Energy Research & Social Science 107 (2024) 103341

Contents lists available at ScienceDirect

Energy Research & Social Science

journal homepage: www.elsevier.com/locate/erss

Original research article

A dollar well spent: Monetizing the societal benefits of low-income weatherization programs in the United States

Bruce Tonn *, Michaela Marincic, Erin Rose

Three[3], Inc., USA

ARTICLE INFO

Keywords:
Weatherization
Non-energy impacts
Monetization

ABSTRACT

Low-income residential energy efficiency programs save energy and can yield numerous co-benefits or non-energy impacts (NEIs). This paper presents a two-component framework that can be used to measure and monetize household-related NEIs. Two examples of using the framework are presented, one associated with an evaluation of a low-income single family home weatherization program implemented in the Southeastern United States (U.S.) and a second associated with a broad NEI assessment of weatherized affordable multifamily buildings in the Northeastern and Midwestern regions of the U.S. Seventeen NEIs were subject to monetization, including reductions in medical interventions for being too cold or too hot in one's home and reductions in use of predatory loans. The results of the two monetization exercises indicate that the monetary value of the NEIs is equal to or exceeds the energy efficiency job costs and energy cost savings. It is also clear that the value of the NEIs differs quite substantially based on home type. Future research can focus on better estimating changes in NEI variables and expressing ranges of uncertainty in final monetization values.

1. Introduction

Energy efficiency programs can produce a plethora of non-energy impacts (NEIs), also known as non-energy benefits and co-benefits. The seminal report published by the International Energy Agency [1] identified reductions in greenhouse gas emissions, and in baseload and peak electricity demands among many potential NEIs. Assessments of the co-benefits of energy efficiency have also considered energy security, air quality, economic development, and health [2]. NEI assessments have been conducted in many energy efficiency sectors, including the residential [3] and commercial and industrial sectors [4,5]. The co-benefits of energy efficiency have so grown in importance that Chatterjee et al. [6] argue that co-benefits can be used to incentivize energy efficiency investments.

This paper addresses the NEIs of a specific class of energy efficiency programs that fall under the rubric of residential low-income weatherization. In the U.S., residential weatherization programs are funded by the U.S. federal government and energy utilities. These programs install free to households many energy efficiency measures, including air sealing, wall and ceiling insulation, heating and cooling system repair and replacement, and new lights and refrigerators. Home energy audits are conducted to determine which cost-effective measures should be installed. Finally, homes are inspected post-weatherization for work quality, health, and safety problems.

This paper presents a generic framework for monetizing the non-energy impacts of energy efficiency programs and applies this framework to monetize NEIs in two low-income weatherization contexts. The next section presents a brief history of NEI research in the low-income weatherization space and our general approach to this research. Section 3 presents our two-component framework for assessing changes in NEI variables and monetizing the changes. The fourth section introduces two low-income residential NEI studies that included monetization that highlight the application of our framework. Section 5 presents demographic and monetization results for these two studies. The penultimate section addresses issues surrounding the use of monetization results and pathways for improving such estimates in future studies.

2. Literature review and general approach

The origins of NEI research in the United States can be traced back to the 1970s and1980s. During these decades, energy efficiency programs were initiated by both the federal government and utility companies. Among the early leaders in this area were the U.S. Department of Energy (USDOE) and the Bonneville Power Administration (BPA). USDOE's low-

* Corresponding author at: Three[3], Inc., 520 W. Summit Hill Drive, Suite 1101, Knoxville, Tennessee, USA.
E-mail address: btonn@threecubed.org (B. Tonn).

https://doi.org/10.1016/j.erss.2023.103341
Received 8 June 2023; Received in revised form 3 November 2023; Accepted 7 November 2023
Available online 27 November 2023
2214-6296/© 2023 Elsevier Ltd. All rights reserved.

income residential Weatherization Assistance Program (WAP) was established "…*to increase the energy efficiency of dwellings owned or occupied by low-income persons, reduce their total residential energy expenditures, and improve their health and safety, especially low-income persons who are particularly vulnerable, such as the elderly, the disabled, and children.*"[1] From its origin, WAP was intended to address energy poverty, which is problem not only in the U.S. [7,8] but also across the globe [9].

One of BPA's notable projects was called the Hood River Conservation Project (HRCP). This project was designed to assess the maximum penetration of residential energy efficiency that could be attained in a community, this being the town of Hood River, Oregon [10]. For this and many other projects and programs, these agencies and utility companies quickly found that they needed rigorous methods to estimate the energy savings attributable to their programs. A new field of study called energy program evaluation emerged to estimate energy savings attributable to energy efficiency programs.[2]

In the 1990s, energy efficiency program evaluations began to encompass NEIs. One of the seminal pieces of work was conducted by Brown et al. [11], which estimated a comprehensive set of NEIs attributable to WAP. NEIs addressed by Brown et al. included reductions in outdoor air pollutants, increases in local employment, and increases in property values. Succeeding evaluations expanded the NEIs under consideration to include national security [12] and home comfort [13]. Schweitzer and Tonn [14] summarize the state of NEI research, including monetizations of NEIs, up to the beginning of the 21st century.

Over the past couple of decades, NEI research has expanded its assessment of weatherization benefits accruable to households. Concurrently, research on the positive health impacts of energy efficient housing increased across the world. For example, research supports hypotheses that improving the energy efficiency of homes could improve general health [15], mental health [16] and social well-being [17,18]. Other research has found that weatherization can reduce thermal stress [19] and improve respiratory conditions [20]. Outcault et al. [21] suggest five categories: physiological, psychological, economic, practical, and sociological. We use these five categories: home conditions, general health, acute health events, finances, and life satisfaction [22].

These strands of research came together in the assessment of health and other household-related NEIs of WAP conducted by Tonn et al. [23]. This research utilized social science survey and quasi-experimental design techniques to explore new classes of NEIs (e.g., reductions in short-term, high interest loans) and eschewed contingent valuation approaches to monetization to rely on cost estimates published by reputable sources, such as U.S. federal agencies, or actual medical cost records [20]. Recent publications that describe NEIs of low-income weatherization programs in the U.S. include [22,24–26].

The audience for NEI research has similarly expanded in the U.S. Of course, energy efficiency program administrators continue to fund comprehensive evaluations of their programs and wish to include NEIs in their evaluations. Additionally, program managers are interested in communicating the benefits of their programs to potentially gain additional funding for their programs. Building evidence about the health benefits of weatherization is especially important to attract the attention of the healthcare and public health sectors.

