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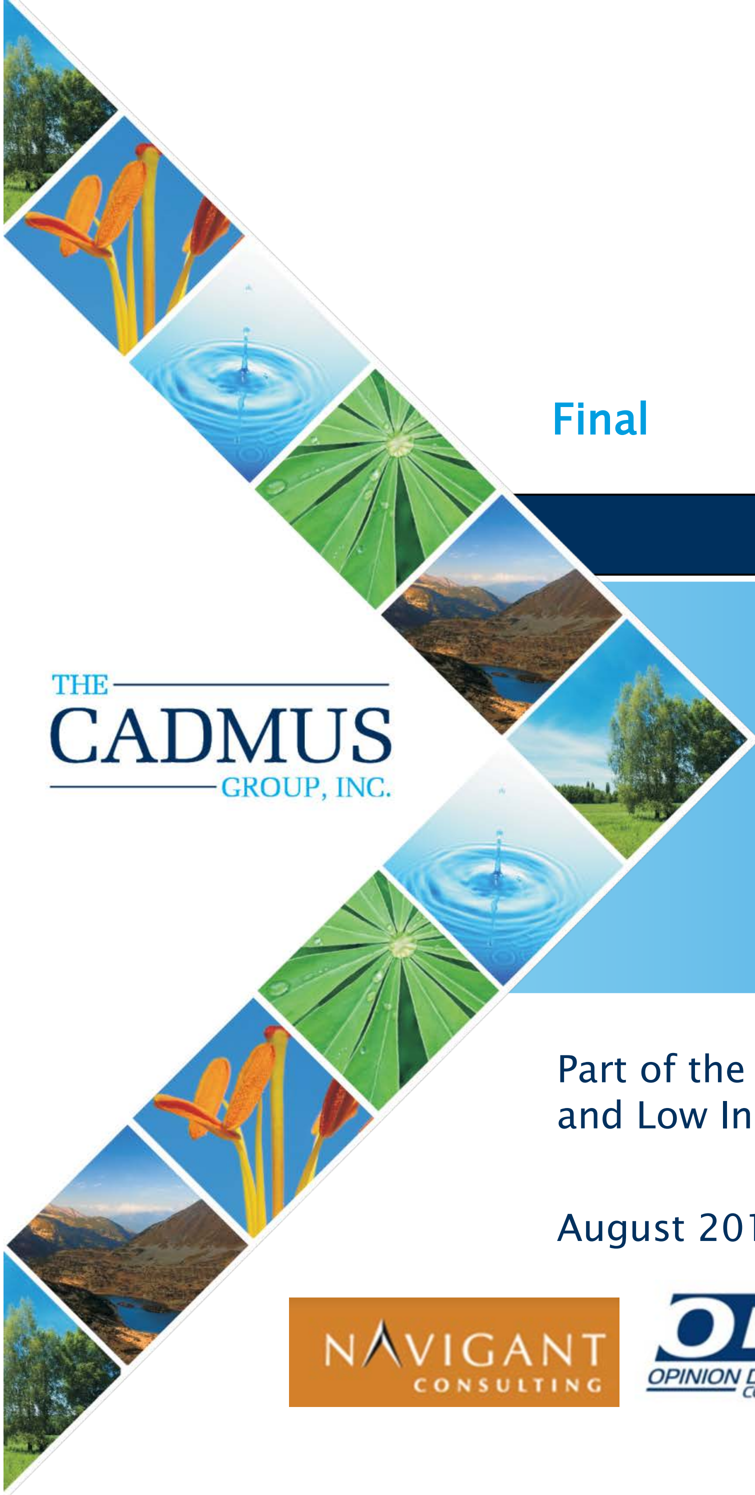

Home Energy Services Impact Evaluation

Part of the Massachusetts Residential Retrofit and Low Income Program Area Evaluation

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Prepared by:

The Cadmus Group, Inc. / Energy Services
720 SW Washington Street, Suite 400
Portland, OR 97205
503.228.2992

Prepared for:

The Electric and Gas
Program Administrators
of Massachusetts

Prepared by:
Bryan Ward
Doug Bruchs
Anna Carvill
Matei Perussi
Noah Lieb
The Cadmus Group, Inc.

and

Ken Seiden
Marca Hagenstad
David Basak
Laura Tabor
Navigant Consulting

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ACRONYM GLOSSARY

Acronym	Full Name
BTU	British thermal units
CAA	Community Action Agencies
CDD	Cooling degree day
CFL	Compact fluorescent lights
CSA	Conditional savings analysis
DHW	Domestic hot water
EISA	Energy Independence and Security Act
HDD	Heating degree day
HEHE	High Efficiency Heating and Water Heating
HES	Home Energy Services
HOU	Hours-of-use
HVAC	Heating, ventilating, and air conditioning
ISM	??
kWh	Kilowatt hour
PA	Program Administrator
pre-NAC	Pre-retrofit normalized annual consumption
PRISM	Princeton Scorekeeping Method
RCS	Residential Conservation Services
SAE	Statistically Adjusted Engineering
TRM	Technical Reference Manual
TYM3	Typical meteorological year
WMECO	Western Massachusetts Electric Company

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EXECUTIVE SUMMARY

This report summarizes the gross impact evaluation findings of the 2010 Home Energy Services (HES) Program conducted by The Cadmus Group, Inc., and Navigant Consulting (collectively referred to as the Evaluation Team). The Evaluation Team performed an array of evaluation tasks to inform the reported estimates of per-unit gross savings for each HES measure, including billing analysis, engineering analyses, and calibrated simulation modeling.

Methodology

The Evaluation Team assessed the gross per-unit savings generated by each HES measure using two approaches: a billing analysis and an engineering analysis. A brief description of each is provided below:

- ***Billing Analysis.*** The Evaluation Team specified a fixed-effects conditional savings regression model with paired pre- and post-participation months to estimate measure-level savings for measures installed by Program Administrators (PAs) that provide electricity and/or natural gas. We leveraged these weather-normalized models with detailed measure data and home characteristics provided by each PA's HES implementer. For the billing analysis, The Team also utilized a control group composed of 2011 HES participants to account for macroeconomic factors that might have impacted energy consumption between the pre- and post-periods.
- ***Engineering Analysis.*** The Team utilized two engineering analysis approaches to estimate measure-specific savings for all three fuel types (electric, natural gas, and heating oil). Both engineering approaches were informed by the same detailed measure data and home characteristics we utilized in the billing analysis.
    - For program measures known to generate interactive effects (i.e., those that increase or decrease the energy consumption of another end use), we estimated savings using a DOE-2-based simulation model, which we calibrated using the average pre-program energy consumption of HES participants.
    - For measures not typically subject to interactive effects, we estimated savings using standard industry engineering algorithms.

A billing analysis captures actual changes in energy consumption within participating homes from energy-efficiency and behavioral improvements. Hence, we report the measure- and fuel-specific results of the billing analysis whenever they meet the acceptable threshold of precision (20% or less at the 90% confidence level). The Team derived the savings for all other measures using the engineering analysis. Table 1 details which approach we used for each HES measure, by fuel type. The precision associated with each billing analysis-based savings estimate is also provided.

Table 1. Methodological Approach to Calculating Savings by Measure and Primary Fuel Type

Category	Measure	Natural Gas (therms/year)	Electric (kWh/year)	Oil (MMBtus/year)
Insulation & Air Sealing	Insulation (overall)*	Billing Analysis (±9%)	Simulation Modeling	Simulation Modeling
	- Attic Insulation	Billing Analysis (±19%)	Simulation Modeling	Simulation Modeling
	- Wall Insulation	Billing Analysis (±16%)	Simulation Modeling	Simulation Modeling
	- Basement Insulation	Simulation Modeling	Simulation Modeling	Simulation Modeling
	Air Sealing	Billing Analysis (±18%)	Simulation Modeling	Simulation Modeling
	Furnace Fan (due to insulation)	Simulation Modeling	--	Simulation Modeling
	Cooling Savings (due to insulation)	Simulation Modeling	--	Simulation Modeling
Heating System	Oil Furnace Replacement	--	--	Engineering Algorithm
	Furnace Fan (due to oil furnace replacement)	--	--	Engineering Algorithm
	Oil Boiler Replacement	--	--	Engineering Algorithm
	Boiler Reset Controls	Engineering Algorithm	--	Engineering Algorithm
	Boiler Pipe Wrap	Engineering Algorithm	--	Engineering Algorithm
	Programmable Thermostat	Engineering Algorithm	Engineering Algorithm	Engineering Algorithm
Lighting & Appliances	Refrigerator Replacement	--	Billing Analysis (±12%)	--
	CFLs	--	Billing Analysis (±4%)	--
Domestic Hot Water	Showerhead	Engineering Algorithm	Engineering Algorithm	Engineering Algorithm
	Faucet Aerator	Engineering Algorithm	Engineering Algorithm	Engineering Algorithm
	Pipe Wrap	Engineering Algorithm	Engineering Algorithm	Engineering Algorithm
	Indirect Water Heater	Engineering Algorithm	--	Engineering Algorithm
Distribution	Duct Insulation	Engineering Algorithm	Engineering Algorithm	Engineering Algorithm
	Duct Sealing	Engineering Algorithm	Engineering Algorithm	Engineering Algorithm

* This row refers to any participant that received attic, and/or wall, and/or basement insulation.

The overall methodology The Team used to evaluate HES was substantively identical to the one used for the 2010 Low Income Single Family Program impact evaluation.

Results

The statewide per-unit gross *ex post* energy savings by measure and primary fuel type determined through this evaluation are summarized in Table 2.

Table 2. Annual *Ex Post* Gross Savings by Measure and Primary Fuel Type

Category	Measure	Natural Gas (therms/year)	Electric (kWh/year)	Oil (MMBtus/year)
Insulation & Air Sealing	Insulation (overall)*	96	903	12.2
	- Attic Insulation	77	793	9.2
	- Wall Insulation	99	972	11.8
	- Basement Insulation	14	99	1.4
	Air Sealing	53	710	5.6
	Furnace Fan (due to insulation)	142 (kWh)	--	152 (kWh)
	Cooling Savings (due to insulation)	67 (kWh)	--	72 (kWh)
Heating System	Oil System Replacement**	--	--	6.5
	Oil Furnace Replacement	--	--	8.4
	Furnace Fan (due to oil furnace replacement)	--	--	98 (kWh)
	Oil Boiler Replacement	--	--	6.0
	Boiler Reset Controls	45	--	4.7
	Boiler Pipe Wrap	13	--	1.4
	Programmable Thermostat	32	330	3.4
Lighting & Appliances	Refrigerator Replacement	--	714	--
	CFLs	--	37	--
Domestic Hot Water	Overall***	11.7	283	1.6
	- Showerhead	11.7	237	1.3
	- Faucet Aerator	2.4	49	0.3
	- Pipe Wrap	2.3	64	0.4
	Indirect Water Heater	40	--	6.4
Distribution	Duct Insulation	68	1,613	7.7
	Duct Sealing	36	428	4.1

* This row refers to any participant that received attic, and/or wall, and/or basement insulation.

** Oil system replacement is the weighted average of oil and furnace savings, based on the number of installation observed in 2010 and Q1-Q3 2011.

*** These are the average savings for a household that received at least one DHW measure (does not include indirect water heaters)

INTRODUCTION

Program Overview

The HES Program has been in place since the early 1980s, targeting non-low-income residential customers living in single family houses or multifamily buildings with one to four units.[1] The program offers home energy audits to participating customers, regardless of their heating fuel type. Through these audits, technicians identify opportunities for the customers to save energy through a variety of home improvements, including:

- Building envelope measures, such as insulation and air sealing
- Heating system replacements, such as furnace and boilers
- Heating distribution systems, such as duct and pipe insulation
- Thermostats
- Boiler reset controls
- Lighting
- Refrigerator removal and replacement
- Water heating measures, such as low-flow showerheads and faucet aerators
- Water heating system replacements, such as on-demand and indirect water heaters

The PAs' primary goal for the program is to achieve significant energy savings by promoting a whole-house approach, and by offering education, incentives, and financing options for gas and electric measures. All cost-effective, energy-saving improvements are targeted.

By calling the program hotline or a PA's customer service line, customers are screened for qualification and then directed to the correct program and services (outlined below). Technicians provide these services over several visits.

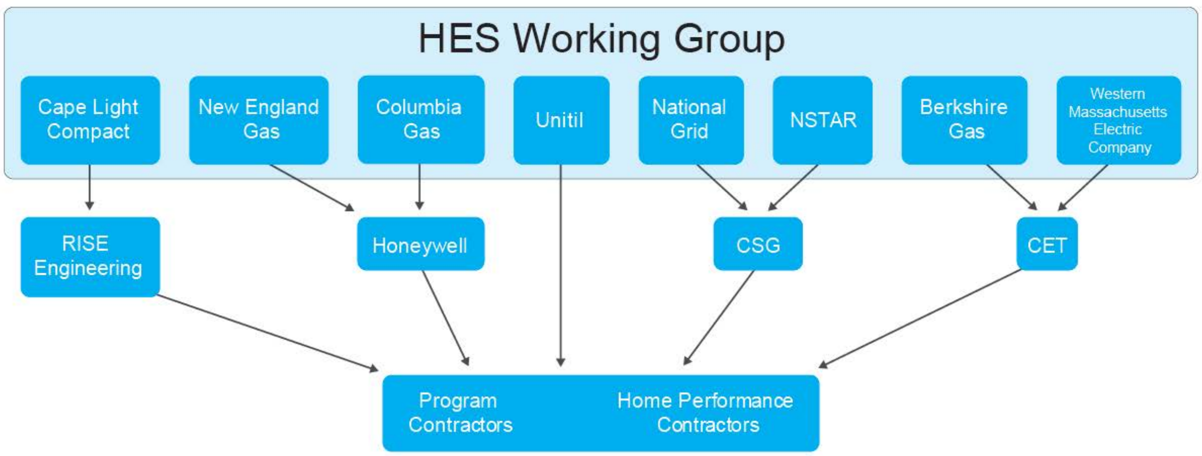
1. ***Screening and Diagnostic Visit.*** During the initial high-level audit, the technician installs various free measures—compact fluorescence lights (CFLs), low-flow showerheads, faucet aerators—and either conducts the diagnostic tests or encourages the customer to schedule a diagnostic visit. During the diagnostic visit, the technician conducts area blower door test, infrared scanning, duct testing, and, when feasible, installs—at no cost to the customer—air sealing, duct sealing, and programmable thermostats. Also during this visit, the technician: (1) recommends specific energy-efficient upgrades that require a professional program contractor and a co-pay from the customer; and (2) provides information regarding available, energy-efficiency financial incentives offered through the relevant PA.
2. ***Installation Visit.*** If the customer decides to have additional energy-efficient measures and upgrades installed, program contractors conduct the specified work in one or several visits, depending on the customer's needs.

[1] Prior to 2010, the HES Program was commonly referred to as the MassSave® Program, which is the name it is known as by the majority of PAs, vendors, contractors, and participants. In 2010, MassSave was transitioned into the overarching brand used for Massachusetts' efficiency programs umbrella marketing efforts.

3. ***Quality Assurance Visit.*** The quality assurance component of this process is currently conducted via one site visit and, in some cases, is followed up with a phone survey, postcard, or e-mail to ensure all measures were installed properly.

In recent years, the PAs have put significant effort into standardizing the HES Program across Massachusetts and implementing MassSave® such that customers can easily access all PA efficiency offers, thereby experiencing one program as opposed to multiple offerings. Figure 1 illustrates how several PAs interact within the program structure. As evident in the figure, the PAs collectively formed the Residential Conservation Services (RCS) Working Group, and collectively subcontract with four different MassSave vendors.

Figure 1. HES Program Structure



Report Organization

The remaining report sections are presented in the following order:

- ***Methodology***, which explains the impact evaluation tasks and how The Evaluation Team gathered and analyzed data for this project.
- ***Findings***, which detail the key results from the impact evaluation.
- ***Appendices,*** which contain detailed measure-specific methodologies for the engineering analysis, including engineering algorithms and simulation modeling methodology.

METHODOLOGY

The Evaluation Team assessed the gross per-unit savings generated by each HES measure using two approaches: a billing analysis and an engineering analysis. A brief description of each is provided below, while significant detail is provided in the body and appendices of this report:

- ***Billing Analysis.*** The Team specified a fixed-effects conditional savings regression model with paired pre- and post-participation months to estimate measure-level savings for measures installed by PAs that provide electricity and/or natural gas. We leveraged these weather-normalized models with detailed measure data and home characteristics provided by each PA's HES implementer. For the billing analysis, The Team also utilized a control group composed of 2011 HES participants to account for macroeconomic factors that might have impacted energy consumption between the pre- and post-periods.
- ***Engineering Analysis.*** The Team utilized two engineering analysis approaches to estimate measure-specific savings for all three fuel types (electric, natural gas, and heating oil). Both engineering approaches were informed by the same detailed measure data and home characteristics we utilized in the billing analysis
    - For program measures known to generate interactive effects (i.e., those that increase or decrease the energy consumption of another end use), we estimated savings using a DOE-2-based simulation model, which we calibrated using the average pre-program energy consumption of HES participants.
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A billing analysis captures actual changes in energy consumption within participating homes from energy-efficiency and behavioral improvements. Hence, we report the measure- and fuel-specific results of the billing analysis whenever they meet the acceptable threshold of precision (20% or less at the 90% confidence level). The Team derived the savings for all other measures using the engineering analysis. Table 3 specifies which approach we used for each HES measure, by fuel type. The precision associated with each billing analysis-based savings estimate is also provided.

