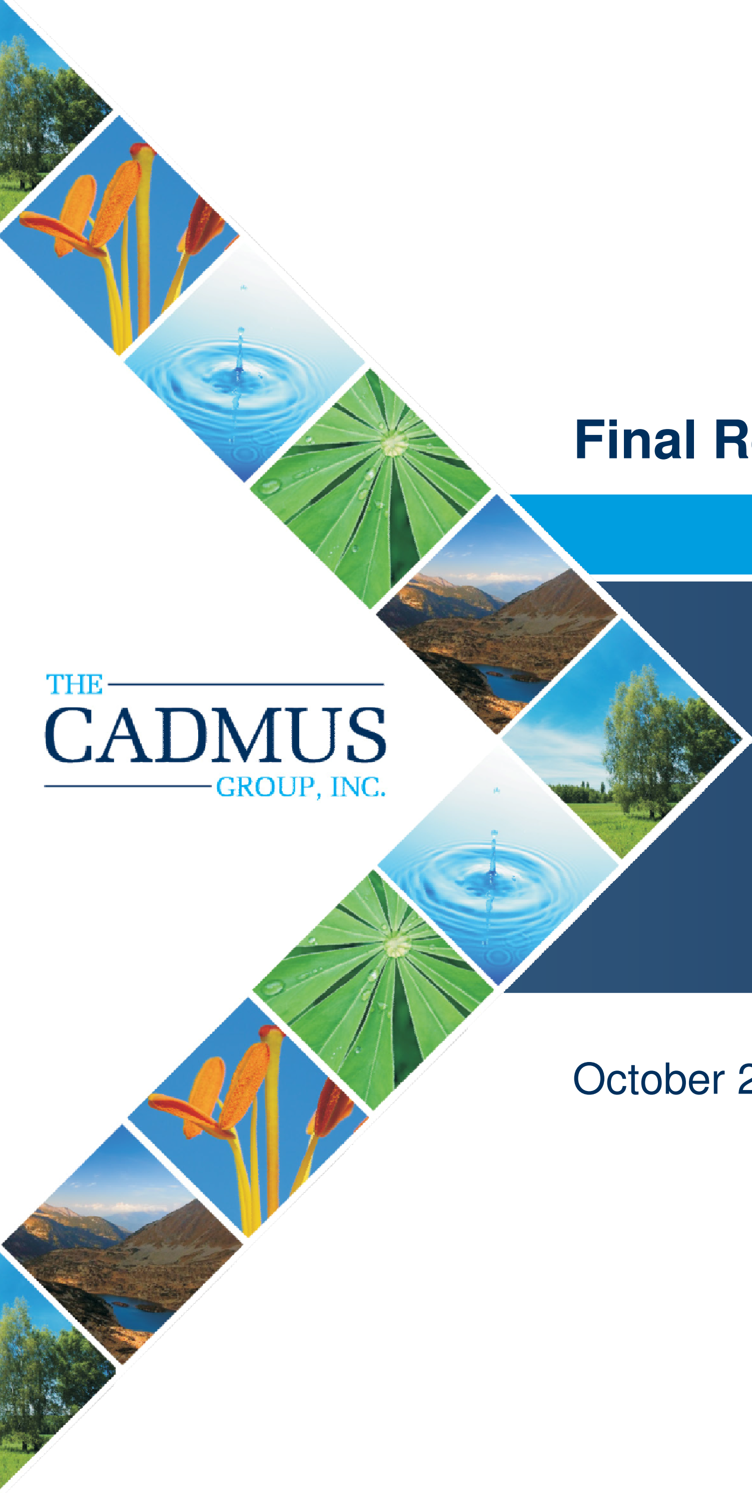

THE CADMUS GROUP, INC.

Final Report

Rhode Island EnergyWise Single Family Impact Evaluation

October 2012

Prepared by:

The Cadmus Group, Inc.
Energy Services Division
720 SW Washington Street, Suite 400
Portland, OR 97205
503.467.7100

Prepared for:

National Grid
Attn: Rachel Henschel

Prepared by:
Bryan Ward
Doug Bruchs
Matei Perussi
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
CDD	Cooling degree day
CFL	Compact fluorescent light
CSA	Conditional savings analysis
DHW	Domestic hot water
EISA	Energy Independence and Security Act
GPM	Gallons per Minute
HDD	Heating degree day
HEHE	High Efficiency Heating and Water Heating
HES	Home Energy Services (Massachusetts)
HOU	Hours-of-use
HVAC	Heating, ventilating, and air conditioning
kWh	Kilowatt hour
pre-NAC	Pre-retrofit normalized annual consumption
PRISM	Princeton Scorekeeping Method
TRM	Technical Reference Manual

EXECUTIVE SUMMARY

This report summarizes the gross impact evaluation findings of the EnergyWise Program, conducted by The Cadmus Group, Inc., and Navigant Consulting (collectively referred to as the Evaluation Team).

Methodology

The Evaluation Team assessed the gross per-unit savings generated by each EnergyWise 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 electricity and/or natural gas measures installed by National Grid. We informed these weather-normalized models with detailed measure data provided by National Grid's EnergyWise implementer, RISE. The Team also used a control group composed of future EnergyWise participants to account for macroeconomic factors that might have impacted current participants' energy consumption between the pre- and post-periods.
- ***Engineering Analysis.*** The Team used 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 we used for 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 EnergyWise 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 (40% or less at the 90% confidence level). The Team derived the savings for all other measures using engineering analysis. Table 1 details which approach we used for each EnergyWise 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 (MMBtu/year)
Weatherization	Insulation (overall) with Air Sealing*	Billing Analysis (±22%)	Simulation Modeling	Simulation Modeling
	Insulation (overall) without Air Sealing**	Billing Analysis (±20%)	Simulation Modeling	Simulation Modeling
	- Attic Insulation	Billing Analysis (±34%)	Simulation Modeling	Simulation Modeling
	- Wall Insulation	Billing Analysis (±24%)	Simulation Modeling	Simulation Modeling
	- Basement/Floor Insulation	Simulation Modeling	Simulation Modeling	Simulation Modeling
	Air Sealing	Billing Analysis (±37%)	Simulation Modeling	Simulation Modeling
	Furnace Fan (due to insulation)	Simulation Modeling	--	Simulation Modeling
	Cooling Savings (due to insulation)	Simulation Modeling	--	Simulation Modeling
	Programmable Thermostat	Engineering Algorithm	Engineering Algorithm	Engineering Algorithm
Lighting & Appliances	Compact Fluorescent Lights	--	Billing Analysis (±13%)	--
	Fixtures	--	Billing Analysis (±13%)	--
	Refrigerator Replacement	--	Billing Analysis (±30%)	--
	Refrigerator Brushes	--	Engineering Algorithm	--
Domestic Hot Water	Overall***	Engineering Algorithm	Engineering Algorithm	--
	- Showerhead	Engineering Algorithm	Engineering Algorithm	--
	- Faucet Aerator	Engineering Algorithm	Engineering Algorithm	--
	- Pipe Wrap	Engineering Algorithm	Engineering Algorithm	--
Other****	All Other Measures (duct sealing, Thermadomes, access measures)	Billing Analysis (±57%)	--	--

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

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

*** Average savings for a household that received at least one domestic hot water measure.

**** Since this measure category contains miscellaneous measures, it was assessed in aggregate through the billing analysis despite not meeting the specified precision requirements.

Results

The per-unit gross *ex post* energy savings by measure and primary fuel type determined through this evaluation are summarized in Table 2, Table 3, and Table 4.

Table 2. Annual *Ex Post* Gross Savings by Measure for Natural Gas

Category	Measure	Sample Size*	*Ex Ante*** Savings (therms/year)	*Ex Post* Savings (therms/year)	Realization Rate
Weatherization	Insulation (overall) with Air Sealing***	409	213	190	90%
	Insulation (overall) without Air Sealing****	380	143	124	87%
	- Attic Insulation	302	102	87	85%
	- Wall Insulation	146	131	110	84%
	- Basement/ Floor Insulation	132	32	35	109%
	- Air Sealing	353	93	87	94%
	Furnace Fan (due to insulation)	N/A	N/A	202 (kWh)	N/A
	Cooling Savings (due to insulation)	N/A	N/A	49 (kWh)	N/A
	Programmable Thermostat	N/A	N/A	31	N/A
Domestic Hot Water	Overall+	312	4.6	4.9	105%
	- Showerhead	N/A	6	11.0	183%
	- Faucet Aerator	N/A	3	2.4	80%
	- Pipe Wrap	N/A	3	2.2	73%
Other*****	All Other Measures (duct sealing, Thermadomes, access measures)	308	31	58	187%
Total	**All Measures++**	**646**	**152**	**151**	**99%**

* These sample sizes are based on 2010 and Q1 and Q2 2011 participation counts (which align with customers included in the billing analysis). All measure-specific sample sizes reference the number of measures installed, while the total (n=646) is the total number of unique participants.

** Calculated using participant and measure-specific savings estimated by RISE in 2011. Air Sealing measures initially included duct sealing savings. Those savings have been placed into the other measure category.

