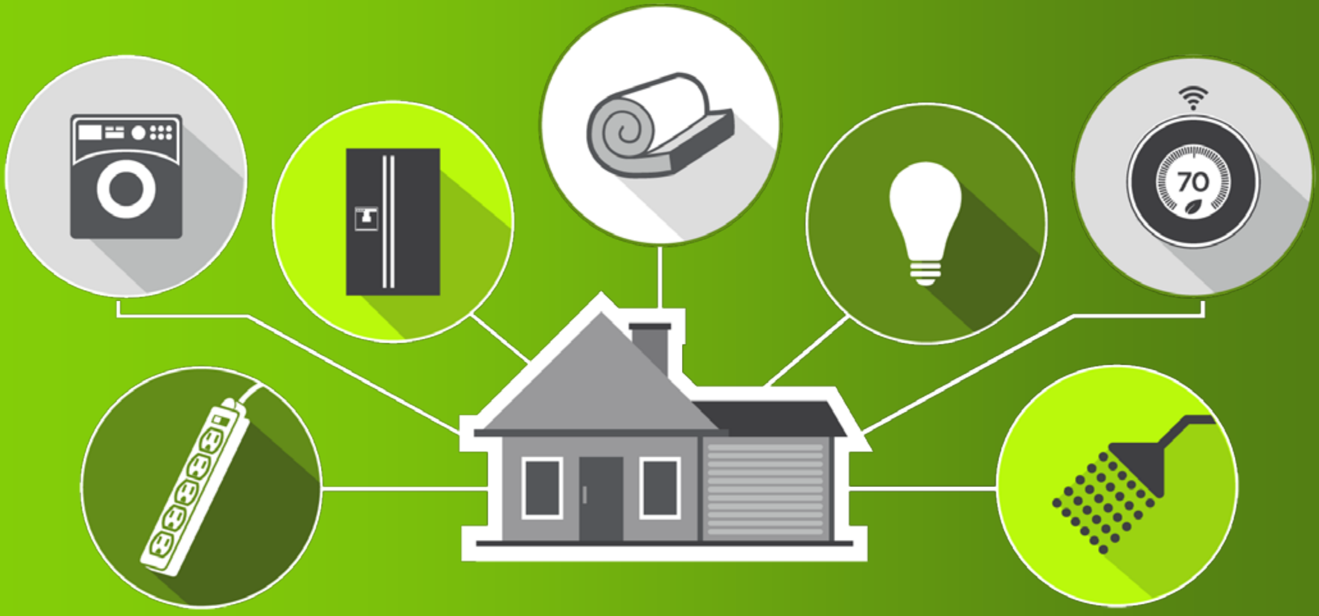


HOME ENERGY SERVICES

Impact Evaluation (Res 34)

August 2018

PRODUCED IN COLLABORATION BETWEEN NAVIGANT cadeo

PREPARED FOR: THE ELECTRIC AND GAS PROGRAM ADMINISTRATORS OF MASSACHUSETTS
PART OF THE RESIDENTIAL EVALUATION PROGRAM AREA

HES: IMPACT EVALUATION

About HES

The Home Energy Services (HES) initiative is the primary mechanism through which the Massachusetts Program Administrators (PA) deliver energy efficiency to residential customers living in 1- to 4-unit homes. Through the initiative's whole home energy assessment (HEA), the PAs install instant savings measures (e.g., efficient lighting, efficient showerheads and faucet aerators, advanced smart strips, and thermostats) and promote weatherization measures (e.g., air sealing, attic, wall, and basement insulation). The HEA also provides an opportunity to identify and refer customers to other residential initiatives that incentivize heating, cooling, and water heating equipment upgrades. Approximately 75,000 customers receive an HEA each year.

Study Goal

This HES Impact Evaluation was designed to estimate the gross per-unit energy savings associated with the HES measures offered in 2015 and 2016. In total, the team evaluated 29 measures across four fuel types (natural gas, electric, heating oil, and propane); nine of which were not part of the previous evaluation (completed in 2012).

The evaluation also yielded realization rates, for insulation and air sealing, that the PAs will use to adjust the ex ante gross savings produced by each HES Lead Vendor's (LV) proprietary energy modeling software.

The scope of this evaluation did not include LED lighting or smart strips—both common HES measures— since both measures were being evaluated through a different, concurrent, evaluation effort.

Approach

The evaluation team relied on three complementary evaluation methodologies to estimate savings:

Billing Analysis

- Specified a Monthly Post Program Regression (PPR) model
- Created a matched control group of future HES participants
- Generated statewide and LV-specific results
- Used for weatherization measures

Building Simulation

- Modeled using BEopt (Building Energy Optimization) software
- Simulated ten different scenarios, reflecting various building type, heating fuel, and heating system combinations
- Calibrated using HES billing data
- Used for fan savings and distribution system measures

Engineering Algorithms

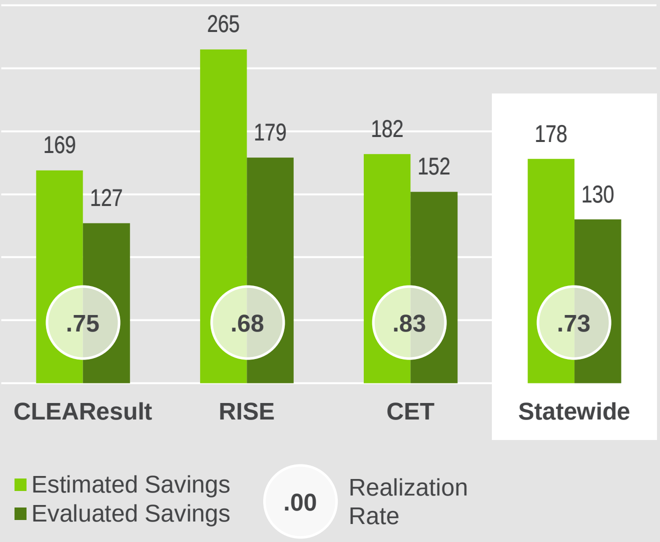
- Relied primary on current Massachusetts Technical Reference Manual
- Leveraged LV data and best available, regionally appropriate, secondary data sources
- Included extensive literature review
- Used for programmable and Wi-Fi thermostats, as well as various hot water measures

KEY FINDINGS

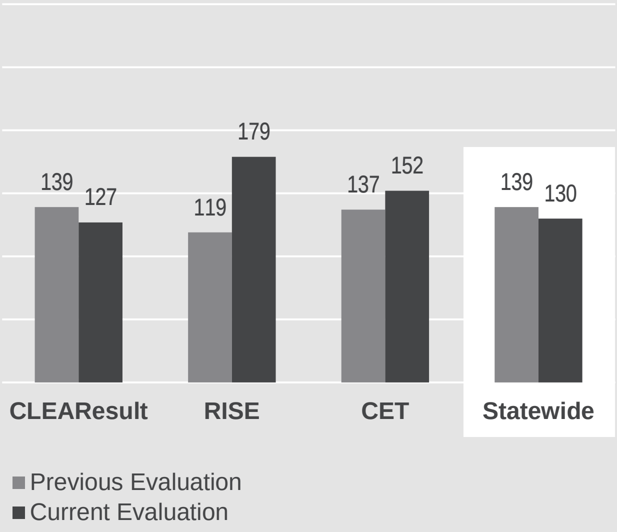
Weatherization

The evaluation team’s billing analysis determined that HES participants who weatherized their natural gas heated homes (i.e., installed air sealing and/or insulation) saved, on average and statewide, 130 therms per year. This result is somewhat lower than the statewide findings from the previous evaluation in 2012. The PAs should use the realization rates shown below to adjust their LV-estimated weatherization savings.

Weatherization Realization Rates
therms/year



Comparison to Previous Evaluation
therms/year



Thermostats

- Programmable and Wi-Fi thermostats are estimated to have save 3.6% and 6%, respectively, of HES participants’ annual heating consumption
- Savings are based on a literature review of more than a dozen thermostat studies, PAs should consider undertaking primary research

Furnaces and Boilers

- Used gas billing data to determine separate annual heating energy loads for HES participants with furnaces and boilers
- Leveraged this analysis for heating oil and propane
- Increased heating load, relative to the previous evaluation, resulted in ex post savings exceeding ex ante savings for furnaces (while the opposite is true for boilers)

Refrigerators

- HES LVs meter older refrigerators to determine if they are eligible (i.e., sufficiently inefficient) for replacement through the initiative
- Using this HES-specific data, the evaluation team determined that the savings associated with refrigerator replacement is greater than the previous evaluation (1,001 kWh/year, compared to 661 kWh/year)

SUMMARY OF EX POST SAVINGS

Measure	**Natural Gas** (therms)	**Electric** (kWh)	**Oil** (MMBtu)	**Propane** (MMBtu)
INSULATION & AIR SEALING				
Weatherization (Insulation and/or Air Sealing)	130	1,298	13	13
Insulation (Overall)	102	1,043	10	10
• Attic Insulation	83	1,092	8.5	8.3
• Basement/Floor Insulation	66	425	6.7	6.6
• Wall Insulation	72	673	7.3	7.2
• Furnace Fan Savings (Associated with Insulation), kWh	67	-	68	67
• Cooling Savings (Associated with Insulation), kWh	31	33	32	31
Air Sealing	32	274	32	3.2
HEATING SYSTEMS				
Furnace Replacement	85	-	2.9	8.5
• Furnace Fan Savings (Associated with Furnace Replacement), kWh	80	-	26	80
Furnace Replacement (Early Retirement)	157	-	8.2	16
• Furnace Fan Savings (Associated with Furnace Early Retirement), kWh	135	-	70	135
Steam Boiler Replacement	23	-	2.2	2.3
Steam Boiler Replacement (Early Retirement)	87	-	11	8.7
Forced Hot Water Boiler Replacement	91	-	2.1	9.1
Forced Hot Water Boiler Replacement (Early Retirement)	146	-	13	15
Boiler Reset Controls	51	-	5.2	5.1
Pipe Wrap (Space Heating)	14	-	1.5	1.4
Programmable Thermostat	35	251	3.5	3.5
• Cooling Savings, kWh	27	27	27	27
Wi-Fi Thermostat	58	419	5.9	5.8
• Cooling Savings, kWh	46	46	46	46
LIGHTING & APPLIANCES				
Refrigerator Replacement	-	55	-	-
Refrigerator Replacement (Early Retirement)	-	1,001	-	-
LED Recessed Trim Kits	3.7	94	0.4	0.4
Clothes Washer (Early Retirement)	Varies – see Engineering Workbook			
DOMESTIC HOT WATER				
Showerhead	9.2	187	1.0	0.9
Faucet Aerator	2.1	43	0.2	0.2
Pipe Wrap (Water Heating)	2.9	28	0.2	0.3
Indirect Water Heater	-	-	4.7	4.0
On-Demand Water Heater, 82%	-	-	-	4.1
On-Demand Water Heater (Early Retirement), 82%	-	-	-	5.4
On-Demand Water Heater, 94%	-	-	-	5.5
On-Demand Water Heater (Early Retirement), 94%	-	-	-	6.8
Combo Condensing Boiler/Water Heater 90%	-	-	-	8.4
Combo Condensing Boiler/Water Heater 95%	-	-	-	11
DISTRIBUTION				
Duct Insulation	73	726	7.4	7.3
Duct Sealing	39	442	4.0	3.0

🟩 Billing Analysis 🟩 Engineering Algorithm 🟩 Building Simulation 🟩 Billing Analysis & Building Simulation

RECOMMENDATIONS & CONSIDERATIONS

Upon completion of this impact evaluation, the evaluation team offers the following recommendations and considerations:

Recommendations

1. **Use the ex post results determined through this evaluation as ex ante savings for future program years.** The results of this impact evaluation reflect the most recent and relevant set of gross savings values for the measures installed through HES. While the PAs will likely continue to evolve how they serve their residential customers programmatically, these savings represent the best estimates of future measure-specific savings for single-family family customers in Massachusetts. The evaluation team therefore recommends the PAs use the results included in this evaluation as part of ongoing three-year planning efforts. This includes the LV- and weatherization-specific realization rates contained in this report.