Table 3. Methodological Approach to Calculating Savings by Measure and Primary Fuel Type

Category	Measure	Natural Gas (therms/year)	Electric (kWh/year)	Oil (MMBtus/year)
Insulation & Air Sealing	Insulation (overall)*	Billing Analysis (±9%)	Simulation Modeling	Simulation Modeling
	- Attic Insulation	Billing Analysis (±19%)	Simulation Modeling	Simulation Modeling
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Heating System	Oil Furnace Replacement	--	--	Engineering Algorithm
	Furnace Fan (due to oil furnace replacement)	--	--	Engineering Algorithm
	Oil Boiler Replacement	--	--	Engineering Algorithm
	Boiler Reset Controls	Engineering Algorithm	--	Engineering Algorithm
	Boiler Pipe Wrap	Engineering Algorithm	--	Engineering Algorithm
	Programmable Thermostat	Engineering Algorithm	Engineering Algorithm	Engineering Algorithm
Lighting & Appliances	Refrigerator Replacement	--	Billing Analysis (±12%)	--
	CFLs	--	Billing Analysis (±4%)	--
Domestic Hot Water	Showerhead	Engineering Algorithm	Engineering Algorithm	Engineering Algorithm
	Faucet Aerator	Engineering Algorithm	Engineering Algorithm	Engineering Algorithm
	Pipe Wrap	Engineering Algorithm	Engineering Algorithm	Engineering Algorithm
	Indirect Water Heater	Engineering Algorithm	--	Engineering Algorithm
Distribution	Duct Insulation	Engineering Algorithm	Engineering Algorithm	Engineering Algorithm
	Duct Sealing	Engineering Algorithm	Engineering Algorithm	Engineering Algorithm

* This row refers to any participant that received attic, and/or wall, and/or basement insulation.

Treatment Group

For the impact analysis (billing analysis, engineering algorithm, and simulation modeling), The Team utilized a treatment group composed of 2010 HES participants that installed measures between January 1, 2010, and September 31, 2010. Quarter 4 2010 participants were excluded from the analysis, as insufficient heating season post-program data were available for these participants at the time of analysis.

The billing analysis specifically required that participants included in the treatment group had not moved since participating, have at least 11 months of pre-period billing data—including a minimum of three winter months (to sufficiently capture the heating season)—and were not flagged as outliers. (Outliers exhibited annual kWh or therm consumption that was outside three standard deviations of the population mean).[2] The imposition of these additional filters reduced the size of the treatment group available for the billing analysis, as shown in Table 4.

Table 4. Treatment Group – Analysis Datasets

Analysis Approach	Electric	Natural Gas
Billing Analysis[3]	11,788	2,635

Control Group

To account for macroeconomic factors and other influences on pre- and post-program energy consumption that are unrelated to the installation of program measures (such as the number of household occupants changing), The Evaluation Team utilized a control group composed of HES participants that participated during the first three quarters of 2011.

The use of future participants as a control group yields multiple benefits. First, 2011 participants are a more representative control group than a random sample of residential customers, since they are likely to closely resemble participants from the prior year in terms of energy awareness and pre-program building characteristics. Second, using these customers ensures that the billing analysis results primarily identify gross savings, as this population was generally unlikely to install program rebated measures during the analysis time period. The only measure this logic does not apply to is CFLs, which participants may have installed independently prior to participating in HES. (Participants are, by definition, interested in energy-efficiency opportunities). Details regarding how the Evaluation Team addressed this issue for CFLs are provided in the Findings section.

The Evaluation Team only used the billing data from January 2009 through the earliest 2011 installation date in the billing analysis (i.e., only pre-program consumption). We conducted the same data screens for the control group as for the 2010 participants (i.e., the treatment group) included in the analysis.

The number of future control group participants The Team used in the billing analysis[4] for the electric and gas models is presented in Table 5.

Table 5. Control Group – Analysis Dataset

Analysis Approach	Electric	Natural Gas
Billing Analysis	9,952	2,616

2 The engineering analysis did not rely on billing data, and therefore did not impose similar requirements.

3 The engineering analysis did not exclude Q4 2010 participants or those removed due to insufficient billing data.

4 The engineering analysis and simulation modeling did not require a control group.

Analysis Period

For the billing analysis, The Evaluation Team focused on changes in participants' energy consumption between January 2009 and August 2011. We demarcated this time period into pre- and post-periods based on the date of each participant's audit and the date the last measure was installed. Specifically, we designated any billing data months occurring before the participant's first audit as the pre-period. Conversely, we designated any billing data months occurring after the latest measure installation date as the post-period. This approach ensured that we excluded billing records from the analysis that occurred while measures were in the process of being installed.

For participants with less than 12 months of pre- or post-period billing data, we paired the pre- and post- months. For example, if a customer participated in September 2010 and the available post-billing data was from October 2010 through August 2011, then we only used the corresponding pre-period months from October through August. This ensured that we used the same months in both the pre- and post-periods.

To ensure that there was only one month of pre- and post-period paired data for any given month during the analysis period, we systematically searched for and removed duplicate records. For example, if the pre-period included both February 2010 and February 2009 billing data, we only used the February 2010 billing data. We selected the months closest to the install dates, as they best represent the participant's pre-conditions at the time of participation. This ensured that there was no bias introduced from uneven month distributions between the pre- and post-periods and that each paired month is represented only once in the pre- and post-periods.

Weighting

Unlike the concurrent Low Income Single Family Program impact evaluation, which relied on data for sample of participants collected on-site at participating Community Action Agencies (CAAs), it was not necessary to apply weights to the results of the HES billing and engineering analysis. This is because The Evaluation Team was able to leverage detailed tracking data for the entire population of 2010 HES participants. These data were provided by each HES implementer for the PAs they serve. More detail about the detailed tracking data is provided in subsequent Data Sources section.

Data Sources

To inform the impact evaluation, we utilized data from the following sources:

- HES Tracking Data
- COOL SMART and High Efficiency Heating and Water Heating (HEHE) Programs Tracking Data
- Opower Data
- Billing Data from PAs
- Weather Data

- Massachusetts Technical Reference Manual (TRM)
- Other TRMs

HES Tracking Data

The majority of our analysis was grounded in robust, detailed tracking data provided by each PAs' lead HES implementation contractor. The data contained records of each HES audit provided and each measure installed from January 2010 through June 2011 (or through October 2011 for some PAs). We combined the data from each implementer to the PA tracking data through account numbers, audit IDs, or other available information.

Table 6 shows the number of home audits conducted by each implementer providing data.

Table 6. Implementer Data Tracking Summary

PA	Implementer	Audit Records
National Grid	CSG	29,404
NSTAR	CSG	24,051
Berkshire	CET	1,024
CLC	RISE	6,927
Columbia	Honeywell	5,495
NE Gas	Honeywell	309
Unitil	Self Implemented	N/A
WMECO	Honeywell	560

Not all implementers provided the same level of detail, but all provided more detailed information than that contained in the PA's program databases, thereby increasing the Evaluation Team's ability to accurately estimate the program's impacts and avoiding the need for site visits. The tracking data also included valuable information about the existing or pre-program conditions of participating homes and information about the homes (square footage, heating fuel, etc.) and occupants (household size, demographics, etc.). The Team leveraged this data for the engineering analysis.

Other examples of details commonly included in the implementer data were:

- Hot water fuel type
- Pre- and post-efficiency ratings for heating and water heating equipment
- Existing, proposed, and installed measure quantities
- Whether or not a new heating system was recommended through HEHE
- Whether or not central air conditioning was present

COOL SMART and HEHE Tracking Data

The Evaluation Team merged the detailed HES tracking data with tracking data provided for the COOL SMART and HEHE programs. This allowed us to identify HES participants who had central air conditioning or space/water heating improvements recommended during their HES audit (for the COOL SMART and HEHE programs, respectively), but installed the measures through another program.

Understanding whether these energy-efficiency improvements happened outside of HES was critical to accurately estimating savings for HES. Without merging COOL SMART and HEHE data, it is likely that changes in energy consumption resulting from participation in those programs would have been misattributed to HES.

Table 7 shows the data provided for each program by PA. As HEHE is a gas-only program administered by Gas Networks, only gas and dual-fuel utilities provided program data. Likewise, COOL SMART is an electric-only program, so only electric utilities provided participant data.

Table 7. HEHE and COOL SMART Data Provided by PA

PA	HEHE	Cool Smart
National Grid	Yes	Yes
NSTAR	Yes	Yes
Berkshire	Yes	--
Cape Light Compact (CLC)	--	Yes
Columbia	Yes	--
New England Gas	Yes	--
Unitil	Yes	Yes
Western Massachusetts Electric Company (WMECO)	--	Yes

Opower Data

Opower is a separate program offered by National Grid and NSTAR during the analysis period. Opower focuses on reducing energy consumption through education by increasing customers' awareness of their own energy usage relative to their neighbors. In total, National Grid and NSTAR had 444,258 and 94,490 customers participate in Opower, respectively. A subset of these customers also participated in HES in 2010 (treatment group) or 2011 (control group).

Because Opower prompts behavior changes, participation in this program could be partially responsible for changes in the energy consumption observed in homes that also participated in HES. To control for the potential influence of Opower and ensure that any energy savings associated with that program were not misattributed to HES, all customers that participated in both programs were flagged. This was accomplished by matching the customer account numbers between the two programs' participation tracking databases.

Then, rather than excluding Opower participants from the HES analysis (which would have decreased National Grid and NSTAR's treatment and control groups by nearly 20% each), The Evaluation Team utilized the Opower participation flag as a dummy variable when specifying both the natural gas and electric billing analysis models. This controlled for the impact of the customer's behavior in Opower and ensured that changes in energy consumption determined for HES were not biased by Opower participation.

Billing Data

For the billing analysis, we utilized participants' energy consumption records provided by each PA. Although some PAs provided data for 2008, we only included data from 2009 through the latest available month in the billing analysis, as was described in the Analysis Period section.

Table 8. Dates of Billing Data Analyzed, by PA

PA	Electric	Natural Gas
National Grid	September 2008 – August 2011	September 2008 – August 2011
NSTAR	July 2008 – September 2011	July 2008 – September 2011
Berkshire	--	December 2008 – August 2011
CLC	March 2009 – June 2011	--
Columbia	--	January 2008 – December 2011
New England Gas	--	--
Unitil	August 2008 – September 2011	August 2008 – September 2011
WMECO	December 2008 – August 2011	--

Weather Data

The Evaluation Team collected weather data from the National Climatic Data Center for 32 stations across the State to account for weather impacts in our billing analysis. For each station, we calculated the base 65 heating degree days (HDDs) and cooling degree days (CDDs). We matched each billing data period for the associated HDDs and CDDs based on the nearest weather station using participants' ZIP codes.

Massachusetts TRM

When implementer tracking data were not available to inform engineering analysis assumptions, The Evaluation Team first turned to the Massachusetts TRM as a secondary source for input assumptions.[5] The Evaluation Team valued the TRM as a source of Massachusetts-specific information, but also recognized that some data in the TRM were not appropriate. For example, many savings estimates in the TRM came from past billing analyses, so it is difficult to extract the underlying assumptions. In cases where the TRM did not provide adequate information, we used other resources.

Other TRMs and Secondary Sources

In cases where the Massachusetts TRM and implementer tracking data did not provide adequate inputs, The Evaluation Team used the following other TRMs and published studies (more details on the sources for each measure and the full source citations are outlined in Appendix B):

- 2010 Vermont TRM
- 2010 Ohio TRM
- 2012 Pennsylvania TRM
- Federal efficiency standards

[5] 2011 Massachusetts Electric and Gas Energy Efficiency Program Administrators. *Massachusetts Technical Reference Manual for Estimating Savings from Energy Efficiency Measures: 2012 Program Year—Plan Version.* October 2011.

Engineering Analysis

The Evaluation Team utilized two approaches for the engineering analysis: simulation modeling and standard engineering algorithms. Both approaches were primarily informed by the same detailed implementer tracking data we utilized for the billing analysis. We assessed all HES measures—including those for which the billing analysis results were ultimately used to report evaluated savings—as part of the engineering analysis. Table 9 shows the approach we used for each major measure category.

Table 9. Summary of Engineering Methodology by Measure Category

Measure Category	Engineering Approach
Insulation & Air Sealing	Simulation
Heating System	Algorithm
Lighting & Appliances	Algorithm
Domestic Hot Water	Algorithm
Distribution	Algorithm

Simulation Modeling

For program measures known to generate interactive effects, such as insulation and air sealing, we estimated savings using a DOE-2-based simulation model calibrated to the average pre-program energy consumption for 2010 HES participants. This approach is more accurate than standard engineering algorithms at capturing the interactive effects and savings attributed to the improved efficiencies for those measures that tend to increase or decrease the energy consumption of another end use.

The following bullets detail the advantages of simulation modeling over a simple engineering algorithmic approach:

- Simulation modeling accounts for internal gains, thermostat set-point variations due to occupant behavior, and solar gains within the modeled structure.
- Simulation modeling accounts for the thermal mass of a building assembly, instead of exclusively examining the heat transfer through the assembly.

To perform the simulation modeling on the select program measures that are subject to interactive effects, we created individual simulation models for each participant category (gas, oil, and electric). To accomplish this, we leveraged the detailed implementer tracking data to accurately inform the creation of HES-specific building characteristics. Next, we calibrated each model to the various end-use consumption values (heating, cooling, domestic hot water (DHW), lighting, and plug loads/appliances) to match the pre-retrofit normalized annual consumption (pre-NAC) as determined through billing analysis.

Appendix A offers a detailed explanation of our DOE-2-based simulation modeling approach and calibration techniques.

Engineering Algorithms

For measures that are not typically subject to interactive effects, we estimated savings using standard industry engineering algorithms. To accomplish this, The Evaluation Team relied on several TRMs and technical studies, as well as on engineering methods used in past evaluations.

For most measures, we estimated baseline and energy-efficient scenarios with engineering algorithms to calculate savings. For some measures, the many factors that influence savings could not be captured by straightforward algorithms. In these cases, The Evaluation Team estimated savings as a percentage of the calculated baseline consumption. We set baseline consumptions equal to the average heating portion of the pre-NAC as determined through billing analysis and simulations. The Evaluation Team used implementer tracking data for as many inputs as possible. As the data permitted, we averaged each input within the pool of participants that installed each measure.

Appendix B offers for a complete description of the algorithms and assumptions we used for each measure.

Billing Analysis

The Evaluation Team evaluated several different specification options to model savings before selecting the fixed-effects, conditional savings analysis (CSA), paired-months modeling approach detailed in this section. Other specification options we considered, but were not as explanatory or reliable, included a Statistical Adjusted Engineering (SAE) model and account-level Princeton Scorekeeping Method (PRISM) model. Neither of these model types was as statistically significant as the CSA approach. Furthermore, the CSA model has an added advantage for gas measures: when the savings are interacted with HDDs, it is straightforward to obtain the normal year savings estimates.

Appendix C provides the models specified for both the natural gas and electric analysis, as well as an explanation of all independent variables utilized.

Billing Data Screening

To ensure only the highest quality data were included in the analysis, we excluded customers based on the following:

- Inability to merge the audit data with the billing data
- Insufficient billing data
- Extreme values and vacancies in the billing data (outliers)

To inform the natural gas billing analysis, the Evaluation Team began with a sample of 4,128 participants who had program measures installed in Q1-Q3 2010. We screened out a total of 1,493 sites based on the criteria noted above and detailed in Table 10. Attrition was due to the inability to merge the vendor-provided audit data with the billing data provided by the PAs, failed PRISM screens, and insufficient pre- and post-billing data. Collectively, these screening criteria led to a final analysis dataset of 2,635 gas participants (36% attrition). We also screened out any control group customer having less than one year of billing data from the analysis.

Table 10. Gas Billing Data Screening Criteria

Screening Criteria	Number of Sites Removed
Inability to merge audit data to billing data	675
Insufficient pre and post billing data or had less than three winter months of billing data	231
Failed PRISM screening by having negative slopes in either the pre or post period[6]	440
Vacancies, and audit savings were more than 70% of pre-period usages	122
Percent Change was beyond 3 standard deviations from the average percent change. In effect, accounts increasing usage by more than 50%, or decreasing usage by more than 60% of pre-period usage, were dropped	25
Total Billing Accounts Screened	1,493

To inform the electric billing analysis, the Evaluation Team began with a sample of 18,169 participants who had program measures installed in Q1-Q3 2010. In total, 6,381 participants (35%) were removed from the analysis, based on the criteria shown in Table 11. As with the natural gas billing analysis, we screened out any control group customer having less than one year of billing data.

Table 11. Electric Billing Data Screening Criteria

Screening Criteria	Number of Sites Removed
Inability to merge audit data to billing data	2,330
Accounts with less than 6 months of pre or post period data	1,813
Vacancies, and audit savings were more than 70% of pre-period usages	483
Remove weatherization participants, non-baseload measure participants[7]	510
Remove CoolSmart participants[8]	389
Percent Change was beyond 2 standard deviations from the average percent change. In effect, accounts increasing usage by more than 50%, or decreasing usage by more than 50% of pre-period usage, were dropped	856
Total Billing Accounts Screened	6,381

6 As part of the model selection, PRISM models were estimated for each account in both the pre and post periods. Accounts that had negative heating slopes were indicative of problems with the billing data, since a clear heating signature is expected for gas-heated homes.

7 These participants were removed because their number was too small and the space heating savings could not be reliably estimated through the model. Their inclusion also skewed the lighting and refrigerator base load estimates.

8 Since the predominant measures installed through the electric program are baseload measures, CoolSmart participants were dropped because they confounded the small percentage of changes in consumption,

FINDINGS

This section presents evaluated gross savings estimates for all HES measures, covering electric, natural gas, and oil fuel types. The results are grouped by measure type and primary heating fuel type, although some measures have savings for more than one fuel type. (These cases are noted in the tables. where applicable.)

Energy Savings: Natural Gas

Insulation and Air Sealing

As shown in Table 12, the most common gas weatherization measure was air sealing: 46% of natural gas participants included in the billing analysis installed this measure. Fewer participants (29%) installed at least one type of insulation (attic/wall/basement). Of these 763 insulation customers, attic insulation was the most common (71%), followed by wall insulation (41%) and basement insulation (25%). On average, insulation participants had 1.4 different insulation types installed per home.

Table 12. Distribution of Natural Gas Insulation & Air Sealing Measures Billing Analysis (Total Sample, n=2,635)

Measure	n	Percent Installed
Insulation (overall)*	763	29%
-Attic Insulation	545	71%***
-Wall Insulation	310	41%***
-Basement Insulation**	187	25%***
Air Sealing	1,222	46%

* Any participant that installed attic insulation, and/or wall insulation, and/or basement insulation.