For this paper, our approach is to concentrate on household NEIs within the categories mentioned above that can be monetizable (i.e., that one can place a dollar value on).[3] Fundamentally, realization of these NEIs can improve household finances. In other words, we consider monetizing any household NEI that can decrease the amount of money that low-income households have to spend to improve their quality of life. For instance, we include the reduction of out-of-pocket medical expenses that may result because of fewer asthma flare-ups or fewer headaches post-weatherization. We also include reductions in deductibles required to be paid by households to insurance plans for emergency department visits and hospitalizations, for example for asthma or injuries incurred during home fires. As another example, we include reductions in predatory interest payments for short-term loans as fewer loans may be taken out to pay energy bills because households benefit from energy cost savings and reductions in other expenditures like those just mentioned.

NEIs whose benefits extend beyond individual households to broad sectors of the economy and society fall into the societal NEI category. In this research, we focus on societal NEIs that are intertwined with household NEIs. NEIs that fall into this category save society money. Here we include reductions in insurance-paid medical costs for doctor's office visits, visits to the emergency department, and hospitalizations. We also include reductions in various government subsidies needed by households for energy or food, which may result if household finances improve.

To be complete, we need to mention that weatherization programs can also positively benefit ratepayers (i.e., utility customers). Weatherization could contribute to grid reliability, utility GHG reduction targets, and meeting utilities' equity goals. With respect to ratepayer NEIs intertwined with household NEIs, if households are better able to pay their utility bills, then utility costs associated with arrearages, disconnect notices, and disconnections could all be reduced. Finally, costs to utilities through Percentage of Income Payment Programs (PIPPs) could be reduced if unpaid participant generated energy costs are reduced.[4] Ratepayer benefits are not included in this research because our primary data collection and analyses focused on the first two benefit categories.

Monetization of NEIs is vitally important for several reasons. Placing monetary values on NEIs contributes to the systemic and comprehensive evaluation of energy efficiency programs. The values can be used in benefit-cost analyses to provide a fuller picture of how the monetary benefits of a program compare to its costs. Though investments in residential energy efficiency are typically cost-effective [27,28], pressures have built upon utility programs to find more ways to justify the cost effectiveness of their programs in the wake of the high market penetration of highly cost-effective LED lights that utilities install in homes [29]. Accounting for the monetary values of NEIs can positively contribute to cost-effectiveness tests used by public utility commissions to justify expenditures on energy efficiency programs [30]. Distinguishing between household and societal NEIs provides clarity about the nature of the NEIs. It can also be important in situations where utilities are limited with regard to the types of NEIs they are allowed to include in their total resource cost (TRC) tests. In Massachusetts, for instance, utilities are only allowed to include monetized household NEIs in their rate applications.

Monetization of health benefits of weatherization in particular can help make the argument that the healthcare and public health sectors should also support these energy efficiency programs. These exercises further reveal that other government subsidy programs may also benefit from weatherization programs, such as energy and food assistance programs.

[1] https://www.energy.gov/scep/wap/about-weatherization-assistance-program.

[2] The professional association and conference for this new field is called International Energy Program Evaluation Conference https://www.iepec.org. IEPEC now operates in Western Europe and its activities are also spreading to Asia.

[3] See Appendix B for a more complete definition of this term.

[4] Under these programs, households pay a pre-defined percentage of their monthly income to utilities for energy services, regardless how high their energy bills might be each month. Utilities and their ratepayers make up the difference between the household payment and the actual energy costs. https://development.ohio.gov/individual/energy-assistance/2-percentage-of-income-payment-plan-plus#:~:text=How%20does%20PIPP%20work%3F,of%20your%20gross%20household%20income.

Two additional points need to be made before moving on. First, an important characteristic of the NEIs addressed in this research is that the benefits can emerge in the short-term (e.g., impacts on household budgets) or even immediately in the case of thermal stress and asthma (e.g., immediately after weatherization the home is more comfortable and less dusty). Future research should endeavor to encompass potential NEIs that may emerge in the mid- to long-term, such as reductions in cardiovascular disease.[5]

The second point is made with respect to the value of a statistical life (VSL). We believe that weatherization can save lives. For example, more thermally sound homes can prevent deaths from thermal stress (i.e., being too cold or too hot in one's home). Decreasing fires through weatherization supported minor electrical repairs and the repair and replacement of unsafe combustion furnaces can also save lives. The installation of CO monitors, which are part of comprehensive weatherization programs in the U.S., can also have this outcome. Several of our NEI algorithms include estimates of lives saved attributable to weatherization [13]. We use value of life estimates published by federal agencies such as the U.S. Environmental Protection Agency and the U.S. Department of Transportation.[6]

A question very pertinent in the NEI context is whether VSL should be counted as a household or societal benefit. This is because in some instances only the monetized household NEIs estimates can be used in utility program cost effectiveness testing. The two studies presented below count VSL as a household benefit because they were estimated to contribute to utility rate cases. One can argue that this is reasonable because VSL estimations are based upon individual behaviors (i.e., how much more does someone need to be paid to accept a job with a higher risk of death) and individual elicitations about how much they believe their lives are worth.[7] We do not adjust VSL estimates based on the age of individuals whose lives are saved.

This paper makes several important contributions to the literature. First, the paper presents a complete methodology for estimating and monetizing NEIs accruable to households and society from low-income weatherization programs. Second, the paper presents the results of two comprehensive evaluations of NEIs for comparison and contrast. The results show how NEI estimates can differ across home types and how the aggregated monetary estimates compare to weatherization job costs and energy cost savings estimates. Third, the Discussion section includes a much-needed comprehensive overview of the methodological challenges of this area of research and sets out several avenues for future research.

3. Monetization framework

Our general approach is (1) to measure changes of NEI-related variables and then (2) use estimates of actual costs that could be saved for the monetization component. For example, for thermal stress due to being too cold in one's home, we survey households pre- and post-weatherization about the number of times household members went to the emergency department for being too cold and then use actual medical records data or publicly available healthcare cost databases to monetize this change.

