Weatherization + Health

Health and Climate Change Co-Benefits of Home Weatherization in Vermont

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VERMONT
DEPARTMENT OF HEALTH

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Weatherization + Health in Vermont

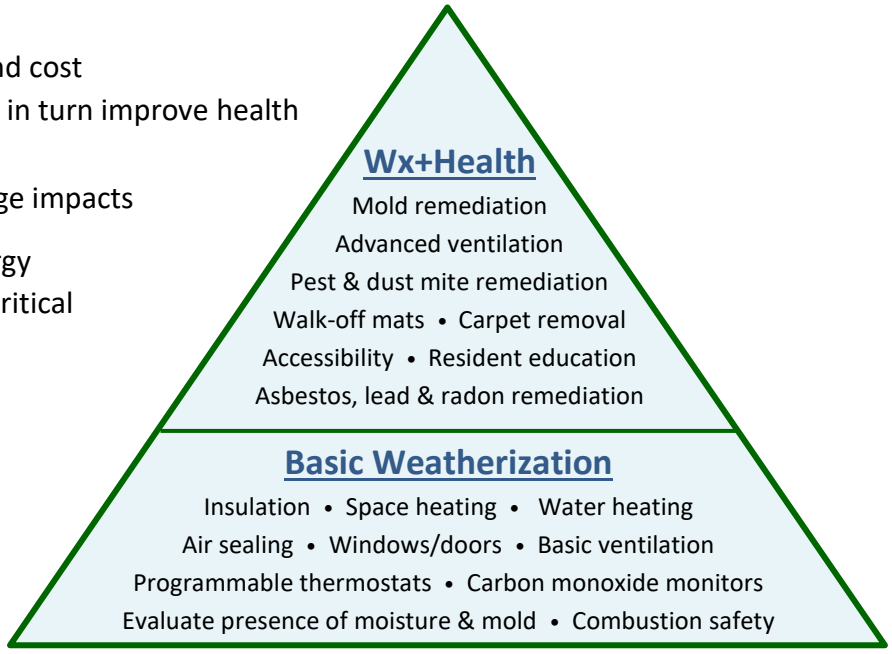
Home weatherization addresses energy, health and environmental problems

Benefits of home weatherization include:

- Reduced household energy usage and cost
- Improved housing conditions, which in turn improve health
- Reduced greenhouse gas emissions
- Increased resilience to climate change impacts

Basic weatherization (Wx) prioritizes energy efficiency improvements but can include critical health and safety improvements.

Weatherization + Health (Wx+Health) prioritizes delivery of health benefits by including specific health and safety improvements in addition to basic Wx strategies, which may be especially helpful for those with chronic health conditions or accessibility challenges.



Wx+Health builds on basic weatherization strategies

Weatherization improves home conditions that affect health

Wx improves the home

- Reduced energy bills
- Improved temperature control
- Improved indoor air quality
- Enhanced safety
- Reduced humidity
- Reduced mold
- Reduced pest intrusion

**Published evidence about the indoor environmental quality and health impacts of Wx was reviewed to identify the expected effects. The strength of evidence for each finding was based on the quality and amount of evidence available.*

Wx benefits health in many ways

Health benefits…	…are associated with these improvements to home conditions.	Strength of evidence*
General Health	$ 🌡 🏠 ⊕ 💧 ⚙ 🐞	High
Productivity	🌡 🏠 ⊕ 💧 ⚙ 🐞	High
Social Health	🌡 🏠 💧 ⚙ 🐞	High
Upper Respiratory	🌡 🏠 💧 ⚙ 🐞	High
Asthma	🌡 🏠 💧 ⚙ 🐞	Medium
Cardiovascular	🌡 🏠	Medium
Financial Stress	$ 🌡 🏠 ⊕ 💧 ⚙ 🐞	Medium
Mental Health	$ 🌡 🏠 ⊕ 💧 ⚙ 🐞	Medium
Health Care Utilization & Costs	🌡 🏠 ⊕ 💧 ⚙ 🐞	Medium
Accidental Injury	⊕	Low
Infectious Disease	🌡 🐞	Low
Neurological	💧 ⚙	Low

Weatherization in action: Vermont case studies

Referrals to Health Services

The Vermont Weatherization Assistance Program (VT WAP) provides free Wx services to income-qualifying households across Vermont. About 20 percent of its funding is used to address critical health and safety issues like electrical or combustion hazards.

VT WAP also uses One Touch, an electronic referral system that connects clients to health, housing and energy programs. The One Touch questionnaire, used during the energy audit, automatically refers clients to local partners for help with asthma management, accessibility needs, and other health-related issues.

Partnering with Hospitals

NeighborWorks of Western Vermont runs a HEAT Squad program that provides low-to-moderate income residents with low-cost energy audits and assistance in identifying, contracting, and financing Wx improvements.

The HEAT Squad began partnering with Rutland Regional Medical Center (RRMC) in 2016 to provide Wx+Health services to RRMC patients with respiratory issues and mobility limitations. Through this partnership, the HEAT Squad and RRMC deliver services that help keep residents healthy and out of the hospital.

Evaluating Health Impacts

Efficiency Vermont (EV) is a public energy efficiency utility that provides energy efficiency services and financial incentives to market-rate clients across Vermont.

EV launched a *Healthy Homes* pilot study in 2018 in partnership with Northeastern Vermont Regional Hospital (NVRH). EV and NVRH will deliver Wx+Health services to 10 low-income households with at least one person managing a chronic respiratory condition. Data will be collected from each home to evaluate the health benefits of Wx+Health services.

What weatherization can do for Vermonters' health: costs and benefits

Low Costs but Limited Funding

The current weatherization rate of 900 low-income homes each year is far below what is needed to meet the state's statutory goal of weatherizing 80,000 homes by 2020, including 20,000 low-income homes. The average cost of a VT WAP project is $8,500, and funding is one barrier to doing more.

This is a missed opportunity for low-income Vermonters, who spend more of their income on energy and whose health is more likely to be affected by asthma, cold and heat.

Substantial Benefits for Household and Public Health

Weatherizing 2,000 low-income homes in Vermont would help prevent an estimated 223 emergency department visits, 13 hospitalizations, and 0.5 deaths over a 10-year period, associated with reduced health impacts caused by asthma, cold and heat.*

Wx also benefits public health by reducing fine particulate emissions from heating systems. The estimated 10-year value of energy and health benefits is at least $24,757 per household, or about three times the initial cost. Larger benefits are expected if Wx+Health services are offered to people with existing chronic health conditions.

The estimated 10-year economic benefit per household is nearly three times greater than the initial expense.

Benefit category	Primary beneficiary	First-year benefit	10-year benefit
Thermal and electric energy cost savings	Household	$1,174	$11,740
Reduced impacts of asthma, cold, and heat*	Household	$276	$2,762
Reduced fine particulate emissions	Public	$1,026	$10,255
Total	**Household + public**	**$2,476**	**$24,757**

**More benefits are expected but could not be quantified, such as better mental and social health, fewer accidental injuries, and increased productivity.*

Visit **healthvermont.gov/climate** to learn more about these findings and estimated impacts.

1. Introduction

The purpose of this technical report is to summarize published and local evidence about the potential health co-benefits of building weatherization strategies. By improving the home's thermal envelope, ventilation, and electrical efficiency, the primary goal of weatherization retrofits is to increase building energy efficiency and reduce household thermal and electrical energy usage, thus lowering energy demand and household costs. Weatherization can also produce substantial non-energy benefits and is increasingly being recognized as an important strategy for addressing health and environmental problems. One of the goals of Vermont's 2016 Comprehensive Energy Plan is to "improve the health of indoor environments and reduce energy bills through improved building weatherization."

Building heating accounts for about 30% of all energy consumption in Vermont, with the average Vermont household spending between $1,500 and $2,000 per year on heating costs (PSD 2016). With nearly 80,000 homes in Vermont constructed before 1940, there are substantial opportunities for weatherization to improve building efficiencies and reduce energy costs. The Vermont legislature adopted a goal in 2007 to weatherize 25% of the state's housing stock, or approximately 80,000 housing units, by the year 2020, including 20,000 low-income homes. The rate of weatherization has slowed in recent years, largely due to decreased funding, leaving the state on pace to fall well short of meeting its goal. Wait times for the Vermont Weatherization Assistance Program typically range from 6-18 months. About 2,000 homes are currently weatherized each year (including about 900 low-income homes) through the efforts of the Vermont Weatherization Assistance Program, energy efficiency utilities, and other service providers.

Weatherization Overview

Home weatherization retrofits begin with an energy audit in which trained professionals comprehensively assess the home to determine the weatherization and electrical strategies that would be most appropriate and cost effective for improving energy efficiency. The audit delivers a customized list of cost-effective weatherization interventions for that home. Common weatherization strategies considered in Vermont are listed in Table 1.1.

Table 1.1. Common basic weatherization strategies in Vermont.

Mechanical	Building Shell	Critical Health & Safety	Additional Strategies
• Repair/replace heating & cooling systems • Repair/replace duct work, including air sealing and insulation • Repair/replace water heaters, including insulation needs • Install programmable thermostat	• Repair roof/wall leaks • Perform air sealing • Install insulation • Repair windows & doors	• Safety testing and repair of heating system & combustion appliances • Install/repair/replace ventilation systems to protect indoor air quality • Install/replace smoke & carbon monoxide detectors • Evaluate presence of mold & moisture levels, lead, asbestos, and knob & tube wiring	• Install energy efficient lighting and low-flow showerheads • Replace appliances with energy efficient models • Basic residential education regarding energy use, hazards of indoor air quality, safe use of equipment • Referrals to other needed programs and resources

While weatherization does directly address some critical health and safety issues, delivery of health benefits is typically not the primary focus of weatherization projects. Regardless, it is commonly understood that housing conditions affect the health of the occupants. For example, a lack of appropriate indoor temperature control, inadequate ventilation, and the presence of mold or pests can lead to adverse health outcomes including thermal discomfort, asthma and other respiratory illness, infectious disease, and detrimental effects on mental health (CDC 2006). Weatherization provides incidental benefits to health by addressing some of these housing deficiencies. Home weatherization was recently identified by the Centers for Disease Control as a recommended intervention in their Health Impact in 5 Years (HI-5) initiative, due to evidence of positive health impacts, results within five years, and cost effectiveness over the lifetime of the population served (CDC 2018).

Weatherization + Health

Weatherization + Health (Wx+Health) is a wholistic approach that prioritizes delivery of health benefits through weatherization and other building improvement services. This approach aims to deliver additional services during weatherization that will further enhance occupant health and safety beyond those typically addressed by basic weatherization (see Figure 1.1, next page).

The health and safety benefits of basic weatherization are most often either byproducts of energy efficiency improvements that address air movement, humidity, and temperature control, or are otherwise necessary as a prerequisite to providing other weatherization services, such as mitigating electrical hazards or improper ventilation of combustion appliances. Wx+Health services may include health and safety strategies not typically associated with energy efficiency improvements, such as removing asthma triggers like bedroom carpeting, remediating toxic hazards such as asbestos, lead, and radon, or making home accessibility improvements including mitigation of trip and fall hazards (see Table 1.2 below).

Table 1.2. Common strategies included in Weatherization + Health programming (Wilson et al. 2016, Opportunity Council, E4TheFuture)

Weatherization + Health Strategies	
• Advanced ventilation (kitchen, bath, whole-house)	• Removal of dust mite habitats
• Removal & remediation of mold & moisture	• Distribution of HEPA vacuums
• Lead hazard remediation	• Walk-off mats
• Radon testing & mitigation	• Mattress covers
• Pest exclusion	• Accessibility-related repairs & installations
• Carpet removal, floor replacement	• Advanced resident education
	• Housing policies (e.g. no smoking indoors)

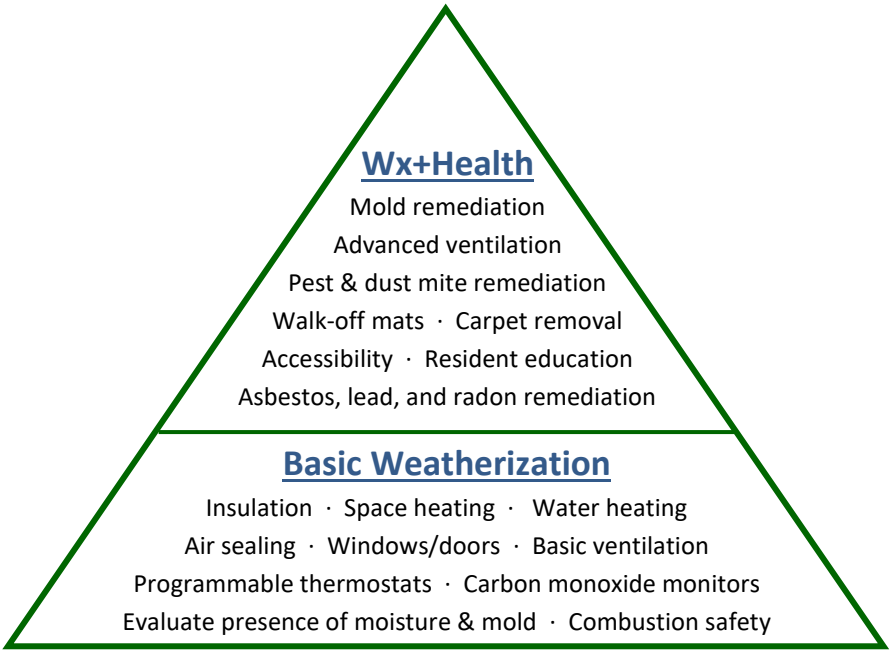


Figure 1.1. The energy efficiency techniques of traditional weatherization create a foundation on which Wx+Health builds to create a wholistic approach to enhancing health and safety of the home.