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

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

***** Since this measure category contains miscellaneous measures, it was assessed in aggregate through the billing analysis despite not meeting the specified precision requirements.

+ Average savings for a household that received at least one domestic hot water measure.

++ Weighted average of measure-specific *ex ante* and *ex post* savings, by installation. Thermostats were excluded because ex ante savings were not available and only 2 installations occurred in 2009 - not part of the analysis period.

Other notes:

- The measure-weighted total savings of 151 therms per household is nearly identical to the household-level billing analysis result (144 therms).

Table 3. Annual *Ex Post* Gross Savings by Measure for Electric

Category	Measure	Sample Size*	*Ex Ante*** Savings (therms/year)	*Ex Post* Savings (therms/year)	Realization Rate
Weatherization	Insulation (overall) with Air Sealing***	33	939	1,558	166%
	Insulation (overall) without Air Sealing****	29	N/A	772	N/A
	- Attic Insulation	26	N/A	774	N/A
	- Wall Insulation	3	N/A	1,216	N/A
	- Basement Insulation	8	N/A	171	N/A
	- Air Sealing	26	N/A	995	N/A
	Programmable Thermostat	254	50	330	660%
Lighting & Appliances	Compact Fluorescent Lights	29,789	47	47	100%
	Fixtures	1,552	65	65	100%
	Refrigerator Replacement	123	479	770	161%
	Refrigerator Brushes	2,125	58	37	64%
Domestic Hot Water	Overall+	94	155	109	71%
	- Showerhead	N/A	N/A	222	N/A
	- Faucet Aerator	N/A	N/A	49	N/A
	- Pipe Wrap	N/A	N/A	28	N/A
Total	**All Measures++**	**3,581**	**486**	**508**	**105%**

* These totals are based on 2010 participation counts (which aligns with customers included in the billing analysis). All measure-specific sample sizes reference the number of measures installed, while the total (n=3,581) is the total number of unique participants.

** Based on 2009 Cadmus evaluation, except CFLs.

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

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

+ Average savings for a household that received at least one domestic hot water measure.

++ Weighted average of measure-specific *ex ante* and *ex post* savings, by installation.

Other notes:

- The overall ex post savings for overall insulation/air sealing includes 115 kWh cooling savings.
- The measure-weighted total savings of 508 kWh per household is 6% less than the household-level billing analysis results (539 kWh)

Table 4. Annual *Ex Post* Gross Savings by Measure for Oil

Category	Measure	Sample Size*	*Ex Ante*** Savings (therms/year)	*Ex Post* Savings (therms/year)	Realization Rate
Weatherization	Insulation (overall) with Air Sealing***	70	N/A	24.0	N/A
	Insulation (overall) without Air Sealing****	68	N/A	15.0	N/A
	- Attic Insulation	54	N/A	11	N/A
	- Wall Insulation	28	N/A	11	N/A
	- Basement/Floor Insulation	29	N/A	4	N/A
	- Air Sealing	66	N/A	10	N/A
	Furnace Fan (due to insulation)	N/A	N/A	266 (kWh)	N/A
	Cooling Savings (due to insulation)	N/A	N/A	70 (kWh)	N/A
	Programmable Thermostat	1	N/A	3.2	N/A
Total	**All Measures+**	**71**	**13.7**	**23.7**	**173%**

* Based on 2010 and 2011 program participation

** *Ex ante* based on 2012 Planning estimates (no data on many of the measures to derive oil savings).

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

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

+ Weighted average of measure-specific *ex ante* and *ex post* savings, by installation.

INTRODUCTION

Program Overview

Through their EnergyWise Program, National Grid offers energy-efficiency audits and incentives for residential customers. Residential customers may participate regardless of their heating fuel type; however, the incentive amount varies based on the type of heat fuel and the number of units in the facility. Through the 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 distribution systems, such as duct and pipe insulation
- Thermostats
- Lighting
- Refrigerators
- Water heating measures, such as low-flow showerheads and faucet aerators
- Water heating systems

The goal of the EnergyWise 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.

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 the simulation modeling methodology.

METHODOLOGY

The Evaluation Team assessed the gross per-unit savings generated by each EnergyWise 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 National Grid. We informed these weather-normalized models with detailed measure data provided by National Grid's EnergyWise implementer, RISE. The Team also used a control group composed of future EnergyWise participants to account for macroeconomic factors that might have impacted current participants' energy consumption between the pre- and post-periods.
- ***Engineering Analysis.*** The Team used 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 we used for 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 EnergyWise 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 (40% or less at the 90% confidence level). The Team derived the savings for all other measures using the engineering analysis. Table 5 specifies which approach we used for each EnergyWise measure, by fuel type. The precision associated with each billing analysis-based savings estimate is also provided.

Table 5. Methodological Approach to Calculating Savings by Measure and Primary Fuel Type

Category	Measure	Natural Gas (therms/year)	Electric (kWh/year)	Oil (MMBtu/year)
Weatherization	Insulation (overall) with Air Sealing*	Billing Analysis (±22%)	Simulation Modeling	Simulation Modeling
	Insulation (overall) without Air Sealing**	Billing Analysis (±20%)	Simulation Modeling	Simulation Modeling
	- Attic Insulation	Billing Analysis (±34%)	Simulation Modeling	Simulation Modeling
	- Wall Insulation	Billing Analysis (±24%)	Simulation Modeling	Simulation Modeling
	- Basement/Floor Insulation	Simulation Modeling	Simulation Modeling	Simulation Modeling
	Air Sealing	Billing Analysis (±37%)	Simulation Modeling	Simulation Modeling
	Furnace Fan (due to insulation)	Simulation Modeling	--	Simulation Modeling
	Cooling Savings (due to insulation)	Simulation Modeling	--	Simulation Modeling
	Programmable Thermostat	Engineering Algorithm	Engineering Algorithm	Engineering Algorithm
Lighting & Appliances	Compact Fluorescent Lights	--	Billing Analysis (±13%)	--
	Fixtures	--	Billing Analysis (±13%)	--
	Refrigerator Replacement	--	Billing Analysis (±30%)	--
	Refrigerator Brushes	--	Engineering Algorithm	--
Domestic Hot Water	Overall***	Engineering Algorithm	Engineering Algorithm	--
	- Showerhead	Engineering Algorithm	Engineering Algorithm	--
	- Faucet Aerator	Engineering Algorithm	Engineering Algorithm	--
	- Pipe Wrap	Engineering Algorithm	Engineering Algorithm	--
Other****	All Other Measures (duct sealing, Thermadomes, access measures)	Billing Analysis (±57%)	--	--

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

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

*** Average savings for a household that received at least one domestic hot water measure.

**** Since this measure category contains miscellaneous measures, it was assessed in aggregate through the billing analysis despite not meeting the specified precision requirements.

Treatment Group

For the impact analysis (which consisted of billing analysis and engineering analysis), the Team used a treatment group composed of 2010 EnergyWise participants that installed measures between January 1, 2010, and December 31, 2010. Additionally, we included January 1, 2011 to June 30, 2011 participants in the gas analysis in order to have more post-period billing data available, as the sample sizes were low.

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).[1] The imposition of these additional filters reduced the size of the treatment group available for the billing analysis, as shown in Table 6.

Table 6. Treatment Group Analysis Datasets

Analysis Approach	Electric	Natural Gas
Billing Analysis	2,581*	646

* This is the total number of participants. This includes 2,460 non-electric participants and 121 electric heat participants.

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 used a control group composed of 2011 EnergyWise participants for the electric billing analysis, and Q3 and Q4 2011 participants for the gas analysis.

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 more likely to resemble previous year participants 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.[2]

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 treatment group participants included in the analysis.

The number of future control group participants the Team used in the billing analysis[3] for the electric and gas models is presented in Table 7.

Table 7. Control Group Analysis Dataset

Analysis Approach	Electric	Natural Gas
Billing Analysis	5,083	569

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

2 The only measure this logic may not apply to is CFLs, as customers in the control group (which consists of future HES participants) may have installed independently prior to participating in HES. (Participants are, by definition, interested in energy-efficiency opportunities and may have taken action lower-cost efficiency action prior to their audit. As a result, the CFL savings presented in this report is neither a pure gross or pure net value and the additional application of a net-to-gross to this value would likely result in an underestimate of actual net savings.

3 The engineering analysis (using engineering algorithms 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 June 2012. We demarcated this time period into pre- and post-periods based on the date of each participant's initial measure installation and the date the last measure was installed. Specifically, we designated any billing data months occurring before the participant's earliest install date 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, 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.

Data Sources

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

- EnergyWise Measure Tracking Data
- ENERGY STAR®HVAC[4] Program Tracking Data
- Rhode Island Billing Data from National Grid
- Weather Data
- Rhode Island and Massachusetts Technical Reference Manuals (TRM)
- Other TRMs and Secondary Sources

EnergyWise Measure Tracking Data

The majority of our analysis was grounded in robust, detailed measure tracking data. The data contained records of each gas and electric measure installed from January 2010 through December 2011. We combined the measure tracking data by account numbers.