3.1. Approaches to measuring changes in NEIs

There are several approaches to measuring changes in NEI variables. Here are three for consideration:

3.1.1. Surveys

The approach is to survey weatherization participants pre- and post-weatherization. The survey needs to include questions that can measure changes that are monetizable. It is also recommended that questions be included that could provide additional evidence that the monetizable changes can be attributed to weatherization. To take asthma as an example, questions could focus on emergency department and hospital visits. Additional questions could focus on dust levels and infestations of pests. If the latter improve, then explanations are available for reductions in medical care needed for asthma post-weatherization. We typically also include several questions related to general health that can help make the case that weatherization can improve health.[8] It is recommended that a control group be surveyed at the same times as the treatment group. In this way differences-in-differences statistical tests can be used to determine whether the measured changes in NEI variables are statistically significant.[9]

3.1.2. Direct measurements

Let's assume that it is hypothesized that weatherization could reduce high blood pressure, due in part to reduced stresses on household budgets and improved indoor comfort. Instead of posing a survey question about blood pressure, the blood pressure of occupants could be measured directly. Instead of asking about improvements in sleep, occupants could be asked to wear sleep monitors. Other methods of direct measurement include breathing and blood tests, and extensively monitoring food intake and use of prescriptions. Overall, direct measurement approaches can be more accurate than surveys but may be more expensive and maybe more intrusive from the point of view of participants.

3.1.3. Special studies

In some cases, it may not be practical or possible to measure changes within the scope of an NEI evaluation. For example, it may take years to collect enough data to estimate NEIs attributable to the installation of CO monitors. This is because CO poisoning is a rare event, compared to, for example, asthma emergency department visits. In these instances, the recommendation is to search the literature for special studies that present NEI-relevant impacts that can be attributable to the installation of individual or combinations of weatherization measures. In the case of CO, the there is only a small number of papers that estimate the reduction in CO poisoning from the installation of CO monitors [31,32]. We also used this approach to estimate the fire prevention NEIs [23].

3.2. Approaches to monetizing changes in NEIs

The approaches used to monetize changes in NEI variables mirror the three approaches to measuring changes in NEI-relevant variables just presented. The three monetization approaches are to use:

3.2.1. Publicly available databases (PADB)

This approach uses cost estimates that have been compiled in publicly available databases by reputable organizations. For example, healthcare costs are collected by the U.S. federal government and are

[5] NEI research has shown that weatherization can improve sleep and rest by improving indoor temperature conditions and reducing the intrusion of outdoor noise. Other research has correlated improvements in sleep to reductions in cardiovascular disease.

[6] https://www.epa.gov/environmental-economics/mortality-risk-valuation#whatvalue https://www.transportation.gov/office-policy/transportation-policy/revised-departmental-guidance-on-valuation-of-a-statistical-life-in-economic-analysis.

[7] It should be noted that VSL was counted as a societal benefit in our WAP NEI study [23]. This decision follows a pattern where U.S. federal agencies treat VSL as a programmatic (i.e., societal) benefit.

[8] Appendix C contains an example of the questionnaire we used to survey households living in affordable multifamily buildings.

[9] For legal, programmatic, and ethical reasons, we have found that it is rarely feasible to implement randomized control trials in our energy program evaluation research and therefore rely on quasi-experimental designs. This is common in the energy research and social science space [38].

published in publicly accessible databases like the Medical Expenditure Panel Survey[10] and the Health Care Utilization Project.[11] Other federal and state databases contain a wealth of other cost estimates, such as the per hour wages of low-income workers,[12] and average subsidies provided to households that are on food assistance.[13] Also falling into this category are federal government estimates for the value of a statistical life (VSL) that are used to monetize lives saved.

3.2.2. Primary data

It is also possible to collect and/or acquire primary cost data. An example of primary data is direct medical costs that are paid by the U.S. Medicaid program, as reported in claims data. Actual Medicaid costs can be tracked for specific individuals pre- and post-weatherization (e.g., associated with asthma). Typically, it takes a good deal of time and effort to gain approval to access such databases and very strict procedures are needed to protect the privacy of these data. However, direct cost data for specific individuals could be more informative than data collected from secondary data sources.

3.2.3. Special studies

Numerous special studies have been conducted to estimate costs associated with specific issues. For example, we have used special studies which have estimated the costs to the U.S. attributable to prescription non-adherence, interest costs associated with short-term predatory loans, and improvements in work productivity that can be gained from improved sleep. In these cases, we pair these costs with answers to survey questions about being able to afford prescriptions, use of predatory loans (e.g., payday, pawn shops), and improvements in sleep, respectively.

It should be noted that we do not use willingness-to-pay, contingent valuation, or other subjective approaches for monetary estimates (e.g., questions that ask respondents to value improvements in home comfort as a percentage of their savings on utility bills). Our point of view is that monetizations based on subjective approaches are harder to defend in public discourse. Conversely, basing monetization on real dollar values experienced by households (e.g., savings on interest payments for predatory loans) and society (e.g., reductions in emergency department visits for arthritis) produces estimates that are more salient and actionable for stakeholders.

4. Two examples of NEI evaluations with monetization estimates

Two examples of monetizing NEIs are presented in this section. One example is related to the NEI evaluation of a residential, mainly single-family, low-income weatherization program implemented in the Tennessee Valley [18]. The second example encompasses affordable multifamily buildings located in the Northeastern and Midwestern regions of the U.S. [26,33]. These two examples offer contrasts in climate zones – moderate versus cold – and housing types – mostly owner-occupied single-family (SF) homes versus renter (i.e., tenant) occupied multifamily (MF) buildings with five or more units. On the other hand, the NEIs addressed by both studies are almost identical, as discussed in Section 4.3.

4.1. Home Uplift (HU)

The Home Uplift (HU) Initiative is a low-income weatherization program funded by the Tennessee Valley Authority (TVA)[14] and local power companies in its jurisdiction. The five major cities in TVA's region participated in HU: Knoxville, Nashville, Chattanooga, and Memphis, (in Tennessee), and Huntsville, (in Alabama). There are also a small number of rural communities in Mississippi and Kentucky represented in our sample of homes. HU's eligibility requirements and weatherization procedures are directly taken from WAP. HU weatherizes SF homes and a small number of mobile homes. Most are owner-occupied. The small number of homes from Huntsville is owned by its public housing program.

TVA provided funds to estimate NEIs attributable to HU. The Center for Applied Research and Evaluation (CARE) of the University of Tennessee, Knoxville administered the phone surveys just a few days after homes received their energy audits but prior to weatherization, and again one year later. All HU homes that received energy audits between 2018 and 2019 were contacted by CARE. The control group sample was drawn from waiting lists, mailing lists, and lists of income-eligible homes that received housing and energy assistance. Households were provided a $30 incentive to complete each survey. The demographic results reported in Section 5 were collected pre-weatherization in 2019/2020 from 997 treatment and control homes.

