MEMORANDUM

To: Chris Chan, Eversource and the NEI Study Group

From: Greg Clendenning, Nicole Rosenberg and Monica Nevius, NMR; Beth Hawkins, Bruce Tonn and Erin Rose, Three[3]

Cc:

Date: July 12, 2019

Re: TXC50 LIMF NEI Phase 1 Findings

Purpose and Objectives

This memo presents qualitative results from the first phase of a two-phase study that is being conducted by Three[3], Inc. and NMR Group (the study team) as part of the Special and Cross-cutting NEIs contract. The study team was tasked by the Program Administrators (PAs) of the Commonwealth of Massachusetts (MA) to evaluate the health and safety-related non-energy impacts (NEIs) attributable to improvements in the energy efficiency (EE) of income-eligible multifamily (MF) buildings served through the Mass Save® program.

This report complements past MA research that estimated NEIs attributable to weatherizing low-income single-family (LISF) homes.[1] This research was funded by the MA PAs, and is being conducted in conjunction with a larger, national evaluation managed by Three[3] and Slipstream[2] through a grant awarded by the JPB Foundation (JPB). The results are based on the data set from the first phase (Phase 1).[3]

The specific research objectives for Phase 1 of this study were to develop health and safety-related NEI estimates for low-income multifamily (LIMF) households to complement the LISF health and safety NEI estimates developed in 2016. Due to sample sizes that were smaller than expected, some demographic differences among the study groups, and other methodological concerns discussed in this memo, Phase 1 reporting focuses on qualitative assessments of the NEIs. Phase 2 will quantify the NEIs prioritized in this qualitative assessment. In addition, Phase 2 will involve incorporating pre- and post-weatherization data into the analysis of the core NEIs previously monetized by the LISF study and/or the national evaluations of the U.S. Department

---

[1] Three[3] and NMR 2016.
[2] Slipstream was formed through the recent merger of Seventhwave and the Wisconsin Energy Center.
[3] Phase 1 data collection is completed in all other states with the exception of Pennsylvania. Survey distribution ceased no later than April 2019.

of Energy's (DOE) Weatherization Assistance Program (WAP), as well as developing estimates of potential new NEIs. It will also yield insights into how health and safety impacts may differ across the following parameters:

- Building types (e.g., low-rise, high-rise)
- Building functions (e.g., family, senior, supportive housing)
- Populations

Key Findings and Results

Qualitative Assessment of Core NEIs

In Phase 1, the study team developed preliminary NEI estimates for all 13 *core* NEIs that were previously monetized by the MA PA's LISF study and/or the 2014 national evaluations of the U.S. DOE's WAP. The study team also developed a new NEI for reductions in arthritis symptoms (Table 1).[4] Because of difficulties achieving the expected response rate and some demographic differences among the study groups, and thus generalizing to the population of interest, it is not appropriate to report NEI values based on Phase 1 data alone.[5] For this reason, the NEIs will be quantified and reported as monetary values in Phase 2 only. That said, the Phase 1 results offer qualitative insights to help the PAs set expectations for Phase 2 results. This memo summarizes the Phase 1 research, key findings, and methodological issues the study team encountered. It also outlines plans for NEI monetization with more complete data in Phase 2.

Table 1 presents our qualitative assessment of the core NEIs examined in Phase 1. We differentiate between (1) NEIs for which we found statistically significant impacts of weatherization while attempting to control for confounding factors, such as age or employment status, with a regression analysis, and (2) NEIs for which we found evidence *without* attempting to control for confounding factors. For example, we found either statistically significant differences between responses of the Comparison with Treatment (CwT) group versus the Treatment (t) or Control (C) groups in the resident survey or other evidence of NEIs, such as data developed from FEMA's National Fire Incident Reporting System. Note that for both (1) and (2) the findings could be due to differences in study groups rather than to weatherization impacts.

---

[4] ThreeCubed and NMR. 2016. Massachusetts Special and Cross-Cutting Research Area: Low-Income Single-Family Health- and Safety-Related Non-Energy Impacts (NEIs) Study. Prepared for the Massachusetts Program Administrators. http://ma-eeac.org/wordpress/wp-content/uploads/Low-Income-Single-Family-Health-and-Safety-Related-NonEnergy-Impacts-Study.pdf
Tonn, B., Rose, E., Hawkins, B., and Conlon, B. 2014. Health and Household-Related Benefits Attributable to the Weatherization Assistance Program. ORNL/TM-2014/345, Oak Ridge National Laboratory, Oak Ridge, Tennessee, September. https://weatherization.ornl.gov/wp-content/uploads/pdf/WAPRetroEvalFinalReports/ORNL_TM-2014_345.pdf

[5] For example, more than half (53%) of the C group identifies as Black or African American, compared to less than one-quarter (23%) of the CwT group and 24% of the T group. In addition, in the asthma subsample we found statistically significant differences between the CwT and T+C groups in age, gender, and race.

Table 1: Core NEIs Examined in Phase 1

Core NEI Examined in Phase 1	Qualitative Assessment of NEI	Summary of NEI Metrics
Thermal stress – cold	Initial evidence of NEI from linear regression analysis	Reduced medical treatment (hospitalizations, ED visits, and physician office visits) and avoided deaths due to exposure to extreme temperatures in the home
Thermal stress – hot	Initial evidence from resident survey analysis	Reduced medical treatment (hospitalizations, ED visits, and physician office visits) and avoided deaths due to exposure to extreme temperatures in the home
Asthma	Initial evidence of NEI from linear regression analysis	Reduced medical treatment (hospitalizations, ED visits, and urgent care visits) due to asthma flares
Missed days of work	Initial evidence from resident survey analysis	Reduced incidence of lost wages due to illnesses or injuries (to respondent or member of the household)
Reduced fire risk	Evidence from secondary data analysis[1]	Reduced medical treatment and avoided deaths from reduced occurrences of home fires
Home productivity	Initial evidence from resident survey analysis	Household savings attributable to increases in annual non-market household production (i.e., housework) due to better sleep and rest
Short-term loans	Initial evidence from resident survey analysis	Annual household savings attributable to reduced need for taking out short-term high-interest (predatory) loans due to improved budget situations
Low-birth-weight infants	Initial evidence from resident survey analysis	Reduced rates of high food insecurity and associated reduced likelihood to have low birth weight infants
Food assistance	Initial evidence from resident survey analysis	Reduced needs for food assistance payments
Trips and falls (inside)	No evidence from resident survey analysis	Reduced rate of trips and falls requiring medical attention (hospitalizations, ED visits, urgent care visits, and physician office visits)
CO poisoning	No evidence of CO monitor installation (MA only)	Reduced medical treatment and avoided deaths from reduced occurrences of CO poisoning
Prescription medicine	Initial evidence from resident survey analysis	Improved prescription medication adherence and reduced hospitalization rates (due to improved household budgets).
Work productivity	Initial evidence from resident survey analysis	Increased annual work productivity due to better sleep and rest
Arthritis	Initial evidence from resident survey analysis	Reduced medical treatment (hospitalizations, ED visits, and urgent care visits) due to arthritis flares

[1] Evidence of reduced fire risk from weatherization is based on data on fire suppressors or ignitors developed from FEMA's National Fire Incident Reporting System (NFIRS). More details are available in the following study: Three[3] and NMR. 2016. Massachusetts Special and Cross-Cutting Research Area: Low-Income Single-Family Health- and Safety-Related Non-Energy Impacts (NEIs) Study. Prepared for the Massachusetts Program Administrators. http://ma-eeac.org/wordpress/wp-content/uploads/Low-Income-Single-Family-Health-and-Safety-Related-NonEnergy-Impacts-Study.pdf

The Phase 1 results suggest that many NEIs associated with health and safety impacts may have improved post-weatherization. Comparing the post-weatherization survey responses to responses from the combined pre-weatherization groups (control and treatment groups), the results suggest that draftiness, dustiness, rodent infestation, intrusion of outdoor noise, and presence of mold may have been reduced due to weatherization. A common single-family (SF) NEI found in previous research, reduction in cockroaches and other insects, was reported much less frequently by LIMF respondents than by LISF respondents.

Overall, these results offer tentative, initial support for the hypotheses that (1) improving the EE of LIMF buildings results in positive NEIs and (2) both NEIs and NEI values are different for residents of MF housing than for residents of SF homes. The demographic characteristics of the survey respondents and their self-reported health conditions differ enough from those upon which the LISF study was based to support the assertion that SF NEI values should not be generalized to the MF sector. The data show that the LIMF household NEIs that are directly related to specific health conditions (i.e., asthma and thermal stress) are potentially greater than those observed in the LISF population. Conversely, NEIs related to financial stability or general health (i.e., missed days of work and home productivity) for the LIMF population appear to be lower than for the LISF population.

NEIs for Consideration

In addition to the 13 core NEIs, Phase 1 gathered data to provide the foundation for the estimation of 22 additional NEIs that could be the focus of new monetization research given their observable and policy-relevant magnitudes of impact.

In identifying additional NEIs for monetization in Phase 2, the study team considered evidence from the Phase 1 research of the likelihood of change from pre- to post-weatherization and the likely magnitude of the NEI. We propose to evaluate these NEIs in Phase 2 using one of two methods, either a cross-sectional approach or a matched pairs analysis approach[6] We will use the same data sources to monetize additional health-related NEIs as those we used to monetize health-related core NEIs such as asthma and thermal stress. Table 2 shows justification for considering each NEI and the proposed analysis method.

[6] For the purposes of this memo, we define a matched pairs approach as one that identifies subjects with characteristics of interest (e.g. respondents that reported they "still have asthma") and each study group has two treatment conditions (in this case, pre-weatherized vs post-weatherized), allowing subjects to be grouped into pairs based on the weatherization variable. Then, within each pair, subject outcomes from two different points in time are compared between same respondents, and the change in the metric is calculated with the following equation: $(T_{pre} - T_{post}) - (C_{pre} - C_{post})$. For the cross-sectional approach we will compare changes between the T and C groups in health and household-related outcomes affected by weatherization while trying to control for potentially confounding differences between groups, such as demographic differences, by using multiple regression analysis. For each NEI, the regression analysis will produce a regression coefficient (β) that estimates the change attributable to weatherization while attempting to controlling for confounding factors.

Table 2: NEIs to Consider for Future Monetization

NEI	Justification	Proposed Approach
Arthritis	Sound theory of change[7]; very high incidence in MF population; initial evidence from resident survey analysis	Matched pairs
Spoiled food	Sound theory of change; high incidence of event; initial evidence from resident survey analysis	Cross-sectional
Energy assistance[2]	Sound theory of change; initial evidence from resident survey analysis	Matched pairs[1]
Odors[2]	Theory of change; initial evidence from resident survey analysis	Matched pairs[1]
Noise pollution	Sound theory of change; initial evidence from resident survey analysis	Matched pairs[1]
Mental health and well-being[2]	Sound theory of change; initial evidence from resident survey analysis	Matched pairs
Refrigerated medicines[3]	Initial statistical results suggest this is an important issue for MF population and could have a high monetary benefit; however, the weatherization may not impact this NEI	Cross-sectional
Electrical medical equipment[3]	Initial statistical results suggest this is an important issue for MF population and could have a high monetary benefit; however, the weatherization may not impact this NEI	Cross-sectional
Residential instability	Sound theory of change (re thermal conditions initial evidence from resident survey analysis	Cross-sectional
COPD	Sound theory of change; fairly high incidence MF population; initial evidence from resident survey analysis	Matched pairs
CVD	Sound theory of change; initial evidence from resident survey analysis	Matched pairs
Diabetes	Theory of change argument can be made; high incidence in MF population; some initial evidence from resident survey analysis	Matched pairs
Headaches	Sound theory of change; initial evidence from resident survey analysis	Matched pairs[1]
Dental health	Theory of change argument can be made; some initial evidence from resident survey analysis	Cross-sectional

[1] We will use a cross-sectional approach if sample sizes are too small for matched pairs analysis.
[2] NEIs that may be removed from the Phase Two analysis.
[3] May drop from Phase 2 analysis as outcomes are more likely directly attributable to power outages and building resiliency than weatherization.

