability adversely impacts mental health. Rolfe et al. [12] found that good property quality and satisfactory neighborhood conditions are positively correlated with measures of health and wellbeing.

Many studies have reported on how a very specific type of housing improvement, weatherization, can produce a wide range of non-energy impacts (NEIs) [13–15]. These types of studies also show that weatherization can positively impact the quality of life of occupants. For example, Willand et al. [16] explain how residential energy efficiency interventions can improve health. Thomson and Thomas [17] developed logic diagrams to track causal pathways, supported by research, from improvements in energy efficiency and housing conditions to a range of impacts, including:

- Improved general health [18–22].
- Improved mental health [23–25].
- Improved social well-being [26–28].

Our previous research supports conclusions that weatherization can improve general health, mental health, and social well-being [29–32]. Additional research indicates that weatherization can:

- Improve indoor air quality (IAQ) by preventing the intrusion outdoor air pollutants and pests through air sealing measures and improved ventilation [33–42].
- Reduce thermal stress by keeping homes from being too cold or too hot through a combination of new insulation, air sealing, and improvements to heating and cooling systems [43–55].
- Reduce uncontrolled asthma and headaches through the installation of all of the energy efficiency measures just mentioned [38–42, 56–60].
- Reduce noise, which can then improve mental health and rest and sleep [61–73].
- Reduce energy burdens [74] and water costs [14,75], and lessen financial stresses [29–31,76].

One observation that can be made about this previous research is that the studies focus on exploring how housing conditions can impact various aspects of quality of life. The research does not explore how those aspects of quality of life may actually impact housing conditions and, in turn, each other. For example, one could hypothesize that bad mental or physical health could prevent occupants from engaging in activities that could keep their homes in good condition. Declining home conditions could then have a negative feedback effect upon mental and physical health. Improvements in general health and physical activities, which could be fostered by weatherization, can lead to improvements in mental health [77–79]. Improvements in mental health can then reduce the impacts of chronic conditions such as hypertension [80–82] and ischemic heart disease [83–85].

Previous research also does not often explore energy poverty, which is an international issue [86–100], from a comprehensive systems perspective. While previous research indicates that energy poverty is linked to bad mental and physical health [29–31,101], one could also hypothesize that poor household finances in general could prevent investments to maintain good home conditions. Stressful household financial situations could also adversely impact mental and physical health, which could also work to reduce human capital investments in home maintenance [102]. Households headed by elders, for example, have been found to only invest their housing as a last resort [103]. This is quite relevant to the administration of weatherization programs because the majority weatherization recipients are elderly or near-elderly. Additional research has shown that poor mental health can exacerbate household financial problems (i.e., by making households more likely to be victims of scams and poor financial judgements and management [104,105]).

Lastly, it could be argued that previous research may have focused too much on the statistical significance of individual variables and not enough on broader patterns of results. For example, in our own previous research, one study may find that there is a statistically significant reduction in asthma-related emergency department visits [29] but another may not [31]. We also note that all of the studies find that aspects of general health may improve post-weatherization but not all of the results may be statistically significant [29–31]. Examinations of changes in variables related to home conditions, health, and financial issues found that over 60% of the measured changes in the treatment group were in the expected direction and only 20% in an unexpected direction and 70% of the variables used in comparison group analyses changed in the expected direction [30,31]. The systems approach used in this research to aggregate categories of variables into composite variables may be able to better express overall positive statistical outcomes seen in our data.

Table 1 provides a summary of the previous research just cited. Most of the papers present results of the impacts of home conditions and changes in home conditions on one topic of interest, with most papers focusing on physical health, followed by mental health, IAQ, financial problems, general health, and well-being. Only a few papers address multiple topics, which include some combination of mental health, well-being, and general health. Very few papers address how aspects of household health and well-being may impact home conditions. We found no previously published papers that take a systems approach to explore how housing conditions may be situated in a household-centric system.

## 3. Research approach

This section presents our research approach. Section 3.1 presents the research question. Section 3.2 describes study area in the Southeastern U.S. and Section 3.3 the study's design and sample of homes used in this research. Section 3.4 presents details of the household survey administered as part of this study. Lastly, Section 3.5 discuss the construction of the five aggregate variables that compose the household system developed for this research.

### 3.1. Research question

Our motivating research question is whether home conditions can be an important component of a household system that also encompasses financial issues, general health, life satisfaction, and life events (i.e.,

**Table 1**
Previous research involving home conditions and other components of a household system.

| | Impacts On | General Health | Financial Problems | Physical Health | Mental Health | Well Being | IAQ | Relevant References |
|---|---|---|---|---|---|---|---|---|
| Home Conditions | → | | | X | | | | 16, 38–45, 50-60 |
| Home Conditions | → | | | | X | | | 11, 23–25, 61-73 |
| Home Conditions | → | | | | | | X | 33–42 |
| Home Conditions | → | | | | X | X | | 1-10, 12 |
| Home Conditions | → | X | | | X | X | | 17 |
| Home Conditions | → | X | | | | | | 18–22 |
| Home Conditions | → | | | | | X | | 26–28 |
| Home Conditions | → | | X | | | | | 74, 14, 75, 29-31 |
| Mental Health | → | | | X | | | | 80–85 |
| Mental Health | → | | X | | | | | 104, 105 |
| Home Conditions | ← | | | X | | | | 102, 103 |
| Mental Health | ← | X | | X | | | | 77–79 |

events requiring serious medical interventions).[1] More specifically, we hypothesize that all five components of this household system would be highly correlated with each other. As suggested in Fig. 1, not only could home conditions impact general health, but general health could also impact home conditions. General health could impact financial problems, which then could impact home conditions. As explained in the previous section, many papers describe research that documents the impacts of changes of home conditions on no more than a few components of this household system. Only a few studies focus on the impacts of say, household finances, on home conditions. We found no papers in the literature that quantitatively attempt to explore how home conditions and changes in home conditions fit into a comprehensive household model such as illustrated in Fig. 1. As such, this paper makes a unique contribution to the literature.