4.2. Low-income multifamily (LIMF)

The JPB Foundation and the Energy Efficiency Program Administrators in the Commonwealth of Massachusetts provided funds to estimate the health and resilience benefits attributable to weatherizing low-income MF buildings (LIMF) located in the Northeastern and Midwestern regions of the United States. MF buildings in our sample had five or more units. We worked with state and local weatherization programs, utilities that offer MF weatherization, non-profit low-income and affordable housing advocates, and non-profit and commercial owners of affordable MF buildings to construct a convenience sample of treatment (i.e., will be weatherized), control (i.e., will not be weatherized), and comparison (i.e., already weatherized) buildings.

Treatment, control, and comparison group households were first surveyed between 2018 and 2019. Based on recommendations provided by property managers and owners, paper questionnaires were translated into Spanish, Mandarin and Russian. The project team asked property managers and property owners for permission to enter buildings to hang survey packets on residents' doorknobs and in the appropriate language if known. Each clear bag contained a cover letter, a paper questionnaire, and a pre-paid return envelope. Survey packets were hung on every door in a visited building, except for the largest MF buildings, where survey packets were hung on every other or every third door, though in some buildings project staff personally handed the packets to primary respondents and were able to wait in the building until the questionnaires were completed. Over 7700 questionnaires were distributed. Potential participants were also given the option of completing the questionnaires over the phone or via the web, though most chose to fill out the paper version.

Respondents mailed completed paper questionnaires to CARE for processing; CARE also administered the phone and web versions. Households were provided a $25 to complete each Phase 1 questionnaire and $45 for Phase 2 to increase response rate. Data provided by the LIMF sample presented in this paper are from the treatment and control groups pre-weatherization (N = 1268) that were surveyed in 2018–2019.

4.3. NEIs monetized

As noted above, our NEI research is situated in our evaluation of WAP. Our succeeding NEI evaluations use the survey data and

[10] Medical Expenditure Panel Survey, n.d. https://meps.ahrq.gov/mepsweb/.
[11] Healthcare Cost & Utilization Project, n.d. https://hcup-us.ahrq.gov.
[12] See https://www.bls.gov/ces/data/employment-and-earnings/2022/home.htm.
[13] See https://www.fns.usda.gov/SNAP-household-state-averages.
[14] https://www.tva.com.

monetization algorithms from the WAP evaluation as foundations. Only a small number of new NEIs, such as arthritis, have been added over time. This accounts for the consistency in sets of NEIs encompassed across our NEI evaluations. This consistency is evident in Table 1, which indicates that the NEIs encompassed in the HU and LIMF evaluation efforts are virtually identical.[15] Only three of the seventeen differ across evaluations. CO poisoning and disconnections were not included in the LIMF study because the typical affordable weatherization programs included in our study did not install CO monitors in units (though installed in central boiler rooms) and a substantial number of renters do not receive utility disconnection notices because energy costs are included in their rent. Questions about arthritis were included in the HU post-weatherization survey after arthritis emerged as a significant NEI from the LIMF study.

Table 1 indicates that most of the NEIs were measured through the pre-post survey approach and most of the monetization estimates were drawn from public databases.

Detailed descriptions of the monetization approaches used for each NEI for HU and LIMF can be found in Rose et al. [18] and Three[3] and NMR Group [33], respectively. Examples of approaches to measure and monetize predatory loans (for HU) and arthritis (for LIMF) are contained in Appendix B.

It should be noted that the residential questionnaire includes many more questions about health and household finances than are represented in Table 1. Some questions pertain to important topics but approaches for monetization had not yet been developed. For example, our surveys consistently indicate that occupant physical and mental health improve post-weatherization, but we have not yet developed approaches to monetize these NEIs. Answers to some questions may show positive improvements but not statistically significant changes from pre- to post-weatherization. Thus, NEIs such as headaches, scalding from hot water, and missed days of work are not included in Table 1.

5. Results

This section presents results pertaining to the monetization of NEIs attributable to HU and LIMF. The first subsection presents demographic descriptive statistics. The second subsection presents annual and present value monetization results.

5.1. Demographics

Table 2 presents descriptive statistics for selected demographic variables. The sample sizes (N) documented in the table are the number households from each sample that answered the pre-weatherization residential questionnaire. There are several similarities across the two evaluations.[16] First, the ages of the main respondents are in the upper 50s to lower 60s, which is quite common among weatherization program recipients. Secondly, it is also common for most of the respondents to identify as female. Third, most of the samples have relatively small household sizes at well under 2 persons per household, whereas the national average is about 2.5 persons per household. Fourth, employment rates are low and, correspondingly, retirement rates are high. Fifth, educational attainment is similar across the programs and samples.

The biggest difference in the demographic variables is race. A large majority of households in the HU samples self-identify as black, whereas 50 % or fewer self-identify as black in the LIMF samples. One reason for this disparity is that the HU program established a priority to recruit homes in predominately low-income black communities. For comparison purposes, approximately 90 % of households that participated in the WAP residential survey self-reported as white [25].

5.2. Monetization results

Table 3 presents estimated annual values of 17 categories of NEIs, given by household and societal benefit. NEIs with cells containing N/A were judged to be not applicable to the category of beneficiaries noted in the column heading. NEIs with cells containing two dashes (i.e., –) were not included in the surveys for that study, or it was judged that the NEI did not apply to that particular program. For example, the CO poisoning NEI was not estimated for LIMF because CO monitors were not installed by the major programs included in that study (e.g., Mass Save in Massachusetts[17]). Values of $0.00 in cells indicate that the changes measured by the surveys were not statistically significant,[18] and therefore no values were claimed for the NEI. For instance, NEI variables associated with asthma and COPD did not produce statistically significant changes, and thus all of those NEI values are $0.00.[19]

The differences in NEI monetary values are due primarily to differences in demographics and context. For example, HU households accrued more benefits related to predatory loans than the LIMF households. We hypothesized that almost all HU households pay their own utility bills whereas a substantial percentage of LIMF households have their energy costs included in their rents. Thus, there is no context for the latter to take out predatory loans to pay for utility bills. On the other hand, LIMF households contributed to a larger societal benefit with respect to prescription adherence, which may be due to the LIMF affordable multifamily population being in poorer health than occupants of HU single family homes. The societal benefits related to fire risks are lower for the LIMF program because fires in multifamily homes, at the baseline, are much less prevalent than in single family homes. We hypothesize that this is the case because affordable multifamily properties are closely regulated and frequently inspected for health and safety violations, unlike the single-family home sector in the U.S.

