Saving Lives through Energy Efficiency: Valuing the Health- and Safety-Related Benefits of Weatherization in Low-Income Homes

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ABSTRACT

"Non-energy benefits" (NEBs) – such as improved comfort, health, safety, and productivity – are an important, yet often difficult to measure, component of determining and recognizing the full, "real" value of the country's energy efficiency (EE) programs. A comprehensive, integrative study was conducted to reexamine and quantify the health and safety-related NEBs of the single-family low-income (LI) weatherization program in Massachusetts (MA), which include reduced asthma, thermal stress, home fire, and carbon monoxide (CO) poisoning; reduced losses in work income; reduced use of short-term predatory loans; and increased home productivity. This study employed the methodology developed in a 2015 U.S. Department of Energy (DOE) study of its Weatherization Assistance Program (WAP).

Applying the occupant survey data and methodology of the well-designed and large-scope national WAP study, which had passed review by a national expert panel, along with a robust set of secondary medical and wage data resulted in a much improved quantification of these NEBs. Although not all the occupant survey findings are statistically significant, supplemental evidence from the literature and previous study sufficiently supports their application. The study produced NEB values that are substantially higher and considered more robust than their previous counterparts, which is due primarily to the study's ability to better detect, quantify, and monetize improvements in health status and mortality from weatherization. In particular, the value of the avoided lives lost from exposure to dangerously cold or hot temperatures and unsafe heating equipment, while subject to considerable uncertainty, is substantial. The total value of the health-related NEBs is $769 per weatherized home annually and $172 without including the avoided death benefit.

Introduction

Weatherization can produce health- and safety-related non-energy benefits (NEBs) directly by changing the physical condition of homes. For example, improving the thermal performance of the building envelope, which at a minimum increases comfort, also reduces thermal stress experienced by occupants. Thermal stress can have significant adverse effects on health requiring medical attention (e.g., hypothermia, hyperthermia, dehydration, heat exhaustion, heat stroke) as well as on mortality, particularly of the elderly, pregnant women, toddlers and infants, and individuals with chronic medical conditions. Additionally, installation of a comprehensive set of weatherization measures can synergistically reduce a plethora of asthma triggers such as mold, pests, dust, other particulate matter, and byproducts of combustion. Weatherization is also intended to increase occupant safety in several ways: through the testing of carbon monoxide (CO) in homes with fossil fuel-fired heating equipment; the repair and replacement of faulty, leaky, or even unsafe sources of combustion and heat in homes; and the installation of CO monitors and smoke detectors. Improved health and energy cost savings, in

turn, can reduce missed days of work, increase productivity at home, and lead to household budget benefits that then are invested to produce additional household and societal benefits.

Although these types of NEBs are often difficult to measure, they are an important component of determining and recognizing the full, "real" value of the country's energy efficiency (EE) programs that perform home weatherization. While including the value of NEBs in the cost-effectiveness testing of EE programs varies by state or jurisdiction, NEBs help promote the adoption of EE because they often represent substantially more "real" benefits to customers beyond just the energy savings. As a result, more research has been completed recently to evaluate and quantify these benefits.

In 2015, an evaluation of the U.S. Department of Energy's (DOE) Weatherization Assistance Program (WAP) was completed that included the assessment and monetization of numerous health and household-related impacts attributable to the weatherization of low-income (LI) single-family homes, at a national level (Tonn et al. 2014).[1] The Massachusetts (MA) EE Program Administrators (PAs) retained the national study's research staff (currently employed at Three[3], Inc.) to draw upon the methodologies and results from the national WAP evaluation to estimate the following health- and safety-related NEBs of weatherization for LI residents in MA (Three[3] and NMR 2016):[2]

1) reduced asthma (avoided medical costs);
2) reduced cold-related thermal stress (avoided medical costs and deaths);
3) reduced heat-related thermal stress (avoided medical costs and deaths);
4) reduced missed days at work (reduction in income lost due to illness);
5) reduced use of short-term, high interest loans (lower interest payments and loan fees);
6) increased home productivity due to improvements in sleep (higher productivity for housekeeping activities);
7) reduced carbon monoxide (CO) poisoning (avoided medical costs and deaths); and
8) reduced home fires (avoided medical costs for fire-related injuries and avoided deaths).