The measure tracking data included valuable information about the existing or pre-program conditions of participating homes and other general information about the homes (heating fuel, etc.). The Team leveraged this data for the engineering analysis.

4 Previously called COOL SMART and High Efficiency Heating and Water Heating (HEHE)

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

- Pre- and post-efficiency ratings for space and water heating equipment
- Existing, proposed, and installed measure quantities

ENERGY STAR HVAC Tracking Data

The Evaluation Team merged the detailed EnergyWise tracking data with tracking data provided for the ENERGY STAR HVAC program. This allowed us to identify EnergyWise participants who installed heating and air conditioning measures through the ENERGY STAR HVAC program.

Understanding whether participants' energy-efficiency improvements happened outside of the EnergyWise Program was critical to accurately estimating savings for EnergyWise. Without merging ENERGY STAR HVAC data, it is likely that changes in energy consumption resulting from participation in those programs would have been misattributed to the EnergyWise Program.

Billing Data

For the billing analysis, we utilized all the available participants' energy consumption records provided by National Grid. Due to an update in the gas billing data, data was only available through June 2012. The electric billing data was generally available up to February 2012. We only included data from 2009 through the latest available month in the billing analysis, as was described in the Analysis Period section.

Weather Data

The Evaluation Team collected weather data from the National Climatic Data Center for three stations across Rhode Island 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.

Rhode Island and Massachusetts TRMs

When implementer tracking data were not available to inform engineering analysis assumptions, the Evaluation Team first turned to the Rhode Island TRM as a secondary source for input assumptions, and then the Massachusetts TRM. The Evaluation Team valued the TRM as a source of Rhode Island-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 Rhode Island 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

Engineering Analysis

The Evaluation Team used two approaches for the engineering analysis: simulation modeling and standard engineering algorithms. Both approaches were primarily informed by the tracking data we utilized for the billing analysis. We assessed all EnergyWise measures—including those for which the billing analysis results were ultimately used to report evaluated savings—as part of the engineering analysis. Table 8 shows the approach we used for each major measure category.

Table 8. Summary of Engineering Methodology by Measure Category

Measure Category	Engineering Approach
Insulation & Air Sealing	Simulation
Programmable Thermostat	Algorithm
Lighting & Appliances	Algorithm
Domestic Hot Water	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 EnergyWise 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 advantages of simulation modeling over a simple engineering algorithmic approach are:

- Simulation modeling accounts for internal gains, thermostat setpoint 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 type of fuel (gas, oil, and electric). To accomplish this, we leveraged the EnergyWise tracking data for pre- and post-values and used the Massachusetts Home Energy Services (HES) Program audit data for the modeled building characteristics (as this information was not included in the EnergyWise data). Next, we calibrated each model to the various end-use consumption values (weatherization, 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 we have 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. Where Rhode Island data was not available, the Evaluation Team used Massachusetts HES and TRM data as a first alternative.

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

Billing Analysis

The Evaluation Team evaluated several different specification options for modeling 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 an account-level Princeton Scorekeeping Method (PRISM) model. This model type was not 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 the independent variables utilized.

Billing Data Screening

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

- 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 1,140 participants who had program measures installed in 2010 or Q1 or Q2 2011. We screened out a total of 494 participants based on the criteria noted above and detailed in Table 9. Attrition was due primarily to insufficient billing data and failed PRISM screens. Collectively, these screening criteria led to a final analysis dataset of 646 gas participants (43% attrition). We also screened out control group customer with less than one year of billing data from the analysis.

Table 9. Gas Billing Data Screening Criteria

Screening Criteria	Number of Sites Removed
Insufficient pre- and post-installation billing data or less than three winter months of billing data	287
Failed PRISM screening by having negative slopes in either the pre- or post-period*	160
Vacancies	31
Percent change was beyond three standard deviations from average. In effect, accounts increasing usage by more than 64% or decreasing usage by more than 70% of pre-period usage were dropped	16
Total Billing Accounts Screened	**494**

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

To inform the electric billing analysis, the Evaluation Team began with the population of 3,581 participants who had program measures installed in 2010. In total, we removed 1,000 participants from the analysis (28% attrition), based on the criteria shown in Table 10. Collectively, these screening criteria led to a final analysis dataset of 2,581 electric participants. As with the natural gas billing analysis, we screened out any control group customers with less than one year of billing data.

Table 10. Electric Billing Data Screening Criteria

Screening Criteria	Number of Sites Removed
Accounts with less than six months of pre- or post-period data	641
Vacancies	8
COOL SMART participants*	300
Percent change was beyond two standard deviations from average. In effect, accounts increasing usage by more than 50% or decreasing usage by more than 50% of pre-period usage were dropped	51
Total Billing Accounts Screened	**1,000**

* Since the predominant measures installed through the electric portion of the EnergyWise Program are baseload measures, we excluded COOL SMART participants because they confounded the small percentage of changes in consumption.

FINDINGS

This section presents evaluated gross savings estimates for all EnergyWise 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

Weatherization

As shown in Table 11, insulation and air sealing measures had similar participation rates; of the natural gas participants included in the billing analysis, 59% installed at least one type of insulation (attic/wall/basement) and 55% installed air sealing measures. Of the 380 customers who installed insulation, attic insulation was the most common (79%), followed by wall insulation (38%) and basement insulation (35%). On average, insulation participants had 1.5 different insulation types installed per home. Overall, 63% of the natural gas participants included in the billing analysis installed at least one insulation or air sealing measure.

Table 11. Distribution of Natural Gas Weatherization Measures Billing Analysis (Total Sample, n=646)

Measure	Sample Size*	Percent Installed
Insulation (overall) with Air Sealing**	409	63%
Insulation (overall) without Air Sealing***	380	59%
-Attic Insulation	302	79%***
-Wall Insulation	146	38%***
-Basement/Floor Insulation+	132	35%***
Air Sealing	353	55%

* These sample sizes are based on 2010 and Q1 and Q2 2011 participation counts (which align with customers included in the billing analysis). All measure-specific sample sizes reference the number of measures installed, while the total (n=646) is the total number of unique participants.

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

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

**** These percentages are based on the 59% of natural gas fuel customers (n=380) that installed at least one insulation measure.

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

The Evaluation Team calculated the average insulation levels (weighted by square footage installed) using the detailed implementer tracking data for R-values and square feet installed (Table 12).

Table 12. 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	302	10.6	44.3	1,017
Wall Insulation	146	3.7	13.2	1,257
Basement/Floor Insulation*	132	6.6	18.9	579

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

Table 13 summarizes the billing analysis results for insulation and air sealing. Specifically, the Evaluation Team used billing analysis to report savings for the following measures, as each met the precision requirement of less than ±40% of the estimated value: attic insulation (±34%), wall insulation (±24%), and air sealing (±37%). Estimated savings for basement insulation did not meet the precision requirements for billing analysis.

The evaluated savings for attic and wall insulation were 7% and 10%, respectively, of the pre-installation usage. Air sealing evaluated savings was 87 therms/year, or 7% of the pre-installation usage.

Table 13. 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
Attic Insulation	302	87	34%	1,177	7%	912	10%
Wall Insulation	146	110	24%	1,155	10%	905	12%
Air Sealing	353	87	37%	1,172	7%	908	10%

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 14 shows savings for all natural gas insulation and air sealing measures, including those estimated using the billing analysis and the engineering analysis (simulation modeling and engineering algorithms).

Table 14. Evaluated Natural Gas Energy Savings for Insulation and Air Sealing

Category	Measures	Evaluated Savings (therms/year)
Weatherization	Overall Insulation with Air Sealing	190*
	Overall Insulation without Air Sealing (1.5 average installations)	124*
	- Attic Insulation (79% installed)	87*
	- Wall Insulation (38% installed)	110*
	- Basement/Floor Insulation (35% installed)	35
	- Air Sealing	87*
	Furnace Fan (due to insulation)	202 (kWh)
	Cooling Savings (due to insulation)	49 (kWh)
	Programmable Thermostat	31

* These savings values were determined through the billing analysis. The basement/floor insulation, furnace fan, and cooling savings values were determined through simulation modeling. The programmable thermostat savings value was determined through an engineering algorithm.

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, these data were not measured. As a result, we estimated the baseline to be 2.5 gallons per minute (GPM), which has been the federal standard since 1994.

Table 15 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 15. Distribution of Hot Water Measures for Gas Participants

Measure	Participants*	Amount Installed per Participant	Percent of Participants Receiving Measure (Weight)**
Showerheads	59	1.2 units	21%
Faucet Aerators	61	1.2 units	37%
Pipe Wrap	233	8 feet	75%
Overall	**312**		**133%**

* The Team normalized the number of participants to that used in the billing analysis (n=312) for DHW measures. Individual measure participation data was not available for the billing analysis, and we used a larger dataset for the engineering algorithm analysis.
**Weighting account for when multiple showerheads or faucet aerators were installed.