[7] "Theory of change" refers to the rationale of why weatherization may lead to a particular NEI. We consider theory of change to be "sound" if we expect weatherization to lead directly to an NEI, such as reduced thermal stress or asthma. NEIs such as diabetes and oral health would be indirect and thus not rest on a "sound" theory of change.

Overview of Non-Energy Impacts

Weatherization has the potential to directly change the physical condition of homes, resulting in two major impacts. First, weatherization changes have direct impacts on resident health and safety. For example, improvements in dwelling quality reduce exposure to known asthma triggers such as mold, dust, extreme temperatures, and psychosocial stress, thereby reducing the incidence of acute asthma symptoms. Weatherization can also reduce risks of thermal stress on occupants[8] and health risks associated with home fires and carbon monoxide (CO) poisoning.[9] [10] Second, EE improvements result in energy cost savings and cost savings in other areas.[11] Figure 1 presents a comprehensive conceptual framework that shows the complex relationships between weatherization and impacts on human health. This framework recognizes that weatherization can provide many direct and second-order benefits to households, and that increases in income as a result of weatherization can result in expenditures that yield societal benefits.

As Figure 1 illustrates, improvements in household members' health and financial situations can result in a virtuous cycle of positive feedback effects that reinforce and amplify each other. Improved health of those employed and of school-aged children can result in reduced missed days of work and school, directly and positively impacting household budgets. Improved budget situations allow households to better afford food, pregnant women to avoid *heat-or-eat* predicaments,[12] individuals to better comply with prescription drug recommendations, and households to afford other healthcare expenses. These, in turn, have additional positive impacts on household members' health.

In most cases, comprehensive weatherization of homes is required to produce the most impactful health outcomes. For example, air sealing, insulation, heating/cooling system replacements and efficiency, and mechanical ventilation are a few weatherization measures that can reduce the frequency of exposure to asthma triggers. Most of the health impacts accrue from the installation of standard weatherization measures intended to save energy, and not from energy-related health and safety measures, such as repairing unsafe combustion appliances or damaged light fixtures.[13,14]

---

[8] For example, air sealing and insulation decrease drafts and unsafe temperatures inside the home and improve the resilience of homes during extreme weather events.

[9] Through the installation of CO monitors and ensuring that combustion appliances vent properly.

[10] It should be noted that asthma rates are higher than the national averages amongst low-income individuals (Rose, et al., 2015). Additionally, thermal stress is another example of a national health inequity (Madrigano 2013) and is expected to worsen over time due to the observed increased in frequency and duration of heat waves attributable to climate change (Wu et al. 2014). See: Rose, E., Hawkins, B., Tonn, B., Paton, D. and Shah, L. 2015. Exploring the Potential of Weatherization and Healthy Homes Interventions on Asthma-related Medicaid Claims and Costs in a Small Cohort in Washington State. ORNL/TM-2015/213, Oak Ridge National Laboratory, Oak Ridge, TN, July. Madrigano, J. et al. 2013.Vulnerability to Extreme Heat in New York City. Environment and Health – Bridging South, North, East and West, Basel, Switzerland, August 19-23, 2013. http://www.ehbasel13.org/
Wu, J. et al. 2013. Uncertainties in estimating future heat wave mortality in the eastern U.S. Environment and Health – Bridging South, North, East and West, Basel, Switzerland, August 19-23. http://www.ehbasel13.org/

[11] For example, reduced costs for water and utility disconnect and reconnect fees.

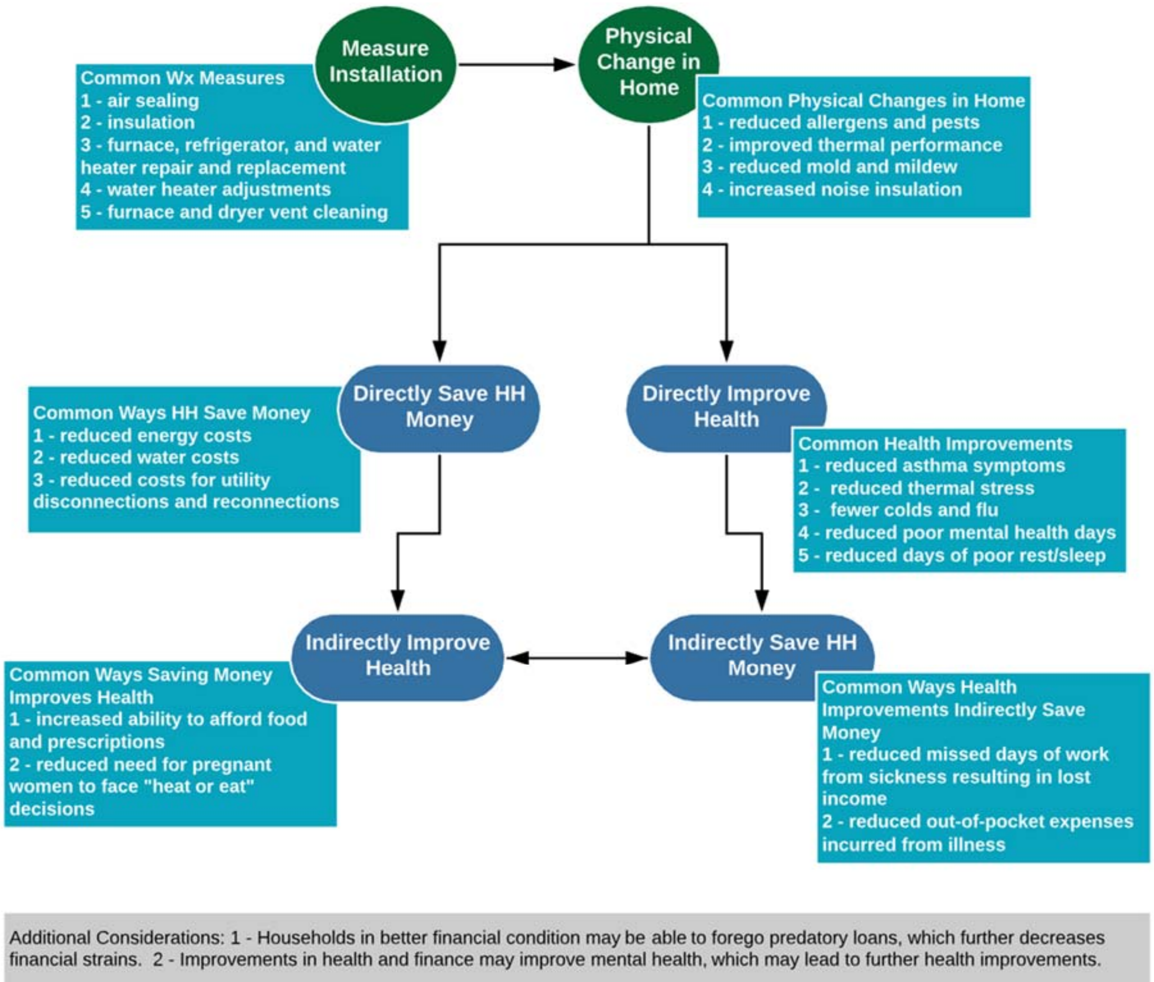
[12] Frank et al. 2006. Heat or Eat: The Low Income Home Energy Assistance Program and Nutritional and Health Risks among Children Less Than 3 Years of Age. Pediatrics, Vol. 118, No. 5, November 1, pp. e1293 -e1302.

[13] Health and safety measures include, but are not limited to, repair of unsafe combustion appliances; grab bars in the bathrooms; installation/repair of railings; and repair of damaged light fixtures, steps, carpet, and linoleum.

[14] Tonn et al 2014; Tonn et al. 2018.

Certain measures can unilaterally impact health. For example, installing CO monitors can reduce CO poisoning, and installing smoke detectors can reduce injuries and deaths from home fires. Lowering the temperature on water heaters to save energy can also potentially reduce the number of incidents of scalding. Installing energy-efficient and superior lighting technologies can lead to reductions in trips and falls both inside and outside of MF buildings. Finally, replacing inefficient refrigerators that also work poorly can reduce instances of food poisoning and food loss.

Figure 1: How Weatherization Can Yield Health Impacts



Research Methodology

RESIDENT SURVEY

A Resident Survey (RS) is the cornerstone of this research. The study team leveraged the national occupant survey used for DOE WAP evaluations[15] to develop the survey instrument, with additional questions to measure relevant NEIs from the 2016 MA LISF study (e.g., asthma, thermal stress, missed days of work). We added new questions to explore other health, well-being, and safety issues that could be impacted by weatherization, such as arthritis, injuries from trips and falls, perceptions of safety,[16] and social impact and building systems resilience indicators. Wherever possible, we drew on existing reputable surveys to develop new questions.

STUDY GROUPS

We stratified the sample into three groups: Comparison with Treatment (CwT), Treatment (T), and Control (C). The C group is composed of two subgroups: the Non-Program Control (NPC) and Control on Waiting List (CWL). We define the groups and subgroups in Figure 2. In Phase 1, we collected data from sites in all three groups.

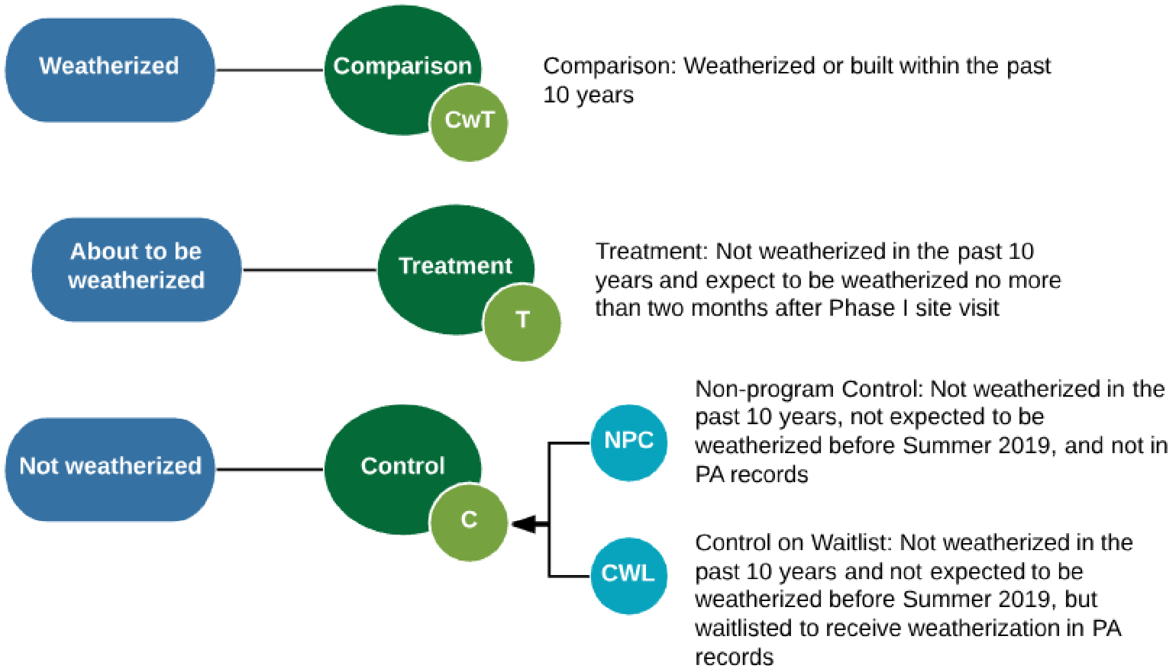
In Phase 2, we will only collect follow-up data from respondents in the T and C groups as the Phase 2 analysis will focus on a matched pairs approach analysis when possible, aiming to measure outcomes within a single group pre- and post-weatherization (e.g., T group Phase 1 survey responses compared to T group Phase 2 survey responses). If a matched pairs approach is not possible for some NEIs (for example, due to inadequate sample sizes), the study team will explore a cross-sectional analysis between T and C groups.

