Massachusetts Income Eligible Single Family Impact Evaluation

(MA23R56-B-IESF)

Prepared for:

Massachusetts Program Administrators

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Reference No.: 219516
September 2024

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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 Income Eligible (IE) Single Family (SF) initiative. The primary goal of the evaluation was to update the initiative's 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 (MA23R56-B-IESF), which is one of several concurrent studies informing the PAs' three-year planning process for the IE initiative. The other studies include an impact evaluation focused on IE Multifamily (MF) measures, a process evaluation of the entire IE initiative (SF and MF), and a robust heat pump metering study that includes IE and non-IE participants.

Methodology

The evaluation team used a combination of **building simulation, engineering algorithms, and bill disaggregation** to evaluate savings for every IE SF 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.

This study focuses on several key IE SF measures: air sealing and insulation (collectively referred to as **weatherization**) and **heat pumps**, as weatherization is the long-standing driver of IE SF savings. In 2022 weatherization comprised half (51%) of IE SF annual savings across all fuel types. Heat pumps currently make up a smaller portion of the initiative's current savings, but the measure is central to meeting the PAs' greenhouse gas (GHG) emissions targets and will play an increasingly prominent role in the IE SF initiative in the future.

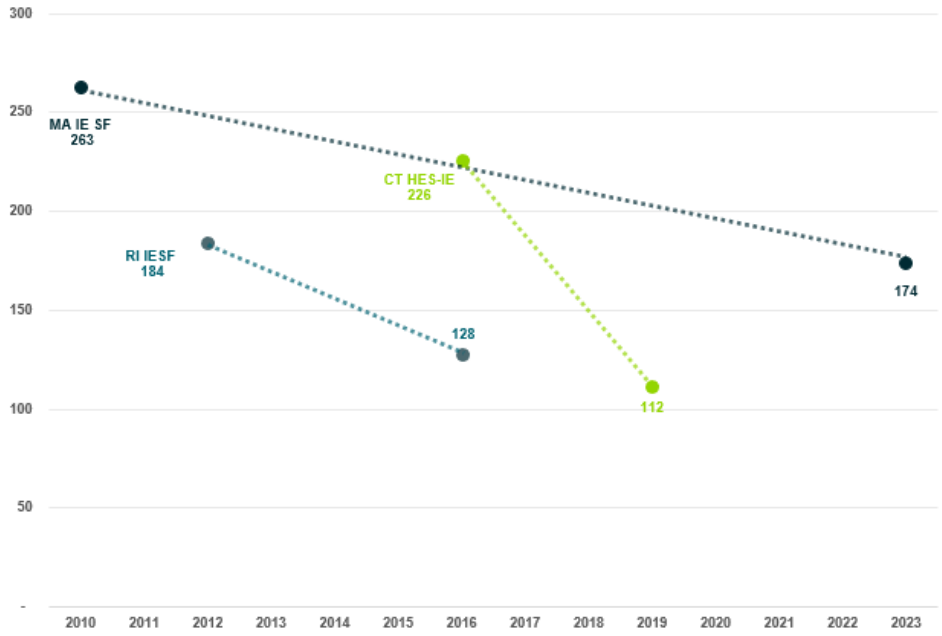
Results

Key results from this study include:

- **Lower average natural gas weatherization savings relative to the previous evaluation.** The average natural gas weatherization savings found through this study (174 therms) is lower than the comparable result (263 therms) from the previous IE SF impact evaluation completed in 2012. A comparison of the pre- and post-air infiltration values from both evaluations provides context for the difference. The previous evaluation, which focused on 2010 and 2011 participants, had both a higher pre-air sealing ACH50 (18) *and* a lower post-air sealing ACH50 (12) relative to the current evaluation (17 and 15 ACH50, respectively). In other words, based on available initiative data for both evaluations, the homes served in 2010 and 2012 were leakier before IE SF and tighter after IE SF than the homes served in 2023. Further, natural gas weatherization participants in 2023 installed fewer types of insulation (1.5) than 2021 participants (1.8) and had more existing insulation in their home prior to IE SF.
- **Less natural gas weatherization savings is consistent with long-term regional trends.** IE SF is not the only initiative with declining evaluation results. Similar offerings in neighboring Connecticut and Rhode Island have also seen a general decline in average savings over time. As Figure A shows, every subsequent impact

evaluation has resulted in a lower average evaluated savings for natural gas weatherization. The downward historical trend in savings is a function of multiple factors including increasing natural gas heating equipment efficiencies, greater customer penetration by long-standing efficiency initiatives, and updates to the weather files used to normalize annual consumption that reflect warmer winters. The same trend exists for non-IE initiatives.

Figure A. Regional Evaluation Trends: Average Natural Gas Weatherization Savings (therms/year) for Six IE Impact Evaluations in Three Northeast States

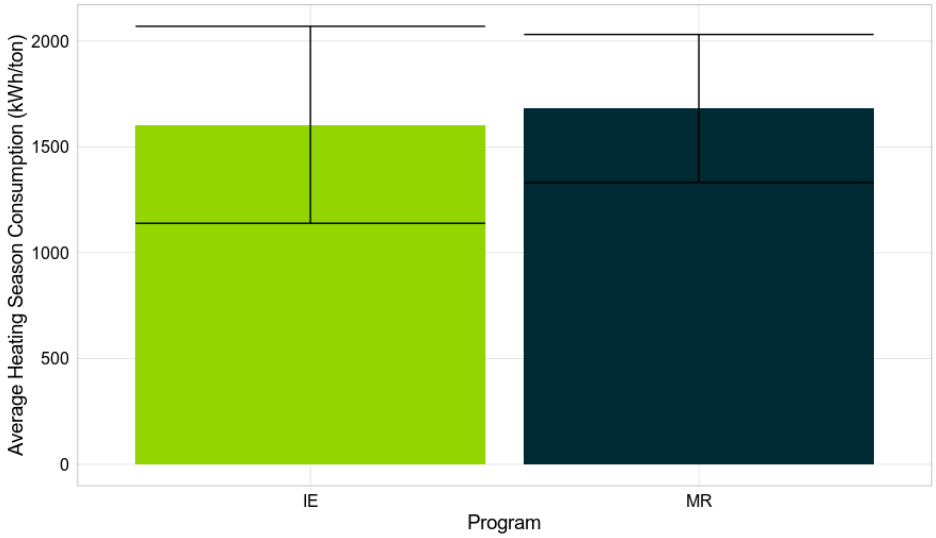


Source: Cadeo analysis

- **IE SF savings compare favorably to regional benchmarks.** Although the evaluated natural gas weatherization savings are lower than the previous evaluation, the savings are higher than similar initiatives offered in neighboring states.
- **IE SF weatherization savings for homes heated by electricity or delivered fuels are similar to weatherization savings in gas heated homes.** Savings relative to baseline heating consumption were 28% for electrically heated homes, and 25% for delivered fuel heated homes.
- **IE and non-IE customers heat their homes with heat pumps similarly.** A concurrent heat pump metering study, which focused primarily on heat pumps incentivized through the PAs' Retail Initiative and a similar market rate offering in Connecticut (n=195), included a sample of IE customers that received a heat pump through IE SF (n=19). The metering study team compared the heating season usage of IE SF and Retail Initiative participants (Figure B shows) and found similar heating usage across the two income groups. As Figure B shows (via the box and whisker plot), heating usage between IE and non-IE was not statistically different at the 90% confidence level. (Metered data showing how both customer types use heat pumps to cool their homes will be available this fall.) Consequently, the team combined usage data from all metered sites when analyzing the energy impact of heat pumps.

However, as the baseline assumptions differ across the initiatives (the derated efficiency of the existing system for IE versus the efficiency of the new HVAC system that the Retail Initiative customer would have installed had they not installed the heat pump), the evaluated, per-ton savings for IE SF heat pumps are higher than units installed through the Retail initiative (see Table A).

Figure B. Comparison of the Average Heating Season Heat Pump Consumption: IE and Non-IE (Market Rate) Participants



Source: MA22R51-B-HPMS

Savings Summary

Table A summarizes this evaluation's findings for each IE SF measure and relevant fuel type. The table also indicates which methodology—or combination of methodologies—the evaluation team used to evaluate the savings.

Table A. Evaluated Gross Energy Savings by Measure

Measure	Natural Gas (therms)	Electric (kWh)	Oil (MMBtu)	Propane (MMBtu)
BUILDING SHELL				
Weatherization (Insulation and Air Sealing)	174	1,931	19.6	20.3
—Insulation (Overall)	151	1,685[1]	16.9	17.6
-Distribution Savings (Associated with insulation for natural gas/oil/propane heated homes), kWh		49/43/42		
-Cooling Savings (Associated with Insulation for natural gas/oil/propane heated homes), kWh		93/83/79		
-Air Sealing	23	246	2.5	2.6

[1] The building simulation methodology resulted in combined electricity savings for electrically heated homes; furnace fan and cooling savings are included in the combined totals for air sealing and insulation.

Measure	Natural Gas (therms)	Electric (kWh)	Oil (MMBtu)	Propane (MMBtu)
-Distribution Savings (Associated with air sealing for natural gas/oil/propane heated homes), kWh		6/5/5		
-Cooling Savings (Associated with air sealing for natural gas/oil/propane heated homes), kWh		-1/-1/-1		
Window - Electric Resistance		254		
Window - Heat Pump		127		
Window - Fossil Fuel	13		1.3	1.3
Window - Electricity savings (kWh) associated with fossil fuel savings for oil/propane heated homes			7	7
HVAC				
Furnace Replacement	105		3.7	10.5
—Furnace Fan Savings, kWh	92		34	92
Boiler Replacement	114		6.1	11.4
Boiler Reset Controls	33	-	3.4	
Central Heat Pump (Propane Partial Displacement, savings per ton)	-	-839	-	9.8
Central Heat Pump (Oil Partial Displacement, savings per ton)	-	-832	10.5	-
Central Heat Pump (Natural Gas/Propane Full Displacement, savings per ton)	155	-1,249	-	15.5
Central Heat Pump (Oil Full Displacement, savings per ton)	-	-1,238	16.6	-
Mini-Split Heat Pump (Natural Gas/Propane Partial Displacement, savings per ton)	163	-960	-	16.3
Mini-Split Heat Pump (Oil Partial Displacement, savings per ton)	-	-961	15.9	-
Mini-Split Heat Pump (Electric Heat Full Displacement, savings per ton)	-	2,547	-	-
Mini-Split Heat Pump (Natural Gas/Propane Full Displacement, savings per ton)	175	-1,206	-	17.5
Mini-Split Heat Pump (Oil Full Displacement, savings per ton)	-	-1,208	17.1	-
Pipe Wrap (Space Heating)	-	-	1.0	-
Programmable Thermostat	20	280	2.3	2.0
Wi-Fi Thermostat (AC only for electric savings)	22	18	2.4	2.2
Dehumidifier	-	489	-	-
Window AC replacement	-	48	-	-
Duct Insulation	9	35	0.8	0.9
Duct Sealing	7	22	0.7	0.7
PROCESS				

Measure	Natural Gas (therms)	Electric (kWh)	Oil (MMBtu)	Propane (MMBtu)
Refrigerator Replacement	-	651	-	-
Freezer Replacement	-	713	-	-
Appliance Removal	-	968	-	-
Smart Strips	-	105	-	-
HOT WATER				
Faucet Aerators	3	63	0.4	0.3
Showerheads	14	245	1.4	1.4
Early Retirement CW Elec DHW & Elec Dryer	-	214	-	-
Early Retirement CW Gas DHW & Elec Dryer	-	140	-	-
Early Retirement CW Elec DHW & Gas Dryer	-	75	-	-
Early Retirement CW Gas DHW & Gas Dryer	-	39	-	-
Early Retirement CW Oil DHW & Elec Dryer	-	140	0.2	-
Early Retirement CW Propane DHW & Elec Dryer	-	140	-	0.2
Pipe Wrap (Water Heating)	3	73	1.1	0.3
Solar Hot Water	-	2,264	-	-
Indirect Water Heater	87	-	-	-
Heat Pump Water Heater, <55 gallon[2]	-5	1,799	-0.1	-0.1
Heat Pump Water Heater, >55 gallon[3]	-	360	-	-
Heat Pump Water Heater displacing Oil	-	-1,138	17.4	-
Heat Pump Water Heater displacing Propane	-	-831	-	16.4
Stand Alone Water Heater	57	-	-	-
BEHAVIOR				
TLC Kit	-	69	-	-

Source: Cadeo analysis

Building Simulation
Engineering Adjusted Building Simulation
Engineering Algorithm
Heat Pump Metering Study

[2] The negative values are associated with the heating penalty for gas, oil, or propane heating systems.

[3] Federal standard essentially requires a heat pump water heater (HPWH) for electric water heating >55 gallons. The study therefore assumes a HPWH baseline without a heating penalty.

Recommendations

The evaluation team recommends:

- **Increasing robustness of required electronic tracking data.** The Community Action Program (CAP) agencies that deliver IE SF maintain electronic participation records that meet the PAs' current reporting requirements for the initiative. However, the required customer, building, and measure data in the electronically available datasets is insufficient to support robust impact evaluations. For example, the available electronic tracking data indicates that a given participant received air sealing through IE SF, the date the air sealing was performed, and expected savings from the measure. The available electronic data does not, however, include critical details, such as the participant's pre- or post-initiative air infiltration rates, which would allow an evaluator to independently model air sealing savings.

  Without it, this evaluation—again like the previous study—had to manually gather this information. Specifically, the team had to extract essential evaluation data points, such as an air sealing participant's air infiltration rates, from scans of handwritten energy assessments and measure installation forms for a subset of participants. This manual process has multiple drawbacks. It adds cost, yields less information (i.e., results in data for a sample of participants versus the whole population), and introduces uncertainty (as the team must interpret assessor's notes). Collectively, these factors adversely impact the quality of an impact evaluation, which, in turn, adversely impacts the PAs' ability to confidently forecast savings for the IE SF initiative.

  The evaluation team recommends—as the evaluation team did as part of the previous evaluation more than 10 years ago—that the PAs require CAPs to increase the robustness (i.e., the level of customer and measure detail) maintained electronically in the initiative's tracking systems. In addition to the data already required by the PAs for reporting, the PAs should require CAPs to store the following information electronically in dedicated data fields to support future evaluation efforts:

  - Home size (square feet of conditioned space)
  - Pre- and post-air sealing blower door air infiltration values (CFM50)
  - Location of installed insulation (wall, attic, floor)
  - Pre- and post-insulation R-values by location
  - Areas of installed insulation (e.g., percentage of total wall area insulated)
  - Existing HVAC efficiency (i.e., rated AFUE), system type (e.g., furnace, boiler), and estimated age (for derating)
  - Existing DHW efficiency (i.e., rated EF or UEF), system type (e.g., storage), and estimated age (for derating)
  - Heat pump type (central, ground source, single or multi-zone zone mini-split) and outdoor unit model number
  - Heat pump control strategy (manual or integrated) and, if integrated, the switchover temperature setting
  - Presence and type of secondary heating sources
  - Existing window type (single pane, double pane, etc.)
  - New window SHGC and U-value

Ensuring these essential data elements are available electronically for every relevant IE SF participant will increase the validity, reliability, and value of future IE SF impact evaluations, especially for key measures such as air sealing and insulation that make up the majority of the initiative's savings.

This enhanced electronic data management practice is long overdue; robust tracking databases containing the customer and measure details listed above are available for most initiatives, including Residential Coordinated Delivery (RCD), the PAs' non-IE residential home energy assessment initiative. It should not be necessary to manually extract critical initiative information from handwritten forms.

The evaluation team recognizes that CAPs provide a wide range of services in their communities (beyond delivering the PAs' IE SF initiative) and that those services have their own data collection and management requirements. The team also recognizes that the CAPs may need financial and technical support to institute this improvement. As such, the PAs should work closely with the CAPs, as well as other stakeholders in Massachusetts, including the Energy Efficiency Advisory Council and Department of Public Utilities, to act on this recommendation in a way that achieves the necessary data improvement while not adversely impacting CAP staff and their delivery of other important community services.

The evaluation team is indifferent with respect to specific software the initiative uses to create this richer dataset but resolute that the identified solution must efficiently collect, store, and export the detailed electronic information required for robust evaluation. Such a database would not only improve the robustness, reliability, and accuracy of future IE SF evaluations but also serve as a valuable resource for the diverse stakeholders that serve and support the IE population in the Commonwealth.

- **Enabling access to information regarding non-PA funded measures.** The CAP agencies that implement IE SF on behalf of the PAs braid federal and other non-PA funding with IE dollars to provide more comprehensive service for IE SF participants. The team attempted to gather information on these non-PA funded measures—first from the CAPs and then from Executive Office of Housing and Livable Communities (EOHLC)—throughout this evaluation. However, the evaluation team's efforts were unsuccessful, which left the team with a partial perspective of what happened in participating IE SF homes. This limited understanding of the full range of interventions in participating homes had an adverse impact on the team's ability to specify reliable billing analysis to estimate weatherization savings—IE SF's primary measure. The team recognizes that EOHLC is the ultimate decision-maker on what information they share about measures they fund, but the team recommends the PAs engage the CAPs and EOHLC to proactively create a data sharing plan that benefits all IE stakeholders and that will support the next IE SF evaluation effort.