** Includes insulation installed on basement ceilings and/or basement walls.

*** These percentages are based on the 29% of customers that installed at least one insulation measure.

The Evaluation Team calculated the average insulation levels (weighted by square footage installed) using detailed implementer tracking data (Table 13).

Table 13. Average R-Values and Installed Square Feet for Natural Gas Customers

Measure	n	Pre-R-Value	Post-R-Value	Square Feet Installed per Customer
Attic Insulation	545	9.4	36.9	955
Wall Insulation	310	3.7	14.0	1,092
Basement Insulation*	187	6.6	23.6	251

* Includes insulation installed on basement ceilings and/or basement walls.

Table 14 summarizes the billing analysis results for insulation and air sealing. Specifically, The Evaluation Team used billing analysis to report savings for the following four measures, as each met the required precision requirement of less than ±20% of the estimated value: insulation overall (±9%), attic insulation (±19%), wall insulation (±16%), and air sealing (±18%). Estimated saving for basement insulation did meet the defined precision requirements for billing analysis.

With the average weather-normalized pre-period usage of 1,112 therms, the evaluated overall insulation savings of 96 therms represents 9% savings over the pre-installation usage. With the average heating pre-period usage of 862 therms, the gas insulation represents 11% savings over the heating pre-replacement usage.

Table 14. Billing Analysis Energy Savings Results for Natural Gas Insulation and Air Sealing

Measure	n	Energy Savings (therms/year)	Relative Precision at 90% Confidence Level	Average Household Pre-NAC	Average Household Percent Savings	Average Heating Pre-NAC	Average Heating Percent Savings
Insulation (overall)	763	96	9%	1,112	9%	862	11%
-Attic Insulation	545	77	19%	1,131	7%	870	9%
-Wall Insulation	310	99	16%	1,102	9%	875	11%
Air Sealing	1,222	53	18%	1,187	4%	923	6%

While precision requirements did not allow for billing analysis of basement insulation, the simulation modeling we employed as part of the engineering analysis produced savings estimates for this insulation type. We also used simulation modeling to estimate electric savings due to reduced furnace fan run times and reduced cooling loads due to the presence of program insulation.

Table 15 shows savings for all natural gas insulation and air sealing measures, including those estimated using the billing analysis and simulation modeling.

Table 15. Evaluated Natural Gas Energy Savings for Insulation and Air Sealing

Category	Measures	Evaluated Savings (therms/year)
Insulation and Air Sealing	Insulation (overall 1.4 average installations)	96*
	-Attic Insulation (71% installed)	77*
	-Wall Insulation (41% installed)	99*
	-Basement Insulation (25% installed)	14
	Air Sealing	53*
	Furnace Fan (due to insulation)	142 (kWh)
	Cooling Savings (due to insulation)	67 (kWh)

* These savings values were determined through the billing analysis. All other savings values were determined through simulation modeling.

Heating Systems

The Evaluation Team estimated savings for all three natural gas-related heating system measures (programmable thermostats, boiler reset controls, and boiler pipe wrap) using engineering algorithms. An overview of each is provided below, while more details are provided in Appendix B.

The Evaluation Team reviewed several programmable thermostat studies for both heating and cooling climates. Because these studies have conflicting results, we recommend using a conservative estimate of 3.6% to calculate savings. We again used the pre-NAC from the billing analysis (average of all participants) to calculate savings. The key inputs for boiler reset controls are listed in Table 16. The Evaluation Team reviewed the 2006 ACEEE report[9] on this measure. The report concludes that "*for conventional boilers, adequate add-on controls may cost from $150 (time-delay relay) to over $1,000 (reset with automatic post purge) and save up to 6-8% or more of fuel used.*"

Given that the type of controls is not specified and the TRM has no guidelines as to whether retrofitted boilers must be condensing or cold-start (where savings are maximized), The Evaluation Team recommends a more conservative estimate of 5% of heating load. We used the pre-NAC from the billing analysis (average of all participants) to calculate savings for this measure.

Table 16. Boiler Reset Control Assumptions

Measure	Percent Savings	MMBtu Savings	Source
Evaluation Estimate	5%	4.7	Conservative estimate based on literature review
Current PA Estimate	6-8%	7.9	Massachusetts TRM

The Evaluation Team used a percent savings approach to calculate energy savings for boiler pipe wrap. We again used the pre-NAC from the billing analysis (average of all participants) as the baseline for this measure. The key inputs for boiler pipe wrap are listed in Table 17.

Table 17. Boiler Pipe Wrap Assumptions

Percent Savings	MMBtu Savings	Source
1.5%	1.4	ACEEE*

* American Council for an Energy-Efficient Economy, Summit Blue Consulting, Vermont Energy Investment Corporation, ICF International, and Synapse Energy Economics. *Potential for Energy Efficiency, Demand Response, and Onsite Solar Energy in Pennsylvania.* Report Number E093, April 2009, pp. 104,108. Available online: http://neep.org/uploads/EMV%20Forum/EMV%20Studies/PA%20Potential-ACEEE%20Report.pdf.

Table 18 shows savings for all natural gas heating system measures. All evaluated savings for this measure category were determined using engineering algorithms.

Table 18. Evaluated Natural Gas Energy Savings for Heating Systems

Category	Measures	Evaluated Savings (therms/year)
Heating System	Boiler Reset Controls	45
	Boiler Pipe Wrap	13
	Programmable Thermostat	32

[9] The American Council for an Energy Efficient Economy. *Emerging Technology Report: Residential Boiler Controls.* May 2006.

Domestic Hot Water

We used the engineering algorithm approach to calculate savings for DHW measures (aerators, showerheads, and pipe wrap) based on a combination of tracking data inputs and researched assumptions. Although the tracking data provided estimates of baseline shower flow, implementers confirmed that these data were not measured. Also, the average value reported was unreasonably high considering that the federal minimum flow rate has been 2.5 gallons per minute since 1994.

Table 19 lists both the frequency of DHW installations and the average installation quantity. The total number of unique participants receiving a DHW measure is less than the sum of the measure-specific participation counts, as some participants received more than one DHW measure.

Table 19: Distribution of Hot Water Measures for Gas Participants

Measure	Participants	Amount Installed per Participant	Percent of Participants Receiving Measure (Weight)
Showerheads	3,704	1.2 units	80%
Faucet Aerators	3,455	1.2 units	76%
Pipe Wrap	1,110	8 ft	20%
Overall	5,638		176%

Table 20 summarizes our evaluation findings for individual natural gas DHW measures, as well as for the average home receiving at least one natural gas DHW measure.

Table 20. Evaluated Natural Gas Energy Savings for DHW Measures

Category	Measures	Evaluated
Domestic Hot Water	Domestic Hot Water (1.76 measures per household)*	11.7
	- Showerhead (80% installed)	11.7
	- Faucet Aerator (76% installed)	2.4
	- Pipe Wrap (20% installed)	2.3
*Average savings for a household that received at least one DHW measure.		

Distribution

The Evaluation Team calculated savings estimates for two distribution measures: duct sealing and duct insulation. Table 21 shows the estimated therm savings for each distribution measure, and Appendix B contains details of the calculation methods.

Table 21. Evaluated Energy Savings for Distribution Measures

Category	Measure	Evaluated Savings (therms/year)
Distribution	Duct Insulation	68
	Duct Sealing	36

Summary of Natural Gas Savings

The Evaluation Team also completed a household-level analysis to compare to its measure-specific analysis. The household-level model showed an average household savings of 63 therms for any HES customer who installed at least one natural gas measures. As this value is slightly higher than the weighted average of our measure-specific savings (59 therms), the measure-specific values maybe slightly understated. However, there is no way to adjust them given the insignificance observed for floor insulation, DHW measures, and programmable thermostats in the billing analysis.

Table 22 summarizes the overall evaluation findings for all natural gas measures.

Table 22. Evaluated Energy Savings for All Natural Gas Measures

Category	Measure	Natural Gas Savings (therms/year)
Insulation & Air Sealing	Insulation (overall)*	96
	- Attic Insulation	77
	- Wall Insulation	99
	- Basement Insulation	13
	Air Sealing	53
	Furnace Fan (due to insulation)	142 (kWh)
	Cooling Savings (due to insulation)	67 (kWh)
Heating System	Boiler Reset Controls	45
	Boiler Pipe Wrap	13
	Programmable Thermostat	32
Domestic Hot Water	Overall **	11.7
	- Showerhead	11.7
	- Faucet Aerator	2.4
	- Pipe Wrap	2.3
	Indirect Water Heater	40
Distribution	Duct Insulation	68
	Duct Sealing	36

* This row shows the average savings for any participant that received attic, and/or wall, and/or basement insulation.

** These are the average savings for a household that received at least one DHW measure (does not include indirect water heaters)

Energy Savings: Electric

The billing analysis only provided reliable estimate of electric savings for two HES measures: CFLs and refrigerator replacements. All other estimates of electric savings presented in this section were determined through engineering algorithms and simulation modeling.

Insulation and Air Sealing

The Evaluation Team used a calibrated simulation approach to evaluate insulation measures for electrically heated homes. The model relied on characteristics of electrically heated HES participant homes and was calibrated using the pre-NAC value determined through the billing analysis.[10] We determined the overall insulation savings value using a weighted average of the insulation installation rates shown in Table 23.

Table 23. Distribution of Electric Insulation Measures

Measure	n	Percent Installed
Insulation (overall)*	115	128%
-Attic Insulation	106	92%
-Wall Insulation	18	16%
-Basement Insulation**	23	20%

* Any participant that installed attic insulation, and/or wall insulation, and/or basement insulation.

** Includes insulation installed on basement ceilings and/or basement walls.

The Evaluation Team calculated average insulation levels (weighted by square footage installed) using the detailed implementer tracking data (Table 24).

Table 24. Average R-Values and Installed Square Feet for Electric Customers

Measure	n	Pre-R-Value	Post R-Value	Square Feet Installed per Customer
Attic Insulation	106	13.9	41.8	929
Wall Insulation	18	3.7	14.0	744
Basement Insulation*	23	6.9	25.5	282

* Includes insulation installed on basement ceilings and/or basement walls.

The average electric insulation participant had 1.28 types of insulation installed, which was lower than the average observed for natural gas insulation participants (1.37). Both the overall average electric insulation savings and the insulation type-specific savings estimates are provided in Table 25.

With the average household baseline consumption at 17,822 kWh, the overall insulation savings of 903 kWh represent 5% savings. With the average baseline heating consumption at 9,650 kWh, the electric insulation savings represent 9% savings. The electricity savings from reduced furnace fan usage and mitigated cooling loads are embedded in the overall insulation savings value.

[10] Although the electric billing analysis sample was not large enough to discern measure-specific savings, we were able to determine the average normalized consumption.

Table 25. Evaluated Electric Energy Savings for Insulation and Air Sealing

Category	Measure	Evaluated Savings (kWh/year)
Insulation and Air Sealing	Insulation (overall – 1.3 installations)*	903
	-Attic Insulation (92% installed)	793
	-Wall Insulation (16% installed)	972
	-Basement Insulation** (20% installed)	99
	Air Sealing	710

* Any participant that installed attic insulation, and/or wall insulation, and/or basement insulation.

** Includes insulation installed on basement ceilings and/or basement walls.

Heating System

Only one HES heating system measure generated electric savings: programmable thermostats. The Evaluation Team determined savings for programmable thermostats installed in electrically heated homes in the same manner as for homes with natural gas heating. Our analysis of programmable thermostats installed in electrically heated homes yielded an average annual savings of 330 kWh.

More detail regarding the energy savings factor applied (determined through a robust literature review) and the average heating pre-NAC observed for electric participants is provided in Appendix B.

Lighting & Appliances

The Team determined evaluated electric savings for the two HES lighting and appliance measures—refrigerator replacements and CFLs—through billing analysis.

To decrease HES participants' electric baseload, the HES Program offers a rebate for the purchase of a new, ENERGY STAR refrigerator to replace eligible older and less efficient models. Our billing analysis dataset of 11,788 electric participants included 632 that replaced their unit (5%). While this percentage is relatively small, the number of replaced refrigerators and the magnitude of the generated savings relative to total household electrical usage allowed The Evaluation Team to estimate savings with sufficient precision (±12%). Specifically, the billing analysis determined an average savings of 714 kWh per replacement.

The Evaluation Team was also able to accurately evaluate energy savings for CFLs through the electric billing analysis. While the per-unit savings of CFLs are relatively small, the large number of bulbs installed in participating homes (18.9 on average) and the large number of homes in our analysis that received bulbs (n=11,643) allowed us to estimate CFLs savings with the greatest precision of any evaluated HES measure (±4%).

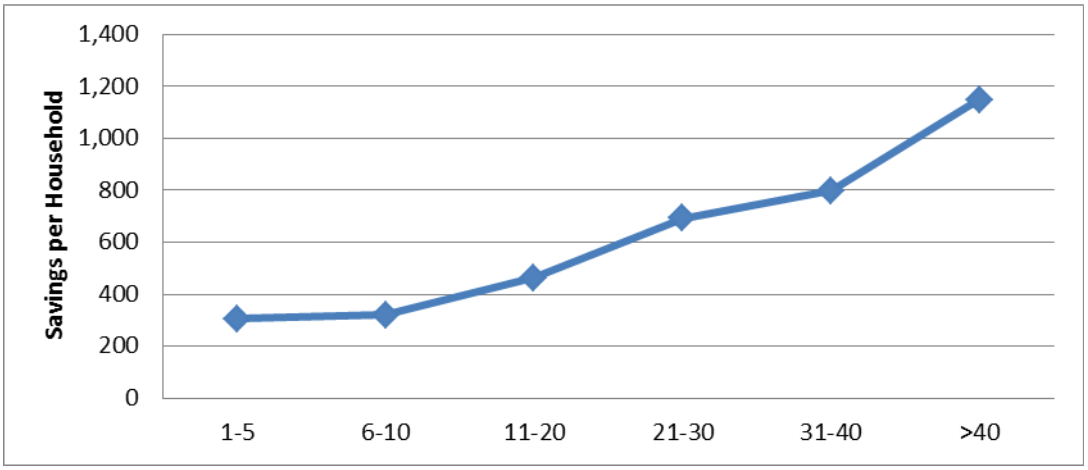
Specifically, through the billing analysis we determined an average household-level CFL savings of 548 kWh/year, which equates to an average per-CFL savings of 29 kWh/year. This result is lower than the expected savings used by all PAs, which appears to be a function of the large number of CFLs installed in participating homes. CFL savings are largely a function of the number of hours the bulb is used (known as hours-of-use, or HOU),[11] and the prevailing evaluation theory is that HOU decreases as a greater number of bulbs are installed within a home (as CFL saturation increases, bulbs are installed in less additional sockets and in less frequently used locations).[12] This theory appears valid for HES (which installed an average of nearly 19 CFLs/home) when household and per-CFL savings are presented based on the number of customers receiving a specific number of CFLs (CFL groups).

11 The other driver of savings is the change in wattage between the existing and replacement bulb. Please see Appendix B for more information about deriving CFLs savings using an engineering-based approach.

12 Program implementers train auditors to install CFLs in the highest usage locations first in order to maximize savings.

While total household savings increases as a greater number of CFLs are installed (Figure 2), the per-CFL saving decreases (Figure 3).

Figure 2. CFL Savings per Household Based on Number of CFLs Installed



As shown in Figure 3, per-CFL savings dropped dramatically after bulbs were installed in the highest usage areas.

Figure 3. Savings per CFL Based on Number of CFLs Installed

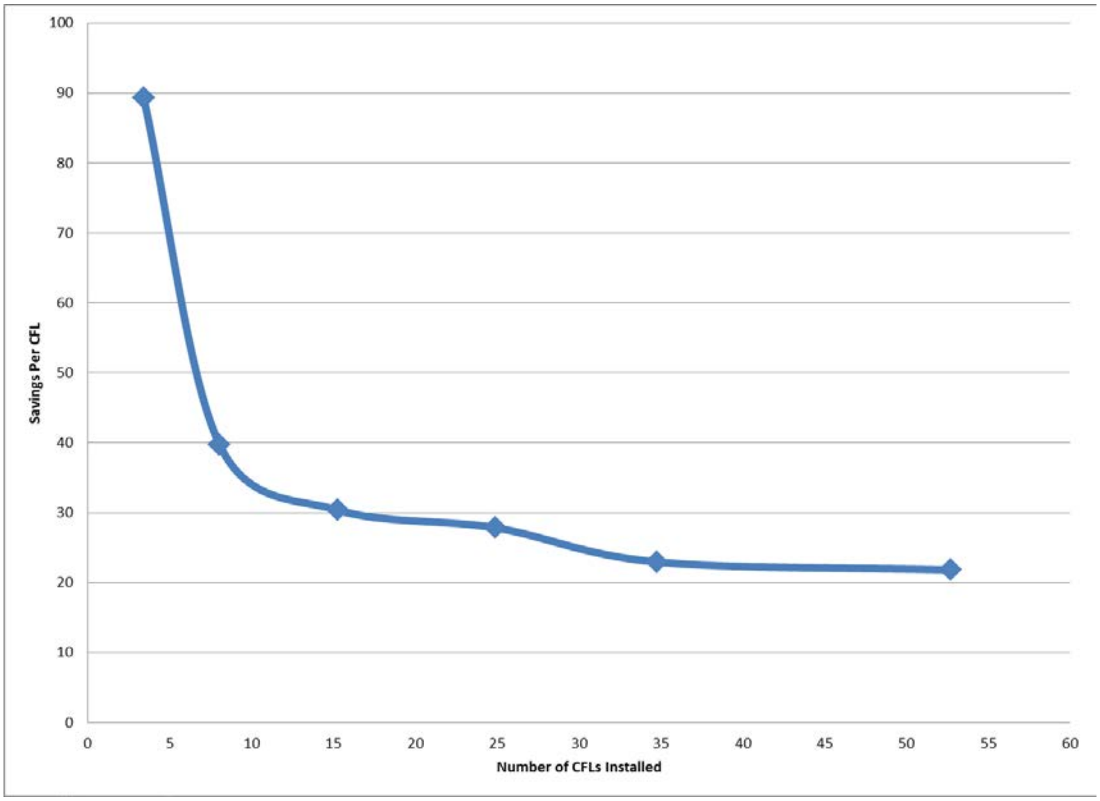


Table 26 details the information shown in Figure 3 in tabular form, while also presenting the billing analysis-based estimate of average HOU for each CFL group. As shown in the table, HOU values dropped precipitously as a greater number of CFLs were installed and then leveled out. The billing analysis-based estimate of HOU for the program overall is 1.8 hours/day, a full hour less than that documented in the current MA TRM (2.8 hours/day).