2. **Investigate programmable and wi-fi thermostats further.** The evaluation team's thermostat-related recommendation consists of two parts. First, the current design of HES allows Energy Specialists and HPCs to leave uninstalled thermostats with participants. If future iterations of HES continue this practice, the evaluation team recommends that PAs estimate a thermostat installation rate as part of the next evaluation. Second, this evaluation—as well as the previous impact evaluation—relied on a literature review to estimate savings for thermostats. Literature reviews offer insight into possible savings generated by programmable and wi-fi thermostats but are not specific to Massachusetts and the customers who participate in HES. Given the increasing importance of thermostats as an energy efficiency and demand response measure, the team recommends the PAs conduct primary research to more definitely understand the impact of these important residential measures in their region.

Considerations

1. **Future evaluations should more closely explore the disparity between LV-generated ex ante savings and evaluator ex post savings for weatherization measures.** Similar to the previous HES impact evaluation, the evaluation team found ex post savings for weatherization (i.e., air sealing and insulation) in natural gas-heated homes that were lower (~25–30% less) than the savings estimated by HES LVs. Given the consistent disparity between these estimates, future evaluators should seek to understand the drivers of this disparity in greater detail. Specifically, the assessment should elucidate differences by LV, heating fuel type (e.g., natural gas vs. propane heated homes), and climate zone, as well as consider actions that might bring weatherization ex ante and ex post values into closer alignment.

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Cape Light Compact
Columbia Gas of Massachusetts
A NiSource Company

EVERSOURCE ENERGY
Liberty Utilities
mass save
nationalgrid
Unitil

Home Energy Services (HES) Impact Evaluation

Final Report

Prepared for:

The Electric and Gas Program Administrators of Massachusetts
Part of the Residential Evaluation Program Area

Submitted by:
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1. INTRODUCTION

1.1 About the Home Energy Services Initiative

The Home Energy Services (HES) initiative is the primary mechanism through which the Massachusetts Program Administrators (PAs) deliver energy efficiency to residential customers living in 1- to 4-unit homes. Through the initiative's whole home energy assessment (HEA), the PAs install instant savings measures (e.g., efficient lighting, efficient showerheads and faucet aerators, advanced smart strips, and thermostats) and promote weatherization measures (e.g., air sealing and attic, wall, and basement insulation). The HEA also provides an opportunity to identify and refer customers to other residential initiatives that incentivize heating, cooling, and water heating equipment upgrades.

The PAs deliver HES through two complementary channels:

- **Lead vendors (LVs):** The PAs work with one of the following LVs to implement HES on their behalf: CLEAResult, RISE Engineering (RISE), and the Center for EcoTechnology (CET).[1] LVs complete HEAs for customers that enter HES through traditional channels, such as the MassSave statewide phone number or MassSave.com. LVs are responsible for managing an extensive network of independent installation contractors (IICs) that air seal and insulate homes following HEAs, including providing quality assurance and quality control (QA/QC) services. The LVs and PAs collaborate through a statewide HES Working Group. While the LVs offer relatively consistent services statewide, some differences exist between LVs. Most notably, CET and CLEAResult use one energy specialist to complete each HEA, whereas RISE employs two. Further, each LV uses its own proprietary energy modeling software to estimate and report savings for air sealing and insulation measures. The PAs rely on periodic impact evaluations, such as this study, to independently estimate air sealing and insulation savings for the average customer served by the LVs and validate each LV's modeled savings values.
- **Home performance contractors (HPCs):** Beginning in 2011, the PAs created a second participation channel. HPCs independently market and recruit customers for HEAs. HPCs differ from the LV and IIC delivery approach as they provide end-to-end services to customers. HPCs complete the assessment and install any energy efficiency improvements customers decide to complete. These improvements can include weatherization measures incentivized through HES and measures through other PA initiatives (e.g., HVAC equipment installation).

1.2 Study Goals

This HES Impact Evaluation (RES 34) was designed to estimate the gross per-unit energy savings associated with the HES measures offered in 2015 and 2016. In total, the team evaluated 28 measures across four fuel types (natural gas, electric, heating oil, and propane), nine of which were not part of the previous evaluation (completed in 2012).[2]

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[1] CLEAResult is the LV for Eversource and National Grid, while RISE is the LV for Cape Light Compact, Columbia Gas, Liberty Utilities, and Unitil. CET is the LV for Berkshire Gas.

[2] http://ma-eeac.org/wordpress/wp-content/uploads/Home-Energy-Services-Impact-Evaluation-Report_Part-of-the-Massachusetts-2011-Residential-Retrofit-and-Low-Income-Program-Area-Evaluation.pdf

The evaluation also yielded realization rates for insulation and air sealing that the PAs will use to adjust the ex ante gross savings produced by each LV's proprietary energy modeling software. Realization rates are only applicable to insulation and air sealing because the PAs do not use LV-generated savings estimates for any other HES measures.

The scope of this evaluation did not include LEDs or smart strips, both common HES measures, because both measures were being evaluated through a different, concurrent evaluation effort.

1.3 Research Questions

To meet the goals detailed above, this study answered the following questions, which are detailed in the Stage 3 evaluation plan:

- What are the electric, gas, propane, and oil gross energy savings associated with all HES measures?
- How do evaluated per-unit savings compare with the per-unit savings estimated by each of the three HES LVs?[3]
- How do the evaluated savings from this study compare to the savings from the previous HES impact evaluation?[4]

1.4 Key Terminology

The evaluation team uses the language defined in Table 1-1 throughout the report to explain important impact evaluation concepts. Some of the terms are specific to HES, while others are common to impact evaluations across programs.

Table 1-1. Summary of Key HES and Evaluation Terminology

Term	Definition
Customer	An individual or household (identified by a unique account number) that receives an HEA.
Participant	An individual or household (also identified by a unique account number) that installs at least one major HES measure (such as air sealing, insulation, an appliance, or a heating system) following an HEA. HES participants are a subset of HES customers.
Ex Ante Savings	Savings assumed by the PAs prior to an evaluation, usually based on the prior HES impact evaluation and/or the state's Technical Reference Manual (TRM).
Ex Post Savings	Savings determined through this evaluation.

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[3] The team developed LV-specific savings for weatherization measures since, as noted above, each LV generates its own ex ante savings for air sealing and insulation using proprietary building simulation models. Because the PAs use consistent statewide savings values for all other HES measures, the team did not develop LV-specific savings for any other measures.

[4] The most recent comprehensive HES evaluation was completed in 2012. However, in 2013, the PAs completed another evaluation that focused on determining updated realization rates for air sealing and insulation measures. http://ma-eeac.org/wordpress/wp-content/uploads/Home-Energy-Services-Realization-Rate-Results-Memo-6-28-12.pdf

Term	Definition
Realization Rate	The ratio of ex ante to ex post savings (ex ante/ex post). The resulting value reflects the percentage the ex ante savings that the PAs can officially claim for HES, which can be greater than 1.0. For air sealing and insulation, the PAs apply the evaluation's realization rate to LV-specific ex ante savings.
Treatment Group	The HES participants for which the team estimated ex post savings: customers that received an HEA in 2015 and 2016. The treatment group for the billing analysis was limited to HES participants that installed a major measure in 2015 (because billing analysis requires sufficient post-participation energy consumption data).
Control Group	The set of customers used in a billing analysis to serve as a counterfactual for estimating a program's impact and account (or control) for exogenous factors such as moves and rate changes that can otherwise obscure program-generated savings. In the context of this evaluation, the team used future HES participants (i.e., customers that had their HEA in 2016) as the control group.
Weatherization	A general term used to describe air sealing and/or insulation (one of more of attic, wall, or floor insulation). References to air sealing or insulation in the report are specific to that measure, whereas weatherization refers to one or both measures.

1.5 How to Use the Results of this Evaluation

This report of this study are presented in two parts: **Evaluation Summary** and **Appendix**.

The **Evaluation Summary,** which this section is part of, summarizes the results of the evaluation and briefly outlines the evaluation methodologies used. It includes a comparison of the initiative's ex ante and ex post savings for each measure. For key HES measures, such as air sealing and insulation, the Evaluation Summary includes a more detailed explanation of how the team calculated ex post savings and why ex ante and ex post savings differed, when relevant. The Evaluation Summary does not, however, include details such as the engineering algorithm and specific primary and secondary data used to develop ex post savings for water heater pipe wrap.

For these types of details, users of this evaluation should rely on the following:

- **Engineering Workbook**. This Excel workbook includes a tab for each HES measure that details the Massachusetts TRM engineering algorithm used to evaluate that measure and all the values (and sources) for all inputs used in that algorithm. Each measure-specific tab includes a direct comparison of ex ante and ex post input values and sources. Each of these tabs link to common participant, housing stock, and engineering assumptions to ensure consistency across measures and complete transparency.
- **BEopt Building Simulation Models and Workbook**. While admittedly less accessible than the Excel workbook detailed above, the evaluation team has also provided the PAs with 10 BeOpt building simulation files and a workbook demonstrating how the team combined the collective results of these models to accurately reflect HES participation.

Readers interested in accessing the detailed Engineering Workbook or BEopt Building Simulation models should request access from a PA evaluation manager.

The second part of this report is the **Appendix,** which contains the two other deliverables the evaluation team created as part of this study:

- Memo describing the methodology and results of the power analysis
- Memo outlining the steps used to match HES customers in the treatment and control group based on their pre-HES energy consumption

2. METHODOLOGY

2.1 Overview of Methods

Consistent with the previous impact evaluation, the evaluation team relied on three complementary evaluation methodologies: billing analysis, engineering algorithms, and building simulation. Table 2-1 briefly summarizes each methodology.

Table 2-1. Summary of Evaluation Methodologies

Methodology	Details
Billing Analysis	• Used to report ex post savings when measure-specific billing analysis results met pre-determined threshold of better than ±20% precision at the 90% confidence level • Conducted power analysis to identify the subset of HES measures for which a billing analysis could produce results within the precision and confidence threshold* • Combined customer billing records with weather and program participation data (HES and non-HES) to get a broad view of each customer's energy consumption drivers • Conducted a structured screening process to ensure that the evaluation team's model uses only those customers with sufficient billing data and without spurious billing records • Matched each treatment group customer to a control group (future HES participants)** customer with a similar, monthly, preinstallation period energy consumption pattern • Specified and refined a monthly post-program regression (PPR) model • Generated statewide and LV-specific results, which were weather-normalized using 30-year historical weather data for five different weather stations across the state, mapped to the closest HES participants
Engineering Algorithms	• Relied primarily on current Massachusetts TRM • Where the Massachusetts TRM did not specify a savings algorithm, the team relied on previous studies to ensure consistency in methodology • Leveraged LV data to calculate baseline and efficient cases for each measure • When LV data was not collected or unavailable, the team relied on regionally appropriate secondary data sources and other relevant studies (Residential Energy Consumption Survey, ENERGY STAR® standards, Building America Benchmark Program Database, etc.) • Included extensive literature review of recent studies, relevant US Department of Energy appliance standards, other state TRMs, and similar evaluations in other states
Building Simulation	• Modeled using BEopt (Building Energy Optimization) software developed by the National Renewable Energy Laboratory • Constructed baseline home geometry and building characteristics based on LV data; inputs like square footage, air sealing infiltration rates, wall and attic insulation, and building envelope, among others were all informed by LV program data • Simulated 16 different scenarios reflecting various building types (1-story detached, 2-story detached, low-rise multiunit), heating fuels, and heating system combinations • Calibrated each model using billing data • Disaggregated billing data into specific end uses (heating, water heating, and baseload) • Weighted the result of the 16 models into a statewide average using the actual building type, heating fuels, and heating type characteristics of 2015 and 2016 HES customers

*See Appendix A for more detail.