Weatherization, Health, and Climate Change

Climate change is expected to worsen negative health impacts associated with indoor temperature extremes (especially hotter temperatures), humidity, flooding, and periods of poor air quality (IOM 2011). As such, weatherization also serves as a climate change adaptation strategy by helping to reduce the increased risks of housing-related health impacts exacerbated by climate change. Home weatherization and energy efficiency improvements are also important strategies for reducing greenhouse gas emissions, helping to reduce the severity of climate change and associated health impacts.

2. Literature Review Methods and Interpretation

Methods

A review of the literature was performed to assess the potential health co-benefits of weatherization. While not intended to be exhaustive, the review did attempt to gather sufficient evidence of the state of knowledge regarding causal links between weatherization strategies and associated health co-benefits. The review emphasized primary research (articles or documents reporting original research or findings by the original author) and secondary reviews (sources that compile, interpret, and analyze a set of original findings) published in peer-reviewed, scientific journals. Secondary reviews were identified first to synthesize a broad array of research findings, with additional collection and review of primary research to identify newer research and to address topics not adequately covered in the secondary reviews.

Some additional reports and articles were included in the literature review if they were published by reputable organizations, such as reports by government organizations and practitioners in the fields of energy efficiency and health (commonly referred to as "gray literature"). These types of reports often undergo extensive scrutiny and peer-review by colleagues and partners, but not through the formal process used by scientific journals.

Electronic public health and medical journal databases, primarily PubMed, were searched using keywords such as "(energy efficiency) and health" and similar variations. Evidence was eligible for inclusion based on the premise that the energy efficiency interventions used in the study were related to either basic weatherization or Wx+Health, including "green" construction and renovation. The weatherization strategies referenced in a study were assessed to determine whether the study more closely aligned with basic weatherization or with Wx+Health (see Figure 1.1). Studies were limited to those occurring in the United States or other high-income countries.

Evaluation of Confidence and Direction of Effect of a Finding

The reviewed evidence was grouped into categories of indoor environmental quality components affected by housing conditions (e.g., air quality, moisture) and health outcomes (e.g., asthma, cardiovascular). Within each impact category, two metrics were evaluated to summarize the evidence: the direction of effect and confidence level in the finding. These metrics are described further below. Tables summarizing the metrics for each impact category can be found in Appendix 1 and Appendix 2.

Direction of Effect

The direction of effect refers to the association, either positive (+) or negative (–), between the weatherization intervention and the outcome in question (either indoor environmental quality or a health outcome). This indicator reflects the consensus finding (if any) from the reviewed evidence. Within each impact category, each literature source that addressed the impact was assessed as either finding a positive (+), negative (–), or null (0) association with the outcome. Where a study evaluated multiple, related outcomes within the same impact category, the predominant conclusion was reported, and any discrepancies were noted in the evidence summary table.

An effort was made to avoid identifying and double-counting evidence from primary studies that was also included in a secondary review, though this could not entirely be avoided. It is also possible that multiple secondary reviews included some of the same primary studies. The direction of effect was evaluated separately for primary and secondary sources before combining them into an overall assessment.

+ Positive	– Negative	0 Inconclusive
Available evidence suggests a positive association between the weatherization intervention and outcome, indicating an improvement in health or indoor environmental quality outcome following the intervention.	Available evidence suggests a negative association between the weatherization intervention and outcome, indicating a worsening in health or indoor environmental quality outcome following the intervention.	Available evidence is inconclusive, either due to small study sample sizes, non-significant analytical findings, mixed results, or other research design shortcomings.

Confidence Level

The assessment of confidence in the research findings takes into consideration the number of studies and the quality of the evidence for each outcome. Quality considerations include research design of the original studies, if the article was peer-reviewed, and if the conclusions for an outcome were drawn only from individual primary studies or also validated by secondary review articles. Three especially high-quality, peer-reviewed studies were identified, and their findings were given extra consideration (Thomson et al. 2013, Maidment et al. 2014, Willand et al. 2015). The confidence level assessment ranged from low confidence (limited or inconclusive evidence) to high confidence (strong, consistent evidence).

High	Medium	Low
Multiple sources; consistent results among peer-reviewed studies; strong consensus between primary studies and secondary reviews; strong evidence for intervention to produce outcome.	Several sources; consistent results but few peer-reviewed studies; secondary reviews are based on few studies or do not exist; moderate evidence for intervention to produce outcome.	Few sources; inconsistent or inconclusive findings across studies; intervention may be logically plausible to produce outcome, but more research is needed.

3. Environmental Determinants of Health Related to Housing

Much research has demonstrated that building characteristics can affect the health of its occupants (IOM 2011, Morley et al. 2011). Researchers at the Harvard T.H. Chan School of Public Health recently identified the "9 Foundations of a Healthy Building", as shown below in Figure 3.1 (Allen et al. 2017).

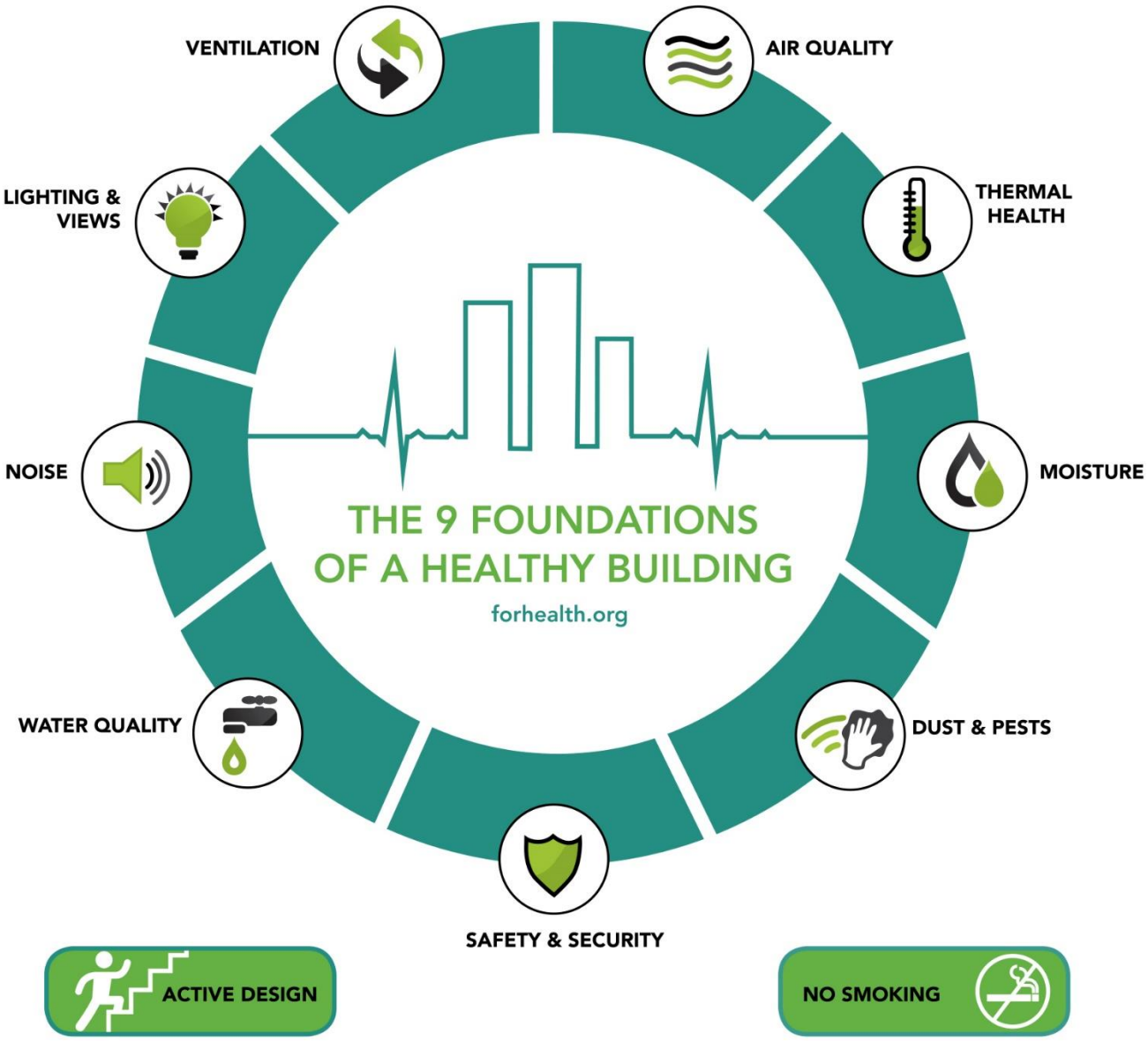


Figure 3.1. The "9 Foundations of a Healthy Building" (Allen et al. 2017).

Weatherization can provide health benefits by modifying the indoor environmental conditions that affect health, comfort, and quality of life. Most of the reviewed studies reported on the impacts of one or more changes to indoor environmental conditions that were related to health outcomes of interest, including temperature; levels of humidity, dampness or moisture levels within the unit; presence of mold; presence of pests; other allergens; and measures of air quality including levels of carbon monoxide, radon, formaldehyde, and others.

Tables summarizing the evidence and literature review informing the assessment of direction of effect and confidence level for the impact of weatherization interventions on indoor environmental quality measures can be found in Appendix 1.

Temperature

Studies reporting change in temperature after weatherization unanimously found significant improvements in thermal comfort inside the home, generally defined as the improved ability to maintain comfortable indoor temperatures, particularly during periods of extreme heat or cold (Tonn et al. 2014, Wilson et al. 2014, Rose et al. 2015, Willand et al. 2015, Wilson et al. 2016, Poortinga et al. 2018). Two studies specifically assessed occupant satisfaction regarding indoor temperatures after weatherization and electrical efficiency measures, finding that fewer occupants reported uncomfortable temperatures following weatherization (Rose et al. 2015) and that occupant comfort and satisfaction with indoor temperature following retrofit was positively associated with the measured temperature of the unit (Haverinen-Shaughnessy et al. 2018).

Uncomfortable indoor temperatures, whether excessively hot or cold, have been associated with poor general health, respiratory illness, cardiovascular disease, and poor mental and social health (Krieger and Higgins 2002, Wilkinson et al. 2009, Milner et al. 2012, Gillespie-Bennett et al. 2013). One recent study found that individuals with chronic obstructive pulmonary disease reported worse respiratory symptoms and increased rescue inhaler use on days with higher indoor temperatures (McCormack et al. 2016).

In addition to thermal comfort, better temperature control also results in lower relative humidity and reduced problems with condensation and dampness, and subsequently, mold (Willand et al. 2015).

Table 3.1. Summary assessment of weatherization impacts on indoor temperatures

Housing Characteristic	Impact of Wx Intervention	Direction of Effect	Confidence	Related Health Outcomes
Indoor Temperature	Improvements in indoor temperature and thermal comfort	+	High	General health, respiratory health, cardiovascular health, mental health

Humidity

Studies reporting change in humidity levels, dampness, or moisture levels after weatherization intervention largely found significantly improved conditions (Takaro et al. 2011, Jacobs et al. 2014, Tonn et al. 2014, Wilson et al. 2014, Jacobs et al. 2015, Rose et al. 2015, Willand et al. 2015, Francisco et al. 2016, Wilson et al. 2016). A few studies reported occasional findings of increased humidity or new mold growth following renovations (Willand et al. 2015, Wilson et al. 2016, Breysse et al. 2015). These negative impacts were usually attributed to either insufficient ventilation or venting in humid air without dehumidifying it. Both issues can be avoided through appropriate design of an energy-efficient ventilation system and installation of an efficient dehumidifier if needed.

Damp indoor spaces are associated with upper respiratory symptoms and increases in asthmatic symptoms among people with asthma (IOM 2004), recurrent headaches (Krieger and Higgins 2002), and negative effects on mental health (Krieger and Higgins 2002, Liddell and Guiney 2015). In addition

to the direct impacts of humidity on health, high humidity levels can also lead to mold growth and dust mites within the unit, causing additional health impacts (IOM 2004, Willand et al. 2015). Excess moisture may also promote the release of toxic chemicals from building materials and furnishings within the unit (IOM 2004).

Table 3.2. Summary assessment of weatherization impacts on indoor humidity

Housing Characteristic	Impact of Wx Intervention	Direction of Effect	Confidence	Related Health Outcomes
Humidity, Dampness & Moisture Levels	Improvements in measures of humidity, with some findings of worsening humidity due to insufficient ventilation or high outdoor humidity	+	High	General health, respiratory health, neurological health, mental health

Mold

Similar to the reported reduction in humidity levels, findings largely indicated a significant reduction in the presence of mold following weatherization (Takaro et al. 2011, Jacobs et al. 2014, Tonn et al. 2014, Rose et al. 2015, Willand et al. 2015, Wilson et al. 2016). Several review authors reported occasional contradictory results of new mold growth following the intervention (Willand et al. 2015, Wilson et al. 2016). As with the occasional findings of increased relative humidity, new mold growth was typically attributed to inadequate ventilation, and can be avoided.

