Massachusetts Residential Coordinated Delivery Single Family Impact Evaluation

(MA23R58-B-RCD)

Prepared for:

Massachusetts Program Administrators

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Executive Summary

As part of the 2022-2024 three-year energy efficiency plan, the Massachusetts (MA) Program Administrators (PAs) identified the need for an impact evaluation of the Residential Coordinated Delivery (RCD) initiative. The primary goal of the evaluation was to update the initiative's gross energy savings for prospective application as part of the forthcoming 2025-2027 three-year implementation cycle. Cadeo, as part of a Guidehouse-primed evaluation team, led this study (MA23R58-B-RCDIMPACT).

Methodology

The evaluation team used a combination of **billing analysis, building simulation, and engineering algorithms** to evaluate gross savings for every RCD measure. Through this multifaceted approach, the team was able to apply the most appropriate methodology—or, in some cases, combination of approaches—to accurately evaluate each measure. In general, the team relied on billing analysis whenever the model produced measure-specific results at 90% confidence and greater than 20% precision. When billing analysis did not produce statistically significant results, the team evaluated savings using engineering algorithms (for measures that do not generate interactive effects) or calibrated building simulation (for measures that do).

This study focused heavily on two specific RCD measures: air sealing and insulation, collectively referred to as weatherization. This focus is because weatherization is the primary driver of RCD savings. In 2022, weatherization comprised more than three-quarters (83%) of total RCD vendor estimated annual savings across all fuel types.

The evaluation team used billing analysis with a matched control group to evaluate savings for RCD weatherization participants that heat their homes with natural gas. The team used the statistically significant result for natural gas participants and, through a series of thoughtful engineering adjustments, generated weatherization savings for RCD participants that heat their homes with electricity, heating oil, and propane. These adjustments accounted for key differences across fuel types that impact savings including home size, heating equipment efficiency, pre-program building envelope conditions, and the quantity of installed insulation.

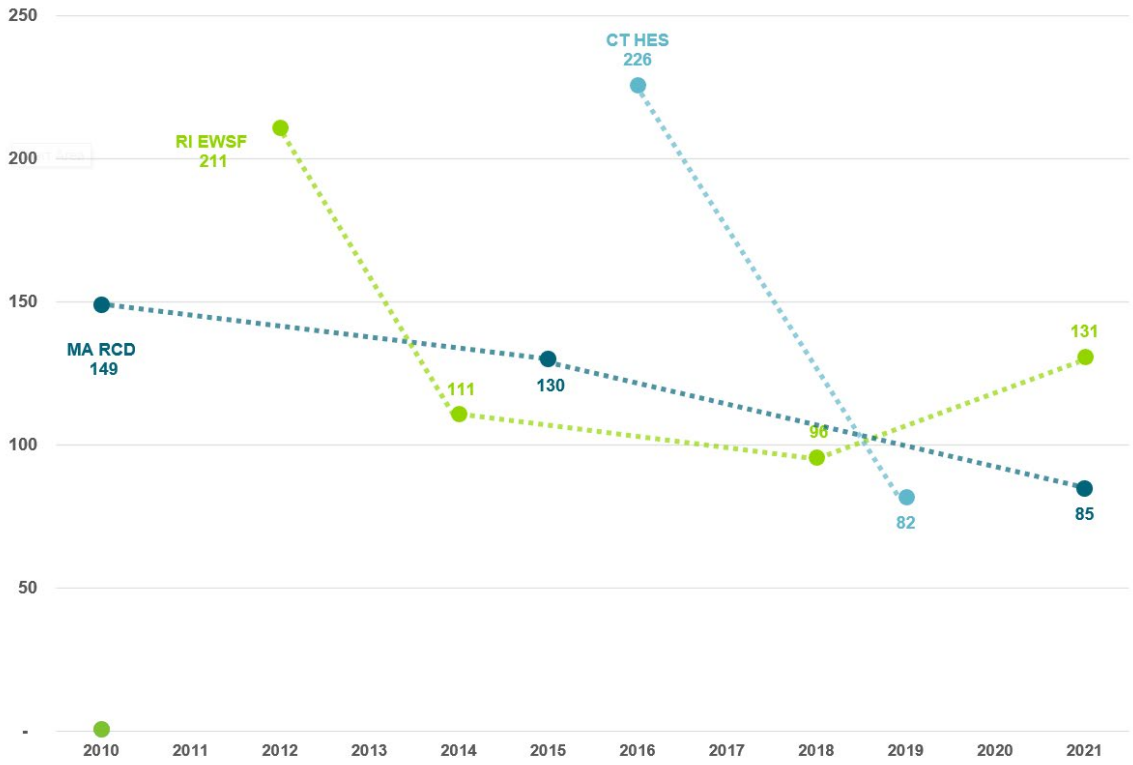
Results

Key results from this study include:

- **Lower average natural gas weatherization savings relative to the previous evaluation.** The evaluated statewide average natural gas weatherization savings found through this study for 2021 participants (85 therms) is much lower than the comparable result (130 therms) from previous RCD (then Home Energy Services or HES) impact evaluation completed in 2018. The lower savings are driven—at least in part—by lower average pre-program heating consumption (~20% less for 2021 participants relative to 2015 and 2016 participants evaluated as part of the 2018 study). Lower pre-program consumption is, in turn, driven by a multitude of factors including ever increasing natural gas heating equipment efficiencies, improving building stock, and updates to the weather files used to normalize annual consumption. In fact, in terms of the percentage of heating consumption saved, the disparity between this and the previous HES evaluation is far more modest (11% vs. 13%, respectively).

- **Less natural gas weatherization savings is consistent with long-term regional trends.** For the reasons listed earlier, RCD is not the only initiative with declining evaluation results over time. Similar offerings in neighboring Connecticut and Rhode Island have also seen a general decline in average savings over time. As the following graphic shows (Figure A), every subsequent impact evaluation for a given PA (with one exception) has resulted in a lower average evaluated savings for natural gas weatherization. The PAs should keep this trend in mind when forecasting the potential savings associated with weatherization as part of future program cycles.

Figure A. Evaluated Savings Over Time by State – Average Weatherization Savings (therms/year) for Natural Gas-Heated Customers



- **Lead Vendors (LVs) continue to overestimate weatherization savings.** This evaluation—like the previous two HES impact evaluations (2018 and 2012)—found gross realization rates for weatherized natural gas-heated homes well below 100%. In other words, RCD LVs have consistently overestimated weatherization savings for more than a decade. In fact, the PAs commissioned a study into the causes of persistently low gross realization rates (RES 39) in 2020. Among other factors, that study found the LVs do not calibrate their weatherization to participants' consumption. Discussions with LVs identified some changes since that study (e.g., RISE Engineering noted transitioning to a more conservative air sealing assumption), but none of the LVs have started calibrating their models with actual participant billing data. The implications of the overestimating savings are two-fold: 1) it can set unrealistic savings expectations with customers, which could impact customer satisfaction, and 2) the PAs must make proactive adjustments to the LV estimated savings reported to them. The fact that a third consecutive impact

evaluation found low weatherization realization rates—coupled with the current evaluation's rate being even lower than the previous study—suggests a persistent, systemic issue and highlights the need for the PAs and LVs to consider fundamental changes to the current vendor estimation process.

- **Natural gas results drive delivered fuel results, which are facing similar issues.** As billing analysis is not possible for delivered fuels, the team made a series of engineering adjustments to the natural gas analysis to evaluate heating oil and propane. Because the delivered fuel results are grounded in the natural gas billing analysis, the evaluation team's analysis resulted in a similar dip in average weatherization savings for heating oil and propane (8.7 and 6.4 MMBtu/year, respectively) relative to the previous evaluation (13 MMBtu/year for both). The discussion above regarding longer term downward trends in weatherization savings and persistently low gross realization rates focuses on natural gas-heated homes. However, the same patterns are true for weatherized homes heating with a delivered fuel. At a statewide level, weatherized heating oil and propane heated homes were found to have gross realization rates of 42% and 43%, respectively.
- **Savings for most non-weatherization measures are similar to current estimates.** Pipe wrap, thermostats, and other non-weatherization measures that make up the remaining ~16% of RCD reported savings saw decreases in evaluated savings relative to current estimates, while showerheads and aerators saw increases in per unit savings.

Savings Summary

Table A summarizes this evaluation's findings for each RCD SF measure and relevant fuel type. The table also indicates which methodology—or combination of methodologies—the evaluation team used to evaluate the savings. Although Table A includes four fuel types, it is important to note that more than 90% of RCD savings come from natural gas and heating oil measures.

Table A. Evaluated Gross Energy Savings by Measure

Measure	Natural Gas (therms)	Electric (kWh)	Oil (MMBtu)	Propane (MMBtu)
BUILDING SHELL				
Weatherization (Insulation and/or Air Sealing) – Statewide	85	562	8.7	6.4
Insulation (Overall)	42	317	4.3	3.2
Distribution Savings, kWh		21/19/11		
Cooling Savings, kWh		36/35/21		
Air Sealing	43	253	4.4	3.2
Distribution Savings, kWh		11/10/6		
Cooling Savings, kWh		3/2/1		
Secondary Electric Heating, kWh[1]		52/52/52		
HVAC				

[1] Secondary electric heating savings for homes heated with fossil fuels. Secondary electric heating for homes heated with electricity is included in the Weatherization savings in (kWh). Source: Rhode Island EnergyWise Single Family (EWSF) Weatherization Impact Evaluation (2023).

Measure	Natural Gas (therms)	Electric (kWh)	Oil (MMBtu)	Propane (MMBtu)
Boiler Reset Controls	43	-	-	-
Pipe Wrap (Space Heating)	13	-	1.3	1.3
Programmable Thermostat				
Heating savings	23	113	2.1	2.1
Cooling Savings, kWh	23	9	21	19
Wi-Fi Thermostat				
Heating Savings	31	167	3.1	2.6
Cooling Savings, kWh	22	14	17	17
Duct Insulation	10	46	1.0	1.0
Duct Sealing	17	73	1.7	1.7
Heat Recovery Ventilator (HRV)	86	-	-	-
HOT WATER				
Showerhead	11	204	1.2	1.1
Faucet Aerator	4	63	0.4	0.4
Pipe Wrap (Water Heating)	3	42	0.5	0.3
PLUG LOAD				
Smart Strips	-	105	-	-

Source: Cadeo analysis

Billing Analysis
Engineering Adjusted Billing Analysis
Engineering Algorithm
Billing Analysis and Building Simulation

Table B includes a summary of the realization rates that the evaluation team calculated for weatherization savings across all four fuel types for each LV, as well as statewide. As discussed earlier, the gross realization rates determined as part of this evaluation—like the previous two RCD impact studies—were low relative to vendor estimated weatherization savings. This was true across all LVs and heating fuel types. As the billing analysis of natural gas-heated weatherization participants informed the heating oil and propane engineering analysis, the gross realization rates for natural gas and delivered fuel participants are generally similar. The gross realization rates for weatherized customers heating with electricity, which are a very small part of the initiative (less than 3%), are particularly low. The disparity is in part driven by the evaluation's analysis of participants' electric consumption data, which found electrically heated customers used less total energy to heat their homes relative to participants heating with natural gas, which is likely due to smaller home sizes and generally higher existing insulation levels.

Table B. Evaluated Weatherization Gross Realization Rates

Lead Vendor	Natural Gas	Electric	Oil	Propane
Abode	0.48	0.14	0.42	0.45
CLEAResult	0.49	0.13	0.41	0.44
RISE	0.42	0.11	0.42	0.29
Statewide	0.47	0.13	0.42	0.43

Source: Cadeo analysis

Recommendations

The evaluation recommends:

- **Working with LVs to improve vendor estimate savings.** As three consecutive impact evaluations have determined that RCD LVs overestimate weatherization savings, the team recommends the PAs proactively work with their LVs to improve savings estimations. Improvements should include, but are not limited to, calibrating models using individual customers' pre-RCD energy consumption and using more recent weather data files (TMYx not TMY3) to reflect winter warming trends. If the PAs and LVs determine that these potential changes are impractical (due to access to data or the time required for calibration), the PAs should consider alternative approaches to estimating and/or claiming weatherization savings. These alternatives could include transitioning air sealing and insulation to deemed savings measures or using a simplified method that results in more conservative estimates. Regardless of the improvements made, the PAs should ensure these changes happen early in the process so that the savings estimates shared with participants (after their home energy assessment or HEA) are more reflective of the savings they are likely to achieve.

Considerations

The evaluation team also suggests the PAs consider:

- **Revisiting moderate income-specific savings.** Limited participation in the newer Moderate Income Qualified (MIQ) weatherization offer meant this study did not observe MIQ-specific savings that were statistically different than weatherization for non-MIQ customers. The team suggests the PAs revisit this MIQ/non-MIQ comparison if participation in MIQ increases as it is possible—with greater sample sizes—that subsequent evaluations could find a meaningful difference in savings between the two groups.

1. Introduction

As part of the 2022-2024 three-year energy efficiency plan, the Massachusetts (MA) Program Administrators (PAs) identified the need for an impact evaluation of the Residential Coordinated Delivery (RCD) initiative. The primary goal of the impact evaluation was to update the existing gross energy savings associated with each measure offered through the RCD initiative and related sub offerings. The existing gross energy savings were established in August 2018 as part of the prior impact evaluation (RES 34) when RCD was known as Home Energy Services (HES).[2] The PAs will apply the updated RCD gross energy savings prospectively as part of the forthcoming 2025-2027 three-year implementation cycle.

Cadeo, as part of a Guidehouse-primed evaluation team, led this study (MA23R58-B-RCDIMPACT) to evaluate the gross energy impact of every RCD measure. As discussed in this report, the evaluation team used a combination of billing analysis, building simulation, and engineering algorithms to evaluate savings. This multifaceted approach applies the most appropriate methodology—or, in some cases, multiple approaches—to each measure.