### 3.2. Study area

The data used in this research was collected as part of an evaluation of the Tennessee Valley Authority's Home Uplift pilot initiative.[2] Home Uplift funds the installation of a comprehensive set weatherization measures in low-income homes in the Tennessee Valley. The program is co-funded by participating local power companies (LPCs). 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.

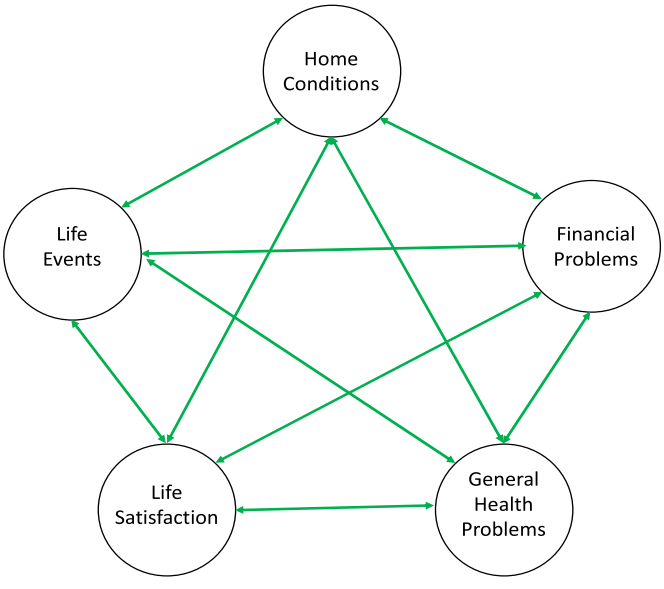


**Fig. 1.** Household system graphic.

The four major metro areas in TVA's region participated in the Home Uplift 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).[3] The pilot focused on weatherizing single family, owner-occupied homes and a small number of mobile homes. The small number of homes weatherized in Huntsville were owned by its public housing program. To be eligible for the program, households' income must be less than or equal to 200% of the federal poverty level.

### 3.3. Study design and sample frame

Three[3] employed a quasi-experimental research design that included surveying households that received Home Uplift weatherization (treatment group) and households of similar socioeconomic status that had yet to – and were not likely to – receive weatherization in the near future (control group). Nearly all Home Uplift homes that received energy audits between 2018 and 2019 were included in the sample frame for the treatment group.

Control group households were recruited through several means depending on the Home Uplift site. For example, in some locations, staff working in Home Uplift operations would contact households on waiting lists that were not likely to receive weatherization in the next year. At other Home Uplift sites, local community organizations recruited interested control group households by going door-to-door. In the more difficult areas to recruit control group households, postcards were sent to publicly available addresses they had been eligible for the area's tax freeze programs. In another location, postcards were sent to addresses on previously compiled lists for households living in high energy burdened zip codes.

The power calculations aimed to provide a very high level of confidence in the research results and the capability to detect statistically significant changes in health and other outcomes from one year to the next. The power calculations were developed to be able to detect statistically significant changes in asthma-related emergency room visits. Data for the power calculations were taken from the results of a previous study [29]. Table 2 displays the final sample frame for the Home Uplift NEI survey for each metro area site that participated in the pilot. The results of the power calculations are presented in the rows labeled final

[1] Detailed descriptions of these five variables are provided in Section 3.5.
[2] https://energyright.com/residential/home-uplift/https://www.tva.com.
[3] https://www.energy.gov/eere/wap/weatherization-assistance-program.

**Table 2**
Home uplift metro area NEI evaluation sample.

| Home Uplift Pilot NEI Evaluation Sample | | | |
|---|---|---|---|
| **Treatment Group** | | Pre-Weatherization/ Year 1 | Post-Weatherization/Year 2 |
| | Sample Frame | 893 | 625 |
| | Projected Response Rate | 70% | 80% |
| | **Final Sample Goal** | **625** | **500** |
| | **Actual Sample** | **701** | **570** |
| **Control Group** | | Round 2/Year 1 | Round 2/Year 2 |
| | Sample Frame | 750 | 375 |
| | Projected Response Rate | 50% | 80% |
| | **Final Sample Goal** | **375** | **300** |
| | **Actual Sample** | **300** | **222** |

sample goals. The table displays the breakout of survey completions by each research group.

Table 2 also indicates the actual number of surveys administered to the treatment and control groups pre- and post-weatherization. Sample size goals were exceeded for the treatment group and not met for the control group. The former outcome can be attributed to the goodwill generated by the Home Uplift program amongst the program's recipients. The latter outcome was not surprising and helps explain why so many approaches were used to recruit control homes.

### 3.4. Survey instrument

The survey instrument for the Home Uplift NEI evaluation for the metro areas 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; access to healthcare; energy security, affordability, and trade-offs of basic essentials. The majority of survey questions were drawn from pre-existing survey instruments used by the study team in other weatherization evaluation work. We note that the majority of the questions used in our previous surveys are themselves drawn from frequently administered federal surveys, such as the Residential Energy Consumption Survey (RECS)[4] and the Behavioral Risk Factor Surveillance System (BRFSS).[5] As a form of best practice, survey questions from government sponsored research and tracking mechanisms are used for comparability.