---

[15] Three[3] staff designed the occupant survey, managed the national WAP evaluations, and conducted the health and household-related impacts attributable to WAP study while employed as research staff under the auspices of Oak Ridge National Laboratory.

[16] The RS asks about trips and falls, in general; trips and falls attributable to poor lighting within the common areas of the building (e.g., hallways, stairs); and perceptions of safety directly outside the building that may be correlated with lighting, or the lack thereof.

Figure 2: Study Groups



SAMPLING

The study team conducted a power analysis to set sample size targets for the number of surveys. The power analysis relied on two variables: asthma-related emergency department (ED) visits and missed days of work. We based our estimates of these variables on results from the national evaluation of WAP occupant survey, using an alpha of 0.1. We set sample size targets to achieve a confidence interval of 90% or higher, with the assumption that our analysis would combine MA and JPB results.

Sample Frame Sources

We derived the MA CwT and T sample frames from data provided by the MA PAs and one Community Action Program (CAP) agency.[17] We obtained the sample frame for other states from numerous lists of eligible buildings provided by state and local agencies, owners of affordable MF buildings, and utility companies.

Initially, we limited the MA C group to CWL group projects that had gone through the PAs'/CAP program intake processes and were deemed eligible but were not expected to be weatherized before the start of Phase 2. After fielding commenced, stakeholders raised concerns about using sites exclusively from the program. There were three reasons: (1) the list of projects on the PAs'/CAP waiting lists was relatively small; (2) projects on the waiting list might be treated during the study period, and will therefore no longer qualify as C sites; and (3) there was a possibility of bias among sites not treated during the study period (i.e., the lack of treatment might be due to

[17] Action for Boston Community Development (ABCD) provided data on behalf of Eversource, Columbia Gas, and Cape Light Compact (CLC).

challenges rendering them unrepresentative of the overall population). Because of these concerns, we used multiple non-PA data sources to develop an NPC group of low-income MF sites in MA not associated with the program. (See Developing a Non-Program Control Group for details.)

Table 3 summarizes the sample frame. The JPB sample frame included seven other states from the Northeast and Midwest. In addition to weatherization status, our original sampling plan considered rise, number of units, ownership structure, and metropolitan-statistical area (MSA).[18,19] Sites in the sample frame were most often low-rise (less than five floors), in buildings with fewer than 80 units, and in urban areas. Our recruitment approach originally attempted to mirror the distribution of these characteristics.

[18] The National Center for Health Statistics (NCHS) developed a six-level urban-rural classification scheme for U.S. counties. We considered the two most urban levels (large central metro and large fringe metro) to be one metro area, and the four most rural levels (medium metro, small metro, micropolitan, and non-core) to be a second metro area. This site describes the MSA categories and provides the classifications by county: https://www.cdc.gov/nchs/data_access/urban_rural.htm

[19] We considered developing targets by housing function (e.g., senior, family), but PA data did not widely capture this characteristic.

Table 3: Sample Frame Property Site Characteristics[1]

Property Characteristic	Comparison with Treatment				Treatment				Control[3]			
	MA		Other States[2]		MA		Other States		MA		Other States	
	Sites	Units	Sites	Units	Sites	Units	Sites	Units	Sites	Units	Sites	Units
n	**474**	**33,580**	**239**	**14,605**	**55**	**4,288**	**126**	**6,715**	**458**	**4,216**	**63**	**3,804**
Rise												
Low-rise (< 5 stories)	82%	61%	71%	38%	76%	51%	58%	47%	11%	48%	75%	54%
Mid-rise (5 to 9 stories)	11%	19%	10%	16%	13%	28%	10%	9%	2%	14%	13%	26%
High-rise (10+ stories)	5%	14%	12%	44%	6%	20%	5%	18%	1%	15%	6%	19%
Unknown	3%	6%	7%	3%	6%	1%	26%	25%	86%	22%	6%	2%
Size (housing units)												
5 to 10 units	17%	2%	47%	14%	18%	1%	33%	4%	3%	2%	30%	4%
11 to 79 units	50%	27%	29%	25%	42%	23%	48%	26%	9%	33%	41%	24%
80 to 149 units	17%	26%	19%	40%	20%	26%	10%	19%	2%	26%	14%	25%
150 + units	12%	45%	5%	21%	15%	50%	10%	50%	2%	39%	14%	47%
Unknown	3%	†	0%	0%	5%	†	1%	†	84%	†	0%	0%
Metro-Statistical Area												
Large central and fringe metro	75%	71%	26%	12%	69%	74%	62%	57%	91%	68%	51%	58%
Medium and small metro and micropolitan	25%	29%	74%	88%	31%	26%	38%	43%	7%	32%	49%	42%

[1] Percentages may not sum to 100% because property site characteristics were not always available, and due to rounding.
[2] Other states include Illinois, Michigan, Wisconsin, New York, Rhode Island, New Hampshire, and Vermont.
[3] Only includes sites we could verify or clearly observe eligibility.
† Data not available.

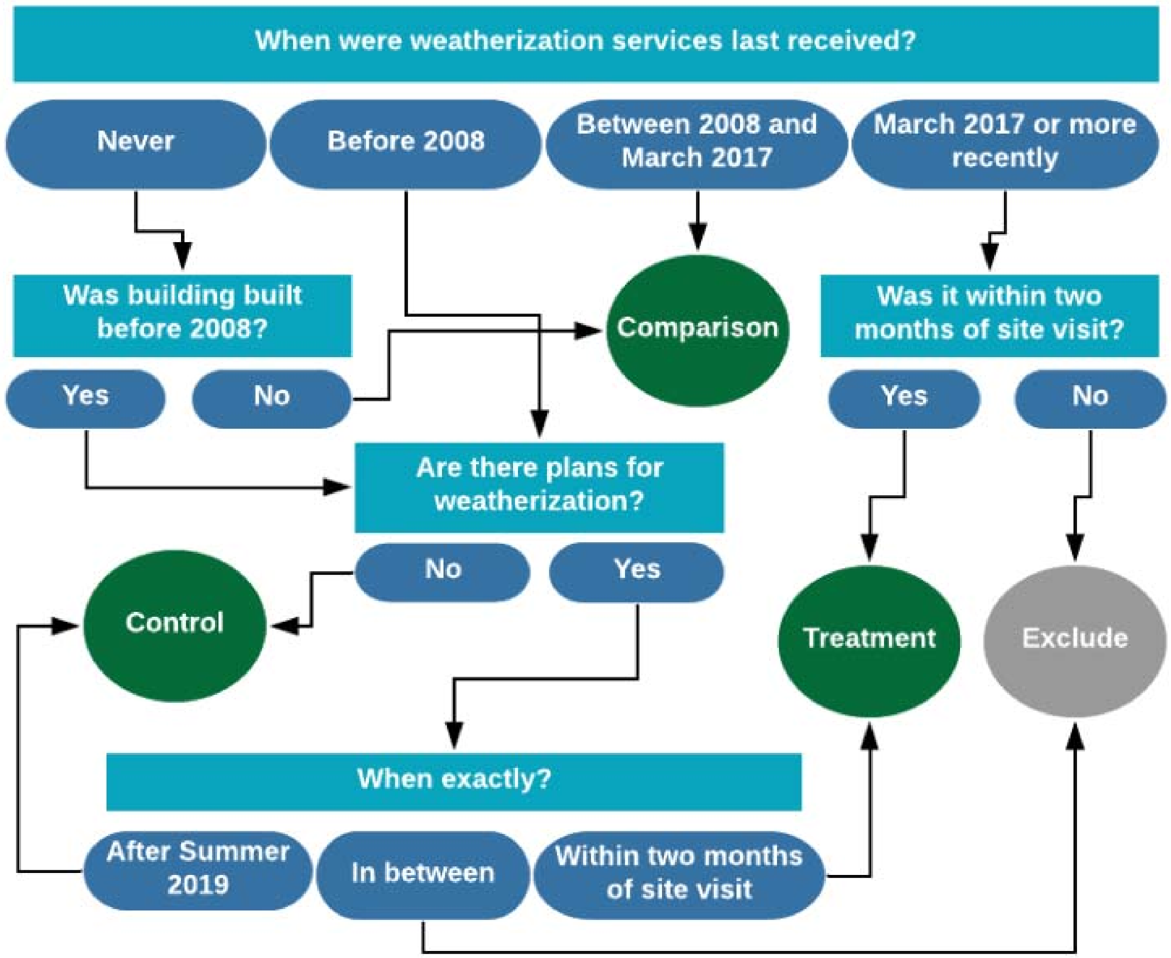
Classifying Projects' Weatherization Status

We used program participation data fields such as Application Status and Project Status to preliminarily classify MA project sites into study groups, using the following order of operations:

1. **Comparison (CwT)**. If a project's Application Status was designated in the database as *paid*, *invoiced*, or *installation complete,* or if the Project Status was *completed* prior to March 2017, we classified them as CwT.
2. **Treatment (T)**. We classified projects with an Application Status of *audit complete* or Project Status of *audited/work pending*, *installation contractor selected*, or *contract signed* as T projects.
3. **Control on Waitlist (CWL)**. If a project did not have an install date and had an Application Status of *pre-audit* or a Project Status of *not yet audited,* we placed them in the CWL group.
4. **Excluded**. If sites were unlikely to be MF based on the ratio of number of housing units to buildings (i.e., an average of less than five units per building), weatherized after March 2017, listed as *canceled,* or for any other reason appeared to be currently in the process of receiving weatherization services, we excluded them from the sample.

Recruiters verified each site's status by asking when weatherization services were last received, when the building was built, and near-term plans for receiving weatherization services. We considered a site to be weatherized if it had been insulated, been air- or duct-sealed, or had energy-efficient heating or cooling equipment installed within the past ten years. We also considered sites built in the last ten years as weatherized. Figure 3 maps the classification process. To qualify as a T project in Phases 1 and 2, a site had to have been weatherized within two months before and two months after the Phase 1 site visit.

Figure 3: Weatherization Classification Process



Developing a Non-Program Control Group

As noted earlier, we used multiple non-PA data sources to develop the NPC group. For MA sampling, this involved contacting roughly 50 housing authorities; reviewing publicly listed properties through community and economic development corporations; and cataloguing over 250 low-income properties using the Boston Metrolist, a clearinghouse of income-restricted and affordable housing opportunities in Boston and neighboring communities, posted by the city of Boston.[20] The broader JPB study undertook similar types of research to develop their sample frame for other states.

We also collaborated with the *RES38 Income-Eligible Process Evaluation* team, who prepared a database of income-eligible properties in MA using property tax data. Additionally, as in other JPB states, our MA recruiters asked *all* property managers (not just C group property managers) if they managed or owned other sites that they did not expect would receive weatherization in the coming two years.