Table 26. Energy Saving Based on Number of CFLs Installed

CFLs Received	Percent of Analysis Dataset	Average # of Installed CFLs	Billing Analysis kWh Saved/CFL	Billing Analysis Derived HOU*
1-5	10%	3.4	89	5.5
6-10	18%	8.0	40	2.5
11-20	36%	15.3	30	1.9
21-30	21%	24.9	28	1.7
31-40	9%	34.8	23	1.4
>40	6%	52.7	22	1.4
Overall	100%	18.9	29	1.8

* Based on a change in wattage of 44 kWh (the average based on HES tracking data).

As noted in the Methodology section, the results of the billing analysis for CFLs is not a purely gross value, since it is possible—perhaps even likely—that the 2010 participants included in the billing analysis independently installed some CFLs outside the program. To avoid double-counting the freeridership (by applying a NTG value to a billing analysis result that already accounts somewhat for net impacts), the Evaluation Team adjusted the result of the billing analysis by applying an inverse NTG ratio. To apply this ratio, The Team used the CFL-specific findings of the concurrent HES NTG study to convert the billing analysis result into a gross value and eliminate concerns about double penalization.

Table 27 summarizes this process. As evident in the table, the evaluated per-CFL savings increased from 29 to 37 kWh/year.

Table 27. Evaluated CFL Savings Adjusted for Net Effects

Input	Value
Billing Analysis Savings (approximately net)	29 kWh/year
CFL NTG	0.73
CFL Inverse NTG	1.27
Evaluated CFL Savings (gross)	37 kWh/year

To estimate the effects of the new federal Energy Independence and Security Act (EISA) standards on first-year CFL savings, The Evaluation Team projected a possible baseline shift scenario from 2011 to 2016. Our goal with this analysis was to predict the change in $\text{Watts}_{\text{base}}$ over the course of implementing the EISA standard. For this simple scenario, we made basic assumptions about the lag in market adoption, but we did not attempt to account for customers changing to different types of incandescent or halogen bulbs as the standards come into effect.

Nexus Market Research (NMR) is conducting a broader analysis of how EISA standards will affect residential lighting programs in Massachusetts. NMR will use a sensitivity analysis to estimate additional and more complex repercussions (e.g., customers shifting to CFLs, customers bin-jumping to purchase halogen incandescents). The Evaluation Team spoke to NMR and confirmed that our approach to estimating the CFL baseline shift aligns with its respective baseline assumptions. Since a more complex analysis was outside the scope of the current effort, The Evaluation Team has provided these values for context only.

We determined the CFL baseline shift from three main factors:

1. New EISA baselines
2. EISA effective dates for each incandescent wattage
3. Assumed market lag factors

Table 28 summarizes the EISA standards for each rated lumen range and their effective dates.

Table 28. Summary of EISA Standards and Timelines

Rated Lumen Range	Typical Current Lamp Wattage	Maximum Rated Wattage	Effective Date
1,490 – 2,600	100	72	1/1/2012
1,050 – 1,489	75	53	1/1/2013
750 – 1,049	60	43	1/1/2014
310 - 749	40	29	1/1/2014

Table 29 summarizes the estimated percentage of the baseline share for EISA-compliant lamps each year after a given component of the standard takes effect. The Evaluation Team used these factors to project the baseline for each wattage range over a five-year period and then used a weighted average of the wattages replaced to determine a single baseline for each year.[13]

Table 29. Estimated EISA Market Lag Factors

Years Since Effective Date	Estimated EISA Baseline Share
Year 1	30%
Year 2	80%
Year 3	90%
Year 4	100%
Year 5	100%

This revealed two changes: (1) an estimated baseline shift from 63 watts in 2011 to 46 watts in 2016; and (2) a corresponding change in savings from 37 kWh in 2011 to 25 kWh in 2016, as illustrated in Table 30.

Table 30. Potential CFL Baseline Shift and Corresponding Savings Estimates

Year	Baseline (Watts)	Savings (kWh)
2011	63	37
2012	62	36
2013	59	35
2014	54	31
2015	48	26
2016	46	25

[13] We estimated this weighted average based on typical residential uses, which we adjusted to match the average HES baseline of 63 watts.

Table 31 summarizes the savings results for lighting and appliance measures.

Table 31. Evaluated Electric Energy Savings for Lighting and Appliances

Category	Measures	Evaluated Savings (kWh/year)
Lighting & Appliances	Refrigerator Replacement	714
	CFLs	37

Domestic Hot Water

As with natural gas DHW measures, The Evaluation Team used engineering algorithms to estimate savings for all three electric DHW measures: showerheads, faucet aerators, and pipe wrap. The overall approach we used is identical to that described in the natural gas section above and detailed in Appendix B.

Table 32 summarizes the frequency of DHW installations, as well as the average installation quantity. The total number of unique participants receiving a DHW measure is less than the sum of the measure-specific participation counts as some participants received more than one DHW measure.

Table 32. Distribution of Hot Water Measures for Electric Participants

Measure	Participants	Amount Installed per Participant	% of Participants Receiving Measure (Weight)
Showerheads	991	1.3 units	105%*
Faucet Aerators	658	1.3 units	71%
Pipe Wrap	31	8 ft	3%
Overall	1,190		178%
*Since the weights are a combination of the number of participant's receiving the measure and the average quantity installed in each participating home, it is possible for the measure weight to exceed 100%.			

Table 33 summarizes our evaluation findings for both individual natural gas DHW measures and the average home receiving at least one natural gas DHW measure.

Table 33. Evaluated Electric Energy Savings for DHW Measures

Category	Measures	Evaluated
Domestic Hot Water	Domestic Hot Water (1.78 measures per household)*	283
	- Showerhead (105% installed)	237
	- Faucet Aerator (71% installed)	49
	- Pipe Wrap (3% installed)	31
* Average savings for a household that received at least one DHW measure.		

Distribution

The Evaluation Team calculated savings estimates for two distribution measures: duct sealing and duct insulation. Table 34 shows the estimated kWh savings for each measure, including both cooling and heating savings.

Table 34. Evaluated Energy Savings for Distribution Measures

Category	Measure	Evaluated Savings (kWh/year)
Distribution	Duct Insulation	1,613
	Duct Sealing	428

The Evaluation Team used reported duct areas insulated and post-retrofit R-value to calculate savings, and also adjusted savings to account for typical heating system locations. Details on the calculation method are included in Appendix B.

Summary of Electric Savings

Table 35 summarizes all electric energy savings estimates for HES.

Table 35. Evaluated Energy Savings for All Electric Measures

Category	Measure	Electric Savings (kWh/year)
Insulation & Air Sealing	Insulation (overall)*	903
	- Attic Insulation	793
	- Wall Insulation	972
	- Basement Insulation	99
	Air Sealing	710
Heating System	Programmable Thermostat	330
Lighting & Appliance	Refrigerator Replacement	714
	CFLs	37
Domestic Hot Water	Overall**	283
	- Showerhead	237
	- Faucet Aerator	49
	- Pipe Wrap	64
Distribution	Duct Insulation	1,613
	Duct Sealing	428

* This row shows the average savings for any participant that received attic, and/or wall, and/or basement insulation.
**Average savings for a household that received at least one DHW measure.

Evaluated Energy Savings: Oil

Insulation & Air Sealing

As with electric insulation and air sealing, The Evaluation Team used a calibrated simulation model to estimate oil savings. The average oil participant installed 1.42 measures, which is similar to gas participants who averaged 1.37 installations. As with the gas participants, attic insulation was the most common measure, installed by 83% of oil participants.

Table 36 shows the number of installations and the measure weights for each oil insulation and air sealing measure.

Table 36. Distribution of Oil Insulation and Air Sealing Measures

Measure	n	Percent Installed
Insulation (overall)*	1,398	142%
-Attic Insulation	1,157	83%
-Wall Insulation	501	36%
-Basement Insulation**	323	23%

* Any participant that installed attic insulation, and/or wall insulation, and/or basement insulation.

** Includes insulation installed on basement ceilings and/or basement walls.

We calculated the average insulation levels (weighted by square footage installed) using implementer tracking data (Table 37).

Table 37. Average R-Values and Installed Square Feet for Oil Heating Customers

Measure	n	Pre R-Value	Post R-Value	Square Feet Installed per Customer
Attic Insulation	1,157	10.2	37.7	1,067
Wall Insulation	501	3.7	14.0	1,057
Basement Insulation	323	6.5	24.6	250

With the average household baseline consumption of 113 MMBtu, the estimated overall insulation savings of 12 MMBtu represents 11% savings (Table 38).

Table 38. Evaluated Oil Energy Savings Results for Insulation and Air Sealing

Category	Measure	Evaluated Savings (MMBtu/year)
Insulation and Air Sealing	Insulation (overall)*	12.2
	-Attic Insulation	9.2
	-Wall Insulation	11.8
	-Basement Insulation**	1.4
	Furnace Fan (due to insulation)	152 (kWh)
	Cooling Savings (due to insulation)	72 (kWh)
	Air Sealing	5.6

* Any participant that installed attic insulation, and/or wall insulation, and/or basement insulation.

** Includes insulation installed on basement ceilings and/or basement walls.

With the average heating pre-period usage of 81 MMBtu, the oil insulation savings represent 15% savings over the heating pre-replacement usage. As with natural gas, electric savings generated by decreased furnace fan usage and decreased cooling loads are also presented (estimated through the simulation model).

Heating System

Table 39 shows the oil heating system replacement assumptions we used to evaluate both furnace and boiler replacements. For detailed results, see Appendix B.

Table 39. Oil Heating System Replacement Assumptions

Parameter	Furnace		Boiler	
	Evaluation Assumption	Evaluation Source	Evaluation Assumption	Evaluation Source
Baseline Efficiency	78%	Federal standards	80%	Federal standards
New Efficiency	86%	Average of available ENERGY STAR units	86%	Average of available ENERGY STAR units
Baseline Annual Heating Usage (MMBtu)	89.2	Gas billing analysis and baseline efficiency	86.9	Gas billing analysis and baseline efficiency
Savings (MMBtu)	8.4	Calculation	6.0	Calculation

Based on the participation levels for boilers and furnaces during 2010 and Q1-Q3 2011, we calculated the average oil heating system replacement savings shown in Table 40.

Table 40. Distribution of Oil Boilers and Furnaces Replacements

Measure	Total Units	Percent of Units	Evaluated Savings (MMBtu/year)
Furnace	4,533	22%	8.4
Boiler	15,953	78%	6.0
Overall	20,486	100%	6.5

The Evaluation Team conducted a literature review to inform a percentage of savings estimate for boiler reset controls, pipe wrap, and programmable thermostats—similar to that undertaken for the comparable natural gas measures. (Details regarding this review are provided in Appendix B.) We then applied this factor to the base heating load we had determined in the gas billing analysis.

Table 41 summarizes the evaluated energy savings for oil heating system measures.

Table 41. Evaluated Energy Savings for Oil Heating Systems

Category	Measure	Evaluated Savings (MMBtu/year)
Heating System	Overall (Oil Heating System Replacement)	6.5
	Oil Furnace Replacement	8.4
	Furnace Fan (due to oil furnace replacement)	98 (kWh)
	Oil Boiler Replacement	6.0
	Boiler Reset Controls	4.7
	Boiler Pipe Wrap	1.4
	Programmable Thermostat	3.4

Domestic Hot Water

As with electric and natural gas hot water heating measures, The Team used an algorithm to determine savings for oil hot water heating measures. Table 42 summarizes the frequency of DHW installations, as well as the average installation quantity. The total number of unique participants receiving a DHW measure is less than the sum of the measure-specific participation counts as some participants received more than one DHW measure.

Table 42. Distribution of Hot Water Measures for Oil Participants

Measure	Participants	Amount Installed per Participant	Percent of Participants Receiving Measure (Weight)
Showerheads	2,006	1.3 units	110%*
Faucet Aerators	1,269	1.3 units	70%
Pipe Wrap	9	8 ft	<1%
Overall	2,362		180%
*Since the weights are a combination of the number of participant's receiving the measure and the average quantity installed in each participating home, it is possible for the measure weight to exceed 100%.			

Table 43 summarizes our evaluation findings for both individual natural gas DHW measures and the average home receiving at least one natural gas DHW measure.

Table 43. Evaluated Oil Energy Savings for DHW Measures

Category	Measures	Evaluated
Domestic Hot Water	Domestic Hot Water (1.8 measures per household)*	1.6
	- Showerhead (110% installed)	1.3
	- Faucet Aerator (70% installed)	0.3
	- Pipe Wrap (<1% installed)	0.4
	Indirect Water Heater	6.4
* Average savings for a household that received at least one DHW measure (does not include indirect water heaters)		

Distribution

The Evaluation Team calculated savings estimates for two oil distribution measures: duct sealing and duct insulation. Details on the calculation method are included in Appendix B. Table 44 shows the estimated MMBtu savings for each measure.

Table 44. Evaluated Energy Savings for Distribution Measures

Category	Measures	Evaluated Savings (MMBtu/year)
Distribution	Duct Insulation	7.7
	Duct Sealing	4.1

Summary of Oil Savings

Table 45 summarizes the overall evaluated energy savings for all oil fuel measures. Due to the nature of oil billing data, we used an engineering algorithm approach for all oil measures. However, we leveraged the gas customer model to estimate oil savings, changing the input assumptions where necessary (such as heating efficiency).

Table 45. Evaluated Energy Savings for All Oil Measures

Category	Measure	Natural Gas Savings (MMBtu/year)
Insulation & Air Sealing	Insulation (overall)*	12.2
	- Attic Insulation	9.2
	- Wall Insulation	11.8
	- Basement Insulation	1.4
	Air Sealing	5.6
	Furnace Fan (due to insulation)	152 (kWh)
	Cooling Savings (due to insulation)	72 (kWh)
Heating System	Oil System Replacement**	6.5
	Oil Furnace Replacement	8.4
	Furnace Fan (due to oil furnace replacement)	98 (kWh)
	Oil Boiler Replacement	6.0
	Boiler Reset Controls	4.7
	Boiler Pipe Wrap	1.4
	Programmable Thermostat	3.4
Domestic Hot Water	Overall***	1.6
	- Showerhead	1.3
	- Faucet Aerator	0.3
	- Pipe Wrap	0.4
	Indirect Water Heater	6.4
Distribution	Duct Insulation	7.7
	Duct Sealing	4.1

* This row shows the average savings for any participant that receives attic, and/or wall, and/or basement insulation.
** Oil system replacement is the weighted average of oil and furnace savings, based on the number of installation observed in 2010 and Q1-Q3 2011.
*** Average savings for a household that received at least one DHW measure (does not include indirect water heaters)

APPENDIX A. SIMULATION MODELING METHODOLOGY

The Evaluation Team's simulation modeling approach consisted of four tasks:

1. First, **analyzing participant billing data** for each fuel type (gas, oil, and electric).
2. Next, **disaggregating billing data** into end-uses for model calibration targets.
3. Then, **calibrating the model** using participant audit data to inform building characteristics.
4. Finally, **deriving measure-level savings** by running simulation models with baseline and efficient values pulled from the audit data.

Analysis of Participant Billing Data

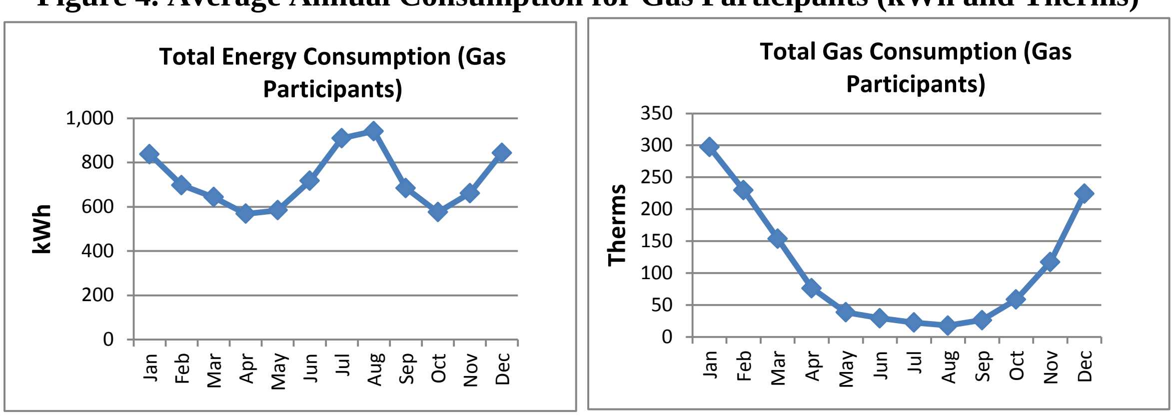
To determine energy consumption targets for the model calibrations, The Evaluation Team analyzed billing data provided by each PA on a per-site basis.

The PAs delivered this data in the form of a spreadsheet with rows of energy consumption data for the past billing period, along with the billing date. We cleaned and then converted the data into energy consumption values for each calendar month using the following process:

1. Summed all consumption values for a particular month and year for each site to remove erroneous data and possible duplicates.
2. Determined consumption for each calendar month by adjusting the monthly billing data by billing date to reflect the actual consumption used each month.
3. Removed program years 2010 and 2011 to ensure pre-install consumption.
4. Calculated the average monthly consumption for each fuel type.

We plotted the average consumption for each fuel type (gas is shown in therms) and examined the results to ensure there was a linear slope between calendar months. Figure 4 shows the average annual results for gas participants.

Figure 4. Average Annual Consumption for Gas Participants (kWh and Therms)



We established that the annual consumption and monthly breakdowns were suitable for the calibration process.