The PAs are already claiming a number of health- and safety-related NEBs to currently test the cost-effectiveness of their LI weatherization initiatives and program. These NEBs were examined and to the extent possible, quantified in a study conducted by the NMR Group in 2011 (NMR 2011). Consequently, the PAs also retained NMR to review the WAP-based study methodology and determine the extent to which the NEBs being reevaluated and quantified overlap with, augment, or supersede the health- and safety-related NEBs previously examined and/or currently claimed by the PAs, and to develop recommendations for integrating the results. In fact, at the time of its 2011 NEB study, NMR had noted that several health and safety NEBs, such as heat stress and cold exposure, were being examined by the WAP evaluation and recommended deriving values from the WAP evaluation when it became publicly available.

[1] Fowlie, Greenstone, and Wolfram (2015) contend that the costs of the WAP substantially outweigh its benefits, based on their own experimental evaluation of the realized energy savings and avoided CO_2 emissions of more than 30,000 Michigan households that were presumptively eligible for participation in WAP (Fowlie, Greenstone, and Wolfram 2015). However, their research does not account for the substantial health- and safety-related benefits that are being discussed and quantified in this paper. In response, the U.S. Department of Energy (DOE) published an article that compares the results and merits of the Fowlie, Greenstone, and Wolfram (2015) and DOE evaluation studies (DOE 2015).

[2] Three[3] research staff, under the auspices of Oak Ridge National Laboratory, managed the national WAP evaluation (Tonn et al. 2014). The MA PAs are National Grid, Eversource, Columbia Gas of MA, Berkshire Gas, Unitil, Liberty Utilities, Blackstone Gas Company, and Cape Light Compact. With the exception of the reduced use of short-term predatory loans, the NEBs being evaluated in this study are largely related to improvements in the health and safety of household occupants due to weatherization. Increased home productivity is associated with better sleep due to the improved thermal comfort and noise levels in a weatherized home.

Massachusetts Low-Income Health- and Safety-Related NEBs

The national WAP NEB evaluation research was utilized as the foundation for the MA NEB study conducted by Three[3] and NMR (also referred herein as the "2016 study"); although, in order to conduct a state-level analysis, several inputs were modified to better reflect the LI population and medical costs in MA (Three[3] and NMR 2016). Figure 1 illustrates the general approach for estimating each NEB, exemplified by the one for reduced thermal stress.

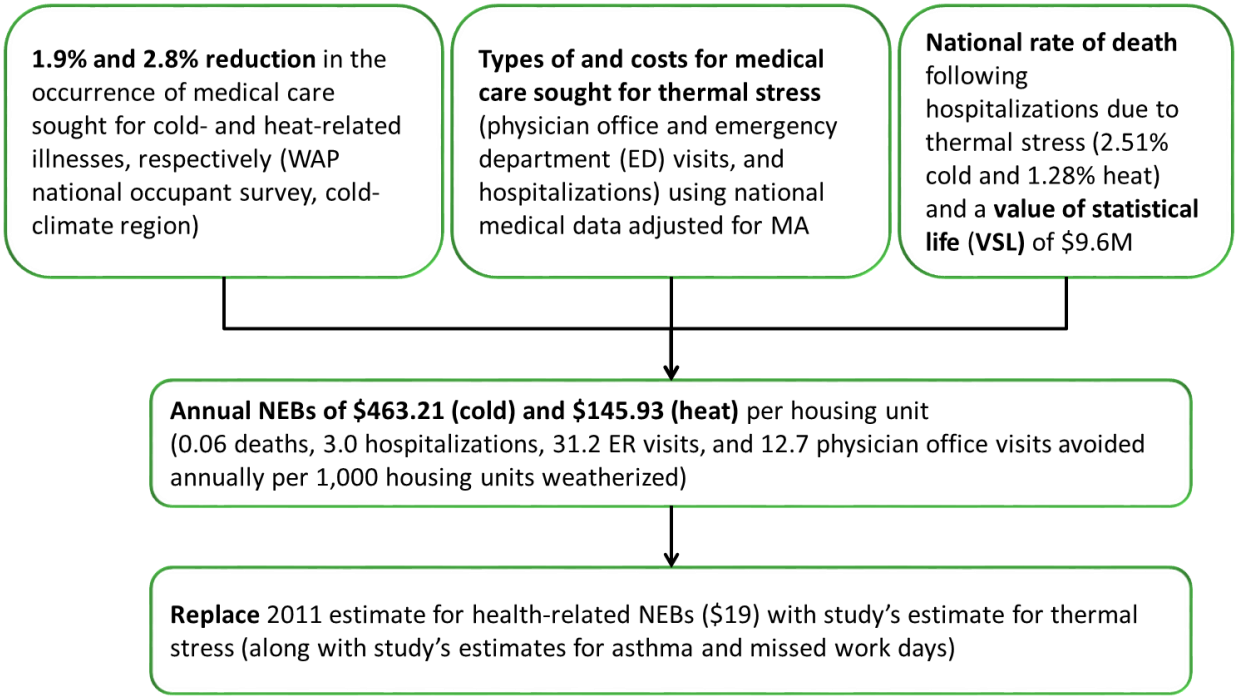

Figure 1. General study methodology exemplified by the one used to estimate the NEB for reduced thermal stress.