Considerations

The evaluation team suggests the PAs also consider:

- **More frequent impact evaluations.** This IE SF impact evaluation comes 12 years after the prior study. More frequent evaluations—enabled and informed by improved data tracking—will help the PAs keep IE SF measure savings more current and prospectively applicable.
- **Accounting for historical weatherization trends.** The PAs should keep this trend in mind when forecasting the potential savings associated with weatherization as part of future program cycles.

1. Introduction

The Strategic Evaluation Plan (SEP) included in the Massachusetts (MA) Program Administrators' (PAs) 2022-2024 energy efficiency plan identified the need for an Income Eligible (IE) Single Family (SF) Impact Evaluation. Per the SEP, the primary goal of the impact evaluation was to estimate the gross, per-unit savings associated with every IE SF electric, natural gas, propane, and heating oil measure.

Cadeo, as part of a Guidehouse-primed evaluation team, led this study (MA23R56-IESF) to evaluate the gross energy impact of every IE SF 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. The PAs will apply the updated IE SF gross energy savings prospectively as part of the forthcoming 2025-2027 three-year implementation cycle. Most of the initiative's existing gross energy savings come from the prior IE SF impact evaluation, which was completed in June 2012.[4]

This impact evaluation is one of several concurrent and complementary studies completed in 2024 to inform the PAs' plan for the next three-year implementation cycle. This specific **impact evaluation focuses on IE SF participants** (i.e., customers living in buildings with less than 5 units at or under 60% of the state median income [SMI]).

One of the other studies is an IE process evaluation:

- **MA22R55-B-IEP.** As part of the same Guidehouse-primed evaluation team, ILLUME completed an IE process evaluation that covered both SF and multifamily (MF) participants. That study included a combination of quantitative analysis (tracking data and surveys) and qualitative research (ride-alongs, listening sessions, and interviews). With its process focus, MA22R55-B-IEP used these primary data collection activities to assess the current and proposed future delivery of the SF and MF IE offerings with the goal of identifying insights and offering recommendations that will help the initiative reach and comprehensively serve IE customers throughout Massachusetts.

The other three related studies were impact focused:

- **MA22R51-B-HPMS.** Guidehouse, as part of a study jointly funded by MA PAs and the Sponsors of Energize Connecticut℠ (Energize CT), completed a metering study that included 204 heat pumps across both states. The goals of the study included learning about usage patterns for heat pumps and other heating equipment, electric peak demands for heat pumps, the performance and efficiency of heat pumps, and the ability of heat pumps to meet customers' full heating needs down to low outdoor air conditions. Most of the metered sample were market rate (i.e., non-IE) customers (n=194). However, Guidehouse also metered a subset of MA IE SF participants that

[4] The Cadmus Group, *Low Income Single Family Program Impact Evaluation,* June 2012, https://ma-eeac.org/wp-content/uploads/Low-Income-Single-Family-Program-Impact-Evaluation_Part-of-the-Massachusetts-Residential-Retrofit-Low-Income-Program-Area-Evaluation.pdf.

received heat pumps (n=19). The evaluation team leveraged the results of this joint metering study to evaluate savings for IE SF heat pumps.

- **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 Community Action Program (CAP) agencies and non-IE participants served through RCD. Collectively, the current MF-focused impact evaluation and this SF-focused impact study evaluated the complete suite of IE offerings in Massachusetts.

- **MA23R58-B-RCD.** The evaluation team's impact evaluation of the Residential Coordinated Delivery (RCD) SF initiative is analogous to this study but focused on market rate customers that live in buildings with less than five units. These customers are served through the PAs' RCD lead vendors (LVs), as well as Home Performance Contractors (HPCs) managed by Abode Energy Management (Abode). The RCD study offers a point of comparison with this IE SF study and highlights differences in MA across income thresholds.

1.1 About IE SF

The PAs', in collaboration with the Low Income Energy Affordability Network (LEAN) and CAPs, have implemented successful programming for IE customers for more than two decades. The IE program serves both SF and MF buildings, helping to reduce energy costs in buildings occupied by families living at or under 60% of the SMI for SF and at least 50% of households in an MF building living at or below 60% of the area median income (AMI). In addition to helping customers save energy and energy-related costs, participation in the IE program can yield health and safety benefits for participants and their families (e.g., improved indoor air quality). Further, the program's focus on the Commonwealth's IE building stock means it can address equitable access to PA efficiency programming while lowering greenhouse gas (GHG) emissions (through decarbonization and electrification).

The IE program is a statewide initiative of the Sponsors of Mass Save. The program is designed to provide cost-effective insulation and weatherization, air sealing, HVAC and water heating (including heat pumps and heat pump water heaters), appliance upgrades, and other energy efficiency measures to IE families residing in SF or MF homes. SF customers are homeowners and renters living in buildings with one to four units. MF customers, not evaluated as part of this study, are homeowners and renters living in buildings with five or more units. The program also targets property owners and managers (or landlords) of MF buildings, as they give final approval for renters to participate in the program for instances in which they, rather than the renter, pay the energy bill.

At the time of this study, the program was implemented by 18 community action agencies, all connected through LEAN. All 18 agencies offered programming for SF customers, and six offered programming for MF customers. Eight agencies operated as lead agencies that liaised between the six PAs and the 12 other agencies to manage the distribution of program funds and provide technical support with program implementation.

Agencies use program funds to deliver three types of home energy assessments through the Mass Save IE program: the weatherization audit, the Appliance Management Program

(AMP) audit, and the heating system audit. This impact evaluation includes measures installed as part of all three assessment types. A brief description of each is provided below:

- **Weatherization audit.** Often referred to as a general home energy assessment, the weatherization audit brings an energy specialist, or an auditor, into the customer's home to assess its current energy use. As deemed necessary, this audit can result in the customer receiving free weatherization upgrades. Weatherization upgrades are installed by a contractor after the audit.
- **AMP audit.** This program is an electrical audit that focuses on the efficiency of a home's electric usage. During this audit, auditors install energy savings products at no cost to the resident. Types of measures typically installed include advanced power strips, low-flow showerheads, faucet aerators, and programmable thermostats. Customers may also qualify for home appliance replacements such as refrigerators, washing machines, and air conditioners. AMP audits are available to rate payers every 3-5 years, depending on the policies and procedures of the local PA.
- **Heating system audit.** If a home's heating system is electric, then the heating system audit may be included in the electrical audit. If the home is heated by gas or oil, then an auditor with the required certifications and areas of expertise must conduct a separate heating system audit. Eligible customers can receive clean and tune or new, more energy efficient heating units such as heat pumps, boilers, and furnaces at no cost. Services identified through a heating system audit can be assessed as needed depending on available measures and customer need.

CAP agencies also deliver other services, including federal Weatherization Assistance Program (WAP), Heating System Repair and Replacement program (HEARTWAP), and other funding (as available). They braid federal and other funding into IE program dollars to provide more comprehensive services to customers.

1.1.1 Lead Vendor Implementation

Historically, CAPs have exclusively delivered the IE program to customers in their service areas. With the new Lead Vendor Implementation (LVI) initiative, HPCs may also deliver all three types of IE audits. HPCs can submit their own leads to the LEAN Statewide Client Services Center (SCSC), operated by ABCD. SCSC staff also may refer leads to HPCs if the Local Agency does not have the capacity to meet the 4–6-week time to assess metric or if the referring Community Partner has a preferred vendor (HPC). They refer customers who have worked with CAPs in the past to their local agencies. For more information about IE program delivery, including the LVI initiative, review the IE process evaluation report (MA22R55-B-IEP).

1.2 Key Research Questions

For each study topic area, the team identified a central research question along with related sub-questions that the team used this impact evaluation to answer.

What energy savings are associated with every IE SF measure, especially key traditional measures (i.e., weatherization) and important, newer electrification measures (i.e., heat pumps)?

Sub-questions:

- Where is the program achieving the most impact? Which measures? Which customers? What building types? Where is the opposite happening?
- How do the evaluated savings compare with the previous IE SF impact evaluation in Massachusetts? What about with other 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 IE SF measures, each measures contribution toward total IE SF savings, and trends in recent participation.

1.3.1 Relevant Measures

As Table 1 shows, this study evaluated 31 discrete IE measures associated with six measure end uses. For each measure, the team evaluated savings separately by fuel type (as relevant). The team's measure and fuel-specific results will allow the PAs to readily integrate the results of this evaluation into their latest benefit cost ratio (BCR) model—the tool the PAs use to plan and assess performance toward energy and GHG targets.

It is important to acknowledge an end use that is notably missing from Table 1: lighting. LEDs, and, before that, CFLs directly installed during assessments have historically been a significant source of electric savings for the initiative. However, due to shifts in the residential lighting market—in part due to the PAs' long-standing program activity—the PAs decided to remove lighting from IE SF (as well as RCD) as part of the upcoming 2025-2027 three-year cycle. As evaluation results are applied prospectively in Massachusetts, the team did not evaluate any lighting measures as part of this study.

Table 1: Evaluated IE SF Measures

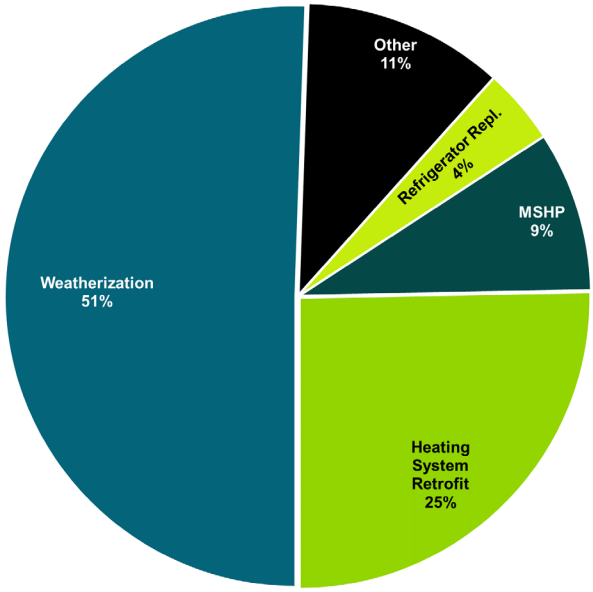
Measure End Use	Measures
Envelope	• Air Sealing • Insulation • Window
HVAC	• Furnace Replacement • Boiler Replacement • Boiler Reset Controls • Central Heat Pumps (Full and Partial Displacement) • Mini-Split Heat Pumps (Full and Partial Displacement) • Pipe Wrap (Space Heating) • Programmable Thermostat • Wi-Fi Thermostat • Duct Insulation • Duct Sealing • Dehumidifier • Window AC Replacement
Process	• Refrigerator Replacement • Freezer Replacement • Appliance Removal
Domestic Hot Water	• Faucet Aerator • Low-Flow Showerhead • Pipe Wrap (Water Heating) • Solar Hot Water • Indirect Water Heater • Heat Pump Water Heater (HPWH) • Stand Alone Water Heater • Early Retirement CW Elec DHW & Elec Dryer • Early Retirement CW Gas DHW & Elec Dryer • Early Retirement CW Elec DHW & Gas Dryer • Early Retirement CW Gas DHW & Gas Dryer • Early Retirement CW Oil DHW & Elec Dryer • Early Retirement CW Propane DHW & Elec Dryer
Plug Load	• Smart Strips
Behavior	• TLC Kit (includes basic educational measures such as refrigerator thermostats, hot water thermostats, refrigerator coil brush, wall plate stoppers)

Source: Cadeo analysis

1.3.2 Savings Distribution

To understand why the evaluation team focused much of this report on weatherization, it is helpful to see the important role that weatherization plays in delivering initiative energy savings. In 2021, weatherization (i.e., air sealing and insulation) comprised half (51%) of total annual IE SF energy savings across all fuel types.[5]

Figure 1. Savings by IE SF Measure – 2022



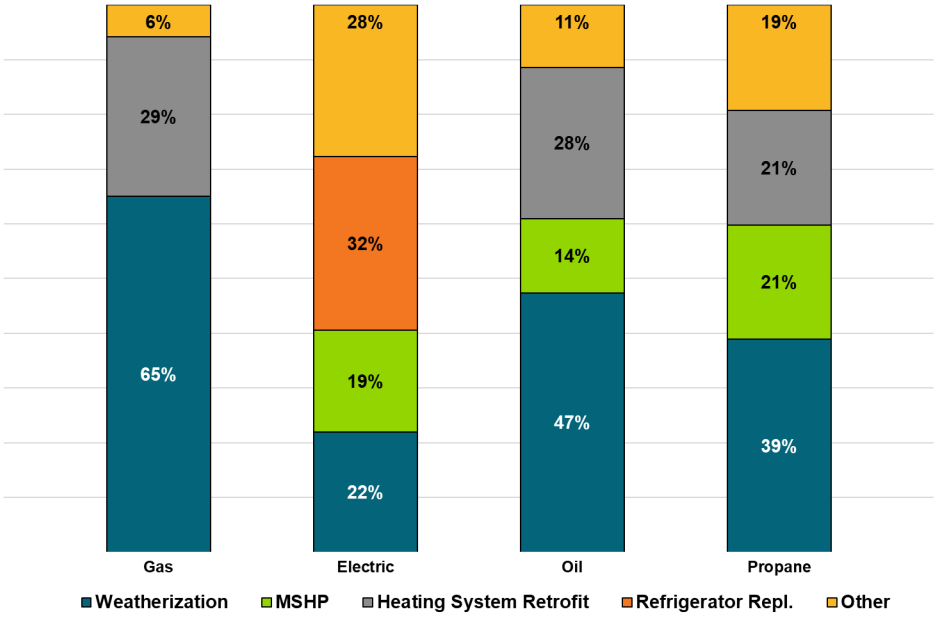
Other measures include Central Heat Pumps, Wi-Fi Thermostats, Programmable Thermostats, Low-Flow Showerheads, Water Heaters, etc.

Source: MassSaveData.com.

The overall importance of weatherization measures—again, air sealing and insulation—to IE SF is not specific to any single heating fuel type. As Figure 2 shows, weatherization represented the largest share of vendor estimated gross energy savings (in MMBtus) for all heating fuel types in 2022, except for electric.

[5] The team converted all reported savings to MMBtus to assess each measure's contribution to total IE SF savings across fuel types; excludes savings from lighting as the PAs no longer offer lighting through IE SF.

Figure 2. Gross Savings by Measure by Fuel Type (2022)

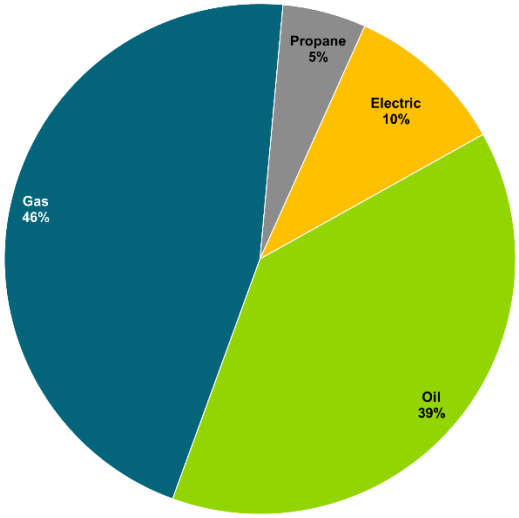


Other measures include Central Heat Pumps, Wi-Fi Thermostats, Programmable Thermostats, Low-Flow Showerheads, Water Heaters, etc.

Source: MassSaveData.com

Figure 3 provides a complementary perspective: total gross saving by fuel. As evident in the figure, natural gas savings (46%) were the largest contributors to total savings in 2021. Heating oil (36%) and electric (17%) savings made up most of the remaining savings in 2021; propane savings were a much smaller portion (5%).

Figure 3. IE SF Savings by Fuel (2022)



Source: MassSaveData.com

1.4 How to Use the Results of this Evaluation

This report summarizes the results of the IE SF evaluation and the evaluation methodologies used to generate those results. For key measures, primarily weatherization and heat pumps, the report includes a more detailed explanation of how the team developed evaluated savings and how those savings compare to previous evaluations in MA and neighboring states.

This report does not include details such as the engineering algorithm and specific primary and secondary data used to develop savings for less impactful IE SF 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 IE SF 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 tab links 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.

Further, to aid the PAs' prospective application of the results, the team has also provided a second Excel workbook with measure-level results for **every relevant IE SF 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.

1.5 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 IE SF measures. To do so, the body of the report includes six sections:

- Methodology
- Results Summary
- Key Findings: Weatherization
- Key Findings: Heat Pumps
- Key Findings: Other Measures
- Considerations

To supplement these sections, the report includes two appendices that elaborate and expand upon methodologies used as part of this study:

- Appendix A: Additional Billing Analysis Details
- Appendix B: Copy of the Massachusetts and Connecticut Heat Pump Metering Study (MA22R51-B-HPMS/CT R2246)

2. Methodology

The evaluation team used a combination of calibrated building simulation, engineering algorithms, and billing data disaggregation to evaluate the impact of every IE SF measure. As noted in Table 2, the evaluation team also undertook a billing analysis to assess weatherization savings in homes heated with natural gas. However, unlike the concurrent RCD SF study, the evaluation team's billing analysis of IE SF natural gas weatherization participants did not yield statistically significant results (i.e., greater than 20% precision at the 90% confidence level) to official report savings.