The largest monetized values are related to thermal stress cold. This is because there was a statistically significant decrease in the need for medical interventions for thermal stress cold from pre- to post-weatherization. This is also because our monetization algorithm assumes that a small percentage of individuals who are hospitalized for thermal stress cold will die from this health condition in the hospital. Preventing hospitalizations due to thermal stress cold can save lives. In this research, we assigned a value per saved life of $9.2 million based on guidance provided by the U.S. Department of Transportation and the Environmental Protection Agency. Even saving what would be a fraction of one life contributes a relatively high value to the aggregated monetization estimates.

Table 4 presents the annual totals for the monetization of HU and LIMF NEIs by household and societal categories, and also with VSL and without VSL. The latter were calculated simply by dropping estimates for lives saved from the thermal stress cold, thermal stress hot, CO, and fire algorithms. The biggest difference between the annual totals between the programs falls within the annual societal benefit category. Here we see that the value for that benefit is larger for LIMF than HU, primarily because of the inclusion of arthritis as an NEI in the former. The differences between the annual totals with and without VSL indicate how much the VSL aspects of the thermal stress NEIs in particular can influence these monetizations. For comparison purposes, the most recent national evaluations of WAP estimated that the average annual energy cost savings accrued to households living in weatherized SF homes was $283 [34] and weatherized affordable MF was $122 [35].

[15] See Appendix A for definitions of the NEIs.

[16] See Tonn et al. [25]) for a more in-depth discussion about the characteristics of households that receive weatherization services.

[17] https://www.masssave.com.

[18] At the $p < 0.10$ level.

[19] Other NEI variables not included in the table that also did not present statistically significant changes in the survey results include headaches, oral health, and exercise.

Table 1
Non-energy impacts – definitions and estimation approaches.

Non-energy impact	Benefit categories		Project		Measurement change approach	Monetization approach
	HHD	Societal	HU	LIMF		
CO Poisoning	√	√	√	–	Special Study	PADB
Disconnections	√		√	–	Survey	PADB
Fire Risk Reduced	√	√	√	√	Special Study	PADB
Food Spoilage	√		√	√	Survey	Special Study
Predatory Loans	√		√	√	Survey	Special Studies
Home Productivity	√		√	√	Survey	PADB
Work Productivity		√	√	√	Survey	Special Study
Prescription Adherence		√	√	√	Survey	Special Study
Thermal Stress Hot	√	√	√	√	Survey	PADB
Thermal Stress Cold	√	√	√	√	Survey	PADB
Arthritis	√	√	–	√	Survey	PADB
Food Assistance			√	√	Survey	PADB
Low-birth weight Infants		√	√	√	Survey	PADB
Missed Days of Work	√	√	√	√	Survey	PADB
Trips & Falls	√	√	√	√	Survey	PADB
Asthma	√	√	√	√	Survey	PADB
COPD	√	√	√	√	Survey	PADB

Table 2
Comparative demographics.

Variable	Home Uplift Treatment ($n = 701$)[a]	Home Uplift Control ($n = 300$)	LIMF Treatment ($n = 417$)	LIMF Control ($n = 892$)	LIMF comparison ($n = 612$)
Average Age (years)	62	58	58	57	64
Gender – Female (%)	81 %	84 %	69 %	62 %	70 %
Primary Wage Earner Employed (%)	26 %	30 %	27 %	24 %	20 %
Primary Wage Earner Retired (%)	44 %	36 %	46 %	41 %	60 %
Average Household Size (persons)	1.8	2.4	1.8	1.4	1.4
Single Person Household (%)	54 %	34 %	55 %	76 %	77 %
High School Grad or Less (%)	48 %	54 %	61 %	57 %	58 %
White (%)	22 %	15 %	37 %	38 %	63 %
Black (%)	77 %	80 %	24 %	50 %	20 %
Hispanic (%)	1.3 %	1.3 %	14 %	3 %	4 %

[a] 'n' indicates the number of households who completed the resident questionnaire pre-weatherization.

Table 4 also contains estimations of the present value of the annualized monetized NEIs. Present values are the sum of values over a time period (n) divided by $(1 + r)^n$.[20] To arrive at the present values, a discount rate (r) of 0.1 % was used over a ten-year time horizon (i.e., $n = 10$). These two parameters were first used in the monetization of WAP NEIs. The discount rate was provided by the U.S. Office of Management and Budget. We chose the ten-year time horizon, instead of the average lifetime of the measures installed (20 years), to be conservative. This is because it is not well known how persistent the health and household-related NEIs could be. We also believe that changes in the ages and health of occupants over time may favor the selection of a shorter, rather than longer, time frame for this type of analysis.[21]

To provide some perspective on the magnitude of the present value estimates relative to job costs, it should be noted that the average weatherization cost per HU home was about $10,000. LIMF job costs were not collected as part of our evaluation, but from the WAP evaluation it was estimated that costs for affordable multifamily weatherization were $2818 per unit [35]. Estimating energy cost savings was also not included in our HU and LIMF work. However, the WAP evaluation found that the present value of energy cost savings for single family and mobile homes was $5337 based on an average cost of measures per job of $3096 [34]; for large multifamily buildings the savings was $1710 [35]. Even allowing for inflation and fluctuations in energy costs, 10-year present value estimates of the NEIs used in this study are similar to, if not higher than, estimated energy cost savings - even without including VSL.[22]

6. Discussion

The total annual value of the NEIs reported in Table 4 could be considered conservative in a couple of manners. First, several plausible NEIs were not included in either analysis. For example, the resident survey results have consistently found that occupants' mental health improves post-weatherization. Work is needed to develop an approach and algorithm to monetize this potential NEI (e.g., explore reduction in mental health costs paid by households and covered by insurance). Other research, not yet peer reviewed, has found that those who suffer from poor general and mental health are less able to pay their bills in time, thereby incurring late fees, and are also more susceptible to phone and internet scams, which can empty out checking accounts [36]. Weatherization improves sleep, which is also linked to fewer automobile accidents [37]. Also missing are NEIs that could take several years to emerge, such as improvements to cardiac health or prevention of cardiac disease through the reduction of mental and thermal stresses.

The VSL estimates used in our studies may be underestimates. Saved lives were not estimated with respect to asthma or trips & falls, for

[20] https://www.wallstreetmojo.com/present-value-formula/.