Underpinning the methodology utilized to estimate the NEBs was a pre-tested, national occupant survey of a random and representative sample of weatherized single-family homes pre- and post-weatherization, along with a comparison group of homes (Carroll et al. 2014).[3] The occupant survey was administered in two phases. In the first phase, the survey was administered just prior to the energy audits completed in the treatment group households (during calendar year 2011, referred to as the "pre-weatherization treatment" group). In the second phase, the survey was administered post-weatherization, approximately 18 months later (during calendar year 2013, referred to as the "post-weatherization treatment" group). In addition, a group of homes that had already been weatherized one year before the treatment group received weatherization services was surveyed during the first phase; this group of homes served as the "post-weatherization comparison" group.[4]

Like in the national WAP evaluation, the 2016 MA study used the differences between the pre-weatherization and post-weatherization treatment groups and between the pre-weatherization

[3] Single-family homes studied included mobile homes and small multifamily buildings consisting of between two and four units.

[4] While it would have been ideal to survey a true control group and employ a difference in differences approach, the national study researchers and local weatherization agencies did not feel it was appropriate or ethical to unnecessarily delay weatherization to WAP households. In addition, it would have been cost prohibitive to identify, recruit, and survey a WAP-comparable control group consisting of non-weatherized, non-WAP LI homes.

treatment and post-weatherization comparison groups (averaging the two sets of differences) to estimate a change in the NEB attributable to home weatherization and used secondary data, such as state-specific or -adjusted medical incidence and cost and wage data, to quantify and monetize the value of the NEB. However, for the reduced CO poisoning and reduced home fire NEBs, the study relied largely on secondary data (e.g., fire cause, CO monitor prevention, and medical cost data for fire- and CO-related injuries) to quantify their value.

Cold Climate Region Survey Cohort and Descriptive Statistics

National occupant survey data for LI households located in states with a climate comparable to that of MA (collectively called the "cold climate" region) were selected as the representative cohort for the MA study. These cold climate states include Utah, Colorado, Nebraska, Iowa, Illinois, Indiana, Ohio, West Virginia, Pennsylvania, New York, New Jersey, Massachusetts, Connecticut, and Rhode Island. Data for households located in the very cold region of the U.S. such as Maine, Vermont, Michigan, Montana, Wisconsin, and New Hampshire were also considered, but were not included because the study team preferred consistency with respect to climate region.[5] However, data relating to the incidence of asthma were based on the entire national sample because the prevalence of asthma does not vary significantly by climate region and using a more robust sample size improves the ability to capture the potential benefits.

Table 1 presents the sample groups (pre- and post-weatherization treatment groups and the post-weatherization comparison group) and their respective sizes from the cold climate region, which were used to evaluate seven of the eight NEBs; and the larger national sample size used for evaluating the NEB of reduced asthma. Table 2 characterizes the cohort sample with respect to housing and demographics.

Table 1. Cohort sample groups and sizes for Massachusetts NEB study

Cohort sample group	Pre-weatherization treatment group	Post-weatherization treatment group	Post-weatherization comparison group
Cold Climate Region	318	190 (a)	331
National (asthma NEB only) (b)	94	61 (a)	123

(a) Not all of the original respondents in the pre-weatherization treatment group responded to or were successfully contacted for the post-weatherization survey.

(b) Represents the subset of the national occupant survey population that has a history of and could sufficiently respond to questions related to asthma.

[5] For most of the NEBs, the size of the cold climate region cohort was more than sufficient, and combining cold and very cold climate regions did not increase the statistical significance by much, if any. Furthermore, in a few instances, the survey results between the two climate zones were too different to justify combining them.

Table 2. Housing and demographic characteristics

	Pre-weatherization treatment group	Post-weatherization comparison group
Single-family homes (a)	75%	80%
Heating fuel - natural gas	61%	57%
Heating fuel - electric	11%	10%
Heating fuel - fuel oil	12%	22%
Heating fuel - propane	7%	6%
Heating fuel - kerosene	7%	5%
Heating fuel - wood	3%	0.3%
Age of respondent (in years)	56	68
Household size	2.6	2.2
Respondent employed	33%	34%
Home in rural area	29%	29%
Respondent married	34%	34%
Respondent - high school education	41%	42%

(a) Mobile homes and small multi-family (2 to 4 units) constituted the remaining 25%.