Disaggregate Consumption Data into End Uses

Once The Evaluation Team determined the average monthly consumption for each fuel type, we broke those monthly total values down by end use using the Navigant billing data end-use disaggregation method. This method, which is Navigant's standard practice, has been used for numerous residential evaluations nationwide. The basic steps are these:

1. **Determined the average monthly consumption** for each model group by aggregating monthly participant billing data (as described above).
2. **Estimated lighting and DHW usage** based on the U.S. DOE's Building America Research Benchmark (BARB)[14] and based on a lighting usage study conducted for the California investor-owned utilities (IOUs).[15] To create this estimate, we used the average building size and electric hot water heater saturation for each region of Massachusetts.
3. **Calculated the remaining consumption,** which is attributable to HVAC and miscellaneous equipment (all uses other than lighting and DHW), by subtracting lighting and DHW consumption from the monthly average.
4. **Calculated miscellaneous equipment consumption** by:
    a. Identifying the base month, defined as the month with the lowest remaining consumption per day, assuming that heating and cooling (HVAC) consumption accounts for a small fraction of the base month total (usually 10% to 15% in colder climates with both heating and cooling).
    b. Subtracting the HVAC consumption in the base month from the remaining consumption, assuming that this miscellaneous equipment consumption per day is constant throughout the year.
5. **Calculated HVAC consumption** by subtracting lighting, DHW, and equipment consumption from the monthly average.

[14] U.S. Department of Energy. *Building America Benchmark Program Database.* 2010.

[15] KEMA, Inc. *CFL Metering Study, Final Report.* Prepared for Pacific Gas and Electric, San Diego Gas and Electric, and Southern California Edison. February 25, 2005.

6. **Split the HVAC consumption into heating and cooling** by assigning all winter season HVAC consumption (November through March) to heating and all summer season HVAC consumption (June through August) to cooling. We then split the swing season HVAC consumption by assuming that heating and cooling are proportional to the HDDs and CDDs in each month.[16]
7. **Adjusted the heating and cooling consumption** in each month by multiplying the ratio of average HDDs or CDDs for that month's billing period to those same months in a typical year.[17]

The first step to disaggregate monthly energy consumption into end-uses entails breaking out the uses that can reliably be calculated using engineering algorithms and primary research (in this case, lighting and DHW).

Lighting

The Evaluation Team estimated annual lighting consumption per household using an equation from the BARB, which gives lighting consumption as a function of square footage of floor area as follows:

$$\boldsymbol{Annual\ Lighting\ Consumption\ (kWh) = 0.8 * Floor\ Area\ (sf) + 805}$$

To break the annual consumption into monthly values, it was necessary to derive a seasonal load profile, due to the fact that lighting use increases during the winter months when there is less daylight. We derived the seasonal lighting variation profile from the KEMA 2005 CFL monitoring study performed for the California IOUs. The basic steps are as follows:

1. **Determine the percent of total hours and weighted average hours per lamp** that are daylight-sensitive; assume family, kitchen/dining, and living rooms are daylight sensitive. These input data and calculated result are shown in Table 46 and Table 47.

[16] We determined the HDDs and CDDs from www.degreedays.net, a Website that aggregates data from the Weather Underground (www.wunderground.com).

[17] We determined HDDs and CDDs for a typical year from the EnergyPlus Simulation software available at: http://apps1.eere.energy.gov/buildings/energyplus/cfm/weather_data3.cfm/region=4_north_and_central_america_wmo_region_4/country=1_usa/cname=USA.

Table 46. Number of Fixtures in KEMA Study and Average Daily Usage by Room Type

Room	Daylight Sensitivity	Number of Fixtures in KEMA Study	Percent of Household Fixtures	Average Daily Hours per Lamp
Bedroom	No	669	27%	1.6
Bathroom	No	400	16%	1.5
Family	Yes	194	8%	2.5
Garage	No	72	3%	2.5
Hallway	No	184	7%	1.6
Kitchen/dining	Yes	484	19%	3.5
Living	Yes	342	14%	3.3
Laundry/utility	No	68	3%	1.2
Other	No	94	4%	1.9

* Column may not add to 100% due to rounding.

Table 47. Percent of Total Annual Hours and Weighted Average Daily Usage by Daylight Sensitivity

Sensitivity	Percent of Total Annual Hours	Weighted Average Daily Hours per Lamp
Daylight Sensitive	58%	3.24
Non-Daylight Sensitive	42%	1.65
All Lamps	100%	2.57

2. **Calculate an average percent night adder** by assuming an average adder of 0.75 hours-per-day for daylight-sensitive lamps and 0.25 hours-per-day for non-daylight-sensitive lamps; divide these values by the average hours-per-day and weight by the percent of total hours to calculate the average night adder (which The Evaluation Team calculated to be 20% for this program).
3. **Determine the relative daily usage factor for each month** by assuming that usage varies linearly from a minimum of (1-Night Adder) in June to a maximum of (1+Night Adder) in December; add an additional 20% to December to account for an observed spike in energy consumption in this month, which is assumed to be from holiday lighting.
4. **Calculate relative monthly usage** by multiplying the relative daily usage factor by the number of days in the month.
5. **Derive the monthly variation profile** by dividing each month's relative usage by the average monthly relative usage for the whole year (30.93). Steps 3, 4, and 5 are shown in Table 48.

Table 48. Daily Usage, Monthly Usage, and Lighting Variation Profile

Month	Relative Daily Usage Factor	Days/Month	Relative Monthly Usage	Lighting Variation Profile
January	113%	31	35.09	1.13
February	107%	28	29.85	0.96
March	100%	31	31.00	1.00
April	93%	30	28.02	0.91
May	87%	31	26.91	0.87
June	80%	30	24.06	0.78
July	87%	31	26.91	0.87
August	93%	31	28.95	0.94
September	100%	30	30.00	0.97
October	107%	31	33.05	1.07
November	113%	30	33.96	1.10
December	140%	31	43.40	1.40

The Evaluation Team then calculated the average monthly lighting electricity consumption by multiplying the lighting variation profile by the annual lighting consumption estimate.

Domestic Hot Water

The starting point we used for determining seasonal DHW end usage was the DHW end-use profiles from the 2010 BARB. The BARB details the average gallons per day of DHW used each month for the dishwasher, clothes washer, baths, showers, and sinks, along with the average temperature of the water mains (i.e., inlet/supply water). An example of this data for Massachusetts is shown in Table 49.

Table 49. Domestic Hot Water Profile for Massachusetts (gallons/day)

Month	Mains Temp (ºF)	Dishwasher	Clothes Washer	Baths	Showers	Sinks	Total*
January	43.3	3.0	8.3	5.6	22.5	20.1	59.5
February	41.7	3.0	8.4	5.7	22.6	20.2	59.9
March	42.8	3.0	8.3	5.6	22.6	20.1	59.6
April	46.5	3.0	8.0	5.6	22.3	19.9	58.8
May	51.7	3.0	7.6	5.5	21.9	19.5	57.4
June	57.1	3.0	7.1	5.3	21.3	19.0	55.8
July	61.3	3.0	6.6	5.2	20.9	18.6	54.3
August	63.2	3.0	6.4	5.2	20.6	18.4	53.6
September	62.2	3.0	6.5	5.2	20.7	18.5	53.9
October	58.7	3.0	6.9	5.3	21.2	18.9	55.2
November	53.6	3.0	7.4	5.4	21.7	19.3	56.9
December	48.2	3.0	7.9	5.5	22.2	19.8	58.4

* The sum of the total hot water usage across all equipment types may not reflect the values found in the total column due to rounding.

To calculate the total monthly DHW consumption, we multiplied the consumption of each end use by the saturations of that end use among participants.[18]

Next, we calculated the monthly electricity consumption for homes with electric DHW using the total monthly gallons of hot water and the seasonally adjusted mains water temperatures. This consumption was composed of two parts: the water heating load and the standby heat loss coefficient (UA load), which is equal to the amount of heat required to compensate for heat loss from the water heater tank. The equations we used are as follows:[19]

$$Heating\ Load\ (kWh/day) = Consumption\ (gal/day) * 8.31\ (Btu/(gal\ °F)) * (Water\ Temp - Mains\ Temp)(°F)/(Heating\ Efficiency * 3{,}412\ (Btu/kWh))$$

$$UA\ Load\ (kWh/day) = Tank\ UA\ (Btu/(hr\ °F)) * (Water\ Temp - Ambient\ Temp)(°F) * 24\ (hr/day)\ /(Heating\ Efficiency * 3{,}412\ (Btu/kWh))$$

Similar to the lighting variation profile, we then calculated the DHW variation profile by finding the average consumption for each month divided by the average consumption for all months. Table 50 shows these results for Massachusetts.

Table 50. Domestic Hot Water Electricity Consumption and Variation Profile for Massachusetts

Month	Gal/Day	Mains Temp (°F)	Heating Load (kWh/day)	UA Load (kWh/day)	Days/ Month	Total kWh/ Month	DHW Variation Profile
January	47.7	43.3	9.5	1.9	31	390.3	1.1
February	48.0	41.7	9.7	1.9	28	359.5	1.1
March	47.8	42.8	9.6	1.9	31	392.5	1.2
April	47.1	46.5	9.0	1.9	30	363.1	1.1
May	46.0	51.7	8.0	1.9	31	350.6	1.0
June	44.7	57.1	7.2	1.9	30	314.6	0.9
July	43.5	61.3	6.6	1.9	31	305.3	0.9
August	42.9	63.2	6.3	1.9	31	296.4	0.9
September	43.2	62.2	6.5	1.9	30	291.1	0.9
October	44.3	58.7	7.0	1.9	31	317.3	0.9
November	45.6	53.6	7.8	1.9	30	330.6	1.0
December	46.8	48.2	8.6	1.9	31	367.3	1.1

Next, we derived the average household monthly DHW electric consumption by multiplying the monthly DHW electricity consumption by the electric hot water saturation. The Evaluation Team

[18] We assigned 100% saturation to dishwashers because we assumed that households without a dishwasher use the same amount of hot water for washing dishes by hand.

[19] We assumed the following variables for this calculation: Hot Water Temp = 120°F, Heating Efficiency = 0.75, Tank UA = 7, Ambient Temp = 70°F.

utilized this same procedure for a sample of homes with gas water heaters, and then converted the units to therms.

Miscellaneous Equipment

After subtracting the DHW and lighting end uses from the monthly household electricity consumption, the remaining consumption is composed of HVAC and miscellaneous equipment, which includes appliances and plug loads. To determine the portion of the remaining consumption that is used by miscellaneous equipment, The Evaluation Team calculated the remaining consumption per day for each month, and identified the month with the minimum daily remaining consumption. This month is generally during the spring or the fall, and corresponds to the time of lowest HVAC use.

Next, The Evaluation Team assumed that during this minimum consumption month, HVAC accounted for 10% of the total consumption for electric-only customers and 5% for natural gas customers. We split the HVAC consumption evenly between heating and cooling, then estimated the daily equipment consumption for this minimum month by subtracting the total consumption per day from the consumption used for lighting, DHW, and HVAC. The Evaluation Team assumed that the equipment consumption per day remains constant throughout the year.

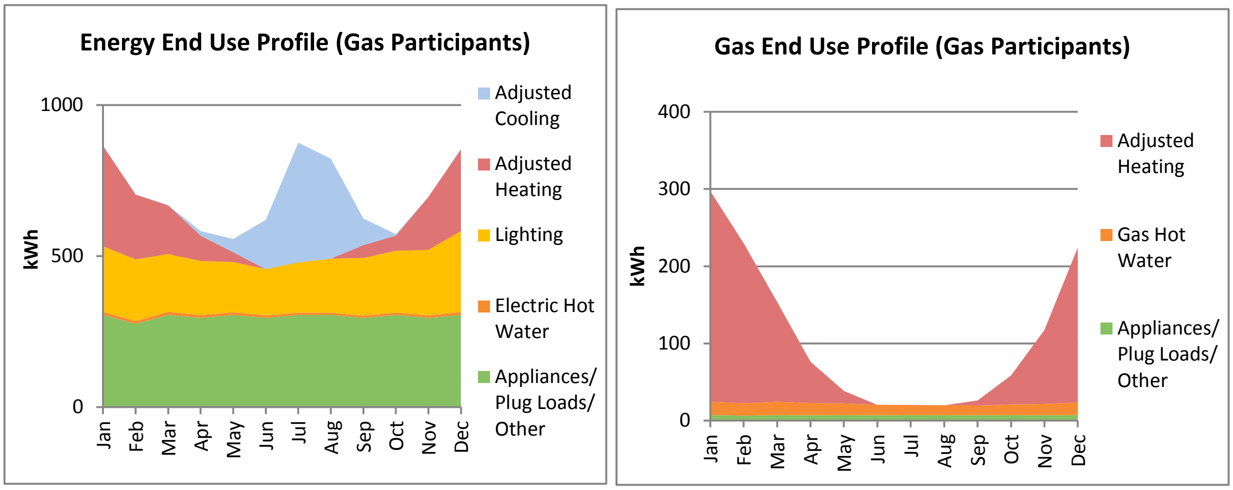
Heating and Cooling

The Evaluation Team's experience conducting multiple evaluations has revealed that heating and cooling energy makes up 10% of the total electricity consumption in a typical home during the minimum consumption month. After assuming that the minimum consumption month included 5% heating and 5% cooling, we calculated the monthly heating and cooling electricity by subtracting the DHW, lighting, and base end uses from the total for each month.

For June through September, we assumed that all the HVAC electricity was for cooling. For December through March, we assumed that all HVAC electricity was for heating. For the shoulder months (April, May, October, and November), we split the HVAC consumption in half by assuming that heating and cooling are proportional to the HDDs and CDDs in each month. We then calculated the annual heating and cooling end-uses by summing the monthly heating and cooling end uses.

The Evaluation Team utilized the same methodology for gas homes. Figure 5 shows the disaggregated end-use profiles for gas participants.

Figure 5. Disaggregated End-Use Profile for Gas Participants (kWh and Therms)



Model Calibration Process

With established monthly end-use profiles, The Evaluation Team constructed and adjusted the models to represent the actual functions of the average participant home. The following sections detail the intricate processes involved in model alterations.

Create Energy Simulation Models

The Evaluation Team built the energy models we used for this evaluation using the DOE-2.2 engine, based on models Navigant previously created for an impact evaluation. Each of the models consists of four buildings: two each of one- and two-story homes, oriented north-south and east-west. We created one base model for each model group, with differing HVAC types specific to each participant fuel type; see Table 51 for corresponding HVAC fuel types.

Table 51. Simulation Modeling HVAC Types for the Each Fuel Type

Fuel Type	HVAC Type
Gas	Gas Furnace and Central Air Conditioning
Oil	Oil Furnace and Central Air Conditioning
Electric	Air-Source Heat Pump with Electric Resistance Supplemental*

* Due to the multiple types of heating systems in Massachusetts (wood burning fireplaces, electric baseboard heat, electric furnaces, heat pumps, etc.), we used a heat pump for the electric model, but decreased the duct losses and moved 50% of the ducts into a conditioned space. With this approach, we attempted to capture characteristics for each variation of system combinations. Since we adjusted the total consumption to match actual participant billing data, the results are not skewed from these HVAC adjustments.

The Team altered these models to match the participants in each model group by changing the average building size and other characteristics when this participant audit data was available.

When the audit data did not contain building characteristics—such as for window specifications and typical insulation values—we used the BARB[20] spreadsheet to inform the models.

Calibrate Energy Simulation Models

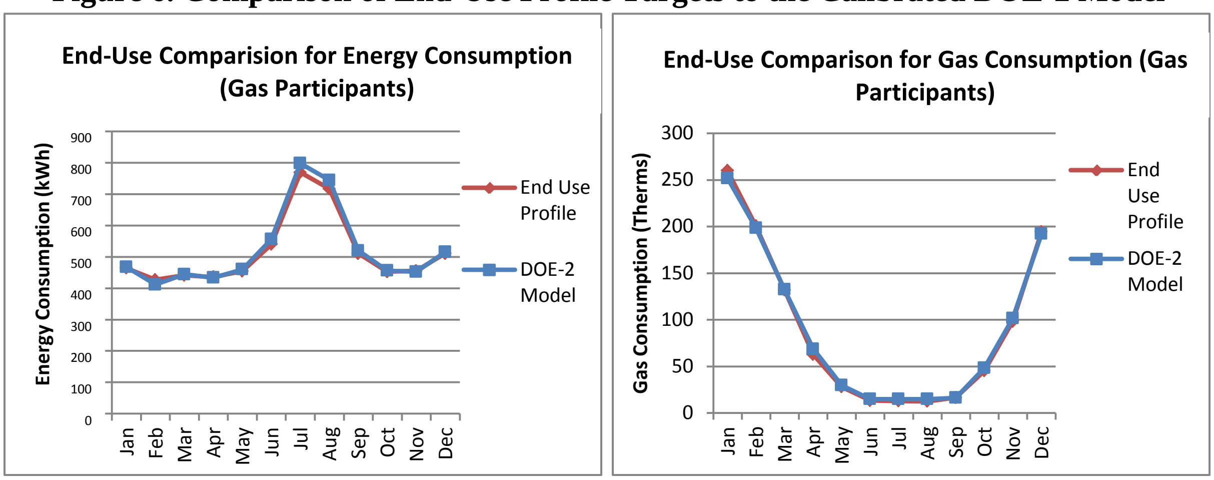
The Evaluation Team calibrated each model group in order to match the modeled energy consumption to the end-use targets for that group. This calibration was an iterative process, involving the following steps:

1. **Derived modeled end-use consumption for each model group** by weighting the two sets of results (one- and two-story homes) from each simulation run in each participant group.
2. **Compared the modeled end-use consumption to the calculated participant end-use consumption.**
3. **Adjusted calibration parameters and re-ran the models.**

We repeated the above process until the monthly error and total annual error in each end use was no more than 1% of the annual end use target.

Figure 6 shows a comparison of the end-use targets and final calibrated model.

Figure 6. Comparison of End-Use Profile Targets to the Calibrated DOE-2 Model



To avoid getting unrealistic building characteristics, we adjusted the calibration parameters to within pre-determined reasonable ranges. After the models were properly calibrated and produced the same consumption values as the average participant homes, we adjusted the models to calculate savings for the desired measures.