---

[20] https://www.boston.gov/metrolist

Our C sample frame did not encompass all possible C sites due to the following reasons:

1. Not all housing authorities and property management agencies of NPC properties were willing to speak with us about their properties. Site characteristics were not always included in the publicly available lists. (The Fielding section discusses recruitment rates.)
2. Not all sites provided by the MA PAs and CAP met study eligibility criteria. Of the 535 MA sites we contacted, 83 (16%) were ineligible.[21]
3. The RES38 property tax data did not include the site details needed to determine if sites met study eligibility criteria. In an attempt to mirror population characteristics, we prioritized RES38 sites based on their size and metro area and contacted 80 of them.[22] Twelve (15%) were ineligible.

Air-Source Heat Pumps

The PAs asked the study team to prioritize projects where air-source heat pumps (ASHPs) were installed with program support.[23] Given the potential for additional health and safety impacts for ASHPs – including those associated with cooling – and PA concerns about the cost-effectiveness of ASHPs, assessing health and safety characteristics of these projects offers opportunities for NEIs to be factored into the measure's cost-benefit ratio. The sample frame included 24 sites where program data indicated ASHPs had been installed through the program: one CWL, three T, and 20 CwT. The study team attempted to contact and recruit all sites with ASHPs and looked for ASHPs while in the field to identify sites not captured in the original program data. Ultimately, we visited five sites with ASHPs.

FIELDING

From January through June 1, 2018, the study team visited 67 sites in MA, and from January through November 15, 2018, the study team visited 123 sites in the other states. We distributed 2,629 survey packets to MA residents and 4,585 survey packets to residents outside of MA, interviewed the sites' property managers, sketched building floor plans, recorded building orientation, and photographed and characterized central heating and cooling equipment.

Recruitment and Site Visits

As noted above, our recruiters verified each site's status by asking property owners or managers when weatherization services were last received, when the building was built, and near-term plans for receiving weatherization services. Recruiters also confirmed building attributes such as number of units and buildings, rise, ownership structure, and function. To participate in the study, property managers needed to be able to provide us entry to the buildings so that we could distribute the survey packets.

Staff distributed survey packets to residents by hanging a bag containing a paper survey, cover letter, project description, informed consent form, and a postage-paid envelope on residents'

[21] On average, each C site was contacted over three times, T site over six times, and CWT sites about three times.
[22] The RES38 data included over 1,700 properties.
[23] This was ultimately only relevant for CwT sites since we had to conduct census sampling for T and CWL sites.

doors. We undertook this participant recruitment approach as the most effective option given that household contact information was unavailable. The survey packet cover letter invited occupants to respond to the survey via one of three modes: the paper version we distributed, an online format, or by phoning a call center. We distributed multi-lingual paper and web surveys where appropriate.[24]

Challenges

The completed study sample sizes were not as large as planned.[25] First, property managers were often unresponsive to our recruitment efforts. To boost response rates, mid-fielding we began offering property managers an additional $100 to allow us on site. Table 4 shows MA recruitment statistics. Because the T group sample frame was small, we made more contact attempts than usual. On average, we contacted the 54 T sites more than six times to complete 13 site visits.

Table 4: Site Recruitment Summary

(MA Only)

Statistic	Comparison with Treatment	Treatment	Control
Sites Contacted[1]	**435**	**54**	**405**
Confirmed Eligible[2]	8%	24%	5%
Confirmed Ineligible	13%	24%	9%
Unresolved	61%	2%	73%
Refused	18%	50%	13%
Average Contact Attempts	**2.6**	**6.1**	**3.2**
Sites Visited	**33**	**13**	**21**
Recruitment Rate[3]	**8%**	**24%**	**5%**

[1] We did not contact all CwT and C sites because, in an effort to achieve balance across groups, we needed to focus on our lagging T group.
[2] This includes sites that cancelled their scheduled visits and were ultimately counted as "refused."
[3] Includes completed visits only.

[24] During recruitment, we asked property managers to estimate the percentage of households with adult occupants where English was a second language. If they represented greater than or equal to 30% of units, then we distributed surveys in both English and Spanish to each unit. If property managers were certain that a unit's occupants spoke neither English nor Spanish, we did not leave a packet at that unit to minimize cost associated with printing, packaging, and postage. For JPB, we incorporated Mandarin and Russian versions as well.

[25] For Phase 1, the study team anticipated 25 sites and 225 survey respondents from each study group in MA (an average of nine respondents per site). For the entire study, the study team anticipated 65 sites and 625 survey respondents for the CwT group and 145 sites and 1,425 survey respondents in each of the T and C groups (2,850 survey respondents combined).

We expected a survey response rate of 33% but experienced an initial response rate of only 6% after four weeks of fielding. As a result, we lifted over-representation limitations[26] and undertook the following steps to increase survey response rates:

- Distributed flyers to common spaces notifying residents about the survey packets they received;
- Sent property managers mail in advance of the study that provided background about the study that they could distribute to their residents;
- Increased the incentive for residents to complete the survey from $20 to $25;
- Knocked on doors during site visits to *personalize* the effort and answer residents' questions;
- Offered an *instant* gift card for same-day survey completion (versus being mailed a gift card after completing the survey at a later date);
- Re-visited sites to deliver postcard reminders and distribute reminder flyers for common spaces; and
- Provided property managers templates for reminder emails to encourage residents to complete the survey.

After implementing these steps, the average MA survey response rate across all groups rose to 18%.[27] By comparison, using the same steps, the average response rate across the other states was 23%.

Characteristics of Sample

While the study design set targets of over 3,000 completed surveys across all states, we were able to achieve a total sample of 1,660 households. Table 5 profiles the 165 sites (361 buildings) of the 1,660 households that completed the surveys.

[26] Initially, we limited the number of units sampled at larger buildings (i.e., buildings within 80+units) to prevent over-representation by an individual site.
[27] A total of 2,629 MA households received the survey and 462 MA households completed the survey.

Table 5: Profile of Sites with Participating Households

(All States Combined)

Characteristic[1]		Comparison with Treatment		Treatment		Control	
		Sites	HHs[2]	Sites	HHs	Sites	HHs
Total		**69**	**521**	**46**	**319**	**50**	**820**
Rise							
Low-rise (< 5 stories)		83%	74%	76%	63%	80%	56%
Mid-rise (5 to 9 stories)		10%	18%	15%	30%	16%	37%
High-rise (10+ stories)		3%	6%	2%	4%	4%	7%
Unknown		4%	1%	7%	3%	0%	0%
Size (housing units)							
5 to 10		46%	21%	44%	32%	30%	10%
11 to 79 units		44%	54%	46%	38%	54%	43%
80 to 149 units		7%	25%	11%	30%	12%	27%
150 or more units		0%	0%	0%	0%	4%	20%
Unknown		1%	0%	0%	0%	0%	0%
Ownership							
Apartments, condominiums, & private		58%	46%	41%	34%	56%	42%
Non-profit and public		35%	51%	28%	52%	30%	35%
Unknown		7%	3%	30%	14%	14%	24%
Housing Function							
Family		33%	13%	57%	27%	32%	22%
Mixed use		10%	5%	4%	2%	16%	8%
Senior		29%	53%	13%	15%	22%	27%
Supportive		1%	6%	9%	9%	8%	29%
Unknown		26%	23%	17%	47%	22%	14%
Metro-Statistical Area							
Large central and fringe metro		54%	53%	59%	37%	64%	73%
Medium and small metro and micropolitan		46%	47%	41%	63%	36%	27%
Region/State							
Midwest	Illinois	17%	16%	2%	1%	32%	64%
	Wisconsin	23%	13%	28%	10%	14%	4%
Northeast	Vermont	6%	5%	4%	4%	2%	0%
	New York	7%	12%	30%	18%	6%	3%
	Rhode Island	6%	13%	9%	41%	4%	8%
	New Hampshire	1%	3%	0%	0%	0%	0%
	Massachusetts	39%	40%	26%	27%	42%	21%

[1] Percentages may not sum to 100% due to rounding.
[2] HHs = households.

EXISTING SYSTEMS AND INSTALLED MEASURES DATA

The research efforts have yielded three sets of data: (1) RS results, (2) building characteristics and conditions observed on site, and (3) existing (i.e., pre-weatherization) mechanical systems and weatherization measures installed. The installed measures data reported by participating partners informs NEI estimates and allows us to correlate specific NEIs with specific measures or combinations of measures installed.

We extracted many of the questions for our Installed Measures Data Collection Form (IM-DCF) from the WAP evaluations. We programmed our IM-DCF as a fillable PDF data form and asked weatherization agencies to complete it for every participating building in our sample. While our IM-DCF design was intended to reduce the data collection burden for implementers, it has been more challenging than expected for two reasons:

- First, it is difficult to identify which MA agency served which building, as buildings are often served by two different agencies or vendors – one installing measures related to gas and the other installing lighting or additional electric measures.
- Second, the agencies report being overwhelmed with data requests and explain that the data are not always readily available.

We have received installed-measures data for all participating sites in MA that have been weatherized, as well as verification of weatherization status for the T buildings.

Descriptive Statistics

As we noted in the introduction, our previous research suggests that there are substantial differences between MF and SF buildings, the households who live in them, and the communities in which they are located.

There are several construction design- and weatherization-related reasons why health- and household-related NEI outcomes for residents of MF buildings might differ from those of residents of SF homes. For example, from a building science perspective, SF homes and MF buildings function differently with respect to heating, cooling, and ventilation. Many MF buildings have central heating and hot water systems serving multiple units, while SF homes each have individual systems. While stack effects are present in both types of housing, they can be much more complicated in MF buildings due to shared walls between units, multiple floors, and elevator shafts. Often, the kitchen and bathroom are unable to be effectively exhausted to the outside of MF buildings. Additionally, *packages* of weatherization measures installed in SF differ from those installed in MF buildings. Major MF weatherization projects focus on replacing central heating systems, installing energy management systems, and insulating roofs rather than insulating or air-sealing individual units.

Differences in demographic characteristics of the SF and MF populations could also drive differences in the health- and household-related NEIs experienced by residents of each type of dwelling. Data collected as part of the WAP evaluations found that households living in MF buildings are, on average, of a lower socio-economic status than residents of SF weatherized homes, and are less likely to own the units they occupy. In addition, households in SF homes are larger than households in MF units (2.4 individuals versus approximately 1.5, respectively).

Finally, the percentage of elderly and minorities are higher in MF units than in SF homes. These demographic characteristics also serve as social determinants of health and signal different rates of pre-existing health conditions that are related to several NEIs explored here. For these reasons, it is not appropriate to generalize from research on the health and household-related NEIs for households residing in SF homes to households residing in MF homes. To date, relatively little quantitative research has been conducted on the NEIs of MF households.

This section provides Phase 1 estimates of the magnitude of key characteristics of MF households that are related to NEIs of interest and provides evidence that highlights the importance of developing MF-specific NEI estimates. Here, we present results for six sets of descriptive statistics, by the three housing sample groups separately or the combined T + C group, to represent *pre-weatherized* buildings:

- Characterization – Housing and Demographics
- Installed Measures
- Dwelling Quality, Safety, and Other Conditions
- General Health
- Asthma
- Household Budget and Affordability Issues

SAMPLE CHARACTERIZATION

Table 6 shows differences among the sample groups of participating households for the entire sample.[28] The Phase 1 data assessment shows two primary differences between the pre-weatherization (i.e., T+C groups combined) and the post-weatherization (CwT) group.

First, the CwT group is spread more evenly between family and senior housing than the T+C sample, which has a much higher concentration of family housing than senior housing. Second, the CwT group has substantially more electrically heated units than the T+C group. However, more than 75% of the buildings in both groups are fewer than five stories high. The distribution of low-, mid-, and high-rise buildings is also comparable between the groups.