The Center for Applied Research and Evaluation (CARE), University of Tennessee, Knoxville (UTK) administered the survey by phone. Households that participated in the survey were provided a $20 incentive for the first round of survey completion and a $40 incentive to complete the second-year survey.

Unexpectedly, the Coronavirus 2019 (COVID-19) pandemic caused many weatherization organizations to paused on-site operations in 2020. When UTK closed its buildings in March 2020, UT CARE survey operators stopped the administration of the Home Uplift survey. When survey operations resumed in August 2020, a number of survey questions were added to try to control for the impacts of COVID-19 on survey responses and to better understand who the Home Uplift pilot was helping. Analyses were conducted on the survey data using the full sample and then comparing treatment and control group households stratified by if they had been surveyed pre-pandemic or after the pandemic had fully impacted local economies and policies. No statistically significant differences were detected in answers on the core survey questions that were answered pre-versus several months into the pandemic. Therefore, all data collected as part of the study were used in the quantitative analyses presented below.

### 3.5. Aggregate variables construction

The survey was developed with the primary goal of evaluating the potential non-energy impacts of the Home Uplift pilot. Similar to past evaluations of low-income weatherization programs, the survey questions focused on changes to home conditions, financial stresses, and occupant health. Questions that address the latter relate to general health conditions (e.g., mental health) and also instances where medical intervention is required (e.g., visits to emergency departments). Questions that pertain to life satisfaction were also added to this survey.

The five composite variables constructed for this research are set out in Table 3. These composite variables capture each of the main issues presented above. The home conditions composite variable is composed of 9 individual variables, such as home being too drafty or dusty. Each of the variables was coded to be a binary variable if they were originally asked as Likert scale questions. The same approach was used with respect to the 13 variables that contributed to the construction of the financial problems composite variable. Integer variables that contributed to the general health (e.g., bad days of physical health) and life events variable (e.g., number of hospitalizations for being too cold in one's home) were also coded to be binary variables to create variables that have equal range (i.e., 0 or 1). The three variables that contribute life satisfaction composite all had the same Likert scales, but were also recoded into binary variables.

The variables used to construct three of the home conditions, financial problems, and life satisfaction composite variables are intuitively straightforward. It was felt that the health-related variables needed to be split into two composite variables, general health and life events. The general health variables capture day-to-day descriptions of occupant health. Are they plagued by bad mental and physical health or bad days of rest and sleep? Do they have headaches and frequent symptoms of asthma and COPD? Conversely, the life events composite variable is constructed with variables that can be seen as relatively infrequent but serious from a health perspective. For example, few people need to be hospitalized for thermal stress from being too cold in their homes but it is a traumatic experience if that happens. It can be argued that emergency department visits are also traumatic experiences. The term 'medical intervention' that is used in the life events column refers to whether the respondent or an occupant in the home was hospitalized or needed to visit the emergency department.

## 4. Results

This section presents the results of this study. Section 4.1 presents a comprehensive set of demographic descriptive statistics. Section 4.2 presents results of analyzing the aggregate variables pre- and post-weatherization and also presents the correlations between the five aggregate variables. Section 4.3 presents the results of a 3SLS model, which has five equations, one for each of the endogenous aggregate variables, as well as a range of demographic exogenous variables.

### 4.1. Respondent demographics

Table 4 presents the characterization of the study sample for the treatment and control groups for each survey year. The overwhelming majority of primary survey respondents in both research groups identified as female and as Black or African American. Only a small percentage of respondents self-identified with a different ethnicity. More pre-weatherization respondents identified as White than the control group sample during the first year – by about 7%. The average age of the primary survey respondent was deemed to be statistically different

[4] https://www.eia.gov/consumption/residential/.
[5] https://www.cdc.gov/brfss/questionnaires/index.htm.

**Table 3**
Composite variables.

| *Home Conditions (yes, no)* | *Financial Problems (yes, no)* | *General Health Problems (yes, no)* | *Life Satisfaction (yes, no)* | *Life Events (yes, no)* |
|---|---|---|---|---|
| Home Kept at Unsafe Temperature | Household Has Problems Paying Medical Bills | Respondent Physical Health Bad Last 30 Days | Respondent Satisfied with Life in General | Respondent Required COPD-Related Medical Intervention |
| Home Too Drafty | Household Cannot Afford Prescriptions | Respondent Sleep/Rest Bad Last 30 Days | Respondent Satisfied with Health | Respondent Required Asthma-Related Medical Intervention |
| Home Too Dusty | Household Did Not Pay Prescriptions to Pay Energy Bills | Respondent Mental Health Bad Last 30 Days | Respondent Satisfied with Standard of Living | Household Member Required Medical Intervention from Being Too Cold in Home |
| Outside Odors Infiltrate Home | Household Did Not Pay Energy Bills to Pay Prescriptions | Respondent Has Headaches | | Household Member Required Medical Intervention from Being Hot Cold in Home |
| Outdoor Noise Bothersome | Hard for Household to Pay Energy Bills | Respondent Had Asthma Symptoms Last 3 Months | | Household Member Required Medical Intervention Due to Fire in Home |
| Mold Seen in Home | Household Did Not Pay Energy Bills to Pay Other Utilities | Respondent Had COPD Symptoms Requiring Doctors Visit | | Household Member Required Medical Intervention Due to Food Poisoning Related to Malfunctioning Refrigerator |
| Standing Water in Home | Household Did Not Pay Other Utilities to Pay for Energy Bills | | | Household Member Required Medical Attention Due to Trip/Fall in Home |
| Insect Infestation in Home | Household Received Utility Disconnect Notice | | | Household Member Required Medical Intervention Due to CO Poisoning in Home |
| Mice Infestation in Home | Household Did Not Pay for Food to Pay Energy Bills | | | Respondent Required Medical Intervention for Migraines |
| | Household Did Not Pay Energy Bills to Pay for Food | | | Household Member Required Medical Intervention Due to Burns from Hot Water in Home |
| | Household Received Food Assistance | | | |
| | Household Used Short-term Predatory Loan | | | |