Of the 646 natural gas participants included in the analysis, 312 (48%) received at least one DHW measure. Table 16 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 16. Evaluated Natural Gas Energy Savings for Domestic Hot Water Measures

Category	Measures	Evaluated Savings (therms/year)
Domestic Hot Water	Overall – DHW*	4.9
	- Showerhead	11.0
	- Faucet Aerator	2.4
	- Pipe Wrap	2.2

* Average savings for a household that received at least one DHW measure.

Other Measures

The Evaluation Team calculated savings estimates for other measures (such as duct sealing and Thermadomes and access measures). Of the 646 natural gas participants included in the analysis, 308 (47%) received at least one measure that was not a part of weatherization or DHW measures assessed above. Collectively, the evaluated savings for these other measures was 58 therms/year.

Summary of Natural Gas Savings

Table 17 summarizes the overall evaluation findings for all natural gas measures.

Table 17. Evaluated Energy Savings for All Natural Gas Measures

Category	Measure	Natural Gas Savings (therms/year)
Weatherization	Overall Insulation with Air Sealing*	190
	Overall Insulation without Air Sealing**	124
	- Attic Insulation	87
	- Wall Insulation	110
	- Basement/Floor Insulation	35
	- Air Sealing	87
	Furnace Fan (due to insulation)	202 (kWh)
	Cooling Savings (due to insulation)	49 (kWh)
	Programmable Thermostat	31
Domestic Hot Water	Overall – DHW***	4.9
	- Showerhead	11.0
	- Faucet Aerator	2.4
	- Pipe Wrap	2.2
Other	All Other Measures (duct sealing, Thermadomes, and access measures)	58

* This row refers to any participant that received air sealing, and/or attic, and/or wall, and/or basement/floor insulation.
** This row refers to any participant that received attic, and/or wall, and/or basement/floor insulation.
*** Average savings for a household that received at least one DHW measure.

Energy Savings: Electric

The billing analysis only provided reliable estimate of electric savings for three EnergyWise measures: compact fluorescent lights (CFLs), fixtures, and refrigerator replacements. All other estimates of electric savings presented in this section were determined through engineering algorithms and simulation modeling.

Weatherization

The Evaluation Team used a calibrated simulation approach to evaluate weatherization measures for electrically heated homes. The model relied on characteristics of electrically heated EnergyWise participant homes, and we calibrated it using the pre-NAC value determined through the billing analysis.[5] We determined the overall insulation savings value using a weighted average of the weatherization installation rates shown in Table 18.

Table 18. Distribution of Electric Weatherization Measures (Total Sample, n=3,581)

Measure	Sample Size*	Percent Installed
Insulation (overall) with Air Sealing**	33	1%
Insulation (overall) without Air Sealing***	29	1%
-Attic Insulation	26	90%****
-Wall Insulation	3	11%****
-Basement/Floor Insulation+	8	26%****
Air Sealing	26	1%
Programmable Thermostat	254	7%

* These totals are based on 2010 participation counts (which aligns with customers included in the billing analysis). All measure-specific sample sizes reference the number of measures installed, while the total (n=3,581) is the total number of unique participants.

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

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

**** These percentages are based on the 1% of customers using electric heat (n=29) that installed at least one insulation measure.

+ 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 for R-values and square feet installed (Table 19).

Table 19. 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	26	12.5	43.7	992
Wall Insulation	3	3.7	13.0	1,279
Basement/Floor Insulation*	8	6.6	18.9	581

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

The average electric insulation participant had 1.3 types of insulation installed, which was lower than the average observed for natural gas insulation participants (1.5). Both the overall average electric insulation savings and the insulation type-specific savings estimates are provided in Table 20. The overall insulation savings is 1,558 kWh/year with air sealing and 772 kWh/year without air sealing. The electricity savings from reduced furnace fan usage and mitigated cooling loads are embedded in the overall insulation savings value.

[5] 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 20. Evaluated Electric Energy Savings for Insulation and Air Sealing

Category	Measure	Evaluated Savings (kWh/year)
Weatherization	Overall Insulation with Air Sealing*	1,558
	Overall Insulation without Air Sealing** (1.3 average installations)	772
	- Attic Insulation (90% installed)	774
	- Wall Insulation (11% installed)	1,216
	- Basement/Floor Insulation*** (26% installed)	171
	- Air Sealing	995
	Programmable Thermostat	330

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

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

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

Lighting and Appliances

The Team determined evaluated electric savings for three EnergyWise lighting and appliance measures (refrigerator replacements, CFLs, and fixtures) through billing analysis and one measure (refrigerator brushes) through engineering algorithm.

To decrease EnergyWise participants' electric baseload, National Grid offers a rebate for the purchase of new, ENERGY STAR refrigerators that replace eligible older and less efficient models. Our billing analysis dataset of 2,581 electric participants included 71 that replaced their refrigerator (3%). While this percentage is relatively small, the number of replaced units and the magnitude of the generated savings relative to total household electrical usage allowed the Evaluation Team to estimate savings with sufficient precision (±30%). Specifically, the billing analysis determined an average savings of 770 kWh per replacement.

The Evaluation Team was also able to accurately evaluate electric energy savings for CFLs through the billing analysis. While the per-unit savings of CFLs are relatively small, the large number of bulbs installed in participating homes (9.2 on average) and the large number of homes in our analysis that received bulbs (n=2,397) allowed us to estimate CFLs savings with the greatest precision of any evaluated EnergyWise measure (±13%).

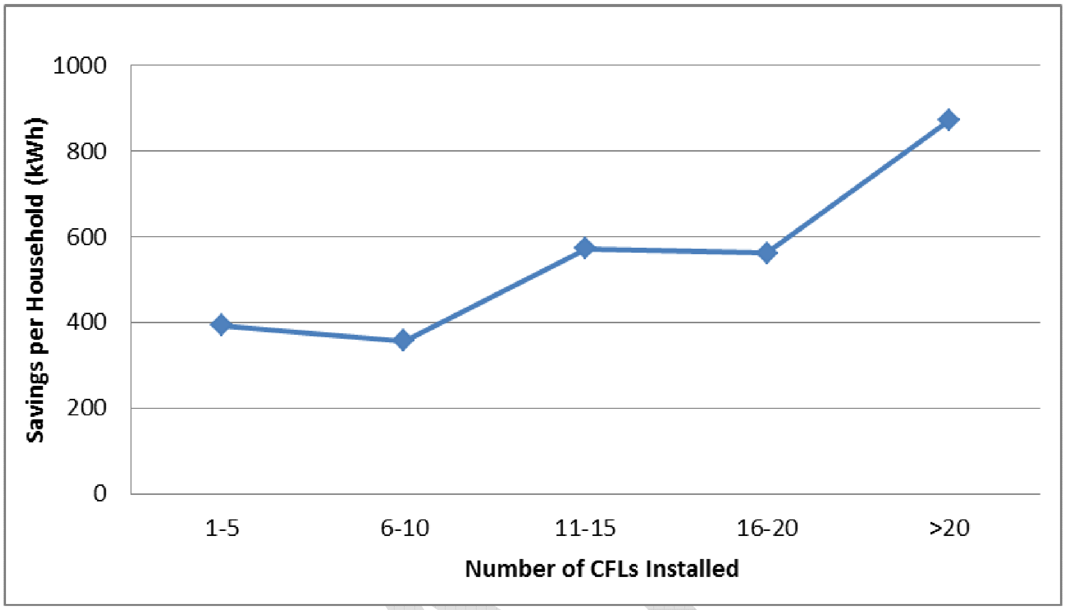
Specifically, through the billing analysis we determined an average household-level CFL savings of 432 kWh/year, which equates to an average per-CFL savings of 47 kWh/year. CFL savings are largely a function of the number of hours the bulb is used (known as hours-of-use, or HOU),[6] and the prevailing 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).[7] This theory appears valid for EnergyWise (which averaged 9.2 CFLs installed/home) when household and per-CFL savings are presented based on the number of customers receiving a specific number of CFLs (CFL groups).

6 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 algorithm.

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

While total household savings increase as a greater number of CFLs are installed (Figure 1), the per-CFL savings decrease (Figure 2).

Figure 1. CFL Savings per Household Based on Number of CFLs Installed



As shown in Figure 2, per-CFL savings dropped dramatically after bulbs were installed in the highest usage areas.

