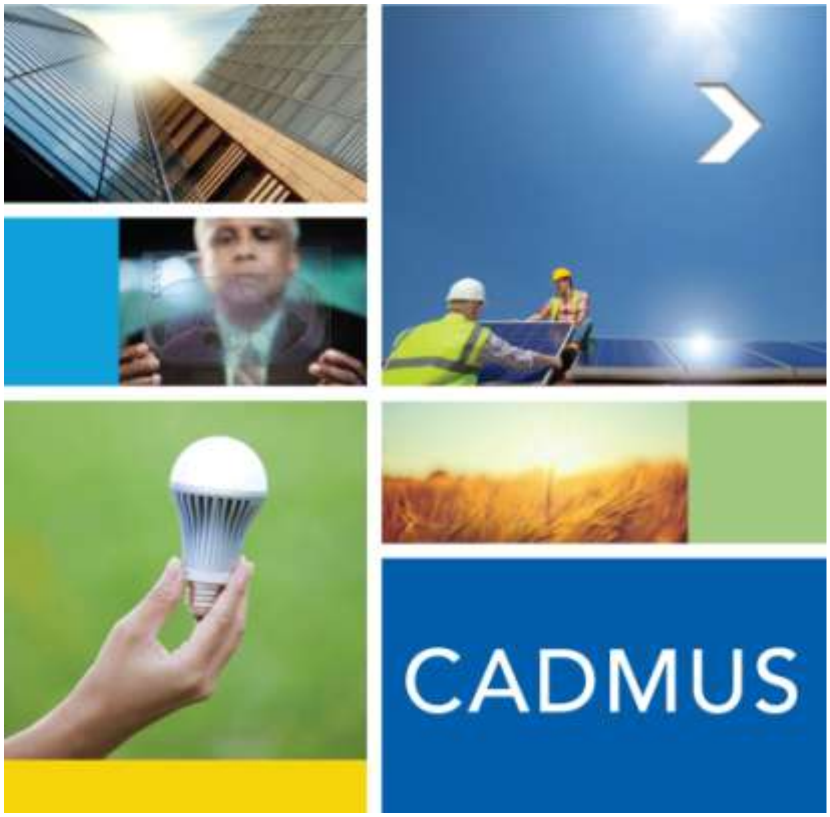

REVIEW DRAFT

Impact Evaluation: Home Energy Services—Income-Eligible and Home Energy Services Programs: Volume 2 (R16)

June 2, 2014 – Revised 7/2/14

Connecticut Energy Efficiency Fund

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Glossary of Terms

Adjusted Gross Realization Rate

The adjusted gross realization rate is calculated by comparing the adjusted gross model savings estimate to the average per-participant *ex ante* savings for participants included in the billing analysis sample.

Adjusted Gross Savings

Adjusted gross savings are model savings estimates that account for differences in consumption changes between the participant group and comparison group model savings from the billing analyses.

Billing Analysis

A billing analysis is a statistical regression analysis of utility billing consumption data used to quantify gross and adjusted gross energy savings.

Evaluated Adjusted Gross Savings

Evaluated adjusted gross savings are calculated by applying the adjusted gross realization rate (derived from the billing analysis models compared to *ex ante* savings) to the reported gross savings by utility program (from the *2013–2015 Electric and Natural Gas Conservation and Load Management Plan*).

***Ex Ante* Savings**

Ex ante savings represent savings that provide the utility tracking data for the HES and HES-IE programs, and can include total per-participant savings or savings by specific measures.

Model Savings

Model savings represent average, per-participant savings estimates, determined through the regression analysis and based on an analysis sample. Model savings estimates for the participant analysis sample are referred to as participant savings or gross savings. Model savings estimates for the comparison group sample are referred to as comparison group or nonparticipant savings. Model savings estimates that account for the differences between participant and comparison group changes are referred to as adjusted gross savings.

PRENAC and POSTNAC

In the regression analysis, weather-normalized annual consumption (NAC) estimates for the pre- and post-periods are called PRENAC and POSTNAC.

Realization Rate

A realization rate is a metric that compares an evaluated savings estimate to a reported or *ex ante* savings estimate, represented as a percentage change.

Relative Precision at 90% Confidence

The Evaluation Team calculated relative precision estimates to assess: the uncertainty levels for results of distinct billing analysis models (Model Savings); and the overall, evaluated, adjusted gross savings (reported at the program level). These values represent the uncertainty of the modeled results and the variation in observed impacts on energy consumption. The Evaluation Team estimated precision at 90% confidence, meaning one could be 90% confident the true impact falls within an interval equal to the estimated impact plus/minus the precision.