Thus, when we calibrated a model, we used different parameters as knobs (e.g., insulation values, temperature set points, shading schedules) to adjust our consumption to match the actual

20 This spreadsheet details existing homes and is available online at: http://www1.eere.energy.gov/buildings/building_america/analysis_spreadsheets.html.

participant billing data. These knobs have reasonable ranges that we did not adjust above or below without hard evidence that abandoning these pre-defined ranges made sense. One example is the temperature set point for heating. Our range is 64-72°F, as it would be unreasonable to assume that someone would have their thermostat set at 80°F or 50°F for an extended period of time. We used this approach to simulate occupant behaviors, and these ranges kept us within reasonable actual behaviors.

Derive Measure-Level Savings

The Evaluation Team used the simulation model approach to estimate savings for program measures known to generate interactive effects, such as insulation and air sealing (weatherization). The following sections outline how we modeled each measure and the methodology we used to calculate savings.

Altering Model Parameters

Utilizing the calibrated models, we ran a parametric model for each model group by altering the measure parameters in the calibrated models while leaving all other parameters constant. We created baseline and efficient parametrics to model the home's pre- and post-installation energy usage. This alteration of the parametric runs varied for each measure; the following lists the individual adjustments we made:

- ***Air Sealing (weatherization).*** We adjusted the whole-house infiltration rate.
- ***Attic Insulation***. We adjusted the baseline and efficient R-Values, as well as the whole-house infiltration rate.

Deriving Savings from Model Results

Another approach was necessary to model the insulation upgrades due to unknown parameters for the remainder of the home. Although the audit data provided both pre- and post-values for insulation measures, these values typically dealt with a portion of the entire home, therefore leaving an unknown value for areas that did not receive upgrades. Consequently, we simulated the building as if the entire attic, wall, or floor area received insulation in order to determine the overall whole-house savings. We then normalized these savings on a per-square-foot basis by dividing the overall savings by the percentage of the total area that received insulation (attic, wall, or floor). Finally, we applied this value to the installed quantity listed in the audit data to derive measure-level savings for each of the insulation types offered by the HES Program.

APPENDIX B. ENGINEERING ALGORITHMS

This appendix provides detailed explanations of the algorithms The Evaluation Team used to calculate the energy impacts of measures that were not covered by our billing analysis or calibrated simulation. Table 52 lists these measures and the approach we used for each.

Table 52. Summary of Analysis Approach by Measure and Heating Fuel Type

Category	Measure	Natural Gas (Therms/year)	Electric (kWh/year)	Oil (MMBtus/year)
Insulation & Air Sealing	Insulation (overall)*	Billing Analysis (±9%)	Simulation Modeling	Simulation Modeling
	- Attic Insulation	Billing Analysis (±19%)	Simulation Modeling	Simulation Modeling
	- Wall Insulation	Billing Analysis (±16%)	Simulation Modeling	Simulation Modeling
	- Basement Insulation	Simulation Modeling	Simulation Modeling	Simulation Modeling
	Air Sealing	Billing Analysis (±18%)	Simulation Modeling	Simulation Modeling
	Furnace Fan (due to insulation)	Simulation Modeling	-	Simulation Modeling
	Cooling Savings (due to insulation)	Simulation Modeling	-	Simulation Modeling
Heating System	Oil Furnace Replacement	-	-	Engineering Algorithm
	Furnace Fan (due to oil furnace replacement)	-	-	Engineering Algorithm
	Oil Boiler Replacement	-	-	Engineering Algorithm
	Boiler Reset Controls	Engineering Algorithm		Engineering Algorithm
	Boiler Pipe Wrap	Engineering Algorithm	-	Engineering Algorithm
	Programmable Thermostat	Engineering Algorithm	Engineering Algorithm	Engineering Algorithm
Lighting & Appliances	Refrigerator Replacement	-	Billing Analysis (±12%)	-
	CFLs	-	Billing Analysis (±4%)	-
Domestic Hot Water	Showerhead	Engineering Algorithm	Engineering Algorithm	Engineering Algorithm
	Faucet Aerator	Engineering Algorithm	Engineering Algorithm	Engineering Algorithm
	Pipe Wrap	Engineering Algorithm	Engineering Algorithm	Engineering Algorithm
	Indirect Water Heater	Engineering Algorithm	-	Engineering Algorithm
Distribution	Duct Insulation	Engineering Algorithm	Engineering Algorithm	Engineering Algorithm
	Duct Sealing	Engineering Algorithm	Engineering Algorithm	Engineering Algorithm

* This row refers to any participant that received attic, and/or wall, and/or basement insulation.

The following sections summarize the engineering approaches we used for each measure.

Heating System

This category includes four measures: oil heating system replacement (furnaces and boilers, including furnace fan savings), oil boiler reset controls, oil boiler pipe wrap, and programmable thermostats for oil-heated homes. Table 53 summarizes the savings estimates for these measures.

Table 53. Heating System Savings Summary

Category	Measure	Natural Gas (Therms/year)	Electric (kWh/year)	Oil (MMBtus/year)
Heating System	Oil Furnace Replacement	-	-	8.4
	Furnace Fan (due to oil furnace replacement)	-	-	98 (kWh)
	Oil Boiler Replacement	-	-	6.0
	Boiler Reset Controls	45		4.7
	Boiler Pipe Wrap	13	-	1.4
	Programmable Thermostat	32	330	3.4

Heating System Replacement (and associated furnace fan)

The Evaluation Team used the following algorithm to calculate the impacts of heating-only system replacements:

$$MMBtu\ Save = Baseline\ Consumption\ \times \left(1 - \frac{AFUE_{ee}}{AFUE_{base}}\right)$$

We set the baseline consumption equal to the heating pre-NAC of corresponding gas customers.

The audit data did not provide the efficiency of installed units. Because this is a replace-on-burnout measure, the baseline is the federal minimum efficiency. The Evaluation Team used the average efficiency of available ENERGY STAR units as reported by the PAs for the measure efficiency. These values are shown in Table 54.

Table 54. Summary of Oil Heating System Replacement Inputs

System Type	Base Consumption (Btu)	Baseline Efficiency	Measure Efficiency
Oil Furnace	89,180	78%	86%
Oil Boiler	86,950	80%	86%

For forced air systems, we also calculated associated fan savings. We assumed that the bulk of these systems are furnaces, and thus used the above furnace savings to inform the analysis. The Evaluation Team assumed that fan savings are proportional to heating system fossil fuel savings:

$$Fan\ Savings = Fan\ Base\ Load \times Percent\ Heating\ System\ Savings$$

We calculated the fan base load as follows:

$$Fan\ Base\ Load = \frac{Fan\ Motor\ Horsepower \times Fan\ Run\ Hours \times 0.746}{Fan\ Motor\ Efficiency}$$

Table 55 shows the inputs we used to calculate the fan base load.

Table 55. Furnace Fan Calculation Inputs

Input	Value	Source
Furnace Fan Run Hours	1,014	2012 Massachusetts Brushless Motors Fan Study*
Fan Motor Horsepower	0.5	2012 Pennsylvania TRM**
Fan Motor Efficiency	0.5	2012 Pennsylvania TRM**
Base Fan Load (kWh)	756	Calculation

* ERS and The Cadmus Group, *Massachusetts Residential Retrofit Brushless Fan Motors Impact Evaluation*. 2012.

** Pennsylvania Public Utility Commission. *Technical Reference Manual*. 2012.

Programmable Thermostats

The key inputs for programmable thermostats are listed in Table 56.

Table 56. Programmable Thermostat Assumptions

Measure	Percentage of Savings	Oil Savings (MMBtu)	Gas Savings (Therm)	Electric Savings (kWh)	Source
Evaluation Estimate	3.6%	3.4	32	330	Conservative estimate based on literature review
Current PA Estimate	6.2%	7.7	77	N/A	2012 Massachusetts TRM*

* *Massachusetts Technical Reference Manual for Estimating Savings from Energy Efficiency Measures: 2012 Plan Year—Plan Version.* October 2011.

The Evaluation Team reviewed several programmable thermostat studies for both heating and cooling climates. Because these studies have conflicting results, we recommend using a conservative estimate of 3.6% to calculate savings. We again used the pre-NAC from the billing analysis (average of all participants) to calculate savings.

The current TRM value is based on a 2007 study by RLW Analytics[21] which claims that programmable thermostats save, on average, 6.2% of heating load in gas heated homes. However, this study does not include all sources of uncertainty in their confidence intervals, so the true confidence interval could cross zero, making the result not statistically significant. Furthermore, estimated savings resulting from the use of a participation indicator—which is more common in billing analyses—resulted in a much lower point estimate of between 1.7% and 1.8%.

21 RLW Analytics. *Validating the Impact of Programmable Thermostats.* 2007.

The Evaluation Team reviewed the following additional studies (with some high-level outcomes listed). While some sources indicate high savings, such as ENERGY STAR, most empirical studies showed more conservative results.

- GDS Associates. *Programmable Thermostats.* Report to KeySpan Energy Delivery on Energy Savings and Cost Effectiveness. Marietta, Georgia. 2002.
    - Savings of 3.6% by using programmable thermostats based on metering study, which accounts for variability of actual set back/set up settings.
    - Savings from programmable thermostats account for 56% of realization rate.
- KEMA Inc., Southern California Edison, and Quantum Consulting. *Can Programmable Thermostats Be Part of a Cost-Effective Residential Program Portfolio?* 2007. Based on 2004 evaluation results from a California statewide single family rebate program.
    - There is an increased market penetration of programmable thermostats (which have a dominant share of contractor thermostat installations and represent about half of retail thermostat sales).
    - Programmable thermostats have high levels of free-ridership.
    - There is evidence that customers are not using programmable thermostats to save energy.
    - There has been negligible savings from programmable thermostats in California.
- Energy Center of Wisconsin. Programmable Thermostats That Go Berserk? Taking a Social Perspective on Space Heating in Wisconsin. 1999.
    - Study of energy use in 299 single family homes in Wisconsin.
    - Homes with programmable thermostats have 2.5% lower heating energy usage (there is large uncertainty in this estimate).
    - The potential for savings from programmable thermostats is low: out of the two-thirds of homeowners that do not already have one installed, most either already set back their thermostats manually or are resistant to doing so.
- ENERGY STAR equipment calculator.
    - Programmable thermostats lead to 16% savings for central cooling and 14% savings for heating.
- ENERGY STAR programmable thermostat calculator.
    - Programmable thermostats lead to 2.4 MMBtu/degree of savings for heating (703 kWh/degree) and lead to 0.2 MMBtu/degree of savings for central cooling (59 kWh/degree).

- Southern California Edison. Programmable Thermostats Installed into Residential Buildings: Predicting Energy Saving Using Occupant Behavior & Simulation. 2004.
    - Programmable thermostat savings are based on combining the RASS analysis on usage with DOE-2 simulation results.
    - Cooling savings for Climate Zone 16 (coldest zone in California) are approximately 2%.
    - Programmable thermostats lead to negative heating savings.
    - Referenced by 2005 California DEER Database, main source of deemed savings for California.
- California Energy Commission: http://www.consumerenergycenter.org/home/heating_cooling/thermostats.html.
    - Estimates that programmable thermostats lead to 15-25% savings for cooling and 20-75% savings for heating.

Boiler Reset Controls (oil only)

The key inputs for boiler reset controls are listed in Table 57. The Evaluation Team reviewed the 2006 ACEEE report[22] on the measure. The report concludes that "*for conventional boilers, adequate add-on controls may cost from $150 (time-delay relay) to over $1,000 (reset with automatic post purge) and save up to 6-8% or more of fuel used.*"

Given that the type of controls is not specified and the TRM has no guidelines as to whether retrofitted boilers must be condensing or cold-start (where savings are maximized), the Evaluation Team recommends a more conservative estimate of 5% of heating load. We used the pre-NAC from the billing analysis (average of all participants) to calculate savings for this measure.

Table 57. Boiler Reset Control Assumptions

Measure	Percent Savings	MMBtu Savings	Source
Evaluation Estimate	5%	4.7	Conservative estimate based on literature review
Current PA Estimate	6-8%	7.9	MA TRM

[22] The American Council for an Energy Efficient Economy. *Emerging Technology Report: Residential Boiler Controls.* May 2006.

Boiler Pipe Wrap (oil only)

The Evaluation Team used a percent savings approach to calculating energy savings for boiler pipe wrap. We again used the pre-NAC from the billing analysis (average of all participants) as the baseline for this measure. The key inputs for boiler pipe wrap are listed in Table 58.

Table 58. Boiler Pipe Wrap Assumptions

Percent Savings	MMBtu Savings	Source
1.5%	1.4	ACEEE*

* American Council for an Energy-Efficient Economy, Summit Blue Consulting, Vermont Energy Investment Corporation, ICF International, and Synapse Energy Economics. *Potential for Energy Efficiency, Demand Response, and Onsite Solar Energy in Pennsylvania.* Report Number E093, April 2009, pp. 104,108. Available online: http://neep.org/uploads/EMV%20Forum/EMV%20Studies/PA%20Potential-ACEEE%20Report.pdf.

Lighting

This section presents the engineering approach The Evaluation Team used to estimate savings for CFLs, which could be compared to the results of the billing analysis (used to report savings).

CFLs

The Evaluation Team used the following standard engineering equation to estimate first-year savings for CFLs installed in 2010:

$$kWh\ saved = \frac{(Watts_{base} - Watts_{ee})}{1000} \times HOU$$

We used numerous data sources to inform the equation. First, The Evaluation Team used agency and PA tracking data to establish pre- and post-retrofit lamp wattages, as shown in Table 59**Error! Reference source not found.**. Without CFL metering as part of this evaluation, we used the default of 2.8 hours-of-use recommended by the Massachusetts TRM. The average installed quantity was 18.9 CFLs per household.

As shown in Table 59, we calculated the evaluated per-CFL savings to be 45 kWh/year.

Table 59. CFL Energy Savings Calculation Summary*

Parameter	Estimate	Source
Average Pre-retrofit Wattage (2011)	63	Audit Data
Average Post-retrofit Wattage	13	Audit Data
Delta Watts	49	Calculated
Annual Hours-of-Use (based on 2.8 hours-of-use per day)	1,022	MA TRM
In-Service Rate	90%	MA TRM
Savings (kWh/year)	45	Calculated

* This calculation also included a weighted average of interactive terms across fuel types with and without air conditioning.

Domestic Hot Water

This section reviews the methodology The Evaluation Team used to estimate savings from the following DHW measures:

- Showerheads
- Faucet aerators
- Water heater pipe wrap
- Indirect water heaters

Generally, we were not able to compare our evaluation inputs with PA-specific values, because most PAs only provided deemed savings values, rather than algorithms and specific inputs. The majority of PAs currently claim a single deemed value for all of these measures. The Evaluation Team calculated a unique value for each measure. Table 60 summarizes the evaluated savings for these measures.

Table 60. Domestic Hot Water Savings Summary

Category	Measure	Natural Gas (Therms/year)	Electric (kWh/year)	Oil (MMBtus/year)
Domestic Hot Water	Showerhead	12	237	1.3
	Faucet Aerator	2	49	0.3
	Pipe Wrap	3	64	0.4
	Indirect Water Heater	40	-	6.4

Showerheads

The Evaluation Team began evaluating this measure by reviewing the HES audit data for the key inputs to the low-flow showerhead energy savings algorithm. Table 61 lists the inputs for low-flow showerheads, indicating both the original audit data inputs and final assumptions.

Table 61. Showerhead Inputs

Input	Audit Data Values	Values Used in Calculations	Source
Household Members	2.9	2.9	HES audit data
Showers (pcpd)	-	0.7	Default is 0.7; +,++
Shower Length (min)	-	8.2	**,++
Proportion Affected	0.73	0.73	HES audit data
Baseline Rated Flow	-	2.5	Federal standard
Baseline As-used Flow (linear)	-	2.05	Calculated from rated flow;* ,+
Retrofit Rated Flow	1.7	1.7	HES audit data
Retrofit As-used Flow (linear)	1.61	1.61	Calculated from rated flow;* ,+
Shower Temperature (°F)	-	105	1
Cold Water Temperature (°F)	-	56.04	Average of Massachusetts locations; +++
Water Heater Recovery Efficiency	-	Electric: 0.97 Gas: 0.67 Oil: 0.59	Federal standard; varies by fuel type

* For linear adjustments, we used the following equation: as-used flow = 0.542 * (Rated Flow) + 0.691.

**Biermayer, Peter J. *Potential Water and Energy Savings from Showerheads.* Lawrence Berkeley National Laboratory. 2006.

+Cook, G. and B. Barkett. *Resource Savings Values in Selected Residential DSM Prescriptive Program.* Summit Blue Consulting, Inc. 2008.
++Mayer, P.W. et al. *Residential End Uses of Water.* AWWA Research Foundation. 1999. Referenced by Biermayer 2006.
+++U.S. Department of Energy. *Building America Benchmark Program Database.* 2010.

The following algorithm is identified in Biermayer 2006 and Cook 2008:

*Shower water use (gallons/year) = household members * showers per capita per day * shower length * proportion of showering activity affected by replacement * as-used water flow rate*

In that equation, we set the as-used water flow rate equal to the maximum rated flow rate, after scaling it back linearly to account for water pressure at the residence that has less than 80 psi rating pressure. That rating pressure is meant for limiting the flow by throttling back (closing) the control valve during the shower, and it is due to partial clogging in household pipes, which led to the following equation:

Shower water energy saved = shower water use reduction (Temperature of shower - Temperature of incoming cold-water) * conversion to energy/water heater recovery efficiency*

Faucet Aerators

The Evaluation Team used the following algorithm to calculate faucet aerator savings:

*Faucet energy savings = Water savings per year * (average faucet mix temperature - temperature of incoming cold water) * conversion to energy/water heater recovery efficiency*

Where:

Water savings per year (gallons/year)	=	Household water use * flow reduction
Household water use	=	Household members * total daily household faucet use per capita * 365 days * % of use affected by replacement
Flow reduction	=	% flow rate reduction * % of straight-down-the-drain use
Straight-down-the-drain use	=	Percent of water that flows straight down the drain (since water volume that fills a sink for batch use is not affected by the flow rate)

Table 62 shows the values we used for each input. Because faucets are rarely used at their rated flows, The Evaluation Team recommends that the PAs determine actual flow rates through water metering studies. Several studies have been conducted nationwide using flow-trace analysis, a method which can disaggregate metered water use data by end-use fixture (e.g., faucets, dishwaters, showerheads). The values we recommend represent an average of the values presented by those nationwide studies.