Several factors explain the low precision and reliability of IE SF billing analysis results compared with RCD:

- **Less participants.** The total volume of weatherization participants in IE SF is smaller (relative to the PA's market rate retrofit initiative, RCD), which results in smaller sample sizes for the billing analysis and, in turn, lower model precision and less reliable results.

- **Non-PA funded measures.** The evaluation team was unable to get data on non-PA funded measures. Consequently, these measures were unaccounted for in the billing analysis for the subset of IE SF participants that received them. Without this information, the model is subject to omitted variable bias, which leads to poor precision and the misattribution of measure impacts.

As a result, the team used non-statistical approaches (i.e., calibrated building simulation and engineering analysis) to evaluate savings for all four fuels (natural gas, electricity, heating oil, and propane). Although the team's billing analysis assessment of changes in consumption before and after weatherization through IE SF did not produce sufficiently reliable results, the billing analysis' disaggregation (i.e., using weather data to break participants' total consumption into heating, cooling, and baseload) was successfully completed and used to inform the engineering tasks.

2.1 Activities

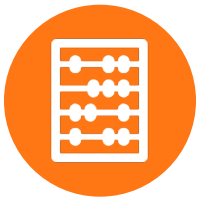
Table 2 summarizes the methodology the team used to complete the three activities scoped as part of this impact evaluation.[6] In addition to these tasks, the IE SF evaluation team coordinated closely with the evaluation team leading the previously mentioned MA22R51-B-HPMS to leverage the metering and analysis of that study to report savings for IE SF heat pumps. For more information about MA22R51-B-HPMS, see the Key Findings: Heat Pumps section of this report, as well as Appendix B, which includes a copy of the full report.

[6] The Stage 3 plan for the IE SF impact evaluation includes a fourth activity: estimating the monetary impact of heat pump conversions. In other words, how much, on average, does an IE SF participant's annual energy costs to heat and cool their home change when they convert to a heat pump? As this analysis required results from the heat pump metering study (MA22R51-B-HPMS) completed recently (May 15, 2024), it was not possible to include this analysis in this initial draft report. The team will finish the ongoing analysis using the now-complete metering study results and include the findings of the monetary impact activity in a subsequent draft of this report.

Table 2. Summary of Evaluation Activities

- Used the Residential Energy Efficiency and Demand Response (REEDR) tool, energy modeling software funded by the Regional Technical Forum (RTF), to model representative IE homes.[7]
- 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, were all informed by LV program data.
- Calibrated each model using disaggregated (heating, cooling, and baseload) monthly energy consumption data.
- Simulated four different scenarios reflecting heating fuels and whether buildings had cooling systems.
- Weighted the result of the four models into a statewide average using the heating fuel and cooling data of the customers listed in the L

Engineering Algorithms



- Relied on algorithms from the Technical Reference Manual (TRM) or previous evaluations in Massachusetts, including the 2012 Low Income Single Family Program Impact Evaluation, that formed the basis for many of 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 building simulation results to inform savings estimates for delivered fuel measures, particularly for air sealing and insulation.

[7] REEDR is a front-end energy modeling software used to run energy models for residential buildings in EnergyPlus. It is 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.

Billing Analysis

- Attempted natural gas and electric billing analyses with the intention to report evaluated savings for air sealing and insulation.
- Matched each treatment group participant (IE SF participant from 2021) to a control group participant (an IE SF participant from 2022) with a similar monthly pre-program energy consumption pattern.
- Specified, refined, and experimented with multiple monthly post-program regression (PPR) mode specification, as well as other types of models and non-modeling approaches (i.e., difference-of-differences)
- None of the model specifications met the pre-determined qualifying threshold (per the study's Stage 3 plan) of better than ±20% precision at the 90% confidence level for reporting evaluation results.
- While the team did not use the billing analysis to evaluate savings, the team used the tasks' bill disaggregation subtask (i.e., breaking individual participants' annual consumption into heating, cooling, and baseload components), which informed the building simulation calibration process and served as an input for the engineering analysis.
- Using TMYx weather data from the nearest weather station, the team completed a variable degree day (VBDD) analysis to identify the optimal base temperatures for determining heating degree days (HDDs) and cooling degree days (CDDs) for each participant. 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° increments for both ranges.

For additional details about the attempted billing analysis, see Appendix A.

Source: Cadeo Analysis

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 every customer that installed an IE SF measure in 2021 or 2022.
- **Weather data.** To control for the effect of weather as part of the billing analysis and bill disaggregation analysis, as well as to normalize the results to reflect a typical meteorological year, the evaluation team acquired actual and typical meteorological year weather data (TMYx)

WHY CHANGE WEATHER FILES? WHAT ARE THE IMPLICATIONS?

The TMY3 weather dataset represents a typical year based on data from 1991-2005 and 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. For Massachusetts specifically, TMYx (2007-2021) captures the warmer winters, which reduce opportunities for heating savings from weatherization. Based on guidance from the PAs, the evaluation team used the more recent TMYx weather data to normalize energy savings estimates for this study.

from the National Oceanic and Atmospheric Administration for all Massachusetts weather stations. The team mapped each IE SF customer to the closest weather station based on the customer's ZIP code. 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.[8]

- **DNV measure data.** A list of all installed measures funded by the PAs in IE SF homes participating in 2021 and 2022. The measure-level data included 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.
- **LVI assessment data.** The CAPs maintain an electronic database that fully meets the PAs' current data reporting requirements for IE SF. As discussed elsewhere in this report, data that the PAs' currently require CAPs to report is not granular enough to inform robust impact evaluation methodologies.[9] Key information (existing R-values in customers' attics, pre-air sealing infiltration rates, etc.) is not included as part of the CAPs' current reporting. As such, the evaluation team has included a recommendation in this report that the PAs expand their IE SF data requirements to include the detailed data necessary to support future impact evaluations.

WHAT ABOUT NON-PA FUNDED MEASURES?

CAPs braid federal and other non-PA funding with IE program dollars to provide more comprehensive services to IE SF participants. The team attempted to gather information on these non-PA funded measures—first from the CAPs and then from Executive Office of Housing and Livable Communities (EOHLCs)—throughout this evaluation. However, the evaluation team's efforts were unsuccessful, which left the team with a partial perspective of what happened in participating IE SF homes. This limited understanding of the full range of potential interventions in participating homes had an adverse impact on the team's ability to specify reliable billing analysis.

- As these building-, customer-, and measure-level details are the essential building blocks of a reliable impact evaluation and not present in the CAPs' current reporting, the evaluation team convened a series of meetings with representatives from ABCD and Action (two of the PAs' IE Lead Agencies) to discuss alternative sources of similar information to inform this evaluation. After several discussions, the evaluation team and

[8] 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.

[9] The 2012 Low Income Evaluation faced similar issues accessing sufficiently detailed electronic tracking data. To overcome this same issue in 2012, the evaluation team traveled to 21 CAPs to extract the required information from sampled participants' physical assessment forms and installation documentation. The effort was time consuming and expensive. In many ways, the path used as part of this study is a more digitized means to the same end. See the *Agency Data Collection* section of the 2012 impact evaluation for details.

agencies identified the best available option: previously scanned assessment forms sent to ABCD by HPCs that served IE SF participants in 2023 through the LVI channel described earlier in this report. According to ABCD, roughly 45%-50% of all IE SF participants in 2023 were served through the LVI channel.

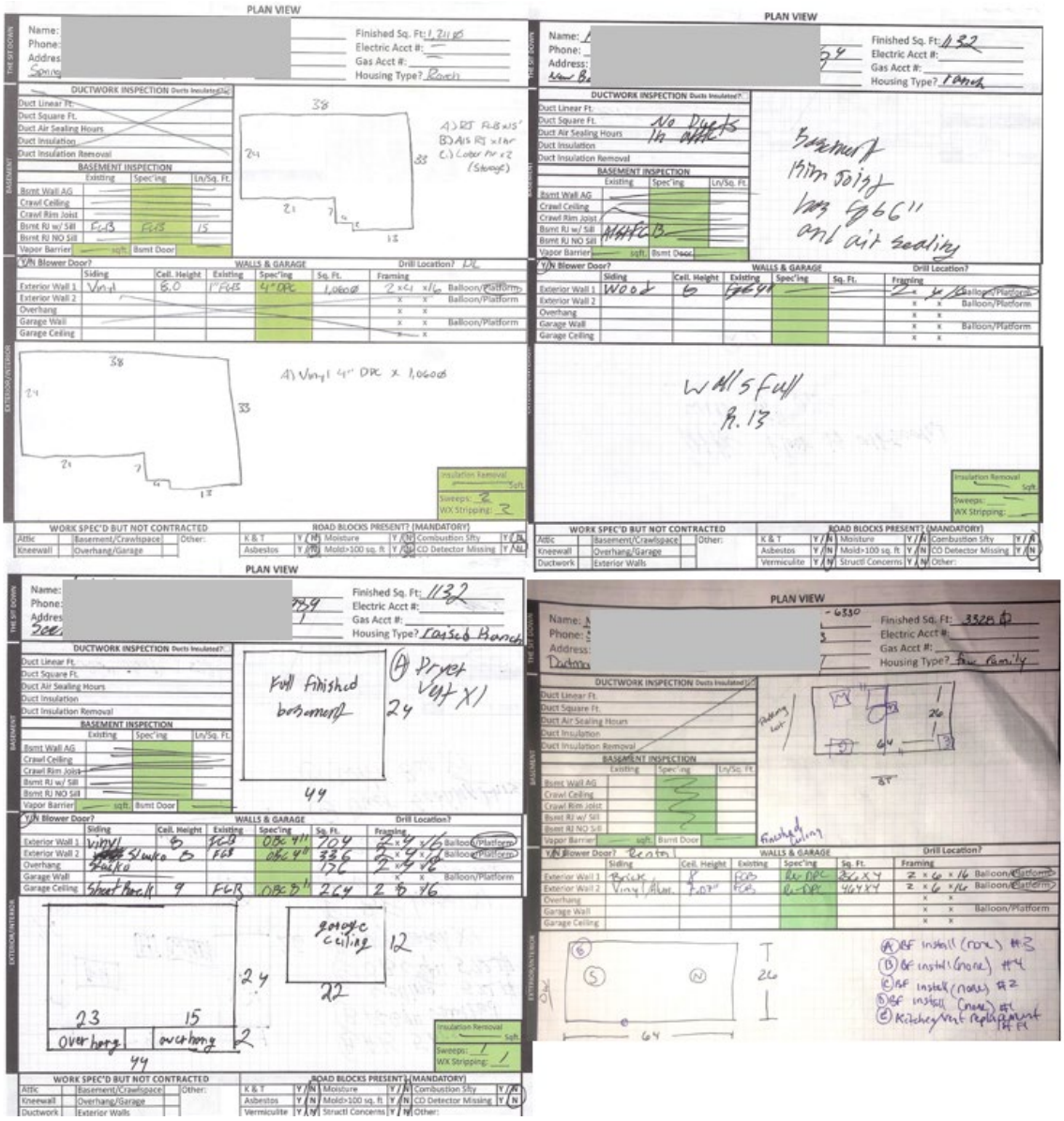
Although the CAPs have similar documentation for 2021 and 2022 participants served directly by the CAPs (the evaluation team's original request), those forms were not already scanned (i.e., only paper copies) and therefore posed a larger administrative burden for the CAPs to provide. Importantly, ABCD and Action confirmed the representativeness of using LVI data to evaluate the broader IE SF initiative during the data-focused discussions listed earlier.

Over the course of 3 weeks, ABCD securely transferred the scanned files associated with 170 randomly sampled LVI participants to the evaluation team. The exact forms, as well as the number of pages, varied for each participant depending on their assessment and the measures they received. On average, a participant's scan included two to three different documents totaling 10-12 pages.

Once the scanned files arrived, the evaluation team reviewed each set, manually extracted the required information, and populated a bespoke tracking database that informed much of the evaluation activities described in this report.

Figure 4 provides an example of the files the evaluation team received; it shows the Plan View form for four randomly selected LVI participants. As evident by the variation in documentation in these examples, extracting the relevant information was a specialized and time-consuming process. To yield the most reliable results, the evaluation team leaned on a subset of evaluation team members with direct experience working as in-home residential energy assessors to pull information from the scanned files and create a database with the information required for the evaluation.

Figure 4. Example LVI Forms



Source: LVI assessment files provided by ABCD

The dataset created by the evaluation team using the provided LVI documentation in many ways mirrored the format and structure of tracking data the team received from RCD LVs. Given the variation in the provided files, the team was not able to populate every field for every participant. In some cases, information was missing or illegible.

Table 3 offers a summary of the data elements the team extracted from the provided documentation to inform this evaluation. Table 3 provides an overview and should not be viewed as a comprehensive list.

Table 3. LVI Data Summary

Data Type	Key Data Fields
Customer Information	• Participant Name • Address • Number of Occupants • Assessment Date
Building Information	• Year Built • Conditioned Square Footage • Number of Units • Housing Type • Space Heating Fuel • Water Heating Fuel • Existence of Cooling Equipment
Measure Data	• Measure • Measure Fuel Type • Measure Efficiency Rating • Installation Date • Infiltration Rates (Pre and Post) • Building Shell Conditions (Pre and Post for Attics, Walls, and Basement/Floor) • Quantity of Installed Insulation (Added R-Value and Square Feet) • HVAC Distribution System Conditions

Source: Cadeo analysis of LVI assessment documentation

2.2.1 Comparing LVI and CAP served Participants

To independently verify the CAPs' perspective that the customers served and measures installed through LVI are representative of the IE SF initiative overall (and therefore suitable to inform this impact evaluation), the evaluation team compared the limited information the team had for both groups. Specifically, using the information the team extracted from the LVI assessment forms and the basic information available in the DNV data, the team compared the following characteristics using a two-sample t-test:

- **Building area.** The DNV data included tax parcel information (for a subset of participants) with an overall average dwelling area of 1,500 square feet, which is smaller and significantly different from the LVI average (1,960 square feet). The evaluation team's analysis accounted for this difference by a) modeling savings for air sealing and insulation on a per square foot basis, and b) normalizing the building simulation results using disaggregated energy consumption from the population of participants in the DNV dataset.

- **Year of construction**. The tax parcel included in the DNV data also included building age, which reported an overall average building vintage of 1944 (versus the significantly different LVI average vintage of 1924). The team's modeling does not explicitly account

for year of construction, although some of the pre-initiative characteristics used for modeling from the LVI data (e.g., existing attic R-values) are likely correlated with building age.

- **Building stories:** There was no statistical difference between the DNV and LVI averages of 1.9 stories and 2.0 stories per building.

3. Results Summary

Table 4 summarizes this evaluation's findings for each IE SF measure and relevant fuel type. The table also indicates which methodology—or combination of methodologies—the evaluation team used to evaluate the savings. While a particular measure may result in savings for fuels other than those listed (e.g. fossil fuel savings for solar hot water heaters), the table only includes TRM-defined fuel type savings associated with IE initiative measures.

Table 4. Evaluated Gross Energy Savings by Measure

Measure	Natural Gas (therms)	Electric (kWh)	Oil (MMBtu/ gal)	Propane (MMBtu/ gal)
BUILDING SHELL				
Weatherization (Insulation and Air Sealing)	174	1,931	19.6	20.3
—Insulation (Overall)	151	1,685[10]	16.9/122	17.6/192
-Distribution Savings (Associated with insulation for natural gas/oil/propane heated homes), kWh		49/43/42		
-Cooling Savings (Associated with Insulation for natural gas/oil/propane heated homes), kWh		93/83/79		
-Air Sealing	23	246[10]	2.5/18	2.6/29
-Distribution Savings (Associated with air sealing for natural gas/oil/propane heated homes), kWh		6/5/5		
-Cooling Savings (Associated with air sealing for natural gas/oil/propane heated homes), kWh		-1/-1/-1		
Window - Electric Resistance		254		
Window - Heat Pump		127		
Window - Fossil Fuel	13		1.3/9	1.3/14
Window - Electricity savings (kWh) associated with fossil fuel savings for oil/propane heated homes			7	7
HVAC				
Furnace Replacement	105		3.7/27	10.5/115
—Furnace Fan Savings, kWh	92		34	92
Boiler Replacement	114		6.1/44	11.4/125
Boiler Reset Controls	33	-	3.4/25	
Central Heat Pump (Propane Partial Displacement, savings per ton)	-	-839	-	9.8
Central Heat Pump (Oil Partial Displacement, savings per ton)	-	-832	10.5	-
Central Heat Pump (Natural Gas/Propane Full Displacement, savings per ton)	155	-1,249	-	15.5
Central Heat Pump (Oil Full Displacement, savings per ton)	-	-1,238	16.6	-

[10] The building simulation methodology resulted in combined electricity savings for electrically heated homes; distribution and cooling savings are included in the combined totals for air sealing and insulation.