Across the board, roughly half of all heating systems in the sample are boilers. Despite attempts to oversample ASHPs, the number of households with ASHPs is quite low. The CwT group reported existing ASHPs in 1% of the total sites visited, while there were zero reports in the T+C group.

[28] The characterization data presented for the CwT group in Table 5 reports the current characteristics for each study group. More specifically, characterization data presented for the CwT group was collected post-weatherization, while T data was collected pre-weatherization. No distinction needs to be made for the C group as this group will not be weatherized. Table 9 presents pre-weatherization characterization data for the CwT group only. Table 10 presents the rate at which measures were installed as part of the weatherization process for the CwT group only. Post-weatherization characterization and installed measures data for the T group will be collected as part of Phase 2.

Table 6: Housing Characteristics[1]

(by Sites by Sample Group, all States)

	(CwT) (n=69)	(T) (n=46)	(C) (n=50)	(T+C) (n= 96)
Heating Type				
Boiler	46%	59%	68%	64%
Furnace	25%	13%	24%	19%
Electric	23%	15%	2%	8%
ASHP	1%	0%	4%	2%
Individual Split System	1%	2%	0%	1%
PTAC	1%	0%	2%	1%
Unknown/Other	3%	11%	0%	5%
Cooling Type				
Window/Wall Unit	64%	63%	66%	65%
None	13%	20%	6%	13%
Central	12%	7%	18%	13%
ASHP	1%	0%	0%	0%
Mixed	1%	2%	0%	1%
PTAC	1%	0%	6%	3%
Individual Split System	1%	2%	2%	2%
Unknown/Other	6%	7%	2%	3%
Housing Function				
Family	33%	57%	32%	44%
Senior	29%	13%	22%	18%
Mixed Use	10%	4%	16%	10%
Supportive	1%	9%	8%	8%
Unknown	27%	17%	22%	20%
Rise				
Low- (< 5 stories)	83%	76%	80%	78%
Mid- (5 to 9 stories)	10%	15%	16%	16%
High- (10+ stories)	3%	2%	4%	3%
Unknown	4%	7%	0%	3%
Size (housing units)				
5-10	46%	44%	30%	37%
11-79	44%	46%	54%	50%
80-149	9%	11%	12%	12%
150+	0%	0%	4%	0%
Unknown	1%	1%	0%	1%

[1] Percentages may not sum to 100% due to rounding.

Table 7 shows race and ethnicity by research group sampled. More than half (53%) of the C group identifies as Black or African American, compared to less than one-quarter (23%) of the CwT group and 24% of the T group. Because race correlates strongly with certain health outcomes and treatment type (e.g., asthma), researchers attempted to monitor racial composition and differences between surveyed groups to sample accordingly. Due to the study team's reliance on a convenience sampling approach – rather than random stratification – the racial and ethnic imbalance between groups persisted.

Table 7: Demographics

(by Household Members by Sample Group, All States)

Demographics	(CwT) (n=725)	(T) (n=552)	(C) (n=1,171)	(T+C) (n=1,723)
Age (mean) – All persons in the home***	55	41	46	45
Age (mean) - Respondent ***	64	56	58	57
Gender (female) - Other persons in the home only	50%	51%	47%	48%
Gender (female) - Respondent *	62%	59%	55%	61%
Employed - Other persons in the home only	27%	20%	28%	24%
Employed - Respondent	18%	22%	19%	20%
Retired - Respondent ***	58%	38%	42%	41%
Household Size (mean) ***	1.4	1.7	1.4	1.5
Single Person Household ***	77%	60%	76%	72%
Respondent Education				
High school diploma	35%	32%	36%	35%
College graduate *	23%	15%	19%	18%
Some college *	21%	18%	25%	23%
No high school diploma	10%	15%	14%	14%
Unreported	11%	20%	6%	10%
ace/Ethnicity[1] ***				
White ***	60%	41%	35%	37%
Black or African-American ***	22%	24%	53%	45%
Hispanic or Latino Origin ***	11%	41%	9%	18%
Asian ***	8%	1%	1%	1%
Hispanic or Latino (if volunteered) ***	3%	12%	3%	6%
Native Hawaiian/Other Pacific Islander	1%	1%	1%	1%
Other (if volunteered) ***	5%	14%	7%	9%

[1] Sum of totals does not equal 100% for race/ethnicity because respondents had a choice to self-identify with more than one race.
* Difference is statistically significant at the p<.05 level.
** Difference is statistically significant at the p<.01 level.
*** Difference is statistically significant at the p<.001 level.

Table 8 presents the demographic characteristics of the asthma subsample. We found statistically significant differences between the CwT and T+C groups in age, gender, and race. As we noted above, race and ethnicity are social determinants of both health (e.g., prevalence of health issues) and health outcomes (e.g., morbidity and mortality). The study team employed cross-sectional analysis of the two groups in this report. We also performed linear regressions to determine the influence of demographic characteristics on the effect of weatherization on select asthma outcome variables (e.g., hospitalizations, ED visits, and urgent care visits) as well as four other NEIs (see Regression Analysis Results). We note that when comparing the results of the regression analysis to the cross-sectional analysis, asthma hospitalization is statistically significant at the $p<.05$ level and ED visits is statistically significant at the $p<.001$ level in the cross-sectional analysis but asthma hospitalizations is not statistically significant and ED visits is less robust at p the < 0.1 level (one-sided p-value) in the regression analysis. This suggests that study group differences may account for some of the differences in health outcomes. In Phase 2, we intend to conduct matched pairs analysis to measure changes pre- and post-weatherization.

Table 8: Demographic Characteristics of Asthma Sub-Sample

(All States)

Asthma Sub-Sample	Post-Wx (CwT) (n=129)	Pre-Wx (T + C) (n=309)
Age of Person with Asthma (mean)**	56	47
Person with Asthma is > 65 years old (%)**	44%	30%
Gender (female) (%)**	78%	63%
Race/Ethnicity (%)[2]		
Hispanic or Latino Origin	18%	24%
White***	59%	39%
Black or African-American***	21%	41%
Asian***	8%	1%
Native Hawaiian/Other Pacific Islander	2%	1%
Other (if volunteered)	7%	9%

** Difference is statistically significant at the $p<.01$ level.
*** Difference is statistically significant at the $p<.001$ level.
Note: Wx = Weatherized

Existing Mechanical Systems and Installed Measures

We analyzed data collected on existing (i.e., pre-weatherization) mechanical systems and weatherization measures installed through the PAs' program, as well as from the other states. Participating agencies provided these data through the IM-DCF discussed in Existing Systems and Installed Measures Data. Table 9 shows the prevalence of pre-weatherization mechanical systems (i.e., ventilation, heating, and cooling systems) in the CwT group only.[29] Table 10 presents the rate at which measures were installed as part of the weatherization process for the

[29] Table 9 presents pre-weatherization characterization data for the CwT group only; whereas, Table 10 presents post-weatherization characterization data for the CwT group.

CwT group only. The data collection phase in other states has been extended in an effort to increase sample sizes; therefore, results presented in Table 9 and Table 10 represent only 46% of the CwT buildings participating in this Phase 1 analysis. Post-weatherization characterization and installed measures data for the T group will be collected as part of Phase 2.

Examining weatherization measures installed at the building level, in-unit lighting improvements (e.g., new bulbs and/or new fixtures) were the most common set of measures reported as having been installed (75% of buildings), followed by floor/wall/ceiling insulation (65%), building level air sealing (61%), hallway/stairway lighting improvements (61%), heating equipment replacement (51%), domestic hot water repair/replacement (49%), and mechanical ventilation (37%). Cooling equipment installation/replacement was least often reported (12%). Other key findings include the following:

Mechanical ventilation systems:

- Thirty percent of CwT buildings did not have an existing mechanical ventilation system prior to weatherization (Table 9).[30]
- Of those buildings with ventilation systems pre-weatherization, kitchen range hoods that vent outside were present in only 17% of the buildings, but 67% reported having bathroom fans that vent outside (Table 9).
- In-unit central exhaust systems were found in only 14% of the buildings, while in-unit central supply systems went unreported. Corridor exhaust systems were found at a much lower rate (3% of buildings), while 11% of the buildings had corridor supply ventilation systems (Table 9).
- Post-weatherization, 37% of all buildings received some type of mechanical ventilation system (Table 10).[31]

Heating/Cooling Systems:

- Pre-weatherization, 72% of all units utilized a central hot water boiler system for heating purposes, while 19% were heated by electric baseboards (Table 9).
- Slightly more than half of the buildings (51%) reported installing or repairing heating systems as part of weatherization efforts (Table 10). Of these, 83% stated the replacements were justified by energy savings. There were no reports of heating systems installed or repaired for health and safety purposes.
- There were no reports of existing ASHPs being used as a heating source pre-weatherization, but 1% units reported ASHPs being used as a cooling source pre-weatherization (Table 9).
- A surprisingly high percentage of buildings had no cooling systems pre-weatherization (33%) (Table 9). Ten percent of buildings had some type of cooling system installed as

[30] Of those that reported having no existing ventilation systems pre-weatherization, 29% received ventilation measures; specifically, they received in-unit ducted furnaces.
[31] Of those that reported having existing ventilation systems pre-weatherization, 40% received one or more additional ventilation measures.

part of weatherization (two-thirds of which were reported to have been justified for health and safety purposes) (Table 10).

Health and Safety Measures:

There were few reports (10% of buildings) of measures installed specifically to improve health and safety, such as CO monitors, smoke detectors, and electrical repairs (Table 10). Note that the CO monitors were installed in buildings outside of MA.

Table 9: Existing Mechanical Systems

(CwT Buildings Only)

Existing (Pre-Wx) Mechanical Systems	% of Buildings (n=166) % of Units (n=3,001)[1]
Ventilation System (% of Buildings (n=166))	
No Working Mechanical Ventilation System	**30%**
Bath Fan [2]	67%
Kitchen Range Hood (vents outside) [2]	17%
Central Exhaust (In Unit) [2]	14%
Corridor Supply [2]	11%
Elevator Shaft [2]	8%
Corridor Exhaust [2]	3%
Trash Chute [2]	3%
Central Supply (In Unit) [2]	0%
Other (no description provided) [2]	6%
Heating System (% of Units (n=3,001))	
No Working Heating System	**0%**
Central Hot Water Boiler	72%
Electric Baseboard	19%
Individual Forced Air Furnace	5%
Individual Split System Heat Pump	2%
PTAC or ASHP (In Unit)	0%
Other (no description provided)	2%
Cooling System (% of Units (n=3,001))	
No Working Cooling System	**33%**
Window/Wall Unit[3]	35%
Central Chiller[3]	34%
Sleeve A/C (In Unit) [3]	25%
Individual Split-system or Heat Pump (In Unit) [3]	4%
PTAC or ASHP (In Unit) [3]	1%

[1] Some totals do not equal 100% as not all answers were mutually exclusive.
[2] Of those that reported having some type of ventilation system present pre-weatherization.
[3] Of those that reported having a cooling system present pre-weatherization.