**Table 4**
Household characterization: Primary respondent demographics.

| Variable/Research Group[1] (n = Number of Respondents) | Treatment Pre-wx (n = 701) | Treatment Post-wx (n = 572) | Control Year 1 (n = 300) | Control Year 2 (n = 222) |
|---|---|---|---|---|
| Gender: Female | 81.2% | 82.9% | 84.0% | 86.5% |
| Age (mean) | 62 | 64 | 58*** | 60*** |
| Black or African American | 76.6% | 78.5% | 80.3% | 81.5% |
| White | 21.7% | 20.1% | 14.7%* | 16.7% |
| Hispanic or Latino Origin | 1.3% | 1.2% | 1.3% | 0.9% |
| American Indian/ Alaska Native | 0.7% | 0.7% | 0.7% | 0.9% |
| Other Race | 0.9% | 0.2% | 2.3% | 0.5% |

***p < .001 **p < .01 * p < .05 + p < .10.
[1]The two research groups are found to be statistically different at either: *p < .05, **p < .01, or ***p < .001 in a Pearson Chi-Square test or independent samples test (means) comparing treatment and control group samples for each Survey Round (1 and 2).

between the treatment and the control group samples for both rounds of the survey; by four years. Other than the difference in average age and difference in respondents identifying as White during the first round of the survey, no other statistical differences were found between the two groups on these demographics.

#### 4.1.1. Household composition

The Home Uplift pilot that operated in metro areas across the Tennessee Valley primarily served households that owned their own homes (Table 5). Households in this sample had an average household size of 1.8 people and lived in their homes an average of 23 years. Households in the control group were, on average, larger in size, lived in their home fewer years, and had much lower homeowner rates; at statistically significant levels.

Just over 26% of Home Uplift households in this sample reported that the primary wage earner of the household is employed full-time, and that 44% are currently retired (Table 6). Another quarter of households reported the primary wage earner is unable to work mostly

**Table 5**
Household characterization: Household size, owner status, years lived in home.

| Variable/Research Group[1] (n = Number of Respondents) | Treatment Pre-Wx (n = 701) | Treatment Post-Wx (n = 570) | Control Year 1 (n = 300) | Control Year 2 (n = 222) |
|---|---|---|---|---|
| Average household size (mean) | 1.8 | 1.9 | 2.4*** | 2.4*** |
| Own home (not rent or other situation) | 85.0% | 85.0% | 58.5%*** | 58.5%*** |
| Number of years lived in home (mean) | 23 | 25 | 20 | 18*** |

***p < .001 **p < .01 * p < .05 + p < .10.
[1]The two research groups are found to be statistically different at either: *p < .05, **p < .01, or ***p < .001 in a Pearson Chi-Square test or independent samples test (means) comparing treatment and control group samples for each survey year (Year 1 and Year 2).

**Table 6**
Household characterization: Employment and education status.

| Variable/Research Group (n = Number of Respondents) | Treatment Pre-Wx (n = 701) | Treatment Post-Wx (n = 572) | Control Year 1 (n = 300) | Control Year 2 (n = 222) |
|---|---|---|---|---|
| Employed (primary wage earner) | 26.4% | 25.1% | 30.0% | 26.2% |
| Retired (primary wage earner) | 43.5% | 47.7% | 36.4%* | 37.8%* |
| Unable to work (primary wage earner) | 25.0% | 23.1% | 23.2% | 23.9% |
| Health keeps respondent from working a job | 52.7% | 48.3% | 48.5% | 50.2% |
| High school diploma/GED only | 33.7% | 33.2% | 35.7% | 31.5% |
| College degree(s) | 23.1% | 23.2% | 22.8% | 25.8% |

***p < .001 **p < .01 * p < .05 + p < .10.

because their health keeps them from working a job. About one third of Home Uplift households reported their highest level of education is a high school diploma or GED; a little less than a quarter reported having a college degree. The percentage of primary wage earners that are retired is the only statistical difference observed between the Home Uplift treatment group and the control group; with the control group having fewer retired individuals by about 7%. In addition, just over 5% of homes served through the Home Uplift program contained someone who served on active duty in the U.S. Armed Forces, Reserves or National Guard.

An income question was added to the survey instrument prior to households being surveyed during the second year of the study. Income ranges (i.e., bands) were designed to calculate poverty status using federal poverty thresholds for 2019 (Table 7). Based on income estimates,[6] approximately 43% of Home Uplift households were living below the federal poverty line (FPL) in the second year of the study. There was a statistically significant difference between the number of weatherized participants (7%) and unweatherized participants (18%) who were living below 50% FPL; but not for 100 or 200% FPL.

The majority of households that received Home Uplift services reported that at least one person living in the home receives either Social Security or Supplemental Security Income from the U.S. government (Table 8). A statistically significant difference was observed in the percentage of treatment households that received either of these benefits when compared to the control group. Small percentages of survey respondents in both research groups reported receiving welfare payments or cash assistance, Veteran's payments, or unemployment compensation, with the exception of control group households in the second year of the survey. A much higher rate of unemployment compensation is observed in both treatment and control group households when the sample is stratified by when the survey was completed. In the second-year survey, but prior to the COVID-19 pandemic,[7] less than one percent of treatment and control group households reported that someone in the home received unemployment benefits, compared to 10 and 13%, respectively, during the pandemic.