Measure	Natural Gas (therms)	Electric (kWh)	Oil (MMBtu/ gal)	Propane (MMBtu/ gal)
Mini-Split Heat Pump (Natural Gas/Propane Partial Displacement, savings per ton)	163	-960	-	16.3
Mini-Split Heat Pump (Oil Partial Displacement, savings per ton)	-	-961	15.9	-
Mini-Split Heat Pump (Electric Heat Full Displacement, savings per ton)	-	2,547	-	-
Mini-Split Heat Pump (Natural Gas/Propane Full Displacement, savings per ton)	175	-1,206	-	17.5
Mini-Split Heat Pump (Oil Full Displacement, savings per ton)	-	-1,208	17.1	-
Pipe Wrap (Space Heating)	-	-	1.0/7	-
Programmable Thermostat	20	280	2.3/16	2.0/22
Wi-Fi Thermostat (AC only for electric savings)	22	18	2.4/18	2.2/24
Dehumidifier	-	489	-	-
Window AC replacement	-	48	-	-
Duct Insulation	9	35	0.8/6	0.9/9
Duct Sealing	7	22	0.7/5	0.7/8
PROCESS				
Refrigerator Replacement	-	651	-	-
Freezer Replacement	-	713	-	-
Appliance Removal	-	968	-	-
Smart Strips	-	105	-	-
HOT WATER				
Faucet Aerators	3	63	0.4/3	0.3/3
Showerheads	14	245	1.4/10	1.4/15
Early Retirement CW Elec DHW & Elec Dryer	-	214	-	-
Early Retirement CW Gas DHW & Elec Dryer	-	140	-	-
Early Retirement CW Elec DHW & Gas Dryer	-	75	-	-
Early Retirement CW Gas DHW & Gas Dryer	-	39	-	-
Early Retirement CW Oil DHW & Elec Dryer	-	140	0.2/2	-
Early Retirement CW Propane DHW & Elec Dryer	-	140	-	0.2/2
Pipe Wrap (Water Heating)	3	73	1.1/8	0.3/3
Solar Hot Water	-	2,264	-	-
Indirect Water Heater	87	-	-	-
Heat Pump Water Heater, <55 gallon[11]	-5	1,799	-0.1/-1	-0.1/-1

[11] The negative values are associated with the heating penalty for gas, oil, or propane heating systems.

Measure	Natural Gas (therms)	Electric (kWh)	Oil (MMBtu/ gal)	Propane (MMBtu/ gal)
Heat Pump Water Heater, >55 gallon[12]	-	360	-	-
Heat Pump Water Heater displacing Oil	-	-1,138	17.4/126	-
Heat Pump Water Heater displacing Propane	-	-831	-	16.4/179
Stand Alone Water Heater	57	-	-	-
BEHAVIOR				
TLC Kit	-	69	-	-

Source: Cadeo analysis

Building Simulation
Engineering Adjusted Building Simulation
Engineering Algorithm
Heat Pump Metering Study

[12] Federal standard essentially requires a HPWH for electric water heating >55 gallons. The study therefore assumes a HPWH baseline without a heating penalty.

4. Key Findings – Weatherization

Because more than half of all IE SF gross energy savings in 2021 come from air sealing and insulation, the first key findings section focuses on these two measures, which, again, the team collectively refers to as weatherization.

The following four subsections describe the evaluation team's methodology and evaluation results for weatherization participants that heat their homes with natural gas, electricity, heating oil, and propane.

4.1 Natural Gas

4.1.1 Methodology

The evaluation used calibrated building simulation to evaluate the savings associated with weatherization installed through IE SF in natural gas heated homes. This approach differed from the 2012 IE SF impact evaluation, which used billing analysis.

As discussed in greater detail in Appendix A, the evaluation team attempted a billing analysis to estimate savings for weatherized natural gas heated homes. However, the various model specifications used by the team did not achieve the pre-determined level of statistical significance (better than ±20% precision at the 90% confidence level) for use to officially report savings. The primary reasons for the low precision and reliability of IE SF billing analysis results include:

- **Less participants.** The total volume of weatherization participants in IE SF is smaller (relative to the PAs' market rate retrofit initiative, RCD), which results in smaller sample sizes for the billing analysis and, in turn, lower model precision and less reliable results.

- **Non-PA funded measures.** The evaluation team was unable to get data on non-PA funded measures. Consequently, these measures were unaccounted for in the billing analysis for the subset of IE SF participants that received them. Without this information, the model is subject to omitted variable bias which leads to poor precision and the misattribution of measure impacts.

As a result, the team used calibrated building simulation to evaluate savings for participants that weatherized their home through IE SF and heat with natural gas. Billing analysis disaggregation (i.e., using weather data to break participants' total consumption into heating, cooling and baseload) was successfully completed and used to inform the engineering tasks.

The team's building simulation-based methodology included the following steps:

- **Developing Baseline Models.** Using available IE SF audit data about average pre-IE SF building characteristics (also known as existing conditions), develop baseline models for each model segment.

- **Calibration.** Using monthly natural gas energy consumption of IE SF participants, calibrate each baseline model to reflect pre-IE SF energy consumption.

- **Develop Efficient Models.** Update the calibrated baseline models with information about installed IE SF measures (e.g., updated R-values and infiltration rates) and re-run the models to determine post-IE SF consumption.

- **Weighting Results.** Calculate initiative savings for each measure by weighting the observed difference between the baseline and efficient models (i.e., measure savings) using each model segments weight (i.e., the portion of total IE SF participation reflected by that model segment)

4.1.1.1 Developing Baseline Models

The team leaned on the detailed LVI assessment files provided by ABCD to develop baseline models for weatherized natural gas-heated homes. These files included existing (i.e., pre-IE SF) information about the participant's home, including square footage, insulation levels, and outdoor air infiltration rates.

Table 5 summarizes the number of data points available to the team (via the LVI assessment files) to develop the natural gas baseline models. To be clear, the values the evaluation team used to develop the baseline models, such as those shown below, reflect the conditions in homes—prior to weatherization—for only the subset of IE SF participants that received weatherization (i.e., not all IE SF participants). The table also includes the percent of all natural gas weatherization participants that received the given measure and, when received, the average baseline for that measure (i.e., the existing condition prior to IE SF intervention).[13]

Table 5. Natural Gas Building Simulation Baseline (Pre-IE SF) Values

	Participants (Sample Size)	% of Weatherized Natural Gas-Heated Participants	Baseline Value
Attic Insulation (R)	35	58%	13.0
Basement/Floor Insulation (R)	9	15%	4.4
Wall Insulation (R)	48	80%	4.4
Air Sealing (ACH50)	27	100%	17.4
Duct Insulation (R)	3	5%	2.0
Duct Sealing (% Leakage)	-	0%	-
Total	**60**	**100%**	-

Source: Cadeo analysis of LVI assessment documentation

[13] The LVI data indicated that some of the participants' attics, basement/floors and walls had an existing R-value of 0 (i.e., the space was uninsulated). This is not uncommon in tracking data for assessment-based initiatives like IE SF (i.e., that an assessor indicates a lack of insulation as R=0). However, even uninsulated spaces, which provide a barrier to the outside, have insulative properties (i.e., the R-value for these spaces is not actually 0.) Consistent with the previous IE SF evaluation – as well as ASHRAE 90.1 – the evaluation team replaced these R=0 values with the following default R-values before calculating the averages shown in Table 5: attics (R=8.2), floors (R=3.4), and walls (R=3.4).

4.1.1.2 Calibration

The team calibrated the natural gas baseline models using billing data provided by DNV for all 2021 IE SF natural gas weatherization participants. It is important to note that this dataset is different—and included far more participants—than the LVI dataset that the team used to develop the baseline models. In other words, the team had information about consumption for all IE SF participants (via DNV) but information about existing conditions and measure installation details for a subset of participants (the LVI data via ABCD).

Specifically, the team leveraged the results of the billing analysis's VBDD analysis, which yielded information about the average IE SF participant's heating, cooling, and baseload for natural gas (and electricity).[14] As a quality control measure, the team thoroughly inspected the consumption data to remove outliers (below the 5th and above the 95th percentile of IE SF natural gas consumers) prior to applying the VBDD analysis.

IF THE BILLING ANALYSIS WAS INSUFFICIENTLY PRECISE, IS IT OKAY TO USE BILLING DATA FOR MODEL CALIBRATION?

Yes, because the two analyses—while relying on the same source data—are answering fundamentally different questions.

The billing analysis sought to model the average change in participant's natural gas consumption before and after weatherization using a series of explanatory variable in a regression model. For IE SF, that assessment was unsuccessful (i.e., did not yield statistically significant results attributing changes to a source) due to limited sample size, lack of measure details, and no information about non-PA funded measures).

The bill disaggregation that informs model calibration does model individual customers' consumption as a function of their local weather and determined pre- and post-weatherization balance points (i.e., the temperature at which they heat or cool their home). This analysis is more straightforward, serves an entirely different purpose, and is not subject to the data insufficiencies and omitted variable bias that adversely impacted the billing analysis.

The team used the output of the VBDD analysis to construct natural gas target curves for each segment. These targets represent the monthly consumption for the average IE SF participant in a natural gas-heated home and provide the basis for the team's calibration.

The calibration process involved running dozens of model iterations to find the collection of inputs that created homes whose consumption most closely aligned with the billing data. The team calibrated participant's base load, heating load, and, when applicable cooling load using the VBDD disaggregated billing data. The team considered models sufficiently calibrated once modeled annual energy consumption was within 10% of the total annual billing data usage for each disaggregation, and no individual modeled monthly consumption value was more than 20% different from than the actual average for that month in the billing data.

4.1.1.3 Develop Efficient Models

The team again turned to the LVI data to assess the changes to natural gas heated homes after weatherization through IE SF. Table 6 summarizes this information, which serves as counterpart to the pre-IE SF conditions summarized in Table 5.

[14] For more details about the VBDD analysis, see the Billing Analysis section of Table 2.

Table 6. Natural Gas Building Simulation Efficient (Post-IE SF) Values

	Participants (Sample Size)	Percentage of Weatherized Natural Gas-Heated Participants
Attic Insulation (R)	35	58%
Basement/Floor Insulation (R)	9	15%
Wall Insulation (R)	48	80%
Air Sealing (ACH50)	27	100%
Duct Insulation (R)	3	5%
Duct Sealing (% Leakage)	-	0%

Source: Cadeo analysis of LVI assessment documentation

4.1.2 Results

Table 7 summarizes the results of the team's calibrated building simulation modeling of weatherized IE SF participants that heat their homes with natural gas. As shown below, the average weatherization participant—i.e., an IE SF customer that received air sealing and one or more types of insulation—saved 174 therms. This result is based on the pre- and post-IE SF building envelope and measure details gleaned from the 60 natural gas heated weatherization participants included in the LVI data provided to the evaluation team.

As part of the billing disaggregation, the evaluation team determined that weatherized IE SF participants used, on average, 687 therms annually to *heat* their home before participating in IE SF. Therefore, weatherization savings of 174 therms/year means the average weatherization participant saved 25% of their pre-IE SF weather normalized annual heating consumption.

Table 7 also breaks down overall weatherization savings into its contributing components. As shown in the table, most of the modeled weatherization savings come from insulation (151 therms or 87%) with air sealing contributing 23 therms (13%). Per the LVI data, the average natural gas weatherization participants received 1.5 types of insulation: 58% received attic, 15% baseline/floor, and 80% wall. The evaluation team's modeling found wall insulation saved the most, followed by attic insulation and then basement/floor insulation. Combining the percentages of participants that received each type of insulation with the modeled insulation-specific savings yields the total insulation savings of 151 therms.

Table 7. Evaluated Weatherization Savings – Natural Gas

Measure	Evaluated Savings (therms/year)	Percent of Natural Gas Weatherization Participants That Received the Measure
Weatherization (Air Sealing & Insulation)	**174**	**100%**
• Air Sealing	23	100%
• Insulation	151	100%
○ Attic Insulation	48	58%
○ Basement/Floor Insulation	11	15%
○ Wall Insulation	152	80%

Source: Cadeo analysis

4.1.3 Benchmarking

Benchmarking is an essential part of all impact evaluations. The practice provides critical insight into how the results of a given evaluation compare to 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.

4.1.3.1 Relative to the Previous Evaluation

The previous IE SF evaluation, which was completed in 2012 and evaluated the savings associated with customers that participated in 2010 and 2011, used a billing analysis to evaluate overall natural gas weatherization savings and building simulation to estimate the savings associated with each weatherization element (air sealing, attic insulation, etc.). While the studies used somewhat different methodologies, it is still possible to compare the results and infer reasons for the disparity between the results.

Table 8 compares the evaluated statewide result for 2021 natural gas-heated weatherization participants from this evaluation to the result for the 2010 and 2011 participants evaluated as part of the 2010 study. The most notable difference in Table 8 is air sealing: the previous evaluation found an average of 105 therms/year, whereas the current evaluation modeled 23 therms/year.

Table 8. Comparison of Evaluated Weatherization Savings – Natural Gas

Measure/Metric	Previous Evaluation (therms/year)	Current Evaluation (therms/year)
Heating Annual Energy Consumption (pre-program)	891	687
Weatherization (Air Sealing & Insulation)	**263***	**174**
• Air Sealing	105	23
• Insulation	171**	151
○ Attic Insulation	83	48
○ Basement/Floor Insulation	13-15	11
○ Wall Insulation	115	152

*Determined using billing analysis. The rest of the previous evaluation values—and all the values from the current evaluation—are based on building simulation.
**Not included in 2012 report; calculated by team using the savings and installation rates included for each type of insulation.
Source: Cadeo analysis and 2012 Low Income Impact Evaluation (Table 19)

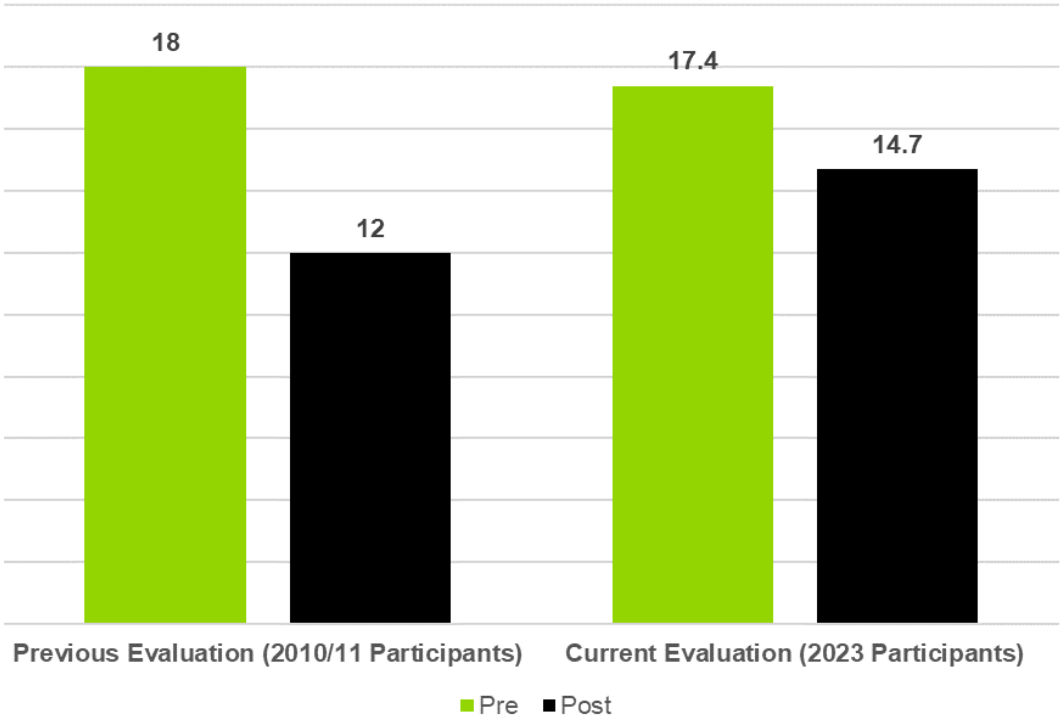
A comparison of the pre- and post-air infiltration values from both evaluations provides some context for the disparate air sealing results. As Figure 5 shows, the previous evaluation, which focused on the 2010 and 2011 IE SF participants had both a higher pre-air sealing ACH50[15] (18) *and* a lower post-air sealing ACH50 (12) relative to the current evaluation (17 and 15 ACH50, respectively). In other words, based on available initiative data for both evaluations, the homes served in 2010 and 2012 were leakier before IE SF and tighter after IE SF than the homes served in 2021. This difference in delta ACH50 between studies is largely driving the difference in the evaluated savings.

In addition, the decreased air sealing savings can be partially attributed to the presence of smaller homes in the 2021 cohort. While the pre-measure gas consumption for gas-heated homes in the prior evaluation was 1,168 therms, this value in the current evaluation was calculated to be 887 therms. This higher consumption in the previously evaluated homes could be related to larger home sizes compared to homes in this evaluation (average home size was not available in the previous evaluation). Furthermore, the modeled square footage for gas-heated homes in the current evaluation, 1,577 square feet (calculated from the 2021 Tax Parcel data), is relatively small for an SF home. This would have a much larger impact on the air sealing savings than on the insulation savings due to the relationship that air sealing and insulation savings have with home size.

As all of the surfaces in which insulation measures are applied are two-dimensional, insulation savings have a quadratic (second-degree) relationship to building size. Air sealing savings, however, are proportional to the volume of a building, and thus have a cubic (third-degree) relationship to building size. The presence of smaller homes in the current evaluation, therefore, has a larger influence on air sealing than on insulation savings and is another factor driving the difference in the evaluated air sealing savings.