Table 3 presents frequencies from the occupant survey for the health and household related variables. Statistical tests were conducted to assess the differences between the pre-weatherization treatment and post-weatherization treatment and comparison groups. Notations shown in the second and third columns of Table 3 indicate whether a statistically significant difference exists between the pre-weatherization treatment and post-weatherization treatment groups and the pre-weatherization treatment and post-weatherization comparison groups, respectively.

Table 3. Health and household variables related to evaluated NEBs (cold climate region except for asthma)

	Pre-weatherization treatment group	Post-weatherization treatment group	Post-weatherization comparison group
Required medical attention in last 12 months – too cold	4.1%	2.6%	1.8%
Required medical attention in last 12 months – too hot	3.8%	1.1%	0.9% (a)
Missed days of work (average no. of days in last 12 months)	10.6	4.1	9.1 (b)
Used at least one short-term loan in last 12 months	18%	9%	13% (b)
At least one bad day of rest or sleep the previous month	68%	66%	60% (a)
Have working CO monitor	54%	81% (c)	90% (c)
Have working smoke detector	94%	97%	98% (c)
Asthma ED visit	15.8%	4.3% (a)	N/A
Asthma hospitalization	13.7%	10.6%	N/A
Asthma symptoms less than 3 months ago (high-cost patient)	70.5%	58.7%	N/A

(a) $p<0.05$
(b) $p<0.01$
(c) $p<0.001$

Although not all differences are statistically significant using the cold climate region cohort, the survey findings are supported by other "triangulating" lines of evidence, including the survey research and extensive literature review conducted in the 2011 NMR study, that clearly indicate health improvements from weatherization. Additionally, these health and safety-related findings are augmented by anecdotal evidence offered by the human stories shared by the weatherization agencies and by recipients of the programs themselves. Ultimately, these benefits were analyzed from multiple angles and their attribution to weatherization was based on triangulation and a preponderance of evidence.[6] Triangulation as a research method (i.e., arriving at conclusions by using multiple sources of information) is common within the social sciences. Because the benefits selected for analysis were approached in this way, the researchers were able to confidently monetize changes in occurrences even if they did not achieve statistical significance. A national panel of experts reviewed all methodologies and assumptions of the national WAP evaluation study and did not question the validity of any of the NEBs or dismiss the findings as inconsiderable as there was a clear indication of health improvements.

Monetization Approach

For six of the eight NEBs addressed by this research, the results of the national occupant survey were used as the basis for the monetization approaches as sample size was deemed sufficient to indicate observable impacts from pre- to post-weatherization. For two of the NEBs, carbon monoxide (CO) poisoning and fire prevention, the data sources were different. The occupant survey did include questions specific to instances of CO poisoning and home fires; however, these events are relatively rare given the sample size, which is supported by national data. Nonetheless, preventing fires and CO poisoning are policy relevant and important NEBs of weatherization; therefore, the researchers believed that estimating the monetized benefits of reducing fires and CO poisoning are worthwhile given that deaths could be prevented. So, in these two instances, the methodology relied on data collected from the local weatherization agencies on the weatherization measures and smoke detectors installed (e.g., those measures that map specifically to fire ignition risks or serve as fire suppressors) that could reduce the probability of home fires and the CO monitors installed that may reduce the incidence of CO poisoning.

The reduction in adverse health and household impacts, with the exception of asthma, between pre- weatherization and post-weatherization treatment groups and between pre-weatherization treatment and post-weatherization comparison groups was calculated using the first equation below (i.e., an average of the differences). For asthma, due to diverging sample characteristics between the treatment and comparison groups, the second equation was used to calculate the decrease in occurrence. Table 4 presents the calculated reductions using these two equations.

1) [(Pre-Wx Treatment - Post-Wx Treatment) + (Pre-Wx Treatment - Post-Wx Comparison)] / 2
2) Pre-Wx Treatment - Post-Wx Treatment

[6] A preponderance-of-evidence approach involves drawing a conclusion that a fact or occurrence is more probable than not based on weighing all available evidence.