This impact evaluation is one of three concurrent and complementary impact studies completed in 2024 to inform the PAs' efforts to plan the next three-year implementation cycle (2025-2027). **This impact evaluation focuses on RCD single family (SF) participants** (i.e., customers living in buildings with less than five units that do not qualify for the PA's Income Eligible [IE] program). The other two studies include:

- **MA23R56-B-IESFI.** The IE SF Impact Evaluation is analogous to MA23R58-B-RCDIMPACT but focused on income-qualified customers that live in buildings with less than five units served through the PAs' network of Community Action Program (CAP) partners.

- **MA23R59-B-MFI.** The MF Impact Evaluation covered all MF participants (i.e., the owners, managers, and tenants in buildings with more than five units) regardless of income. This includes both IE participants served through CAPs and non-IE participants served through RCD.

1.1 About RCD

The RCD initiative is the primary mechanism through which the PAs deliver energy efficiency to residential customers living in one- to four-unit homes. Through the initiative's whole home energy assessment (HEA), the PAs install instant savings measures (e.g., efficient lighting, efficient showerheads and faucet aerators, advanced smart strips, and thermostats) and promote weatherization measures (e.g., air sealing and attic, wall, and basement insulation). The HEA also provides an opportunity to identify and refer customers to other residential initiatives that incentivize heating, cooling, and water heating equipment upgrades.

The PAs deliver RCD through two complementary channels:

- **Lead Vendors (LVs).** The PAs work with one of the following four LVs to implement RCD: CLEAResult, RISE Engineering (RISE), Center for EcoTechnology (CET), and

[2] Navigant and Cadeo, Home Energy Services Impact Evaluation, August 2018, https://ma-eeac.org/wp-content/uploads/RES34_HES-Impact-Evaluation-Report-with-ES_FINAL_29AUG2018.pdf.

Abode Energy Management (Abode).[3] Abode, which manages the statewide network of Home Performance Contractors (HPCs) for all the PAs, is different than the other three LVs. (More on Abode and HPCs in the next bullet)**.** CLEAResult, RISE, and CET complete HEAs for customers that enter RCD through the initiative's traditional channels, such as via the MassSave statewide phone number or enrolling on MassSave.com. These LVs conduct HEAs using in-house Energy Specialists, manage the extensive network of independent installation contractors (IICs) that air seal and insulate homes following HEAs, and provide quality assurance and quality control (QA/QC) services following installation. As the PAs contract separately with each LV, the LVs and PAs collaborate through a statewide RCD Working Group to ensure residential customers across Massachusetts have a similar experience participating in RCD. Although the LVs coordinate and offer relatively consistent services statewide, some differences exist between LVs. For example, LVs estimate participant-specific savings for air sealing and insulation measures using their own proprietary energy modeling software or software provided by the PA they serve. Each LV reports these savings to the PAs as claims against initiative goals. The PAs rely on periodic impact evaluations, such as this study, to independently estimate air sealing and insulation savings for the average customer served and to develop gross realization rates that adjust LV-specific modeled savings to reflect evaluated values.

- **HPCs.** Over a decade ago, the PAs created a second participation channel that tapped into the extensive network of contractors in the state with energy efficiency experience. HPCs independently market and recruit customers for HEAs. HPCs differ from the LV and IIC delivery approach as they provide end-to-end services to customers: completing the assessment and installing any of the recommended energy efficiency improvements customers decide to complete. These improvements can include weatherization measures incentivized through RCD, measures through other PA initiatives (e.g., HVAC equipment installation), and other home improvements of interest to a customer, whether energy related or not. In some instances, the home improvements are energy related (e.g., installing solar panels) while, in other instances, the improvements are not (e.g., remodeling a bathroom). The work HPCs do on behalf of the RCD is also subject to the LV-managed QA/QC processes noted earlier. HPCs also estimate savings for weatherization measures using software prescribed by Abode, the aforementioned LV responsible for managing the statewide HPC network.[4]

[3] CLEAResult is the LV for Eversource and National Grid, while RISE is the LV for Cape Light Compact, Liberty Utilities, and Unitil. (RISE also served natural gas National Grid customers on the Cape.) CET is the LV for Berkshire Gas.

[4] Abode originally managed just HPCs completing jobs within National Grid's service territory. In the summer of 2022, their role expanded to managing HPCs across the state.

1.2 Key Research Questions

This study sought answers to the following central research question and related sub-questions:

What are the gross energy savings generated by each RCD measure?

Sub-questions:

- How do these heating and cooling savings associated with weatherization (air sealing and/or insulation) vary across fuel types (included delivered fuels), participant types, and housing stock?
- Where is the initiative achieving the most impact? Which measures? Which customers? What building types? Where is the opposite happening?
- How do the evaluated savings compare with the current savings assumptions and regional benchmarks in Rhode Island and Connecticut? What are the potential reasons for any observed differences? Are they related to differences in program delivery, the population served, or evaluation methodologies/assumptions?
- What are the longer term trends in savings for historical measures? What do these trends imply for expected savings in the future?

1.3 Participation Summary

To provide readers with context for study findings, this section provides a brief overview of the evaluated RCD measures, each measure's or end use's contribution toward total RCD vendor estimated savings, and trends in recent participation.

1.3.1 Relevant Measures

As Table 1 shows, this study evaluated 11 discrete RCD measures associated with four measure end uses. The evaluation team also attempted to separately assess savings for envelope measures delivered through the PAs' more nascent MIQ offer, as these participants are tracked separately within the PA's Benefit Cost Ratio (BCR) model. However, the team did not ultimately develop separate savings for MIQ weatherization participants. The MIQ program did not include indicators for any participants in the 2021 data, and there were a very small number of participants indicated in the 2022 data (n=167). This small number of 2022 MIQ customers exhibited similar pre- and post-weatherization characteristics, which did not suggest the need to differentiate savings.

As suggested in the Considerations section, the PAs should revisit the comparison between MIQ and non-MIQ weatherization participants once more MIQ customers participate. Although the relatively small sample of initial MIQ participants in the dataset for this study were similar to non-MIQ participants, it is possible a more established and mature MIQ offering could reach participants in meaningfully different homes that merit MIQ-specific savings.

Table 1: Evaluated RCD Single Family Measures

Measure End Use	Measure
Envelope	• Air Sealing* • Insulation*
HVAC	• Boiler Reset Controls • Pipe Wrap (Space Heating) • Programmable Thermostat • Wi-Fi Thermostat • Duct Sealing • Duct Insulation • Heat Recovery Ventilators
Domestic Hot Water	• Faucet Aerator • Low-Flow Showerhead • Pipe Wrap (Water Heating)
Plug Load	• Smart Strips

*Measures for which LVs provide customer-specific estimated savings; also known as vendor estimated savings. The PAs use deemed values to claim gross energy savings for all other measures.

Source: Cadeo analysis of PA BCR models

This RCD impact evaluation covered fewer measures than the previous study in 2018. This coverage shift is the results of two notable changes:

Q1. **Heating systems in the Residential Retail initiative.** Since the previous RCD evaluation, the PAs shifted delivery of like-for-like delivered fuel heating system upgrades (i.e., replacing a less efficient heating oil furnace with a higher efficiency model) out of RCD and into the Residential Retail initiative. That initiative now covers all heating system updates, including all heat pump technologies associated with PAs' increasing focus on electrification. Energy specialists delivering HEAs still identify opportunities for heating system updates while in the home and offer recommendations for replacement. However, what has changed is that the installation of recommended heating equipment measures and processing of related rebates are no longer part of RCD.[5] RCD's remaining HVAC measures focus on saving energy through controls and pipe wrap.

Q2. **No lighting.** The previous RCD (then HES) impact evaluation included gross savings estimates for LEDs directly installed by energy specialists during HEAs. However, as evaluation results are applied prospectively and the PAs no longer incentivize lighting, the team did not evaluate any lighting measures as part of this study even though some of the 2021 and 2022 participants in this analysis received them.[6]

[5] As discussed later in this report, the evaluation team collected information about heating system installation that occurred through the Residential Retail initiative and, when relevant, controlled for the installation of these measures when assessing the savings associated with RCD measures.

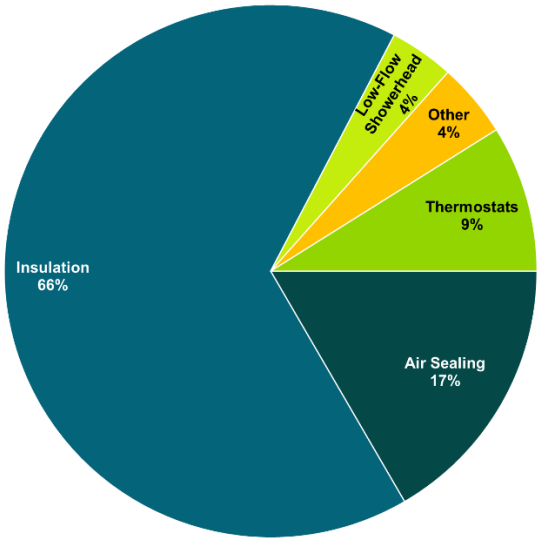
[6] Like measures installed through non-RCD initiatives, the evaluation team controlled for the installation of LEDs as part of the weatherization billing analysis for electrically heated customers (to avoid omitted variable bias and the conflation of savings).

Although this study will not develop prospective savings for heating systems or lighting—nor any other efficiency improvements incentivized through another PA residential initiative—the evaluation team did collect information about these measures to support this evaluation. Having this information enabled the team to control for non-RCD measures installed in participating RCD homes and avoid conflating savings across measures and initiatives.

1.3.2 Savings Distribution

Weatherization (i.e., air sealing and insulation) is the primary driver of RCD savings. In 2022, weatherization comprised more than three-quarters (83%) of total RCD vendor estimated annual savings[7] across all fuel types.[8]

Figure 1. Vendor Estimated Savings by RCD Measure – 2022



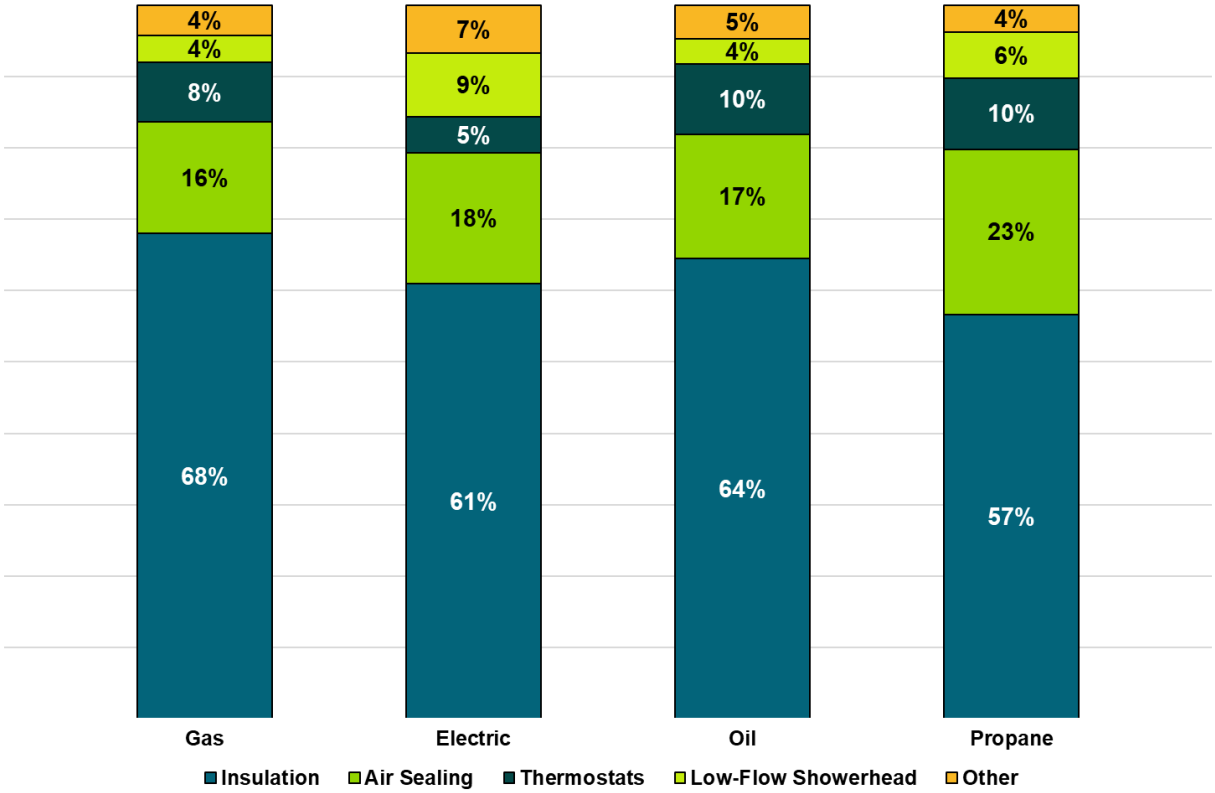
Source: MassSaveData.com

The overall importance of weatherization measures—again, air sealing and insulation—to RCD is not specific to any single heating fuel type. As Figure 2 shows, weatherization represented the majority of vendor estimated gross energy savings (in MMBtus) for all heating fuel types in 2022. It is important to remember that the majority of customers heat their homes with natural gas or heating oil, so while on a percentage basis, the savings are similar across all heating fuel types, the aggregate savings for electricity and propane are small in comparison with natural gas and heating oil (Figure 3). Furthermore, as discussed in subsequent sections in this report, the team identified differences inherent to the building stock across different fuel types, which resulted in differences in heating consumption and resulting savings.