The presence of mold is associated with overall poor health, including respiratory symptoms, neurological symptoms such as headaches, gastrointestinal symptoms such as nausea and vomiting, and other symptoms including fever and sore throat (Krieger and Higgins 2002, IOM 2004, Gillespie-Bennett et al. 2013).

Table 3.3. Summary assessment of weatherization impacts on mold

Housing Characteristic	Impact of Wx Intervention	Direction of Effect	Confidence	Related Health Outcomes
Mold	Reductions in mold result from better control of humidity levels	+	High	General health, respiratory health, neurological health

Air Quality

Building-level interventions, such as air sealing and ventilation improvements, can affect the concentrations of various airborne pollutants inside the home (IOM 2011). Studies reported on a wide range of different airborne pollutants, largely finding significant reductions in airborne pollutants and subsequent improvement in air quality following weatherization (Breysse et al. 2011, Frey et al. 2014, Breysse et al. 2015, Francisco et al. 2016, Wilson et al. 2016). Airborne pollutants addressed included carbon monoxide, carbon dioxide, nitrogen dioxide, formaldehyde, radon, and environmental tobacco smoke. One review within gray literature indicated a small number of studies that reported increases in carbon dioxide, nitrogen dioxide, formaldehyde and radon following weatherization (Wilson et al. 2016). The authors attributed these air quality problems to either insufficient ventilation or "over-tightening" a house, though over-tightening is rarely a concern using current standard practices.

Indoor air pollutants, such as those listed above, are associated with a wide array of acute and chronic health conditions, ranging from immediate eye, nose and throat irritation, headaches, dizziness, and fatigue to more long-term effects following repetitive exposure such as respiratory diseases, cardiovascular disease and cancer (EPA 2018).

Table 3.4. Summary assessment of weatherization impacts on indoor air quality

Housing Characteristic	Impact of Wx Intervention	Direction of Effect	Confidence	Related Health Outcomes
Air Quality	Reductions in levels of numerous airborne pollutants, with some increases possible due to substandard ventilation practices	+	High	General health, respiratory health, cardiovascular health

Pests

Pests such as rodents, cockroaches, and dust mites are considered allergen and asthma triggers, and some can spread infectious diseases (CDC 2006). Some studies observed changes in the presence of pests following weatherization, reporting significant reductions or elimination in pests due to weatherization strategies such as air sealing (Breysse et al. 2011, Takaro et al. 2011, Jacobs et al. 2014, Tonn et al. 2014, Jacobs et al. 2015, Wilson et al. 2016). A reduction or elimination in the presence of pests also contributes to a reduction in pesticide use, further reducing human exposure to toxic chemicals (Breysse et al. 2011, Jacobs et al. 2014, Jacobs et al. 2015).

Table 3.5. Summary assessment of weatherization interventions on presence of pests

Housing Characteristic	Impact of Wx Intervention	Direction of Effect	Confidence	Related Health Outcomes
Pests	Improvements in presence of pests and pest-related allergens	+	High	General health, respiratory health

4. Health Benefits of Weatherization

Three especially high-quality, peer-reviewed studies were identified and summarized directly below (Thomson et al. 2013, Maidment et al. 2014, Willand et al. 2015).

In 2013, Thomson et al. completed a Cochrane systematic review of 39 studies on the health and socio-economic impacts of housing improvements. They found a high degree of heterogeneity in study methods, making meta-analyses or syntheses across studies very challenging. They reported that warmth and energy efficiency interventions can lead to improvements in general health, respiratory health, and mental health, especially when the intervention targeted homes with inadequate warmth and individuals with existing chronic respiratory disease. They also found that warmth improvements helped to increase usable space, privacy, and social relationships, while reducing absences from school and work. They noted few reports of adverse health impacts following housing improvements.

In 2014, Maidment et al. conducted a meta-analysis of 36 individual research studies that involved over 33,000 weatherization recipients. The authors found that "household energy efficiency interventions led to a small but significant improvement in the health of residents." They found that low-income recipients of weatherization services exhibited greater improvements in health, and that more recent studies showed larger health improvements, which they attributed to improvements in interventions and targeting of those most in need. The authors found detrimental effects in very few studies.

In 2015, Willand et al. conducted a systematic review of 28 studies on the health impacts of residential energy efficiency interventions. They found that improved warmth and lowered relative humidity provided benefits for cardiovascular and respiratory health. They also found that energy efficiency improvements resulted in higher perceived autonomy and enhanced social status, increasing feelings of the house as a "safe haven." Psychosocial benefits appeared more related to satisfaction with the home than with financial savings. They also found that negative health impacts were rare.

Findings for specific health outcomes are summarized below. Tables summarizing the evidence and literature review informing the assessment of the confidence level and direction of effect for the impact of weatherization interventions on health outcomes can be found in Appendix 2.

General Health

Evidence across numerous studies and reviews indicates that the health benefits of weatherization and Wx+Health are positive and valuable. Studies often measured improvements in general health as a category including various aspects of health such as physical health, mental health, sleep quality, and quality of life. A number of studies and reviews indicated significant improvements in general health due to both weatherization and Wx+Health (Breysse et al. 2011, Thomson et al. 2013, Jacobs et al. 2014, Colton et al. 2015, Jacobs et al. 2015, Thomson and Thomas 2015, Willand et al. 2015, Ahrentzen et al. 2016, Francisco et al. 2016, Wilson et al. 2016, Tonn et al. 2018). Further, one meta-analysis of thirty-six studies investigating the effect of household energy efficiency on health and well-being concluded that weatherization has a significant improvement on health (Maidment et al. 2014).

Table 4.1. Summary assessment of weatherization and Wx+Health impacts on general health

Health Outcome	Finding	Direction of Effect	Confidence	Related Housing Conditions
General health	Improvements in measures of general health, including physical health, mental health, sleep quality and quality of life	+	High	Indoor temperature, humidity, mold, air quality, pests

Asthma

Asthma symptom severity consistently improved in response to Wx+Health interventions (Breysse et al. 2011, Takaro et al. 2011, Colton et al. 2015, Jacobs et al. 2015, Wilson et al. 2016). A 2014 study of an in-home asthma intervention for children in Washington with poorly-controlled asthma found that 29 percent reported having poorly controlled asthma after receiving Wx+Health services and an in-home education program, compared to 52 percent that only received the in-home education program (Breysse et al. 2014).

The impact of basic weatherization services on asthma was less clear, largely because only a relatively small percentage of weatherization recipients reported having asthma. In the national weatherization evaluation with nearly 1900 participants, only 16 percent reported currently having asthma (Tonn et al. 2014). The Cochrane review generally reported improvements in asthma symptoms, but most findings were not statistically significant (Thomson et al. 2013). One weatherization study indicated a worsening of asthma symptoms following weatherization, although the same study also found contradictory findings in reporting a reduction in use of rescue asthma medication (Wilson et al. 2014). A second study found that emergency room visits and hospitalizations for asthma decreased following weatherization, but the result was not statistically significant, largely due to a small sample size (Tonn et al. 2014).

Weatherization plus health is expected to provide similar benefits for reducing severity and improving control of chronic obstructive pulmonary disease (COPD), but this connection has been minimally evaluated to-date (Osman et al. 2010, De Souza et al. 2018).

Asthma is associated with higher healthcare costs and days missed from school or work (Gillespie-Bennett et al. 2013), and some reported asthma improvements were based on a reduction in self-reported school or work days lost due to asthma symptoms (Jacobs et al. 2015). Having asthma increases the risk for developing COPD (Salvi et al. 2009), and COPD is associated with more health care utilization, higher treatment costs, and about 30 times more early deaths than asthma (VDH 2018).

Table 4.2. Summary assessment of weatherization and Wx+Health impacts on asthma

Health Outcome	Finding	Direction of Effect	Confidence	Related Housing Conditions
Asthma	Reduction in frequency of experiencing asthma symptoms, symptom severity, asthma attacks and use of medication	+	Medium	Indoor temperature, humidity, mold, air quality, pests

Upper Respiratory

Studies investigating symptoms of upper respiratory illness consistently found a significant positive association between weatherization and a reduction of symptoms for hay fever, respiratory allergies and sinusitis (Breysse et al. 2011, Thomson et al. 2013, Wilson et al. 2014, Jacobs et al. 2015, Willand et al. 2015, Wilson et al. 2016, Haverinen-Shaughnessy et al. 2018). A 2011 study of Minnesota residents in a low-income, multi-family apartment building that received services similar to Wx+Health (renovation using Enterprise Green Community standards) reported significant reductions in the percentage of adults and children reporting non-asthma respiratory conditions immediately post-renovation (Breysse et al. 2011). The Cochrane review indicated that respiratory improvements were more common when the intervention specifically targeted those with chronic respiratory issues (Thomson et al. 2013).

Table 4.3. Summary assessment of weatherization and Wx+Health impacts on upper respiratory symptoms

Health Outcome	Finding	Direction of Effect	Confidence	Related Housing Conditions
Upper Respiratory Illness	Reductions in upper respiratory symptoms, including hay fever, sinusitis, and respiratory allergies	+	High	Indoor temperature, humidity, mold, air quality, pests, other allergens

Cardiovascular

Few studies addressed potential associations between weatherization and measures of cardiovascular health. These studies indicated improvements in measures of cardiovascular health, including blood pressure and presence of hypertension and angina (Wilson et al. 2014, Jacobs et al. 2015, Willand et al. 2015, Wilson et al. 2016). A 2014 study of 248 homes across Boston, Chicago and New York City found that 18 percent of responding adults reported an improvement in hypertension or no longer having hypertension following weatherization (Wilson et al. 2014).

Table 4.4. Summary assessment of weatherization and Wx+Health impacts on cardiovascular health

Health Outcome	Finding	Direction of Effect	Confidence	Related Housing Conditions
Cardiovascular	Improvements in cardiovascular health, such as hypertension	+	Medium	Indoor temperature, air quality

Neurological

Few studies addressed neurological symptoms, but some did indicate improvements in symptoms such as recurring headaches following weatherization (Jacobs et al. 2015, Francisco et al. 2016, Wilson et al. 2016). A 2017 study of 42 families of low-income in Indiana and Illinois reported that 31 percent fewer children experienced frequent or severe headaches after weatherization (Francisco et al. 2016).

Table 4.5. Summary assessment of weatherization and Wx+Health impacts on neurological symptoms

Health Outcome	Finding	Direction of Effect	Confidence	Related Housing Conditions
Neurological	Reduction in frequency of headaches	+	Low	Humidity, mold

Infectious Disease

Poor housing conditions are associated with increased viral transmission due to pest intrusion (Krieger and Higgins 2002) and residential crowding for warmth (Gillespie-Bennett et al. 2013). Since weatherization helps to eliminate pests and reduce the need to crowd for warmth, researchers expect weatherization to help decrease disease transmission (Gillespie-Bennett et al. 2013). Only two studies were identified that evaluated weatherization impacts on infectious diseases, both finding reduced symptoms of occurrence of cold or flu (Howden-Chapman et al. 2007, Tonn et al. 2014). One study in gray literature reported a significant reduction in the number of occupants that experienced common cold symptoms lasting more than 14 days following weatherization (Tonn et al. 2014).

Table 4.6. Summary assessment of weatherization and Wx+Health impacts on infectious disease

Health Outcome	Finding	Direction of Effect	Confidence	Related Housing Conditions
Infectious Disease	Reduction in frequency of common cold symptoms	+	Low	Indoor temperature, pests

Accidental Injury

Poor housing conditions can increase risk of accidental injury, including trips, falls, burns and electrocutions (Krieger and Higgins 2002, Gillespie-Bennett et al. 2013). Only one study was identified that evaluated the change in accidental injuries following a Wx+Health intervention. A 2015 study of a low-income apartment building for elderly residents in Minnesota found a 62 percent reduction in the number of residents reporting falls in the past year following the intervention (Breysse et al. 2015).

Although most of the reviewed literature regarding weatherization did not address accidental injury or accessibility issues, published evidence for the effectiveness of programs designed to prevent trip and fall injuries through hazard identification and remediation in the home suggests that providing these services through Wx+Health interventions could provide substantial additional health benefits for older and disabled residents (Chase et al. 2012, Pynoos et al. 2012, CDC 2015).

Table 4.7. Summary assessment of weatherization and Wx+Health on accidental injury

Health Outcome	Finding	Direction of Effect	Confidence	Related Housing Conditions
Accidental Injury	Reduction in frequency of trips and falls	+	Low*	Household health and safety hazards

*This metric would be "High" confidence if based only on the published evidence that home interventions are effective at reducing accidental injuries. However, in nearly all cases the injury prevention intervention was offered independently of weatherization. Assigning "Low" here is due to identifying only one study where injury prevention was offered and assessed as part of a Wx+Health intervention.

Mental Health

Studies reporting measures of changes in mental health consistently indicated significant improvement following weatherization (Thomson et al. 2013, Breysse et al. 2015, Jacobs et al. 2015, Willand et al. 2015, Francisco et al. 2016, Wilson et al. 2016). Living in housing units with excessive indoor temperatures, high levels of humidity and presence of mold can impact mental health (Krieger and Higgins 2002, Wilkinson et al. 2009, Milner et al. 2012). Mental health improvements are likely to be

mediated by comfort and psychosocial factors, including issues surrounding financial stress or physical health issues (Willand et al. 2015).