**Table 7**
Household characterization: Poverty status.

| Variable/Research Group[1] (n = Number of Respondents) | Treatment Pre-Wx | Treatment Post-Wx (n = 572) | Control Year 1 | Control Year 2 (n = 222) |
|---|---|---|---|---|
| Household living below 50% FPL | | 7.4% | | 17.8%*** |
| Household living below 100% FPL | | 43.2% | | 50.5% |
| Household living below 200% FPL[a] | | 90.5% | | 88.6% |

***p < .001 **p < .01 * p < .05 + p < .10.

[1] The two research groups are found to be statistically different at either: *p < .05, **p < .01, or ***p < .001 in a Pearson Chi-Square test or independent samples test (means) comparing treatment and control group samples for each Survey Round (1 and 2).

[a] The mid-point of an income band and household size were used to calculate poverty status. Because of this, households on the lower end of an income band might still be living at or under 200% poverty thresholds, but might appear to be living above the threshold in our tables. It appears as though just under 10% of Home Uplift households in this pilot were at the upper limits of the eligibility thresholds.

[6] The mid-point of an income band and household size were used to calculate poverty status. Because of this, households on the lower end of an income band might still be living at or under 200% poverty thresholds, but might appear to be living above the threshold in our tables. It appears as though 10% of Home Uplift households in this pilot were at the upper limits of the eligibility thresholds or moved above 200% FPL during the second year.

[7] For the purposes of this study, pre-COVID-19 surveys are considered those completed before CARE shut down its survey center in March 2020.

**Table 8**
Household characterization: Government assistance.

| Variable/Research Group[1] (n = Number of Respondents) | Treatment Pre-Wx (n = 701) | Treatment Post-Wx (n = 572) | Control Year 1 (n = 300) | Control Year 2 (n = 222) |
|---|---|---|---|---|
| Someone in the home received income from: | | | | |
| Social Security | 60.6% | 70.5% | 50.7%** | 65.3% |
| Supplemental Security Income | 20.8% | 16.8% | 27.3%* | 22.1% |
| Welfare payments or cash assistance | 1.6% | 0.5% | 2.7% | 0.9% |
| Veteran's payments (VA benefits) | 0.9% | 1.9% | 2.0% | 3.2% |
| Unemployment compensation | 1.3% | 3.8% | 2.0% | 9.0%** |

***p < .001 **p < .01 * p < .05 + p < .10.

[1] The two research groups are found to be statistically different at either: *p < .05, **p < .01, or ***p < .001 in a Pearson Chi-Square test or independent samples test (means) comparing treatment and control group samples for each Survey Round (1 and 2).

#### 4.1.2. Healthcare coverage

The vast majority of main respondents in the treatment group reported having had healthcare coverage in the past 12 months during both survey years; pre and post-weatherization (Table 9). Although a slightly lower percentage of households in the control group had healthcare coverage – by about 5% at baseline – this difference between research groups was determined to be statistically significant during both years of the survey. A statistically significant difference was also observed between the research groups during the second year of the survey with nearly 5% fewer households in the control group having a health plan that covers at least some cost of prescription medications.

Due to the evaluation's quasi-experimental design, it was important to generate a representative sample of treatment homes and a comparable sample of control homes. Recruitment of control group homes was unique to each metro area site and dependent upon the availability of internal resources, extensive waiting lists for weatherization that could provide contact information for unweatherized homes (as described above). As a result, the control group diverged from the treatment group on several sample characteristics and baseline statistics (documented in [32] 3). For example, more treatment group homes reported owning their own home than control group households (by about 40%). Treatment group respondents appear to be slightly older and are more likely to be retired than control group respondents. Finally, treatment group households appear to have struggled more with maintaining comfortable temperatures inside their homes and had more broken heating and cooling equipment at baseline (e.g., before weatherization). The average household size and number of households with children are higher in the control group, which also has higher rates of respondents that smoke cigarettes and households exposed to environmental tobacco smoke

**Table 9**
Household characterization: Healthcare coverage.

| Variable/Research Group (n = Number of Respondents) | Treatment Pre-Wx (n = 701) | Treatment Post-Wx (n = 572) | Control Year 1 (n = 300) | Control Year 2 (n = 222) |
|---|---|---|---|---|
| Main respondent has had healthcare coverage (past 12 months) | 93.4% | 97.0% | 88.0%** | 91.4%** |
| Health plan pays for at least some of the cost of prescriptions | 96.4% | 95.0% | 96.3% | 90.4%* |

***p < .001 **p < .01 * p < .05 + p < .10.

(ETS).

Despite these differences in the treatment and control groups, it can be argued that these differences are not so great as to cause concerns about the results of this research. In many ways, the groups are much more similar to each other than to the general U.S. population. The households are all low-income. The majority of both groups received government financial assistance. Their demographics are also more similar to themselves that to the U.S. population with respect to race, age and gender. The results presented in Table 10 suggest that there is not much difference in the aggregate variables pre-weatherization across the groups, either.

### 4.2. Aggregate variable descriptive statistics and correlations

Table 10 presents descriptive statistics for each of the five aggregate variables. Presented are means for each variable pre- and post-for all homes combined and also by the treatment and control groups. Our first observations are that the means for the home conditions, financial problems, and general health composite variables were slightly lower than expected. In other words, we expected that the composite variables would depict homes in worse condition and that households would suffer from more financial problems and general health issues. Conversely, the means for the life satisfaction were slightly higher than we expected. While we are not saying that these means suggest that the low-income households in our study enjoy the highest quality of life, our expectations may reveal a bias that we might have with respect to understanding the lives of low-income households. On the other hand, the average values for the life events aggregate variable seem slightly higher than we anticipated. Ten to twenty percent of this population engages the healthcare sector annually with issues serious enough to require hospitalization or emergency department visits.