[7] The savings, aggregated by DNV as the PAs' Data Management team and provided to the evaluation team, are akin to ex ante savings. The provided data included all RCD measures, which are a mix of vendor estimated values (for air sealing and insulation) and measures with deemed savings (all other measures). The savings provided in these datasets reflect first-year, annual savings. Given the longer effective useful life (EUL) for air sealing and insulation (relative to the other RCD measures), a recalculation of the figure above using lifetime savings would only further increase the contribution of weatherization measures toward total RCD savings.

[8] The team converted all reported savings to MMBtus to assess each measure's contribution to total RCD savings across fuel types.

Figure 2. Gross Weatherization Savings by Measure and Fuel Type – 2022

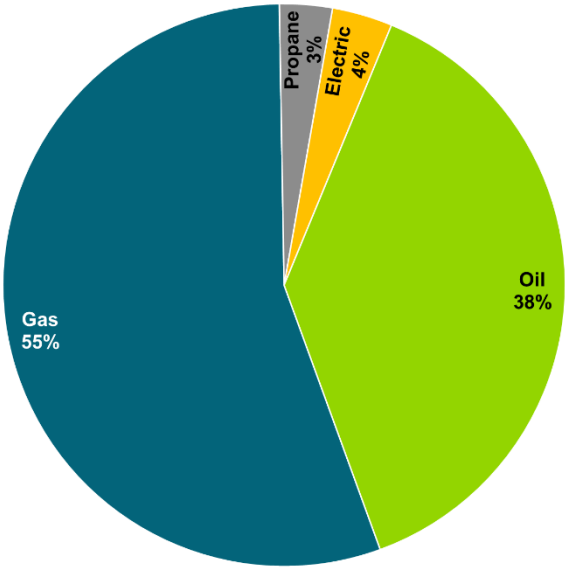


Source: MassSaveData.com

A significant portion of this report focuses on the evaluation team's billing analysis of weatherization participants that heat their home with natural gas. This focus is because the evaluation team had access to monthly energy consumption data for these participants (unlike heating oil or propane weatherization participants) and a large number of natural gas-heated customers participated (unlike electric weatherization participants), which enabled the team to complete a robust billing analysis.

These practical limitations, and resulting focus on natural gas weatherization measures, can obscure an important truth about the RCD initiative: delivered fuels, chiefly heating oil, are a significant source of RCD savings. As Figure 3 shows, gas savings (55%) were the largest contributors to total RCD savings, followed by oil savings (38%). Propane and electric savings made up a much smaller portion (3% and 4%, respectively) of total vendor estimated RCD gross energy savings in 2022.

Figure 3. RCD Savings by Fuel (2022)



Source: MassSaveData.com

1.4 Key Terminology

The evaluation team uses the language defined in Table 2 throughout the report to explain important impact evaluation concepts. Some of the terms are specific to RCD, while others are common to impact evaluations across programs.

Table 2. Summary of Key Evaluation Terminology

Term	Definition
Vendor Estimated Savings	Savings assumed by the PAs prior to an evaluation, which are either LV-specific modeled savings (for air sealing and insulation) or a deemed value based on the prior HES impact evaluation, a different evaluation report, and/or the state's Technical Reference Manual (TRM). In this report, vendor estimated savings are akin to ex ante savings (i.e., the savings expected from a given measure prior to an evaluation).
Evaluated Savings	Savings determined through this evaluation. In this report, evaluated savings are akin to ex post savings (i.e., the savings determined for a given measure as part of an evaluation).
Gross Realization Rate	The ratio of vendor estimated to evaluated savings that the PAs can officially claim for RCD, which can be greater than 1.0. For air sealing and insulation, the PAs apply the evaluation's realization rate to LV-specific estimated savings.
Treatment Group	The HES participants that installed a measure in 2021.
Control Group	The set of customers used in a billing analysis to serve as a counterfactual for estimating a program's impact and account (or control) for exogenous factors such as moves and rate changes that can otherwise obscure program-generated savings. In the context of this evaluation, the team used future RCD participants (i.e., customers that had their HEA in 2022) as the control group.
Normalized Annual Consumption (NAC)	The modeled annual consumption of a dwelling experiencing a typical meteorological year as defined by the Typical Meteorological Year x [TMYx] 2007-2021 data set. The model identifies a baseload and weather-dependent heating and cooling (heating only for natural gas). The NAC reflects all components.
Heating Normalized Annual Consumption (HNAC)	The modeled annual heating consumption of a dwelling experiencing a typical meteorological year as defined by the TMYx 2007-2021 data set. The model identifies a baseload and weather-dependent heating and cooling (heating only for natural gas). The HNAC reflects only the heating component.
Weatherization	A general term used to describe air sealing and/or insulation (one or more of attic, wall, or floor insulation). References to air sealing or insulation in the report are specific to that measure, whereas weatherization refers to one or both measures. Weatherization, as defined and used in this report, does not include duct sealing or duct insulation, which occur much less frequently as part of RCD.

Source: Cadeo

1.5 How to Use the Results of this Evaluation

This report summarizes the results of the RCD SF evaluation and the methodologies used to generate those results. For key RCD measures, primarily air sealing and insulation, the report includes a detailed explanation of the evaluated savings, how those savings compare with previous evaluations in MA and neighboring states, and, when relevant, why evaluated savings may differ from the initiative's vendor estimated savings and/or the benchmarked programs.

This report does not include details such as the engineering algorithm and specific primary and secondary data used to develop savings for less impactful RCD measures (e.g., faucet aerators). For these types of details, users of this evaluation should refer to the report's supplementary **Engineering Workbook**.

This Excel workbook includes a tab for each RCD measure that details the engineering algorithm used to evaluate that measure and all the values (and sources) for all inputs used in that algorithm. Each of these tabs link to common participant, housing stock, and engineering assumptions to ensure consistency across measures and complete transparency. The study determined, early in the evaluation process, that such a workbook (versus similar details provided in a static report appendix) was a more functional format for conveying these details. This reporting approach mirrors that of the previous RCD (then HES) impact evaluation.

To aid the PAs' prospective application of the results, the team also provided a second Excel workbook with measure-level results for **every relevant RCD BCR measure ID** (identification number). The PAs can directly use this workbook as part of their 2025-2027 planning process. Readers interested in utilizing these supplementary evaluation outputs should request access from a PA evaluation manager.

1.6 Report Organization

This report is designed to prioritize summarizing the study's key findings while providing insight into the evaluation's approach and information about all RCD measures. To achieve this goal, the body of the report includes four summary sections:

- Methodology
- Results Summary
- Key Findings: Weatherization
- Considerations

To supplement these summary sections, the report includes a set of appendices that elaborate and expand upon methodologies used as part of this study: These appendices include:

- Appendix A: Participant Survey Instrument
- Appendix B: Additional Billing Analysis Details
- Appendix C: Additional Building Simulation Details

2. Methodology

The evaluation team used a combination of billing analysis, engineering algorithms, and calibrated building simulation to evaluate the impact of every RCD measure. Specifically, the team used billing analysis whenever the model can produce measure-specific results at 90% confidence and greater than 20% precision.

When billing analysis cannot produce statistically significant results, the team evaluated savings using engineering algorithms (for measures that do not generate interactive effects) or calibrated building simulation (for measures that do).

2.1 Activities

The team completed four tasks as part of this impact evaluation.

Table 3. Summary of Evaluation Activities

Participant Survey

- Surveyed 665 randomly sampled 2021 (treatment) and 2022 (control) RCD participants that heat with natural gas and weatherized their home through RCD in 2021 and 2022.
- Completed using web-based survey via email in batches (~13% response rate).
- Provided all participants who completed the survey with a $25 incentive.
- Focused on any non-programmatic changes in the home (people moving in or out, adding or removing end uses, changes in working-from-home behavior, etc.) that occurred before or after participating in RCD.

The team has provided a copy of the participant survey instrument in Appendix A.

Billing Analysis

- Used to report evaluated savings when measure-specific billing analysis results met the pre-determined threshold of better than ±20% precision at the 90% confidence level.
- Combined customer billing records with weather and program participation data (HES and non-HES) to get a complete view of each customer's energy consumption drivers.
- Conducted a structured screening process to ensure that the evaluation team's model uses only those customers with sufficient billing data and without spurious billing records.
- Matched each treatment group participant (participated in 2021) to a control group (future HES participants from 2022) participant with a similar monthly pre-program energy consumption pattern.
- Specified and refined a monthly post-program regression (PPR) model.
- Validated PPR results using a variety of other billing analysis model specifications.
- Generated statewide and LV-specific results, which were weather-normalized using variable-based degree day (VBDD) analysis of TMYx weather data from 15 different weather stations across Massachusetts (mapped to the closest HES participant).

For additional details about the billing analysis methodology, see Appendix B.

Engineering Algorithms

- Relied primarily on algorithms from the TRM or previous evaluations in Massachusetts, including RES 34, that formed the basis for the current deemed savings estimates.
- Leveraged LV data to calculate program-specific inputs for each measure.
- When LV data was unavailable or insufficient, the team relied on regionally appropriate secondary data sources and other relevant studies—most notably the Massachusetts Residential Baseline Study, ENERGY STAR standards, Building America Benchmark Program Database, etc.
- Included literature review of recent relevant studies, US Department of Energy appliance standards, other state TRMs, and similar evaluations in other states.
- Made engineering adjustments to billing analysis results to inform savings estimates for delivered fuel measures, particularly for air sealing and insulation.

Calibrated Building Simulation

- Used REEDR[9] (Residential Energy Efficiency and Demand Response tool) software, an energy modeling program funded by the Regional Technical Forum (RTF), to model representative RCD homes.
- Constructed baseline home geometry and building characteristics based on LV data; inputs such as square footage, air sealing infiltration rates, wall attic and floor insulation, and building envelope, among others that were all informed by LV program data.
- Calibrated each model using disaggregated (heating, cooling, and baseload) monthly natural gas and electric consumption data.
- Simulated eight different scenarios reflecting various building types (detached SF and attached low rise homes), heating fuels, and whether buildings had cooling systems.
- Weighted the result of the eight models into a statewide average using the building type, heating fuel, and cooling data of the customers in the LV program data.

For additional details about the building simulations methodology, see Appendix C.

Source: Cadeo

2.2 Data Sources

The team used the following data sources to inform evaluation activities.

- **Billing data.** The PAs, via DNV (their data manager) provided 3 years of billing data (2020-2022) for each HES customer that had an assessment and/or installed a measure in 2021 or 2022.
- **Weather data.** To control for the effect of weather during the billing analysis period and to normalize the results to reflect a typical meteorological year, the evaluation team

[9] REEDR is a front-end energy modeling software solution used to run energy models for residential buildings in EnergyPlus. It was well-suited for this analysis due to its ability to define a myriad of inputs for a large sample size of residential buildings and process batches of parametric runs, which is vital during the calibration of energy models. Although REEDR was developed by a consultancy based in the northwest, it still runs on the same software as the vast majority of energy modeling front-ends (EnergyPlus) and does not contain any defaults or assumptions that are inherent to the northwest. More information can be found here: https://github.com/PtarmiganConsulting/REEDR.

acquired actual and TMYx data from the National Oceanic and Atmospheric Administration for all Massachusetts weather stations. The team mapped each HES customer to the closest weather station based on the customer's ZIP code. For each station, the team used a VBDD analysis to identify the optimal base temperatures for each participant by calculating heating degree days (HDDs) and cooling degree days (CDDs). The participant-specific base for calculating HDD was selected from a range of 55°F to 75°F while CDD selected a base from the range 65°F to 80°F using 5°F increments for both ranges. The team modeled each time span (pre- and post-participation) independently and so they can have different bases. The team used actual weather in the billing analysis regression model to quantify weatherization savings and then used normal weather data (TMYx 2007-2021) to adjust the savings estimates to reflect a typical meteorological year.[10]

- **DNV RCD measure data.** This data includes a list of all installed measures, including installation dates, BCR IDs, descriptions, and reported savings. Information for participating homes, including address, age of building, number of units, and square footage, was provided as linked tax parcel data.
- **LV RCD tracking data.** CLEAResult, RISE, CET, and Abode provided the evaluation team with detailed RCD tracking data for customers that received an HEA and/or installed measures in 2021 and 2022. These datasets contained information about each participant's home, the HES measures recommended after their HEA, and the measures installed by customers. The team combined these details with the aggregated PA data provided by DNV; the resulting dataset served as the backbone for all aspects of this evaluation. In particular, the team's engineering algorithm analysis drew heavily from these datasets to develop HES-specific input values, while the building simulation leveraged the datasets to model the average HES participant's home.[11]
- **Cross-program data.** As noted earlier, a subset of RCD participants installed measures incentivized by a different (i.e., not RCD) PA residential initiative before or after participating in RCD. To avoid conflating the savings associated with non-RCD measures when evaluating RCD measures, the team requested and received a dataset containing all non-RCD measures installed in RCD customer homes in 2020, 2021, and 2022. The team included variables in the billing analysis specification to account for the presence of these non-RCD measures as part of the team's analysis.

[10] The team used TMYx 2007-2021 weather data—not TMY3—to be consistent with the PAs' recent decision that all evaluations use the more recent weather file given the prospective application of evaluation results. While consistent with the PAs' guidance and concurrent evaluations, the shift to TMYx represents a shift from the previous evaluation (RES 34), as well as the weather data (TMY3) used by LVs. Please see Appendix B for more information about how the team adjusted the vendor estimated savings for air sealing and insulation to reflect TMYx weather conditions and ensure the appropriateness of this study's prospective gross realization rate for weatherization measures.