Reported Gross Savings

Reported gross savings derive from savings reported in the *2013–2015 Electric and Natural Gas Conservation and Load Management Plan*.

Executive Summary: Combined Report

The Connecticut Energy Efficiency Board (EEB) requires an impact evaluation of the Home Energy Services (HES) and Home Energy Services-Income Eligible (HES-IE) programs offered by the following Connecticut utilities: Connecticut Light & Power (CL&P), The United Illuminating Company (UI), Connecticut Natural Gas (CNG), Southern Connecticut Gas (SCG), and Yankee Gas Services Company (YGS). The impact evaluation sought to provide evaluated estimates of energy and demand savings associated with measures installed through these programs. The NMR Group and Cadmus, its subcontractor, (collectively referred to as the Evaluation Team) conducted this evaluation.

The results have been provided in two volumes, each focusing on a different approach for evaluating the impacts for the program year 2011 HES and HES-IE programs:

- ***Volume 1*** provides the results of a whole-house billing analysis that estimates average participant (household-level) electric and natural gas impacts.
- ***Volume 2*** includes a measure-level impact evaluation, providing estimates of per-unit savings for measures offered through the HES and HES-IE programs and using an array of evaluation tasks, such as billing analysis, calibrated simulation modeling, and engineering analyses. Volume 2 also includes a whole-house billing analysis that estimates the electric and gas energy impacts for two of four HES-IE subprograms.[1]

Both methods are considered industry "best practice", and both provide valuable information for Connecticut's programs.

- **Whole-house billing analysis** is a statistical analysis (using fixed-effects regression models) provided household-level savings estimates, which then informed the calculation of realization rates. The billing analysis uses data from participating households that had sufficient billing data both prior to participation and after participation to support the analysis. Statistical billing analyses are considered a best practice approach for estimating impacts associated with whole-building programs.[2] Results based on whole house billing analysis are used around the nation to provide best practice results for estimating savings impacts and associated realization rates for a variety of energy-efficiency programs, in particular whole-house programs. The Evaluation Team performed the whole-house billing analysis for HES and HES-IE (in Volume 1), including two CL&P-specific subprograms (i.e., SP1 and SP4) (included in Volume 2).

[1] Whole-house billing analysis results for HES-IE subprograms 1 and 4 will ultimately be moved to the section of the final report presenting other whole-house results.

[2] UMP Whole-Building Retrofit with Consumption Data Analysis Evaluation Protocol (https://www1.eere.energy.gov/wip/pdfs/53827-8.pdf); IPMVP Option C (http://www.nrel.gov/docs/fy02osti/31505.pdf); California Energy Efficiency Evaluation Protocols (http://www.calmac.org/events/EvaluatorsProtocols_Final_AdoptedviaRuling_06-19-2006.pdf)

- **Measure-level analysis** uses a multiple-method approach to identify the best estimates of energy savings for individual measures. The analysis used fixed-effects, savings regression models and two engineering analysis approaches (addressing measures with and without interaction effects) to estimate measure-specific savings for the most common fuel types (e.g., electric, natural gas, propane, and heating oil). The measure-based evaluation and realization rates provide specific information to refine PSD savings calculations. The results of the measure-level analysis for HES and HES-IE are include in Volume 2., with the exception of two CL&P-specific HES-IE subprograms (i.e., SP1 and SP4), which were addressed using a whole-house billing analysis (also presented in this volume).

The realization rates resulting from the different analytical approaches used in Volume 1 and Volume 2 are presented below in Table 1. The differences in the realization rates for each type program (HES vs. HES-IE) and each type of savings (electric vs. gas) is largely due to slight differences in the measure distributions between the sample of households included in whole-house billing analysis and the program populations as reflected in the program tracking data. For HES-IE, there are also some differences related to differences in the treatment of HES-IE subprograms.

Table 1. Comparison of Realization Rates by Report Volume

Program	Electric Savings		Gas Savings	
	Volume 1*	Volume 2**	Volume 1*	Volume 2**
HES	117%	111%	58%	64%
HES-IE	82%	79%	50%	55%

* Volume 1 realization rates for HES-IE present an average that includes model realization rates for SP2 and SP3, proxy realization rates for SP1 (based on building- and utility-specific models), and excludes SP4.
** Volume 2 realization rates for HES-IE present an average that includes measure-level impacts for HES-IE SP2 and SP3 and whole-house impacts for SP1 and SP4.