*A priori*, we hypothesized that weatherization would improve home conditions, reduce financial and health problems, reduce the number of health-related life events, and improve life satisfaction. All of the changes for these variables pre-to post-weatherization for the treatment group support this hypothesis. We hypothesized that changes in the control group variables would not be statistically significant. The results do not really support this hypothesis, as the control group reported statistically significant improvements in home conditions, financial problems, and life satisfaction. Lastly, we hypothesized that the beneficial changes for the treatment group would be higher than beneficial changes for the control group. The differences in differences (DID) assessments support this hypothesis in three instances, home conditions, general health problems, and life satisfaction.

**Table 10**
Aggregate variable means pre-post.

| Aggregate Variable (Range) | *Home Conditions (0–9)* | *Financial Problems (0-13)* | *General Health Problems (0–6)* | *Life Satisfaction (0–3)* | *Life Events (0-10)* |
|---|---|---|---|---|---|
| Avg. Pre-Wx | 2.1 | 3.9 | 1.9 | 2.4 | .17 |
| Avg. Post-Wx | 1.1 (742) *** | 3.2 (737) *** | 1.6 (718) *** | 2.7 (776) *** | .10 (755) *** |
| Avg. T-Pre-Wx | 2.1 | 3.9 | 1.9 | 2.4 | .16 |
| Avg. T-Post-Wx | 1.1 (533) *** | 3.1 (536) *** | 1.5 (514) *** | 2.7 (561) *** | .09 (549) ** |
| Avg. C-Pre-Wx | 1.8 | 4.2 | 2.0 | 2.4 | .22 |
| Avg. C-Post-Wx | 1.3 (209) *** | 3.7 (201) ** | 1.8 (204) | 2.6 (215) ** | .13 (206) |
| DID | −.6 (742) *** | −.6 (737)+ | −.2 (718) *** | +.1 (776) | 0.0 (755) |

***p < .001 **p < .01 * p < .05 + p < .10.

Fig. 2 presents the Spearman's correlations amongst the aggregate variables. *A priori,* we anticipated that the signs for the correlations for these four variables – home conditions, general health problems, financial problems, and life events would be positive and for these four variables to the life satisfaction variable would be negative. These expectations were met for the full sample pre-weatherization, the full sample post-weatherization, and for the treatment group both pre- and post-weatherization. All of the correlations are statistically significant at the p < .001 level and many of the correlation coefficients have high effect sizes.[8] These results strongly support the contentions that home conditions are part of a larger household system and that all components of the system are strongly interrelated. That all of the correlations would be highly statistically significant and have such large coefficient values was certainly surprising.

One more observation about the correlations results is worth noting at this point. This is that the correlations involving life events are lower in magnitude than the correlations involving the other variables. We hypothesize that life event as used herein – i.e., instances where serious health issues require hospitalization and emergency department visits – are more random and acute features of life than regular and chronic conditions of life. Even though the frequency of the life events is higher than we expected, the frequencies are still relatively low. For several of the variables, such as those related to thermal stress hot and cold, outdoor conditions that could create the conditions for the life events may not arise each and every year. The model results presented immediately below also suggest that life events can best be viewed as being relatively random and less tied to the other components of the household system.

### 4.3. Simultaneous equation model design and results

To explore relationships between home conditions and the other four aggregate variables, a five-equation simultaneous equation model was estimated using three-stage least squares (3SLS).[9] The five equations specified each have one of the five post-weatherization aggregate variables as its dependent variable. Also included was a lagged variable (i.e., the pre-weatherization value of the dependent variable). Over the course of the model development exercise, each endogenous variable was included in each equation. The endogenous variables were dropped from the equations when the p values were highly insignificant. Most of the beta-coefficients for the endogenous variables that remain in the model are statistically significant, though a couple of the p-values are over 0.20.

A treatment dummy variable was tested in each of five equations, though only remain in three of the five equations. A robust set of exogenous variables was also tested in all of the equations during the model development process in ways that did not cause the model to be unable to be estimated. These variables include: age, gender, education level, and race of the respondent; having health insurance, household size, smoking allowed in home, and household income. Allow exogenous variables with p-values greater than 0.20 were dropped from the model.

The final model presented in Table 11 was judged to be reasonable and defensible. The $R^2$ for each equation is highly statistically significant. The high magnitudes of the $R^2$'s is most likely due to the presence of the lagged variables in the equations, which were all highly significant. An examination of the endogenous variables that remain in the model indicate that general health is the central component of the model. In other words, general health shows up in other equations as an endogenous variable more than the other variables and more endogenous variables impact this variable as a dependent variable than other variables. These observations can be more clearly understood through

[8] http://psychology.emory.edu/clinical/bliwise/Tutorials/SCATTER/scatterplots/effect.htm#:~:text=The%20Pearson%20product%2Dmoment%20correlation,relationship%20between%20the%20two%20variables.

[9] The Stata software package was used for this modeling exercise.