[15] Air changes per hour at 50 pascals (Pa) pressure differential

Figure 5. Comparison of Pre- and Post-Air Sealing ACH50 Values – Natural Gas



Source: Cadeo analysis and 2012 Low Income Impact Evaluation (Table 19)

Table 9 shifts the comparison from air sealing to building envelope conditions. As with air sealing, the comparison shows that the participants in the previous evaluation lived in homes with lower existing insulation levels than participants in the current evaluation. The post-R-values below are generally similar across studies (with higher R-values for 2023 participants receiving attic insulation). However, given the non-linear, diminishing returns associated with incremental insulation, it is the pre-initiative conditions that drive energy savings.

Table 9. Comparison of Pre- and Post-Insulation R-Values – Natural Gas

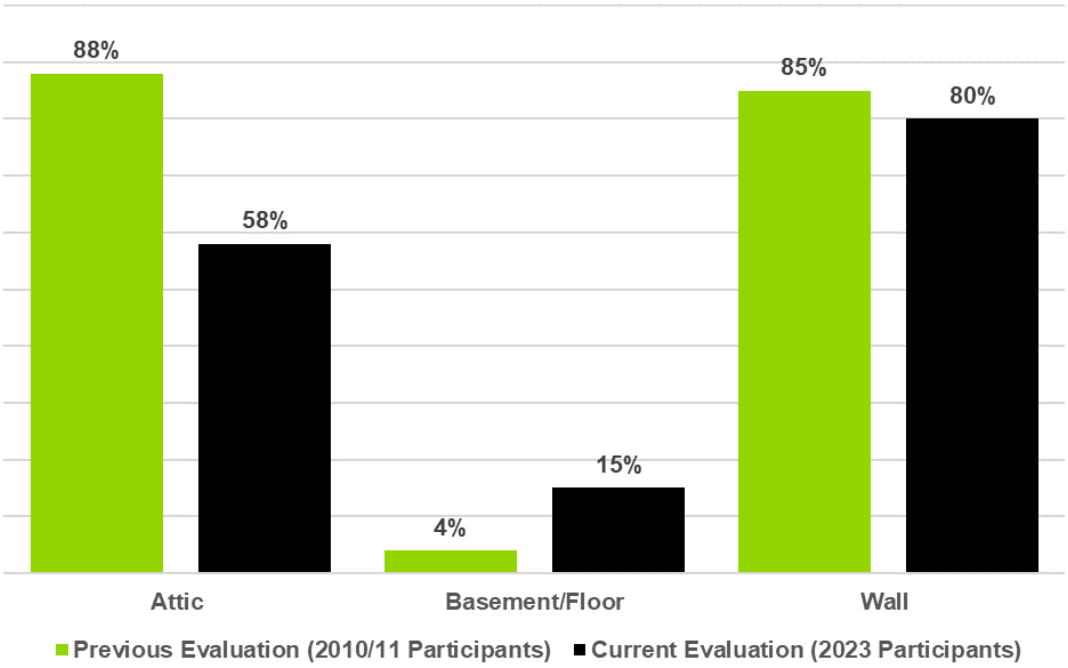
	Previous Evaluation (2010/11 Participants)		Current Evaluation (2023 Participants)	
Insulation Type	**Pre**	**Post**	**Pre**	**Post**
Attic	8.2	27.0	13.0	33.8
Basement/Floor	3.4/6.6	23.3/23.6	4.4	21.3
Wall	3.4	14.4	4.4	13.4

Source: Cadeo analysis and 2012 Low Income Impact Evaluation (Table 16)

Figure 6 offers a final comparison of the natural gas weatherization participants across the two studies: the percentage of weatherization IE SF participants that had each type of insulation installed in their home. As a reminder, to qualify as a weatherization or insulation participant, an IE SF participant only needs to receive at least one type of insulation. However, many weatherization participants receive more than one type.

As Figure 6 shows, participants in the previous evaluation—on average—installed slightly more types of insulation than the participants included in the current study (1.8 versus 1.5). Participants from the previous evaluation also exhibited a different profile: less basement/floor insulation and more attic insulation. As found in this evaluation, on average, attic insulation saves four times as much energy as than basement/floor insulation (Table 8) so this shift is also likely contributing to the disparity between the two evaluations.

Figure 6. Comparison of Installed Insulation Types – Natural Gas

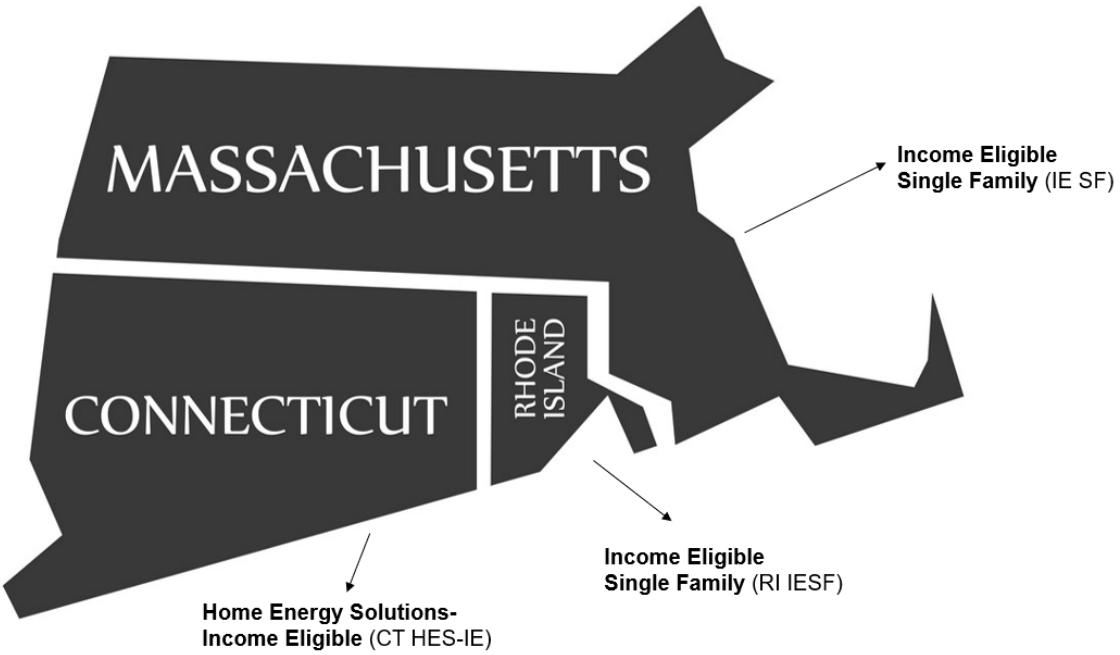


Source: Cadeo analysis and 2012 Low Income Impact Evaluation (Table 19)

4.1.3.2 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 offerings in neighboring states: Home Energy Solutions-Income Eligible in Connecticut and Income Eligible Single Family in Rhode Island.

Figure 7. Relevant Regional Benchmarks



Source: Cadeo analysis

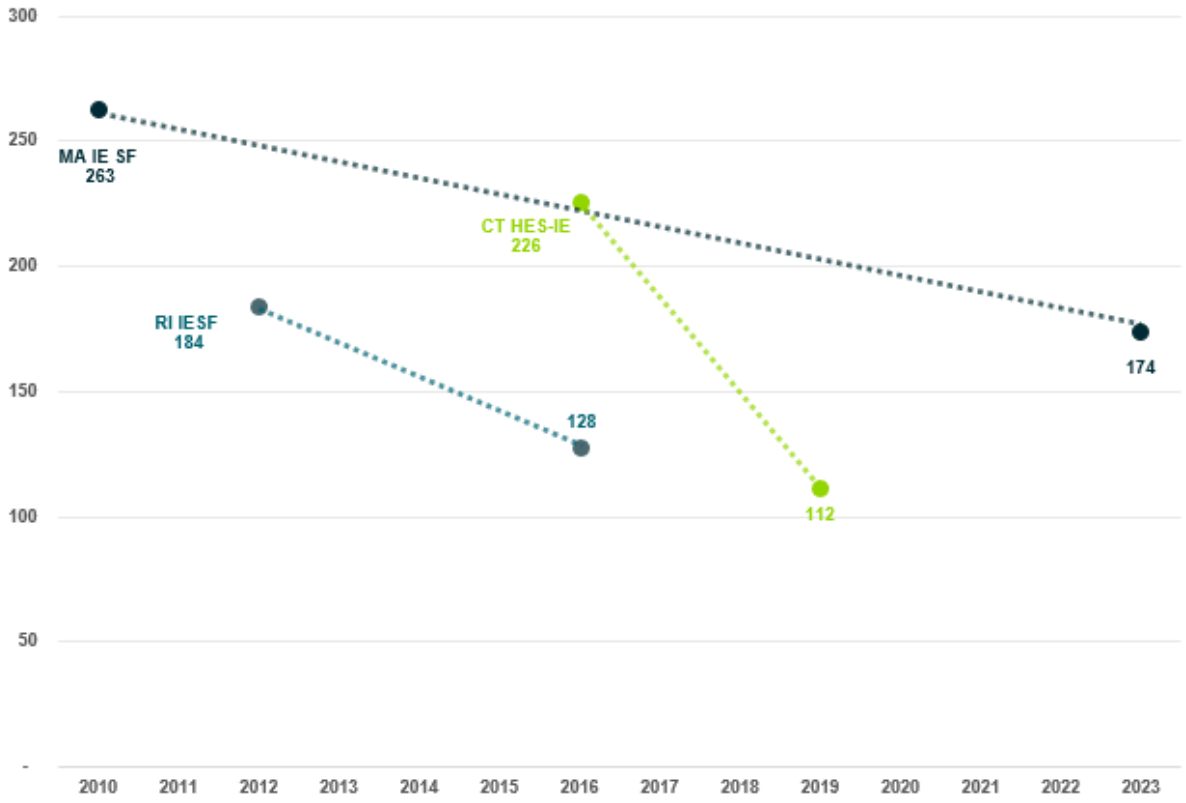
Figure 8 compares the results of this—and the previous IE SF impact evaluation in Massachusetts—to IE evaluations in Connecticut and Rhode Island. While the design and delivery of each program differs somewhat,[16] all three programs are assessment-based and offer measures to participants at no cost. In addition, the impact evaluation approaches differ: both studies in Connecticut and Rhode Island, like the previous study in Massachusetts, relied on billing analysis; again, this study used building simulation.

As shown below, the lower average savings for IE SF relative to the previous evaluation is consistent with a long-term, regional trend of declining average natural gas weatherization savings. As Figure 8 shows, the programs in Connecticut and Rhode Island have also exhibited a downward trend in savings over the past decade. In fact, every subsequent study within a state has found lower average savings than the prior study.

Beyond this long-term, regional trend, Figure 8 offers two additional insights. First, the average weatherization savings determined through this evaluation are higher than the more recent evaluations in Connecticut and Rhode Island. Second, the interval of time between IE impact evaluations is much longer in Massachusetts. It's worth noting that Connecticut is planning an IE impact evaluation now, while a study is already underway in Rhode Island.

[16] The most notable difference is that the Home Energy Solutions (HES) program in Connecticut conducts air and duct sealing during the initial home energy assessment itself (versus during a subsequent visit to install insulation like MA IE SF and RI IESF.

Figure 8. Evaluated Savings Over Time by State – Average Weatherization Savings (therms/year) for Natural Gas-Heated IE Customers



Source: Cadeo analysis

4.2 Electricity

This section summarizes the evaluation team's approach and findings for electrically heated homes receiving weatherization, which have historically represented a small portion of IE SF participants. (Most heat with natural gas or heating oil.)

4.2.1 Methodology

Like natural gas weatherization, the evaluation used calibrated building simulation to evaluate the savings associated with weatherization installed through IE SF in electrically heated homes. The following sections briefly provide electric-specific details regarding the team's approach which mirrored that described above for natural gas.

4.2.1.1 Developing Baseline Models

Because far fewer weatherized IE SF participants heat their homes with electricity, the sample of such participants in the LVI data was very small (n=3) compared to natural gas (n=60). Unlike natural gas, the electric weatherization sample size was insufficient to support a reliable heating fuel-specific modeling.

For this reason, the team had to make a simplifying assumption: that the baseline conditions in electrically heated homes are the same as the baseline conditions in *all* IE SF weatherized homes (i.e., regardless of the heating fuel).[17] Making this assumption allowed the team to combine available baseline data for weatherized electric (n=3), natural gas (n=60), and heating oil (n=15) participants, which increased the total available sample to 78.

Table 10 summarizes the number of data points available to the team (via the LVI assessment files) to develop the electric baseline models, as well as the percent participants that received each measure and, when received, the average baseline for that measure (i.e., the existing condition prior to IE SF intervention).

Table 10. Electric Building Simulation Baseline (Pre-IE SF) Values

	Participants (Sample Size)[18]	Percentage of Weatherized Participants	Baseline Value
Attic Insulation (R)	50	64%	13.1
Basement/Floor Insulation (R)	14	18%	5.1
Wall Insulation (R)	60	77%	4.4
Air Sealing (ACH50)	35	100%	17.2
Duct Insulation (R)	4	5%	2.0
Total	**78**	**100%**	-

Source: Cadeo analysis of LVI assessment documentation

4.2.1.2 Calibration

Like the natural gas modeling, the team leveraged the results of the billing analysis's VBDD analysis, which yielded information about the average IE SF participant's heating, cooling, and baseload for electricity. The team used the same calibration process described in the natural gas modeling, including running dozens of model iterations to refine the inputs used to calculate savings.

4.2.1.3 Develop Efficient Models

The team again turned the LVI data to assess the changes to electrically heated homes after weatherization through IE SF. Table 10 summarizes this information, which serves as counterpart to the pre-IE SF conditions summarized in Table 11.

[17] This simplifying assumption does not account for the fact that building energy codes took effect for electrically heated homes before other fuels. Thus, older electrically heated homes may be better insulated – prior to participating in IE SF – than comparably aged homes that heat with another fuel. However, the evaluation team did not have access to sufficiently detailed population-level electronic participation tracking data to develop a model specifically for electrically heated homes and therefore needed to apply this simplifying assumption. It is also important to note that because so few IE SF participants heat with electricity (compared with natural gas and heating oil), this assumption does not have a material impact on the initiative's overall energy savings.

[18] As noted in the text, this column reflects all heating fuel types.

Table 11. Electric Simulation Efficient (Post-IE SF) Values

	Participants (Sample Size)[19]	Percentage of Weatherized Participants	Baseline Value
Attic Insulation (R)	50	64%	35.7
Basement/Floor Insulation (R)	14	18%	25.1
Wall Insulation (R)	60	77%	13.4
Air Sealing (ACH50)	35	100%	14.7
Duct Insulation (R)	4	5%	7.0
Total	**78**	**100%**	-

Source: Cadeo analysis of LVI assessment documentation

4.2.1.4 Weighting

To translate the savings generated from running the calibrated models into final statewide values, the team weighted the results between a variety of electric heating and cooling systems. The team divided the electric heating systems present in participants' homes into three categories: ducted heating, non-ducted heating, and heat pumps. Both the ducted and non-ducted heating systems were differentiated into those with room AC, a CAC, or no AC. The full list of HVAC systems and the weights[20] assigned to them are shown in Table 12.

Table 12. Electric Simulation Segment Weights

Heating Type	Cooling Type	Weight
Non-ducted heating	CAC	0.15
	No AC	0.15
	Room AC	0.44
Ducted heating	CAC	0.02
	No AC	0.02
	Room AC	0.07
Heat pumps	Cooling	0.16

Source: Cadeo analysis of LVI assessment documentation

4.2.2 Results

Table 13 summarizes the results of the team's calibrated building simulation modeling of weatherized IE SF participants that heat their homes with electricity.

As shown below, the average weatherization participant—i.e., an IE SF customer that received air sealing and one or more types of insulation—saved 1,932 kWh/year. This result is based on

[19] Ibid.

[20] The weight reflects a combination of the weights of the heating and cooling systems. The weights for the heating systems were obtained from finding the relative proportions in ResStock of these heating types in electrically heated homes in MA with an annual income of less than $40,000. The weights for the cooling types reflect the cooling distributions found in MA22R51-B-HPMS, the concurrent heat pump metering study mentioned earlier.

the pre- and post-IE SF building envelope and measure details gleaned from all 78 weatherization participants included in the LVI data provided to the evaluation team. As a reminder, the electric weatherization sample was too small (n=3) to model electric-specific results, so the team made the simplifying assumption that the pre- and post-IE SF conditions in weatherized electric heating homes is similar to that of the average weatherization participant regardless of their heating fuel.

Table 13 also breaks down overall weatherization savings into its contributing components. As shown in the table, most of the modeled weatherization savings come from insulation (1,685 kWh or 87%) with air sealing contributing 246 kWh (13%). Per the LVI data, the average weatherization participant (across all heating fuel types) received 1.5 types of insulation: 64% received attic, 18% baseline/floor, and 77% wall. The evaluation team's modeling found wall insulation saved the most, followed by attic insulation and then basement/floor insulation. Combining the percentages of participants that received each type of insulation with the modeled insulation-specific savings yields the total weatherization savings of 1,931 kWh. This total represents 28% savings compared to the pre-program heating annual consumption of 6,895 kWh.