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

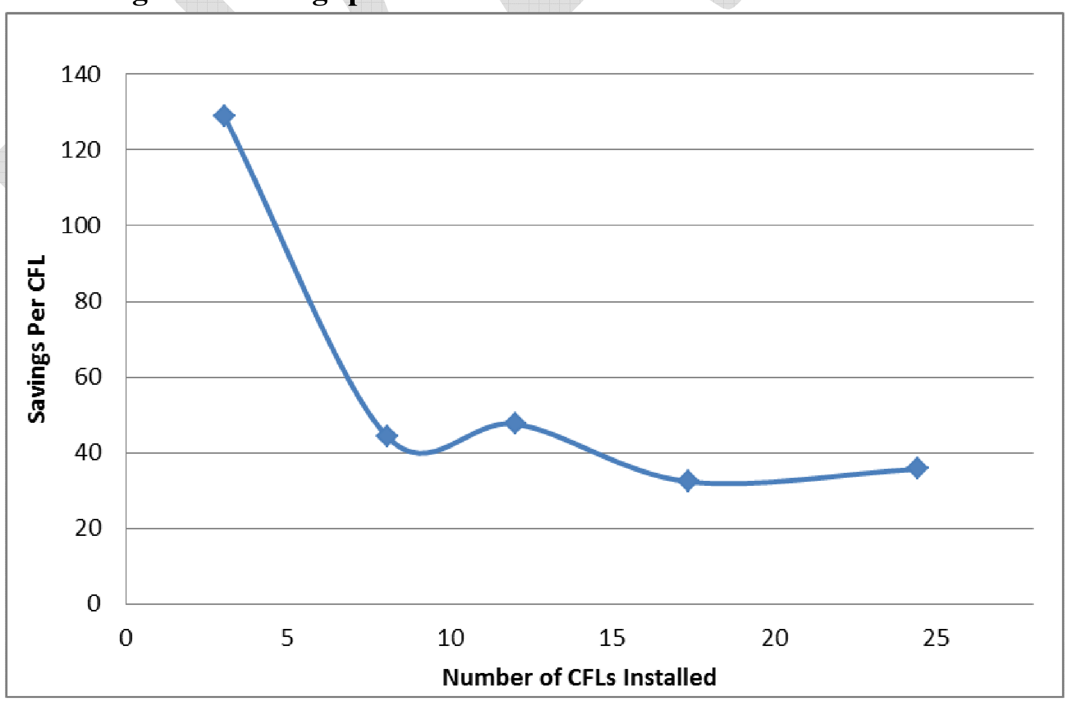


Table 21 details the information shown in Figure 2 in tabular form.

Table 21. Energy Saving Based on Number of CFLs Installed

CFLs Received	Percent of Analysis Dataset	Average Number of Installed CFLs	Billing Analysis kWh Saved/CFL
1-5	21%	3.0	129
6-10	30%	8.1	44
11-15	45%	12.0	48
16-20	3%	17.4	32
>20	1%	24.4	36
Overall[8]	**100%**	**9.2**	**50**

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 $Watts_{base}$ 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 become effective.[9]

We based the CFL baseline shift on three main factors:

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

Table 22 summarizes the EISA standards for each rated lumen range and their effective dates.

Table 22. 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 23 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

8 The weighted average savings estimate of 50 kWh per CFL is slightly different than the overall savings estimate of 47 kWh per CFL because the CFL models include only participants that installed lighting measures.

9 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.

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.[10]

Table 23. 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 analysis revealed two changes: (1) an estimated baseline shift from 61 watts in 2011 to 45 watts in 2016; and (2) a corresponding change in savings from 47 kWh in 2011 to 29 kWh in 2016, as illustrated in Table 24.

Table 24. Potential CFL Baseline Shift and Corresponding Savings Estimates

Year	Baseline (Watts)	Savings (kWh)
2011	61	47
2012	60	46
2013	59	44
2014	54	39
2015	47	30
2016	45	29

Table 25 summarizes the savings results for lighting and appliance measures.

Table 25. Evaluated Electric Energy Savings for Lighting and Appliances

Category	Measures	Evaluated Savings (kWh/year)
Lighting & Appliances	CFLs	47
	Fixtures	65
	Refrigerator Replacement	770
	Refrigerator Brushes	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 26 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

10 We estimated this weighted average based on typical residential uses, which we adjusted to match the average EnergyWise baseline of 61 watts.

of the measure-specific participation counts, as some participants received more than one DHW measure.

Table 26. Distribution of Hot Water Measures for Electric Participants

Measure	Participants*	Amount Installed per Participant	Participants Receiving Measure (Weighted Percent)
Showerheads	24	1.3 units	30%
Faucet Aerators	29	1.3 units	57%
Pipe Wrap	52	10 feet	56%
Overall	**94**		**143%**

* The Team normalized the number of participants to that used in the billing analysis (n=312) for DHW measures. Individual measure participation data was not available for the billing analysis, and we used a larger dataset for the engineering algorithm analysis.

Table 27 summarizes our evaluation findings for individual natural gas DHW measures and for the average home receiving at least one natural gas DHW measure.

Table 27. Evaluated Electric Energy Savings for DHW Measures

Category	Measures	Evaluated Savings (kWh/year)
Domestic Hot Water	Overall – DHW*	109
	- Showerhead	222
	- Faucet Aerator	49
	- Pipe Wrap	28

* Average savings for a household that received at least one DHW measure.

Summary of Electric Savings

Table 28 summarizes all electric energy savings estimates for EnergyWise.

Table 28. Evaluated Energy Savings for All Electric Measures

Category	Measure	Electric Savings (kWh/year)
Weatherization	Overall Insulation with Air Sealing*	1,558
	Overall Insulation without Air Sealing**	772
	- Attic Insulation	774
	- Wall Insulation	1,216
	- Basement/Floor Insulation	171
	- Air Sealing	995
	Programmable Thermostat	330
Lighting & Appliance	CFLs	47
	Fixtures	65
	Refrigerator Replacement	770
	Refrigerator Brushes	37
Domestic Hot Water	Overall – DHW***	109
	- Showerheads	222
	- Faucet Aerators	49
	- Pipe Wrap	28

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

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

*** Average savings for a household that received at least one DHW measure.

Evaluated Energy Savings: Oil

Weatherization

As with electric fuel weatherization, the Evaluation Team used a calibrated simulation model to estimate oil savings. The average oil participant installed 1.6 insulation measures, which is similar to gas participants who averaged 1.5 installations. As with the electric and gas participants, attic insulation was the most common measure, installed by 79% of oil participants who installed insulation.

Table 29 shows the number of installations and the measure weights for each oil insulation and air sealing measure.

Table 29. Distribution of Oil Insulation and Air Sealing Measures (Total Sample, n=71)

Measure	Sample Size*	Percent Installed
Insulation (overall) with Air Sealing**	70	99%
Insulation (overall) without Air Sealing***	68	96%
-Attic Insulation	54	79%****
-Wall Insulation	28	41%****
-Basement/Floor Insulation+	29	43%****
Air Sealing	66	93%
Programmable Thermostat	1	1%

* These sample sizes are based on 2010 and 2011 program participation counts, while the total (n=71) is the total number of unique participants.
** This row refers to any participant that received air sealing, and/or attic, and/or wall, and/or basement/floor insulation.
*** This row refers to any participant that received attic, and/or wall, and/or basement/floor insulation.
**** These percentages are based on the 96% of oil fuel customers (n=68) that installed at least one insulation measure.
+ 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 30).

Table 30. 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	54	8.2	45.2	1,099
Wall Insulation	28	3.7	13.0	1,160
Basement/Floor Insulation*	29	6.6	18.6	556

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

The estimated overall insulation savings are 15 MMBtu without air sealing for oil heating fuel participants (Table 31).

Table 31. Evaluated Oil Energy Savings Results for Insulation and Air Sealing

Category	Measure	Evaluated Savings (MMBtu/year)
	Overall Insulation with Air Sealing*	24
	Overall Insulation without Air Sealing** (1.6 average installations)	15
	- Attic Insulation (79% installed)	11
	- Wall Insulation (41% installed)	11
Weatherization	- Basement/Floor Insulation*** (43% installed)	4
	- Air Sealing	10
	Furnace Fan (due to insulation)	266 (kWh)
	Cooling Savings (due to insulation)	70 (kWh)
	Programmable Thermostat	3.2

* This row refers to any participant that received air sealing, and/or attic, and/or wall, and/or basement/floor insulation.
** This row refers to any participant that received attic, and/or wall, and/or basement/floor insulation.
*** Includes insulation installed on basement ceilings and/or basement walls.

As with natural gas, the table reflects electric savings generated by decreased furnace fan usage and decreased cooling loads (which we estimated through the simulation model).

Summary of Oil Savings

Table 32 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 32. Evaluated Energy Savings for All Oil Measures

Category	Measure	Oil Savings (MMBtu/year)
Weatherization	Overall Insulation with Air Sealing*	24
	Overall Insulation without Air Sealing** (1.6 average installations)	15
	- Attic Insulation (79% installed)	11
	- Wall Insulation (41% installed)	11
	- Basement/Floor Insulation (43% installed)	4
	- Air Sealing	10
	Furnace Fan (due to insulation)	266 (kWh)
	Cooling Savings (due to insulation)	70 (kWh)
	Programmable Thermostat	3.2

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

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** leveraging participant audit data from the Massachusetts HES evaluation to inform building characteristics.
4. Finally, **deriving measure-level savings** by running simulation models with baseline and efficient values pulled from the RISE audit data.