Table 4. Calculated reductions in adverse health and household impacts related to evaluated NEBs

	Reduction from pre-weatherization to post-weatherization treatment groups	Reduction from pre-weatherization treatment to post-weatherization comparison groups	Average reduction
Required medical attention in last 12 months – too cold	1.5%	2.3%	1.9%
Required medical attention in last 12 months – too hot	2.7%	2.9%	2.8%
Reduction in missed days of work (no. of days in last 12 months)	6.5	1.5	4.0
Used at least one short-term loan in last 12 months	8.3%	4.6%	6.45%
At least one bad day of rest or sleep the previous month	2%	8%	5%
Asthma ED visit	11.5%	N/A	11.5%
Asthma hospitalization	3.1%	N/A	3.1%
Asthma symptoms less than 3 months ago (high-cost patient)	11.8%	N/A	11.8%

Secondary data. To monetize the reductions reported by the survey respondents, medical incidence and cost data, such as the types of treatment sought for heat- and cold-related illnesses and their proportional share and associated costs, were drawn from numerous sources. These sources include the U.S. Department of Health and Human Services (DHHS) Healthcare Cost and Utilization Project, DHHS Medical Expenditure Panel Survey, Massachusetts Center for Health Information and Analysis, and the National Fire Incident Reporting System.

Avoided death benefits. To monetize the benefit of avoided deaths from thermal stress, CO poisoning, and fire, the "value of a statistical life" (VSL) was adjusted and updated from the $7.5M (2008 dollars) used in the national WAP evaluation to $9.6M (2015 dollars), as published in a forthcoming U.S. Department of Transportation (DOT) guidance document for 2016.[7] The DOT issues annual updates to the VSL to adjust for changes in prices and real incomes. Federal agencies including DOT and U.S. Environmental Protection Agency (EPA) use the VSL to assess the benefits of their regulations or policies intended to reduce deaths or fatalities (e.g., from traffic accidents or adverse environmental events/conditions). The last known VSL published by the EPA is $7.4M (2006 dollars), which is to be updated to the year of analysis.[8] An article published in Risk Analysis provides an overview of VSL application in federal regulatory analyses and states: 1) EPA's and DOT's estimates have become

[7] At the time this study was being conducted, DOT's annual VSL guidance for 2016 was forthcoming (*Guidance on Treatment of the Economic Value of a Statistical Life (VSL) in U.S. Department of Transportation Analysis*). In the interim, the updated VSL was published in DOT's Benefit-Cost Analysis (BCA) Resource Guide, updated March 1, 2016 (DOT 2016), available at https://www.transportation.gov/sites/dot.gov/files/docs/BCA%20Resource%20Guide%202016.pdf. DOT's 2015 guidance document, dated June 17, 2015 (DOT 2015), is available at https://www.transportation.gov/sites/dot.gov/files/docs/VSL2015_0.pdf.

[8] EPA. Mortality Risk Valuation. Available at https://www.epa.gov/environmental-economics/mortality-risk-valuation#whatisvsl.

remarkably similar; both now use central VSL estimates somewhat above $9 million; 2) this increasing similarity appears to result at least in part from reliance on the same type of research (wage risk studies); and 3) DOT has updated its guidance more frequently than EPA (Robinson and Hammitt 2015, 1088).

It is also important to note that the VSL does not refer to the "value of a life" but rather as the value of a change in one's mortality risk. From the DOT guidance, the VSL is "defined as the additional cost that individuals would be willing to bear for improvements in safety (reductions in risks) that, in the aggregate, reduce the expected number of fatalities by one...what is involved is not the valuation of life as such, but valuation of reductions in risk."

Discussion arose regarding whether a VSL more specific to the low-income population has been developed and can therefore be applied in this study. Age-specific VSLs, which have been studied, can be related, in part, to income level. However, the literature shows "that the relationship between age and WTP (willingness to pay) for mortality risk changes is ambiguous" and the empirical evidence and stated preference results are mixed (EPA 2010, B-5). Furthermore, for policy reasons and because DOT regulations typically affect a broad cross-section of people, DOT guidance explicitly assigns a single, nationwide VSL regardless of “age, income, or other distinct characteristics of the affected population, the mode of travel, or the nature of the risk." EPA similarly applies a single VSL value and had discontinued its use of age adjustments (lower VSL for older age groups) after its "review of emerging research suggested that the effects of age on VSL were highly uncertain" (Robinson and Hammitt 2015, 1090). Regardless if VSLs had been developed specific to age-groups or income-level, the study team decided that any such adjustment would reflect a devaluation of life in both circumstances and therefore seemed unethical.

The study team also explored whether a different VSL value is being used by regulatory agencies in MA (e.g., MA Department of Transportation (MADOT), MA Department of Environmental Protection (MADEP)), but did not find any in the published literature or through inquiries made to agency personnel. However, the study team did find a 2010 MADOT publication that references the USDOT’s 2009 VSL to monetize the value of accidental traffic deaths that can be prevented through improvements to freight infrastructure and operations in the Commonwealth (MADOT 2010, 4-10 through 4-11).