The natural gas weatherization results in Table 7 focused on heating savings. As part of the natural gas modeling effort, the evaluation team also calculated the electric savings—from decreased fan usage and air conditioning (when applicable)—that occur in weatherized natural gas homes, which can be found in Table 4.

Since the heating, cooling, and fan savings associated with the weatherization of an electric home are all electric, the modeled results in Table 13 reflect the full range of electric savings associated with weatherization: heating savings, cooling savings, and reduced furnace fan usage.[21]

Table 13. Evaluated Weatherization Savings – Electricity

Measure	Evaluated Savings (kWh/year)	Percent of Electricity Weatherization Participants That Received the Measure
Weatherization (Air Sealing & Insulation)	**1,931**	**100%**
• Air Sealing	246	100%
• Insulation	1,685	100%
○ Attic Insulation	578	64%
○ Basement/Floor Insulation	114	18%
○ Wall Insulation	1,682	77%

Source: Cadeo analysis

[21] As Table 4 shows, the team also developed electric cooling and furnace fan savings for natural gas and delivered fuel weatherization participants. However, because those customers heat with non-electric fuel, those electric savings associated with weatherization are shown separately from their heat fuel-specific heating related savings.

4.3 Delivered Fuels – Heating Oil and Propane

The team did not have access to usage data for weatherized IE 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.

Consequently, the team leveraged the natural gas building simulation results—first to estimate the annual pre-program heating consumption for delivered fuel participants and, second to estimate the percent of that consumption they saved after weatherizing their home through the IE SF program in 2021.

4.3.1 Calculating Annual Pre-Consumption

The team estimated the delivered fuel pre-period heating consumption by adjusting the building simulated natural gas pre-period heating consumption (687 therms or 68.7 MMBtus) by two factors: 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,[22] the team compared the average home size for natural gas and delivered fuel heated participants in 2021. As shown in Table 14, delivered fuel homes were meaningfully larger on average (1,807 and 1,841 for heating oil and propane, respectively, compared to 1,577 square feet for natural gas). As a result, the team made an upward adjustment to the observed natural gas pre-program heating consumption when converting it to reflect likely delivered fuel consumption (Table 14).

Table 14. Delivered Fuels Average Annual Pre-Period Heating Consumption

Fuel Type	Home Floor Area (SF)[23]	Home Floor Area relative to Natural Gas
Natural Gas	**1,577**	**100%**
Heating Oil	1,807	115%
Propane/Other	1,841	117%

Source: Cadeo analysis

- **Heating equipment efficiency.** For delivered fuel heating equipment, the team reviewed the baseline equipment efficiencies contained within the Residential Baseline Study,[24] 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 15.

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

[23] Floor area extracted from 2021 Tax Parcel data.

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

Table 15. Equipment Efficiency Comparisons and Assumptions

Source	Rated Efficiency	Derated Efficiency
Gas/Propane Furnace	84%	80%
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 77 MMTBUs/year heating oil and 80 MMBtus/year propane to heat their homes before they participated in IE SF (Table 16, Table 17).

Table 16. Estimating Heating Oil Heating Consumption

Metric	Value	Notes
Natural Gas Heating Consumption (therms/year)	**687**	Based on building simulation analysis; weather normalized using TMYx (2007-2021)
Adjustment Factor #1: Home Size	115%	Heating oil heated homes are larger than gas heated homes
Adjustment Factor #2: Equipment Efficiency	98%	Adjustment accounting for marginally more efficient heating oil equipment compared to natural gas
Fuel Conversion (therms-to-MMBtu)	0.1	-
Heating oil Heating Consumption (MMBtu/year)	**77**	**-**

Source: Cadeo analysis

Table 17. Estimating Propane Heating Consumption

Metric	Value	Notes
Natural Gas Heating Consumption (therms/year)	**687**	Based on building simulation analysis; weather normalized using TMYx (2007-2021)
Adjustment Factor #1: Home Size	117%	Propane heated homes are larger than gas heated homes
Fuel Conversion (therms-to-MMBtu)	0.1	-
Propane Heating Consumption, attached low rise / SF detached (MMBtu/year)	**80**	**-**

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. The team also did not have access to sufficient detailed information about the installed insulation characteristics or other pre-program conditions for homes heated with delivered fuels. 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.

4.3.3 Results

Using this approach, the evaluation team determined that IE SF participants that use delivered fuels as their primary heating fuel saved 25% of pre-participation household delivered fuel heating consumption, or 19.6 MMBtu/year on average for heating oil heated homes and 20.3 MMBtu/year for propane heated homes.

Table 18. Delivered Fuel Weatherization Results (2021 Participants)

Measure	Fuel Type	Energy Savings (MMBtu/year)	Percentage of Heating NAC
Weatherization	Heating Oil	19.6	25%
	Propane	20.3	25%

Source: Cadeo analysis

5. Key Findings – Heat Pumps

As previously noted, Guidehouse completed a robust residential heat pump metering study (MA22R51-B-HPMS) in May 2024 on behalf of the MA PAs and the Sponsors of EnergizeCT. That study, which included metering at over 200 homes across both states, was undertaken in recognition of the essential role heat pumps will play achieving GHG goals in MA, as well as in the region more broadly. More specifically, the MA PAs (and Sponsors of EnergizeCT) undertook the metering study because of the importance of developing reliable estimates of the net change in energy consumption that results from heat pump installations under a variety of scenarios. The PAs needed this information to establish deemed, per-cooling ton energy impacts for prescriptive heat pump measures installed during the upcoming 2025-2027 cycle. Given the similar objectives of this study (i.e., developing prospectively appropriate savings estimates), the IE SF evaluation team began to collaborate with MA22R51-B-HPMS metering study team.

The original scope for MA22R51-B-HPMS, finalized in August 2022, focused exclusively on metering heat pumps incentivized through the PAs Retail HVAC initiative. It did not include any IE installed units. While not technically limited to market rate customers (i.e., non-income-eligible customers), the general understanding is that Retail HVAC initiative does not serve IE customers. Rather, IE customers are more likely to receive a heat pump by participating in the IE SF initiative through their local CAP.

When reviewing the draft Stage 3 plan for the IE SF evaluation, stakeholders expressed concern about estimating savings for IE SF using metering data collected exclusively from Retail HVAC participants. Stakeholder understandably asked the question: *Do IE participants use their heat pumps differently than non-IE qualifying customers going through the Retail HVAC initiative?*[25]

To answer this question, the Stage 3 plan for the IE SF impact evaluation included a task and associated budget to add IE-specific sites to the ongoing MA22R51-B-HPMS study. The explicit goal was to directly address the question of whether heat pumps in IE homes are operated differently than heat pumps in non-IE homes.

Table 19 summarizes the sample of customers included by the multi-state study, including the IE-specific sample added to inform this evaluation. As shown below, the study collected heat pump usage data from Fall 2022 through Winter 2024 at a total of 204 homes across Massachusetts and Connecticut. The sample included a mix of central heat pumps, mini-split heat pumps, and ground source heat pumps as well as a combination of full and partial displacement scenarios.

[25] This question – about usage – is separate from established differences in baseline assumptions between the IE (existing equipment) and the Retail HVAC (systems the customer would have installed if they did not install the heat pump that they did) initiative that must be accounted for when determining the energy impact of heat pumps through both programs.

Table 19. Onsite Usage Metering

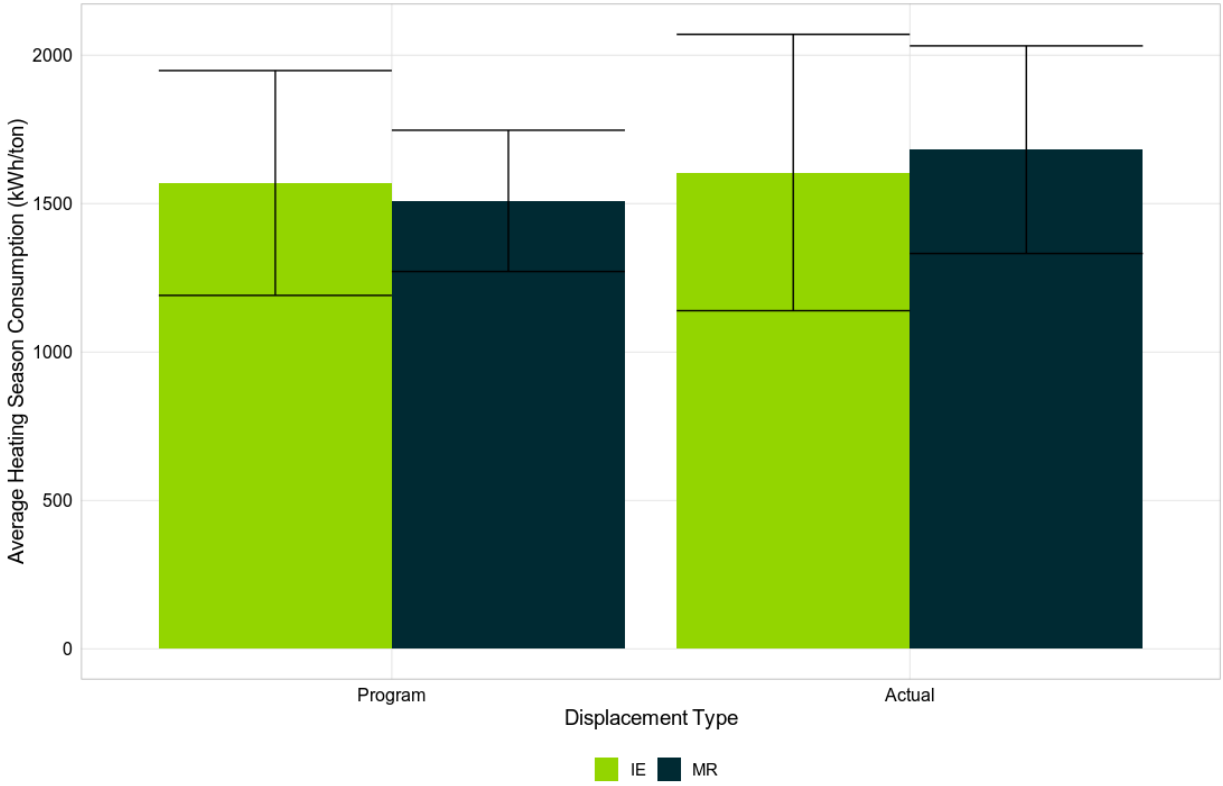
Building Type	System Type	Displacement Scenario	MR Sites Installed in MA	MR Sites Installed in CT	IE Sample Installed MA	Total Sites Installed
SF (Detached and Attached)	Mini-Split Heat Pump	FD	31	16	17	64
		PD	23	8	2	33
	Central Heat Pump	FD	29	9	0	38
		PD	12	25	0	37
	Ground Source Heat Pump	FD	1	25	0	26
MF (5+ units)	Mini-Split Heat Pump	FD	4	0	0	4
	Central Heat Pump	FD	1	1	0	2
Total			**101**	**84**	**19**	**204**

Source: MA22R51-B-HPMS

Leveraging results from fourteen[26] of the IE sites, the team compared average seasonal energy consumption for IE and non-IE metered sites. This comparison, illustrated in Figure 9, shows that IE and non-IE metered customers exhibited a very similar average heating season consumption when looking at Program or Actual groupings. Program values group metered data by displacement type listed in the program data. Actual values group metered data by displacement type as confirmed during field visits. The field team confirmed if a site was using their back-up heating system or if the backup heating system was removed/disconnected. As shown below (via the box and whisker plot), usage between IE and non-IE was not statistically different at the 90% confidence level.

[26] Five of the IE sites did not yield usable data.

Figure 9. Market Rate and IE Average Heating Season Consumption Comparison



Source: MA22R51-B-HPMS

Due to this similarity, as well as comparable results between Massachusetts and Connecticut,[27] the MA22R51-B-HPMS study team combined all metered sites (i.e., MA—both MR and IE—and CT) to bolster the sample size and generate more robust savings estimates for both states and income levels.

After establishing that it was appropriate to combine datasets, the study developed IE heat pump measures savings using the following methodology:

- Clean and process the metered data.
- Calculate in situ heat pump performance.
- Estimate typical-year heat pump usage with site-specific weather-normalization models.
- Estimate typical-year heat pump energy production using custom-fit models of heat pump performance.
- Estimate typical-year usage of hypothetical baseline heating and cooling systems based on assumed baseline system efficiencies.
- Estimate site-level measure impacts (savings) as the aggregate difference between typical year heat pump usage and typical year baseline usage.

[27] Similarly, the MA22R51-B-HPMS study also found no statistical difference between metered sites in Massachusetts and Connecticut.

- Aggregate site-level impacts to the stratum level (heat pump type and displacement type) and measure level (heat pump type, displacement type, and pre-existing fuel type). This step also uses weights for the baseline equipment types based on participant survey responses.

An important difference when calculating savings for IE heat pumps—relative to non-IE or MR heat pump participants going through the Retail HVAC initiative—is the baseline system assumptions. For IE, the team used existing unit derated efficiencies for the baseline, which are consistent with the initiative's retrofit, direct install delivery model and were agreed upon through a collaboration between the HPMS evaluation team, the PAs. and Energy Efficiency Advisory Council (EEAC) consultants. Table 20 summarizes the rated and derated baselines used to calculate IE measure savings.

Table 20. Baseline HVAC Unit Efficiency Assumptions*

HVAC Type	Existing Unit Efficiency	
	Rated	Derated
Central AC	13.0 *SEER* 12.4 *SEER2* 11.0 *EER*	10.4 *SEER* 9.9 *SEER2* 8.8 *EER*
Window AC	11.0 *CEER*	8.8 *CEER*
Gas Furnace	84.0%	80.0%
Propane Furnace	84.0%	80.0%
Oil Furnace	85.0%	81.0%
Gas Boiler	83.0%	75.0%
Propane Boiler	83.0%	75.0%
Oil Boiler	85.0%	77.0%
Electric Resistance	3.41 *HSPF*	3.41 *HSPF*

*SEER2 estimated as SEER/1.05, HSPF2 estimated as HSPF/1.17

Source: Massachusetts Residential Building Use and Equipment Characterization Study (2023), evaluation team analysis

Using the information above, the MA22R51-B-HPMS study team developed the deemed, per-ton savings for the program (Table 21) and actual displacement (Table 22) scenarios for all IE SF heat pumps. The tables below provide annual electric (kWh) and fuel savings (MMBtu) by heat pump/displacement type and pre-existing fuel for each IE SF BCR Measure ID and Measure Name.

Relative to the previous savings documented in the PAs' BCR model, the savings for roughly half of the mini-split heat pump measures increased marginally. For other types of heat pumps, the savings in the tables below reflect a modest decrease compared to the existing savings.