[11] The data provided by each LV varied. When possible, the evaluation team used a participation-weighted statewide average to develop inputs and model building characteristics. In the instances where one or more LVs provided a specific data field that the other LVs did not, the team used the available data to represent all participants.

3. Results Summary

Table 4 summarizes this evaluation's findings for each RCD measure, relevant fuel, and sub offering (i.e., SF and Attached Low Rise). The table also indicates which methodology—or combination of methodologies—the evaluation team used to evaluate the savings.

The team used engineering algorithms to evaluate most measures, while the billing analysis was limited to air sealing and insulation. Again, the evaluation team only reported ex post savings via billing analysis if the results were better than ±20% precision at the 90% confidence all level. This was only the case for air sealing and insulation in natural gas-heated homes. The team used a billing analysis-informed engineering approach for weatherized electric (insufficient statistical precision due to lesser participation), as well as heating oil and propane heated homes (lack of billing data). For more details about air sealing and insulation savings—for all four heating fuels—please see the Key Findings section.

Table 4. Evaluated Gross Energy Savings by Measure

Measure	Natural Gas (therms)	Electric (kWh)	Oil (MMBtu)	Propane (MMBtu)
BUILDING SHELL				
Weatherization (Insulation and/or Air Sealing) – Statewide	85	562	8.7	6.4
Insulation (Overall)	42	317	4.3	3.2
Distribution Savings, kWh		21/19/11		
Cooling Savings, kWh		36/35/21		
Air Sealing	43	253	4.4	3.2
Distribution Savings, kWh		11/10/6		
Cooling Savings, kWh		3/2/1		
Secondary Electric Heating, kWh[12]		52/52/52		
HVAC				
Boiler Reset Controls	43	-	-	-
Pipe Wrap (Space Heating)	13	-	1.3	1.3
Programmable Thermostat				
Heating savings	23	113	2.1	2.1
Cooling Savings, kWh	23	9	21	19
Wi-Fi Thermostat				
Heating Savings	31	167	31	2.6
Cooling Savings, kWh	22	14	17	17
Duct Insulation	10	46	1.0	1.0
Duct Sealing	17	73	1.7	1.7

[12] Secondary electric heating savings for homes heated with fossil fuels. Secondary electric heating for homes heated with electricity is included in the Weatherization savings in (kWh). Source: Rhode Island EnergyWise Single Family (EWSF) Weatherization Impact Evaluation (2023).

Measure	Natural Gas (therms)	Electric (kWh)	Oil (MMBtu)	Propane (MMBtu)
Heat Recovery Ventilator (HRV)	86	-	-	-
HOT WATER				
Showerhead	11	204	1.2	1.1
Faucet Aerator	4	63	0.4	0.4
Pipe Wrap (Water Heating)	3	42	0.5	0.3
PLUG LOAD				
Smart Strips	-	105	-	-

Source: Cadeo analysis

Billing Analysis
Engineering Adjusted Billing Analysis
Engineering Algorithm
Billing Analysis and Building Simulation

4. Key Findings – Weatherization

Because the overwhelming majority (83%) of RCD gross energy savings come from air sealing and insulation, the team has focused the key findings section on these two key measures, which, again, the team collectively refers to as weatherization. For information on non-weatherization measures, readers are referred to the previous Results Summary section, as well as the supplementary Engineering Workbook.

4.1 Natural Gas

Savings from weatherizing natural gas-heated homes is one of the primary drivers of total RCD savings. According to participation data, more than 10,000 RCD gas-heated customers air sealed their home and/or installed insulation in 2021.

4.1.1 Model Specification

The evaluation team used a Post-Program Regression (PPR) model specification to assess the impact of RCD weatherization in natural gas-heated homes. The PPR model specification is consistent with RES 34 (the prior HES evaluation), as well as several recent evaluations of comparable HEA-based residential retrofit programs in nearby Connecticut and Rhode Island.

In 2021, 99% of RCD participants that installed insulation also had their home air sealed through the initiative. This marked an increase from the prior evaluation (87%), as well as the evaluation before that (62%).[13] The near perfect overlap between air sealing and insulation participants is a positive sign: air sealing prior to installing insulation is best practice.

From an evaluation perspective, the significant overlap—while a good thing for the program—means it is not possible to separately assess air sealing and insulation using billing analysis. The reason is that the PPR model requires variation to accurately differentiate and quantify the effect of each independent variable. As nearly every insulation participant also had received air sealing, the model is unable to reliably parse the relative effect of each on a participant's total observed change in energy consumption. This phenomenon is common for residential retrofit impact evaluations; in fact, RES 34 faced the same issue. As a result, the team—as with the prior evaluation—modeled overall weatherization (i.e., air sealing and insulation together) savings via billing analysis and then subsequently used the concurrent building simulation modeling to disaggregated total weatherization savings into its constituent parts.

After careful consideration, the team employed the following PPR model specification to evaluate natural gas weatherization savings:

[13] The Cadmus Group, Home Energy Services Impact Evaluation, August 2021, https://ma-eeac.org/wp-content/uploads/Home-Energy-Services-Impact-Evaluation-Report_Part-of-the-Massachusetts-2011-Residential-Retrofit-and-Low-Income-Program-Area-Evaluation.pdf.

$$ADC_{ct} = \sum_{measure\ group\ m} b_{0m}Treatment_c + b_{1m}Measure_{mc} + b_2 LagADC_{ct} + \sum_{month\ i} b_{3i}Month_{it} + \sum_{month\ i} b_{4i}Month_{it} * LagADC_{ci} + b_5 CrossProg_c + e_{ct}$$

Where:

- ADC_{ct} = Average, weather-normalized daily energy consumption for customer *c* at calendar month *t.*
- $Treatment_c$ = 1 if customer *c* is in treatment, 0 if customer *c* is in control group.
- $Measure_{mc}$ = The reported savings from customer *c* if customer *c* is in received measure group *m*, 0 otherwise.
- $LagADC_{ct}$ = Average weather-normalized daily consumption from customer *c* during calendar month *t* of the pre-program period.
- $Month_{it}$ = 1 when index *i* = calendar month *t*, 0 otherwise. The evaluation team include this series of 12 terms to capture month-specific effects in the analysis.
- $CrossProg_c$ = 1 if customer *c* also installed a PA-incentivized energy-efficiency measure through another (non-RCD) residential initiative.
- e_{ct} is a cluster-robust error term from the regression model.

The evaluation team specified models that included independent variables for other natural gas measures sometimes installed through RCD, such as showerheads, aerators, or thermostats identified as measure groups earlier. Duct sealing and duct insulation round out the other measure groups. The team ran multiple variants of the primary specification to test the robustness of estimates. The team removed certain measure group terms when they did not significantly impact savings (p-value > 0.05) and the exclusion of the terms did not meaningfully impact the primary savings values of interest (weatherization) by 5%. This decision was consistent with the team's practice of limiting the terms in the final model specifications to only the independent variables with statistically significant coefficients. This practice reduces the chances of spurious results due to overspecification. The final model specification included terms for duct sealing, duct insulation, and aerators. The duct sealing and duct insulation measures did not provide significant estimates, but their removal changed the weatherization estimate to a point that was not consistent with the validation results (see section 4.1.4). The aerator term was significant but also highly colinear with other measure types

WHAT ABOUT COVID-19?

Because the natural gas billing analysis relied on customers that weatherized their home in 2022, every evaluated participant's pre-period (i.e., the year before weatherization) and post-period (i.e., the year after weatherization) occurred after societal changes resulting from COVID-19. Thus, differences in consumption observed via the billing analysis are not a function of pre- and post-COVID factors, such as more people working from home. Any changes in "post-COVID" behavior over time (i.e., 2021, 2022, and 2023) are also accounted for by the inclusion of the control group that was experiencing similar societal trends. Further, the fact that this analysis focused entirely on post-COVID years means these results are more prospectively applicable as some changes—such as an increase of work-from-home behaviors—appear likely to continue during the next three-year implementation cycle.

and represents a combination of multiple influences on consumption. Removing terms caused the estimated savings for weatherization to drop 1.6%. The value after removing terms is closer to the validation results.

4.1.2 Data Attrition

To further ensure the reliability of the billing analysis results, the evaluation team removed participants without sufficient billing records or that exhibited extreme or counterintuitive energy consumption. Removal of these customers mitigates their potential bias on the billing analysis result. Table 5 summarizes the team's billing analysis sample attrition factors and disqualifying thresholds.

Table 5. Billing Analysis Sample Attrition – Natural Gas

Attrition Metric	Excluded	Percentage	Remaining
Total gas accounts receiving weatherization	-	-	16,451
Do not heat with natural gas	7	<1%	16,444
Unable to map to billing data	499	3%	15,945
Incomplete billing data (Less than 12 months pre- and post-periods)	3,326	20%	12,619
Extreme consumption (< 150 therms or > 2,500 therms annually in pre- or post-periods)	730	4%	11,889
Significant change (> ±50% change between pre- and post-period, a likely indication of non-programmatic changes impacting consumption)*	1,533	9%	10,356
Total	**6,095**	**37%**	**10,356**

*The team tested the sensitivity of the results to this filter (i.e., did including or excluding participants experiencing a change of ±50% impact the billing analysis results). The team found it did not; including participants with change of ±50% impact had a minimum impact (i.e., less than 2%) on modeled savings and the resulting gross realization rate.

Source: Cadeo analysis

4.1.3 Results

As Table 6 shows, the evaluation team determined that natural gas-heated RCD participants who weatherized their home in 2021 saved, on average, 85 therms/year. This reflects 11% of the average participant's annual pre-program heating consumption. This value represents the average savings for any natural gas-heated RCD in Massachusetts that received air sealing and at least one insulation type of insulation (attic, wall, or floor). The exact amount of air sealing performed, as well as the volume and types of insulation installed, varies by participant. This evaluated savings accounts for that variation—some weatherization participants saved more, some saved less—and represents the average achieved gross energy savings across RCD weatherization participants.

ARE BILLING ANALYSIS RESULTS GROSS OR NET?

Billing analysis produces a result that lies on a spectrum between net and gross savings. The exact location on that spectrum depends on the customers in the control group and the measure in question. As the evaluation team is focusing the billing analysis on weatherization, as well as using future participants as the control group, the results of the billing analysis—per the guidance of the Uniform Methods Project—should be considered **gross**.

Table 6 also includes LV-specific savings for CLEAResult, RISE, and Abode, which manages the HPC network.[14] The billing analysis results for all three LVs exceeded the evaluation team's reporting threshold of ±20% precision at the 90% confidence level. As evident, the results for Abode and CLEAResult had a precision of less than ±10% (9.5% and 8.9%, respectively).

Table 6. Evaluated Weatherization Savings – Natural Gas

LV	Participants (Sample Size)	Evaluated Savings (therms/year)	Precision (±% at 90% CI)	Normalized Annual Heating Consumption (therms)	Percentage of Heating NAC
Abode	5,274	83	9.5%	790	11%
CLEAResult	3,273	106	8.9%	798	13%
RISE[15]	1,809	55	17%	816	7%
Statewide	**10,356**	**85**	**6.9%**	**796**	**11%**

Source: Cadeo analysis

[14] None of the limited number of CET weatherization participants (less than 0.4% of statewide participation) passed the data screening process detailed in Table 5.

[15] The evaluation team also separately modeled RISE-served participants that live on the Cape and those that live in central Massachusetts. The team found the savings were nearly identical.

Table 7 compares the evaluated LV-specific weatherization savings to the vendor estimated weatherization savings[16] for the specific set of 2021 participants included in the evaluation's billing analysis. The ratio of these two values (evaluated savings/vendor estimated savings) yields the relevant gross savings realization rate for each LV, which is the metric the PAs proactively apply to each LV's estimated savings before reporting those savings against their goals.

Table 7. Comparison of Evaluated and Vendor Estimated Weatherization Savings – Natural Gas

LV	Evaluated Savings (therms/year)	Vendor Estimated Savings* (therms/year)	Gross Energy Realization Rate
Abode	83	175	0.48
CLEAResult	106	218	0.49
RISE	55	130	0.42

*Adjusted to reflect TMYx

Source: Cadeo analysis

The gross realization rates Table 7 shows (for prospective application by the PAs) range from 0.42 to 0.49. The gross realization rates from this evaluation are less than the gross realization rates determined as part of the prior impact evaluation (0.68-0.83). This comparison suggests that LV energy modeling practices continue to overestimate weatherization savings relative to periodic, independent impact evaluations, which have (like this study) historically used billing analysis to estimate savings.

Abode and CLEAResult use the same software to estimate weatherization savings and serve customers in the same geographic area. Consequently, the difference in vendor estimated savings in Table 7 are not a function of the software but rather the customers served by each LV. As a reminder, Abode oversees the HPCs that proactively engage customers, conduct HEAs, and install recommended measures, while CLEAResult completes HEAs on behalf of customers enrolling via the Mass Save website or phone number. It is likely the different ways these customers entered the initiative are correlated with differences between the customers themselves, the homes they live in, and their estimated weatherization savings.

The evaluation team studied this phenomenon (i.e., LVs estimating greater savings than evaluations) directly in March 2020 following RES 34, the previous initiative impact evaluation. That study (RES 39) identified several potential causes for the disparity.[17] Chief among the potential causes for the disparity is the fact that none of the LVs calibrate their vendor estimated savings using participating customers' actual pre-RCD energy consumption. Thus, the savings estimates the LV produces, while modeled to reflect the characteristics of each customer's home, are untethered from each participant's actual pre-weatherization usage. While some LVs

[16] The actual vendor estimated savings provided by LV were different from the values Table 7 shows. This is because LVs used TMY3, not TMYx, weather data to develop their estimates. As the PAs are instructing their implementation and evaluation vendors to use TMYx (which the evaluation team did for the billing analysis), it was necessary to weather adjust the LV savings to create an apples-to-apples comparison of the billing analysis results and ensure the evaluation reported gross realization rates that are useful prospectively when the LVs switch to using TMYx. Please see Appendix B for more details about this weather adjustment.