Analysis of Participant Billing Data

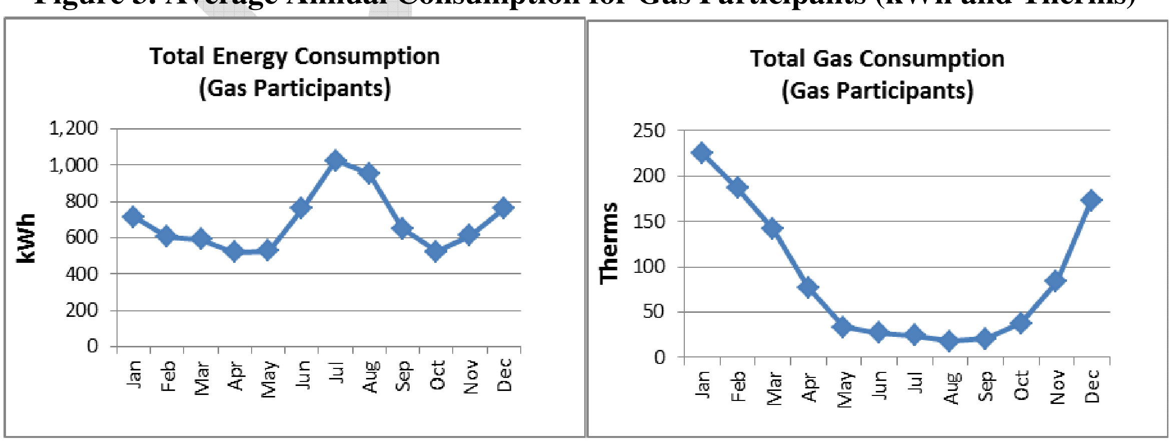
To determine energy consumption targets for the model calibrations, the Evaluation Team analyzed billing data provided by National Grid on a per-site basis for Rhode Island customers.

National Grid 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 post-install consumption values to ensure pre-install calibration targets.
4. Calculated the average monthly consumption for each heating 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 3 shows the average annual results for gas participants.

Figure 3. 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)[11] and based on a lighting usage study conducted for the California investor-owned utilities (IOUs).[12] To create this estimate specific to Rhode Island participants, we used average building characteristics based on the Massachusetts HES program evaluation. The values used were average building size and electric/gas hot water heater saturation for each region of Massachusetts.
3. **Calculated the remaining consumption,** which is attributable to heating, ventilating, and air conditioning (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.

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

[12] 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.[13]
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.[14]

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:

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

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:

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 33 and Table 34.

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

14 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 33. 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 34. 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**

1. **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).
2. **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.
3. **Calculate relative monthly usage** by multiplying the relative daily usage factor by the number of days in the month.
4. **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 35.

Table 35. 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 Rhode Island is shown in Table 36.

Table 36. Domestic Hot Water Profile for Massachusetts (gallons/day)

Month	Mains Temp (°F)	Dishwasher	Clothes Washer	Baths	Showers	Sinks	Total*
January	47.6	3.0	7.9	5.6	22.2	19.8	58.5
February	46.4	3.0	8.0	5.6	22.3	19.9	58.8
March	48.0	3.0	7.9	5.6	22.2	19.8	58.4
April	51.9	3.0	7.6	5.5	21.8	19.5	57.4
May	57.1	3.0	7.1	5.3	21.3	19.0	55.8
June	62.2	3.0	6.5	5.2	20.7	18.5	53.9
July	66.0	3.0	6.0	5.1	20.2	18.0	52.3
August	67.5	3.0	5.8	5.0	20.0	17.8	51.7
September	66.1	3.0	6.0	5.1	20.2	18.0	52.3
October	62.4	3.0	6.5	5.2	20.7	18.5	53.8
November	57.3	3.0	7.1	5.3	21.3	19.0	55.7
December	52.1	3.0	7.6	5.5	21.8	19.5	57.3

* 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.[15]

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:[16]

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

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

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 37 shows these results for Rhode Island.

Table 37. Domestic Hot Water Electricity Consumption and Variation Profile for Rhode Island

Month	Gal/Day	Mains Temp (°F)	Heating Load (kWh/day)	UA Load (kWh/day)	Days/ Month	Total kWh/ Month	DHW Variation Profile
January	43.6	47.6	8.2	3.1	31	350.8	1.2
February	43.8	46.4	8.4	3.1	28	321.6	1.1
March	43.6	48.0	8.2	3.1	31	349.3	1.2
April	42.8	51.9	7.6	3.1	30	321.5	1.1
May	41.6	57.1	6.9	3.1	31	309.3	1.0
June	40.2	62.2	6.1	3.1	30	277.2	0.9
July	39.0	66.0	5.6	3.1	31	269.7	0.9
August	38.6	67.5	5.4	3.1	31	263.4	0.9
September	39.0	66.1	5.6	3.1	30	260.6	0.9
October	40.2	62.4	6.1	3.1	31	285.6	0.9
November	41.5	57.3	6.9	3.1	30	298.4	1.0
December	42.7	52.1	7.6	3.1	31	331.4	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

15 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.

16 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 both electric-only customers and 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.

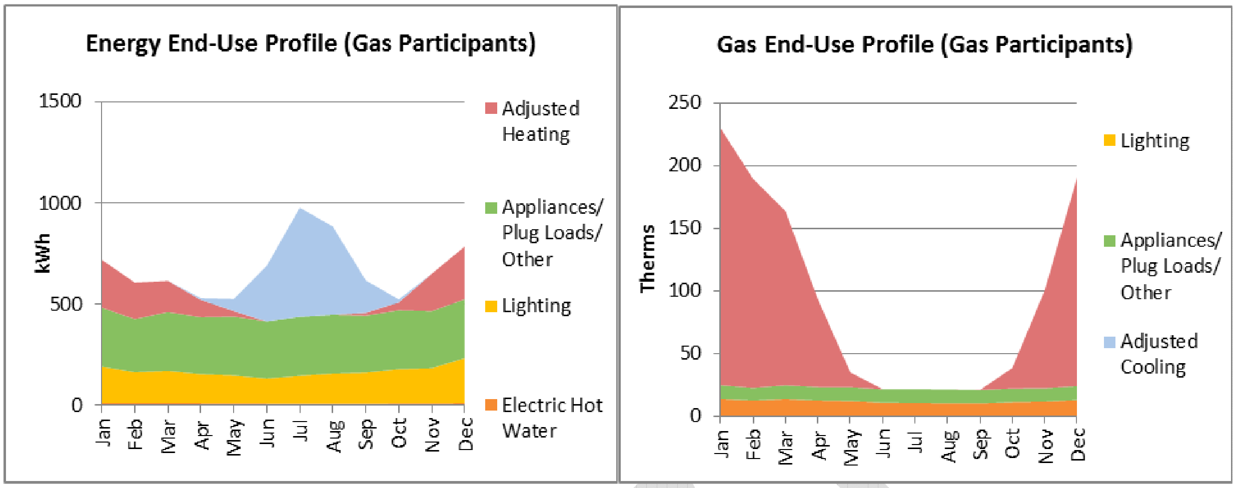
Heating and Cooling

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 August, we assumed that all the HVAC electricity was for cooling. For November through March, we assumed that all HVAC electricity was for heating. For the shoulder months (April, May, September and October), 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 4 shows the disaggregated end-use profiles for gas participants.

Figure 4. 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 38 for corresponding HVAC fuel types.

Table 38. 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 Sup

* Due to the multiple types of heating systems in Rhode Island (wood burning fireplaces, electric baseboard heat, electric furnaces, heat pumps, etc.) 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 using the average building size and other characteristics derived during the EnergyWise evaluation. When the Rhode Island audit data did not contain building characteristics or the Massachusetts HES program —such as for window specifications and typical insulation values—we used the BARB[17] spreadsheet to inform the models.

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

Calibrate Energy Simulation Models

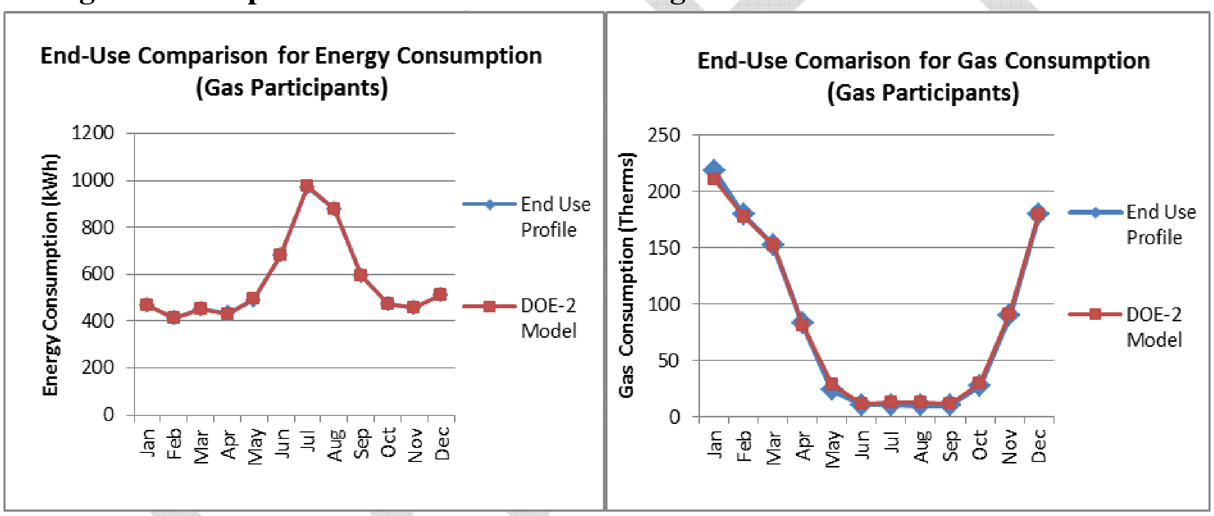
The Evaluation Team calibrated each model group in order to match the modeled energy consumption to the end-use targets for that group. This calibration was an iterative process, involving the following steps:

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

Figure 5. 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. 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 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.