The selected drivers of these improvements varied by study, as some authors indicated improvements in mental health due to less stress associated with improved financial stress (Liddell and Guiney 2015, Willand et al 2015, Hernandez et al. 2016). Others indicated that improvements were associated with better general health, reductions in specific health issues or improved sleep quality (Jacobs et al. 2015, Breysse et al. 2015). Still others attributed improvements in mental health to a mixture of these factors (Willand et al. 2015, Hernandez et al. 2016, Wilson et al. 2016, Poortinga et al. 2018). For example, occupants with lower fuel bills often have more money to allocate to food and prescriptions, alleviating the stress of these responsibilities as well as improving physical health (Frank et al. 2006).

Table 4.8. Summary assessment of weatherization and Wx+Health impacts on mental health

Health Outcome	Finding	Direction of Effect	Confidence	Related Housing Conditions
Mental Health	Improvements in mental health, well-being and feelings of psychological distress	+	Medium	Indoor temperature, humidity, mold, air quality, pests

Social Health

Social health, the ability to form satisfying interpersonal relationships and comfortably navigate different social situations, is likely to be closely related to improvements in mental health, as stress can be a significant threat to healthy relationships. Studies investigating various measures of social health reported significant improvements following weatherization (Jacobs et al. 2015, Poortinga et al. 2018). Evidence indicates that comfortable, affordable housing such as that made possible by weatherization may promote improved social health, including improved social relationships (Thomson and Thomas 2015). One review specifically indicated that weatherization improvements can enrich the meaning of the home to the residents, leading to increased autonomy and improved social functioning due to increased privacy from other household members and a perception of better safety (Willand et al. 2015).

Table 4.9. Summary assessment of weatherization and Wx+Health impacts on social health

Health Outcome	Finding	Direction of Effect	Confidence	Related Housing Conditions
Social Health	Improvements in social functioning, perceptions of safety and meaning of the home	+	High	Indoor temperature, humidity, mold, air quality, pests

Productivity

Weatherization is expected to increase household productivity, specifically reductions in number of days missed from school or work, by way of improved health conditions. Studies investigating this indicated fewer days of school or work missed, or fewer days kept from usual activities following weatherization (Thomson et al. 2013, Tonn et al. 2014, Colton et al. 2015, Willand et al. 2015, Haverinen-Shaughnessy et al. 2018). The Cochrane review identified three studies reporting reduced

school days missed following weatherization, including one in which asthmatic children missed seven fewer days per 100 school days after housing energy efficiency improvements (Thomson et al. 2013).

Further, additional effects of educational attainment and productivity, including higher educational aspirations and academic achievements, following the increased comfort of the home were indicated by one review (Willand et al. 2015). Housing units were also found to be easier to clean following weatherization retrofits (Breysse et al. 2011). Occupant satisfaction with the current state of home repair and number of housing problems that need addressing was also associated with weatherization (Poortinga et al. 2018).

Table 4.10. Summary assessment of weatherization and Wx+Health impacts on productivity

Health Outcome	Finding	Direction of Effect	Confidence	Related Housing Conditions
Productivity	Improvements in days missed from school, work or usual activities	+	High	Indoor temperature, humidity, mold, air quality, pests

Financial Stress

Reduced household expenditures on energy costs following weatherization can indirectly have a positive effect on health outcomes (Milner et al. 2012, Willand et al. 2015, Poortinga et al. 2018). As energy prices and costs increase, residents are often faced with making a choice between buying necessities, such as groceries and medications, and spending money to pay utility bills, often referred to as the "heat or eat" dilemma (Krieger and Higgins 2002, Frank et al. 2006, Hernandez et al. 2013, Tonn et al. 2018). For example, research has revealed that pregnant women facing the heat or eat dilemma often have a higher percentage of low birth weight babies (Frank et al. 2006). Occupants with lower fuel bills often have more money to allocate to food and medications, alleviating the stress of these responsibilities as well as improving physical health (Frank et al. 2006, Poortinga et al. 2018). Further, enhanced financial stability following weatherization may lead to the reduction of households using short-term, high-interest loans, further improving the household's financial situation (Tonn et al. 2014).

Table 4.11. Summary assessment of weatherization and Wx+Health impacts on financial stress

Health Outcome	Finding	Direction of Effect	Confidence	Related Housing Conditions
Financial Stress	Improvements in ability to pay for necessities such as prescription medication and groceries	+	Medium	Household energy and fuel costs

Healthcare Utilization and Costs

Several primary, peer-reviewed studies indicated a decrease in healthcare utilization following weatherization (Takaro et al. 2011, Colton et al. 2015, Jacobs et al. 2015). A 2011 study investigating the asthma-control benefit of moving children into "breathe-easy" homes designed for residents with asthma reported that 41 percent fewer children made an asthma-related urgent care visit following relocation plus in-home asthma education (Takaro et al. 2011). A 2015 study comparing health of Boston residents in low-income green and conventional multi-family homes reported that asthmatic

children in green homes were less likely to experience asthma-related hospital visits after moving into green homes, though no difference was found for adults (Colton et al. 2015).

One gray literature review assessed 16 studies that addressed healthcare utilization and reported that 44 percent of studies indicated decreased healthcare utilization, while the remaining studies were inconclusive; no studies indicated increases in healthcare utilization (Wilson et al. 2016). One specific gray literature study of weatherization impacts in low-income households with asthmatic residents found that asthma-related emergency room visits decreased by 59 percent and hospitalizations by 38 percent following weatherization (Tonn et al. 2014).

Study of the costs of healthcare utilization following weatherization are largely limited to two primary gray literature studies conducted by the United States Department of Energy. One study indicated that residents are better able to afford medical bills following weatherization as resident-estimated household out-of-pocket expenses decreased by an average of $514/household (Tonn et al. 2014). The second study indicated that annualized asthma-related Medicaid costs significantly declined by $421 following weatherization or Wx+Health (Rose et al. 2015).

Table 4.12. Summary assessment of weatherization and Wx+Health impacts on healthcare utilization and costs

Health Outcome	Finding	Direction of Effect	Confidence	Related Housing Conditions
Healthcare Utilization and Costs	Reductions in healthcare utilization, such as emergency department visits and hospitalizations, and associated costs	+	Medium	Indoor temperature, humidity, mold, air quality, pests

Monetization of Health and Household Benefits

Attempts to monetize the non-energy benefits of weatherization are limited to an observational evaluation of the National Weatherization Assistance Program (WAP) conducted by the United States Department of Energy. The primary evaluation reported total health and household-related benefits/household of $14,148 per weatherized unit (present value over 10-year time horizon, 2013 dollars) (Tonn et al. 2018). These health and household-related benefits, not including any energy cost savings or environmental and water benefits, simplify to $2.78 in non-energy benefits per $1 invested in weatherization.

The population of this study consisted of 828 occupants of low-income, single-family detached and mobile homes, that received weatherization services and completed initial and follow-up surveys. Ninety-nine of these participants reported having diagnosed asthma and completed asthma-specific surveys. The sample included a treatment group that was evaluated before and after weatherization and a comparison group that was evaluated one-year post-weatherization and again 12-18 months later. The authors categorized non-energy benefits into three tiers according to the amount of uncertainty underlying the estimates, as determined by the authors. Tier 1 estimates were considered to have the most certainty, while Tier 3 estimates had the least amount of certainty:

- Tier 1: reduced asthma symptoms; reduced cold-related thermal stress; reduced heat-related thermal stress; food assistance reduction; fewer missed work days

- Tier 2: reduced carbon monoxide poisoning; improvement of prescription adherence; reduced use of short-term, high-interest loans
- Tier 3: reduced home fires; increased productivity at work due to improved sleep; increased productivity at home due to improved sleep; reduction in low-birth weight babies from heat-or-eat dilemma

A follow-up study for the state of Massachusetts analyzed a cold-climate state subset of the National WAP data. A similar methodology to the one described above for monetizing health benefits was used, with some modifications to cost estimates to better represent conditions in Massachusetts (Hawkins et al. 2016). The authors monetized benefits for only eight of the 13 impact categories included in the national study, choosing to focus on the impacts that most directly affected household members (as opposed to costs that would be borne more by society at large). The study reported total health and household-related benefits of $25,848 per weatherized unit (present value over a 20-year time horizon, 2016 dollars), or a $1,382 annual per unit benefit.

5. Weatherization and Wx+Health in Vermont

Weatherization and energy efficiency have long been identified as important strategies to increase housing affordability for low-to-moderate income Vermonters. Vermonters living in households of low-income are more likely to live in housing with insufficient insulation and air sealing and inefficient HVAC systems and water heaters. Low-income households spend a larger percent of their household budget on utility costs than medium-to-high income households.

A 2013 assessment indicated that roughly 125,000 Vermonters live in households spending over 10 percent of their income on fuel for electricity, heating, and cooking, which is generally considered as "fuel poor" (VLITE 2014). In comparison, middle-to-upper income households may only spend between one and five percent of income on household fuel. More than 28,000 Vermont households received fuel assistance through Vermont's Low-Income Home Energy Assistance Program during the 2017-2018 heating season.

More recently, weatherization and electrical efficiency have been embraced as critical strategies for reducing greenhouse gas emissions and improving health and the impact of chronic health conditions. Vermonters in low-income households are also more likely to suffer from a variety of chronic diseases, with fewer resources available for treating and managing those diseases. For example, while ten percent of all Vermont adults currently have asthma, 17 percent of Vermont adults in households making less than $25,000 per year currently have asthma (VDH 2016a). Nationally, thermal stress and associated illnesses occur more commonly in low-income households (IOM 2011).

Case Studies

Several ongoing initiatives in Vermont are already working to deliver health and safety benefits through weatherization and Wx+Health services. These examples are described below.

Vermont Weatherization Program & One Touch

As a grantee of the National Weatherization Assistance Program (WAP), the Vermont Weatherization Assistance Program (VT WAP) provides free weatherization services to income-qualifying households across Vermont, prioritizing households of very low income, households receiving winter fuel assistance, households with high fuel intensity/burden and homes with elderly, child, or disabled occupants. The Program's funding allows significant health and safety issues to be addressed that are related to the Weatherization work (e.g. combustion appliance issues, indoor air quality). About 20 percent of the installed measures are used for health and safety improvements, such as improving ventilation of appliances or addressing electrical hazards, combustion safety, and indoor air quality. Through a partnership, VT WAP installs electrical efficiency and other improvements that are funded by Efficiency Vermont's Low-Income Electrical Efficiency Program (LEEP) at the time of weatherization.

The VT WAP also uses One Touch, an electronic referral system used to connect clients to health, housing and energy programs, with all clients. One Touch is used to enhance cross-sector collaboration and deliver cost-effective resources that help to reduce home energy use and improve health outcomes. VT WAP administers the brief One Touch questionnaire during the energy audit, which automatically prompts electronic referrals to local partners for help with asthma reduction,

accessibility improvements, lead poisoning prevention, smoking cessation, and other health and social issues.

VT WAP is seeking to increase the number of partner agencies completing One Touch questionnaires with their clients so that more eligible households will be referred to VT WAP and are made aware of other services for income-eligible households. The 2017 Housing and Urban Development Secretary's Award for Healthy Homes recognized the Vermont Weatherization Program for its role administering the One Touch system.

NeighborWorks of Western Vermont & Rutland Regional Medical Center

NeighborWorks of Western Vermont (NWWVT) works to increase household affordability for low-to-moderate-income households through energy efficiency services provided by their HEAT Squad program. The HEAT Squad provides low-cost energy audits and identifies the most appropriate approach to improving home energy efficiency and reduce energy costs. The HEAT Squad also helps identify contractors for the work and connect clients to loans and other financial assistance such as Efficiency Vermont rebates and incentives.

Beginning in 2016, the HEAT Squad began collaborating with their local hospital, Rutland Regional Medical Center (RRMC), to deliver an integrated residential energy efficiency and home health improvement program. RRMC identifies patients with health conditions that may benefit from Wx+Health services and refers them to the HEAT Squad. About one-quarter of referrals are typically for respiratory issues, such as asthma and chronic obstructive pulmonary disease, with about three-quarters for home accessibility issues. RRMC provides the HEAT Squad with up to $6,000 per patient to pay for the services, which is contingent upon being paired with a matching loan from NWWVT in most cases. For especially costly renovations, these funds are often supplemented by additional sources. For example, low-income customers are eligible to receive free Wx+Health services from the local Weatherization Assistance Program, BROC Community Action.

Once a referral is made, the HEAT Squad proceeds with their standard retrofit process with the added inclusion of the "+Health" services most relevant for each patient. NWWVT is developing methods to more systematically evaluate the health benefits of their services, though anecdotal evidence suggests that the home improvements have allowed patients to reside in safer, healthier homes, both easing symptoms of their conditions and increasing mobility around the home.

Healthy Homes Vermont – Efficiency Vermont & Northeastern Vermont Regional Hospital

Efficiency Vermont is a nonprofit energy efficiency utility that provides services to all Vermont electrical utility customers outside of Burlington, offering a range of services for energy efficiency improvements including free services for income-qualifying households, financial rebates, financing solutions, and technical support.

Efficiency Vermont began partnering with Northeastern Vermont Regional Hospital (NVRH), the Vermont Weatherization Assistance Program, and Northeast Employment and Training Organization in 2018 to launch the Healthy Homes Vermont pilot study. Modelled after the earlier success of the cooperation between NeighborWorks of Western Vermont and Rutland Regional Medical Center, the

Healthy Homes Vermont study will engage 10 low-income households with at least one occupant managing a chronic respiratory condition such as asthma, bronchitis, or emphysema.