Summary of Key Inputs Used to Estimate Each NEB

Table 5 summarizes the key inputs and methodology used to estimate the value of each NEB evaluated in the study.

Table 5. Summary of key inputs and methodology

NEB	Average reduction from survey (Table 4)	Methodology
Reduced asthma	11.5%, 3.1%, and 11.8% reduction in emergency room visits, hospitalization, and the incidence of high cost patients for asthma, respectively	Applies reported reductions to the types of and costs for medical care sought for asthma (physician office and emergency department (ED) visits, and hospitalizations) using MA-specific and national medical data adjusted for MA
Reduced thermal stress	1.9% and 2.8% reduction in the occurrence of medical care sought for cold- and heat-related illnesses, respectively	Applies reported reductions to the types and costs for medical care sought for thermal stress (physician office and ED visits, and hospitalizations) using national medical data adjusted for MA. Also estimates the avoided death benefit by assuming the same national rate of death following hospitalizations due to thermal stress (2.51% cold and 1.28% hot)
Reduced missed days at work	4.0 days	Applies reported reduction to the percentage of LI households with an employed wage earner who does not have sick leave and national average hourly wage rate data adjusted for MA
Reduced use of short-term, high-interest loans	6.45%	Applies reported reduction to the national average of fee and interest payments
Increased home productivity	5%	Applies reported reduction to secondary national data on losses in productivity due to sleep problems and housework-related wage rate data adjusted for MA
Reduced CO poisoning	Survey sample was too small to detect the incidence of CO poisonings and was not intended to measure avoided deaths with respect to CO monitor installation	Makes use of secondary data regarding the preventative safety impact of CO monitors on the incidences of poisonings and death, percentage of LI households using fossil fuel-fired heating systems and without a functional CO monitor, the types of and costs for medical care sought for CO poisoning (ED visits and hospitalizations) using national medical data adjusted for MA, and the VSL (a)
Reduced home fires	Survey sample was too small to properly gauge fire frequency and consequence	Maps an extensive, LI-weighted, set of fire causes (and their probabilities) found in a national fire database to their corresponding weatherization measure(s) that would have likely prevented them, and applies national medical data (for fire-related injuries) adjusted for MA and the VSL (a)

(a) Tonn et al. (2014) and Three[3] and NMR (2016) provide more detail on the secondary CO and fire prevention data used in the analysis.

Results

Table 6 presents the annual estimated values of the monetized NEBs selected for the MA NEB study, per weatherized unit. The overall valuation results are driven quite strongly by the assertion that the program is saving lives; however, given the uncertainty surrounding the estimate of the number of deaths avoided, the NEB estimates are presented both with and without the avoided death benefit.

Table 6. Estimated MA LI NEBs, with and without the avoided death benefit (annually per weatherized housing unit)

NEB	Estimated value of NEB with avoided death benefit	Estimated value of NEB without avoided death benefit
Reduced asthma	$9.99	$9.99
Reduced cold-related thermal stress	$463.21	$4.67
Reduced heat-related thermal stress	$145.93	$8.28
Fewer missed days of work	$149.45	$149.45
Reduced use of short-term, high-interest loans	$4.72	$4.72
Increased home productivity	$37.75	$37.75
Reduced CO poisoning	$36.98	$0.25
Reduced home fires	$93.84	$9.77

Notes: These NEB values are to be applied annually over the expected life of home weatherization, which is generally about 20 years. For the reduced CO poisoning NEB, its value is to be applied annually over the expected life of a CO monitor, which is generally 5 years.

These NEB values reflect the estimated benefits accrued directly by households (e.g., avoided deaths and avoided out-of-pocket medical costs). Avoided medical costs payable by Medicare, Medicaid, or private insurance, as well as the avoided injuries and deaths to firefighters are considered a benefit to society and are not reflected in these values.

As shown in Table 6, the main contributors to the NEB estimates are: avoided deaths from thermal stress, CO poisoning, and home fires; disposable income gains from fewer missed days at work; and increased home productivity. In particular, the application of the VSL to quantify the avoided death benefit drives the monetary value of the NEBs for reduced thermal stress, fire, and CO poisoning. Table 7 provides a breakdown of the avoided number of deaths, if any, and hospitalizations, ED visits, and physician office visits annually for each of the relevant NEBs, per 1,000 units weatherized.