**See Appendix B for more detail.

2.2 Key Data Sources

The evaluation team relied on the following five key data sources.

1. **LV HES customer data:** CLEAResult, RISE, and CET provided the evaluation team with detailed data for customers that received an HEA from 2014 to 2016. These datasets contained information about each participant's home, the HES measures recommended after their HEA, and the measures installed by customers and served as the backbone for this evaluation. In particular, the team's engineering algorithm analysis drew heavily from these datasets to develop HES-specific input values, while the building simulation leveraged the datasets to model the average HES participant's home. The data provided by each LV varied. When possible, the evaluation team used a participation-weighted statewide average to develop inputs and model building characteristics. In the instances where one LV provided a specific data field and another did not, the team used that data to represent the entire state. The *Lead Vendor Data* tab in the Engineering Workbook summarizes the LV data the evaluation team used and indicates the source (one or more LVs).
2. **Energy Federation, Inc. (EFI) incentive data:** The LV data included information about all the measures that each participant was recommended following their HEA. However, it did not include installation data for a subset of HES measures, most notably early retirement heating and water heating systems, clothes washers, and refrigerators. This is because the incentives—and, therefore, the installation records—associated with those measures were processed by EFI, not the LVs. Consequently, the evaluation team worked with the PAs and EFI to acquire this data, which the team combined with the LV data. Once aggregated, the resulting dataset reflected a complete set of HES recommendations and installations (when relevant) for every HES participant.
3. **Residential Heating and Cooling Equipment Program (RHCE) and Behavioral Program participation data:** To avoid conflation between HES savings and savings generated by other residential initiatives offered by the PAs, the evaluation team combined participation records for the Heating and Cooling Equipment Program and the Behavioral Program using each HES customer's account number. The Residential Data Management Team (RDMT) provided this data.
4. **Billing Data:** The PAs, via the RDMT, provided 3 years of billing data (2014-2016) for each HES customer.
5. **Weather Data:** To control for the effect of weather during the billing analysis period and to normalize the results to reflect a typical meteorological year, the evaluation team acquired actual and typical meteorological year weather data for a 30-year period (also known as normalized weather or TMY3 weather) from National Oceanic and Atmospheric Administration weather stations. The team mapped each HES customer to a weather station based on ZIP code. For each station, the team calculated heating degree days (HDDs) and cooling degree days (CDDs) using a 65° F base temperature. The team used actual weather in the billing analysis regression model to quantify weatherization savings and then used normal weather data (TMY3) to adjust the savings estimates to reflect a typical meteorological year.

3. RESULTS SUMMARY

Table 3-1 presents the ex post results for every evaluated HES measure. The table also indicates which methodology the evaluation team used to estimate ex post savings for each HES measure.

The team used engineering algorithms to evaluate most measures, while the billing analysis was limited to air sealing and insulation. Again, the evaluation team only reported ex post savings via billing analysis if the results were better than ±20% precision at the 90% confidence all level.

In general, the mapping of HES measures and methodologies is similar to the previous HES impact evaluation.

Table 3-1. Ex Post Savings – All HES Measures

Measure	Natural Gas (therms)	Electric (kWh)	Oil (MMBtu)	Propane (MMBtu)
INSULATION & AIR SEALING				
Weatherization (Insulation and/or Air Sealing)	130	1,298	13	13
Insulation (Overall)	102	1,043	10	10
• Attic Insulation	83	1,092	8.5	8.3
• Basement/Floor Insulation	66	425	6.7	6.6
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• Cooling Savings (Associated with Insulation), kWh	31	33	32	31
Air Sealing	32	274	32	3.2
HEATING SYSTEMS				
Furnace Replacement	85	-	2.9	8.5
• Furnace Fan Savings (Associated with Furnace Replacement), kWh	80	-	26	80
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Boiler Reset Controls	51	-	5.2	5.1
Pipe Wrap (Space Heating)	14	-	1.5	1.4
Programmable Thermostat	35	251	3.5	3.5
• Cooling Savings, kWh	27	27	27	27
Wi-Fi Thermostat	58	419	5.9	5.8
• Cooling Savings, kWh	46	46	46	46
LIGHTING & APPLIANCES				
Refrigerator Replacement	-	55	-	-
Refrigerator Replacement (Early Retirement)	-	1,001	-	-
LED Recessed Trim Kits	3.7	94	0.4	0.4
Clothes Washer (Early Retirement)	Varies – see Engineering Workbook			
DOMESTIC HOT WATER				
Showerhead	9.2	187	1.0	0.9
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Pipe Wrap (Water Heating)	2.9	28	0.2	0.3
Indirect Water Heater	-	-	4.7	4.0
On-Demand Water Heater, 82%	-	-	-	4.1
On-Demand Water Heater (Early Retirement), 82%	-	-	-	5.4
On-Demand Water Heater, 94%	-	-	-	5.5
On-Demand Water Heater (Early Retirement), 94%	-	-	-	6.8
Combo Condensing Boiler/Water Heater 90%	-	-	-	8.4
Combo Condensing Boiler/Water Heater 95%	-	-	-	11
DISTRIBUTION				
Duct Insulation	73	726	7.4	7.3
Duct Sealing	39	442	4.0	3.0

🟩	Billing Analysis
🟩	Engineering Algorithm
🟩	Building Simulation
🟩	Billing Analysis & Building Simulation

The evaluation team also offers the following context and caveats regarding the savings summarized in Table 3-1.

- **Air Sealing and Insulation Type-Specific (i.e., attic, wall, and floor) Savings**. As detailed later in the report, two primary issues – collinearity and sample sizes – prevented the evaluation team from estimating savings for these measures as part of the natural gas or electric billing analysis. Consequently, the evaluation team estimated savings for weatherization (i.e., air sealing and/insulation) overall that yield statistically robust results. To provide the PAs with the air sealing and insulation-type-specific savings shown Table 3-1, the team used the building simulation analysis to disaggregate the billing analysis-based weatherization estimate into these constituent parts. This disaggregation process is technically sound, but it is important that users of this report understand that the billing analysis-based overall weatherization savings value is a more reliable estimate of savings than the disaggregated savings since building simulation relies on a prototype HES home that may not accurately capture the interactive effects between the measures installed in each individual HES participant's home like a billing analysis can. When possible, users of the information in this report should use the overall weatherization savings estimates rather than the air sealing and insulation type-specific savings.
- **Natural Gas Savings for Water Heaters and Heating Systems.** These measures are important elements of the PA's residential portfolio. However, they are not included in the table above because they are not part of HES. The measures are incentivized through and evaluated as part of the PA's Residential Heating & Cooling Equipment initiative.

Section 5 offers greater detail about the ex post savings associated for weatherization, thermostats, and heating systems. For other measures, detailed users of this evaluation should reference the previously mentioned Engineering Workbook.

4. RECOMMENDATIONS AND CONSIDERATIONS

Upon completion of this impact evaluation, the evaluation team offers the following recommendations and considerations:

4.1 Recommendations

1. **Use the ex post results determined through this evaluation as ex ante savings for future program years.** The results of this impact evaluation reflect the most recent and relevant set of gross savings values for the measures installed through HES. While the PAs will likely continue to evolve how they serve their residential customers programmatically, these savings represent the best estimates of future measure-specific savings for single-family family customers in Massachusetts. The evaluation team therefore recommends the PAs use the results included in this evaluation as part of ongoing three-year planning efforts. This includes the LV- and weatherization-specific realization rates contained in this report.
2. **Investigate programmable and wi-fi thermostats further**. The evaluation team's thermostat-related recommendation consists of two parts. First, the current design of HES allows Energy Specialists and HPCs to leave uninstalled thermostats with participants. If future iterations of HES continue this practice, the evaluation team recommends that PAs estimate a thermostat installation rate as part of the next evaluation. Second, this evaluation—as well as the previous impact evaluation—relied on a literature review to estimate savings for thermostats. Literature reviews offer insight into possible savings generated by programmable and wi-fi thermostats but are not specific to Massachusetts and the customers who participate in HES. Given the increasing importance of thermostats as an energy efficiency and demand response measure, the team recommends the PAs conduct primary research to more definitely understand the impact of these important residential measures in their region.

4.2 Considerations

1. **Future evaluations should more closely explore the disparity between LV-generated ex ante savings and evaluator ex post savings for weatherization measures.** Similar to the previous HES impact evaluation, the evaluation team found ex post savings for weatherization (i.e., air sealing and insulation) in natural gas-heated homes that were lower (~25–30% less) than the savings estimated by HES LVs. Given the consistent disparity between these estimates, future evaluators should seek to understand the drivers of this disparity in greater detail. Specifically, the assessment should elucidate differences by LV, heating fuel type (e.g., natural gas vs. propane heated homes), and climate zone, as well as consider actions that might bring weatherization ex ante and ex post values into closer alignment.

5. KEY MEASURE-SPECIFIC RESULTS

5.1 Weatherization

The evaluation team determined ex post weatherization savings for weatherized participants that heat their homes with natural gas, electricity, heating oil, or propane. The team used billing analysis to evaluate natural gas and electric weatherization savings. Because billing analysis is not possible for delivered fuels, the evaluation team leveraged the billing analysis-based natural gas results for heating oil and propane. That is, the team used an engineering calculation to convert the billing analysis-based savings determined for natural gas weatherization into weatherization savings for heating oil and propane weatherization, based on the relative heating efficiency of those fuels compared to natural gas. More details regarding this conversion are provided later in the report.

5.1.1 Natural Gas

Savings from weatherizing natural gas-heated homes is one of the primary drivers of overall savings at a statewide level. According to MassSaveData.com, more than 32,000 gas-heated customers installed air sealing and/or insulation through HES in 2015 and 2016.

5.1.1.1 Additional Methodological Details

The evaluation team used a billing analysis to develop ex post savings for weatherized natural gas customers. To be consistent with the previous evaluation, the team began by specifying a model that would produce the following:

- Separate results for air sealing and insulation
- Insulation type-specific results (i.e., separate savings estimate for wall, attic, and floor insulation versus insulation more generally)
- PA-specific results

However, the team ran into complications with such a model. Specifically, the following two issues arose:

1. **High correlation between air sealing and insulation.** Of HES participants included in the billing analysis (weatherized in 2015), 87% installed both air sealing and one or more insulation measure. This marked a significant increase from the previous evaluation when only 62% of participants installed both weatherization measures. While an increase in the proportion of HES customers having their homes sealed and insulated is a positive change for the initiative, it complicates billing analyses. Econometric models require variation to accurately differentiate and quantify the effect of each dependent variable; because most HES customers installed multiple measures, the team's models were unable to reliably parse the relative effect of air sealing and each type of insulation on a customer's total observed change in energy consumption. As a result, the team shifted to modeling overall weatherization savings.
2. **LV-specific models were more consistent than PA-models.** To test the robustness of a given model type and specification, the evaluation team compared the results to other model types and specifications. From an econometric perspective, generally consistent results across models is a sign of model robustness, whereas volatile or outlying results indicate a given model does not fit

the underlying data well and/or the model is overly sensitive to a specific term. The team's initial models that included a term for each PA showed far more variability in savings among PAs than would be expected given the similarity in how the programs are implemented. Conversely, similar tests found far less variability across model types and specifications for models estimating weatherization savings at the LV level.