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.

Derive Measure-Level Savings

The Evaluation Team used the simulation model approach to estimate savings for program measures that are 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 and Wall Insulation***. We adjusted the baseline and efficient R-Values, as well as the whole-house infiltration rate.
- ***Floor Insulation***. We adjusted the baseline and efficient R-Values.

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 r-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 RISEe audit data to derive measure-level savings for each of the insulation types offered by the EnergyWise 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. These measures are all listed in Table 39, along with the approach we used for each.

Table 39. Summary of Analysis Approach by Measure and Heating Fuel Type

Category	Measure	Natural Gas (therms/year)	Electric (kWh/year)	Oil (MMBtu/year)
Weatherization	Weatherization*	Billing Analysis	Simulation Modeling	Simulation Modeling
	Furnace Fan (due to insulation)	Simulation Modeling (kWh)	--	Simulation Modeling (kWh)
	Cooling Savings (due to insulation)	Simulation Modeling (kWh)	--	Simulation Modeling (kWh)
	Programmable Thermostat	Engineering Algorithm	Engineering Algorithm	Engineering Algorithm
Lighting & Appliances	CFLs	--	Billing Analysis	--
	Fixtures		Billing Analysis	
	Refrigerator Replacement	--	Billing Analysis	--
	Refrigerator Brushes		Engineering Algorithm	
Domestic Hot Water	Overall – DHW**	Engineering Algorithm	Engineering Algorithm	--
	- Showerhead	Engineering Algorithm	Engineering Algorithm	--
	- Faucet Aerator	Engineering Algorithm	Engineering Algorithm	--
	- Pipe Wrap	Engineering Algorithm	Engineering Algorithm	--
Other***	All Other Measures (duct sealing, Thermadomes, access measures)	Billing Analysis		

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

** Average savings for a household that received at least one domestic hot water measure.

*** Since this measure category contains miscellaneous measures, it was assessed in aggregate through the billing analysis despite not meeting the specified precision requirements.

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

Weatherization

The only measure in this category using an engineering algorithm is the programmable thermostat measure. The methodology for this measure is described here.

Programmable Thermostats

The key inputs for programmable thermostats are listed in Table 40.

Table 40. Programmable Thermostat Assumptions

Measure	Percent Savings	Oil Savings (MMBtu/year)	Gas Savings (Therm/year)	Electric Savings (kWh/year)	Source
Evaluation Estimate	3.6%	3.2	31	330	Conservative estimate based on literature review
Current RI Estimate	--	--	--	50	Ex Ante Estimates from NGrid

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 Evaluation Team reviewed the following 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.

Lighting and Appliances

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).

Refrigerator Coil Brushing

The evaluation team calculated the savings from refrigerator coil brushing using a typical annual consumption value and an estimated percentage savings. We assumed that the coil cleaning takes place once, at the time of the audit. To determine the typical baseline consumption, we summed the billing analysis gross savings (775 kWh) and the typical ENERGY STAR refrigerator consumption (440 kWh).

Input	Value	Source
Baseline Annual Consumption	1,225 kWh	Billing analysis
Percent Savings	3%	SMUD Study*
kWh Savings	37	Calculation

*"SMUD's Refrigerator Graveyard: Conditions of the Deceased," Home Energy Magazine Online, January/February 1993. Accessed online 20 September 2012. http://www.homeenergy.org/show/article/nav/refrigerators/page/4/id/915

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

The Evaluation Team calculated a unique value for each measure. Table 41 summarizes the evaluated savings for these measures.

Table 41. Domestic Hot Water Savings Summary

Category	Measure	Natural Gas (Therms/year)	Electric (kWh/year)	Oil (MMBtus/year)
Domestic Hot Water	Showerhead	11	222	1.3
	Faucet Aerator	2	49	0.3
	Pipe Wrap	2	28	0.4

Showerheads

The Evaluation Team began evaluating this measure by reviewing the Rhode Island EnergyWise and Massachusetts HES audit data for the key inputs to the low-flow showerhead energy savings algorithm. Table 42 shows the inputs for low-flow showerheads, indicating both the original audit data inputs and final assumptions.

Table 42. Showerhead Inputs

Input	Audit Data Values	Values Used in Calculations	Source
Household Members	2.9	2.9	Massachusetts HES audit data
Showers (pcpd)	-	0.7	Default is 0.7; +,++
Shower Length (min)	-	8.2	**,++
Proportion Affected	0.73	0.73	Massachusetts HES audit data
Baseline Rated Flow	-	2.5	Federal standard
Baseline As-used Flow (linear)	-	2.05	Calculated from rated flow;* ,+
Retrofit Rated Flow	1.75	1.75	RI program records
Retrofit As-used Flow (linear)	1.64	1.64	Calculated from rated flow;* ,+
Shower Temperature (°F)	-	105	**
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 due to partial clogging in household pipes. That 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 43 shows the values we used for each input. Because faucets are rarely used at their rated flows, the Evaluation Team recommends that National Grid 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 43. 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	Massachusetts 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	Massachusetts 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:

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

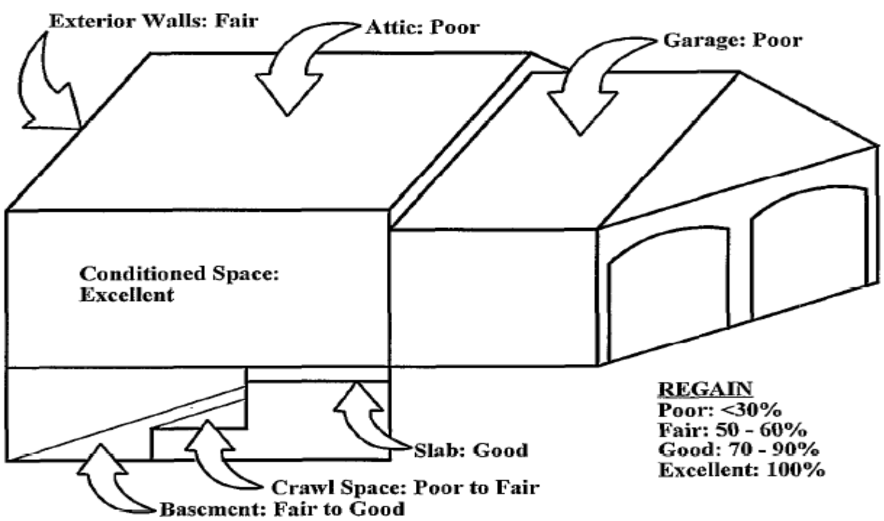
Table 44 shows the assumptions we used to calculate savings.

Table 44. 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

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 6 for an illustration of this process).

Figure 6. 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 6, 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 45 and Table 46 summarize the thermal regain factors we assigned to each system location found in the Massachusetts HES audit data (as this information was not include in the EnergyWise 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 45. 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 46. 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. RI program data showed an average installed length of 5.5 feet.

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:

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

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 air sealing participants

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

β_7 = 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_8 = 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

B_9 = 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_{10} = 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_{11} = 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_{12} = 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_{13} = The incremental average usage per HDD for miscellaneous HVAC, pipe insulation, and other participants

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

β_{14} = 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_{15} = 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_{16} = 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_{17} = 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_{18} = 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_{19} 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_{20} I = The average daily savings for miscellaneous HVAC, pipe insulation, and other participants

$Misc\_HVAC\_Other_i * POST_{it} * HDD_{it}$ = An interaction between the miscellaneous HVAC and other participant flag, the $POST_{it}$ indicator, and average daily HDD

β_{21} = 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_{22} = 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_{23} = 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_{24} = 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

ε_{it} = The model error term

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

$\beta_{14} * 5{,}990$[18]	=	Annual **air sealing** savings using normal typical meteorological year (TMY3) HDDs
$\beta_{15} * 6{,}000$	=	Annual **attic insulation** savings using normal TMY3 HDDs
$\beta_{16} * 5{,}983$	=	Annual **wall insulation** savings using normal TMY3 HDDs.
$\beta_{18} * 5{,}989$	=	Annual **Thermadome & attic access** savings using normal TMY3 HDDs.
$\beta_{20} * 6{,}052$	=	Annual **Misc HVAC & Misc other & Pipe Insulation** savings using normal TMY3 HDDs.