Table 7. Estimated number of avoided deaths, hospitalizations, ED visits, and physician office visits for each health-related NEB (annually per 1,000 housing units weatherized)

NEB	Avoided deaths	Avoided hospitalizations	Avoided ED visits	Avoided physician office visits
Reduced asthma	N/A	9.9 (adult) 4.2 (child)	54.6	N/A
Reduced cold-related thermal stress	0.05	1.9	7.6	9.5
Reduced heat-related thermal stress	0.01	1.1	23.6	3.2
Reduced CO poisoning	0.004	0.07	0.47	N/A
Reduced home fires	0.009	0.013	0.4	0.25

Recommendations

NMR recommended replacement of the health- and safety-related NEBs derived from its 2011 study and currently claimed by the MA PAs with this study's NEB estimates for thermal stress, reduced asthma, fewer missed days at work, increased home productivity, reduced CO poisoning, and reduced fire. NMR's recommendation is based on a review of an extensive body of literature supporting the positive health impacts of weatherization; its own survey research conducted as part of the 2011 NEB study; its view that the WAP-based methodology is logical and comprehensive; and, while not all of the statistical analyses of the changes are statistically significant, that the study consistently finds a positive effect from weatherization and provide evidence for program impacts. However, application of this study's NEB for reduced use of short-term predatory loans was not recommended because it does not likely represent an additional benefit beyond the participant bill savings already claimed by the MA PAs.[9] Table 8 presents a comparison of the 2011 and the 2016 study values for each NEB category.

Table 8. Comparison of 2011 and 2016 study NEB estimates (annually per weatherized home)

NEB category	2011 study	2016 study
Health benefits	$19	$769 (a)
Thermal comfort	$101	$120 (b)
Improved safety	$45	$94 (c)

(a) Reflects total of estimated NEB values for reduced asthma, thermal stress, and missed days at work shown in Table 6.
(b) Reflects NMR 2011 value of $101 for improved thermal comfort plus one-half of the 2016 study's estimate of $37.75 due to potential overlap because the 2016 study attributes its NEB for increased home productivity to making the weatherized homes more comfortable and conducive to better sleep.
(c) Reflects the $36.98 value for reduced CO poisoning plus the $57.48 portion of the total reduced home fire NEB that is attributable to weatherization measures currently included in the MA LI single family program (i.e., does not include the portion attributable by the study to electrical repair, clothes dryer vent repair/replacement, chimney repair, or fans repair/replacement since these measures are currently not being offered in MA).

As shown in Table 8, the NEB values recommended from the 2016 study are substantially higher than their counterparts from the previous 2011 NEB study. The design and much larger scope of the national WAP occupant survey allowed the relatively small changes in self-reported health and household status (as measured from pre- to post-weatherization with a comparison group) to be better detected and subsequently monetized using a more robust set of secondary national and state medical incidence and cost data. In addition, the relatively small number of avoided deaths due to thermal stress, CO poisoning, and fire could be monetized assuming a VSL of $9.6 million, which substantially increases the per unit value of the NEBs from the corresponding 2011 study estimate. On the other hand, the 2011 NEB study estimates were based on a much smaller survey of respondents conducted post-weatherization only, where they valued their self-reported changes in health effects relative to their energy bill savings. In addition, the 2011 study referenced multiple health benefits collectively (e.g., colds, flus, asthma, and other chronic health conditions), whereas the national WAP occupant

[9] The benefit of reduced use of short-term predatory loans could be construed as being derived from customer energy bill savings, which the MA PAs already claim as a benefit for its EE programs. Claiming both benefits concurrently could therefore constitute double-counting.

survey targeted each potential health benefit separately.[10] Finally, the 2011 study estimated the benefit of improved safety from reduced CO poisoning and fires due to a single measure only (heating system replacement), whereas the 2016 study estimated this benefit from a much wider range of measures using a more robust set of secondary national and state CO and fire incidence data.

The substantial increase in the health-related NEB is largely attributable to reduced thermal stress and reduced missed days from work. The increase in the thermal stress NEB is principally attributable to the avoided deaths by reducing the chance of an individual being subjected to dangerously cold or hot temperatures. The risks of thermal stress, including heat and cold-related mortality, are very real and substantial. A recent National Health Statistics Report estimated 2,000 weather related deaths per year in the U.S. from 2006 to 2010, with about 31% of these deaths attributed to exposure to heat-related causes and 63% attributed to exposure to excessive cold (Berko et al. 2014). The report includes estimates by region over a five-year span, which the study team used to estimate 307 heat and cold related deaths per year in the northeast region. Assuming the deaths are roughly proportionate to the population in each state, there are an estimated 36 cold and heat related deaths per year in Massachusetts, 29 of which were cold-related and eight of which are heat-related.[11] While not all of these deaths are preventable by weatherization, statistics show that there are enough cold- and heat-related deaths in MA that can be prevented through home weatherization (as shown in Table 7, a total of about 0.06 lives saved annually per 1,000 units weatherized).