The selected homes will receive targeted Wx+Health services from Efficiency Vermont and the Vermont Weatherization Program to reduce energy costs, remove asthma triggers, and improve ventilation and thermal comfort. NVRH will work with the occupants on behavioral and educational strategies to better manage their respiratory condition. Data will be collected from each home on energy usage and air quality and from occupants on health impacts. The study leaders hope to use the findings to demonstrate the health benefits of Wx+Health interventions in Vermont, and to identify ways to improve the effectiveness of specific Wx+Health strategies.

Estimating Health Benefits from Increased Weatherization in Vermont

Vermont's Weatherization Assistance Program currently weatherizes about 900 low-income homes each year, reducing energy costs by about 25% and greenhouse gas emissions by 1.8 tons per home annually (VCAC 2018). However, this pace of weatherization remains far below what is needed to meet the state's statutory goal of weatherizing 80,000 homes by 2020, including 20,000 low-income homes. The Vermont Climate Action Commission recently recommended strategies for increasing the pace of weatherization, which includes doubling the number of low-income homes weatherized each year. The average cost of a low-income weatherization project in Vermont is $8,500, of which about 20 percent goes towards non-energy health and safety improvements (VT DCF 2018).

To better account for the value of health benefits from weatherization retrofits in low-income Vermont homes, we used the findings from this literature review and Vermont-specific healthcare and cost data to estimate the potential health and related economic impact of weatherizing 2,000 low-income homes (roughly double the current rate) across Vermont each year.

Methods and assumptions

A full description of the methods and assumptions used to estimate the health benefits is provided in Appendix 3. In brief, we assumed that basic weatherization and efficiency services would be provided to 2,000 low-income homes per year, where recipients were not specifically targeted based on pre-existing health conditions, and no "+ Health" services would be provided. We estimated three types of benefits:

1. **Household energy cost savings** resulting from improved thermal and electrical efficiency

   Data from the Vermont Weatherization Assistance Program and Efficiency Vermont were used to estimate household energy cost savings.

2. **Household health benefits** resulting from improved indoor air quality, ventilation, and thermal comfort

   We expect that our estimated household health benefit is a large underestimate of the actual value of all household health benefits.

   Household health benefits were only estimated for three health impacts of weatherization - asthma and cold and heat-related thermal stress. The published evidence was particularly strong for these three health outcomes and studies provided data and methods for quantifying benefits that could be replicated with Vermont data. We did not estimate the benefits for other health impacts identified in the literature review, largely due to research gaps and challenges in translating research findings into estimates of health impacts and costs in Vermont (see Table 5.1 below).

   For asthma, emergency department visits and inpatient hospitalizations only account for about 30 percent of all medical costs (Nurmagambetov et al. 2018). Prescription medications, office visits, and outpatient hospitalizations account for the rest, but no known studies provide evidence about how these types of medical care may be affected by weatherization. Similarly,

COPD has a larger health care utilization and cost burden than asthma, but very little research has been published on the benefits of weatherization for COPD.

Table 5.1 Summary of health conditions and impacts included in the estimated household health benefits.

	Included	**Not included**
Health conditions	Asthma Heat stress Cold stress	Upper respiratory Chronic obstructive pulmonary disease Cardiovascular Mental health Accidental injury Infectious disease Neurological
Health and quality of life impacts	Early deaths Inpatient hospitalizations Emergency department visits	Emergency medical services Other urgent medical care Non-emergency medical care Medication usage Productivity (days of work/ school missed) Financial stress Social health Sleep quality Other quality of life

We would expect greater benefits per household if weatherization services were targeted towards individuals with pre-existing health conditions, and greater benefits (and costs) if "+ Health" services were also included.

3. **Public health benefits** resulting from reduced fossil fuel combustion

   The EPA Co-Benefits Risk Assessment (COBRA) model was used to estimate reduced respiratory and cardiovascular mortality and morbidity associated with reduced emissions from fossil fuel combustion.

All cost and benefit estimates were adjusted to 2017 values. A discount rate of zero percent was assumed for energy and household health benefits, while public health benefits generated by the EPA COBRA model were based on a three percent discount rate.

Energy cost savings

A typical low-income household is expected to save an average of $1,004 annually on thermal energy costs after weatherization and $170 after energy efficiency improvements, for a total savings of $1,174 per year. Over 10 years, the energy cost savings would amount to $11,740 per household.

Household health benefits

Estimated asthma-related health benefits resulting from weatherizing 2,000 low-income homes include 22 fewer emergency department (ED) visits, 1 less hospitalization each year, and 0.03 fewer deaths. The annual economic benefit was estimated to be $56,342 for reduced asthma-related health care utilization and $296,274 for avoided early deaths, for a total asthma-related economic benefit of $352,616 (see Table 5.2).

Estimated thermal-related health benefits include 0.7 fewer ED visits, 0.1 less hospitalization, and 0.02 fewer deaths each year. The annual economic benefit was estimated to be $4,298 for reduced thermal-related health care utilization and $195,572 for avoided early deaths, for a total thermal-related economic benefit of $199,869 (see Table 5.2).

Table 5.2 Annual health benefits expected per 2,000 low-income homes weatherized.

Health impact	Reduced emergency department visits	Reduced hospitalizations	Deaths avoided	Non-mortality economic value	Total economic value	Total economic value per household
Asthma	21.6	1.2	0.03	$56,342	$352,616	$176.31
Cold-related thermal stress	0.21	0.1	0.01	$3,051	$115,433	$57.72
Heat-related thermal stress	0.45	0.03	0.01	$1,246	$84,437	$42.22
Total	22.3	1.3	0.05	$60,640	$552,485	$276.24

In total, weatherization of 2,000 homes is expected to provide an annual health-related economic benefit of $552,485 to households receiving weatherization services, which equates to $276 per household per year for reduced health care utilization for asthma and thermal stress. Some of the economic benefits related to reduced health care utilization will likely accrue to payers outside of the individual household, depending on insurance coverage or other payment arrangements. About 64 percent of the estimated health benefit was associated with reduced asthma, 21 percent with reduced cold stress, and 15 percent with reduced heat stress (Figure 5.1).

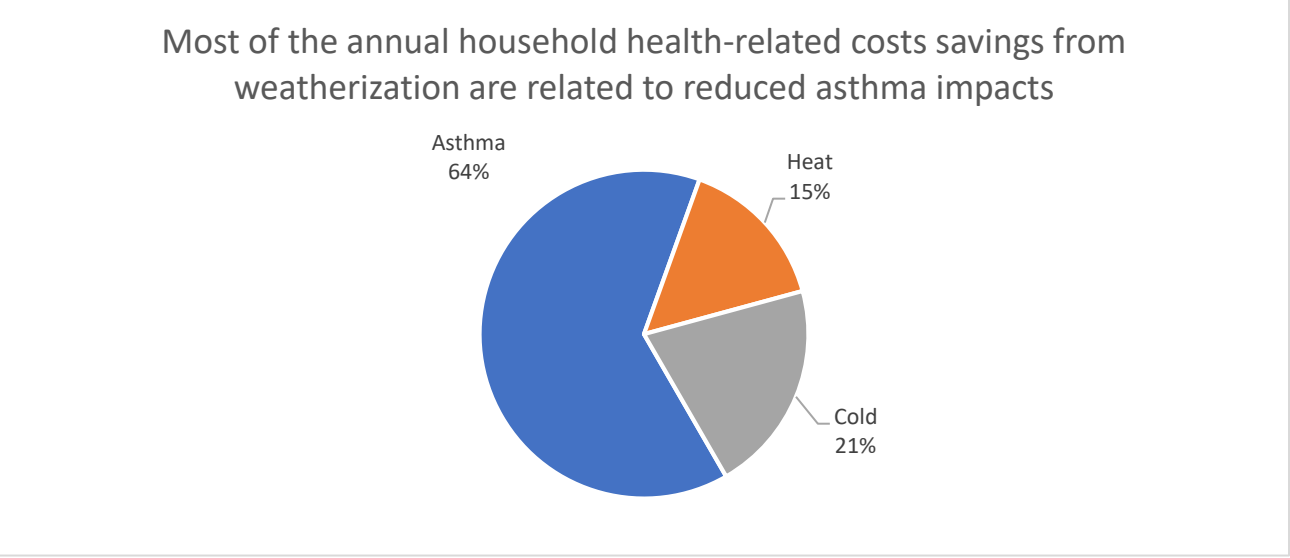


Figure 5.1. Distribution of estimated annual household cost savings due to weatherization across three health impacts.

Reductions in ED visits and hospitalizations due to cold- and heat-related thermal stress are considerably less than those related to asthma, largely because health-care utilization for thermal stress is relatively rare in Vermont. However, health-care utilization for heat-related stress has been increasing in recent years and is expected to continue increasing as a result of climate change. During the 2018 heat wave, there were four deaths in Vermont, all of which occurred at home. The number of heat-related emergency medical service calls and ED visits during the heat wave were 15 times higher than the average during the prior three years.

If 2,000 homes were weatherized each year for 10 years (20,000 homes total), the expected 10-year health impact (e.g., 10 years of follow-up for each household) would be a reduction of 2,229 ED visits, 130 hospitalizations, and five early deaths, which equates to an economic benefit of $55 million.

Weatherization is expected to provide household members with additional health and health-related economic benefits including improved mental health, reduced accidental injury, and increased productivity resulting from reduced absences from work or school. If weatherization is found to be as beneficial for COPD as it is for asthma, even larger health and health-related economic benefits would be expected. However, based on the existing evidence and Vermont-specific data, these benefits could not be quantified with the same confidence with which we estimated the benefits for asthma and thermal stress. In the National Weatherization Assistance Program Evaluation, the benefits for asthma and thermal stress accounted for 48 percent of the total estimated health-related benefits (Tonn et al. 2014).

Weatherization and Wx+Health services targeted towards individuals with chronic health conditions would also likely receive larger benefits, though costs would also likely increase for any “+Health” services provided. For example, if weatherization services were only offered to households with at least one resident with asthma, the estimated asthma-related health benefits would be at least 2.5 times greater than indicated above.

Public health benefits

Reduced energy demand also results in reduced fine particulate ($PM_{2.5}$) emissions from home heating, mostly because of reduced wood stove usage. Reduced $PM_{2.5}$ emissions provide widespread benefits to all Vermonters through improved air quality. Weatherizing 2,000 low-income homes is estimated to reduce $PM_{2.5}$ emissions in Vermont by 16.6 tons per year. Based on the EPA Co-Benefits Risk Assessment (COBRA) model, this reduced $PM_{2.5}$ pollution is expected to prevent 0.13-0.30 early deaths per year, 0.16 hospitalizations for respiratory and cardiovascular issues per year, and 0.24 acute asthma and bronchitis attacks per year. The annual economic value of these Vermont-wide health benefits is estimated to be between $1,258,000 and $2,844,000 per year, or a benefit between $629 and $1,422 per weatherized home.

If 2,000 homes were weatherized each year for 10 years (20,000 homes total), the expected 10-year health impact (e.g., 10 years of follow-up for each household) from reduced $PM_{2.5}$ emissions would be a reduction of 21 early deaths, 16 hospitalizations, and 24 acute respiratory attacks, resulting in an economic benefit between $125 million and $285 million.

Overall economic impact

For the benefit categories evaluated above (for energy cost savings, reduced health care utilization and mortality associated with asthma and thermal stress, and reduced fine particulate emissions), we estimated that weatherization produces a total first-year economic benefit of $2,476 per weatherized unit and a cumulative 10-year benefit of $24,757 per weatherized unit. As mentioned above, these benefits do not account for additional expected health improvements that were more challenging to monetize, nor for greater benefits that would be expected if targeting weatherization services towards individuals with chronic health conditions. At an average weatherization cost of $8,500 per unit, the 10-year return on investment is at least 2.9, with benefits exceeding costs by year four.

Table 5.3 Total 1-year and 10-year economic impact of energy savings and health improvements per weatherized household.

Benefit category	Economic beneficiary	First-year benefit	10-year benefit
Thermal and electric energy cost savings	Household	$1,174	$11,740
Reduced asthma and thermal stress	Household + public	$276	$2,762
Reduced fine particulate emissions	Public	$1,026[1]	$10,255[1]
Total	**Household + public**	**$2,476**	**$24,757**

[1] The midpoint of the estimated range was used for this calculation.

6. Discussion

There is an increasing amount of evidence demonstrating the health benefits of weatherization and energy efficiency projects, but it is still a young and evolving research topic. In particular, little scholarly attention has been given to the expanded concept of Wx+Health. While additional research and evaluation is needed, especially about the design and effectiveness of specific weatherization strategies on specific health outcomes, the existing evidence suggests that weatherization does help to improve indoor environmental quality in numerous ways that benefit health. By improving thermal comfort, air quality, moisture levels, and pest control while reducing energy costs, weatherization retrofits can have positive benefits for both physical and psychosocial health. Further downstream, these benefits can help improve household productivity, reduce household and societal costs for treating chronic health conditions, and reduce the societal impacts of fine particulate and greenhouse gas emissions.