Table 21. Deemed Annual Energy Impacts (Per Ton)

Heat Pump and Displacement Type	Pre-Existing Fuel	BCR Measure ID	Measure Name	kWh Electric Savings	MMBtu Fuel Savings	Average Installed Tonnage (Cooling)	Sites Included in Rollup (n)
Central Heat Pump - FD	Natural Gas	GB1a059	Central Heat Pump fully displacing Gas Heat (SF)	-1,303	15.5	3.7	36
	Oil	EB1a273	Central Heat Pump fully displacing Oil Heat (SF)	-1,293	16.6		

Heat Pump and Displacement Type	Pre-Existing Fuel	BCR Measure ID	Measure Name	kWh Electric Savings	MMBtu Fuel Savings	Average Installed Tonnage (Cooling)	Sites Included in Rollup (n)
	Propane	EB1a272	Central Heat Pump fully displacing Propane Heat (SF)	-1,303	15.5		
Central Heat Pump - PD	Oil	EB1a269	Central Heat Pump partially displacing Oil Heat (SF)	-832	10.5	4.4	32
	Propane	EB1a268	Central Heat Pump partially displacing Propane Heat (SF)	-839	9.8		
Mini-Split Heat Pump - FD	Electric	EB1a266	Mini-Split Heat Pump displacing Electric Heat (SF)	2,752	0	3.5	46
	Natural Gas	GB1a060	Mini-Split Heat Pump fully displacing Gas Heat (SF)	-1,256	18.7		
	Oil	EB1a286	Mini-Split Heat Pump Fully Displacing Oil Heat (SF)	-1,258	18.3		
	Propane	EB1a287	Mini-Split Heat Pump Fully Displacing Propane Heat (SF)	-1,256	18.7		
Mini-Split Heat Pump - PD	Natural Gas	GB1a058	Mini-Split Heat Pump partially displacing Gas Heat (SF)	-960	16.3	3.0	33
	Oil	EB1a271	Mini-Split Heat Pump partially displacing Oil Heat (SF)	-961	15.9		
	Propane	EB1a270	Mini-Split Heat Pump partially displacing Propane Heat (SF)	-960	16.3		

Based on full metered sample and program data designation of displacement type

Source: Guidehouse analysis, results are normalized using TMYx typical weather spanning the years of (2007-2021)

Table 22. Deemed Annual Energy Impacts (Per Ton) – Remove Heat Pump Baseline Weights, Remove/Disconnect Pre-Existing Heat for FD

Heat Pump and Displacement Type	Pre-Existing Fuel	BCR Measure ID	Measure Name	kWh Electric Savings	MMBtu Fuel Savings	Average Installed Tonnage (Cooling)	Sites Included in Rollup (n)
Central Heat Pump - FD	Natural Gas	GB1a059	Central Heat Pump fully displacing Gas Heat (SF)	-1,249	15.5	3.8	14
	Oil	EB1a273	Central Heat Pump fully displacing Oil Heat (SF)	-1,238	16.6		

Heat Pump and Displacement Type	Pre-Existing Fuel	BCR Measure ID	Measure Name	kWh Electric Savings	MMBtu Fuel Savings	Average Installed Tonnage (Cooling)	Sites Included in Rollup (n)
	Propane	EB1a272	Central Heat Pump fully displacing Propane Heat (SF)	-1,249	15.5		
Central Heat Pump - PD	Oil	EB1a269	Central Heat Pump partially displacing Oil Heat (SF)	-832	10.5	4.4	30
	Propane	EB1a268	Central Heat Pump partially displacing Propane Heat (SF)	-839	9.8		
Mini-Split Heat Pump - FD	Electric	EB1a266	Mini-Split Heat Pump displacing Electric Heat (SF)	2,547	0	4.0	12
	Natural Gas	GB1a060	Mini-Split Heat Pump fully displacing Gas Heat (SF)	-1,206	17.5		
	Oil	EB1a286	Mini-Split Heat Pump Fully Displacing Oil Heat (SF)	-1,208	17.1		
	Propane	EB1a287	Mini-Split Heat Pump Fully Displacing Propane Heat (SF)	-1,206	17.5		
Mini-Split Heat Pump - PD	Natural Gas	GB1a058	Mini-Split Heat Pump partially displacing Gas Heat (SF)	-960	16.3	3.0	32
	Oil	EB1a271	Mini-Split Heat Pump partially displacing Oil Heat (SF)	-961	15.9		
	Propane	EB1a270	Mini-Split Heat Pump partially displacing Propane Heat (SF)	-960	16.3		

Based on full metered sample for Partial Displacement, and the subset of Full Displacement installations that removed or disconnected the backup heating system

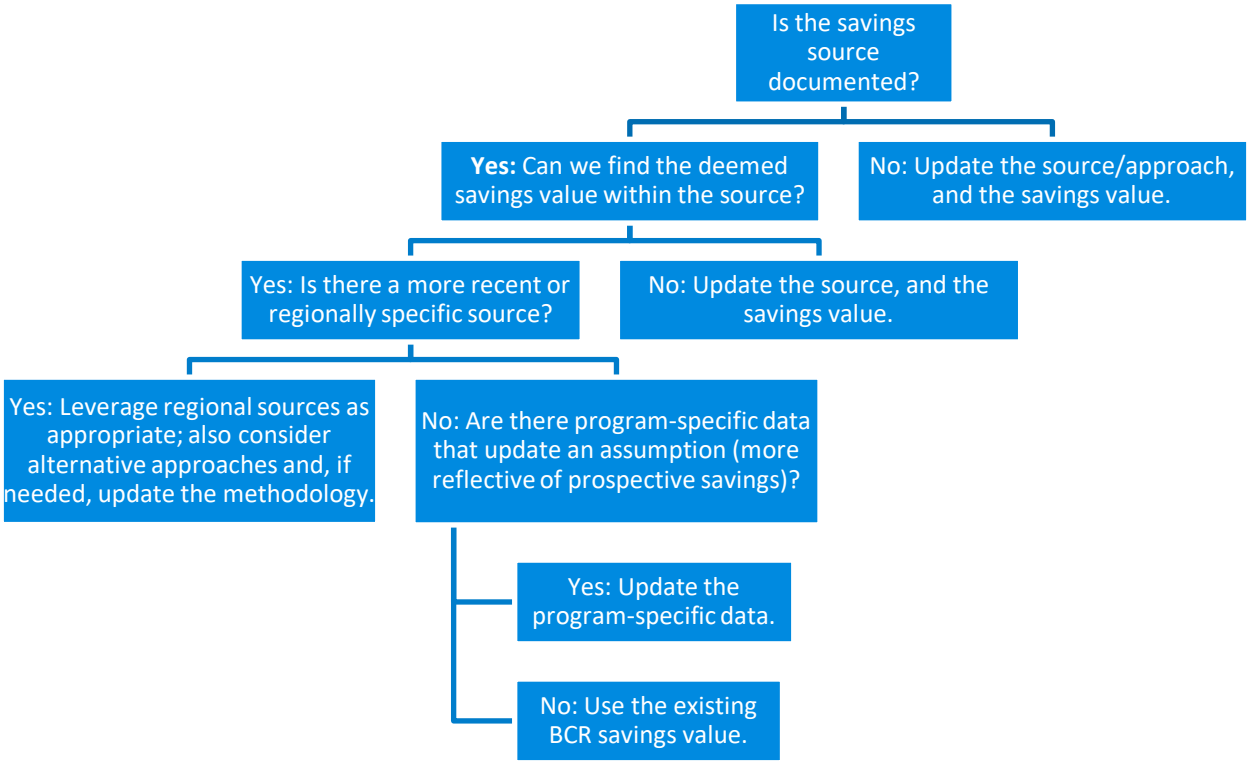
Source: Guidehouse analysis, results are normalized using TMYx typical weather spanning the years of (2007-2021)

6. Key Findings – Other Measures

As noted in the *About IE SF* section early in this report, weatherization and heating systems, such as heat pumps, make up the majority of IE SF gross energy savings across every fuel type. While true, the PAs also incentivize a significant number of other efficiency measures that generate savings and increase comfort alongside these key measures.

The evaluation team followed the process outlined in Figure 10 to assess non-weatherization and non-heat pump IE SF measures. Applying this framework ensured the team applied a consistent approach across measures when considering updating savings inputs and results.

Figure 10. Measure Evaluation Framework



Source: Cadeo analysis

The next four tables summarize the evaluation team's findings for all non-weatherization and non-heat pump measures. Each table includes both this study's evaluated results, the current savings value the PAs currently use in their BCR models and brief explanation of why these savings may differ. As most of these measures were assessed using an engineering algorithm, readers should see the report's supplementary **Engineering Workbook** for more detail.

Table 23. Evaluated Savings Summary – Other Natural Gas Measures (therms/year)

IE SF Measure	Existing Savings	Evaluated Savings	Details
Window[28]	13	13	Windows are a newer measure for the IE program; the deemed savings presented in the TRM are modeled outputs from when the measure was added in 2022 thus the evaluation team recommends maintaining the existing savings values for window replacement savings. Given an average pre-program consumption of 868 therms, this savings represents 1.5% of the total pre-consumption.
Furnace Replacement	207	105	The team calculated evaluated savings using existing HVAC equipment saturation and derated efficiency input assumptions consistent with the concurrent Heat Pump Metering Study results and leveraged building simulation heating loads from this evaluation where relevant. The existing savings incorporated a lower baseline assumption (72%) compared to the 80% used in this evaluation, which is the primary driver for the resulting decrease in deemed savings per unit. The savings per unit are higher for propane/natural gas units compared to heating oil units because the high efficiency propane/natural gas assumption is 95%, which is much higher than the 86% assumption for heating oil furnaces. Given an average pre-program consumption of 868 therms, this savings represents 12% of the total pre-consumption.
Boiler Replacement	194	114	The team calculated savings using existing HVAC equipment saturation and derated efficiency input assumptions consistent with the concurrent Heat Pump Metering Study results and leveraged building simulation heating loads from this evaluation where relevant. The existing savings incorporated a lower baseline assumption (71%) compared to the 75% used in this evaluation, which is a smaller differential compared to the difference in furnace assumptions. The previous evaluation observed a higher heating load in comparison to this evaluation (878 therms per year compared to 687 therms per year observed in this evaluation). This difference, along with the difference in high efficiency unit assumptions (86% compared to 95%) resulted in a decrease in savings for natural gas/propane boilers. Given an average pre-program consumption of 868 therms, this savings represents 13% of the total pre-consumption.

[28] The current window measure allows early replacement of single-pane windows with triple-pane windows, in cases of broken panes, air pockets around window frames, and /or significant leakage that cannot be sealed using standard methods. The evaluation team is currently assessing the feasibility of adding a new measure that replaces double-pane windows that are found to be in a similar condition to the units replaced for the single-pane measure.

IE SF Measure	Existing Savings	Evaluated Savings	Details
Boiler Reset Controls	45	33	Boiler reset controls savings were calculated using a percent savings applied to the building simulated pre-program heating load. The lower heating load observed in this evaluation compared to the previous evaluation resulted in a modest decrease in savings for this measure. Given an average pre-program consumption of 868 therms, this savings represents 4% of the total pre-consumption.
Programmable Thermostat	21	20	The evaluation team's approach leverages the average percent savings results from the 2021 Guidehouse Wi-fi Thermostats study and applies the savings to the building simulated heating and cooling savings from this evaluation. Given an average pre-program consumption of 868 therms, this savings represents 2.3% of the total pre-consumption.
Wi-Fi Thermostat	27	22	The evaluation team's approach leverages the average percent savings results from the 2021 Guidehouse Wi-fi Thermostats study and applies the savings to the building simulated heating and cooling savings from this evaluation. Given an average pre-program consumption of 868 therms, this savings represents 2.5% of the total pre-consumption.
Faucet Aerators	2	3	The team updated IE occupancy information and hot water heater efficiency data leveraging Residential Baseline Study results. Baseline flow rate assumptions were updated to reflect updated sources. Other measure input points did not change. Overall savings values increased slightly. Given an average pre-program consumption of 868 therms, this savings represents 0.3% of the total pre-consumption.
Showerheads	11	14	The team updated IE occupancy information and hot water heater efficiency data leveraging Residential Baseline Study results. Other measure input points did not change. Overall savings values resulted in minimal changes. Given an average pre-program consumption of 868 therms, this savings represents 1.6% of the total pre-consumption.
Pipe Wrap (Water Heating)	4	3	The team updated the baseline hot water tank efficiency assumptions to align with current metrics, used Residential Baseline Study results where relevant, and leveraged RCD program data in absence of IE-specific program data for installed pipe length. Assumptions for pre- and post-program insulation levels were also updated to reflect updated sources. Given an average pre-program consumption of 868 therms, this savings represents 0.3% of the total pre-consumption.

IE SF Measure	Existing Savings	Evaluated Savings	Details
Indirect Water Heater	40	87	The evaluation team followed the general algorithmic approach presented in the MA TRM, referencing the Residential Baseline Study for inputs where program data was not available. The team also leveraged the NY TRM for inputs where a MA-specific value was outdated or not available. Given an average pre-program consumption of 868 therms, this savings represents 10% of the total pre-consumption.
Stand Alone Water Heater	30	57	The evaluation team followed the general algorithmic approach presented in the MA TRM, referencing the Residential Baseline Study for inputs where program data was not available. The team also leveraged the NY TRM for inputs where a MA-specific value was outdated or not available. Given an average pre-program consumption of 868 therms, this savings represents 6.5% of the total pre-consumption.

Source: Cadeo analysis

Table 24. Evaluated Savings Summary – Other Electric Measures (kWh/year)

IE SF Measure	Existing Savings (kWh)	Evaluated Savings (kWh)	Details
Window - Electric Resistance	254	254	Windows are a newer measure for the IE program; the deemed savings presented in the TRM are modeled outputs from when the measure was added in 2022 thus the evaluation team recommends maintaining the existing savings values for window replacement savings. Given an average pre-program consumption of 14,055 kWh, this savings represents 0.9% of the total pre-consumption.
Window - Heat Pump	127	127	
Programmable Thermostat	330	280	The evaluation team's approach leverages the average percent savings results from the 2021 Guidehouse Wi-fi Thermostats study and applies the savings to the building simulated heating and cooling savings from this evaluation. Given an average pre-program consumption of 14,055 kWh, this savings represents 2.0% of the total pre-consumption.
Wi-Fi Thermostat, AC only	64	18	The evaluation team's approach leverages the average percent savings results (5.2%) from the 2021 Guidehouse Wi-fi Thermostats report and applies the savings to the building simulated cooling consumption from this evaluation (472 kWh). Given an average pre-program consumption of 14,055 kWh, this savings represents 0.1% of the total pre-consumption.
Dehumidifier	489[29]	489	The existing TRM savings references a recent study that updated the dehumidifier savings value. The evaluation team did not identify updated data that would result in a different savings value and recommends maintaining the existing deemed savings. Given an average pre-program consumption of 14,055 kWh, this savings represents 3.5% of the total pre-consumption.
Window AC replacement	113	48	The existing savings uses baseline assumptions referenced in the Residential Baseline Study (EER = 10), and ENERGYSTAR requirements (EER = 14.5) for the newly installed unit. The existing savings are based on the previous 2015 evaluation, which likely reflected more energy intensive baseline units, resulting in lower deemed savings per unit in this evaluation compared to the previous evaluation. Given an average pre-program consumption of 14,055 kWh, this savings represents 0.3% of the total pre-consumption.

[29] The savings currently listed in the BCR, 320 kWh, does not reflect the savings value currently listed in the TRM. The TRM value, 489 kWh, matches the value referenced in the source report.

IE SF Measure	Existing Savings (kWh)	Evaluated Savings (kWh)	Details
Refrigerator Replacement	762	651	The team referenced National Grid 2021-2023 program data to determine the average replaced unit age. The Residential Baseline Study along with the Appliance Recycling Impact Evaluation provided additional information regarding average unit capacity and configuration, which the team used as inputs for the ENERGY STAR refrigerator calculator along with average unit age. The resulting savings per unit are slightly lower than the previous evaluation's savings. Given an average pre-program consumption of 14,055 kWh, this savings represents 4.6% of the total pre-consumption.
Freezer Replacement	239	713	National Grid provided program data showing the average replaced freezer age was 20 years. Program data for freezer consumption data was not available and not provided for IE homes in the Residential Baseline Study data (the evaluation team's secondary reference data source), but the study did provide freezer characteristics such as capacity. The team used this information along with other assumptions as inputs to the ENERGY STAR freezer calculator to calculate freezer replacement savings. The resulting savings are greater than the savings determined from the previous evaluation. Given an average pre-program consumption of 14,055 kWh, this savings represents 5.1% of the total pre-consumption.
Appliance Removal	874	968	The team leveraged the results from the Appliance Recycling 2019 Impact Evaluation (MA 21R33-E-ARI) to calculate the deemed savings, which are slightly higher than the previous evaluation. Given an average pre-program consumption of 14,055 kWh, this savings represents 6.9% of the total pre-consumption.
Smart Strips	105	105	The current TRM and BCR savings were determined from the 2019 Advanced Power Strip Metering Study. The team reviewed this study and recommends maintaining the existing deemed savings value. Given an average pre-program consumption of 14,055 kWh, this savings represents 0.7% of the total pre-consumption.
Faucet Aerators	40	63	The team updated IE occupancy information and hot water heater efficiency data leveraging Residential Baseline Study results. Baseline flow rate assumptions were updated to reflect updated sources. Other measure input points did not change. Overall savings values increased slightly. Given an average pre-program consumption of 14,055 kWh, this savings represents 0.4% of the total pre-consumption.

IE SF Measure	Existing Savings (kWh)	Evaluated Savings (kWh)	Details
Showerheads	204	245	The team updated IE occupancy information and hot water heater efficiency data leveraging Residential Baseline Study results. Other measure input points did not change. Overall savings values remained unchanged. Given an average pre-program consumption of 14,055 kWh, this savings represents 1.7% of the total pre-consumption.
Early Retirement CW Elec DHW & Elec Dryer	600	214	The team updated the baseline assumptions to reflect more recent federal efficiency requirements. Previous evaluation assumed baseline units complied with 2007 standards; the team updated the baseline assumptions to reflect 2015 standards. While it is typically the assumption that IE participants are slower to change over appliances due to income restrictions and may purchase used units in absence of program participation, there have been two Federal rulemaking standards since the 2015 standards were established, one in 2018 and another in 2024 (with future compliance date in 2028). Given the equipment lifetime of 12 years, it is likely that even if IE program participants were to purchase a used unit, they would be purchasing used units in compliance with 2015 standards (at a minimum). Given an average pre-program consumption of 14,055 kWh, this savings represents 0.3-1.5% of the total pre-consumption.
Early Retirement CW Gas DHW & Elec Dryer	261	140	
Early Retirement CW Elec DHW & Gas Dryer	375	75	
Early Retirement CW Gas DHW & Gas Dryer	36	39	
Early Retirement CW Oil DHW & Elec Dryer	261	140	
Early Retirement CW Propane DHW & Elec Dryer	261	140	
Pipe Wrap (Water Heating)	41	73	The team updated the baseline hot water tank efficiency assumptions to align with current metrics, used Residential Baseline Study results where relevant, and leveraged RCD program data in absence of IE-specific program data for installed pipe length. Assumptions for pre- and post-program insulation levels were also updated to reflect updated sources. Given an average pre-program consumption of 14,055 kWh, this savings represents 0.5% of the total pre-consumption.
Solar Hot Water	N/A	2,364	The team calculated savings using the TRM-provided algorithm and leveraged Residential Baseline Study results where relevant. Given an average pre-program consumption of 14,055 kWh, this savings represents 16% of the total pre-consumption.
Heat Pump Water Heater, <55 gallon[30]	1,799	1,799	The current savings are deemed based on a 2021 quick hit study. The evaluation team reviewed the quick hit study and found the savings methodology and input

[30] The <55 gallon unit electricity savings also includes a corresponding -5 therms per unit gas penalty.