Table 10: Weatherization Measures Installed
(CwT Buildings Only)

Weatherization Measures Installed (CwT only)	% of Buildings (n=166)
Energy Conservation Measures (ECM)	
Lighting (within unit)	75%
Insulation (building level)	65%
Air Sealing (building level)	61%
Lighting (hallway/stairwell)	61%
Lighting (exterior of building)	59%
Heating Equipment	51%[1]
Domestic Hot Water	49%
Water Saving Device	45%
New Refrigerator	43%
Mechanical Ventilation	37%
Windows	28%
Cooling Equipment	10%[2]
Health & Safety Measures	
Smoke Detectors (in unit)	10%[3]
CO Monitors (in unit)	8%[3]
Trips and Falls prevention measures	0%

[1] Eighty-three percent of changes made to heating systems were justified by energy savings; the remaining 17% did not specify (i.e., either it was missing or reported as other). There were no reports of heating system replacement justified by health and safety reasons.
[2] Sixty percent of changes made to cooling systems were justified by health and safety reasons; the remaining 40% did not specify (i.e., either it was missing or reported as other).
[3] Five sites in states outside of MA reported these installs.

Home Livability and Other Conditions

In this section, we present frequencies from the RS for home livability and other conditions, as well as the reported differences in occurrence (+/-) between the CwT group and the combined T and C group. Table 11 and Table 12 show that dwelling safety and quality are higher in CwT buildings than T and C buildings, though these differences may be due to differences in the study populations rather than to weatherization.

For example, we found evidence that CwT homes had safer indoor temperatures and were less breezy than homes in the T+C group. CwT respondents reported lower rates of the following indicators by 11%, 5%, 7%, and 12%, respectively: (1) unsafe indoor temperatures, (2) home was too drafty/breezy, (3) the temperature of the apartment is hot or very hot in the summer and (4) the temperature of the apartment is cold or very cold in winter. These differences were all statistically significant. These findings provide some initial, tentative support for the qualitative assessment that health-related NEIs, such as reduced thermal stress, may be present. [32]

[32] For a thorough review of the literature on the negative health impacts of thermal stress, see: Tonn, B., Rose, E., Hawkins, B., and Conlon, B. 2014. Health and Household-Related Benefits Attributable to the Weatherization

In addition, we found that several common asthma triggers were lower for the CwT group, providing evidence supporting the decline in asthma-related outcomes.[33] For example, reports of presence of visible mold, the home infested with rodents, and that the home was too dusty were 6%, 4%, and 8% lower, respectively, for the CwT group. These differences were all statistically significant.

We also found that levels of outdoor noise and disturbance from outdoor noise, which can contribute to poor sleep and negative health outcomes, were lower for the CwT group.[34] For example, the percentages of the CwT group that reported hearing a great deal of outdoor noise, having sleep interfered with by outdoor noise (extremely or very much), and being bothered, disturbed or annoyed outdoor noise (a great deal or moderately) were lower by 8%, 5% and 7%, respectively. These differences were all statistically significant. In addition to direct health impacts, the literature posits that lack of sleep can negatively impact productivity.

Assistance Program. ORNL/TM-2014/345, Oak Ridge National Laboratory, Oak Ridge, Tennessee, September. 2014.

[33] For a thorough review of the literature on housing-related asthma triggers, see: Tonn, B., Rose, E., Hawkins, B., and Marincic, M. “Health and Household Benefits Attributable to the Knoxville Extreme Energy Makeover (KEEM) Program: Preliminary Results” (presentation, National Advisory Committee, Robert Wood Johnson Foundation, May 30, 2018).

[34] For a thorough review of the literature on the impacts of noise pollution on health and sleep, see: Tonn, B., Rose, E., Hawkins, B., and Marincic, M. 2018. “Health and Household Benefits Attributable to the Knoxville Extreme Energy Makeover (KEEM) Program: Preliminary Results”. (Presented to the National Advisory Committee, Robert Wood Johnson Foundation. May 30, 2018).

Table 11: Dwelling Safety

RS Question (Respondent Only)	CwT	T + C	(+/-)
During the past 12 months, what was the temperature of your apartment in summer? (hot or very hot)	33.0% (n=463)	39.9% (n=1,005)	-6.9%*
During the past 12 months, what was the temperature of your apartment in winter? (cold or very cold)	15.6% (n=487)	27.1% (n=1,075)	-11.5%***
During the past 12 months, how often was your apartment at a temperature that you felt was unsafe or unhealthy? (almost every month or some months)	15.9% (n=504)	26.5% (n=1,109)	-10.6%*
How bright or dark are hallways and stairwells inside your building? (somewhat dark, very dark)	3.6% (n=502)	6.0% (n=1,076)	-2.4%*
How bright or dark is the outside property of your building? (somewhat dark, very dark)	12.1% (n=495)	17.2% (n=1,065)	-5.1%*
How safe do you feel on your building's property? (somewhat unsafe, very unsafe)	7.2% (n=500)	12.9% (n=1,091)	-5.7%*
In the past 12 months, how many times was the fire department called to put out a fire in your home? (mean)	0.1 (n=461)	0.0 (n=992)	+0.1
In the past 12 months, did any fire start in your home as a result of using an alternate heating source, such as space heaters, electric blankets, your kitchen stove or oven, a heating stove, or a fireplace? (Yes)	0.8% (n=502)	0.6% (n=1,115)	+0.2%
In the past 12 months, did any fire start in your home as a result of the building's primary heating source, such as a furnace? (Yes)	0.0% (n=491)	0.1% (n=1,103)	-0.1%

* Difference is statistically significant at the p<.05 level.
** Difference is statistically significant at the p<.01 level.
*** Difference is statistically significant at the p<.001 level.

Table 12: Dwelling Quality

RS Question (Respondent Only)	CwT	T + C	(+/-)
During the past 12 months, how often have you or other members of your household found your home too drafty (breezy, cold/damp air blowing in)? (All of the time, most of the time)	15.8% (n=482)	20.8% (n=1,040)	-5.0%*
During the past 12 months, how often have you or other members of your household found your home too dusty? (All of the time, most of the time)	21.5% (n=461)	29.3% (n=985)	-7.8%**
How infested is your home with cockroaches or other insects? (Extremely infested, very infested)	5.1% (n=493)	5.5% (n=1,069)	-0.4%
How infested is your home with rats, mice, or other rodents? (Extremely infested, very infested)	3.6% (n=272)	7.8% (n=457)	-4.2%**
Have you seen mold in your home in the past 12 months? (Yes)	14.5% (n=477)	20.1% (n=1,040)	-5.6%**
Have you seen standing water in your home in the past 12 months? (Yes)	6.0% (n=483)	9.0% (n=1,072)	-3.0%*
How much outdoor noise do you hear indoors when the windows are closed? (A great deal)	14.7% (n=498)	23.1% (n=1,095)	-8.4%***
How much does outdoor noise interfere with your sleep at night? (Extremely, very much)	10.6% (n=404)	16.0% (n=918)	-5.4%*
How much does outdoor noise bother, disturb, or annoy you when you are inside your apartment? (A great deal or moderately)	28.9% (n=467)	35.9% (n=1005)	-7.0%**

* Difference is statistically significant at the p<.05 level.
** Difference is statistically significant at the p<.01 level.
*** Difference is statistically significant at the p<.001 level.

GENERAL HEALTH AND ASTHMA

In this section, we present frequencies for general health and asthma-related variables, as well as the reported differences in occurrence (+/-) between the CwT group and the combined T and C group. Table 13 shows that CwT respondents report better general heath than T and C respondents, with primary wage earners missing fewer days of work and CwT respondents having fewer bad days of rest/sleep and mental health. We note, however, that the difference in quality of sleep and rest between the CwT group and the combined T and C group is not statistically significant in the regression analysis (see Regression Analysis Results). Table 14 results indicate that asthma-related hospitalizations and ED visits were lower among CwT respondents than T and C respondents, and the differences were statistically significant. However, in the regression analysis the difference in asthma hospitalizations is not statistically significant and the difference in ED visits is less robust.

Table 13: Changes in General Respondent Health Conditions

RS Question (Respondent Only)	CwT	T + C	(+/-)
In the past 12 months, did anyone in the household see a medical professional because of CO poisoning? (Yes)	0.8% (n=493)	0.6% (n=1,087)	+0.2%
In the past 12 months, how many individuals needed medical attention because of fire-related injuries, such as burns or smoke inhalation? (mean)	0.02 (n=229)	0.03 (n=408)	-0.01
In the past 12 months, about how many days of work did the primary wage earner miss because of illness or injury? (mean)	7.9 (n=76)	7.1 (n=195)	+0.8
In the past 12 months, about how many days of work did the primary wage earner miss because of illness or injury of another household member? (mean)	0.1 (n=60)	0.1 (n=140)	--
During the past 30 days, how many days have you felt you did not get enough rest or sleep? (mean)	6.3 (n=398)	7.2 (n=839)	-0.9*
During the past 30 days, how many days was your mental health not good? (mean)	4.6 (n=394)	5.9 (n=826)	-1.3**
During the past 30 days, how many days did poor physical or mental health keep you from your usual activities? (mean)	4.2 (n=391)	5.1 (n=891)	-0.9

** Difference is statistically significant at the p<.1 level.
** Difference is statistically significant at the p<.05 level.

Table 14: Asthma

RS Question (All Persons in HH)	CwT	T + C	(+/-)
Have you ever been told by a doctor or other health professional that you have asthma? (lifetime asthma) (Yes)	21.2% (n=513)	21.7% (n=1,870)	NA
Do you still have asthma? (current asthma) (Yes)	18.5% (n=141)	18.6% (n=341)	NA
How long has it been since you last had any symptoms of asthma? (< three months ago)	64.5% (n=124)	60.9% (n=297)	+3.6%
During the past three months, how many flare-ups did you have? (mean)	5.8 (n=93)	5.6 (n=219)	+0.2
During the past 12 months, how many times did you visit an urgent care center because of asthma? (mean)	0.8 (n=78)	1.1 (n=177)	-0.3
During the past 12 months, how many times did you have to stay overnight in the hospital because of asthma? (mean)	0.2 (n=76)	0.5 (n=170)	-0.3*
During the past 12 months, how many times did you visit the ED because of asthma? (mean)	0.4 (n=70)	1.0 (n=172)	-0.6***

* Difference is statistically significant at the p<.05 level.
*** Difference is statistically significant at the p<.001 level.

HOUSEHOLD BUDGET AND AFFORDABILITY ISSUES

In this section, we present frequencies related to budget issues from energy affordability and trade-offs to food security, with the reported differences in occurrence (+/-) between the CwT group and the combined T and C group. The number and severity of budget issues among households in CwT buildings was lower than those in T and C buildings. For example, as Table 15 shows, CwT households have less difficulty paying energy bills, are better able to afford prescriptions, and are less likely to use their oven as a space heater or use secondary heating equipment. Moreover, they report higher food security. Table 16 shows that they were less likely to trade-off purchasing food to pay energy bills and were less likely to go without food. It is possible that the direct household income benefits attributable to weatherization may allow some households to reduce their needs for food assistance payments.[35]

[35] For example, households may have enough money for food so that even if they are eligible for food assistance based on their income, they may not believe that re-applying is worth their time and/or may feel relieved at not experiencing the stigma of being on food assistance.