Exposure to substandard housing is not evenly distributed across populations, as people of color and individuals in low-income households are disproportionately affected (Krieger and Higgins 2002, IOM 2011, Hernandez 2013, Gillespie-Bennett et al. 2013). The reviewed evidence emphasizes that these households have the most to gain from weatherization services, as low-income weatherization recipients have often experienced greater improvements in health (Braubach and Ferrand 2013, Maidment et al. 2014). Further, households with individuals that have preexisting chronic health conditions, especially respiratory conditions, and households with inadequate warmth have generally experienced the largest health improvements in response to weatherization services (Thomson and Thomas 2015).

Concerns have been raised regarding the potential for negative health impacts following weatherization due to "over-tightening" a house, or unintentionally reducing air circulation below a level that is healthy (Willand et al. 2015). Although this risk should not be dismissed, current evidence suggests that if industry standards for ventilation are correctly applied, this risk is minimal, and the health benefits of weatherization can be maximized (Smith et al. 2013, Hamilton et al. 2015). Overall, weatherization interventions were rarely found to be detrimental and reports of harmful effects were rare, even when including ventilation concerns.

Wx + Health

Where resources and partnerships allow, Wx+Health further enhances the health benefits of weatherization services and can be an effective mechanism for addressing multiple basic needs for under-resourced households. However, there is a need for much more research on the costs and benefits of potential "+Health" services, and the most effective ways to partner and package these services in tandem with more traditional weatherization services. While there is some emerging evidence about the benefits of Wx+Health services to improve asthma severity and control, there was very little information in the literature about injury prevention and accessibility improvements that can help older adults and people with disabilities stay in their home.

Weatherization programs have indicated a desire to dedicate more resources to health and safety concerns (Wilson and Tohn 2011). While well-positioned to do so, weatherization programs will need

additional support to make this possible. Traditional weatherization funding sources often only support specific energy-related activities, which can limit the type and amount of non-energy improvements that can be made. For example, only a limited portion (typically 10%) of United States Department of Energy funds used by National Weatherization Assistance Program grantees can be used for health and safety services that are unrelated to energy efficiency (Wilson and Tohn 2011). Additional funding sources and partnerships need to be identified and leveraged to enable delivery of larger health and safety benefits.

Conclusion

Weatherization and Wx+Health help to improve housing affordability through reduced energy costs, make progress towards meeting the state's energy goals, and improve health and wellness for under-resourced households. Future funding considerations for weatherization and Wx+Health services should acknowledge both the energy and non-energy benefits for households and society.

Appendix

Appendix 1. Summary Tables, Impacts of Weatherization on Indoor Environmental Quality

Table A1.1. Summary of literature review, weatherization impacts on indoor **temperature**

Authors	Type of Literature	Type of Source & Direction of Effect	
		Primary	Secondary
Tonn et al. 2014	Gray	+	
Wilson et al. 2014	Peer-Reviewed	+	
Willand et al. 2015	Peer-Reviewed		+
Rose et al. 2015	Gray	+	
Wilson et al. 2016	Gray		+, few exceptions
Haverinen-Shaughnessy et al. 2018	Peer-Reviewed	+	
Poortinga et al. 2018	Peer-Reviewed	+	
	Type of Source Totals	5/5 +	2/2 +

Confidence Level	High	**Direction of Effect**	**+**

Table A1.2. Summary of literature review, weatherization impacts on indoor **humidity**

Authors	Type of Literature	Type of Source & Direction of Effect	
		Primary	Secondary
Breysse et al. 2011	Peer-Reviewed	+	
Takaro et al. 2011	Peer-Reviewed	+	
Tonn et al. 2014	Gray	+	
Jacobs et al. 2014	Peer-Reviewed	+	
Wilson et al. 2014	Peer-Reviewed	+	
Breysse et al. 2015	Peer-Reviewed	–	
Rose et al. 2015	Gray	+	
Jacobs et al. 2015	Peer-Reviewed	+	
Willand et al. 2015	Peer-Reviewed		+, few exceptions
Francisco et al. 2016	Peer-Reviewed	+	
Wilson et al. 2016	Gray		+, few exceptions
	Type of Source Totals	8/9 +; 1/9 –	2/2 +

Confidence Level	High	**Direction of Effect**	**+**

Table A1.3. Summary of literature review, weatherization impacts on **mold**

Authors	Type of Literature	Type of Source & Direction of Effect	
		Primary	Secondary
Takaro et al. 2011	Peer-Reviewed	+	
Jacobs et al. 2014	Peer-Reviewed	+	
Tonn et al. 2014	Gray	+	
Rose et al. 2015	Gray	+	
Willand et al. 2015	Peer-Reviewed		+, one exception
Wilson et al. 2016	Gray		+, few exceptions
	Type of Source Totals	4/4 +	2/2 +

Confidence Level	High	**Direction of Effect**	**+**

Table A1.4. Summary of literature review, weatherization impacts on **indoor air quality**

Authors	Type of Literature	Type of Source & Direction of Effect	
		Primary	Secondary
Breysse et al. 2011	Peer-Reviewed	+	
Frey et al. 2014	Peer-Reviewed	+	
Wilson et al. 2014	Peer-Reviewed	0	
Breysse et al. 2015	Peer-Reviewed	+	
Francisco et al. 2016	Peer-Reviewed	+	
Wilson et al. 2016	Gray		+, some exceptions
	Type of Source Totals	4/5+	1/1 +

Confidence Level	High	**Direction of Effect**	**+**

Table A1.5. Summary of literature review, weatherization impacts on presence of **pests**

Authors	Type of Literature	Type of Source & Direction of Effect	
		Primary	Secondary
Breysse et al. 2011	Peer-Reviewed	+	
Takaro et al. 2011	Peer-Reviewed	+	
Jacobs et al. 2014	Peer-Reviewed	+	
Tonn et al. 2014	Gray	+	
Wilson et al. 2014	Peer-Reviewed	0	
Jacobs et al. 2015	Peer-Reviewed	+	
Wilson et al. 2016	Gray		+, few exceptions
	Type of Source Totals	5/6 +	1/1 +

Confidence Level	High	**Direction of Effect**	**+**

Appendix 2. Summary Tables, Health Benefits of Weatherization Interventions

Table A2.1. Summary of literature review, weatherization and Wx+Health impacts on **general health**

Authors	Type of Literature	Type of Source & Direction of Effect		Intervention
		Primary	Secondary	
Breysse et al. 2011	Peer-Reviewed	+		Wx+Health
Thomson et al. 2013	Peer-Reviewed		+	Wx
Jacobs et al. 2014	Peer-Reviewed	+		Wx+Health
Maidment et al. 2014	Peer-Reviewed		+	Wx
Wilson et al. 2014	Peer-Reviewed	+		Wx
Breysse et al. 2015	Peer-Reviewed	0		Wx+Health
Colton et al. 2015	Peer-Reviewed	+		Wx+Health
Jacobs et al. 2015	Peer-Reviewed	+		Wx+Health
Willand et al. 2015	Peer-Reviewed		+	Wx
Ahrentzen et al. 2016	Peer-Reviewed	+		Wx+Health
Francisco et al. 2016	Peer-Reviewed	0		Wx
Wilson et al. 2016	Gray		+	Wx & Wx+Health
Haverinen-Shaughnessy et al. 2018	Peer-Reviewed	0		
Tonn et al. 2018	Peer-Reviewed	+		Wx
Type of Source & Direction of Effect Totals		6/9 +	4/4 +	

Confidence Level	High	**Direction of Effect**	+

Table A2.2. Summary of literature review, weatherization and Wx+Health impacts on **asthma**

Authors	Type of Literature	Type of Source & Direction of Effect		Intervention
		Primary	Secondary	
Breysse et al. 2011	Peer-Reviewed	+		Wx+Health
Takaro et al. 2011	Peer-Reviewed	+		Wx+Health
Thomson et al. 2013	Peer-Reviewed		+/0	Wx
Wilson et al. 2014	Peer-Reviewed	–		Wx
Breysse et al. 2014	Peer-Reviewed	+		Wx+Health
Tonn et al. 2014	Peer-Reviewed	0		Wx
Colton et al. 2015	Peer-Reviewed	+		Wx+Health
Jacobs et al. 2015	Peer-Reviewed	+		Wx+Health
Wilson et al. 2016	Gray		+	Wx & Wx+Health
Type of Source Totals		5/7 +; 1/7 –	1/2 +	

Confidence Level	Medium	**Direction of Effect**	+

Table A2.3. Summary of literature review, weatherization and Wx+Health impacts on **upper respiratory symptoms**

Authors	Type of Literature	Type of Source & Direction of Effect		Intervention
		Primary	Secondary	
Breysse et al. 2011	Peer-Reviewed	+		Wx+Health
Thomson et al. 2013	Peer-Reviewed		+	Wx
Wilson et al. 2014	Peer-Reviewed	+		Wx
Tonn et al. 2014	Gray	0		Wx
Jacobs et al. 2015	Peer-Reviewed	+		Wx+Health
Willand et al. 2015	Peer-Reviewed		+	Wx
Francisco et al. 2016	Peer-Reviewed	0		Wx
Wilson et al. 2016	Gray		+	Wx & Wx+Health
Haverinen-Shaughnessy et al. 2018	Peer-Reviewed	+		Wx
Type of Source Totals		4/6 +	3/3 +	

Confidence Level	High	**Direction of Effect**	+

Table A2.4. Summary of literature review, weatherization and Wx+Health impacts on **cardiovascular health**

Authors	Type of Literature	Type of Source & Direction of Effect		Intervention
		Primary	Secondary	
Wilson et al. 2014	Peer-Reviewed	+		Wx
Jacobs et al. 2015	Peer-Reviewed	+		Wx+Health
Willand et al. 2015	Peer-Reviewed		+	Wx
Wilson et al. 2016	Gray		+	Wx & Wx+Health
Type of Source Totals		2/2 +	2/2 +	

Confidence Level	Medium	**Direction of Effect**	+

Table A2.5. Summary of literature review, weatherization and Wx+Health impacts on **neurological symptoms**

Authors	Type of Literature	Type of Source & Direction of Effect		Intervention
		Primary	Secondary	
Tonn et al. 2014	Gray	0		Wx
Jacobs et al. 2015	Peer-Reviewed	+		Wx+Health
Francisco et al. 2016	Peer-Reviewed	+		Wx
Wilson et al. 2016	Gray		+	Wx & Wx+Health
Type of Source Totals		2/3 +	1/1 +	

Confidence Level	Low	**Direction of Effect**	+

Table A2.6. Summary of literature review, weatherization and Wx+Health impacts on **infectious disease**

Authors	Type of Literature	Type of Source & Direction of Effect		Intervention
		Primary	Secondary	
Howden-Chapman et al. 2007	Peer-reviewed	+		Wx
Tonn et al. 2014	Gray	+		Wx
Type of Source Totals		2/2 +	None	

Confidence Level	Low	**Direction of Effect**	+

Table A2.7. Summary of literature review, weatherization and Wx+Health impacts on **accidental injury**

Authors	Type of Literature	Type of Source & Direction of Effect		Intervention
		Primary	Secondary	
Breysse et al. 2015	Peer-Reviewed	+		Wx+Health
Type of Source Totals		1/1 +	--	

Confidence Level	Low	**Direction of Effect**	+

Table A2.8. Summary of literature review, weatherization and Wx+Health impacts on **mental health**

Authors	Type of Literature	Type of Source & Direction of Effect		Intervention
		Primary	Secondary	
Thomson et al. 2013	Peer-Reviewed		+/0	Wx
Breysse et al. 2015	Peer-Reviewed	+		Wx+Health
Jacobs et al. 2015	Peer-Reviewed	+		Wx+Health
Willand et al. 2015	Peer-Reviewed		+	Wx
Francisco et al. 2016	Peer-Reviewed	+		Wx
Wilson et al. 2016	Gray		+	Wx & Wx+Health
Type of Source Totals		3/3 +	2/3 +	

Confidence Level	Medium	**Direction of Effect**	+

Table A2.9. Summary of literature review, weatherization and Wx+Health impacts on **social health**

Authors	Type of Literature	Type of Source & Direction of Effect		Intervention
		Primary	Secondary	
Thomson et al. 2013	Peer-Reviewed		+	Wx
Jacobs et al. 2015	Peer-Reviewed	+		Wx+Health
Willand et al. 2015	Peer-Reviewed		+	Wx
Poortinga et al. 2018	Peer-Reviewed	+		Wx
Type of Source Totals		2/2 +	2/2 +	

Confidence Level	High	**Direction of Effect**	+

Table A2.10. Summary of literature review, weatherization and Wx+Health impacts on **productivity**

Authors	Type of Literature	Type of Source & Direction of Effect		Intervention
		Primary	Secondary	
Breysse et al. 2011	Peer-Reviewed	+		Wx+Health
Thomson et al. 2013	Peer-Reviewed		+	Wx
Tonn et al. 2014	Gray	+		Wx
Colton et al. 2015	Peer-Reviewed	+		Wx+Health
Willand et al. 2015	Peer-Reviewed		+	Wx
Haverinen-Shaughnessy et al. 2018	Peer-Reviewed	+		Wx
Poortinga et al. 2018	Peer-Reviewed	+		Wx
Type of Source Totals		5/5 +	2/2 +	

Confidence Level	High	**Direction of Effect**	+

Table A2.11. Summary of literature review, weatherization and Wx+Health impacts on **financial stress**

Authors	Type of Literature	Type of Source & Direction of Effect		Intervention
		Primary	Secondary	
Frank et al. 2006	Peer-Reviewed	+		Wx
Willand et al. 2015	Peer-Reviewed		+	Wx
Poortinga et al. 2018	Peer-Reviewed	+		Wx
Tonn et al. 2018	Peer-Reviewed	+		Wx
Type of Source Totals		3/3 +	1/1 +	

Confidence Level	Medium	**Direction of Effect**	+

Table A2.12. Summary of literature review, weatherization and Wx+Health impacts on **healthcare utilization and costs**

Authors	Type of Literature	Type of Source & Direction of Effect		Intervention
		Primary	Secondary	
Takaro et al. 2011	Peer-Reviewed	+		Wx+Health
Tonn et al. 2014	Gray	+		Wx
Colton et al. 2015	Peer-Reviewed	+		Wx+Health
Jacobs et al. 2015	Peer-Reviewed	+		Wx+Health
Rose et al. 2015	Gray	+		Wx & Wx+Health
Wilson et al. 2016	Gray		+	Wx & Wx+Health
Tonn et al. 2018	Peer-Reviewed	+		Wx
Type of Source Totals		5/5 +	1/1 +	

Confidence Level	Medium	**Direction of Effect**	+

Appendix 3. Methods, Assumptions, and Calculations for Health Benefits Estimation

The weatherization rate for our scenario was based on the Vermont Climate Action Commission's recommended strategy of doubling the current rate of low-income home weatherization, which is currently approximately 900 homes per year. This rate was doubled and rounded up to yield a weatherization rate of 2,000 low-income homes per year for this scenario. The average Vermont household size is 2.34 people per household, yielding a total Wx scenario population of 4,680 Vermonters receiving benefit from weatherization across 2,000 low-income households.