In recognition of these factors, the team considered a variety of model types (pooled, two-stage, post program regression [PPR]) and various model specifications. After careful consideration, the team employed the following PPR model specification to estimate natural gas weatherization savings:

$$ADC_{ct} = b_1 HDD_{ct} + b_2 Behavioral_c + b_3(Treatment_c * HDD_t) + b_4 LagADC_{ct} + b_5(RHCE_c * HDD_t) + \mathrm{e}_{ct}$$

Where

- ADC_{ct} = average, daily energy consumption for customer *c* at calendar month *t*
- HDD_t = average monthly HDDs in post period for customer *c* in calendar month *t*
- $Behavioral_c$ = 1 if customer *c* is in the Behavioral program, 0 if customer *c* is not
- $Treatment_c$ = 1 if customer *c* is in treatment group, 0 if customer *c* is in control group, which is equivalent to customers who have installed weatherization measures
- $LagADC_{ct}$ = average daily consumption from customer *c* during calendar month *t* of the pre-program period
- $RHCE_c$ = 1 if customer *c* is in RHCE program, 0 if customer *c* is not
- e_{ct} is the error term from the regression model

The evaluation team also specified interim models that included independent variables for other natural gas measures sometimes installed through HES, such as showerheads, aerator, or thermostats. However, the team excluded these terms from the final model specification above since they did not have statistically significant coefficients (p-value > 0.001); the exclusion of the terms did not meaningfully impact the primary savings values of interest (weatherization). For both the natural gas and electric weatherization models, the evaluation team limited the terms in the final model specifications to only those with statistically significant coefficients. In the case of the natural gas analysis, this meant no other HES measures. As evident in the electric weatherization section later this report, a lighting term was included in the final electric model.

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. A complete summary of the billing analysis sample attrition is provided in Table 5-1.

Table 5-1. Billing Analysis Sample Attrition – Natural Gas

Reason for Exclusion [5]	Removed	%	Remaining
All Weatherized Homes (Between February 2015 and after December 2016)			10,487
Missing Data and Negative Consumption	291	2.8%	10,196
Insufficient Pre- and/or Post-Participation Billing Data	3,309	31.6%	6,887
Outliers (<5th and >95th Percentile)	747	7.1%	6,140
Vacancies, Extreme Changes in Consumption (>50% Change between Pre and Post)	789	7.5%	5,351
Failed Princeton Scorekeeping Method Screening (Not Weather Sensitive)	5	0.0%	5,346
Next Step Living customer[6]	1,989	19.0%	3,357
Total	**7,130**	**68.0%**	**3,357**

5.1.1.2 Results

The results of the evaluation team's billing analysis of weatherized natural gas-heated HES participants is provided in Table 5-2. Statewide weatherization participants—again, an HES customer that installed air sealing and/or one or more types of insulation (attic, wall, or floor)—saved 130 therms/year, on average. As shown in the table, customers served by RISE saved the most, on average (179 therms), while CLEAResult customers saved the least 127 therms. However, RISE's energy modeling software also produced much higher ex ante savings estimates so the LV's realization rate (ex ante/ex post) is actually lower than CLEAResult.

The team also assessed the savings associated with participants served by Next Step Living (NSL) and those who were not, since NSL (a prominent HPC) left the initiative in early 2016. The evaluation team did not find a statistically significant difference in average weatherization savings between weatherized customers served by NSL and those that were weatherized by a LV or another HPC (i.e., the confidence intervals for the two savings point estimates overlapped). Therefore, the PAs can use the savings and realization rates provided in Table 5-2 both retrospectively for evaluation purposes and prospectively for planning purposes.

Important note regarding realization rates: The realization rates shown below represent the relationship between the current evaluation's ex post results and the LV-generated ex ante savings subject to evaluation. The PAs should apply the ex post realization rate determined through this evaluation directly to the LV's ex ante savings. The PAs should not factor in the realization rate from the previous study, which represented the relationship between ex ante and ex post savings determined through that evaluation. It is useful to compare realization rates across studies to see how accurately LVs are anticipating evaluated savings, but the realization rates are not multiplicative across evaluations.

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[5] The team also considered estimating savings using fewer attrition filters (e.g., including accounts showing vacancies) since the purpose of the control group to account for some of these types of events. However, the team found that results were not meaningfully different when these filters were relaxed.

[6] Next Step Living (NSL) was a prominent HPC left the initiative in early 2016.

Table 5-2. Ex Post Weatherization Savings – Natural Gas

LV	Ex Ante (therms/year)	Ex Post (therms/year)	Precision (± %)	Realization Rate
CLEAResult	169	127	2%	0.75
RISE	265	179	5%	0.68
CET	182	152	10%	0.83
Statewide	**178**	**130**	**2%**	**0.73**

It is helpful to consider the ex post results in the previous table in the context of the previous evaluation. As evident below, the annual savings (139 vs. 130 therms/year) and realization rates (0.76 vs. 0.73) are relatively similar at the state level to the previous evaluation. Comparable results across evaluations are unsurprising for a mature initiative such as HES.

It is worth noting that RISE's annual savings value increased considerably since the previous evaluation. This is also true of the LV's ex ante savings, meaning RISE experienced a positive but modest increase (0.63 to 0.68) in its LV-specific realization rate. The higher ex ante and ex post savings for RISE are likely the result of RISE customers being recommended insulation more often and, on average (1.6 vs. 1.3) installing more types of insulation (i.e., attic, wall, and/or floor) than CLEAResult and RISE customers.

Table 5-3. Comparison of Evaluated Ex Post Weatherization Savings – Natural Gas Savings

LV	Ex Post (therms/year)		Realization Rates	
	Previous Evaluation (2013)*	Current Evaluation	Previous Evaluation (2013)*	Current Evaluation
CLEAResult	139-140	127	0.74-0.85	0.75
RISE	119-131	179	0.63	0.68
CET	137	152	0.85	0.83
Statewide	**139**	**130**	**0.76**	**0.73**

*The previous evaluation calculated PA-specific savings. The range of savings and realization rates shown in the table reflect the range of PA-specific savings associated with each LV from the previous evaluation.

Because the billing analysis was unable to reliably estimate specific savings for air sealing and each type of insulation, the evaluation team used building simulation models to disaggregate the billing analysis weatherization results into these sub-elements. As noted in the Results Summary section earlier in the report, overall weatherization results – determined through the billing analysis – are more reliable than the disaggregated air sealing and insulation type-specific savings. Users of this evaluation should therefore leverage the overall weatherization results, rather than the disaggregated weatherization elements, when possible.

Table 5-4. Ex Post Air Sealing and Insulation Type Savings (therms/year) – Natural Gas

	Statewide		CLEAResult		RISE		CET	
	Install %	Savings	Install %	Savings	Install %	Savings	Install %	Savings
Weatherization	**100%**	**130**	**100%**	**127**	**100%**	**179**	**100%**	**152**
Insulation*	96%	102	96%	100	94%	143	100%	119
Attic	85%	83	85%	83	85%	101	87%	97
Floor	23%	66	23%	66	27%	80	20%	77
Wall	22%	72	20%	71	41%	87	23%	84
Air Sealing	88%	32	88%	32	93%	38	87%	37
***Average Types of Insulation**	**1.4**		**1.3**		**1.6**		**1.3**	

5.1.2 Electricity

HES also weatherizes electrically heated customers, although there are fewer than natural gas. According to the provided LV data, the PAs collectively weatherized, in 2015, more than 4,000 customers that heat their homes using electricity.

5.1.2.1 Additional Methodological Details

The evaluation team’s attempt to develop granular and PA-specific billing analysis results ran into similar issues to the natural gas analysis (described in Section 5.1.1). These issues were more pronounced for the electric analysis, however, because of the smaller number of electric weatherization customers. Consequently, the team used a similar model type and specification at the statewide level as shown for natural gas. Specifically, the team employed the following model for the electric analysis:

$$ADC_{ct} = b_1 HDD_{ct} + b_2 Behavioral_c + b_3(Treatment_c * HDD_t) + b_4 LagADC_{ct} + b_5 Lighting_c + \mathrm{e}_{ct}$$

Where

- ADC_{ct} = average, daily energy consumption for customer *c* at calendar month *t*
- HDD_t = average monthly HDDs in post period for customer *c* in calendar month *t*
- $Behavioral_c$ = 1 if customer *c* is in the Behavioral program, 0 if customer *c* is not
- $Treatment_c$ = 1 if customer *c* is in treatment group, 0 if customer *c* is in control group, which is equivalent to customers who have installed weatherization measures
- $LagADC_{ct}$ = average daily consumption from customer *c* during calendar month *t* of the pre-program period
- $Lighting_c$ = Quantity of bulbs customer c had directly installed during their HEA
- e_{ct} is the error term from the regression model

The team also carefully reviewed the pool of potential customers for the model and excluded more than three-quarters of them for one of the reasons detailed in Table 5-5.

Table 5-5. Billing Analysis Sample Attrition – Electric

Reason for Exclusion	Removed	%	Remaining
All Weatherized Homes (Between February 2015 and after December 2016)			3,945
Missing Data and Negative Consumption	478	12.1%	3,467
Outliers (<5th and >95th Percentile)	290	7.4%	3,177
Vacancies, Extreme Changes in Consumption (>50% Change between Pre and Post)	338	8.6%	2,839
Insufficient Pre- and/or Post-Participation Billing Data	855	21.7%	1,984
Next Step Living customer[7]	1,124	28.5%	860
Total	**3,085**	**78.2%**	**860**

5.1.2.2 Results

The evaluation team was able to calculate LV-specific electric weatherization results within the defined precision and confidence thresholds for CLEAResult but not for RISE, which serves a smaller number of electrically heated customers. As shown in Table 5-6, the evaluation team's ex post savings were a little more than half of the LV-estimated ex ante savings, both for CLEAResult specifically and statewide.

The statewide ex post savings and associated realization rates include the RISE customers but were primarily determined by the larger number of Eversource and National Grid electrically heated customers served by CLEAResult. Similar to the natural gas analysis, the team tested for a statistically significant difference between NSL and non-NSL customers and did not find one (i.e., the confidence intervals for the two savings point estimates overlapped).

Table 5-6. Ex Post Weatherization Savings – Electricity

LV	Ex Ante (kWh/year)	Ex Post (kWh /year)	Precision (± %)	Realization Rate
CLEAResult	2,351	1,326	6%	0.56
Statewide	**2,389**	**1,298**	**6%**	**0.54**

Table 5-7 compares this evaluation's statewide ex post savings estimate to the most recent HES evaluation for weatherization measures (the 2013 realization rate study). As shown below, the current realization rate is very similar to previous evaluation. Again, as noted above, the PAs should apply the realization rate determined through the current evaluation directly to the LV's ex ante savings; the realization rate from the previous study is moot and does not factor into the PA's calculation of 2015/2016 savings.

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[7] Ibid.

Table 5-7. Comparison of Evaluated Ex Post Weatherization Savings – Electricity

	Ex Post (kWh /year)		Realization Rates	
	Previous Evaluation (2013)*	Current Evaluation	Previous Evaluation (2013)*	Current Evaluation
CLEAResult	1,459–1,468	1,326	0.54–0.60	0.56
Statewide	**1,445**	**1,298**	**0.57**	**0.54**

*The previous evaluation calculated PA-specific savings. The range of savings and realization rates shown in the table reflect the range of PA-specific savings associated with each LV.