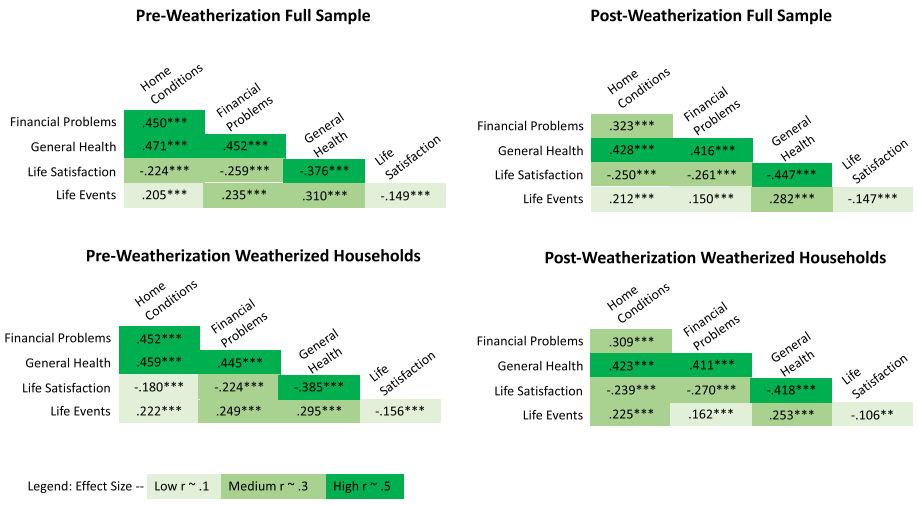


**Fig. 2.** Aggregate Variable Correlations
***p < .001 **p < .01 * p < .05 + p < .10.

**Table 11**
Composite variable five equation 3SLS model (N = 581).

| Endogenous/Exogenous Variables (Post) | $R^2$ (p value) | Beta Coefficient | p value |
|---|---|---|---|
| ***Eq. 1 Home Conditions Post-Wx*** | .30 (.000) | | |
| Home Conditions Pre-Wx | | .31 | .000 |
| General Health Problems Post-Wx | | .39 | .000 |
| Life Events Post-Wx | | −.57 | .301 |
| Treatment Group Home | | −.30 | .012 |
| Household Income | | −.04 | .068 |
| Constant | | .33 | .056 |
| ***Eq. 2 Financial Problems Post-Wx*** | .52 (.000) | | |
| Financial Problems Pre-Wx | | .48 | .000 |
| General Health Problems Post-Wx | | .63 | .000 |
| Respondent Age | | −.02 | .003 |
| Household Income | | −.12 | .000 |
| Constant | | 2.06 | .000 |
| ***Eq. 3 General Health Problems Post-Wx*** | .53 (.000) | | |
| General Health Problems Pre-Wx | | .43 | .000 |
| Financial Problems Post-Wx | | .08 | .010 |
| Life Events Post-Wx | | .48 | .246 |
| Life Satisfaction Post-Wx | | −.15 | .026 |
| Treatment Group Home | | −.27 | .010 |
| Respondent Age | | −.005 | .139 |
| Smoking Allowed in Home | | −.20 | .043 |
| Constant | | 3.1 | .002 |
| ***Eq 4. Life Satisfaction Post-Wx*** | .32 (.000) | | |
| Life Satisfaction Pre-Wx | | .25 | .000 |
| General Health Problems Post-Wx | | −.64 | .000 |
| Respondent Age | | −.011 | .055 |
| Treatment Group Home | | .42 | .017 |
| Household Income | | −.04 | .144 |
| Constant | | 11.4 | .000 |
| ***Eq. 5 Life Events Post-Wx*** | .17 (.000) | | |
| Life Events Pre-Wx | | .17 | .000 |
| General Health Problems Post-Wx | | .06 | .000 |
| Have Health Insurance | | −.14 | .011 |
| Household Size | | −.02 | .055 |
| Household Income | | −.008 | .181 |
| Constant | | .186 | .006 |

an examination of Fig. 3. This means that improvements in general health can cascade more strongly through the model than might improvements in the other endogenous variables.

Also, more clearly seen through Fig. 3 is the fact that home conditions are dependent upon other model components. For example, as general health problems increase, so do the number of problems with the home. One can surmise this is because general health problems can prevent household members from maintaining one's home. On the other hand, weatherization not only improves home conditions but also improves general health, which can then have a positive feedback upon home conditions. Weatherization is also linked to improve life satisfaction, which improves general health and then has a positive impact on home conditions.

A striking finding from the model results is the relative isolation of financial problems in the model. Though financial problems are highly correlated with all of the other aggregate variables, in the model this variable only interacts with the general health endogenous variable. One could hypothesize that general health mediates the impact of financial problems on home conditions (e.g., better financial situations improve general health which then is used as the foundation to improve home conditions, life satisfaction and life events).

Age and income were the most influential demographic variables. As the age of the respondent increases, financial problems and general health problems decline. This finding is consistent with results from previous research that suggests that the health and home conditions of pre-elders (i.e., individuals 55–64 years old) are worse that those who have reached retirement age [86]. Households with higher incomes (though still low enough to qualify weatherization and to be included in the control group) had fewer financial and home condition issues, and suffered fewer serious life events.

Overall, the exogenous variables that remained in the equations had the expected signs, however a few did not. For example, the signs for the beta coefficients for the age and income variables in the life satisfaction equation could have been expected to be positive, but were negative.

Also unexpected were the relatively few exogenous variables that remained in the final model. Some variables dropped out of the model entirely, such as race, gender, household size, and education. This result suggests to us that the household system model conceptualized herein applies equally well across household demographics, with income being the variable that most influences relationships between the components. Conversely, it could be that there is not enough variation across the demographic variables because of the samples developed for this research to express the significance of a larger set of demographic variables.