Low-income households were assumed to be those qualifying for state Weatherization Program services. Income qualification for the state Weatherization Program varies by county and household size. For 2017-2018, for a 2-person household, the eligibility threshold ranges from $44,371 to $52,750; for a 3-person household, the threshold is between $49,906 and $59,350 (VT WAP 2018).

Expected reduction to asthma-related healthcare utilization due to weatherization was derived from the National Weatherization Assistance Program Evaluation conducted by the U.S. Department of Energy (Tonn et al. 2014, Tonn et al. 2018). Similarly, expected reduction to cold and heat-related healthcare utilization was drawn from an evaluation of a subset of data from the National WAP Evaluation for the cold climate region of the United States as specified by the authors (Hawkins et al. 2016), which is assumed to be more representative of Vermont's climate conditions than the national data. We assumed that the reduced demand for medical care applied equally to reductions in deaths, although deaths are extremely rare for all three health outcomes considered. For asthma-related deaths, we used the hospitalization reduction rate (rather than the ED rate) as the proxy for the death reduction rate, as hospitalizations represent a rarer and more severe need for medical care.

Table A3.1 Published evidence for reduced asthma, cold, and heat health care utilization following weatherization.

Health impact	Type of medical care	% with medical visits pre-Wx	% with medical visits post-Wx	% visit reduction	Data source
Asthma	ED	10.6%	4.3%	59.4%	Tonn et al. 2014 p.30
	Hospitalization	17.0%	10.6%	37.6%	Tonn et al. 2014 p.31
Cold	Any	4.1%	2.6%	36.6%	Hawkins et al. 2016 p.24
Heat	Any	3.8%	1.1%	71.1%	Hawkins et al. 2016 p.24

Seventeen percent of the low-income population receiving weatherization services was assumed to have current asthma (VDH 2016a). Baseline rates of asthma-related emergency department visits and hospitalizations among Medicaid insured Vermont residents were used to approximate baseline rates for our Wx scenario population, assuming income levels and other demographics are similar between the Medicaid-insured population and the Wx scenario low-income population (VDH 2016b). Rates of emergency department visits, hospitalizations and deaths due to cold- and heat-related thermal stress, and deaths due to asthma, were derived from hospital discharge and vital records data for Vermont's

general population, as the relative rarity of these incidents made income-specific estimates unreliable. This assumption likely results in an under-estimate of the true impacts, since thermal stress and associated illnesses, and asthma exacerbation, occur more commonly in low-income households (IOM 2011).

Table A3.2 Estimated reductions in health care utilization based on Vermont baseline data and published evidence.

Health impact	Type of medical care	Baseline rate (per 100,000 population)	Baseline pre-Wx visits	% visit reduction	Post-Wx visit reduction	Rate data source years
Asthma	ED	778	36.4	59.4%	21.6	2014
	Hospitalization	67	3.1	37.6%	1.2	2014
	Deaths	1.7	0.08	37.6%	0.03	2011-2015
Cold	ED	14.2	0.7	36.6%	0.2	2012-2016
	Hospitalization	5.9	0.3	36.6%	0.1	2012-2016
	Deaths	0.7	0.03	36.6%	0.01	2012-2016
Heat	ED	13.4	0.6	71.1%	0.4	2012-2016
	Hospitalization	0.8	0.04	71.1%	0.03	2012-2016
	Deaths	0.2	0.01	71.1%	0.01	2014-2018

Estimated economic benefits attributable to reductions in healthcare utilization were based on average costs for emergency department and hospitalization visits in Vermont for asthma (2015 Vermont Uniform Hospital Discharge Data Set, or VUHDDS), and cold- and heat-related thermal stress in (2015-2016 VUHDDS). These values represent initial charges from the health care provider, but not necessarily the amount actually paid, which can vary widely by insurer. Estimated economic benefits due to avoided deaths were based on the 2016 Value of a Statistical Life ($9.6M) as recommended by the U.S. Department of Transportation.

Table A3.3 Estimated economic benefit of reduced health care utilization based on Vermont health care cost data.

Health impact	Type of medical care	Post-Wx visit reduction	Cost per unit	Total cost savings	Total cost savings (2017 $)	Cost data source years
Asthma	ED	21.6	$1,647	$35,641.32	$37,915.76	2015
	Hospitalization	1.2	$14,673	$17,320.91	$18,426.24	2015
	Deaths	0.03	$9,600,000	$290,922.01	$296,273.56	2016
Cold	ED	0.2	$1,495	$364.01	$373.20	2016
	Hospitalization	0.1	$28,975	$2,932.60	$3,063.20	2015-2016
	Deaths	0.01	$9,600,000	$110,351.41	$112,381.34	2016
Heat	ED	0.4	$1,917	$854.01	$875.58	2016
	Hospitalization	0.03	$13,880	$294.77	$307.90	2015-2016
	Deaths	0.01	$9,600,000	$71,472.45	$72,787.20	2016

Reduced fuel consumption due to weatherization was estimated, then used to derive household energy cost savings and reduced fine particulate matter ($PM_{2.5}$) emissions. The average winter heating demand before and after weatherization was estimated from Vermont Weatherization Assistance Program data from the 2018 fiscal year (DCF 2018). Five-hundred and thirty units were weatherized

between July 1, 2017 and June 30, 2018. The average estimated thermal energy demand pre-weatherization was 134 million British Thermal Units (MMBTU) per unit, and weatherization reduced thermal energy demand by an estimated 40 MMBTU, for a thermal savings of 30 percent.

The average energy savings from electrical efficiency improvements through Efficiency's Vermont's Low-Income Energy Efficiency Program (LEEP) were estimated from Efficiency Vermont data for the period from July 1, 2017 to June 30, 2018 (EV 2018). The average estimated annual electrical energy savings per household was 1059.8 kWh, for an average annual savings of $169.57 (based on an electric rate of $0.16 per kWh).

The current distribution of fuel sources used for heating in Vermont was derived from the Energy Action Network's 2017 Energy & Climate Annual Report (EAN 2018). Fuel costs per MMBTU of heating output were provided through email correspondence with the Vermont Department of Public Service, with the exception of cord wood, for which current data were not readily available. We used an average cost of $227 per green wood cord as reported in the most recent Vermont Fuel Price Report from November 2016 (VT PSD 2016).

Table A3.4 Estimated costs and fine particulate ($PM_{2.5}$) emissions by heating fuel source in Vermont.

Fuel source	Percent of heating	Cost per MMBTU	$PM_{2.5}$ pounds per MMBTU
Heating oil	32%	$26.23	0.013
Propane	23%	$34.93	0.0083
Natural gas	21%	$17.63	0.0083
Cordwood	14%	$17.20	2.744
Pellet stoves	5%	$20.81	0.49
Electricity	3%	$35.29	0
Pellet boilers	2%	$20.81	0.27
Weighted average	100%	$25.05	0.42

The cost per MMBTU differs widely between electric resistive heating and electric heat pumps, but no data were readily available for estimating the split between these two types of electric heating in Vermont. We assumed a 50/50 split between the two types of electric heating. This assumption has little impact on the overall average cost per MMBTU, since electricity is such a small source of heating in Vermont. Assuming all resistive heating would increase the overall average cost per MMBTU by 44 cents; assuming all heat pumps would reduce the overall average cost per MMBTU by 44 cents. Either change would modify the estimated annual savings due to weatherization by about $17.

Fine particulate emissions per MMBTU of heating output were derived from U.S. Environmental Protection Agency data (U.S. EPA 2018a). The current mix of wood stoves in use in Vermont was assumed to be 40% pre-1990 (assumed uncertified) and 60% post-1990 (assumed EPA certified), based on data in the 2015 Vermont Residential Fuel Assessment (VT FPR 2016). The EPA source did not provide emissions data for propane or advanced wood heat. Propane emissions were assumed to be identical to natural gas, and advanced wood heat emissions were derived from peer-reviewed research that found pellet boilers to generate 44 percent less particulate emissions than pellet stoves (Ozgen 2014). This assumption has little impact on the overall emissions estimate, since very few pellet boilers

are used in Vermont. The health and related economic benefits of reduced $PM_{2.5}$ from residential heating were estimated using EPA's Co-Benefits Risk Assessment model (U.S. EPA 2018b).

Table A3.5 Estimated energy costs and fine particulate emissions before and after weatherization for a low-income Vermont household.

Pre-Wx energy demand per household	134 MMBTU
Post-Wx energy reduction	40 MMBTU
Pre-Wx cost per household	$3,359.13
Post-Wx cost savings	$1,004.38
Pre-Wx PM2.5 emissions (tons)	55.4 tons
Post-Wx PM2.5 emissions reduction (tons)	16.6 tons

All economic estimates are presented as 2017-dollar values. Dollar values from 2015 and 2016 Health Department data were converted to 2017 dollars using the Consumer Price Index for the Northeast U.S. region. The "All items" index was used for adjusting mortality-related costs and the "Medical care" index was used for adjusting hospitalization and emergency department costs. Monetary estimates from the EPA COBRA model were output directly in 2017 dollars.

Table A3.6 Inflation assumptions for converting monetary values to 2017 equivalents (Consumer Price Index, Northeast U.S.).

Year	All items index	Inflation rate to 2017	Medical care index	Inflation rate to 2017
2015	252.185	1.029	493.725	1.064
2016	254.850	1.018	512.294	1.025
2017	259.538	1.000	525.232	1.000

There is much debate among health economic evaluation experts about whether to adjust future-year costs and benefits by a discount rate. While the Panel on Cost-Effectiveness in Health and Medicine recommends a three percent discount rate (Weinstein 1996), others argue that the discount rate should be lower or even zero (Severens 2004; Paulden 2017). For simplicity in presenting the findings, a zero percent discount rate was assumed. The EPA COBRA model assumes a three percent discount rate.

References

Ahrentzen S, Erickson J, Fonseca E. 2015. Thermal and health outcomes of energy efficiency retrofits of homes of older adults. Indoor Air 26:582-593.

Allen JG, Bernstein A, Cao X, et al. 2017. The 9 Foundations of a Healthy Building. Harvard T.H. Chan School of Public Health. [accessed 2018 Nov 30] https://9foundations.forhealth.org/9_Foundations_of_a_Healthy_Building.February_2017.pdf

Braubach M, Ferrand A. 2013. Energy efficiency, housing, equity and health. International Journal of Public Health 58:331-332.

Breysse J, Jacobs D, Weber W, Dixon S, Kawecki C, Aceti S, Lopez J. 2011. Health outcomes and green renovation of affordable housing. Public Health Reports 126.

Breysse J, Dixon S, Gregory J, Philby M, Jacobs D, Krieger J. 2014. Effect of weatherization combined with community health worker in-home education on asthma control. American Journal of Public Health 104:e57-e64.

Breysse J, Dixon S, Jacobs D, Lopez J, Weber W. 2015. Self-reported health outcomes associated with green-renovated public housing among primarily elderly residents. Journal of Public Health Management and Practice 21:355-367.

CDC (Centers for Disease Control and Prevention), U.S. Department of Housing and Urban Development. 2006. Healthy housing reference manual. Atlanta: US Department of Health and Human Services.

CDC (Centers for Disease Control and Prevention), National Center for Injury Prevention and Control. 2015. A CDC compendium of effective fall interventions: what works for community-dwelling older adults. Atlanta.

CDC (Centers for Disease Control and Prevention). 2018. Health Impact in 5 Years. [accessed 2018 Oct 30] https://www.cdc.gov/policy/hst/hi5/index.html

Chase CA, Mann K, Wasek S, Arbesman M. 2012. Systematic review of the effect of home modification and fall prevention programs on falls and the performance of community-dwelling older adults. American Journal of Occupational Therapy 66:284–291.

Colton M, Laurent J, MacNaughton P, Kane J, Bennett-Fripp M, Spengler J, Adamkiewicz G. 2015. Health benefits of green public housing: associations with asthma morbidity and building-related symptoms. American Journal of Public Health 105:2482-2489.