Audit data was only available for two inputs: number of household members and percentage of faucet use affected. The Evaluation Team used both of those values without modification.

Table 62. Faucet Aerator Inputs

Input	Assumed Values	Source
Bath Baseline Flow (gpm)	1.3	++
Kitchen Baseline Flow (gpm)	1.3	++
Bath Retrofit Flow (gpm)	1	++
Kitchen Retrofit Flow (gpm)	1	++
Household Members	2.9	HES audit data
Total Daily Faucet Use (gallons per capita per day)**	10.9	++
Down the Drain Use (%; kitchen)	0.5	+
Down the Drain Use (%; bath)	0.7	+
Kitchen Use (%)	0.65	+
Bath Use (%)	0.35	+
Kitchen Use Affected (%)	1.00	Assumes that 1 of 1 kitchen faucets were retrofitted
Bath Use Affected (%)	0.62	HES audit data: # installed / # bathrooms
Average Faucet Temperature (°F)	90	++
Cold Water Temperature (°F)	56.04	+++
Water Heater Recovery Efficiency	Electric: 0.97 Gas: 0.67 Oil: 0.59	Federal standard that varies by fuel type; no audit data was available

** This value assumes use for 365 days per year.** Biermayer, Peter J. *Potential Water and Energy Savings from Showerheads.* Lawrence Berkeley National Laboratory. 2006.

+ Cook, G. and B. Barkett. *Resource Savings Values in Selected Residential DSM Prescriptive Program.* Summit Blue Consulting, Inc. 2008.

++ Mayer, P.W. et al. *Residential End Uses of Water.* AWWA Research Foundation. 1999. Referenced by Biermayer 2006.

+++ U.S. Department of Energy. *Building America Benchmark Program Database.* 2010.

Water Heater Pipe Wrap

The Evaluation Team used the following engineering algorithm to estimate savings from DHW pipe wrap:

$$Savings\ per\ linear\ ft = \frac{\left(\frac{1}{R_{pre}} - \frac{1}{R_{post}}\right) \times Pipe\ Circ. \times \Delta T \times 8{,}760}{Hot\ Water\ Recovery\ Efficiency} \times Energy\ Conversion \times Thermal\ Regain\ Factor$$

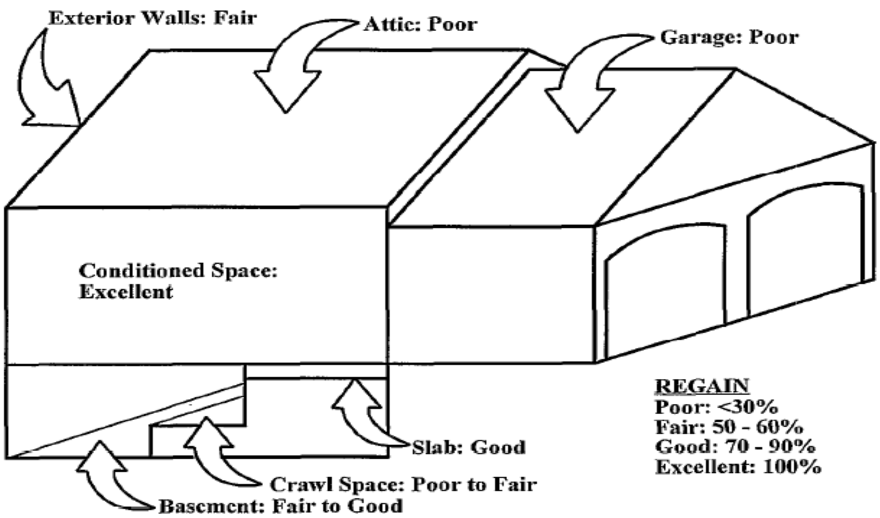
Table 63 shows the assumptions we used to calculate savings.

Table 63. Domestic Water Heater Pipe Wrap Savings

Input	Value	Source
R_{pre}	1	Navigant Consulting Inc. *Measures and Assumptions for Demand Side Management Planning*. Appendix C Substantiation Sheets, pp. 77. April 2009.
R_{post}	5	Low-income data observed in tracking data from Berkshire Gas
Pipe Circumference (feet)	0.13	Calculated assuming typical diameter of 0.5 inches
ΔT	55	Calculated assuming ambient temperature of 65°F and hot water temperature of 120°F
Thermal Regain Factor	42% Gas 33% Electric 41% Oil	Calculated based on typical system location, as found in HES audit data
Water Heater Recovery Efficiency	Electric: 0.97 Gas: 0.67 Oil: 0.59	Federal standard that varies by fuel type; no audit data was available

As with duct sealing and duct insulation, we estimated thermal regain effects, which accounts for the increased heat load in the home due to a reduction in losses from the energy saving measures installed. (See Figure 7 for an illustration of this process.)

Figure 7. Illustration of Thermal Regain by Location



Source: Andrews, John. *Better Duct Systems for Heating and Cooling.* U.S. Department of Energy. 2001.

As shown in Figure 7, thermal regain varies based on the system location. In conditioned spaces, 100% of reductions in losses are added to the heating system load, effectively cancelling out savings. In semi-conditioned spaces, such as basements, a smaller percentage of losses (50% to 90%) directly impact the heating system. In unconditioned spaces, none of the heat losses from pipes or ducts contribute to heating the home, making the insulation more effective.

The Evaluation Team defined thermal regain factors using the following equation, where it is the percentage of theoretical insulation savings that are captured, depending on location. For example, in a conditioned space where regain is equal to 100%, the thermal regain factor is zero.

$$Thermal\ Regain\ Factor = 1 - Regain$$

Table 64 and Table 65 summarize the thermal regain factors we assigned to each system location found in the HES audit data. Due to the lack of hot water-specific information, The Evaluation Team assumed that hot water systems are typically in the same area of the participants' homes as the heating systems.

Table 64. Location Category Assignments

System Location Specified	Assigned Location Category
Attic	Unconditioned
Crawlspace	Unconditioned
Basement	Basement
Garage	Unconditioned
Other Rooms (kitchen, living room, etc.)	Conditioned

Table 65. Assumed Thermal Regain Factors

System Location	Assumed Regain	Thermal Regain Factor
Unconditioned	15%	85%
Basement	60%	40%
Conditioned	100%	0%

Finally, The Evaluation Team used the known amounts of installed pipe insulation to calculate total average savings for each fuel type. We assumed a maximum of six feet of pipe insulated in unconditioned or semi-conditioned spaces.

Indirect Water Heaters

The Evaluation Team also estimated savings for boilers with indirect water heaters. We calculated the water heating component of the savings as follows:

$$Total\ Savings = Standby\ Save + Combustion\ Efficiency\ Save - Summer\ Loss$$

Where:

$$Standby\ Save, MMBtu = \Delta T_{tank,ambient} \times 8{,}760 \times \left(\frac{UA_{base}}{CE_{base}} - \frac{UA_{ee}}{CE_{ee}}\right) \times 10^{-6}$$

$$Combustion\ Efficiency\ Save, MMBtu = Gallons\ per\ year \times \Delta T_{cold,tank} \times \left(\frac{1}{CE_{base}} - \frac{1}{CE_{ee}}\right) \times Energy\ Conversion$$

$$Summer\ Loss = Gallons\ per\ summer \times \Delta T_{cold,tank} \times \left(\frac{1}{EF_{summer,ee}} - \frac{1}{EF_{ee}}\right) \times Energy\ Conversion$$

$$EF_{summer,ee} = Summer\ De-rating\ Factor \times EF_{ee}$$

$$EF_{ee} = Boiler\ AFUE - 0.0019 \times Storage\ Volume$$ [23]

Table 66 presents the inputs we used to calculate savings.

Table 66. Indirect Water Heater Savings Inputs

Input	Oil Value	Gas Value	Source
$\Delta T_{ambient,\ tank}$	50	50	Calculated: 120°F tank, 70°F ambient temperature
UA_{base}	2.38	2.38	Calculated based on storage volume, R-8 insulation
UA_{ee}	1.35	1.35	Calculated based on storage volume, R-16 insulation
Base Thermal Efficiency	0.59	0.67	Federal standard
Base Combustion Efficiency, CE_{base}	0.59	0.67	Calculated
EE Combustion Efficiency, CE_{ee}	0.86	0.86	Average high efficiency boiler AFUE
Annual Hot Water Use, Gallons	23,470	23,470	ENERGY STAR: 64.3 gallons per day
$\Delta T_{cold,\ tank}$	64	64	Calculated: 120°F tank, 56°F entering cold water temperature
Standard Storage Factor	-0.0019	-0.0019	Federal standard
Storage Volume, Gallons	42.2	42.2	HES DHW average
EF_{base}	0.51	0.59	Calculated
EF_{ee}	0.78	0.78	Calculated
Summer Derating Factor	20%	15%	Assumption: EF decreases due to additional boiler mass heating unnecessarily in summer months, variability in performance due to settings
$EF_{summer,ee}$	0.63	0.63	Calculated
Summer Length, Days	122	122	June through September

The savings reported for this measure represent water heating savings only. If a boiler and standalone water heater are replaced with a new indirect system (boiler and indirect tank), boiler savings should be added to the savings values reported for this measure (40 therms for natural gas, 6.4 MMBtu for oil).

23 This equation is per the current federal method to calculate EF standards for oil: EF = 0.59 – 0.0019 x storage volume.

Distribution

This section presents The Evaluation Team's savings methodology for two distribution measures, duct insulation and duct sealing. Table 67 summarizes the final savings estimates for these measures.

Table 67. Distribution Savings Summary

Category	Measure	Natural Gas (therms/year)	Electric (kWh/year)	Oil (MMBtus/year)
Distribution	Duct Insulation	68	1,613	7.7
	Duct Sealing	36	428	4.1

Duct Insulation

The Evaluation Team used HES Program audit data to calculate duct insulation savings. The audit data provided the average number of linear feet of insulation installed, heating system efficiency, and installed R-values. We calculated the savings used the following algorithm:

$$MMBtu\ Savings\ = \frac{\left(\frac{1}{R_{pre}} - \frac{1}{R_{post}}\right) \times Fan\ Run\ Hours \times Area \times \Delta T \times Thermal\ Regain\ Factor \times 10^{-6}}{Heating\ Efficiency}$$

Table 68 shows the input assumptions we used to calculate savings.

Table 68. Duct Insulation Inputs Based on HES Audit Data Averages

Heating Savings	Input: Unconditioned Space	Source
Fan Run Hours (heating)	1,014	2012 Massachusetts Brushless Motors Fan Study*
Area Insulated (square feet)	526	HES audit data
R-value (pre-installation)	1.2	Assumed
R-value (post-installation)	7.06	HES audit data
Average Duct Temperature (°F; 1/2 supply, 1/2 return)	87	Assumed: 105°F supply, 69°F return
Ambient Temperature (°F)	55	Assumed
ΔT	32	Calculated based on duct and ambient temperatures
Heating Efficiency	110% Electric 78% Gas 74% Oil	HES audit data
Thermal Regain Factor	41% Electric 42% Gas 33% Oil	Audit data from US DOE report**

* ERS and The Cadms Group, *Massachusetts Residential Retrofit Brushless Fan Motors Impact Evaluation.* 2012.

** Andrews, J. *Better Duct Systems for Heating and Cooling.* U.S. Department of Energy. 2001. Online: Accessed 2/22/2012. http://www.energycodes.gov/training/res_wbt/pdfs/DOEducts.pdf.

Duct Sealing

We did not collect any useable data from the audits related to duct sealing. Table 69 presents the key assumptions we used to calculate energy savings for this measure. We used the pre-NAC heating load from the billing analysis as the base consumption. Due to the low percentage of participants with air conditioning, we did not calculate cooling savings.

Table 69. Duct Sealing Assumptions

Input	Pre-Retrofit Value	Post-Retrofit Value	Source
Supply Leakage	9.0%	2.6%	Proctor 1996 APS study*
Return Leakage	8.0%	2.4%	Proctor 1996 APS study
Cooling Supply Temperature (°F)	55	55	Engineering estimate
Heating Supply Temperature (°F)	105	105	Engineering estimate
Cooling Return Temperature (°F)**	78	78	Engineering estimate
Heating Return Temperature (°F)**	69	69	Engineering estimate
Heating Savings (unconditioned space)***	-	9.1%	Calculated
Cooling Savings (unconditioned space)+	-	10.7%	Calculated

* Blasnik, M., T. Downey, J. Proctor, and G. Peterson. *Assessment of HVAC Installations in New Homes in APS Service Territory: Final Report.* Prepared for the Arizona Public Service Company by Proctor Engineering Group. 1996.

** These temperatures are theoretical (assuming no duct leakage); we calculated actual values based on assumed leakage.

*** This value is for a ventilated crawlspace.

+ This value is for an attic.

For duct sealing and duct insulation, The Evaluation Team also considered the effect of heating system location. We used HES audit data to determine the percentage of heating units in each location.

Table 70. Heating System Location (forced air systems only)

Location of Heating System	Electric Systems	Gas Systems	Oil Systems
Basement	62.0%	84.2%	55.7%
Unconditioned Space*	19.4%	9.9%	13.0%
Conditioned Space	18.5%	5.9%	31.2%

* These values are for a crawlspace, garage, or attic.

We calculated a weighted average of savings, assuming different levels of thermal regain for different heating system locations and different levels of thermal regain for duct insulation versus DHW pipe wrap (Andrews 2001). We did not include conditioned space the weighted average, because this measure is not provided for ducts in conditioned spaces.

APPENDIX C. BILLING ANALYSIS MODEL SPECIFICATIONS AND MODEL OUTPUTS

Model Specification – Gas Measure Detail

To obtain model savings for gas measures, the Cadmus Team used a fixed effects model specification, as follows:

$$ADC_{it} = \alpha_i + \beta_1 * HDD_{it} + \beta_2 * HEHE\_Boiler_i * HDD_{it} + \beta_3 * HEHE\_Furnace_i * HDD_{it} + \beta_4 * HEHE\_Thermostat_i * HDD_{it} + \beta_5 * HEHE\_DHW_i * HDD_{it} + \beta_6 * OPOWER_i * HDD_{it} + \beta_7 * AirSealing_i * HDD_{it} + \beta_8 * Attic_i * HDD_{it} + \beta_9 * Wall_i * HDD_{it} + \beta_{10} * Floor_i * HDD_{it} + \beta_{11} * Thermostat_i * HDD_{it} + \beta_{12} * Access_i * HDD_{it} + \beta_{13} * Showerhead_i * HDD_{it} + \beta_{14} * Aerator_i * HDD_{it} + \beta_{15} * Misc\_DHW_i * HDD_{it} + \beta_{16} * Misc\_HVAC\_Other_i * HDD_{it} + \beta_{17} * AirSealing_i * POST_{it} * HDD_{it} + \beta_{18} * Attic_i * POST_{it} * HDD_{it} + \beta_{19} * Wall_i * POST_{it} * HDD_{it} + \beta_{20} * Floor_i * POST_{it} * HDD_{it} + \beta_{21} * Thermostat_i * POST_{it} * HDD_{it} + \beta_{22} * Access_i * HDD_{it} * POST_{it} + \beta_{23} * Showerhead\_Aerator_i * POST_{it} + \beta_{24} * Misc\_DHW_i * POST_{it} + \beta_{25} * Misc\_HVAC\_Other_i * POST_{it} + \beta_{26} * HEHE\_Boiler_i * POST_{it} + \beta_{27} * HEHE\_Furnace_i * POST_{it} + \beta_{28} * HEHE\_Thermostat_i * POST_{it} + \beta_{29} * HEHE\_DHW_i * POST_{it} + \beta_{30} * OPOWER_i * POST_{it} + \varepsilon_{it}$$

Where, for customer 'i' and billing month 't':

ADC_{it}	=	The average daily therm consumption in the pre- and post-period
$POST_{it}$	=	An indicator variable that is 1 in the post-installation period and 0 in the pre-installation period
β_1	=	The average usage per HDD for non-participants
HDD_{it}	=	The average daily base 65 HDD for the nearest weather station based on location
β_2	=	The incremental average usage per HDD for HEHE boiler participants
$HEHE\_Boiler_i * HDD_{it}$	=	An interaction between the HEHE boiler participant flag and average daily HDD
β_3	=	The incremental average usage per HDD for HEHE furnace participants
$HEHE\_Furnace_i * HDD_{it}$	=	An interaction between the HEHE furnace participant flag and average daily HDD
β_4	=	The incremental average usage per HDD for HEHE thermostat participants
$HEHE\_Thermostat_i * HDD_{it}$	=	An interaction between the HEHE thermostat participant flag and average daily HDD

β_5 = The incremental average usage per HDD for HEHE water heating participants

$HEHE\_DHW_i * HDD_{it}$ = An interaction between the HEHE water heating participant flag and average daily HDD

β_6 = The incremental average usage per HDD for OPOWER participants

$OPOWER_i * HDD_{it}$ = An interaction between the OPOWER participant flag and average daily HDD

β_7 = The incremental average usage per HDD for air sealing participants

$Air\ Sealing_i * HDD_{it}$ = An interaction between the air sealing participant flag and average daily HDD

β_8 = The incremental average usage per HDD for attic insulation participants

$Attic_i * HDD_{it}$ = An interaction between the attic insulation participant flag and average daily HDD

β_9 = The incremental average usage per HDD for wall insulation participants

$Wall_i * HDD_{it}$ = An interaction between the wall insulation participant flag and average daily HDD

β_{10} = The incremental average usage per HDD for basement insulation participants

$Basement_i * HDD_{it}$ = An interaction between the basement insulation participant flag and average daily HDD

β_{11} = The incremental average usage per HDD for thermostat participants

$Thermostat_i * HDD_{it}$ = An interaction between the thermostat participant flag and average daily HDD

β_{12} = The incremental average usage per HDD for Thermadome & attic access insulation participants