[21] It is possible to apply a higher discount rate along with a longer time horizon. Using the 'social discount rate' of 3 % over the lifetime of the measures, 20 years, yields these present values: HU $23,503.43 with VSL and $3109 w/o VSL; LIMF $41,300 with VSL; and $6144 w/o VSL.

[22] We note that the total present value of the NEIs estimated as part of the WAP evaluation was $14,148, over 10 years with a 0.1 % discount rate.

Table 3
Annual monetized estimates with VSL[a] (per unit weatherized).

Non-energy impact/study	Home Uplift			LIMF		
	Household benefit	Societal benefit	Total benefit	Household benefit	Societal benefit	Total benefit
CO Poisoning[a]	$3.58	$0.02	$3.60	–	–	–
Disconnections	$1.34	N/A	$1.34	–	N/A	–
Fire Risk Reduced[a]	$69.81	$9.14	$78.95	$13.00	$4.00	$17.00
Food Spoilage	$12.33	N/A	$12.33	$57.00	N/A	$57.00
Predatory Loans	$19.80	N/A	$19.80	$2.00	N/A	$2.00
Home Productivity	$15.42	N/A	$15.42	$49.00	N/A	$49.00
Work Productivity	N/A	$5.39	$5.39	N/A	$17.00	$17.00
Prescription Adherence	N/A	$19.22	$19.22	N/A	$59.99	$59.00
Thermal Stress Hot[a]	$2.44	$12.08	$14.52	$0.00	$0.00	$0.00
Thermal Stress Cold[a]	$1312.77	$10.66	$1409.23	$1426.00	$38.00	$1464.00
Arthritis	–	–	–	$49	$892	$941
Food Assistance	N/A	$0.00	$0.00	N/A	$99.00	$99.00
Low-birth weight Infants	$0.00	$0.00	$0.00	$0.00	$10.00	$10.00
Missed Days of Work	$0.00	$0.00	$0.00	$8.00	$3.00	$11.00
Trips & Falls	$0.00	$0.00	$0.00	$3.00	$46.00	$49.00
Asthma	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
COPD	$0.00	$0.00	$0.00	–	–	–

[a] NEI includes VSL; N/A – not applicable, – unable to include in the analyses.

Table 4
Monetizations: annual totals and present value estimations.

	Household annual value	Societal annual value	Total – annual with VSL	Total – annual without VSL	Total – 10-year present value with VSL	Total – 10-year present value without VSL
Home Uplift	$1437.49	$56.51	$1494.00	$208.88	$15,404.72	$2038.84
LIMF	$1607.00	$1168.99	$2775.99	$413.00	$27,608.00	$4107.38

instance. Also, the preventative aspect of weatherization with respect to thermal stress was not addressed. We believe that weatherization programs often replace old and inefficient HVAC systems before they fail, at which point they would be unable to keep homes at safe temperatures. In other words, timely weatherization can prevent the emergence of unsafe indoor temperatures. The residential survey could only collect information about thermal stress medical interventions when indoor temperature conditions actually became unsafe: a questionnaire cannot as accurately capture hypothetical scenarios prevented by timely weatherization. The preventative aspect of weatherization and thermal stress will become more important to understand and monetize as climate change increases the magnitude and duration of extreme temperature events.

We believe that the health-related NEIs of weatherization could be greater if weatherization targeted homes with unhealthy occupants. More specifically, the NEIs could be greater if healthcare were to directly refer patients with health issues that could be ameliorated by weatherization programs. For example, patients with frequent needs for medical interventions for asthma and/or COPD might see their medical costs decrease quite substantially, certainly more than patients that do not need medical interventions for these diseases. Health-related NEIs could also be increased if weatherization programs were more often blended with healthy homes programs, which could conduct mold remediation, implement integrated pest management, and remove dusty carpets and window curtains while weatherization measures are installed.

On the other hand, the present values could be overestimates primarily because it is unclear how persistent the benefits could be. For example, immediate improvements in sleep and mental and physical health could allow those in the workforce to miss fewer days of work. Increased incomes combined with energy cost savings and other posited reductions in some categories of expenses could reduce the needs for food and energy assistance and even for predatory loans. In these examples, does weatherization provide those benefits only in the short-term, or does weatherization continue to provide those benefits for many years thereafter?

These discussions highlight a very interesting characteristic of NEI research and reveal the needs for additional basic and applied research. For example, we do not know what the long-term impacts of weatherization might be on cardiac health. Research funds needed to help answer these types of questions are probably beyond the means of weatherization programs but are within the sights of research organizations such as the U.S. National Institutes of Health. Basic research is also needed to help explain why NEI studies are not consistently finding that weatherization positively impacts some respiratory conditions such as asthma and COPD, (as reported above).

Care should be taken with respect to generalizing the results presented herein or any NEI monetization results. Because of significant differences in building construction, demographics, and who pays for energy bills, we strongly advise against generalizing single family results to the multifamily sector and vice versa. Generalization is also highly conditional upon context. For example, it seems reasonable for affordable multifamily weatherization programs in the U.S. Northeastern and Midwestern regions to use the results presented herein because of consistency in climate, building construction practices, weatherization practices, and demographics. We would not recommend that these results be generalized to hot humid or hot dry climate zones, which may be dominated by different building construction standards and approaches. The single-family results presented herein are tied to a moderate climate zone and should likely not be generalized to colder or warmer climate zones in the U.S. It is not clear to us if any of the results presented above can be generalized to European, African, Asian, or South American contexts. On the other hand, the results can be used to support arguments that weatherization programs in other places likely produce significant NEIs and that efforts should be made to estimate and monetize the NEIs.

There is no lack of interesting issues to explore with respect to future research on and about NEIs. One potential topic is whether and how to address cost/price changes. In the energy cost savings context, present values are calculated using forecast real changes in energy prices. In the U.S., these forecasts are provided by the U.S. Energy Information

Administration (EIA). Weatherization programs appear more cost effective when EIA forecasts higher prices for natural gas, for example, and less cost effective when the forecasts are for lower prices. Putting aside the volatility of energy prices, no attempts have been made to incorporate real price changes associated with NEIs, such as with medical costs, which have been steadily rising in real terms for many years. However, incorporating price changes could require a great deal of additional time and effort since a comprehensive set of NEIs may use several dozen different costs, changes to which would need to be forecasted. It is unlikely that forecasts as handy and accepted as those published by the EIA would be available.