Table 15: Energy Affordability and Trade-Offs

RS Question (Respondent Only)[1]	CwT	T + C	(+/-)
During the past 12 months, did you receive a disconnect, shut-off, or non-delivery notice? (Almost every month, some months)	8.6% (n=304)	12.6% (n=509)	-4.0%
During past 12 months, was your electricity or natural gas disconnected because you were unable to pay your home energy bill?	1.5% (n=343)	4.8% (n=583)	-3.3%**
Did household receive energy assistance this past year?	32.0% (n=325)	33.8% (n=559)	-1.8%
How hard is it to pay energy bills? (Very hard or hard)	26.7% (n=311)	37.8% (n=511)	-11.1%**
During the past 12 months, was there any time your household members needed prescription medicines but didn't get them because you couldn't afford it? (Yes)	9.9% (n=476)	15.7% (n=1070)	-5.8%**
During the past 12 months, how often did your household not fill a prescription for medication in order to pay an energy bill? (Every month, every other month)	1.8% (n=330)	4.2% (n=542)	-2.4%
During the past 12 months, how often did your household not pay an energy bill in order to fill a prescription for medication? (Every month, every other month)	1.3% (n=308)	2.2% (n=500)	-0.9%
During the past summer, were you worried you would not have electricity or cooling? (Yes)	15.5% (n=361)	18.4% (n=613)	-2.9%
During the past winter, were you worried you would not have electricity or heating? (Yes)	13.4% (n=366)	18.3% (n=619)	-4.9%
During the past winter, how often did you use your oven to heat your home? (All of the time, frequently, or sometimes)	11.8% (n=493)	23.9% (n=1069)	-12.1%***
Do you use any (secondary) heating equipment in your home? (Yes)	11.8% (n=499)	18.9% (n=1108)	-7.1%***
In the past year, have you used any of the following to assist with paying your energy bill?			
Payday loan	2.2% (n=358)	4.6% (n=629)	-2.4%
Tax refund anticipation loan	1.1% (n=358)	2.2% (n=629)	-1.1%
Car title loan	0.8% (n=358)	0.6% (n=630)	+0.2%
Other type of short term, high-interest loan	1.7% (n=358)	2.4% (n=631)	-0.7%
Pawn shop	5.4% (n=372)	6.4% (n=641)	-1.0%

[1] It should be noted that many MF residents have their utility bills incorporated into their rent; therefore, sample sizes for those that responded to questions related to energy affordability are much lower than many of the other questions.
* Difference is statistically significant at the p<.05 level.
** Difference is statistically significant at the p<.01 level.
*** Difference is statistically significant at the p<.001 level.

Table 16: Food Security

RS Question (Respondent Only)	CwT	T + C	(+/-)
In the past 12 months, did you or any members of your household receive food stamps or WIC assistance (Women, Infants, and Children nutrition program) to help pay for food?	55.5% (n=499)	61.9% (n=1,086)	-6.4%*
During the past 12 months, how often did your household not purchase food in order to pay an energy bill? (Every month, every other month)	3.6% (n=333)	8.3% (n=557)	-4.7%**
During the past 12 months, how often did your household not pay an energy bill in order to purchase food? (Every month, every other month)	3.2% (n=313)	7.5% (n=506)	-4.3%*
In the past four weeks, did you or household member go a whole day and night without eating anything because there was not enough food? (Yes)	6.0% (n=496)	9.0% (n=1,059)	-3.0%*
In the past four weeks, did you worry household members would not have enough nutritious food? (Yes)	12.2% (n=499)	14.5% (n=1,066)	-2.3%

* Difference is statistically significant at the p<.05 level.
** Difference is statistically significant at the p<.01 level.

Analytical Approach and Methodological Challenges in Phase 1

Analytical Approach, Phase 1

As previously noted, the Phase 1 memo focuses on qualitative assessments of the NEIs due to smaller sample sizes than expected, more demographic differences among the study groups than expected, and other methodological concerns. In this section we present an overview of our analytical approach used in Phase 1, along with a discussion of the limitations, sources of uncertainty and methodological challenges.

Analysis of the impacts of weatherization services on program recipients was focused on changes in health issues and household budgets attributable to weatherization services as reported by residents on the RS.

The analytical approach involves the following steps:

1. *Cross-sectional analysis.* We compared changes between disparate groups in health and household-related issues affected by weatherization, as reported by residents on the RS. The CwT serves as the post-weatherization group and the T and C groups are combined to form a 'pre-weatherization' group. We used health and safety-related outcomes in conjunction with secondary data as inputs in cross-sectional analysis to measure the NEIs.
2. *Controlling for confounding differences between groups.* The study team hypothesized that the values of five NEIs would likely be impacted by regional and demographic

differences between the weatherized CwT group and the pre-weatherized T+C groups.[36] For these five NEIs, the study team performed a regression analysis to control for differences in demographic characteristics and regional differences between the weatherized CwT group and the pre-weatherized T+C groups. For each NEI, the regression analysis produced a regression coefficient (β) that estimated the change attributable to weatherization while attempting to control for confounding factors. This factor can then be used as an input in the analysis to measure the NEIs.

3. *Testing for statistical significance.* The study team then subjected these estimates to the test(s) of statistical significance that were most appropriate for each NEI. For example, for the NEIs for which we performed linear regressions, we subjected the β coefficients for Wx produced by the regression models to a bootstrapping resampling analysis to estimate the statistical precision of the rates of change reported from the RS and the resulting estimated NEI values.

One exception to this approach is Reduced Fire Risks, which are based on secondary data to determine reduced risks associated with installing measures that are fire suppressors or removing materials that may be fire ignitors (or repairing electrical issues/faulty combustion appliances).

Regression Analysis Results

As noted earlier in this memo, the study team hypothesized that five NEIs, listed below, would likely be impacted by the observed demographic differences among the study groups. The study team conducted a linear regression analysis to model the relationship between the predictor variables and outcome variables while attempting to control for the influences of several demographic characteristics (Table 17). The five NEIs were:

- Asthma (hospitalizations, ED, and urgent care)
- Thermal Stress – Hot (hospitalizations, ED, and physician office)
- Thermal Stress – Cold (hospitalizations, ED, and physician office)
- Missed Days of Work
- Home Productivity

Table 17: Predictor Variables Included in Regression Models

• Wx = Weatherization, main effect of interest	• region_MW = located in Midwest region
• region_NYC = located in New York City	• region_NE = located in Northeast region
• age_senior = >65 years of age	• age_child = <17 years of age
• age = between 17 and 65 years of age	• male
• Hispanic	• race_black
• race_other	• noHSdegree = no high school degree
• employed	

For these five NEIs we performed linear multiple regressions using a dummy variable for the main effect of interest, weatherization (Wx=1). The regression coefficient (β) of this Wx effect variable

[36] The factors were region, age, gender, race, ethnicity, employment status, and level of education.

is the estimate of change attributable to weatherization while attempting to control for confounding factors. At least four different models of increasing size were employed for each NEI. We selected the larger, more complete models across all NEIs to avoid omitted-variable bias.

Because the asthma and thermal stress (hot and cold) NEIs incorporate three different care settings, three and six regressions were estimated for those two NEIs, respectively. For the five NEIs for which we performed linear regressions, we subjected the β coefficients for Wx produced by the regression models to a bootstrapping resampling analysis to estimate the statistical precision of the rates of change reported from the RS and the resulting estimated NEI values.

Bootstrap resampling provides a flexible means of estimating sampling error for primary and derived statistics of interest. The technique simulates replication of a survey by repeatedly resampling the data in hand to generate a distribution of statistics of interest across many iterations. These generated distributions form the basis for estimating sampling uncertainty associated with statistics of interest, which may be simple means or proportions of survey data elements, regression coefficients, or complex combinations of survey-derived values.

We used customized programming to replicate the two-stage nature of the study sampling, and thus account for any clustering effects associated with multiple survey respondents per property. At the first stage, we randomly resampled recruited rental properties, with replacement. This was done within the weatherized versus unweatherized groups to preserve the relative sample sizes for each. At the second stage, we randomly resampled survey respondents within each resampled property, again with replacement. Respondent resampling was done by household to account for potential clustering effects in analyses conducted at the level of individual household members. To ensure that each resampling iteration had the same number of observations as the original dataset, we discarded iterations that resulted in fewer cases. For those that resulted in more cases, we randomly sampled down to the original number of respondents in each group. A test with and without this last part of the procedure showed little effect on estimated precision, however.

Regression β coefficients and other statistics of interest were calculated across all resampling iterations, and the standard deviations of the resampled statistics were taken as estimates of the standard error of the point estimates from the original sample. We used these as the basis for constructing confidence intervals, calculating p-values, and assessing statistical significance levels for the five NEIs.

Table 18 presents the results from the bootstrapping analysis, including the β coefficients associated with each predictor and outcome variable combination, its standard error, and its level of significance (p-values). Note that for the regression models we report p-values for a two-sided test, but our recommendation is based on a one-sided test. A two-sided p-value of $p<0.20$ is equivalent to a one-sided p-value of $p< 0.10$. We also note that several of the health outcomes that were statistically significant in the cross-sectional analysis are either not statistically significantly different (asthma hospitalizations, thermal stress-cold ED visits, quality of sleep and rest) or the statistically significant differences are less robust (asthma ED visits, thermal stress-cold doctor office visits) in the regression analysis.

.

Table 18: Regression Analysis Results

NEI Outcome	Parameters	β Coefficient	Std. error	t	p>|t|
Asthma hospitalizations (n=237)	Wx	-0.2604	0.2434	-1.070	0.286
	region_MW	-0.2777	0.4277	-0.649	0.517
	region_NYC	-0.3096	0.4473	-0.692	0.489
	region_NE	-0.2005	0.4151	-0.483	0.630
	age_senior	0.0166	0.2984	0.056	0.956
	male	-0.0253	0.1997	-0.127	0.899
	hispanic	-0.1165	0.3095	-0.376	0.707
	race_black	0.1960	0.2462	0.796	0.427
	race_other	0.2646	0.3410	0.776	0.439
	constant	0.5871	0.5711	1.028	0.305
Asthma ED visits (n=237)	Wx	-0.7849	0.4934	-1.591	0.113
	region_MW	-0.8825	0.8390	-1.052	0.294
	region_NYC	-0.6618	0.6997	-0.946	0.345
	region_NE	-0.6854	0.7821	-0.876	0.382
	age_senior	-0.4503	0.3334	-1.350	0.178
	male	0.0872	0.4975	0.175	0.861
	hispanic	-0.3868	0.4866	-0.795	0.428
	race_black	0.0733	0.4207	0.174	0.862
	race_other	0.0501	0.4867	0.103	0.918
	constant	1.9409	0.9221	2.105	0.036
Asthma urgent-care visits (n=237)	Wx	-0.4361	0.4017	-1.086	0.279
	region_MW	-0.2403	0.6182	-0.389	0.698
	region_NYC	-0.4075	0.6620	-0.616	0.539
	region_NE	-0.6847	0.5118	-1.338	0.182
	age_senior	-0.3260	0.4521	-0.721	0.472
	male	0.2074	0.4987	0.416	0.678
	hispanic	-0.7748	0.5962	-1.300	0.195
	race_black	0.6481	0.4997	1.297	0.196
	race_other	1.0195	0.8615	1.183	0.238
	constant	1.2741	0.5937	2.146	0.033
Hospital stays due to heat (n=1,874)	Wx	-0.0052	0.0053	-0.970	0.332
	region_MW	-0.0006	0.0056	-0.104	0.917
	region_NYC	0.0013	0.0098	0.127	0.899
	region_NE	0.0072	0.0149	0.487	0.626
	age_senior	-0.0105	0.0093	-1.140	0.254
	age_child	-0.0108	0.0078	-1.382	0.167
	male	-0.0069	0.0062	-1.113	0.266
	hispanic	-0.0168	0.0185	-0.910	0.363
	race_black	0.0014	0.0059	0.243	0.808
	race_other	0.0115	0.0220	0.520	0.603
	constant	0.0151	0.0098	1.532	0.126
	Wx	0.0163	0.0236	0.693	0.488