The Evaluation Team recommends using whole-house billing analysis realization rates for estimating electric savings and measure-level realization rates for estimated gas savings, with the exception of HES-IE SP1 and SP4 for which whole-house billing analysis realization rates are all that are available. The combined report will present findings from both analytical approaches.

Executive Summary: Volume 2

The Connecticut Energy Efficiency Board (EEB) requires an impact evaluation of the Home Energy Services (HES) and Home Energy Services-Income Eligible (HES-IE) programs offered by these Connecticut utilities: Connecticut Light & Power (CL&P), The United Illuminating Company (UI), Connecticut Natural Gas (CNG), Southern Connecticut Gas (SCG), and Yankee Gas Services Company (YGS). The impact evaluation's objective is to provide evaluated estimates of the energy and demand savings associated with measures installed through these programs. The NMR Group and Cadmus, its subcontractor, (collectively known as the Evaluation Team) were selected to conduct this evaluation.

This report describes the impact evaluation findings for the program year 2011 HES and HES-IE programs. Volume 1 of the document provides the results of a whole-house billing analysis to estimate average participant (household-level) electric and natural gas impacts. Volume 2 includes a measure-level impact evaluation, providing estimates of per-unit savings for measures offered through the HES and HES-IE programs, and using an array of evaluation tasks, such as billing analysis, calibrated simulation modeling, and engineering analyses. Volume 2 also includes a whole-house billing analysis that estimates the electric and gas energy impacts of several HES-IE subprograms.

Program Overview

Through the HES program, the majority of homes receive a set of core measures, installed at the time of an in-home audit. These measures include: compact fluorescent light bulbs (CFLs), hot-water savings measures (e.g., faucet aerators, low-flow showerheads), and air and duct sealing. After this initial audit, participants have an option to install other measures with HES rebates, including insulation and equipment replacements (appliances and HVAC).

While the 2011 HES participants achieved high installation rates for these core measures, insulation, HVAC upgrades, and appliance replacements exhibited low installation rates.

The HES-IE program follows a similar structure, with the majority of homes receiving a similar set of core measures. The program primarily differs in that add-on measures (identified as audit recommendations) are installed in HES-IE homes at no cost to the participant (although landlords often are subject to co-pays).

Along with these core measures, 2011 HES-IE participants received higher rates of insulation and heating system upgrades (e.g., ductless heat pumps) than those in the HES program.

Methodology

The Evaluation Team assessed gross per-unit savings generated by each HES and HES-IE measure. These assessments used a combination of analytical approaches: (1) a billing analysis; and (2) an engineering analysis, including calibrated simulation modeling and engineering algorithms.

Brief descriptions of each of these approach follows, with significant detail provided in this report's body and appendices:

- ***Billing Analysis.*** The Evaluation Team developed fixed-effects, savings regression models to estimate measure-level savings for measures installed through the HES and HES-IE programs.[3] The developed weather-normalized models incorporated detailed measure information from utility tracking data. For the billing analysis, the Evaluation Team utilized a comparison group, composed of future HES and HES-IE participants (described in more detail in this report's Volume 1) to test for exogenous effects or macroeconomic factors that might have affected energy consumption between the pre- and post-periods.
- ***Engineering Analysis.*** The Evaluation Team utilized two engineering analysis approaches to estimate measure-specific savings for the most common fuel types (e.g., electric, natural gas, propane, and heating oil). Both engineering approaches relied on detailed measure information and home characteristics from utility tracking data:
  - For program measures known to generate interactive effects (e.g., those increasing or decreasing the energy consumption of another end use, such as insulation), the Evaluation Team estimated savings using a DOE-2-based simulation model, calibrated using average, pre-program energy consumption of HES and HES-IE participants.
  - For measures not typically subject to interactive effects, the Evaluation Team estimated savings using standard industry engineering algorithms.

The impact assessment varied slightly per measure to calculate the most accurate savings values. A billing analysis captured participating homes' actual changes in energy consumption due to energy-efficiency and behavioral improvements. The report includes billing analysis measure- and fuel-specific results whenever these met a precision threshold set at ±35% or less at the 90% confidence level.)[4] The Evaluation Team derived savings for other measures using the engineering analysis.[5]

Table 2 and Table 3 specify the approach used for each HES and HES-IE measure, per fuel type. The tables also provide the precision associated with each billing analysis-based savings estimate.