[17] Navigant and Cadeo, Home Energy Services Impact Evaluation, March 2020, https://ma-eeac.org/wp-content/uploads/MA-RES-39-HES-RR-Assessment-Executive-Summary_FINALwES_19MAR2020.pdf.

have updated their savings approach since RES 39 (e.g., RISE shared they had decreased air sealing savings assumptions), informal discussions with the PAs, as well as this evaluation again finding low gross realization rates for natural gas weatherization, suggest that many of the RES 39 findings remain relevant.

The implications of the overestimated vendor savings are two-fold:

- **Unrealistic expectations.** The initiative is setting unrealistic savings expectations with customers. This impact could negatively affect customer satisfaction if and when those savings are not realized. This, in turn, adversely affects word of mouth about the initiative, which previous process evaluations found was a primary reason customers signed up for an assessment.

- **Reporting adjustments.** As the PAs know the LV estimates have historically overestimated savings, the PAs make proactive adjustments to the LV estimated savings before officially reporting. This adjustment is an extra step and adds complexity to the reporting process.

4.1.3.1 Additional Electric Benefits of Weatherization

The previous tables focus on the natural gas savings achieved when participants weatherize their homes and use less natural gas to heat their homes in the winter. However, weatherization can also yield electric savings in homes that use natural gas (or a delivered fuel) as their primary heating fuel.[18] This evaluation accounted for three types of weatherization-related electric savings:

- **Distribution savings.** When weatherized participants run their primary heating systems less frequently (due to the RCD-improved building envelope), their electrically driven furnace fan or circulating pump (which moves the heated air or water through the home) runs less. Based on the team's engineering analysis, the average natural gas-heated weatherization participant saves 32 kWh/year from reduced distribution usage.

- **Cooling savings.** The RCD-improved building envelope also reduces air conditioning usage during the summer. The team used air conditioning equipment type saturations (central systems, room air conditioners, no cooling) from program data and building simulation to estimate air conditioning savings for the average weatherization participants who use natural gas as their primary heating fuel. The team determined that the average participant savings, which, again, reflects a weighted average of all three cooling scenarios, was 39 kWh/year from reduced air conditioning usage.

- **Secondary electric heating savings.** Some households supplement their primary heating – whether natural gas or another heating fuel – with secondary, zonal electric heating (e.g., a portable, plug-in electric resistance or a wall mounted space heater in a bathroom). Weatherization can change how RCD participants use these secondary electric heaters as well as how they use their primary heating system. For example, it is possible that a participant, after weatherizing their home, may stop or reduce using the plug-in heater since their weatherized home is less drafty. It is also possible that a

[18] These three types of additional electric benefits are relevant for all primary heating fuel types (i.e., not just natural gas). See Table 4 for a complete set of electric weatherization savings for all primary heating fuel types.

weatherized participant could use their secondary heating system more because – post weatherization – it can sufficiently heat a portion of their home without turning on the primary heating system. This evaluation did not directly evaluate the saturation of secondary electric heaters in MA homes or the impact of RCD weatherization on how participants used those heaters. However, a recent (2023) impact evaluation of a comparable program in nearby Rhode Island (the EnergyWise Single Family program) conducted a participant survey and secondary electric heating-focused billing analysis.[19] The results of that evaluation, which are applicable to RCD given the similarity of the programs and geographic proximity, found that 25% of weatherized natural gas participants used secondary electric heaters and that those participants saved, on average, 209 kWh/year after being weatherized. This means the average RCD weatherization participant that primarily heats with natural gas saves 52 kWh year (i.e., 25% save 209 kWh/year while 75% save 0 kWh/year since they do not use secondary electric heating).

4.1.4 Validation

To assess the validity of the statewide PPR model results, the team estimated savings using a variety of PPR and non-PPR model specifications, as well as by analyzing unmodeled data. As evident in Table 8, the results were consistent across specifications and approaches, ranging narrowly from 79 and 102 therms/year with a concertation of estimates in the low to mid-80s. This consistency—and similarity to the statewide PPR model savings of 85 therms/year—gave the evaluation team confidence in the results.

Table 8. Alternative Weatherization Model Specifications and Results – Natural Gas

Alternative Specification	Modeled Savings (therms /year)	Explanation
PPR - Wx Only	82	Removed participants that received other measures (instead of controlling for them)
PPR - Categorical Cross-Participation	83	Used a binary indicator for non-RCD installs (instead of reported savings associated with those measures)
PPR - Expanded Control Matching	82	Matched with five most similar “future” participants (instead of the best match)
PPR - Direct HDD Encoding	84	Controlled for temperature using average HDD for each month (instead of month indicators)
Difference in Differences	79	A simplified regression model that does not account for other types of measures
Pooled Fixed Effects	102	This model does not have a specific control group but accounts for individual differences
Difference of Differences	80	The unmodeled difference between savings (pre and post) between the treatment and matched control group

Source: Cadeo analysis

[19] https://rieermc.ri.gov/wp-content/uploads/2024/03/ri-23-rx-ewisepy21_final-report_10oct2023.pdf

To further validate the billing analysis results, the team completed a supplementary billing analysis using information provided by the 665 RCD natural gas weatherization participants (220 treatment and 355 control, after controlling for incomplete responses) who responded to the survey. The survey was designed to gather additional insights into participants' homes and behavior—beyond that available in the LV tracking data—to test for omitted variable bias when conducting population-level billing analysis.

Omitted variable bias occurs when a relevant explanatory variable (i.e., one that impacts the dependent variable) is not included in a regression model specification. In other words, the model specification does not include the full set of relevant independent variables that explain the variation in the dependent variable. Omitted variable bias can cause the coefficient of one or more explanatory variables included in the model specification to be biased. In this case, the explanatory variable could be the impact of the RCD weatherization on a participant's energy consumption.

To mitigate omitted variable bias, the evaluation team used the survey to collect and include a more complete set of explanatory variables in the supplemental model specification. For example, the team collected and specified models that accounted for changes between the pre and post periods related to work (i.e., working from home), occupancy (e.g., people moving in or out, presence of children), and changes in the home (e.g., remodeling or new end uses) to explore whether the inclusion of this additional information yielded a statistically significantly different estimate of weatherization savings for RCD participants.

The team's supplemental, survey-based billing analysis yielded a similar statewide result (75 therms/year) to the population-level results described throughout this section (85 therms/years).[20] As the last column in Table 9 shows, the confidence intervals (CI) for the results for both groups overlap, which means the two values are not statistically significantly different from one another. This result suggests population-level billing analysis results the evaluation team is using to officially report RCD weatherization savings are valid and not adversely impacted by omitted variable bias.

Table 9. Comparison Population- and Survey-Based Billing Analysis Results – Natural Gas

Analysis Group	Participants (Sample Size)	Evaluated Savings (therms/year)	Percentage of Heating NAC	Precision (±% at 90% CI)	Savings Range (therms/year ±% CI)
Population	10,356	85	11%	±7%	79-91
Survey[21]	220	75	13%	±12%	63-87

Source: Cadeo analysis

For more information about this supplemental, survey-based billing analysis, see Appendix B.

[20] The survey sample was not large enough to produce viable LV-specific results (i.e., at least ±20% at 90% CI.)

[21] The specific subset of RCD weatherization participants that responded to the survey had, on average, lower annual pre-program heating consumption than RCD participants overall. This resulted in slightly higher percent savings despite a slightly lower estimate of annual weatherization savings.

4.1.5 Benchmarking

Benchmarking is an essential part of all thorough impact evaluations. The practice provides critical insight into how the results of a given evaluation compare with previous evaluations of the same initiative, as well as to the evaluations of comparable initiatives offered by other program administrators. These comparisons, in turn, build confidence in the results (i.e., helping stakeholders understand why evaluated savings are similar or different to benchmarked values) and yield helpful insights that can lead to program improvements.

4.1.5.1 Relative to the Previous Evaluation

Table 10 compares the evaluated statewide result for 2021 natural gas-heated weatherization participants from this evaluation to the statewide result for the 2015 and 2016 participants evaluated as part of RES 34. Table 11 also compares a variety of factors—average pre-program heating consumption, the average types of insulation installed and home size—understood to impact weatherization savings.

As Table 10 shows, average statewide per-participant weatherization savings decreased by 35% relative to the previous evaluation. Roughly half of this decline is attributable to lower average annual pre-initiative heating consumption, which directly impacts the savings potential in participating homes. The treatment group of RCD participants included in this evaluation (weatherized in 2022) had on average, 17% lower pre-RCD annual heating consumption relative to the cohort of participants in the previous evaluation (weatherized in 2015 and 2016). This decrease in consumption reflects several factors, including higher saturations of efficient heating equipment and smart thermostats. A portion of the decrease – approximately 7% of the 17% - is methodologically driven. The TMYx weather files that the evaluation team used to weather normalize the results of this study reflect less heating degree days than the TMY3 weather files used in the previous evaluation.[22]

However, the decline in percentage of pre-program heating consumption saved by weatherization, which went from 13% to 11% (at 15% change) is less severe due to the lower pre-program heating consumption determined for 2021 weatherization participants.

[22] The PAs have directed all their evaluation contractors to transition to TMYx files to ensure the results of impact studies reflect recent weather patterns, which improves their prospective applicability. See Appendix B for more details.

Table 10. Comparison with Previous RCD (then HES) Impact Evaluation – Natural Gas

	Previous Evaluation*	Current Evaluation**	Directional Effect on Savings	Notes
Evaluated Savings (therms/year)	**130**	**85**		**35% decline in evaluated savings**
Vendor Estimated Savings (therms/year)	178	180		Very similar value (after TMYx adjustment)
Average Annual Pre-Program Heating Consumption (therms/year)	964	796		17% decline in pre-usage, which directly effects size of savings opportunity
Savings as % of Pre-Program Heating Consumption	13%	11%		Modest decrease in savings in percentage terms.
Average # of Installed Types of Insulation (per participant)	1.4	1.6		Modest increase in average since 2015/16
% of Weatherization Participants Installing Attic/Ceiling Insulation	85%	76%		Slight decrease relative to 2015/2016 cohort
% of Weatherization Participants Installing Wall Insulation	22%	53%		The percentage of participants installing wall insulation more than doubled relative to 2015/2016.
% of Weatherization Participants Installing Basement/Floor Insulation	23%	9%		Drop in basement/floor installations
Home Size (Square Feet)	1,860	1,843		Very similarly sized homes

*All savings and consumption values in the "Previous Evaluation" column were modeled—by the LV and evaluation team - using TMY3 weather data, which was standard practice when RES 34 was completed in 2018.

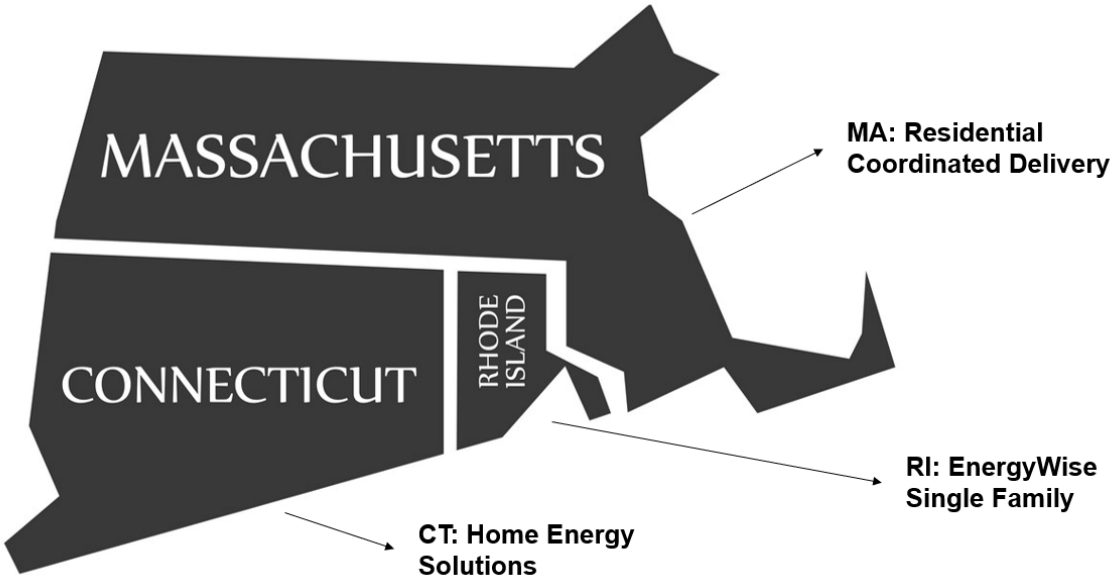
**Alternatively, all savings and consumption values in the "Current Evaluation" column are based on TMYx weather data, which aligns with the PAs' updated weather normalization guidance.

Source: Cadeo analysis

4.1.5.2 Relative to the Other Initiatives

To provide context for these gross savings results, the study compared them to the results of the most recent evaluations of similar programs offered in neighboring states: Home Energy Solutions in Connecticut and EnergyWise Single Family in Rhode Island.

Figure 4: Relevant Regional Benchmarks



Source: Cadeo analysis

Table 11 compares the results of this—and the previous RCD impact evaluation—to recent evaluations in Connecticut and Rhode Island. While the design and delivery of each program differs somewhat,[23] all three programs are assessment-based and encourage participants to weatherize their homes using incentives to offset the upfront cost.

As evident in the Table 11, the average savings for weatherized 2021 natural gas-heated RCD participants is slightly higher than the most recent HES study in CT (80 therms) and decidedly lower than most recent EWSF study in Rhode Island (131 therms).