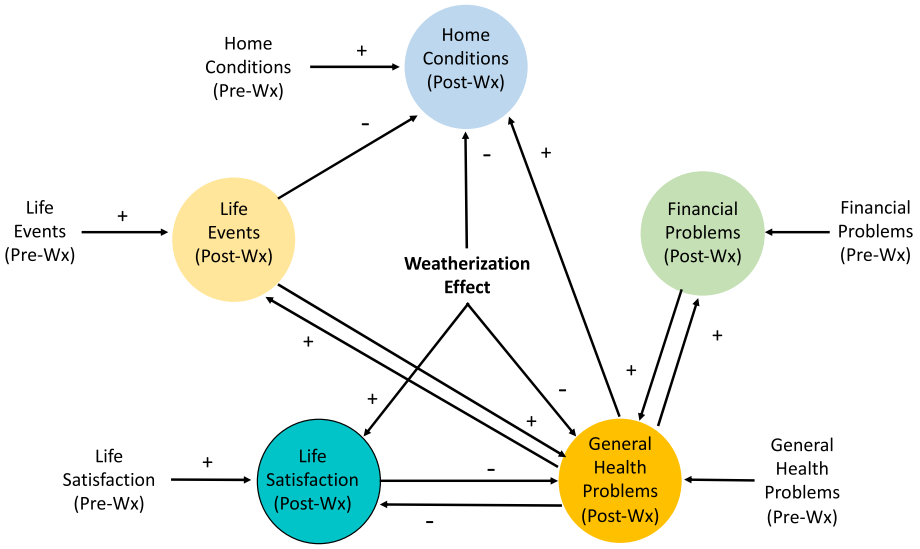


**Fig. 3.** Three-Stage least Squares Systems Diagram.

## 5. Discussion

The results strongly suggest the five-component household system model introduced above is useful for assessing relationships between home conditions and model components that characterize the life of households. In this case, home conditions are strongly correlated with general health and financial problems, life satisfaction, and serious life events. Improving home conditions through weatherization can also be clearly seen to have a cascading impact on the system's components. Not only can weatherization yield specific non-energy impacts (e.g., reductions in thermal stress, reductions in household financial tradeoffs) but can also can produce positive feedbacks throughout the entire household system.

A result that stands out in importance is the centrality of general health in the model. To recap, the general health aggregate variable is composed of variables related to mental and physical health, rest and sleep, headaches, and chronic respiratory conditions, such as asthma, and COPD. General health is highly correlated with the other four model components and according to the results of the 3SLS model, changes in general health can strongly cascade through the household system.

A trend in the weatherization sector in the U.S. is to blend weatherization programs with programs that install what are known as healthy homes measures. The latter are typically designed to reduce asthma symptoms (e.g., by taking up old carpets, installing HEPA filters on furnaces). Of course, improvements in indoor air quality can also be beneficial to those with COPD and headache sufferers. The results presented above provide additional evidence to support the blending of these programs with the co-equal goals of improving energy efficiency and human health.

The results also point to the importance of taking advantage of being in homes to be able to refer households to other social service programs, especially those that provide wrap-around health-related services. Conversely, it is important for other social services, be they related to mental and physical health or food availability, to understand the importance of home conditions on the total household system. Weatherization is exceedingly important because improvements in energy efficiency can directly reduce household energy and water bills. Also important are other home improvements, such as roof repairs, that actually may need to precede weatherization in many cases.

The findings also support other previously observed phenomena. For example, it has been noted that in many cases individuals who end up in emergency departments lack health insurance that could have allowed them to more regularly visit their doctors and therefore avoid having to visit emergency departments. The negative value for the coefficient of the having health insurance exogenous variable in the serious life events equations supports the contention that more available and affordable insurance could reduce these types of life events.

The lack of statistically significant demographic variables is unexpected. However, one could surmise that the system is in some sense universal, that these components interrelate with each other regardless of demographic situations. Future research could delve deeper into the lives of low-income households to better substantiate the higher-level findings of this research. Diaries and/or frequent open-ended verbal reports could be collected that probe how asthma attacks, for example, may limit home maintenance activities. These approaches could provide deeper insights into how bad home conditions may impact mental health, which could them impinge upon life satisfaction.

The lack of significance of the demographic variables might allow the framework to be generalized to other regions of the US and maybe even other countries. The framework was tested with a low-income population that, for the most part, owned single-family homes. However, system dynamics might be different for non-low-income families and families living in large, well-maintained multifamily buildings or in regions with housing situations that are quite different from those in the U.S.

Future research could use different aggregate variables. More or fewer aggregate variables could be specified. Much different variables could be used to create the aggregate variables. As noted above, the variables used in this study were drawn from a survey that had a different purpose; to identify and estimate the non-energy impacts of weatherization. It might be interesting to work into the household model the use of social media and the consumption of media in general (e.g., including television, radio, streaming services). Could overconsumption of social media be correlated with reduced general health and, in turn, worse home conditions?

## 6. Conclusions

This research shows how data collected to assess the impacts of weatherization on homes and households can also be used to model complex relationships between home conditions and other household variables. This research suggests that weatherization has multifaceted impacts on homes and the families living in them. This research provides strong evidence to spur those in the weatherization sector specifically and home repairs and retrofits in general to consider the health benefits of their work. The results provide more evidence to support the

argument that good general health can have cascading impact on the household system and that healthcare should be more proactive in making investments to improve the housing of vulnerable households.

## CRediT authorship contribution statement

**Bruce Tonn:** Writing – review & editing, Writing – original draft, Methodology, Funding acquisition, Formal analysis, Conceptualization. **Erin Rose:** Writing – review & editing, Writing – original draft, Project administration, Methodology, Funding acquisition, Conceptualization. **Michaela Marincic:** Project administration, Methodology, Investigation, Data curation, Conceptualization.

## Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

## Data availability

The data that has been used is confidential.

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