$Access_i * HDD_{it}$ = An interaction between the Thermadome & attic access insulation participant flag and average daily HDD

β_{13} = The incremental average usage per HDD for showerhead participants

$Showerhead_i * HDD_{it}$ = An interaction between the showerhead participant flag and average daily HDD

β_{14} = The incremental average usage per HDD for aerator participants

$Aerator_i * HDD_{it}$ = An interaction between the aerator participant flag and average daily HDD

β_{15} = The incremental average usage per HDD for miscellaneous water heating participants

$Misc\_DHW_i * HDD_{it}$ = An interaction between the miscellaneous water heating participant flag and average daily HDD

β_{16} = The incremental average usage per HDD for miscellaneous HVAC and other participants

$MISC\_HVAC\_OTHER_i * HDD_{it}$ = An interaction between the miscellaneous HVAC and other participant flag and average daily HDD

β_{17} = The savings per HDD for air sealing participants

$Air\ Sealing_i * POST_{it} * HDD_{it}$ = An interaction between the air sealing participant flag, the $POST_{it}$ indicator, and average daily HDD

β_{18} = The savings per HDD for attic insulation participants

$Attic_i * POST_{it} * HDD_{it}$ = An interaction between the attic insulation participant flag, the $POST_{it}$ indicator, and average daily HDD

β_{19} = The savings per HDD for wall insulation participants

$Wall_i * POST_{it} * HDD_{it}$ = An interaction between the wall insulation participant flag, the $POST_{it}$ indicator, and average daily HDD

β_{20} = The savings per HDD for basement insulation participants

$Basement_i * POST_{it} * HDD_{it}$ = An interaction between the basement insulation participant flag, the $POST_{it}$ indicator, and average daily HDD

β_{21} = The savings per HDD for thermostat participants

$Thermostat_i * POST_{it} * HDD_{it}$ = An interaction between the thermostat participant flag, the $POST_{it}$ indicator, and average daily HDD

β_{22} = The savings per HDD for Thermadome & attic access insulation participants

$Access_i * POST_{it} * HDD_{it}$ = An interaction between the Thermadome & attic access insulation participant flag, the $POST_{it}$ indicator, and average daily HDD

β_{23} I = The average daily savings for showerhead and aerator participants

$Showerhead\_Aerator_i * POST_{it}$ = An interaction between the showerhead and aerator participant flag and the $POST_{it}$ indicator

β_{24} I = The average daily savings for miscellaneous water heating participants

$MISC\_DHW_i * POST_{it}$ = An interaction between the miscellaneous water heating participant flag and the $POST_{it}$ indicator

β_{25} I = The average daily savings for miscellaneous HVAC and other participants

$MISC\_HVAC\_Other_i * POST_{it}$ = An interaction between the miscellaneous HVAC and other participant flag and the $POST_{it}$ indicator

β_{26} = The average daily savings for HEHE boiler participants

$HEHE\_Boiler_i * POST_{it}$ = An interaction between the HEHE boiler participant flag and the $POST_{it}$ indicator

β_{27} = The average daily savings for HEHE furnace participants

$HEHE\_Furnace_i * POST_{it}$ = An interaction between the HEHE furnace participant flag and the $POST_{it}$ indicator

β_{28} = The average daily savings for HEHE thermostat participants

$HEHE\_Thermostat_i * POST_{it}$ = An interaction between the HEHE thermostat participant flag and the $POST_{it}$ indicator

β_{29} = The average daily savings for HEHE water heating participants

$HEHE\_DHW_i * POST_{it}$ = An interaction between the HEHE water heating participant flag and the $POST_{it}$ indicator

β_{30} = The average daily savings for OPOWER participants

$OPOWER_i * POST_{it}$ = An interaction between the OPOWER participant flag and the $POST_{it}$ indicator

ε_{it} = The model error term

The following calculations show how we derived the final savings estimates from the model coefficients:

β_{17} * 6,024[24] = Annual **air sealing** savings using normal typical meteorological year (TMY3) HDDs

β_{18} * 6,099 = Annual **attic insulation** savings using normal TMY3 HDDs

β_{19} * 6,029 = Annual **wall insulation** savings using normal TMY3 HDDs.

The model parameters and parameter estimates are provided in Table 71. The bold rows in the table highlight the model terms and coefficients used to report *ex post* savings generated by the billing analysis.

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[24] 6,024 is the average of the typical meteorological year (TMY3; 1991-2005) series HDDs across all the air sealing participants.

Table 71. Gas Savings Measure-Level Model Parameters and Estimates

Variable	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|
HDD	1	0.16165	0.00033878	477.15	<.0001
HEHE_BOILER * HDD	1	0.00364	0.00169	2.15	0.0315
HEHE_FURNACE * HDD	1	-0.0202	0.00167	-12.08	<.0001
HEHE_TSTAT * HDD	1	0.00584	0.0015	3.88	0.0001
HEHE_WH * HDD	1	-0.00183	0.00145	-1.27	0.2054
OPOWER * HDD	1	0.02854	0.00051046	55.91	<.0001
AIR SEALING * HDD	1	0.01196	0.00101	11.88	<.0001
ATTIC INS * HDD	1	-0.00571	0.00136	-4.19	<.0001
WALL INS * HDD	1	0.00095337	0.00151	0.63	0.5282
BASEMENT INS * HDD	1	-0.01132	0.00198	-5.73	<.0001
TSTAT * HDD	1	0.01049	0.00102	10.29	<.0001
ACCESS * HDD	1	-0.00854	0.00175	-4.88	<.0001
SHOWERHEAD * HDD	1	-0.00578	0.00090561	-6.38	<.0001
AERATOR * HDD	1	-0.01162	0.00097	-11.98	<.0001
MISC DHW * HDD	1	-0.01079	0.00126	-8.55	<.0001
MISC HVAC_OTHER * HDD	1	0.00095553	0.00292	0.33	0.7433
AIR SEALING * HDD * POST	1	-0.00887	0.00099262	-8.94	<.0001
ATTIC INS * HDD * POST	1	-0.01255	0.00141	-8.89	<.0001
WALL INS * HDD * POST	1	-0.01642	0.00157	-10.43	<.0001
BASEMENT INS * HDD * POST	1	-0.0009832	0.00206	-0.48	0.6334
TSTAT * HDD * POST	1	-0.00739	0.00105	-7.06	<.0001
ACCESS * HDD * POST	1	-0.00251	0.0018	-1.39	0.1636
SHOWERHEADAERATOR * POST	1	0.01286	0.01909	0.67	0.5004
MISC DHW * POST	1	0.12547	0.03209	3.91	<.0001
MISC HVAC_OTHER * POST	1	-0.00554	0.00307	-1.81	0.0707
HEHE_BOILER * POST	1	-0.3765	0.06183	-6.09	<.0001
HEHE_FURNACE * POST	1	-0.35354	0.05867	-6.03	<.0001
HEHE_TSTAT * POST	1	-0.18278	0.05232	-3.49	0.0005
HEHE_DHW * POST	1	-0.09064	0.05405	-1.68	0.0935
OPOWER * POST	1	-0.09565	0.01436	-6.66	<.0001

Model Specification – Gas Measure Overall Model

To obtain overall model savings across all the gas measures, the Cadmus Team used a fixed effects model specification, as follows:

$$ADC_{it} = \alpha_i + \beta_1 * HDD_{it} + \beta_2 * HEHE\_Boiler_i * HDD_{it} + \beta_3 * HEHE\_Furnace_i * HDD_{it} + \beta_4 * HEHE\_Thermostat_i * HDD_{it} + \beta_5 * HEHE\_DHW_i * HDD_{it} + \beta_6 * OPOWER_i * HDD_{it} + \beta_7 * POST_{it} + \beta_8 * POST_{it} * HDD_{it} + \beta_9 * HEHE\_Boiler_i * POST_{it} + \beta_{10} * HEHE\_Furnace_i * POST_{it} + \beta_{11} * HEHE\_Thermostat_i * POST_{it} + \beta_{12} * HEHE\_DHW_i * POST_{it} + \beta_{13} * OPOWER_i * POST_{it} + \varepsilon_{it}$$

Where, for customer 'i' and billing month 't':

ADC_{it} = The average daily therm consumption in the pre- and post-period

β_1 = The average usage per HDD for non-participants

HDD_{it} = The average daily base 65 HDD for the nearest weather station based on location

β_2 = The incremental average usage per HDD for HEHE boiler participants

$HEHE\_Boiler_i * HDD_{it}$ = An interaction between the HEHE boiler participant flag and average daily HDD

β_3 = The incremental average usage per HDD for HEHE furnace participants

$HEHE\_Furnace_i * HDD_{it}$ = An interaction between the HEHE furnace participant flag and average daily HDD

β_4 = The incremental average usage per HDD for HEHE thermostat participants

$HEHE\_Thermostat_i * HDD_{it}$ = An interaction between the HEHE thermostat participant flag and average daily HDD

β_5 = The incremental average usage per HDD for HEHE water heating participants

$HEHE\_DHW_i * HDD_{it}$ = An interaction between the HEHE water heating participant flag and average daily HDD

β_6 = The incremental average usage per HDD for OPOWER participants

$OPOWER_i * HDD_{it}$ = An interaction between the OPOWER participant flag and average daily HDD

β_7 = The average daily base load savings for participants

$POST_{it}$ = An indicator variable that is 1 in the post-installation period and 0 in the pre-installation period

β_8 = The heating savings per HDD for participants

$POST_{it} * HDD_{it}$ = An interaction between the $POST_{it}$ indicator and average daily HDD

β_9 = The average daily savings for HEHE boiler participants

$HEHE\_Boiler_i * POST_{it}$ = An interaction between the HEHE boiler participant flag and the $POST_{it}$ indicator

β_{10} = The average daily savings for HEHE furnace participants

$HEHE\_Furnace_i * POST_{it}$ = An interaction between the HEHE furnace participant flag and the $POST_{it}$ indicator

β_{11} = The average daily savings for HEHE thermostat participants

$HEHE\_Thermostat_i * POST_{it}$ = An interaction between the HEHE thermostat participant flag and the $POST_{it}$ indicator

β_{12} = The average daily savings for HEHE water heating participants

$HEHE\_DHW_i * POST_{it}$ = An interaction between the HEHE water heating participant flag and the $POST_{it}$ indicator

β_{13} = The average daily savings for OPOWER participants

$OPOWER_i * POST_{it}$ = An interaction between the OPOWER participant flag and the $POST_{it}$ indicator

ε_{it} = The model error term

The following calculations show how we derived the final savings estimates from the model coefficients.

$\beta_7 * 6{,}052$[25] = Annual overall heating related savings using normal TMY3 HDDs

$\beta_8 * 365$ = Annual overall base load savings

[25] 6,052 is the average of the typical meteorological year (TMY3; 1991-2005) series HDDs across all the gas participants.

The model parameters and parameter estimates are provided in Table 72.

Table 72. Gas Savings Overall Model Parameters and Estimates

Variable	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|
HEHE_BOILER * HDD	1	0.00307	0.00169	1.81	0.0703
HEHE_FURNACE * HDD	1	-0.02015	0.00167	-12.04	<.0001
HEHE_TSTAT * HDD	1	0.00532	0.00151	3.53	0.0004
HEHE_WH * HDD	1	-0.00209	0.00145	-1.44	0.1497
OPOWER * HDD	1	0.02948	0.00050549	58.32	<.0001
POST	1	0.04633	0.0086	5.38	<.0001
POST * HDD	1	-0.01324	0.0004988	-26.54	<.0001
HEHE_BOILER * POST	1	-0.37166	0.06197	-6	<.0001
HEHE_FURNACE * POST	1	-0.36014	0.05879	-6.13	<.0001
HEHE_TSTAT * POST	1	-0.18822	0.05247	-3.59	0.0003
HEHE_DHW * POST	1	-0.09006	0.05417	-1.66	0.0964
OPOWER * POST	1	-0.08663	0.01438	-6.03	<.0001

Model Specification - Electric

To obtain model savings for electric base load measures, the Evaluation Team used a fixed effects model specification, as follows:

$$\boldsymbol{ADC_{it}} = \alpha_i + \beta_1 * \boldsymbol{HDD_{it}} + \beta_2 * \boldsymbol{OPOWER_i * HDD_{it}} + \beta_3 * \boldsymbol{Lighting_i * HDD_{it}} + \beta_4 * \boldsymbol{Refrigerator_i * HDD_{it}} + \beta_5 * \boldsymbol{Showerhead\_Aerator_i * HDD_{it}} + \beta_6 * \boldsymbol{Fan_i * HDD_{it}} + \beta_7 * \boldsymbol{CDD_{it}} + \beta_8 * \boldsymbol{OPOWER_i * CDD_{it}} + \beta_9 * \boldsymbol{Lighting_i * CDD_{it}} + \beta_{10} * \boldsymbol{Refrigerator_i * CDD_{it}} + \beta_{11} * \boldsymbol{Showerhead\_Aerator_i * CDD_{it}} + \beta_{12} * \boldsymbol{Fan_i * CDD_{it}} + \beta_{13} * \boldsymbol{Lighting_i * POST_t} + \beta_{14} * \boldsymbol{Refrigerator_i * POST_{it}} + \beta_{15} * \boldsymbol{Showerhead\_Aerator_i * POST_{it}} + \beta_{16} * \boldsymbol{Fan_i * POST_{it} * HDD_{it}} + \beta_{17} * \boldsymbol{OPOWER_i * POST_{it}} + \varepsilon_{it}$$

Where, for customer 'i' and billing month 't':

ADC_{it} = The average daily therm consumption in the pre- and post-period

$POST_{it}$ = An indicator variable that is 1 in the post-installation period and 0 in the pre-installation period

β_1 = The average usage per HDD for non-participants

HDD_{it} = The average daily base 65 HDD for the nearest weather station based on location

β_2 = The incremental average usage per HDD for OPOWER participants

$OPOWER_i * HDD_{it}$ = An interaction between the OPOWER participant flag and average daily HDD

β_3 = The incremental average usage per HDD for lighting participants

$Lighting_i * HDD_{it}$ = An interaction between the lighting participant flag and average daily HDD

β_4 = The incremental average usage per HDD for refrigerator participants

$Refrigerator_i * HDD_{it}$ = An interaction between the refrigerator participant flag and average daily HDD

β_5 = The incremental average usage per HDD for showerhead and aerator participants

$Showerhead\_Aerator_i * HDD_{it}$ = An interaction between the showerhead and aerator participant flag and average daily HDD

β_6 = The incremental average usage per HDD for gas furnace fan participants

$Fan_i * HDD_{it}$ = An interaction between the gas furnace fan participant flag and average daily HDD

β_7 = The average usage per CDD for non-participants

CDD_{it} = The average daily base 65 CDD for the nearest weather station based on location

β_8 = The incremental average usage per CDD for OPOWER participants

$OPOWER_i * CDD_{it}$ = An interaction between the OPOWER participant flag and average daily CDD

β_9 = The incremental average usage per CDD for lighting participants

$Lighting_i * CDD_{it}$ = An interaction between the lighting participant flag and average daily CDD

β_{10} = The incremental average usage per CDD for refrigerator participants

$Refrigerator_i * CDD_{it}$ = An interaction between the refrigerator participant flag and average daily CDD

β_{11} = The incremental average usage per CDD for showerhead and aerator participants

$Showerhead\_Aerator_i * CDD_{it}$ = An interaction between the showerhead and aerator participant flag and average daily CDD

β_{12} = The incremental average usage per CDD for gas furnace fan participants

$Fan_i * CDD_{it}$ = An interaction between the gas furnace fan participant flag and average daily CDD

β_{13} = The average daily savings for lighting participants

$Lighting_i * POST_{it}$= An interaction between the lighting participant flag and and the $POST_{it}$ indicator

β_{14} = The average daily savings for refrigerator participants

$Refrigerator_i * POST_{it}$ = An interaction between the refrigerator participant flag and the $POST_{it}$ indicator

β_{15} = The average daily savings for showerhead and aerator participants

$Showerhead\_Aerator_i * POST_{it}$ = An interaction between the showerhead and aerator participant flag and the $POST_{it}$ indicator

β_{16} = The savings per HDD for gas furnace fan participants

$Fan_i * POST_{it} * HDD_{it}$ = An interaction between the gas furnace fan participant flag and average daily HDD

β_{17} = The average daily savings for OPOWER participants

$OPOWER_i * POST_{it}$ = An interaction between the OPOWER participant flag and the $POST_{it}$ indicator

ε_{it} = The model error term

where,

- β_{13} * 365 = Annual **Lighting** Savings
- β_{14} * 365 = Annual **Refrigerator** Savings

The model parameters and parameter estimates are provided in Table 73. The bolded rows highlight the model terms and coefficients used to report *ex post* savings generated by the billing analysis.

Table 73. Electric Base Load Measure Level Parameters and Estimates

Variable	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|
HDD	1	0.21474	0.00121	177.31	<.0001
OPOWER * HDD	1	0.09569	0.00283	33.79	<.0001
LIGHTING * HDD	1	0.01112	0.00227	4.91	<.0001
REFRIGERATOR * HDD	1	-0.04792	0.00689	-6.95	<.0001
SHOWERHEADAERATOR * HDD	1	0.02496	0.0117	2.13	0.0329
FAN * HDD	1	-0.07136	0.00381	-18.74	<.0001
CDD	1	1.40331	0.00585	239.81	<.0001
OPOWER * CDD	1	0.6131	0.01477	41.51	<.0001
LIGHTING * CDD	1	0.09288	0.01072	8.66	<.0001
REFRIGERATOR * CDD	1	0.02718	0.03466	0.78	0.4329
SHOWERHEADAERATOR * CDD	1	-0.47663	0.0543	-8.78	<.0001
FAN * CDD	1	-0.11678	0.01566	-7.46	<.0001
LIGHTING * POST	1	-1.50028	0.03828	-39.2	<.0001
REFRIGERATOR * POST	1	-1.95545	0.14778	-13.23	<.0001
SHOWERHEADAERATOR * POST	1	-0.81553	0.24752	-3.29	0.001
FAN * POST * HDD	1	0.00237	0.00295	0.8	0.4224
OPOWER * POST	1	-0.15653	0.06985	-2.24	0.025