Like the natural gas analysis, the evaluation team also used the building simulation results to disaggregate the billing analysis-based overall weatherization savings into these sub-elements.

Table 5-8. Ex Post Air Sealing and Insulation Type Savings (kWh/year) – Electric

	Statewide		CLEAResult	
	Install %	Savings	Install %	Savings
Weatherization	**100%**	**1,298**	**100%**	**1,326**
Insulation*	88%	1,043	89%	1,066
Attic	*84%*	1,092	*86%*	1,108
Floor	*7%*	425	*7%*	431
Wall	*13%*	673	*13%*	683
Air Sealing	93%	274	93%	278
***Average Types of Insulation**	**1.2**		**1.2**	

5.1.3 Delivered Fuels – Heating Oil and Propane

5.1.3.1 Additional Methodological Details

Since a billing analysis is not possible for delivered fuels, the evaluation team leveraged the results of natural gas weatherization billing analysis to estimate ex post savings for both heating oil and propane.

Applying the evaluation team's natural gas savings to heating oil and propane customers implies similarity between the customers heating with these different fuels. It is not possible to test some of implicit similarity assumptions—such as natural gas, heating oil, and propane customers heating their home to similar temperatures in the winter. However, since LVs collect square footage for each HES customer it was possible to confirm that weatherization participants using natural gas, heating oil, and propane live in similarly sized homes. The similarity in average home size (Table 5-9) across heating fuels supports the assumption that weatherization savings are also likely similar.

Table 5-9. Average Home Size (Square Feet/Home) by Heating Fuel

Heating Fuel	Average Home Size
Natural Gas	1,860
Heating Oil	1,865
Propane	1,947

For heating oil, the evaluation team adjusted the total savings determined for weatherized customers heating with natural gas to reflect that heating oil systems are slightly less efficient at converting heating oil into heat. As a result, it takes more heating fuel for a customer to heat their home to their desired heating temperature setpoint than it does a natural gas customer. For this reason, the ex post savings associated with weatherized heating oil participants is slightly higher than weatherized natural gas-heated customers (when comparing both savings in similar units, i.e., MMBtus).

For propane, the team directly applied the natural gas savings (converting therms to MMBtu). Propane and natural gas heating systems are comparably efficient when converting their respective fuels into heat. Consequently, it is possible to leverage the natural gas billing result directly.

5.1.3.2 Results

Table 5-10 presents ex post savings for both heating oil and propane. Statewide, the initiative had a realization rate of 77% and 93% for heating oil and propane, respectively.

Unlike Table 5-2 and Table 5-6, which present the billing analysis-based ex post savings for natural gas and electrically heated weatherization participants, this summary table does not include precision estimates. That is because the engineering adjustments and assumptions made for heating oil and propane do not facilitate a measurement of statistical significance.

Table 5-10. Ex Post Weatherization Savings – Heating Oil and Propane

LV	Heating Oil (MMBtus/year)			Propane (MMBtus/year)		
	Ex Ante	Ex Post	Realization Rate	Ex Ante	Ex Post	Realization Rate
CLEAResult	16.7	12.9	77%	12.7	12.7	100%
RISE	23.1	18.2	79%	20.0	17.9	89%
Statewide	**17.2**	**13.3**	**77%**	**14.0**	**13.0**	**93%**

Table 5-11 compares this evaluation's statewide ex post savings estimate to the most recent HES evaluation for heating oil and propane weatherization measures (again, the 2013 realization rate study). As shown below, heating oil ex post savings and realization rates were a little lower than the previous evaluation, whereas the propane savings were a little higher.

Table 5-11. Comparison of Evaluated Ex Post Weatherization Savings – Heating Oil

LV	Ex Post (therms/year)		Realization Rates	
	Previous Evaluation (2013)*	Current Evaluation	Previous Evaluation (2013)*	Current Evaluation
CLEAResult	16.7–16.8	12.9	0.85–0.88	0.77
RISE	13.9–16.4	18.2	0.36–1.0	0.79
Statewide	**16.8**	**13.3**	**0.85**	**0.77**

*The previous evaluation calculated PA-specific savings. The range of savings and realization rates shown in the table reflect the range of PA-specific savings associated with each LV from the previous evaluation.

Table 5-12. Comparison of Evaluated Ex Post Weatherization Savings – Propane

LV	Ex Post (therms/year)		Realization Rates	
	Previous Evaluation (2013)*	Current Evaluation	Previous Evaluation (2013)*	Current Evaluation
CLEAResult	12.6–13.5	12.7	0.88–0.95	1.00
RISE	12.2–12.7	17.9	0.20–0.86	0.89
Statewide	**12.8**	**13.0**	**0.83**	**0.93**

*The previous evaluation calculated PA-specific savings. The range of savings and realization rates shown in the table reflect the range of PA-specific savings associated with each LV from the previous evaluation.

5.2 Thermostats

The PAs offered both standard programmable and Wi-Fi thermostats through HES during the 2015/2016 evaluation period. Programmable thermostats were part of the 2012 impact evaluation, whereas Wi-Fi thermostats were new to this evaluation cycle.

5.2.1 Additional Methodological Details

As with most HES measures, the evaluation team initially attempted to estimate ex post savings for thermostats through the natural gas and electric billing analysis. However, neither billing analysis produced statistically significant results for thermostats (when modeled separately or when combined into a general “thermostats” measure category). Consequently, the evaluation used an engineering approach—specifically a literature review of existing, regionally appropriate, programmable and Wi-Fi thermostat studies or evaluations. This approach is similar to the method employed by the 2012 evaluation team.

The current evaluation team refreshed the previous literature review by identifying thermostat studies and/or evaluations completed since the previous evaluation. The team reviewed these sources, as well as the previously identified sources to determine whether a specific study or the studies (collectively) suggested updating the previous evaluation’s assumed savings percentage (3.6%) for a standard programmable thermostat. As noted above, the previous evaluation did not include Wi-Fi thermostats, so the evaluation team used the newly available sources to develop a similar assumed savings percentage for Wi-Fi thermostats. In total, the team reviewed 13 thermostat studies or evaluations.[8]

5.2.2 Results

Regarding standard programmable thermostats, the evaluation team found that the studies released since the previous evaluation largely corroborated the existing savings assumption of 3.6% of a participant's heating-related energy consumption. None of the more recent studies offered a more definitive estimate for HES and, in general, exhibited the same variance in savings estimates observed in the previous evaluation. As a result, the team did not find evidence to change the existing savings assumption of 3.6%.

The team's review of Wi-Fi thermostat studies, including the National Grid-specific study cited in the MA TRM, found, in general, a higher rate of savings than standard programmable thermostats. Based on the collective information available at this time, the team applied a higher (6.0%) savings assumption for Wi-Fi thermostats.

The previous evaluation, as well as National Grid's Wi-Fi study, did not account for the effect of thermostats on cooling-related energy consumption. Using information from the reviewed studies regarding thermostat's cooling impacts, as well as MA-specific central air conditioner saturations, the team developed an estimate of cooling savings for the average HES participant receiving both types of incentivized thermostats. However, due to the relatively low saturation of central air conditioners, the additional cooling savings included in this evaluation are relatively modest.

Table 5-13 provides the ex post savings for standard and programmable thermostats for all four heating fuels.

Table 5-13. Ex Post Thermostat Savings

	Natural Gas (therms/year)*	Electricity (kWh/year)**	Heating Oil (MMBtu/year)	Propane (MMBtu/year)
Standard Programmable Thermostats				
- Heating	35	251	3.5	3.5
- Cooling (kWh/year)	27	27	27	27
Wi-Fi Thermostats				
- Heating	58	419	5.9	5.8
- Cooling (kWh/year)	46	46	46	46

*Conversion: 1 MMBtu = 10 therms
**Conversion: 1 MMBtu = 0.00029 kWh

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[8] The Literature Review tab in the Engineering Workbook summarizes each reviewed study.

While the evaluation team recommends using 3.6% and 6.0% for standard programmable and Wi-Fi thermostats, respectively, as part of this evaluation, the PAs should conduct primary research to develop Massachusetts-specific thermostat savings based on a metering study or thermostat-specific billing analysis. It is important that any future research also gather information about installation rates as, by design, Energy Specialists and HPCs are permitted to leave behind uninstalled thermostats as part of the HEA. Currently, the evaluation team does not have any information about what percentage of thermostats were directly installed versus left behind with participants, or information about installation rates more generally, to adjust average savings. This means the savings shown above assume a 100% installation rate for both types of thermostats.

5.3 Heating Systems

Although most of the heating system replacements occur through the Residential Heating and Cooling Equipment initiative, the PAs incentivize efficient heating oil and propane systems, as well as the early retirement of select natural gas heating systems, through HES.

5.3.1 Additional Methodological Details

The evaluation team relied exclusively on the engineering algorithms detailed in the MA TRM to estimate ex post savings for all heating system measures. The team populated these algorithms using information provided by LV, contained in the TRM, and with estimates of annual consumption based on the team's disaggregation of the natural gas billing data provided by the gas PAs.

Per the algorithms specified in the TRM, the evaluation team estimated savings for both early retirement (ER, also known as early replacement) and replace on failure (ROF) scenarios. For the early retirement scenario, the baseline for estimating savings is the existing heating system, whereas, for the replace on failure scenario, the baseline is a system compliant with the federal standard in 2015 or 2016.

In addition to estimating the heating savings associated with furnaces, the evaluation team also estimated the fan savings using the MA-specific study cited in the previous HES evaluation and documented in the TRM.

5.3.2 Results

Table 5-14 provides the ex post savings for standard and programmable thermostats for all four heating fuels. The evaluation team found generally higher ex post savings (relative to ex ante) for ER and ROF furnaces and lower savings for boilers. This is due to a change in the average annual heating load calculated during this evaluation's billing analysis. The team disaggregated gas billing data from HES participants to estimate average annual heating consumption. Using baseline assumptions in the current TRM, the team was able to calculate average annual heating loads by multiplying the heating consumption by the respective system efficiencies, an AFUE of 0.75 for a boiler and 0.78 for a furnace. The average heating load for homes with furnaces increased by 15% compared to the ex ante value, and the average heating load for homes with boilers decreased by 25% compared to the ex ante.

Table 5-14. Ex Post Heating System Savings

	Natural Gas (therms/year)*	Heating Oil (MMBtu/year)	Propane (MMBtu/year)
Furnace (ROF)			
- Heating	85	2.9	8.5
- Furnace Fan (kWh/year)	80	26	80
Furnace (ER)			
- Heating	157	8.2	16
- Furnace Fan (kWh/year)	135	70	135
Steam Boiler (ROF)	23	2.2	2.3
Steam Boiler (ER)	87	11	8.7
Forced Hot Water Boiler (ROF)	91	2.1	9.1
Forced Hot Water Boiler (ER)	146	13	15

*Conversion: 1 MMBtu = 10 therms

Appendix A. POWER ANALYSIS SUMMARY MEMO

To: Massachusetts Program Administrators and Energy Efficiency Advisory Council

From: Doug Bruchs and Fred Schaefer, Cadeo

Date: December 13, 2017

Re: HES Impact Evaluation (RES 34): Power Analysis Memo (Task 2)

This memo details a power analysis that the evaluation team conducted as part of Home Energy Services (HES) impact evaluation (RES 34).