The monetization results presented herein are point estimates. Upper and lower bounds with confidence intervals are not presented. We believe future monetization exercises should present ranges and confidence intervals. It is straightforward to present ranges and confidence intervals for the primary variables encompassed by the survey. Ranges and confidence intervals are regularly provided for variables contained in government databases. They are also available calculated for outputs of many models. On the other hand, they may not be provided for many of the key variables and monetizations taken from special studies. Additionally, our custom designed fire and CO models did not incorporate ranges and confidence intervals. There are approaches for dealing with complex combinations of variables. Future research is needed to assess their application to this particular context. It should be noted that point estimates of the monetary values of NEIs have been satisfactory for the program evaluation and total resource costs forums where our results have been used.

It might be possible to assign NEIs to tiers based on how accurate, valid, and reliable the monetization value seems to be. For example, an NEI based upon highly statistically significant survey results combined with high quality cost estimates found in a federal database could be placed in the highest tier. An NEI based on satisfactory statistically significant survey results (i.e., $p < 0.10$) and a cost estimate published by a reputable health-related non-profit organization could fall into a second tier. NEIs underpinned by a spreadsheet model that is based upon numerous assumptions could fall into a lower tier. NEIs developed as a part of the WAP evaluation were placed in three tiers (see [23]), but ultimately all of the estimated NEIs were recommended and accepted regardless of tier.

As a penultimate observation, the framework presented herein can be used to assess and monetize NEIs for energy efficiency programs beyond low-income weatherization. For example, energy efficiency programs that install new and improved lighting in office buildings and insulation around hot pipes in industrial plants can improve productivity and reduce burns, respectively. Both outcomes can be monetized. Electrification of households can produce NEIs by eliminating emissions of natural gas and particulates from natural gas cooktops, for instance, which can produce monetizable health benefits.

Lastly, weatherization can help address energy poverty but is not a cure for energy poverty. Weatherization can yield energy cost savings and help households reduce other costs, as shown above. Saving money is vitally important but weatherization does not directly increase household incomes. However, weatherization can improve home conditions and the general health of occupants, which then could then help employed occupants miss fewer days of work from sickness, either their own or someone else's in the family. Weatherization programs can also be expanded to include solar rooftop installations which, through net metering, can be a new source of income for low-income households.

7. Conclusion and policy implications

This paper presents a generic framework for monetizing non-energy impacts that can be attributed to low-income weatherization programs specifically and other energy efficiency programs more generally. It is found that the two-element framework – measuring changes in NEI variables and then assigning dollar values to those changes derived from existing databases – is readily implementable. The resulting monetary values are on par with the typical costs for weatherizing homes and apartment units as well as with typical energy cost savings. This is still a new field of study, however. Approaches to measuring changes can be made more sophisticated, though such studies may be better supported by healthcare and other sectors beyond the energy efficiency and utility sectors. Approaches to express uncertainties in monetary estimates need the attention of future research as well.

There are several important energy policy implications of this work. The first implication is that the monetary value of household and household-related societal benefits of low-income weatherization programs can be substantial. These benefits should be recognized and incorporated into policy decisions about funding for weatherization programs. In doing so, energy efficiency programs have evidence available to invite other stakeholders into discussions about program funding.

One important stakeholder to include is healthcare. It is evident that weatherization can reduce healthcare costs in numerous manners, such as reducing emergency department visits for thermal stress and arthritis. As noted above, the benefits of weatherization to healthcare could be increased if healthcare were to refer patients with health conditions that could be ameliorated by weatherization, such as uncontrolled asthma. Serious work is needed, though, on behalf of both the energy efficiency and healthcare communities to overcome logistical and funding barriers.

Weatherization can reduce thermal stress, which suggests that weatherization can be viewed as one component of climate resiliency. In this context, energy efficiency programs can strive to collaborate more with climate resiliency and public health stakeholders to promote weatherization. Conversely, weatherization programs should be open to installing additional measures that promote climate resilience, and to working with stakeholders to fund the installation of additional measures.

Declaration of competing interest

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

Data availability

The data that has been used is confidential.

Acknowledgements

Data collection and data analyses were funded by the Tennessee Valley Authority, The JPB Foundation, and the Energy Efficiency Program Administrators of the Commonwealth of Massachusetts. Additional support for the preparation of this paper was provided by the U.S. National Institutes of Health under grant R01ES032157. We wish to acknowledge support for this research provided by NMR Group, Slipstream, and the Center for Applied Research and Evaluation at the University of Tennessee, Knoxville.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.erss.2023.103341.

References

[1] International Energy Agency, Capturing the Multiple Benefits of Energy Efficiency: Roundtable on Health and Well-Being Impacts: Summary Workshop Report, 2013 (Copenhagen, April 18–19, 2013).
[2] O. Finn, P. Brockway, Much broader than health: surveying the diverse co-benefits of energy demand reduction in Europe, Energy Res. Soc. Sci. 95 (2023), 102890.