Table 11. Benchmarking: Previous MA Studies and Other Regional Weatherization Programs (Natural Gas)

State	Program	Evaluated Program Year(s)	Energy Savings (Therms)	Precision (% +/-)	% of HNAC	Billing Analysis Sample N
MA	**RCD**	**2021**	**85**	**7%**	**11%**	**10,356**

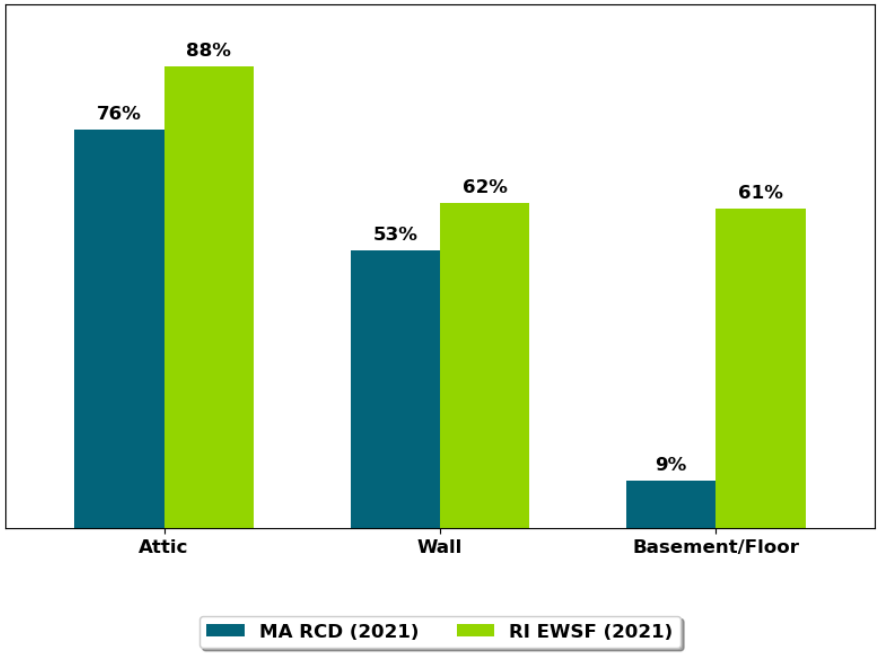
[23] The most notable difference is that the Home Energy Solutions (HES) program in Connecticut conducts air sealing during the initial home energy assessment itself (versus during a subsequent visit to install insulation like RCD and EWSF).

State	Program	Evaluated Program Year(s)	Energy Savings (Therms)	Precision (% +/-)	% of HNAC	Billing Analysis Sample N
MA	HES	2015-2016	130	2%	13%	3,357
RI	EWSF	2021	131	6%	13%	1,955
RI	EWSF	2017-2018	96	6%	8%	2,156
CT	HES	2019	80	11%	7%	1,117
CT	HES	2015-16	226			

Source: Cadeo analysis

A closer comparison between the RCD and the EWSF program in RI sheds light on a likely driver of the savings disparity. In 2021, the average RCD weatherization participant installed 1.4 types of insulation, whereas the average EWSF participant in the same year installed 2.1 types. In fact, EWSF participant installation percentages outpaced RCD participants for all three types of insulation. In summary, EWSF weatherization participants more comprehensively weatherized their homes relative to RCD weatherization participants. This fact, at least in part, likely explains the higher savings for EWSF.[24]

Figure 5. Benchmarking: Comparison of Types of Installed Weatherization – Natural Gas



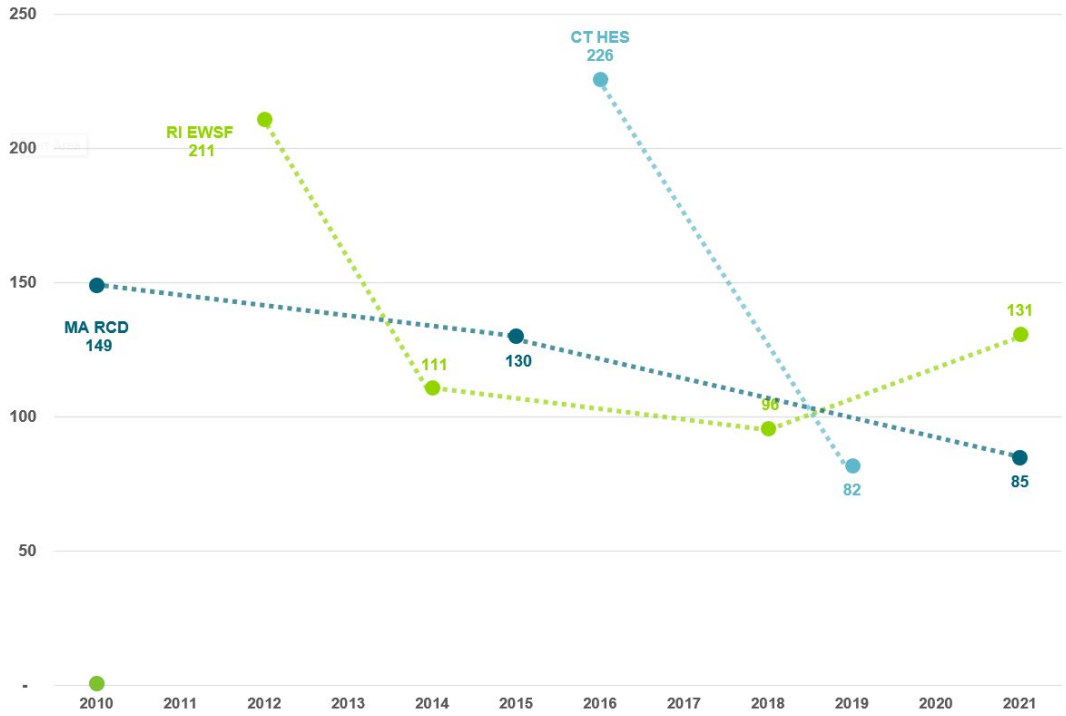
Source: Cadeo analysis

Zooming out, the lower average savings for RCD relative to the previous evaluation is consistent with a long-term, regional trend of declining average natural gas weatherization savings. As shown in Figure 6, the programs in Connecticut and Rhode Island have also exhibited a downward trend in savings over the past decade. In fact, only one study in the

[24] The RI evaluation also used TMYx weather files which resulted in consistent weather-related comparisons across the two studies, though RI does have inherently different weather patterns than MA.

region—the most recent EWSF evaluation in Rhode Island—found higher savings than a prior evaluation.[25]

Figure 6. Evaluated Savings Over Time by State – Average Weatherization Savings (therms/year) for Natural Gas-Heated Customers



Source: Cadeo analysis

4.2 Electricity

This section details the evaluation team's analysis of electrically heated weatherization participants. To begin, the team attempted a billing analysis for electrically heated weatherization participants using a similar approach to natural gas-heated participants. However, despite experimenting with various model specifications, none of the models produced sufficiently reliable (i.e., better than ±20% precision at the 90% confidence level) to use for reporting. Consequently, the team employed an engineering approach—specifically engineering adjusted billing analysis—to evaluate electric weatherization savings. The primary reason the team was unable to specify a model with statistically significant savings estimate was the relatively small number of 2021 RCD weatherization participants that use electricity as their primary heating fuel (n=937). For comparison's sake, the team modeled over 10,000 natural gas-heated customers.

[25] The higher result was due to EWSF weatherization participants installing more types of insulation than their counterparts in the prior evaluation.

4.2.1 Approach

To determine the savings associated with the weatherization of homes using electricity as their primary heating fuel, the team required two steps: determining the amount of electricity weatherization participants used to heat their homes before the RCD and the relevant percentage of that consumption they saved as a result of weatherizing as a result of RCD.

Primary Heating Fuel	Annual Pre-Consumption	% Saved by Wx
Natural Gas	**Known** (Bill disaggregation of provided RCD participant energy consumption data.)	**Known** (Statistically significant billing analysis results)
Electricity	**Known** (Bill disaggregation of provided RCD participant energy consumption data.)	**Unknown** (Unable to complete statistically significant billing analysis)

The team was able to use monthly energy consumption data provided by the PAs to inform the first input, while the latter required the team to make engineering adjustments to—and then apply—the percentage of pre-program heating consumption saved from natural gas billing analysis findings.

4.2.2 Calculating Annual Pre-Consumption

Electric pre-consumption was modelled the same as gas, but electricity has an explicit temperature sensitive cooling component:

$$ADC = \mu + \beta_H H_m + \beta_C C_m.$$

Where:

- H_m is the average daily heating degree days at the base temperature(τ_H) during month m, based on daily average temperatures on those dates.
- C_m is the average daily cooling degree days at the base temperature(τ_C) during month m.

The team calculated base temperatures τ_H and τ_C using a variable degree day analysis. The team fit values μ, β_H & β_C to the data and describe the base, heating, and cooling behaviors of a participant. The team used these parameters to calculate a weather normalized Consumption as $\mu + \beta_H \hat{H}_m + \beta_C \hat{C}_m$ where $\hat{H}_m$ and $\hat{C}_m$ are the average heating and cooling degree days based on average temperatures for the corresponding month m from the TMYx normalized temperature data. The team focuses on the heating component of the electricity consumption which is annualized by calculating $365.25 * \beta_H H_m$.

The data provided by DNV indicated the average weatherized participant heating with electricity consumed 13,412 kWh year. Using billing disaggregation, the team determined that, on average, 5,759 kWh (or 43%) of these participants' total annual electric consumption was heating related.[26]

4.2.3 Estimating Percent Savings

As the team was unable to use billing analysis to estimate weatherization savings for electric primary heating, the team used an engineering approach that leveraged the statistically

[26] The lower electricity HNAC relative to natural gas heated homes could be in part due to smaller home size of electrically heated homes (refer to Table 12 for comparison), as well as generally higher levels of existing insulation.

significant billing analysis result for natural gas. The reason the team uses an approach rooted in the natural gas billing analysis (instead of a separate engineering algorithm or building simulation approach) is because of billing analysis' implicit ability to account for the myriad of factors (e.g., pre-conditions, installation quality, behavioral change, and non-programmatic macro trends) that those approaches do not.

However, applying the natural gas billing analysis results to other fuel types requires care. Specifically, the team applied several engineering adjustments to the natural gas billing analysis results to estimate the weatherization savings in electrically heated homes. These included accounting for the following differences between natural gas and electrically heated customers:

- **Installed insulation.** The data provided by DNV for the 2021 cohort allowed disaggregation of the installed insulation (sqft) by insulation type (e.g., attic, wall, and floor). The result is a weighted average area of installed insulation by fuel type (Table 12). When comparing electrically heated homes to natural gas-heated homes, electrically heated homes installed 98% of the insulation per home (74% divided by 76%) compared with gas-heated homes, after controlling for differences in homes sizes. As a result, the team developed a 98% adjustment factor to apply to the observed natural gas percent savings from the billing analysis to electric weatherization participants.

Table 12. Installed Insulation Area: Comparison of Electrically and Natural Gas-Heated Participants

Fuel Type	Home Vintage	Home Floor Area (sqft)	Insulation Installed Per Home (sqft)	Insulation as Percentage of Total Home Floor Area	Adjustment Factor
Gas	1960	1,843	1,399	76%	1.00
Electricity	1969	1,526	1,131	74%	0.98

Source: Cadeo analysis

- **Pre-program conditions.** The team also explored the necessity of an additional adjustment to account for differences in pre-program insulation levels between natural gas and electrically heated customers. In other words, did natural gas and electrically heated customers enter the program with different existing conditions (e.g., pre-program attic R-values) prior to being weatherized that would impact savings? If so, it would be important for the team to account for that difference when leveraging the natural gas billing analysis results to estimate electric weatherization savings. As shown in Table 13 which represents participants who received insulation, the team found the average[27] pre-program existing conditions in attic, wall, and floor were similar between electric and natural gas participants, but not identical.

[27] Please note the team converted the R-values in the tracking data to U-values before averaging them.

Table 13. Insulation R-Value Comparisons: Electric- and Natural Gas-Heated Participants

Insulation Type	Fuel Type	Average Pre-Program R-value	Average Post-Program R-value	ΔU-factor[28]
Wall	Natural Gas	9.5	23.8	0.063
	Electricity	9.9	23.8	0.059
Attic	Natural Gas	16.4	45.0	0.039
	Electricity	19.6	56.6	0.033
Floor	Natural Gas	12.0	24.2	0.042
	Electricity	11.9	28.6	0.049

Source: Cadeo analysis

The team calculated the difference in the U-factors associated with the pre- and post- condition R-values and weighted those differences by the relative proportion of insulation type to arrive at an overall adjustment factor. The adjustment factor accounts for both the difference in pre- and post- program conditions, as well as the differences in types of installed insulation (wall, attic, and floor), as shown in Table 14.[29]

In general, the electrically heated homes weatherized in 2021 tended to be better insulated prior to participating in RCD than natural gas-heated homes. As a result, the team needed to make a downward adjustment before applying the savings percentage from the natural gas billing analysis to weatherized electrically heated participants.

Table 14. Insulation U-factor Comparisons: Electric- and Natural Gas-Heated Participants

Insulation Type	Fuel Type	ΔU-factor[28]	ΔU-factor Relative to Natural Gas	2021 Insulation Count	Insulation Count Relative to Natural Gas
Wall	Natural Gas	0.063	100%	0.60	100%
	Electricity	0.059	94%	0.38	64%
Attic	Natural Gas	0.039	100%	0.69	100%
	Electricity	0.033	92%	0.79	114%
Floor	Natural Gas	0.042	100%	0.20	100%
	Electricity	0.049	100%	0.25	122%
Weighted average electric adjustment factor compared to natural gas					**94%**

Source: Cadeo analysis

[28] The team converted pre- and post- R-values to U-factors for a more accurate comparison of insulation characteristics across fuel types.