The purpose of the power analysis is to provide an estimate of the sample sizes needed to obtain statistically significant effects in a billing analysis based on each energy efficiency measure's expected energy savings and level of precision.

In the case of RES 34 the power analysis results indicate, by measure and fuel type, which HES measures the evaluation team can reliably evaluate through the proposed billing analysis. For all other HES measures, the evaluation team will use an engineering methodology—either building simulation or engineering algorithms—to evaluate energy savings. The results of power analysis also indicate whether the billing analysis is likely to produce statistically significant Program Administrator specific (PA) results or not, by measure and fuel type.

As detailed in the following methodology section, the team used initial participation data provided by all three HES lead vendors (LVs) and assumptions based on the previous HES impact evaluation to inform the power analysis.[9]

A.1 Methodology

Given the natural variability in monthly energy consumption patterns and the amount of energy saved by a measure, evaluators can use power analysis to estimate the sample sizes needed to obtain the desired statistically significant effect in a billing analysis model. This section discusses the methods and assumptions used by the team in its power analysis in preparation for the HES billing analysis.

The evaluation team completed a comprehensive power analysis on all HES electric and natural gas measures with available installation data. The power analysis scope did not include oil, propane, and other fuels as no billing data was available.

A.1.1 Comparison to Installation Data

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[9] Cadmus, *Home Energy Services Impact Evaluation: Part of the Massachusetts Residential Retrofit and Low Income Program Area Evaluation*, Electric and Gas Program Administrators of Massachusetts, 2012, http://ma-eeac.org/wordpress/wp-content/uploads/Home-Energy-Services-Impact-Evaluation-Report_Part-of-the-Massachusetts-2011-Residential-Retrofit-and-Low-Income-Program-Area-Evaluation.pdf.

For this analysis, the evaluation team looked for sample sizes to produce statistically significant savings at the PA level. Specifically, the team used installation data provided by the three HES LVs to estimate measure-level installation counts by PA and fuel type during the period of January 2015–October 2015. This range of eligibility dates allows participants to have a full year of billing data in the pre- and post-installation period.[10] The team then compared the counts to calculated, minimum sample sizes to determine which combinations of measure, fuel type, and PA are expected to have statistically significant billing analysis results.

A.1.2 Assumptions

The team leveraged the billing analysis savings (effect size) and precision (standard errors) from previous evaluations for this power analysis. The assumption used in this approach was that the savings and precision estimates from previous billing analysis are the best estimates to use in the power analysis.

A.1.3 Effect Size and Standard Error

For gas measures that were not included in the 2011–2014 billing analysis, the team assumed the following:

- **Effect size:** Same as 2011–2014 engineering analysis
- **Standard error:** 7.58 therms for duct insulation and duct sealing; this was the average standard error for all other measures

The savings estimates for all electric measures in the 2011–2014 evaluation utilized engineering algorithms, i.e., none of them were conducted via billing analysis. As such, the team modified its standard error approach as follows:

- **Effect size:** Same as 2011–2014 engineering analysis
- **Standard error:** Used the same ratio of standard error to effect size as gas measures

A.1.4 Other Assumptions

- The team calculated the minimum sample sizes by applying a layer of conservatism to the effects size (25% lower than previous evaluation) and standard errors (50% larger than previous evaluation) described above to guard against setting overly aggressive expectations on which combinations of measures and PAs have statistically significant billing analysis results.
- The team assumed an attrition rate of 60% for this comparison to program data, which exceeds that of the previous evaluation report, where attrition was approximately 35%. The assumption implied that 60% of program participants will not be used in the billing analysis due to one or more of the following analytical reasons:
    - Participant record in audit data was unable to link to participant record in billing data. The evaluation team's initial analysis shows a match rate of 50% to 60% between HES participant data and January 2014–April 2016 billing data; this indicates 40% to 50% attrition due to this step alone.
    - Billing data was insufficient in pre- or post-period.[10]
    - Participant failed an outlier screening; energy savings or consumption is nonsensical or multiple standard deviations from other participants.

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[10] The team has received billing data from the PAs for the period of January 2014 through April 2016 and expects to receive May 2016 through December 2016 billing data in time to conduct the billing analysis. Extending the billing data window will ensure that more participants have sufficient data for billing analysis.

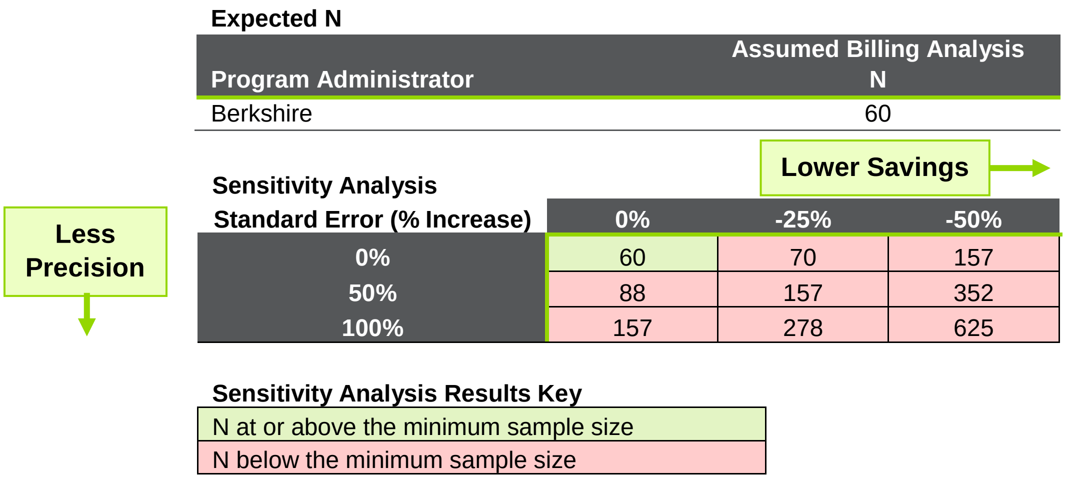
  - Participant billing data fails PRISM screening—i.e., does not have a clear heating signature—for gas heating and weatherization measures.
- Minimum sample size of 60 for the measure included in billing analysis, to ensure a more stable result even if effects could be significant with a smaller sample size.
- Effects are statistically different from zero at a 90% confidence level.
- Participants paired with nonparticipants in equal proportion for billing analysis.
- Samples sizes from the previous billing analysis contributed to the algorithm that the team used to calculate minimum sample size. For measures that were not included in the previous evaluation's billing analysis, assume N = 1,000.

A.1.5 Sensitivity Analysis

In addition to estimating the minimum sample size, the team conducted a sensitivity analysis for each measure, by varying the effect size (estimated energy savings) and standard error (estimated precision) assumptions, as shown in Figure A-1.

Specifically, the team used the sensitivity analysis to identify the measures and PAs that exceeded, but were close, to the minimum required sample size and to understand how changes in effect size and standard error might affect the significance of billing analysis results. In Figure A-1, the sensitivity analysis found that the billing analysis will likely yield Berkshire Gas-specific results for insulation if the assumptions used in the power analysis hold throughout the billing analysis. However, if the effect size is 25% smaller or if the standard error is 50% larger, then Berkshire Gas' participant count of 60 customers will be insufficient to generate Berkshire Gas-specific results at that same confidence and precision.

Figure A-1. Sensitivity Analysis Illustration



Expected N

Program Administrator	Assumed Billing Analysis N
Berkshire	60

Sensitivity Analysis

Standard Error (% Increase)	0%	-25%	-50%
0%	60	70	157
50%	88	157	352
100%	157	278	625

Sensitivity Analysis Results Key

🟩 N at or above the minimum sample size
🟥 N below the minimum sample size

(Source: Cadeo Analysis)

A.2 Results

This section describes the team's power analysis findings, first for the set of natural gas measures, followed by electric measures. For each fuel, the analysis compares the installation counts for each measure, both statewide and for each PA, to the calculated minimum sample size to determine whether the billing analysis is:

- **Likely** to yield significant results
- **Unlikely** to yield significant results
- **Will not** yield significant results

The team also used a sensitivity analysis to take a deeper look at the measures and PAs for which installation counts are close to the minimum sample size.

A.2.1 Gas Measures

Figure A-2. Gas Measures, Minimum Sample Size, and PA-Level Statistical Significance

						Sample Size Assessment							
Measure Type	**Measure**	**Assumed Effect Size (Therms)**	**Assumed Std Error (Therms)**	**Min Sample Size**	**Statewide N (Jan15-Oct15)**	**Statewide**	**National Grid**	**Eversource**	**CLC**	**Unitil**	**Columbia Gas**	**Liberty**	**Berkshire**
Weatherization	Any Insulation	96	5.25	60	3,948	🟩	🟩	🟩	🟩	🟥	🟩	🟥	🟨
	Attic Insulation	77	8.49	72	3,345	🟩	🟩	🟩	🟩	🟥	🟩	🟥	🟥
	Wall Insulation	99	9.63	60	1,113	🟩	🟩	🟩	🟩	🟥	🟩	🟥	🟥
	Basement Insulation	14	12.41	1,591	1,224	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥
	Air Sealing	53.4	5.80	157	3,583	🟩	🟩	🟩	🟩	🟥	🟩	🟥	🟥
Domestic Hot Water	Showerhead	11.7	6.97	3,841	3,862	🟩	🟥	🟥	🟥	🟥	🟥	🟥	🟥
	Faucet Aerator	2.3	6.97	99,386	2,907	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥
Distribution	Duct Insulation	68	7.58	135	10	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥
	Duct Sealing	36	7.58	480	89	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥

Legend

🟩 Likely to have significant billing analysis results
🟨 Unlikely to have significant billing analysis results
🟥 Will not have significant billing analysis results

(Source: Cadeo Analysis)

Based on the power analysis and the team's underlying assumptions (see next section), statistically significant billing analysis results are expected at the PA level for most combinations of weatherization measures and larger PAs (Figure A-2) in gas-heated homes.

The evaluation team is not considering thermostats (programmable or Wi-Fi) in the billing analysis because the correlation between thermostats and weatherization (as well as the heating/cooling measures we'll need to control for) is very high, which makes identifying thermostat-specific savings statistically problematic. The evaluation team will calculate thermostat savings through the engineering analysis and will control for the installation of thermostats in the billing analysis results to ensure that their impact is not double-counted.

After accounting for attrition due to billing data availability, the expected number of statewide participants that installed basement insulation (n=1,222) fell below the minimum sample size (1,591, see Figure A-3). However, the team's sensitivity analysis suggests that the state-level billing analysis result would be significant if the effect size and standard error were more similar to those from the previous study.

Figure A-3. Basement Insulation (Gas) Minimum Sample Size Sensitivity

Standard Error (% Increase)	0%	-25%	-50%
0%	🟩 398	🟩 707	🟥 1,591
50%	🟩 895	🟥 1,591	🟥 3,578
100%	🟥 1,591	🟥 2,827	🟥 6,361

Legend

- 🟩 Statewide N at or above minimum sample size
- 🟥 Statewide N below minimum sample size

Based on Figure A-4, the anticipated sample size for Berkshire insulation installs (n=66) is close to the sample size threshold. However, a higher than expected standard error, a lower than expected effect size, or a final billing analysis sample size lower than 60 would prevent reporting a PA-specific result for Berkshire.