The model parameters and parameter estimates are provided in Table 47. The bold rows in the table highlight the model terms and coefficients used to report *ex post* savings generated by the billing analysis.

18 5,990 is the average of the typical meteorological year (TMY3; 1991-2005) series HDDs across all the air sealing participants.

Table 47. Gas Savings Measure-Level Model Parameters and Estimates

Variable	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|
HDD	1	0.16442	0.00068173	241.19	<.0001
HEHE_BOILER * HDD	1	0.05138	0.00559	9.19	<.0001
HEHE_FURNACE * HDD	1	-0.04517	0.00422	-10.7	<.0001
HEHE_TSTAT * HDD	1	0.00143	0.00274	0.52	0.6012
HEHE_WH * HDD	1	0.00402	0.0037	1.09	0.2774
AIR SEALING * HDD	1	0.00837	0.00299	2.8	0.0051
ATTIC INS * HDD	1	0.00538	0.00275	1.96	0.0505
WALL INS * HDD	1	0.00024762	0.00241	0.1	0.9181
BASEMENT INS * HDD	1	0.006	0.00258	2.33	0.02
ACCESS * HDD	1	-0.00555	0.00268	-2.07	0.0384
SHOWERHEAD * HDD	1	-0.01668	0.00265	-6.28	<.0001
AERATOR * HDD	1	-0.00452	0.0029	-1.56	0.1193
MISC HVAC_OTHER * HDD	1	-0.00472	0.00158	-2.99	0.0028
AIR SEALING * HDD * POST	**1**	**-0.0146**	**0.00329**	**-4.43**	**<.0001**
ATTIC INS * HDD * POST	**1**	**-0.01453**	**0.00305**	**-4.77**	**<.0001**
WALL INS * HDD * POST	**1**	**-0.01836**	**0.00265**	**-6.94**	**<.0001**
BASEMENT INS * HDD * POST	1	-0.00476	0.00285	-1.67	0.0952
ACCESS * HDD * POST	**1**	**-0.00614**	**0.00296**	**-2.08**	**0.0378**
SHOWERHEADAERATOR * POST	1	-0.00302	0.05172	-0.06	0.9535
MISC HVAC_OTHER * HDD * POST	**1**	**-0.00692**	**0.00167**	**-4.13**	**<.0001**
HEHE_BOILER * POST	1	-0.20199	0.31968	-0.63	0.5275
HEHE_FURNACE * POST	1	-0.11954	0.18995	-0.63	0.5292
HEHE_TSTAT * POST	1	-0.36269	0.11831	-3.07	0.0022
HEHE_DHW * POST	1	-0.92731	0.20015	-4.63	<.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:

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

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 average daily savings for participants

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

β_7 = 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_8 = 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_9 = 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_{10} = 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

ε_{it} = The model error term

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

$\beta_6 * 365$ = Annual savings

The model parameters and parameter estimates for the overall model are provided in Table 48. The overall average gas savings are 144 therms per gas participant.

Table 48. Gas Savings Overall Model Parameters and Estimates

Variable	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|
HDD	1	0.15968	0.00055802	286.15	<.0001
HEHE_BOILER * HDD	1	0.0513	0.00564	9.09	<.0001
HEHE_FURNACE * HDD	1	-0.04677	0.00424	-11.02	<.0001
HEHE_TSTAT * HDD	1	0.00088164	0.00276	0.32	0.7494
HEHE_WH * HDD	1	0.00553	0.00373	1.48	0.1376
POST	**1**	**-0.39405**	**0.02131**	**-18.49**	**<.0001**
HEHE_BOILER * POST	1	-0.22914	0.32293	-0.71	0.478
HEHE_FURNACE * POST	1	-0.19191	0.19133	-1	0.3159
HEHE_TSTAT * POST	1	-0.34294	0.1195	-2.87	0.0041
HEHE_DHW * POST	1	-0.90105	0.20216	-4.46	<.0001

Model Specification – Electric

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

$$ADC_{it} = \alpha_i + \beta_1 * HDD_{it} + \beta_2 * Lighting_i * HDD_{it} + \beta_3 * Refrigerator_i * HDD_{it} + \beta_4 * Refrigerator\_Brush_i * HDD_{it} + \beta_5 * Fan_i * HDD_{it} + \beta_6 * CDD_{it} + \beta_7 * Lighting_i * CDD_{it} + \beta_8 * Refrigerator_i * CDD_{it} + \beta_9 * Refrigerator\_Brush_i * CDD_{it} + \beta_{10} * Fan_i * CDD_{it} + \beta_{11} * Lighting_i * POST_t + \beta_{12} * Refrigerator_i * POST_{it} + \beta_{13} * Refrigerator\_Brush_i * POST_{it} + \beta_{14} * Fan_i * POST_{it} * HDD_{it} + \varepsilon_{it}$$

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 lighting participants

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

β_3 = 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_4 = The incremental average usage per HDD for refrigerator brush participants

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

β_5 = 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_6 = 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_7 = 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_8 = 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_9 = The incremental average usage per CDD for refrigerator brush participants

$Refrigerator\_Brush_i * CDD_{it}$ = An interaction between the refrigerator brush participant flag and average daily CDD

β_{10} = 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_{11} = 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_{12} = The average daily savings for refrigerator participants

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

β_{13} = The average daily savings for showerhead and aerator participants

$Refrigerator\_Brush_i * POST_{it}$ = An interaction between the refrigerator brush participant flag and the $POST_{it}$ indicator

β_{14} = 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

ε_{it} = The model error term

where,

- $\beta_{11} * 365$ = Annual **Lighting** Savings
- $\beta_{12} * 365$ = Annual **Refrigerator** Savings

The model parameters and parameter estimates are provided in Table 49. The bolded rows highlight the model terms and coefficients used to report *ex post* savings generated by the billing analysis.

Table 49. Electric Base Load Measure Level Parameters and Estimates

Variable	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|
HDD	1	0.17462	0.00202	86.44	<.0001
LIGHTING * HDD	1	0.0407	0.00537	7.58	<.0001
REFRIGERATOR * HDD	1	-0.05252	0.01992	-2.64	0.0084
REFRIGERATOR_BRUSH * HDD	1	-0.03075	0.00631	-4.88	<.0001
FAN * HDD	1	-0.06001	0.01201	-5	<.0001
CDD	1	1.53211	0.00772	198.53	<.0001
LIGHTING * CDD	1	0.1083	0.02076	5.22	<.0001
REFRIGERATOR * CDD	1	-0.00476	0.07777	-0.06	0.9512
REFRIGERATOR_BRUSH * CDD	1	-0.10575	0.02418	-4.37	<.0001
FAN * CDD	1	0.08421	0.04073	2.07	0.0387
LIGHTING * POST	**1**	**-1.18474**	**0.09721**	**-12.19**	**<.0001**
REFRIGERATOR * POST	**1**	**-2.10963**	**0.38553**	**-5.47**	**<.0001**
REFRIGERATOR_BRUSH * POST	1	-0.23577	0.12279	-1.92	0.0548
FAN * POST * HDD	1	-0.00193	0.01045	-0.18	0.8534

Model Specification – Electric Measure Overall Model

To obtain overall model savings across all the electric measures for both non-electric heating and electric heating , the Cadmus Team used a fixed effects model specification, as follows:

$$ADC_{it} = \alpha_i + \beta_1 * HDD_{it} + \beta_2 * CDD_{it} + \beta_3 * POST_{it} + \varepsilon_{it}$$

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

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

β_2	=	The average usage per CDD
CDD_{it}	=	The average daily base 65 CDD for the nearest weather station based on location
β_3	=	The average daily savings for participants
$POST_{it}$	=	An indicator variable that is 1 in the post-installation period and 0 in the pre-installation period
ε_{it}	=	The model error term

where,

- $\beta_3 * 365$ = Annual Savings

The model parameters and parameter estimates for electrically heated accounts are provided in Table 50. The bolded rows highlight the model terms and coefficients used to report *ex post* savings generated by the billing analysis.

Table 50. Electric Overall Model Parameters and Estimates (Electric Heating)

Variable	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|
HDD	1	1.47851	0.02156	68.58	<.0001
CDD	1	2.01029	0.08562	23.48	<.0001
POST	**1**	**-4.04838**	**0.64215**	**-6.3**	**<.0001**

The model parameters and parameter estimates for non-electrically heated accounts are provided in Table 51. The bolded rows highlight the model terms and coefficients used to report *ex post* savings generated by the billing analysis.

Table 51. Electric Overall Model Parameters and Estimates (Non-Electric Heating)

Variable	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|
HDD	1	0.17051	0.00175	97.2	<.0001
CDD	1	1.55685	0.0067	232.33	<.0001
POST	**1**	**-1.38201**	**0.06443**	**-21.45**	**<.0001**

The overall model savings results from the non-electric (95%) and electric (5%) models were weighted to determine the average savings estimate of 539 kWh for the average electric participant.