IE SF Measure	Existing Savings (kWh)	Evaluated Savings (kWh)	Details
Heat Pump Water Heater, >55 gallon	360	360	assumptions to be reasonable. At this time the evaluation team does not have better data to update the existing savings calculations and recommends maintaining the current savings given the source study's recency. Given an average pre-program consumption of 14,055 kWh, this impact represents 9-13% of the total pre-consumption.
Heat Pump Water Heater displacing Oil	-1138	-1138	
Heat Pump Water Heater displacing Propane	-831	-831	
TLC Kit	69	69	The evaluation team did not find evidence to suggest a change to existing claimed savings. Given an average pre-program consumption of 14,055 kWh, this savings represents 0.5% of the total pre-consumption.

Source: Cadeo analysis

Table 25. Evaluated Savings Summary – Other Heating Oil Measures (MMBTUs/year)

IE SF Measure	Existing Savings	Evaluated Savings	Details
Window - Heating Oil	1.3	1.3	Windows are a newer measure for the IE program; the deemed savings presented in the TRM are modeled outputs from when the measure was added in 2022 thus the evaluation team recommends maintaining the existing savings values for window replacement savings.
Furnace Replacement	14.3	3.7	The team calculated savings using existing HVAC equipment saturation and derated efficiency input assumptions consistent with the concurrent Heat Pump Metering Study results and leveraged building simulation heating load from this evaluation where relevant. The existing savings incorporated a much lower baseline assumption (70%) compared to the 81% used in this evaluation, which is a key reason for the resulting decrease in deemed savings per unit. The savings per unit are lower for heating oil units compared to propane/natural gas units because the efficient case heating oil system efficiency assumption (86%) is much lower than propane/natural gas (95%).
Boiler Replacement	20.4	6.1	The team calculated savings using existing HVAC equipment saturation and derated efficiency input assumptions consistent with the concurrent Heat Pump Metering Study results and leveraged building simulation heating load from this evaluation where relevant. The existing savings incorporated a much lower baseline assumption (69%) compared to the 77% used in this evaluation, which, in combination with the lower observed heating load in this evaluation, are the primary drivers for the resulting decrease in deemed savings per unit.
Boiler Reset Controls	4.4	3.4	Boiler reset controls savings were calculated using a percent savings applied to the building simulated pre-program heating load. The lower heating load observed in this evaluation compared to the previous evaluation resulted in a modest decrease in savings for this measure.
Pipe Wrap (Space Heating)	1.1	1.0	Savings for Pipe Wrap for space heating pipes, like boiler reset controls, were calculated using a percent savings applied to the building simulated pre-program heating load.
Programmable Thermostat	2.1	2.3	The evaluation team's approach leverages the average percent savings results from the 2021 Guidehouse Wi-fi Thermostats study and applies the savings to the building simulated heating and cooling savings from this evaluation.
Wi-Fi Thermostat	2.7	2.4	The evaluation team's approach leverages the average percent savings results from the 2021 Guidehouse Wi-fi Thermostats study and applies the savings to the building simulated heating and cooling savings from this evaluation.

IE SF Measure	Existing Savings	Evaluated Savings	Details
Faucet Aerators	0.2	0.4	The team updated IE occupancy information and hot water heater efficiency data leveraging Residential Baseline Study results. Baseline flow rate assumptions were updated to reflect updated sources. Other measure input points did not change. Overall savings values increased slightly.
Showerheads	0.9	1.4	The team updated IE occupancy information and hot water heater efficiency data leveraging Residential Baseline Study results. Other measure input points did not change. Overall savings values increased marginally.
Early Retirement CW Oil DHW & Elec Dryer	1.54	0.2	The team updated the baseline assumptions to reflect more recent federal efficiency requirements. Previous evaluation assumed baseline units complied with 2007 standards; the team updated the baseline assumptions to reflect 2015 standards. While it is typically the assumption that IE participants are slower to change over appliances due to income restrictions and may purchase used units in absence of program participation, there have been two Federal rulemaking standards since the 2015 standards were established, one in 2018 and another in 2024 (with future compliance date in 2028). Given the equipment lifetime of 12 years, it is likely that even if IE program participants were to purchase a used unit, they would be purchasing used units that are in compliance with 2015 standards at a minimum.
Pipe Wrap (Water Heating)	0.4	1.1	The team updated the baseline hot water tank efficiency assumptions to align with current metrics, used Residential Baseline Study results where relevant, and leveraged RCD program data in absence of IE-specific program data for installed pipe length. Assumptions for pre- and post-program insulation levels were also updated to reflect updated sources.
Heat Pump Water Heater displacing Oil	17.4	17.4	The current savings are deemed based on a 2021 quick hit study. The evaluation team reviewed the quick hit study and found the savings methodology and input assumptions to be reasonable. At this time the evaluation team does not have better data to update the existing savings calculations and recommends maintaining the current savings given the source study's recency.

Source: Cadeo analysis

Table 26. Evaluated Savings Summary – Other Propane Measures (MMBtus/year)

IE SF Measure	Existing Savings	Evaluated Savings	Details
Window - Propane	1.3	1.3	Windows are a newer measure for the IE program; the deemed savings presented in the TRM are modeled outputs from when the measure was added in 2022 thus the evaluation team recommends maintaining the existing savings values for window replacement savings.
Furnace Replacement	20.7	10.5	The team calculated evaluated savings using existing HVAC equipment saturation and derated efficiency input assumptions consistent with the concurrent Heat Pump Metering Study results and leveraged building simulation heating load from this evaluation where relevant. The existing savings incorporated a lower baseline assumption (72%) compared to the 80% (equivalent to natural gas units) used in this evaluation, which is the primary driver for the resulting decrease in deemed savings per unit. The savings per unit are higher for propane/natural gas units compared to heating oil units because the high efficiency heating oil assumption was previously 86%, which is much lower than the 95% assumption for propane/natural gas furnaces.
Boiler Replacement	19.4	11.4	The team calculated savings using existing HVAC equipment saturation and derated efficiency input assumptions consistent with the concurrent Heat Pump Metering Study results and leveraged building simulation heating load from this evaluation where relevant. The existing savings incorporated a lower baseline assumption (71%) compared to the 75% (equivalent to natural gas units) used in this evaluation, which is a smaller differential compared to the difference in furnace assumptions. In addition, the previous evaluation observed a higher annual heating load in comparison to this evaluation. This difference, along with the difference in high efficiency unit assumptions (86% compared to 89%), resulted in a modest decrease in savings for natural gas/propane boilers.
Programmable Thermostat	2.1	2.0	The evaluation team's approach leverages the average percent savings results from the 2021 Guidehouse Wi-fi Thermostats study and applies the savings to the building simulated heating and cooling savings from this evaluation.
Wi-Fi Thermostat	2.7	2.2	The evaluation team's approach leverages the average percent savings results from the 2021 Guidehouse Wi-fi Thermostats study and applies the savings to the building simulated heating and cooling savings from this evaluation.

IE SF Measure	Existing Savings	Evaluated Savings	Details
Faucet Aerators	0.2	0.3	The team updated IE occupancy information and hot water heater efficiency data leveraging Residential Baseline Study results. Baseline flow rate assumptions were updated to reflect updated sources. Other measure input points did not change. Overall savings values increased slightly.
Showerheads	0.9	1.4	The team updated IE occupancy information and hot water heater efficiency data leveraging Residential Baseline Study results. Other measure input points did not change. Overall savings values increased marginally.
Early Retirement CW Propane DHW & Elec Dryer	1.54	0.2	The team updated the baseline assumptions to reflect more recent federal efficiency requirements. Previous evaluation assumed baseline units complied with 2007 standards; the team updated the baseline assumptions to reflect 2015 standards. While it is typically the assumption that IE participants are slower to change over appliances due to income restrictions and may purchase used units in absence of program participation, there have been two Federal rulemaking standards since the 2015 standards were established, one in 2018 and another in 2024 (with compliance date in 2028). Given the equipment lifetime of 12 years, it is likely that even if IE program participants were to purchase a used unit, they would be purchasing used units that are in compliance with 2015 standards at a minimum.
Pipe Wrap (Water Heating)	0.4	0.3	The team updated the baseline hot water tank efficiency assumptions to align with current metrics, used Residential Baseline Study results where relevant, and leveraged RCD program data in absence of IE-specific program data for installed pipe length. Assumptions for pre- and post-program insulation levels were also updated to reflect updated sources.
Heat Pump Water Heater displacing Propane	16.4	16.4	The current savings are deemed based on a 2021 quick hit study. The evaluation team reviewed the quick hit study and found the savings methodology and input assumptions to be reasonable. At this time the evaluation team does not have better data to update the existing savings calculations and recommends maintaining the current savings given the source study's recency.

Source: Cadeo analysis

7. Recommendations and Considerations

Recommendations

The evaluation team recommends:

- **Increasing robustness of required electronic tracking data.** The Community Action Program (CAP) agencies that deliver IE SF maintain electronic participation records that meet the PAs' current reporting requirements for the initiative. However, the required customer, building, and measure data in the electronically available datasets is insufficient to support robust impact evaluations. For example, the available electronic tracking data indicates that a given participant received air sealing through IE SF, the date the air sealing was performed, and expected savings from the measure. The available electronic data does not, however, include critical details, such as the participant's pre- or post-initiative air infiltration rates, which would allow an evaluator to independently model air sealing savings.

  Without it, this evaluation—again like the previous study—had to manually gather this information. Specifically, the team had to extract essential evaluation data points, such as an air sealing participant's air infiltration rates, from scans of handwritten energy assessments and measure installation forms for a subset of participants. This manual process has multiple drawbacks. It adds cost, yields less information (i.e., results in data for a sample of participants versus the whole population), and introduces uncertainty (as the team must interpret assessor's notes). Collectively, these factors adversely impact the quality of an impact evaluation, which, in turn, adversely impacts the PAs' ability to confidently forecast savings for the IE SF initiative.

  The evaluation team recommends—as the evaluation team did as part of the previous evaluation more than 10 years ago—that the PAs require CAPs to increase the robustness (i.e., the level of customer and measure detail) maintained electronically in the initiative's tracking systems. In addition to the data already required by the PAs for reporting, the PAs should require CAPs to store the following information electronically in dedicated data fields to support future evaluation efforts:

  - Home size (square feet of conditioned space)
  - Pre- and post-air sealing blower door air infiltration values (CFM50)
  - Location of installed insulation (wall, attic, floor)
  - Pre- and post-insulation R-values by location
  - Areas of installed insulation (e.g., percentage of total wall area insulated)
  - Existing HVAC efficiency (i.e., rated AFUE), system type (e.g., furnace, boiler), and estimated age (for derating)
  - Existing DHW efficiency (i.e., rated EF or UEF), system type (e.g., storage), and estimated age (for derating)
  - Heat pump type (central, ground source, single or multi-zone zone mini-split) and outdoor unit model number
  - Heat pump control strategy (manual or integrated) and, if integrated, the switchover temperature setting
  - Presence and type of secondary heating sources
  - Existing window type (single pane, double pane, etc.)

- New window SHGC and U-value

Ensuring these essential data elements are available electronically for every relevant IE SF participant will increase the validity, reliability, and value of future IE SF impact evaluations, especially for key measures such as air sealing and insulation that make up the majority of the initiative's savings.

This enhanced electronic data management practice is long overdue; robust tracking databases containing the customer and measure details listed above are available for most initiatives, including Residential Coordinated Delivery (RCD), the PAs' non-IE residential home energy assessment initiative. It should not be necessary to manually extract critical initiative information from handwritten forms.

The evaluation team recognizes that CAPs provide a wide range of services in their communities (beyond delivering the PAs' IE SF initiative) and that those services have their own data collection and management requirements. The team also recognizes that the CAPs may need financial and technical support to institute this improvement. As such, the PAs should work closely with the CAPs, as well as other stakeholders in Massachusetts, including the Energy Efficiency Advisory Council and Department of Public Utilities, to act on this recommendation in a way that achieves the necessary data improvement while not adversely impacting CAP staff and their delivery of other important community services.

The evaluation team is indifferent with respect to specific software the initiative uses to create this richer dataset but resolute that the identified solution must efficiently collect, store, and export the detailed electronic information required for robust evaluation. Such a database would not only improve the robustness, reliability, and accuracy of future IE SF evaluations but also serve as a valuable resource for the diverse stakeholders that serve and support the IE population in the Commonwealth.

- **Enabling access to information regarding non-PA funded measures.** The CAP agencies that implement IE SF on behalf of the PAs braid federal and other non-PA funding with IE dollars to provide more comprehensive service for IE SF participants. The team attempted to gather information on these non-PA funded measures—first from the CAPs and then from Executive Office of Housing and Livable Communities (EOHLC)—throughout this evaluation. However, the evaluation team's efforts were unsuccessful, which left the team with a partial perspective of what happened in participating IE SF homes. This limited understanding of the full range of interventions in participating homes had an adverse impact on the team's ability to specify reliable billing analysis to estimate weatherization savings—IE SF's primary measure. The team recognizes that EOHLC is the ultimate decision-maker on what information they share about measures they fund, but the team recommends the PAs engage the CAPs and EOHLC to proactively create a data sharing plan that benefits all IE stakeholders and that will support the next IE SF evaluation effort.

Considerations

The evaluation team suggests the PAs also consider:

- **More frequent impact evaluations.** This IE SF impact evaluation comes 12 years after the prior study. More frequent evaluations—enabled and informed by improved data tracking—will help the PAs keep IE SF measure savings more current and prospectively applicable.
- **Accounting for historical weatherization trends.** The PAs should keep this trend in mind when forecasting the potential savings associated with weatherization as part of future program cycles.

Appendix A. Additional Billing Analysis Details

A.1 Natural Gas

The evaluation team used a Post-Program Regression (PPR) model specification to assess the impact of IE SF weatherization in natural gas heated homes. The team used a PPR model specification consistent with the concurrent RCD impact evaluation, which yielded statistically significant results for natural gas weatherization customers participating in that initiative.

Like the RCD analysis, the evaluation team accounted for the impact of non-programmatic factors on consumption using a matched control group of "future" participants (i.e. customers weatherized through IE SF in 2022). To further ensure the reliability of the billing analysis results, the evaluation team removed participants without sufficient billing records or that exhibited extreme or counter-intuitive energy consumption. Removal of these customers mitigates their potential bias on the billing analysis result.

Table 31. IE SF Billing Analysis Sample Attrition – Natural Gas

Attrition Metric	Excluded	Percentage	Remaining
Total gas accounts receiving weatherization	-	-	1,654
Unable to map to billing data	111	7%	1,543
Incomplete billing data (Less than 12 months pre- and post-periods)	239	14%	1,304
Extreme consumption (< 150 therms or > 2,500 therms annually in pre- or post)	19	1%	1,285
Significant change (> ±50% change between pre- and post-period)	300	18%	985
Total	**669**	**40%**	**985**

Source: Cadeo analysis

Unfortunately, the evaluation team's IE SF PPR models did not yield statistically significant results (i.e., better than ±20% precision at the 90% confidence level) to report weatherization savings using billing analysis. This was true at both the statewide level as well as for individual PAs. The natural gas billing analysis results all exhibited low precision: none satisfied the evaluation team's reporting threshold of ±20% precision at the 90% confidence level. Only Eversource was the closest at ±28% precision.

Table 32. IE SF Billing Analysis Results – Natural Gas

PA	Sample size	Savings Estimate (therms)	Precision (90% confidence level)
Statewide	**985**	**52**	**49%**
Eversource	254	113	28%
National Grid	497	31	108%
EGMA	175	32	119%
Liberty+ Unitil	59	84	59%

Source: Cadeo analysis

Several factors explain the low precision and reliability of IE SF billing analysis results compared with RCD:

- **Lack of detailed data.** The evaluation team's primary dataset for the IE SF billing analysis (the DNV data) included limited details about the participants, their homes, and the measures installed limits model specification options.
- **Less participants.** The total volume of weatherization participants in IE SF is smaller (relative to the PA's market rate retrofit initiative, RCD), which results in smaller sample sizes for the billing analysis and, in turn, lower model precision and less reliable results.
- **Non-PA funded measures.** The evaluation team was unable to get data on non-PA funded measures. Consequently, these measures were unaccounted for in the billing analysis for the subset of IE SF participants that received them. Without this information, the model is subject to omitted variable bias which leads to poor precision and the misattribution of measure impacts.

A.2 Electricity

Only 10 electrically heated 2021 weatherization participants were eligible for inclusion in the billing analysis, so the team did not attempt a comparable electric PPR model. As previously noted, only a small number of electrically heated IE SF participants are weatherized each year—the majority heat with natural gas or heating oil.

Appendix B. Copy of the Massachusetts and Connecticut Heat Pump Metering Study (MA22R51-B-HPMS/CT R2246)

Embedded below is a copy of the Massachusetts and Connecticut Heat Pump Metering Study used to evaluate savings for various heat pump technologies installed through the IE SF initiative. The report includes significant details about the metering and analysis process that yielded the IE SF savings reported in this impact evaluation.

MA HPMS CT R2246
- Heat Pump Meterir