A.2.2 Electric Measures

Figure A-4. Electric Measures, Minimum Sample Size, and PA-Level Statistical Significance

						Sample Size Assessment							
Measure Type	**Measure**	**Assumed Effect Size (kWh)**	**Assumed Std Error (kWh)**	**Min Sample Size**	**Statewide N (Jan15-Oct15)**	**Statewide**	**National Grid**	**Eversource**	**CLC**	**Unitil**	**Columbia Gas**	**Liberty**	**Berkshire**
Weatherization	Any Insulation	903	49.4	60	442	🟩	🟩	🟩	🟨	🟥	🟥	🟥	🟥
	Attic Insulation	793	87.4	132	415	🟩	🟩	🟥	🟥	🟥	🟥	🟥	🟥
	Wall Insulation	972	94.5	103	99	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥
	Basement Insulation	99	87.8	8,504	58	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥
	Air Sealing	710	77.1	128	462	🟩	🟩	🟨	🟥	🟥	🟥	🟥	🟥
Domestic Hot Water	Showerhead	237	141.2	3,841	1,534	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥
	Faucet Aerator	49	148.5	99,386	1,172	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥
Distribution	Duct Insulation	1,613	179.7	135	0	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥
	Duct Sealing	428	90.1	480	0	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥

Legend

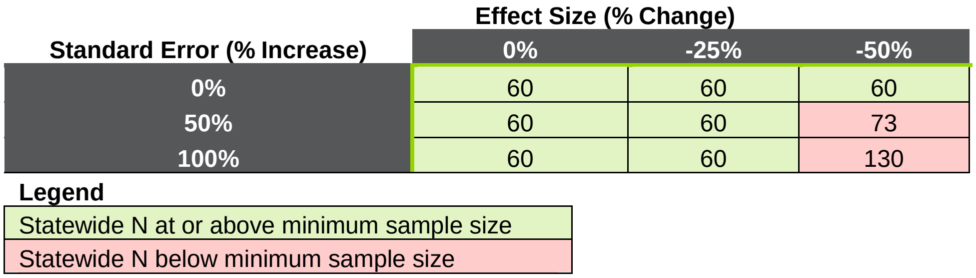
- 🟩 Likely to have significant billing analysis results
- 🟨 Unlikely to have significant billing analysis results
- 🟥 Will not have significant billing analysis results

(Source: Cadeo Analysis)

Based on the power analysis and the team's underlying assumptions, statistically significant billing analysis results were expected at the statewide level for overall insulation, attic insulation, and air sealing installs in electric-heated dwellings. The evaluation team also expects to have PA billing analysis results for overall insulation and air sealing measures for the larger PAs (National Grid and Eversource), though Eversource's air sealing sample size was just over the calculated minimum sample size (n=140 versus minimum sample size of 128).

The team expects that Cape Light Compact (CLC) will have enough insulation installs (expected n=70) to warrant inclusion in billing analysis, though the sensitivity analysis suggests that the team's billing analysis result may be insignificant if the savings estimates come in lower than expected.

Figure A-5. Cape Light Compact insulation (electric) Minimum Sample Size Sensitivity



	Effect Size (% Change)		
Standard Error (% Increase)	**0%**	**-25%**	**-50%**
0%	🟩 60	🟩 60	🟩 60
50%	🟩 60	🟩 60	🟥 73
100%	🟩 60	🟩 60	🟥 130

Legend

🟩 Statewide N at or above minimum sample size

🟥 Statewide N below minimum sample size

A.2.3 Caveats

While a power analysis uses the best available data and assumptions, it precedes the formal data preparation needed for a billing analysis. In this context, two caveats follow:

- Should the actual billing data have more variability or yield smaller sample sizes than expected after merging with participant records, some of the measures that the team expected to have statistically significant savings in a billing analysis model may not be significant in practice.
- The analysis does not include boilers, furnaces, and appliances. Installation data for these measures were not available at the time of writing. At a minimum, the evaluation team will include the measures in the engineering analysis and if the team can link the yet-to-be acquired installation data to participant billing records, it will attempt to include those term in the billing analysis if sample sizes permit.

A.2.4 Theory

Mathematically, the relationship between the estimated standard error in the current evaluation and the previous evaluation is a function of the sample sizes, as shown in Equation 1.

Equation 1. Standard Error Relationship: Current to Previous Evaluation

$$SE_{Curr} = \frac{\sqrt{N_{Prev}}}{\sqrt{N_{Curr}}} * SE_{Prev}$$

The minimum sample size for the current evaluation is the one for which the confidence interval width is equal to the assumed effect size, F_{Curr} (Equation 2). The z_{α} term is the multiplier required to get a confidence interval of (100-α)%.

Equation 2. Effect Size Equal to Confidence Interval Width

$$F_{Curr} = SE_{Curr} * z_{\alpha}^{2}$$

Combining equations 1 and 2, the team obtained the assumed effect size, F_{Curr}, expressed as a function of sample sizes and standard errors from the previous billing analysis.

Equation 3. Augmenting the Confidence Interval Width

$$\boldsymbol{F_{Curr} = \frac{\sqrt{N_{Prev}}}{\sqrt{N_{Curr}}} * SE_{Prev} * z_{\alpha}^{2}}$$

By rearranging the terms in Equation 3, the team got the equation for the minimum required sample size, N_{Curr}, shown in Equation 4.

Equation 4. Minumum Sample Size Calculation

$$N_{Curr} = N_{Prev}\left(\frac{SE_{Prev}}{F_{Curr}}\right)^{2} z_{\alpha}^{2}$$

Appendix B. MATCHED CONTROLS GROUP SUMMARY MEMO

To: Massachusetts Program Administrators and Energy Efficiency Advisory Council

From: Doug Bruchs and Fred Schaefer, Cadeo

Date: January 29, 2017

Re: HES Impact Evaluation (RES 34): Matched Controls Group Memo (Task 3)

This memo details the process by which the evaluation team created a matched control group for the impending Home Energy Services (HES) impact evaluation (RES 34) billing analysis.

High quality and representative control groups are vital for billing analyses. Control groups help evaluators understand participating customers' counterfactual; that is, the amount of energy that participating customers likely would have consumed had they not installed measures through HES. Control groups also account for the impact of various macroeconomic factors and other influences on pre- and post-program energy consumption that are unrelated to the installation of program measures. These include economic swings, the movement of people in and out of homes, and fluctuations in per-unit energy costs.

The evaluation team developed a process for creating a control group and generated an initial sample; however, the team does not yet have the full set of data required to conduct a billing analysis. The evaluation team has a full set of participation data (July 2014 through December 2016), but only a partial set of billing data (January 2014 through April 2016). The team has requested the remaining electric and natural gas billing data (through December 2016), and will create the final sample for the billing analysis when it receives that data from the residential data management team (RDMT).

The purpose of this memo is to document and communicate the matching process that the evaluation team will use, and to demonstrate its viability using the data currently available.

B.1 Methodology

The evaluation team used the quasi-experimental matched control group (MCG) method to identify the most relevant customers for the billing analysis' control group. The MCG method goes beyond random sampling of treatment and comparison groups and instead matches each treatment customer (i.e., participating HES customer) with a specific best match customer from the pool of potential comparison group customers based on pre-program energy usage.

The team's MCG approach used a nearest-neighbor algorithm to match each treatment customer to a control group customer. The team's matching criteria identified the control group customer whose energy consumption pattern over the most recent 12 pre-participation months was most like that of the treatment customer. A summary of the results for both natural gas and electric customers is provided below.

The team applied this matching methodology in the context of a variation in adoption (VIA) modelling approach used by Harding and Hsiaw,[11] creating a MCG based on future HES participants. The term “future” is relative to when customers in the treatment group participated in HES. The team selected the VIA approach for two primary reasons:

1. Future participants are more likely to accurately represent current participants than a random sample of residential customers. By self-selecting into HES, they are identifying themselves as similar in terms of initiative awareness and pre-HES building characteristics.
2. Using future customers as a control group ensures that the billing analysis results in gross, not net, savings. This is because future participants are unlikely to have installed an HES-rebated measure during the analysis period. This is a reasonable assumption since these customers have signed up for HES, which implies they have an interest in potentially installing those measures through the initiative at a later time.

For this memo, the evaluation team temporarily defined the treatment group as any customer that installed at least one HES-rebated measure between January 1, 2015 and March 31, 2015. The team defined future participants as customers that received a home energy assessment between June 2016 and December 2016. While the customers in the treatment and control groups received their assessments at different points in time, it’s important to note the billing analysis will assess changes in both groups energy consumption over the same time period.

As noted, the evaluation team will update these interim time periods and, therefore the customers included in the treatment and control groups, when the RDMT provides additional billing data (full calendar year 2016). Table B-1 summarizes the interim time periods used for the purpose of this memo, and the final time periods the evaluation team anticipates using for the both customer groups as part of the final analysis once RDMT provides the additional data.

As evident in the table, the additional billing data will allow the evaluation team to expand the treatment group from three months of participants (Jan 2015–Mar 2015) to ten months of participants (Jan 2015–October 2015). The additional data and corresponding expansion of the treatment group participation period will effectively triple the number of customers included in the treatment group and greatly increase the robustness of the billing analysis.

Table B-1. Customers Included in Billing Analysis – Treatment and Control Group

Timeframe	Billing Analysis Period	Date of Measure Installation	Date of Home Energy Assessment
		Treatment Group (HES Participants)	Matched Control Group (Future HES Participants)
Interim	Jan 2014–Apr 2016	Jan 2015–Mar 2015	Jun 2016–Dec 2016
Final	Jan 2014–Dec 2016	Jan 2015–Oct 2015	Jun 2016–Dec 2016

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[11] Matthew Harding and Alice Hsiaw, “Goal Setting and Energy Conservation,” Journal of Economic Behavior & Organization 107 (2014): 209-227.

B.2 Results

This section describes the team's matched control findings, first for the natural gas billing analysis, followed by electric. For the final evaluation report, the team will use the same process described below on a more robust set of billing data to update this memo's findings.

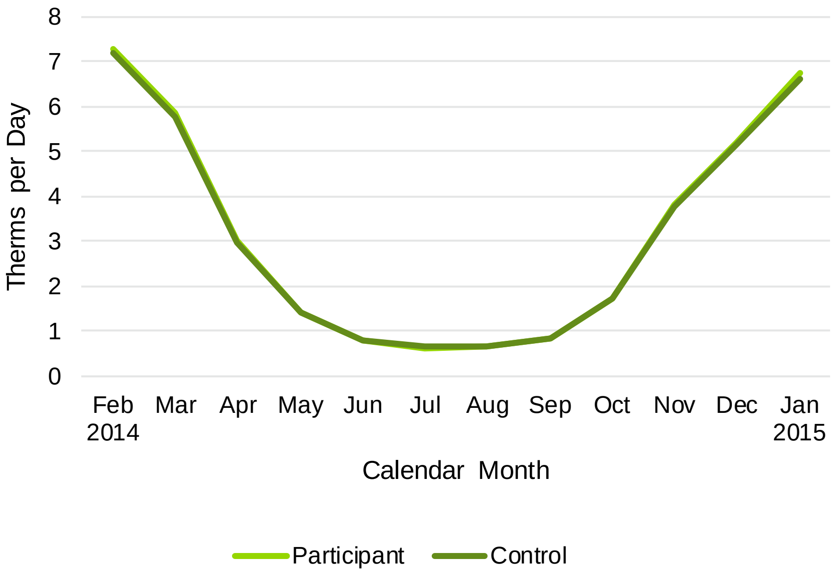
B.2.1 Natural Gas

The evaluation team used available billing and initiative data to identify 1,092 customers with natural gas-heated homes and 12 months of billing data before and after the installation of an HES-rebated measure. The team anticipates the number of customers eligible for inclusion in the billing analysis will rise considerably once the RDMT provides the remaining 2016 billing data.