[3] B. Tonn, D. Carroll, S. Pigg, M. Blasnik, G. Dalhoff, J. Berger, E. Rose, B. Hawkins, J. Eisenberg, F. Ucar, I. Bensch, C. Cowan, Weatherization Works, ORNL/TM-2014/338, Oak Ridge National Laboratory, Oak Ridge, TN, 2014 (September).
[4] E. Cagno, D. Moschetta, A. Trianni, Only non-energy benefits from the adoption of energy efficiency measures? A novel framework, J. Clean. Prod. 212 (2019) 1319–1333.
[5] J. Rasmussen, The additional benefits of energy efficiency investments – a systematic literature review and a framework for categorization, Energ. Effic. 10 (6) (2017) 1401–1418.
[6] S. Chatterjee, N. Rafa, A. Nandy, Welfare, development, and cost efficiency: a global synthesis on incentivizing energy efficiency measures through co-benefits, Energy Res. Soc. Sci. 89 (2022), 102666.
[7] M. Power, Fuel poverty in the USA: the overview and outlook, Energy Action (2006) 98. http://www.opportunitystudies.org/wp-content/uploads/2011/11/fuel-poverty.pdf (Accessed March 20, 2019).
[8] U.S. Energy Information Administration, One in Three U.S. Households Faces a Challenge in Meeting Energy Needs. https://www.eia.gov/todayinenergy/detail.php?id=37072, 2018.
[9] B. Boardman, Fixing Fuel Poverty: Challenges and Solutions, Earthscan, London, UK, 2010.
[10] E. Hirst, R. Goeltz, D. Trumble, Effects of the hood river conservation project on electricity use, Energ. Buildings 13 (1) (1989) 19039.
[11] M.A. Brown, L.G. Berry, R.A. Balzer, E. Faby, National impacts of the weatherization assistance program in single-family and small multifamily dwellings, in: ORNL/CON-326, Oak Ridge National Lab., TN (United States), 1993.
[12] J. Riggert, A. Oh, N. Hall, J. Reed, An Evaluation of the Energy and Non-Energy Impacts of Vermont's Weatherization Assistance Program, TecMRKT Works, Oregon, Wisconsin, 1999.
[13] L. Skumatz, J. Gardner, The Non-Energy Benefits of Wisconsin's Low-Income Weatherization Assistance Program: Revised Report, State of Wisconsin Department of Administration, Division of Energy, Madison, Wisconsin, 2005 (November).
[14] M. Schweitzer, B. Tonn, Non-energy benefits of the U.S. weatherization assistance program: a summary of their scope and magnitude, Appl. Energy 76 (2003) 321–335.
[15] N. Willand, I. Ridley, C. Maller, Towards explaining the health impacts of residential energy efficiency interventions – a realist review. Part 1: pathways, Soc. Sci. Med. 133 (2015) 191–201.
[16] D. Phillips, O. Siu, A. Yeh, K. Cheng, The impacts of dwelling conditions on older persons' psychological well-being in Hong Kong: the mediating role of residential satisfaction, Soc. Sci. Med. 60 (2005) 2785–2797.
[17] M. Gibson, H. Thomson, et al., Understanding the psychosocial impacts of housing type: qualitative evidence from a housing and regeneration intervention, Hous. Stud. 26 (4) (2011) 555e573.
[18] E. Rose, M. Marincic, B. Tonn, B. Hawkins, TVA Home Uplift Metro Areas Final Report on Non-Energy Impacts, Three3, Inc., Knoxville, Tennessee, 2022 (March).
[19] P. Howden-Chapman, N. Pierse, et al., Effects of improved home heating on asthma in community dwelling children: randomised controlled trial, Br. Med. J. 337 (2008) 1411a (Sept 23).
[20] E. Rose, B. Hawkins, B. Tonn, D. Paton, L. Shah, Exploring the Potential of Weatherization Plus Health Interventions on Asthma-related Medicaid Claims and Costs in Washington State, ORNL/TM-2015/213, Oak Ridge National Laboratory, Oak Ridge, TN, 2015 (September).
[21] S. Outcault, A. Sanguinetti, N. Dessouky, C. Magana, Occupant non-energy impact identification framework: a human-centered approach to understanding residential energy retrofits, Energy Build. 263 (2022), 112054.
[22] B. Tonn, E. Rose, M. Marincic, Cascading benefits of low-income weatherization upon health and household well-being, Build. Environ. 242 (2023), 110470.
[23] B. Tonn, E. Rose, B. Hawkins, B. Conlon, Health and Household-Related Benefits Attributable to the Weatherization Assistance Program, ORNL/TM-2014/345, Oak Ridge National Laboratory, Oak Ridge, TN, 2014 (September).
[24] B. Tonn, E. Rose, B. Hawkins, M. Marincic, Health and financial benefits of weatherizing low-income homes in the southeastern United States, Build. Environ. 197 (2021), #107847.
[25] B. Tonn, B. Hawkins, E. Rose, M. Marincic, Income, housing and health: poverty in the United States through the prism of residential energy efficiency programs, Energy Res. Soc. Sci. 73 (2021), 101945.
[26] B. Tonn, B. Hawkins, E. Rose, M. Marincic, S. Pigg, C. Cowan, Saving lives by saving energy: examining the health benefits of energy efficiency in multifamily buildings in the United States, Build. Environ. 228 (2023), 109716.
[27] F. Belaid, Z. Ranjbar, C. Massie, Exploring the cost-effectiveness of energy efficiency implementation measures in the residential sector, Energy Policy 150 (2021), 112122.
[28] B. Tonn, E. Rose, B. Hawkins, Evaluation of the U.S. Department of Energy's weatherization assistance program: impact results, Energy Policy 118 (2018) 279–290.
[29] A. Niederberger, LEDs are the new norm: are utility programs obsolete? Medium (2018) (May 3), https://medium.com/enervee/leds-are-the-new-normal-are-utility-programs-obsolete-8aa5dcf90f1f.
[30] American Council for an Energy Efficient Economy, Cost-effectiveness tests: overview of state approaches to account for health and environmental benefits of energy efficiency, December, https://www.aceee.org/sites/default/files/he-ce-tests-121318.pdf, 2018.
[31] S.S. Yoon, S.C. Macdonald, R. Parrish, Deaths from unintentional carbon monoxide poisoning and potential for prevention with carbon monoxide detectors, JAMA 279 (9) (1998) 685–687.
[32] E.P. Krenzelok, R. Roth, R. Full, Carbon monoxide… the silent killer with an audible solution, Am. J. Emerg. Med. 15 (1996) 484–486.
[33] Three3, Inc, NMR Group, Inc, Low-Income Multifamily Health- and Safety-Related NEIs Study (TXC50), Three3, Inc., Knoxville, Tennessee, 2021 (August).
[34] M. Blasnik, G. Dalhoff, S. Pigg, A. Mendyk, D. Carroll, F. Ucar, National Weatherization Assistance Program Impact Evaluation: Energy Impacts for Single Family Homes. ORNL/TM-2015/13, Oak Ridge National Laboratory, Oak Ridge, Tennessee, 2014 (September).
[35] D. Carroll, G. Dalhoff, D. Johnson, D. Bausch, M. Blasnik, Evaluation of the Weatherization Assistance Program During Program Years 2009–2011 (American Recovery and Reinvestment Act Period): Energy Impacts for Multifamily Buildings, ORNL/TM-2014/583, Oak Ridge National Laboratory, Oak Ridge, Tennessee, 2015 (January).
[36] Money and Mental Health Policy Institute, Money and Mental Health: The Facts. https://www.moneyandmentalhealth.org/money-and-mental-health-facts/.
[37] D. Gottlieb, J. Ellenbogen, M. Bianchi, C. Czeisler, Sleep deficiency and motor vehicle crash risk in the general population: a prospective cohort study, BMC Med. 16 (2018) 44.
[38] N. Bhushan, L. Steg, C. Albers, Studying the effects of intervention programmes on household energy saving behaviors using graphical causal models, Energy Res. Soc. Sci. 45 (2018) 75–80.