NEI Outcome	Parameters	β Coefficient	Std. error	t	p>|t|
ER visits due to heat (n=1,874)	region_MW	0.0223	0.0190	1.175	0.240
	region_NYC	0.0022	0.0152	0.145	0.885
	region_NE	0.0122	0.0165	0.737	0.461
	age_senior	-0.0101	0.0161	-0.626	0.531
	age_child	-0.0178	0.0097	-1.834	0.067
	male	-0.0088	0.0079	-1.112	0.266
	hispanic	0.0080	0.0473	0.169	0.866
	race_black	-0.0026	0.0243	-0.106	0.916
	race_other	0.0005	0.0271	0.019	0.985
	constant	0.0024	0.0250	0.094	0.925
Physician visits due to heat (n=1,874)	Wx	0.0060	0.0185	0.327	0.744
	region_MW	0.0383	0.0272	1.407	0.160
	region_NYC	0.0153	0.0140	1.095	0.274
	region_NE	0.0033	0.0074	0.442	0.658
	age_senior	-0.0183	0.0180	-1.020	0.308
	age_child	-0.0078	0.0128	-0.614	0.539
	male	-0.0173	0.0121	-1.438	0.151
	hispanic	-0.0079	0.0151	-0.524	0.600
	race_black	-0.0313	0.0326	-0.961	0.337
	race_other	-0.0056	0.0188	-0.297	0.767
	constant	0.0220	0.0227	0.966	0.334
Hospital stays due to cold (n=1,874)	Wx	-0.0061	0.0159	-0.384	0.701
	region_MW	-0.0034	0.0189	-0.179	0.858
	region_NYC	0.0022	0.0254	0.086	0.932
	region_NE	0.0096	0.0236	0.405	0.685
	age_senior	0.0163	0.0163	0.997	0.319
	age_child	-0.0051	0.0070	-0.728	0.466
	male	-0.0007	0.0127	-0.056	0.955
	hispanic	-0.0124	0.0206	-0.600	0.549
	race_black	0.0018	0.0141	0.126	0.900
	race_other	0.0086	0.0235	0.367	0.714
	constant	0.0094	0.0209	0.449	0.654
ER visits due to cold (n=1,874)	Wx	-0.0124	0.0106	-1.164	0.245
	region_MW	-0.0072	0.0139	-0.518	0.604
	region_NYC	-0.0109	0.0175	-0.622	0.534
	region_NE	0.0138	0.0193	0.717	0.474
	age_senior	0.0002	0.0100	0.024	0.981
	age_child	0.0197	0.0181	1.085	0.278
	male	-0.0102	0.0100	-1.022	0.307
	hispanic	0.0052	0.0165	0.317	0.751
	race_black	0.0076	0.0140	0.540	0.589
	race_other	0.0091	0.0199	0.457	0.648
	constant	0.0141	0.0161	0.878	0.380
	Wx	-0.0382	0.0237	-1.608	0.108

NEI Outcome	Parameters	β Coefficient	Std. error	t	p>|t|
Physician visits due to cold (n=1,874)	region_MW	-0.0277	0.0452	-0.613	0.540
	region_NYC	0.0280	0.0807	0.347	0.729
	region_NE	-0.0481	0.0480	-1.002	0.316
	age_senior	-0.0298	0.0253	-1.178	0.239
	age_child	0.0460	0.0407	1.129	0.259
	male	-0.0303	0.0185	-1.640	0.101
	hispanic	0.0486	0.0589	0.825	0.409
	race_black	-0.0106	0.0361	-0.294	0.769
	race_other	-0.0124	0.0705	-0.176	0.860
	constant	0.0848	0.0411	2.062	0.039
Missed days of work (n=247)	Wx	-0.7437	1.2035	-0.618	0.537
	region_MW	-1.2748	1.9129	-0.666	0.506
	region_NYC	-1.9829	2.0667	-0.959	0.338
	region_NE	-1.3915	2.1544	-0.646	0.519
	age	-0.0030	0.0012	-2.536	0.012
	male	-1.4115	1.1641	-1.213	0.227
	race_black	-0.5143	1.3300	-0.387	0.699
	noHSdegree	-1.0659	1.9079	-0.559	0.577
	constant	5.8456	1.6399	3.565	0.000
Home Productivity (Days of poor sleep in last 30 days) (n=1,090)	Wx	-0.1001	0.8368	-0.120	0.905
	age	-0.0802	0.0231	-3.475	0.001
	male	-2.2254	0.6908	-3.221	0.001
	race_black	-1.3376	0.9294	-1.439	0.150
	region_MW	0.5663	1.0972	0.516	0.606
	region_NYC	-0.0198	1.5915	-0.012	0.990
	region_NE	-0.0690	1.1919	-0.058	0.954
	constant	12.7026	1.7884	7.103	0.000

Limitations, Sources of Uncertainty, and Methodological Challenges

The limitations and potential sources of uncertainty in this study include recall bias, lack of random assignment to *treatment* and *control* groups, bias from the differences in the characteristics of buildings among the study groups, and that the rate at which MA households responded to the Resident survey was substantially lower than for most other states in the study.

Recall bias refers to systematic error due to respondents' inaccurate or incomplete recall of past events or experiences. The problem of recall bias is inherent when asking for self-reported data about the past, as with the RS.

Another source of uncertainty in this study is inherent to cross-sectional analysis, which involves identifying one or more comparison groups from which we collect the same data as the treatment group. The comparison group serves as the baseline against which the treatment group is compared. This study design assumes that differences between the treatment group and comparison group(s) are due to the *treatment* of weatherization. The subjects in a quasiexperimental group are not randomly assigned; instead, they are selected for collective characteristics that are similar to those of the treatment group. The study found statistically significant demographic differences between the study groups. The study team attempted to control for the influence of these differences, such as age, gender, race, ethnicity, employment status, and level of education, on outcomes by conducting linear regression analyses. This approach assumes that differences in outcomes are either due to treatment or to the influences of demographic characteristics that can be controlled for through regression analysis. If there are other inherent differences in housing or otherwise unidentified characteristics that could affect study outcomes but were not addressed in the regression analysis, they are not being controlled for in this study.

Given the challenges with recruitment and completion rates, we could not be selective in our sampling approach, which may explain why we found some differences among the three sample groups in the building and demographic characteristics of our respondents (see Table 6 and Table 7). In addition, the rate at which households responded to the RS varied from building to building. The response rate for eligible MA households was substantially lower than for most other states in the study (e.g., it was slightly less than half the response rate for IL), which raises the possibility of response bias for MA.

In addition, the NEI study group and the study team have identified several other methodological challenges that the study team will attempt to address in the Phase 2 report. These challenges include potential overlap among NEIs that could result in double counting; proposed analytical approaches, including the use of matched pairs analysis, cross sectional analysis, and secondary data; appropriate levels of statistical significance in assessing NEIs; accounting for differences in study groups when conducting cross-sectional analysis; NEI theory of change; and use of value of statistical life (VSL) in monetization.

Planned Analytical Approach for Phase 2

In Phase 2, we expect to take the following analytical approach for calculating the change in occurrence for an NEI (Table 19). Note that analysis in Phase 2 will be limited to T and C groups (analysis with the CwT group was limited to Phase 1 analysis).

Table 19: Phase 2 Analysis Approach

Core NEI Examined in Phase 1	Cross-sectional	Matched Pairs
Personal illness: Asthma		X
Personal needs dependent on circumstances:		
• Missed days of work	X[1]	X[2]
• Home and work productivity	X[1]	X[2]
• Short-term, high-interest loans	X[1]	X[2]
• Prescription adherence	X[1]	X[2]
• Reduced need for food assistance	X[1]	X[2]
• Missed days of work	X[1]	X[2]
Events experienced, specifically those unlikely to strike household repeatedly		
• Thermal stress	X	
• Low-birth-weight babies	X	
• Trips and falls	X	
[1] If sample sizes are too small for matched pairs analysis [2] If sample sizes are sufficiently large for matched pairs analysis		

After Phase 2 data are collected, for the appropriate NEIs, our matched pairs approach will aim to measure outcomes within a single group pre- and post-weatherization (e.g., T group Phase 1 survey responses compared to T group Phase 2 survey responses). We have identified appropriate statistical tests for this approach based on the types of variables to be measured. For example, we will perform the McNemar test to measure binary outcomes, such as yes or no responses to asthma treatment pre- or post-weatherization. To measure differences in two interval observations per subject (e.g., counts of specific asthma-related hospitalizations), we will conduct a paired samples t-test to test for statistical differences in means pre- and post-weatherization. We will use the Wilcoxon signed rank sum test for matched pairs NEIs where we do not assume an equal distribution between ordinal data (e.g., last time experienced symptoms of asthma). Any other statistical tests we perform for the matched pairs analyses will be based upon the nature of the NEI and the type of variable.

When cross-sectional approaches are used in Phase 2, we will work with the NEI study team to build off of and refine the regression analyses conducted in Phase 1.

In addition, home fires and CO poisoning will rely on secondary data analysis. Both events are relatively rare and difficult to capture. Inputs mined from secondary literature will be used to determine annual household and societal savings attributable to reduced medical treatment and avoided deaths from reduced occurrences of each. For example, Home fires can be prevented by installing measures that are fire suppressors or remove materials (or repair electrical issues/faulty combustion appliances) that may be fire ignitors. Injuries and deaths can also be reduced by the installation of smoke detectors, although based on (limited) data provided by participating agencies there are zero reports of smoke detectors and CO monitors being installed as part of MF weatherization in MA.

MONETIZATION OF NEIS

Monetizing NEIs requires developing analytical approaches and acquiring secondary data to use in conjunction with the primary data collected. To this end, the study team, as part of Phase 1, has rigorously reviewed and vetted dozens of studies and reports to identify the most recent and relevant secondary data sources to use as inputs for monetization. We chose studies that are the most relevant and applicable, not necessarily the most recent. We also reviewed multiple databases to identify the most recent data available to use in monetization calculations. For example, we reviewed online databases from the U.S. Department of Health and Human Services (HHS), such as the Medical Expenditure Panel Survey (MEPS) and Healthcare Cost and Utilization Project (HCUP), the MA Center for Health Information and Analysis (CHIA), and the National Fire Incident Reporting System (NFIRS). Note that many of these are the same secondary online databases that were used for the WAP national evaluations and the MA LISF Study.

We have compiled the most recent information from these databases and MA-specific medical expenditure data. When only national medical costs were available, we adjusted these to reflect medical costs in MA.[37] In all cases, if the medical cost data are outdated, we will adjusted the costs to reflect medical costs for 2019.[38]

As noted in Table 19, the study team will use the RS results in most, but not all, of the selected NEIs. Two of the core NEIs, CO poisoning and home fire prevention, are rare and difficult-to-capture events, so they are not based on RS findings. For these NEIs, the study team has reviewed and analyzed secondary data on the effectiveness of installed weatherization measures that could reduce the probability of fire (e.g., smoke detectors, repairs to electrical systems) and measure installation data collected from participating weatherization agencies (e.g., installation of CO monitors).

We have designed separate analytical approaches for each NEI that consider how weatherization contributes to the NEI and the availability of relevant primary and secondary data. During Phase 1, the study team obtained feedback from external reviewers and the PAs on the soundness and applicability of the algorithms (within the context of the LIMF population being served in MA) and the secondary data sources and specific inputs chosen for the monetization effort. We will continue to work with the NEI study team to review and refine the analytical approaches and data sources.

[37] More specifically, the Boston-Brockton-Nashua metropolitan statistical area (MSA). For more information, see: https://www.bls.gov/regions/new-england/news-release/consumerpriceindex_boston.htm
[38] Medical care price indices provided by the U.S. Bureau of Labor Statistics, http://data.bls.gov/timeseries/CUURA103SAM?data_tool=XGtable