B.2.2 Comparison of Treatment vs. Control Groups Before HES-Rebated Measures were Installed

Figure B-1 shows the average daily natural gas consumption for both participating customers and the matched control customers during the pre-installation period. As evident in the figure, the two lines are barely distinguishable.

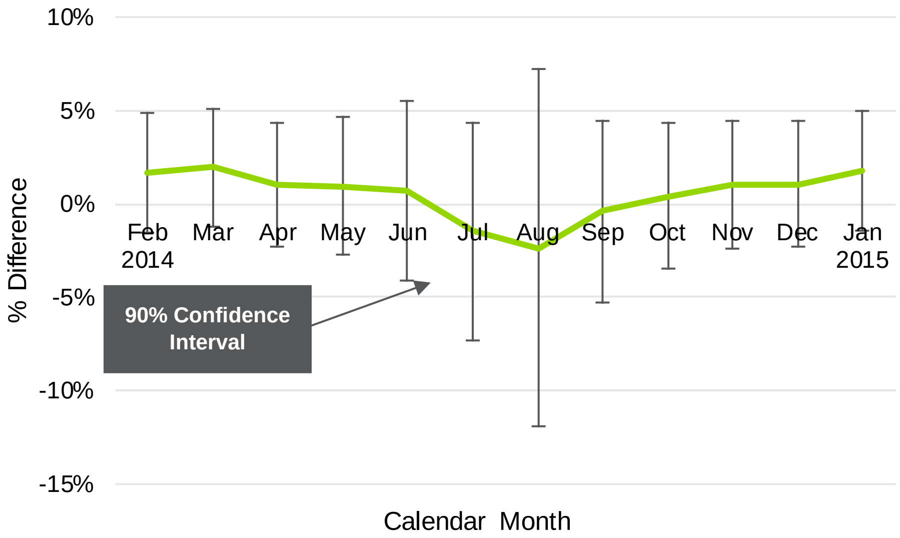
Figure B-1. Comparison of Pre-Installation Period Natural Gas Energy Consumption:



Source: Cadeo Analysis

Figure B-2 shows the relative difference in average daily natural gas consumption for each treatment/control pair. These differences are not statistically significant at the 90% confidence level. This means that before HES-rebated measures are installed, the treatment and control groups are very similar in terms of natural gas consumption. The wide confidence intervals in the summer months (July-October) are a function of the lower natural gas consumption during those months rather than problems with the billing data.

Figure B-2. Mean Paired Difference during Pre-Installation Period (Natural Gas Treatment Compared to Control, in %)

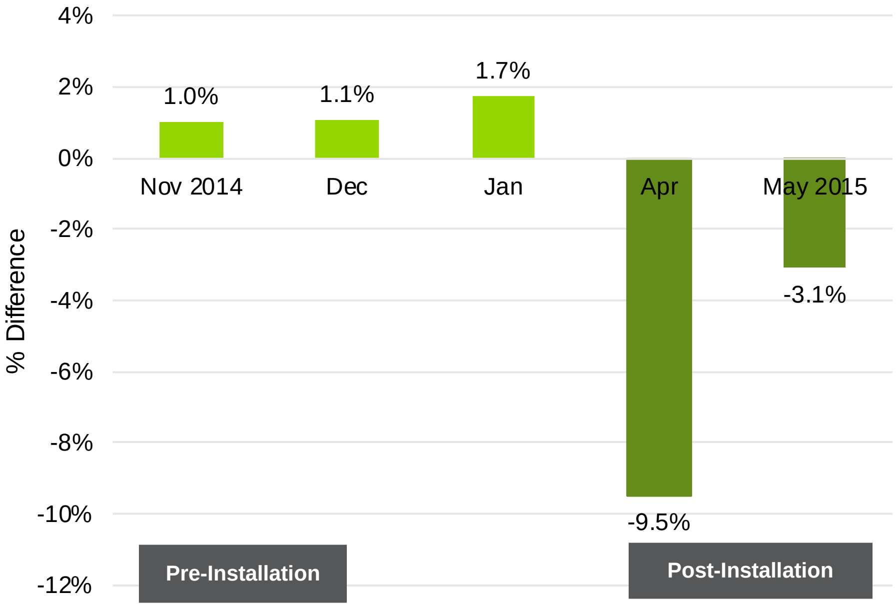


Source: Cadeo Analysis

B.2.3 Comparison of Treatment vs. Control Groups After HES-Rebated Measures were Installed

Figure B-3 shows the relative difference in average daily natural gas consumption for each treatment/control pair after measure installation begins to diverge from the pre-installation trend. However, it is important to note that these are not results of the billing analysis. The team has not weather normalized the billing data or controlled for measures installed through other non-HES residential initiatives. Further, the information below is based on a small number of months that do not include the heating season.

Figure B-3. Pre- and Post-Period Paired Difference (Natural Gas Treatment Compared to Control, in %)



Note: February and March 2016 are omitted because they are during the measure installation period

Source: Cadeo Analysis

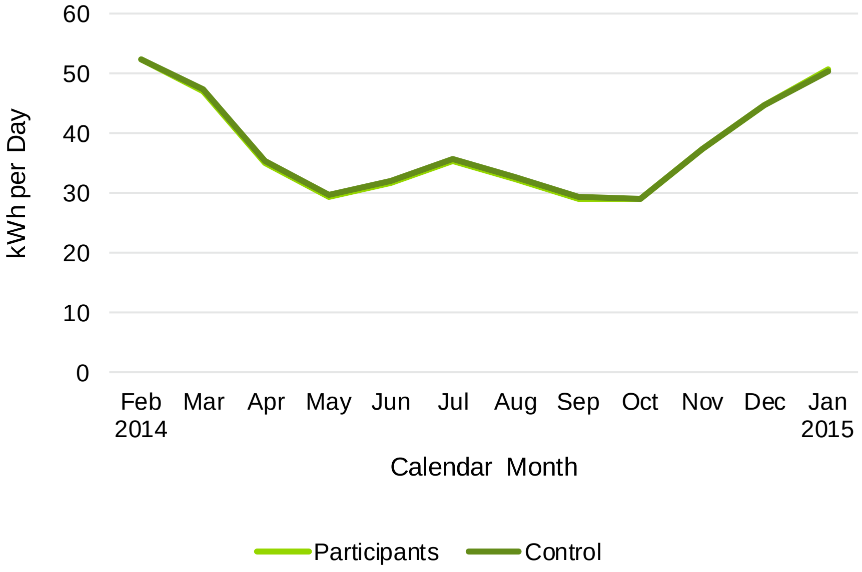
B.3 Electric

The evaluation team used available billing and initiative data to identify 420 customers with electric-heated homes and 12 months of billing data before and after the installation of an HES-rebated measure. As with natural gas, the team anticipates considerably more customers will qualify for inclusion in the billing analysis once the evaluation team has a complete set of 2016 billing data.

B.3.1 Comparison of Treatment vs. Control Groups Before HES-Rebated Measures were Installed

Figure B-4 shows the average daily electric consumption for those participating customers and the matched control customers during the pre-installation period.

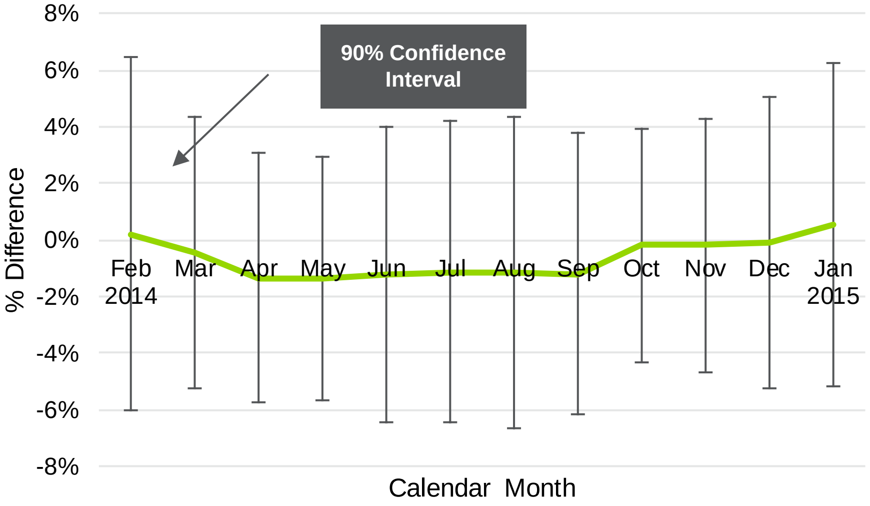
Figure B-4. Comparison of Pre-Installation Period Electric Energy Consumption: Treatment and Control Group



Source: Cadeo Analysis

Figure B-5 shows the relative difference in average daily electric consumption for each treatment/control pair. These differences are not statistically significant at the 90% confidence level. This means, similar to the natural gas comparison above in Figure B-1, that before these HES-rebated measures were installed, the electric treatment and control groups exhibited very similar electricity consumption. The evaluation team expects that the width of the confidence intervals shown in Figure B-5 will decrease with additional sample size afforded by a full set of 2016 billing data.

Figure B-5. Mean Paired Difference during Pre-Installation Period (Electric Treatment Compared to Control, in %)

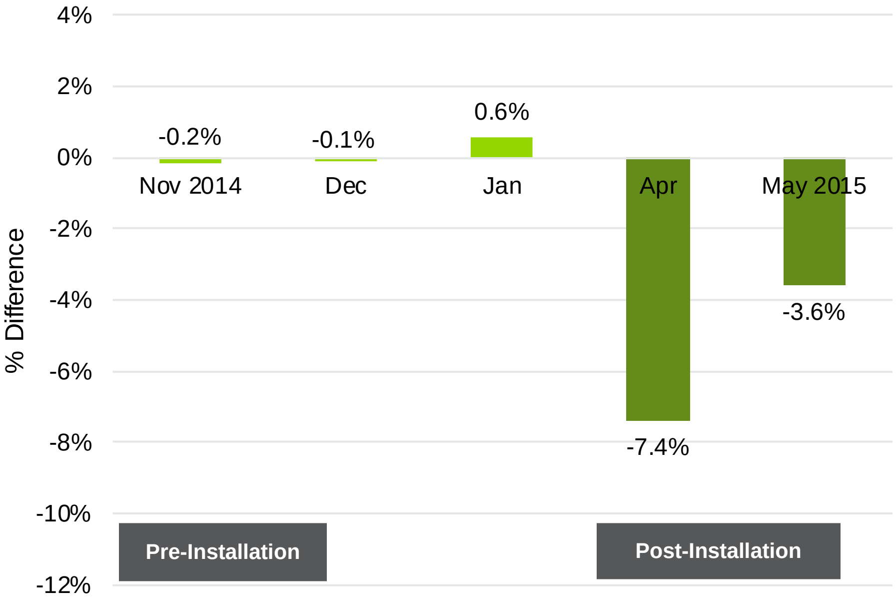


Source: Cadeo Analysis

B.3.2 Comparison of Treatment vs. Control Groups After HES-Rebated Measures were Installed

Figure B-6 shows the relative difference in average daily natural gas consumption for each treatment/control pair after measure installation begins to diverge from the pre-installation trend. Again, it is important to note that these are not results of the billing analysis. Like with the natural gas consumption data shown above, the team has not weather normalized the billing data or controlled for measures installed through other non-HES residential initiatives. Further, Figure B-6 is based on a small number of months that do not include the heating season.

Figure B-6. Pre- and Post-Period Paired Difference (Electric Treatment Compared to Control, in %)



Note: February and March 2016 are omitted because they are during the measure installation period

Source: Cadeo Analysis