Key Limitations and Sources of Uncertainty

Although the 2016 study resulted in a much improved quantification of the health- and safety-related NEBs currently claimed as a benefit of the LI single-family weatherization program in MA, the revised NEB estimates are subject to the following key limitations and sources of uncertainty:

- Because of the design of the national occupant survey for which the results are based, the MA-specific results generally apply only to occupants of and weatherization measures implemented in LI single-family homes. These include housing units in small multifamily buildings consisting of between two and four units in total, which is consistent with the PAs' classification of single-family homes in their programs.
- The treatment and comparison groups drawn from the cold climate region are not entirely comparable given their differences in respondent age and household size. The older-aged comparison group is more likely to experience thermal events and the study may therefore be understating the benefits of weatherization. On the other hand, the study may be overstating the benefits of weatherization, considering the smaller size of households reflected by the comparison group. In addition, the study did not adjust for any differences in the weather experienced between the treatment and comparison groups, which had been surveyed following home weatherization in 2013 and 2011, respectively. To help reconcile this difference, the study computed and based its NEB estimates on the average of the two survey years (average of the difference between the 2011 pre- and 2013 post-weatherization treatment groups and the difference between the 2011 pre-weatherization treatment and 2011 post-weatherization comparison groups).

[10] The 2011 survey asked respondents if they or anyone in their household experienced a change in the frequency or intensity of colds, flus, and other illnesses, such as asthma or other chronic health conditions, and if so, to quantify the value of that change relative to the estimated energy bill savings attributed to the energy efficiency improvements.

[11] The sum of the estimated cold-related and heat-related deaths does not add up to 36 due to rounding.

- The occupant survey was not designed to measure the avoided consequences of thermal stress in the exact same way as the secondary data used to monetize them. The survey asked respondents whether they required any medical attention in the last 12 months for thermal stress, and the study monetized the associated reductions assuming they follow the same pattern as the general population with respect to the types (and their relative proportion) of medical treatment sought for thermal stress (physician visits, ED visits, and hospitalization).
- There is considerable uncertainty in the VSL, which ranged from $5 million to $9 million at the time of the national WAP evaluation. An updated value of $9.6 million (2015 dollars) recommended by USDOT was applied. A more context sensitive VSL could not be found.
- Except for asthma and reduced CO poisoning, only one (1) occupant per household is assumed to be affected for each NEB.
- The prevalence of asthma in MA could be higher (e.g., larger percentage of communities of color), and asthma analysis does not account for multiple re-admittances.
- The analysis of the thermal stress NEB does not account for extreme winter and summer weather events that could occur in any given year. In addition, national (not MA) incidence rates for death from thermal stress are applied.
- Only one (1) short-term, high-interest loan per year per household is assumed to be avoided.
- It is assumed that weatherization reduces the probability of fire to just the average probability of fire.

Conclusions

This study produced health- and safety-related NEB values that are substantially higher than their counterparts from the previous 2011 NEB study. The study results are considered more robust given the design and much larger scope of the national WAP occupant survey, as opposed to the 2011 study's smaller, post-weatherization only, relative-valuation (to energy bill savings) survey. The larger sample size of the national occupant survey increased the researchers' ability to detect infrequent events such as the need for urgent care and potential mortality due to thermal stress that could be avoided from weatherization. Although not all the occupant survey findings are statistically significant, supplemental evidence from the literature and the NMR study sufficiently supports application of the NEBs estimated in this study that was largely based on the methodology and findings of the national expert panel reviewed WAP evaluation study. The application of a VSL to quantify the avoided death benefit drives the monetary value of the NEBs for reduced thermal stress, fire, and carbon monoxide poisoning. For example, the total value of the health-related NEBs (reduced asthma, thermal stress, and losses in work income) increased from $19 to $769 per weatherized home annually, but to $172 without including the avoided death benefit.

The results of this study substantially bolster the benefits of the LI single-family weatherization program in MA and potentially allow the PAs to expand its program offerings. In addition, the NEB values estimated in this study represent a better account of the "real" benefits to LI occupants beyond just the energy savings and could potentially be used to help promote program participation. In particular, this study examined and quantified the lives lost due to exposure to dangerously cold or hot temperatures and unsafe heating equipment in the home that are preventable from weatherization.

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