[29] Please see the evaluation's supporting workbook for more details about this analysis.

The results from applying these adjustment factors accounting for installed insulation and R-value differences are summarized in Table 15.

Table 15. Estimated Electric Percent Heating Savings

Metric	Value	Notes
Natural Gas Percentage of Heating Savings	**11%**	Based on billing analysis bill disaggregation; weather normalized using TMYx (2007-2021)
Adjustment Factor #1: R-value Differences	94%	Electricity participants had more existing insulation pre-program, and thus generally had less frequent insulation installations than natural gas participants
Adjustment Factor #2: Installed Insulation	98%	Electricity participants installed similar amount of insulation per square foot of home floor area as natural gas participants
Electricity Percent Heating Savings	**10%**	

Source: Cadeo analysis

4.2.4 Results

Using this approach, the team determined that RCD participants saved 10% of pre-participation household electricity heating. Applying this value to the electric heating consumption determined through the bill disaggregation resulted in an average savings of 562 kWh (Table 16).

Table 16. Electric Weatherization Results (2021 Participants)

Measure	Energy Savings (kWh/year)	Normalized Annual Consumption (kWh)	Percentage of NAC	Normalized Annual Heating Consumption (kWh)	Percentage of Heating NAC
Weatherization	**562**	13,412	4%	**5,759**	10%

Source: Cadeo analysis

These evaluated electric weatherization energy savings are much less than previous evaluation (1,298 kWh/year) for the following reasons:

- **Lower Pre-Program Heating Consumption.** Participant's normalized annual heating consumption was lower in 2021 at 5,759 kWh on average compared to 6,991 kWh observed in the previous evaluation. This 18% reduction in pre-program annual heating consumption aligns with the 17% reduction the evaluation team observed in natural gas pre-program annual heating consumption.[30]

- **Less Percent Savings.** Savings due to weatherization, which were leveraged from the natural gas billing analysis and modified to reflect electric participants, were much lower

[30] Similar to the natural gas weatherization billing analysis, the electric weatherization participant bill disaggregation completed as part of this study relied on TMYx (compared to TMY3 in RES 34). The lesser HDD associated with TMYx weather data is, at least in part, responsible for this disparity in pre-program electric heating consumption. Please note the increased cooling savings from electric weatherization – from greater CDD in TMYx – is applied separately and not reflected in this heating-only savings value.

as part of this evaluation (10% of pre-program heating consumption) than the previous evaluation's percentage (18%).

Table 17 provides the evaluated electric weatherization savings by LV, compares that value to each vendors' estimated savings, and shows the resulting gross realization rate. While the low observed realization rates are in part due to abnormally high vendor estimated savings it is also important to remember that the majority of participants are heated with fossil fuels and not electricity.[31] Therefore, this low realization rate is not as impactful to overall program energy savings as the fossil fuel realization rates.

Table 17. Electric Weatherization Gross Realization Rates by LV

LV	Evaluated Savings (kWh/year)	Adjusted Vendor Estimated Savings* (kWh/year)	Gross Realization Rate
Abode	454	3,360	0.14
CLEAResult	549	4,085	0.13
RISE	324	2,748	0.12

*Adjusted to reflect TMYx weather data

Source: Cadeo analysis

4.3 Delivered Fuels – Heating Oil and Propane

Unlike the monthly natural gas and electric consumption data provided by the PAs, the team did not have access to usage data for weatherized RCD participants that heat their homes with a delivered fuel (i.e., heating oil or propane.) This meant that the team could not use direct information about delivered fuel usage to determine annual pre-program consumption or to undertake a billing analysis to model savings.

Primary Heating Fuel	Annual Pre-Consumption	% Saved by Wx
Natural Gas	**Known** (Bill disaggregation of provided RCD participant energy consumption data.)	**Known** (Statistically significant billing analysis results)
Delivered Fuels	**Unknown** (No access to participant consumption records)	**Unknown** (Unable to complete billing analysis without consumption records)

Consequently, the team again leveraged the natural gas billing analysis—first to estimate the annual pre-program heating consumption for delivered fuel participants and, second to estimate the percentage of that consumption they saved after weatherizing their home through RCD in 2021.

4.3.1 Calculating Annual Pre-Consumption

The team estimated the delivered fuel pre-period heating consumption by adjusting the observed natural gas pre-period heating consumption (796 therms or 79.6 MMBtus) using the

[31] It is also worth noting that average vendor estimated electric weatherization savings in the 2018 evaluation was 2,389 kWh, notably lower than the current evaluation).

same two factors as the electricity saving: differences in **home size** and **equipment efficiencies** between natural gas and delivered fuels participants.

- **Home size.** The square footage of a home impacts the volume of space that the heating system must heat (i.e., the size of the heating load). Since average home sizes can differ by heating fuel type,[32] the team compared the average home size for natural gas and delivered fuel heated participants in 2021. As shown in Table 18, delivered fuel homes were slightly larger on average (1,889 and 2,098 for heating oil and propane, respectively, compared to 1,843 square feet for gas). As a result, the team made a modest upward adjustment to the observed natural gas pre-program heating consumption when converting it to reflect likely delivered fuel consumption (Table 18).

Table 18. Delivered Fuels Average Annual Pre-Period Heating Consumption

Fuel Type	Home Floor Area (SF)	Home Floor Area relative to Natural Gas
Natural Gas	**1,843**	**100%**
Heating Oil	1,889	102%
Propane	2,098	114%

Source: Cadeo analysis

- **Heating equipment efficiency.** For delivered fuel heating equipment, the team reviewed the baseline equipment efficiencies contained within the Residential Baseline Study,[33] and applied derating factors consistent with the concurrent Heat Pump Metering Study approach that were reviewed by the PAs and EEAC for use. The team compared the efficiencies across equipment types, as shown in Table 19.

Table 19. Equipment Efficiency Comparisons and Assumptions

Source	Rated Efficiency	Derated Efficiency
Gas/Propane Furnace	91%	87%
Gas/Propane Boiler	83%	75%
Oil Furnace	85%	81%
Oil Boiler	85%	77%

Source: Cadeo analysis

Based on these two adjustments to the observed natural gas consumption, the team estimated 2021 delivered fuel-heated weatherization participants used an average of 83.7 MMTBUs/year heating oil and 90.7 MMBtus/year propane to heat their homes before they participated in RCD (Table 20, Table 21).

[32] Fuel types are often associated with specific building types and/or vintages, which are, in turn, correlated with home size.

[33] Guidehouse 2020. Residential Baseline Study Phase 4. Available at https://ma-eeac.org/wp-content/uploads/RES-1-Residential-Baseline-Study-Ph4-Comprehensive-Report-2020-04-02.pdf

Table 20. Estimating Heating Oil Heating Consumption

Metric	Value	Notes
Natural Gas Heating Consumption (therms/year)	**796**	Based on billing analysis bill disaggregation; weather normalized using TMYx (2007-2021)
Adjustment Factor #1: Home Size	102%	Heating oil heated homes are larger than gas-heated homes
Adjustment Factor #2: Equipment Efficiency	102%	Adjustment accounting for marginally less efficient heating oil equipment compared to natural gas
Fuel Conversion (therms-to-MMBtu)	0.1	
Heating oil Heating Consumption (MMBtu/year)	**83.7**	

Source: Cadeo analysis

Table 21. Estimating Propane Heating Consumption

Metric	Value	Notes
Natural Gas Heating Consumption (therms/year)	**796**	Based on billing analysis bill disaggregation; weather normalized using TMYx (2007-2021)
Adjustment Factor #1: Home Size	114%	Propane heated homes are larger than gas-heated homes
Fuel Conversion (therms-to-MMBtu)	0.1	
Propane Heating Consumption (MMBtu/year)	**90.7**	

Source: Cadeo analysis

4.3.2 Estimating Percent Savings

Not having access to delivered fuel consumption records to determine average annual consumption also meant that the team could not conduct a delivered fuel-specific billing analysis. To overcome this and estimate how much energy weatherized delivered fuel participants saved, the team had to make an important assumption: holding other factors constant, the weatherized natural gas and delivered fuel participants save the same percentage of their pre-program heating consumption.

However, rather than apply this assumption unchecked, the team investigated the validity that these "other factors" are indeed the same for natural gas and delivered fuel participants like the approach used for electrically heating homes. Specifically, the team reviewed and made adjustments to the observed percent savings found through the natural gas billing analysis before applying it for delivered fuel participants for the following two factors: pre-program conditions, and the amount and types of insulation installed.

- **Pre-program conditions.** To estimate the delivered fuels heating energy savings, the team checked for potential differences in pre-existing conditions for delivered fuel customers (relative to natural gas participants) and found some differences (Table 22).

Table 22. Insulation R-Value Comparison: Delivered Fuels Homes Compared to Natural Gas

Insulation Type	Fuel Type	Average pre R-value[34]	Average post R-value	ΔU-factor
Wall	Natural Gas	9.5	23.8	0.063
	Heating Oil	9.3	23.1	0.065
	Propane	10.6	24.2	0.053
Attic	Natural Gas	16.4	45.0	0.039
	Heating Oil	16.9	50.3	0.039
	Propane	22.2	57.9	0.028
Floor	Natural Gas	12.0	24.2	0.042
	Heating Oil	12.2	24.5	0.041
	Propane	13.5	26.7	0.037

Source: Cadeo analysis

Consequently, the team made adjustments to the percentage of natural gas savings determined through the billing analysis before applying it to delivered fuel participants (Table 23).

Table 23. Insulation U-factor Comparison: Delivered Fuels Homes Compared to Natural Gas

Insulation Type	Fuel Type	ΔU-factor	ΔU-factor Relative to Natural Gas	2021 Insulation Count	Insulation Count Relative to Natural Gas
Wall	Natural Gas	0.063	100%	0.60	100%
	Heating Oil	0.065	103%	0.56	93%
	Propane	0.053	83%	0.42	70%
Attic	Natural Gas	0.039	100%	0.69	100%
	Heating Oil	0.039	101%	0.83	120%
	Propane	0.028	72%	0.85	124%
Floor	Natural Gas	0.042	100%	0.20	100%
	Heating Oil	0.041	101%	0.19	96%
	Propane	0.037	77%	0.20	100%
Weighted average adjustment factor compared to NG, Heating Oil					**101%**
Weighted average adjustment factor compared to NG, Propane					**77%**

Source: Cadeo analysis

- **Installed insulation.** When comparing delivered fuel heated homes to natural gas-heated homes, heating oil homes installed 4% less insulation per home (73% divided by 76%) and 15% less insulation per propane heated homes (62% divided by 76%), thus

[34] Ibid.

the team applied 96% and 85% adjustment factors to the natural gas savings for heating oil and propane, respectively (Table 24).

Table 24. Installed Insulation Area: Delivered Fuels Homes Compared to Natural Gas

Fuel Type	Home Floor Area (sqft)	Insulation Installed Per Home (sqft)	Insulation as Percentage of Home Floor Area	Adjustment Factor
Gas	1,843	1,399	76%	1.00
Heating Oil	1,889	1,378	73%	0.96
Propane	2,098	1,307	62%	0.85

Source: Cadeo analysis

The results from applying these adjustment factors accounting for the differences in pre-program conditions and installed insulation are summarized in Table 25 and Table 26. Applying adjustments to reflect differences in the installed insulation and pre-program building envelope conditions between weatherized natural gas and delivered fuel participants had a minimal impact on the applied savings rate for heating oil participants. However, these adjustments had a meaningful impact on the smaller number of propane participants. This is because the propane heated homes tended to be better insulated prior to RCD and, relatedly, received less insulation through the program (relative to natural gas participants).

Table 25. Estimated Heating Oil Percent Heating Savings

Metric	Value	Notes
Natural Gas Percentage of Heating Savings	**11%**	Based on billing analysis bill disaggregation; weather normalized using TMYx (2007-2021)
Adjustment Factor #1: Pre-program Conditions	101%	Heating oil participants had less insulation installed prior to program participation
Adjustment Factor #2: Installed Insulation	96%	Heating Oil participants installed similar insulation per square foot of home floor area relative to natural gas participants
Heating Oil Percent Heating Savings	**11%**	

Source: Cadeo analysis

Table 26. Estimated Propane Percent Heating Savings

Metric	Value	Notes
Natural Gas Percentage of Heating Savings	**11%**	Based on billing analysis bill disaggregation; weather normalized using TMYx (2007-2021)
Adjustment Factor #1: Pre-Program Conditions	77%	Propane participants had more existing insulation pre-program installed
Adjustment Factor #2: Installed Insulation	85%	Propane participants installed less insulation per square foot of home floor area likely due in part to more better pre-program conditions, and resulting in less weatherization savings (relative to natural gas)
Propane Percent Heating Savings	**6%**	

Source: Cadeo analysis

4.3.3 Results

Using this approach, the evaluation determined that RCD participants that use heating oil as their primary heating fuel saved 11% of pre-participation household heating fuel heating consumption, or 8.7 MMBtu/year on average. RCD participants using propane as their primary heating fuel saved 6% of pre-participation household heating fuel consumption, or 6.4 MMBtu/year on average.

Table 27. Delivered Fuel Weatherization Results (2021 Participants)

Measure	Fuel Type	Energy Savings (MMBtu/year)	Percentage of Heating NAC
Weatherization	**Heating Oil**	**8.7**	**11%**
	Propane	**6.4**	**6%**

Source: Cadeo analysis

Table 28 provides the evaluated weatherization savings by LV for participants that use heating oil, and Table 29 provides the propane savings for customers using propane for heating. Both tables compare the evaluated savings to each vendors' estimated savings and show the resulting gross realization rate.