De Souza R, Evans-Agnew R, Espina C. 2018. Federal Weatherization and Health Education Team up: Process Evaluation of a New Strategy to Improve Health Equity for People With Asthma and Chronic Obstructive Pulmonary Disease. Journal of Public Health Management & Practice 00:1-4.

EAN (Energy Action Network). 2018. Getting to 90% Renewable by 2050. [accessed 2018 Sept 14] http://eanvt.org/wp-content/uploads/2018/06/EnergyActionNetwork_AR_2017_AA_final.pdf

E4TheFuture. 2016. Occupant health benefits of residential energy efficiency. [accessed 2018 July 16] https://e4thefuture.org/wp-content/uploads/2016/11/Occupant-Health-Benefits-Residential-EE.pdf

EPA (Environmental Protection Agency). 2018. Indoor air pollution and health. US EPA [accessed 2018 July 16] https://www.epa.gov/indoor-air-quality-iaq/introduction-indoor-air-quality

EV (Efficiency Vermont). 2018. Email correspondence with Efficiency Vermont.

Francisco P, Jacobs D, Targos L, Dixon S, Breysse J, Rose W, Cali S. 2016. Ventilation, indoor air quality, and health in homes undergoing weatherization. Indoor Air 27:463-477.

Frank D, Neault N, Skalicky A, Cook J, Wilson J, Levenson S, Meyers A, Heeren T, Cutts D, Casey P et al. 2006. Heat or Eat: The low income home energy assistance program and nutritional and health risks among children less than 3 years of age. Pediatrics 118:e1293-e1302.

Frey S, Destaillats H, Cohn S, Ahrentzen S, Fraser M. 2014. The effects of an energy efficiency retrofit on indoor air quality. Indoor Air 25:210-219.

Gillespie-Bennett J, Keall M, Howden-Chapman P, Baker M. 2013. Improving health, safety and energy efficiency in New Zealand through measuring and applying basic housing standards. New Zealand Medical Journal 126.

Hamilton I, Milner J, Chalabi Z, Das P, Jones B, Shrubsole C, Davies M, Wilkinson P. 2015. Health effects of home energy efficiency interventions in England: a modelling study. BMJ Open 5:e007298-e007298.

Haverinen-Shaughnessy U, Pekkonen M, Leivo V, Prasauskas T, Turunen M, Kiviste M, Aaltonen A, Martuzevicius D. 2018. Occupant satisfaction with indoor environmental quality and health after energy retrofits of multi-family buildings: Results from INSULAtE-project. International Journal of Hygiene and Environmental Health 221:921-928.

Hawkins B, Tonn B, Rose E, Clendenning G, Abraham L. 2016. Massachusetts special and cross-cutting research area: low-income single-family health- and safety-related non-energy impacts (NEIs) study. Prepared by Three^3, Inc. and NMR Group for the Massachusetts Program Administrators.

Hernández D. 2013. Energy Insecurity: A framework for understanding energy, the built environment, and health among vulnerable populations in the context of climate change. American Journal of Public Health 103:e32-e34.

Hernández D, Phillips D, Siegel E. 2016. Exploring the housing and household energy pathways to stress: a mixed methods study. International Journal of Environmental Research and Public Health 13:916.

Howden-Chapman P, Matheson A, Crane J, Viggers H, Cunningham M, Blakely T, Cunningham C, Woodward A, Saville-Smith K, O'Dea D, Kennedy M, Baker M, Waipara N, Chapman R, Davie G. 2007. Effect of insulating existing houses on health inequality: cluster randomised study in the community. BMJ 334:460.

IOM (Institute of Medicine). 2004. Damp indoor spaces and health. Washington, DC: National Academies Press.

IOM (Institute of Medicine). 2011. Climate change, the indoor environment, and health. Washington, DC: National Academies Press.

Jacobs D, Breysse J, Dixon S, Aceti S, Kawecki C, James M, Wilson J. 2014. Health and housing outcomes from green renovation of low-income housing in Washington, DC. Journal of Environmental Health 76.

Jacobs D, Ahonen E, Dixon S, Dorevitch S, Breysse J, Smith J, Evens A, Dobrez D, Isaacson M, Murphy C et al. 2015. Moving into green healthy housing. Journal of Public Health Management and Practice 21:345-354.

Krieger J, Higgins D. 2002. Housing and health: time again for public health action. American Journal of Public Health 92:758-768.

Liddell C, Guiney C. 2015. Living in a cold and damp home: frameworks for understanding impacts on mental well-being. Public Health 129:191-199.

Maidment C, Jones C, Webb T, Hathway E, Gilbertson J. 2014. The impact of household energy efficiency measures on health: A meta-analysis. Energy Policy 65:583-593.

McCormack MC, Belli AJ, Waugh D, Matsui EC, Peng RD, Williams DL, Paulin L, Saha A, Aloe CM, Diette GB, Breysse PN, Hansel HN. 2016. Respiratory Effects of Indoor Heat and the Interaction with Air Pollution in Chronic Obstructive Pulmonary Disease. Annals of the American Thoracic Society. 13: 2125-2131.

Milner J, Davies M, Wilkinson P. 2012. Urban energy, carbon management (low carbon cities) and co-benefits for human health. Current Opinion in Environmental Sustainability 4:398-404.

Morley RL, Mickalide AD, Mack KA. 2011. Healthy & Safe Homes: Research, Practice, & Policy. American Public Health Association.

Nurmagambetov T, Kuwahara R, Garbe P. 2018. The Economic Burden of Asthma in the United States, 2008-2013. Annals of the American Thoracic Society. 15: 348-356.

Osman LM, Ayres JG, Garden C, Reglitz K, Lyon J, Douglas JG. 2010. A randomised trial of home energy efficiency improvement in the homes of elderly COPD patients. European Respiratory Journal 35:303-309.

Opportunity Council. 2004. Weatherization plus health: program materials and protocols to integrate health concerns in to WX projects. [accessed 2018 Aug 2]. http://nchharchive.org/LinkClick.aspx?fileticket=TMV88m6QsP4%3d&tabid=369

Ozgen S, Caserini S, Galante S, Giugliano M, Angelino E, Marongiu A, Hugony F, Migliavacca G, Morreale C. 2014. Emission factors from small scale appliances burning wood and pellets. Atmospheric Environment. 94:144-153.

Paulden M, O'Mahony JF, McCabe C. 2017. Discounting the Recommendations of the Second Panel on Cost-Effectiveness in Health and Medicine. Pharmacoeconomics. 35: 5-13.

Poortinga W, Rodgers S, Lyons R, Anderson P, Tweed C, Grey C, Jiang S, Johnson R, Watkins A, Winfield T. 2018. The health impacts of energy performance investments in low-income areas: a mixed-methods approach. Public Health Research 6:1-182.

PSD (Vermont Department of Public Service). 2016. Comprehensive Energy Plan [accessed 2018 Aug 21]. http://publicservice.vermont.gov/publications-resources/publications/energy_plan

Pynoos J, Steinman BA, Nguyen AQD, Bressette M. 2012. Assessing and Adapting the Home Environment to Reduce Falls and Meet the Changing Capacity of Older Adults. Journal of Housing for the Elderly 26:137-155.

Rose E, Hawkins B, Tonn B, Paton D, Shah L. 2015. Exploring potential impacts of weatherization and Healthy Homes interventions on asthma-related Medicaid claims and costs in a small cohort in Washington state. U.S. Department of Energy. Prepared by the Oak Ridge National Laboratory.

Salvi SS, Barnes PJ. 2009. Chronic obstructive pulmonary disease in non-smokers. Lancet 374:733-43.

Severens JL, Milne RJ. 2004. Discounting Health Outcomes in Economic Evaluation: The Ongoing Debate. Value in Health. 7: 397-401.

Smith K, Frumkin H, Balakrishnan K, Butler C, Chafe Z, Fairlie I, Kinney P, Kjellstrom T, Mauzerall D, McKone T et al. 2013. Energy and Human Health. Annual Review of Public Health 34:159-188.

Takaro T, Krieger J, Song L, Sharify D, Beaudet N. 2011. The Breathe-Easy Home: The Impact of Asthma-Friendly Home Construction on Clinical Outcomes and Trigger Exposure. American Journal of Public Health 101.

Thomson H, Thomas S. 2015. Developing empirically supported theories of change for housing investment and health. Social Science & Medicine 124:205-214.

Thomson H, Thomas S, Sellstrom E, Petticrew M. 2013. Housing improvements for health and associated socio-economic outcomes. Cochrane Database of Systematic Reviews.

Tonn B, Rose E, Hawkins B, Conlon B. 2014. Health and household-related benefits attributable to the Weatherization Assistance Program. U.S. Department of Energy. Prepared by Oak Ridge National Laboratory.

Tonn B, Rose E, Hawkins B. 2018. Evaluation of the U.S. department of energy's weatherization assistance program: Impact results. Energy Policy 118:279-290.

U.S. DOE (Department of Energy), Office of Energy Efficiency & Renewable Energy. 2018. Weatherization works! [accessed 2018 July 16] https://www.energy.gov/sites/prod/files/2018/03/f49/WAP-fact-sheet_final.pdf

U.S. EPA (Environmental Protection Agency). 2018a. Energy Efficiency and Your Wood-Burning Appliance. [accessed 2018 Sept 14] https://www.epa.gov/burnwise/energy-efficiency-and-your-wood-burning-appliance

U.S. EPA (Environmental Protection Agency). 2018b. CO-Benefits Risk Assessment (COBRA) Health Impacts Screening and Mapping Tool. [accessed 2018 Sept 14] https://www.epa.gov/statelocalenergy/co-benefits-risk-assessment-cobra-health-impacts-screening-and-mapping-tool

VCAC (Vermont Climate Action Commission). 2018. Executive order no. 12-17 report to the Governor. [accessed 2018 Aug 14] http://anr.vermont.gov/sites/anr/files/Final%20VCAC%20Report.pdf

VLITE (Vermont Low Income Trust for Electricity, Inc.). 2014. Energy Costs and Burdens in Vermont: Burdensome for Whom? [accessed 2018 Aug 14] http://www-assets.vermontlaw.edu/Assets/iee/VLS%20IEE%20Energy%20Burden%20Report.pdf

VT DCF (Vermont Department for Children and Families), Office of Economic Opportunity. 2018. Email correspondence with Weatherization Assistance Program.

VT FPR (Vermont Department of Forests, Parks, and Recreation). 2016. Vermont Residential Fuel Assessment for the 2014-2015 Heating Season. [accessed 2018 Sept 14] http://fpr.vermont.gov/sites/fpr/files/About_the_Department/Library/Library/FINAL_2015%20Residential%20Fuel%20Assessment%20Report.pdf

VT PSD (Public Service Department). 2016. Vermont Fuel Price Report: November 2016. [accessed 2018 Sept 17] http://publicservice.vermont.gov/sites/dps/files/documents/Pubs_Plans_Reports/Fuel_Price_Report/2016/November%202016%20Fuel%20Price%20Report.pdf

VT WAP (Vermont Weatherization Assistance Program). 2018. 2017-2018 Weatherization Income Eligibility Guidelines. [accessed 2018 Sept 17] http://dcf.vermont.gov/sites/dcf/files/OEO/Docs/Wx-Income-Guidelines.pdf

VDH (Vermont Department of Health). 2016a. Vermont Behavioral Risk Factor Surveillance System 2016 Data Summary. [accessed 2018 Sept 14] http://www.healthvermont.gov/sites/default/files/documents/pdf/summary_brfss_2016.pdf

VDH (Vermont Department of Health). 2016b. The Disparate Burden of Asthma among the Medicaid Insured in Vermont - 2016. [accessed 2018 Sept 14] http://www.healthvermont.gov/sites/default/files/documents/2016/12/data_brief_asthma_medicaid.pdf

VDH (Vermont Department of Health). 2018. The Impact of Tobacco Use Among Vermonters with Lung Disease. [accessed 2018 Nov 7] http://www.healthvermont.gov/sites/default/files/documents/pdf/hsvr_asthma_data_brief_asthma_tobacco_2018.pdf

Weinstein MC, Siegel JE, Gold MR, Kamlet MS, Russell LB. 1996. Recommendations of the Panel on Cost-Effectiveness in Health and Medicine. Journal of the American Medical Association. 276: 1253-1258.

Wilkinson P, Smith K, Davies M, Adair H, Armstrong B, Barrett M, Bruce N, Haines A, Hamilton I, Oreszczyn T et al. 2009. Public health benefits of strategies to reduce greenhouse-gas emissions: household energy. The Lancet 374:1917-1929.

Willand N, Ridley I, Maller C. 2015. Towards explaining the health impacts of residential energy efficiency interventions – A realist review. Part 1: Pathways. Social Science & Medicine 133:191-201.

Wilson J, Tohn E. 2011. Healthy housing opportunities during weatherization work. National Renewable Energy Laboratory.

Wilson J, Dixon S, Jacobs D, Breysse J, Akoto J, Tohn E, Isaacson M, Evens A, Hernandez Y. 2014. Watts-to-Wellbeing: does residential energy conservation improve health? Energy Efficiency 7:151-160.

Wilson J, Jacobs D, Reddy A, Tohn E, Cohen J, Jacobson E. 2016. Home Rx: the health benefits of home performance, a review of the current evidence. U.S. Department of Energy, Energy Efficiency & Renewable Energy. Prepared by the National Center for Healthy Housing.