Table 28. Heating Oil Weatherization Gross Realization Rates by LV

LV	Evaluated Savings (MMBtu/year)	Adjusted Vendor Estimated Savings* (MMBtu /year)	Gross Realization Rate
Abode	7.9	19	0.42
CLEAResult	9.1	22	0.41
RISE	6.8	15	0.46

*Adjusted to reflect TMYx weather data

Source: Cadeo analysis

Table 29. Propane Weatherization Gross Realization Rates by LV

LV	Evaluated Savings (MMBtu/year)	Adjusted Vendor Estimated Savings* (MMBtu /year)	Gross Realization Rate
Abode	5.8	13	0.45
CLEAResult	6.2	14	0.44
RISE[35]	4.0	12	0.33

*Adjusted to reflect TMYx weather data

Source: Cadeo analysis

[35] Because of limited data availability for RISE participants, the evaluation team used statewide averages for pre-program R-values for wall and attic insulation, and both pre- and post- R-values for floor insulation.

5. Recommendations and Considerations

Recommendations
The evaluation recommends:

- **Working with LVs to improve vendor estimate savings.** As three consecutive impact evaluations have determined that RCD LVs overestimate weatherization savings, the team recommends the PAs proactively work with their LVs to improve savings estimations. Improvements should include, but are not limited to, calibrating models using individual customers' pre-RCD energy consumption and using more recent weather data files (TMYx not TMY3) to reflect winter warming trends. If the PAs and LVs determine that these potential changes are impractical (due to access to data or the time required for calibration), the PAs should consider alternative approaches to estimating and/or claiming weatherization savings. These alternatives could include transitioning air sealing and insulation to deemed savings measures or using a simplified method that results in more conservative estimates. Regardless of the improvements made, the PAs should ensure these changes happen early in the process so that the savings estimates shared with participants (after their home energy assessment or HEA) are more reflective of the savings they are likely to achieve.

Considerations

The evaluation team also suggests the PAs consider:

- **Revisiting moderate income-specific savings.** Limited participation in the newer Moderate Income Qualified (MIQ) weatherization offer meant this study did not observe MIQ-specific savings that were statistically different than weatherization for non-MIQ customers. The team suggests the PAs revisit this MIQ/non-MIQ comparison if participation in MIQ increases as it is possible—with greater sample sizes—that subsequent evaluations could find a meaningful difference in savings between the two groups.

Appendix A. Participant Survey Instrument

Embedded below is the participant survey the evaluation team used to gather data for the supplementary, survey-aided natural gas weatherization billing analysis.

MA - RCD
Supplemental Billing A

Appendix B. Additional Billing Analysis Details

B.1 Accounting for Changing Weather Files (TMY3-TMYx Adjustments)

RCD LVs used TMY3 weather data to estimate and report air sealing and insulation savings for 2021 weatherization participants. TMY datasets, generated by the National Renewable Energy Laboratory (NREL), to reflect a synthetic “typical year” for standardized comparison of heating, cooling, and solar collection systems. The TMY3 data was constructed using weather observations selected as “typical” from the years 1991 to 2005.

However, the TMY3 weather dataset does not reflect changes in temperature, humidity, and other weather variables due to changes in climate since 2005, nor does it address future climate predictions. Based on guidance from the PAs, the evaluation team used the more recent TMYx weather data to normalize energy savings estimates for this study.

The advantages of TMYx include:

- Utilizes weather data that is more current than TMY3 and therefore more likely to represent future weather.
- Follows the same format and same methodology as TMY3.
- TMYx is planned to be updated periodically (every 2–3 years).

Since the PAs will use the gross realization rate (reported savings / evaluated savings) from this study prospectively, it is important that the evaluation team accounts for the LVs’ impending transition to TMYx. Without a proactive adjustment, the gross realization rate will overly discount future TMYx-based LV reported savings. To address this issue, the evaluation team used the "Massachusetts Typical Weather – Research and Dataset Development" report to develop LV-specific adjustments factors based on changes in HDD and CDD between TMY3 and TMYx.

The report calculates and compares the annual cooling degree days (CDD) and heating degree days (HDD) associated with each weather data file for two major weather stations (Boston Logan International Airport and Worcester Regional Airport). The CDD and HDD are calculated using the average daily dry bulb temperature and a base temperature of 65°F. The report shows that CDD increased, and the HDD decreased with the use of more recent weather data for both Boston and Worcester indicating warmer temperatures.

The development of the adjustment factors implied a slightly different process for natural gas savings and electric weatherization savings. While the impact of increased CDD and decreased HDD on natural gas usage is straightforward (reduced usage due to less heating), the impact on electricity usage is two-fold (increased cooling load, and decreased heating load). For natural gas savings, the adjustment factor was simply the ratio of HDD in TMYx and TMY3.

$$HDD_change = \frac{HDD_{TMYx}}{HDD_{TMY3}}$$

$$Adjustment\ Factor = HDD_change$$

Table 31 shows HDD_change and CDD_change for Boston and Worcester weather stations. Using the approach above, the evaluation team calculated the LV-specific adjustment factors in Table 30 for weatherization installed in natural gas-heated homes.

Table 30. TMY3-to-TMYx Natural Gas Weatherization Adjustment Factors by LV

Lead Vendor	Adjustment **Factor**
Abode	0.91
CLEAResult	0.89
RISE	0.89

Source: Cadeo analysis

The adjustment factor for electric weatherization vendor estimated savings was calculated as the weighted average of HDD and CDD change factors.

$$HDD_change = \frac{HDD_{TMYx}}{HDD_{TMY3}} \qquad CDD_change = \frac{CDD_{TMYx}}{CDD_{TMY3}}$$

$$W_{HDD} = \frac{HDD}{(HDD + CDD)} \qquad W_{CDD} = \frac{CDD}{(HDD + CDD)}$$

$$Adjustment\ Factor = \left(W_{HDD}\ x\ HDD_{change}\right) + \left(W_{CDD}\ x\ CDD_{change}\right)$$

Following this process, the evaluation team calculated the LV-specific adjustment factors in Table 31 for weatherization installed in electrically heated homes.

Table 31. Heating-only and Cooling-only Adjustment Factors by Weather Station

Weather Station	HDD_change	CDD_change
Boston	0.93	1.27
Worcester	0.89	1.70

Table 32. TMY3-to-TMYx Electric Weatherization Adjustment Factors by LV

Lead Vendor	Adjustment Factor
Abode	0.97
CLEAResult	0.96
RISE	0.98

Source: Cadeo analysis

B.2 Survey-based Supplemental Billing Analysis

In addition to comparing the savings between the population-wide model and the survey-based model (provided in the body of the report), the survey-based supplemental billing analysis offered additional insights. Specifically, adding independent variables into the model specifications (using the survey data) allowed the evaluation team to assess how participant characteristics not contained in the RCD LV tracking data influence weatherization savings.

Table 33 three characteristics more significantly tied to higher weatherization savings, as well as three that less correlated with weatherization savings (i.e., not found to be strongly influential). As a reminder, a lower p-value means the relationship between the independent variable (i.e., the characteristic listed in the table) and the dependent variable (energy savings from weatherization) is stronger.

Table 33. RCD Participant Characteristics Association with Weatherization Savings

More Significant Variables	p-value	Less Significant Variables	p-value
Change in # of people in the house during work hours	0.001	Change type of fuel used by oven	0.44
Household income	0.000	Change in supplemental heating equipment	0.393
# of bedrooms in the house	0.035	Added/removed square footage from home	0.618

Source: Cadeo analysis

Population-level models, such as the one used by the evaluation team, match treatment and control group customers exclusively on the similarity of their monthly pre-program energy consumption patterns.[36] This focus on energy consumption implicitly assumes that all other factors—such as home modifications, population changes, and lifestyle differences—are the same and/or occur at similar rates between treatment and control customers. This survey enabled the evaluation us to test this implicit assumption.

As Table 34 shows, the evaluation team found the treatment and control groups were generally comparable when assessing characteristics not contained in the provided LV tracking data.

Table 34. Comparison of Surveyed Participant Characteristics between Treatment and Control

	Treatment	Control
Change in household size	-0.5 people	-0.2 people
Change in # of people in house during work hours	-0.1 people	-0.005 people
Household income	$150-200K	$150-200K

Source: Cadeo analysis

[36] The evaluation team also explored using PA and ZIP code as additional considerations as part of the matching process. However, the team found these additional match factors had minimal impact on the matches and/or results.

Appendix C. Additional Building Simulations Details

C.1 Calibrated Building Simulation Segmentation

The evaluation team ran building simulations by creating baseline models calibrated against natural gas and electric billing data, and then inputting post-measure values to calculate savings. In total, the team created eight calibrated models to reflect differences in RCD sub offerings, heating fuel, and the presence of cooling (Table 35).

Table 35. Segments Modeled Through Building Simulation

Sub Offering	Heating Fuel	Cooling
Detached Single Family	Gas	Cooling
		No Cooling
	Electric	Cooling
		No Cooling
Attached Low Rise	Gas	Cooling
		No Cooling
	Electric	Cooling
		No Cooling

Source: Cadeo analysis

The team considered other segmentation variables, such as building age, but determined that sub offering and HVAC type had the strongest correlation to consumption in the billing data. The team did not, however, directly model every HVAC type found in the LV program data. Instead, the team applied input-based and output-based adjustments to HVAC types that lacked sufficient data to calibrate. The input-based and output-based adjustments are defined as follows:

- **Input-based Adjustments:** These adjustments involve using calibrated building characteristics from a similar segment to run measure models. This would include using the calibrated models for electrically heated homes with cooling to calculate savings for homes heated by heat pumps. In this example, a heat pump with characteristics that align with residential baseline study data would be input into the calibrated model for electric heat with cooling.

- **Output-based Adjustments:** This process describes when the team modified the outputs from calibrated models to account for differences in equipment that are not impacted by weather. An example includes using the calibrated models for natural gas-heated segments to calculate savings for delivered fuels by accounting for efficiency differences between furnaces heated by natural gas and by delivered fuels. In addition, this would include calculating savings for hydronic heating systems through removing the furnace fan savings output from the calibrated natural gas-heated models.

The full list of HVAC types found in the LV program data, their calculation approach, and the segment they were modeled as, is shown in Table 33 and Table 34 for gas and electrically

heated systems, respectively. Note that all participants with homes heated by delivered fuels had their savings calculated through the output-based adjustment described above.

Table 36. Different HVAC Systems for Natural Gas-Heated Homes in LV Program Data

Heating Type	Cooling	Calculation Approach	Modeled HVAC System
Ducted	Zonal	Calibrated Model	Gas furnace with cooling
	Ducted	Calibrated Model	Gas furnace with cooling
	None	Calibrated Model	Gas furnace no cooling
Hydronic	Zonal	Output-based adjustment	N/A
	Ducted	Output-based adjustment	N/A
	None	Output-based adjustment	N/A

Source: Cadeo analysis

Table 37. Different HVAC Systems for Electrically Heated Homes in LV Program Data

Heating Type	Cooling	Calculation Approach	Modeled HVAC System
Zonal	Zonal	Calibrated Model	Resistance wall heat with room AC[37]
	Ducted	Output-based adjustment	N/A
	None	Calibrated Model	Resistance wall heat no cooling
Heat Pump	Ducted	Input-based adjustment	N/A
	Zonal	Input-based adjustment	N/A

Source: Cadeo analysis

To translate the savings calculated from each segment into final statewide numbers for gas and electric savings, it was necessary to develop a weighting system between each of the different segments created from the program data. These weights are shown in Table 35 and Table 36, for gas and electrically heated homes, respectively. The weights represent the square footage for all the participants in an individual segment relative to the total square footage of all the participants within a given sub offering (the 'Weight – Sub Offering' column) or all the participants used for building simulations as a whole (the 'Weight – Total' column), for gas and electrically heated homes.

Table 38. Weighting of Different Segments to Generate a Statewide Savings Value for Gas-Heated Homes

Sub Offering	HVAC System	Weight – Sub Offering	Weight - Total
Attached low rise	Gas furnace with cooling	0.50	0.09
	Gas furnace with no cooling	0.50	0.09

[37] There were far more electrically heated systems with zonal cooling found in the program data than there were electrically heated systems with ducted cooling (highlighted in Table 34). Hence, the team created calibrated models with resistance wall heating systems and zonal cooling, rather than electric furnaces with central cooling systems.

Sub Offering	HVAC System	Weight – Sub Offering	Weight - Total
Detached single family	Gas furnace with cooling	0.52	0.42
	Gas furnace no cooling	0.48	0.39

Source: Cadeo analysis

Table 39. Weighting of Different Segments to Generate a Statewide Savings Value for Electrically Heated Homes

Sub Offering	HVAC System	Weight – Sub Offering	Weight - Total
Attached low rise	Resistance wall heat with room AC	0.36	0.07
	Resistance wall heat with no cooling	0.40	0.07
	Electric furnace with cooling[38]	0.07	0.01
	Single-speed ASHP[39]	0.17	0.03
Detached single family	Resistance wall heat with room AC	0.33	0.27
	Resistance wall heat with no cooling	0.46	0.37
	Electric furnace with cooling	0.10	0.08
	Single-speed ASHP	0.12	0.10

Source: Cadeo analysis

[38] This HVAC system represents the zonal heating systems with ducted cooling shown in Table 32. To calculate savings from this HVAC type, an electric furnace with cooling was input into models calibrated with resistance wall heating systems with room AC.

[39] This HVAC system represents the heat pumps with both ducted and zonal cooling shown in Table 32. Like the electric furnaces, savings from this HVAC type were calculated through placing a heat pump with characteristics that align with residential baseline study data into models calibrated with resistance wall heating systems with room AC.