3 For HES-IE, measure-level models only focused on SP2 and SP3, as the structures of SP1 and SP4 made it difficult to isolate measures and savings installed by the program for the reasons Volume 1 discusses in greater detail. This report volume presents separate whole-house models for SP1 and SP4.

4 Though acceptable, these levels fall short of 90/10 confidence and precision for most specific measures, reflecting the relatively low incidence of these measures in the participant population. The Evaluation Team, however, sought to achieve 90/10 for specific measures whenever possible (and at the program levels). The report shows results with up to a 35% sampling error to provide the most information possible for assessing program impacts and for future program planning. The reader, however, should recognize results with a sampling error greater than 10%–20% do not adhere to standard statistical conventions for acceptable levels of precision. In short, it is very possible that another study with similarly small sample sizes or, preferably, larger ones would produce different conclusions about savings from measures with high sampling errors.

5 In several instances, where tracking data did not provide sufficient measure details, the Evaluation Team accepted reported *ex ante* savings estimates without further evaluation adjustments.

Table 2. Methodological Approach to Calculating Savings by Measure and Primary Fuel Type—HES

Category	Measure	HES		
		Electric	Gas	Oil/Propane
Appliance	Clothes Washer	Engineering Algorithm	Engineering Algorithm	–
	Dehumidifier	Engineering Algorithm	–	–
	Freezer	Engineering Algorithm	–	–
	Refrigerator	Engineering Algorithm	–	–
	Appliance Other*	Reported *Ex Ante*	–	–
HVAC	Central AC	Engineering Algorithm	–	–
	Duct Sealing	Simulation Modeling	Simulation Modeling	Simulation Modeling
	Ductless Heat Pump	Billing Analysis (±35%)	–	–
	Ground-Source Heat Pump	Engineering Algorithm	–	–
	Heat Pump	Engineering Algorithm	–	–
	Heating System Replacement	Engineering Algorithm	Engineering Algorithm	–
Lighting	Lighting	Billing Analysis (±6%)	–	–
Other	Other	Reported *Ex Ante*	–	–
Shell	Air Sealing	Billing Analysis (±21%)	Billing Analysis (±14%)	Billing Analysis (±14%)
	Attic Insulation	Simulation Modeling	Simulation Modeling	Simulation Modeling
	Wall Insulation	Simulation Modeling	Simulation Modeling	Simulation Modeling
	Insulation Other**	Reported *Ex Ante*	Reported *Ex Ante*	Reported *Ex Ante*
	Windows	Engineering Algorithm	Engineering Algorithm	–
Water Heat	Domestic Hot-Water (DHW) Bundle***	Billing Analysis (±21%)	Engineering Algorithm	Engineering Algorithm
	Water Heater Replacement	–	Reported *Ex Ante*	–
	Heat Pump Water Heater	Reported *Ex Ante*	–	–

*These projects consist of appliance replacements without specific detail in the measure descriptions.
**These projects consist of insulation installations without locations specified in the measure descriptions.
*** The measure contains a mix of low-flow showerheads, faucet aerators, and pipe insulation.

Table 3. Methodological Approach to Calculating Savings by Measure and Primary Fuel Type—HES-IE

Category	Measure	HES-IE		
		Electric	Gas	Oil/Propane
Appliance	Freezer	Billing Analysis (±32%)	–	–
	Refrigerator	Billing Analysis (±28%)	–	–
	Appliance Other*	Billing Analysis (±24%)	Reported *Ex Ante*	–
HVAC	Central AC	Engineering Algorithm	–	–
	Duct Sealing	Simulation Modeling	Simulation Modeling	Simulation Modeling
	Ductless Heat Pump	Billing Analysis (±32%)	–	–
	Heating System Replacement	–	Billing Analysis (±14%)	Billing Analysis (±14%)
	Window AC	Engineering Algorithm	–	–
Lighting	Lighting	Billing Analysis (±6%)	–	–
Other	Other	Reported *Ex Ante*	Reported *Ex Ante*	–
Shell	Air Sealing	Simulation Modeling	Billing Analysis (±31%)	Billing Analysis (±31%)
	Attic Insulation	Simulation Modeling	Simulation Modeling	Simulation Modeling
	Wall Insulation	Simulation Modeling	Billing Analysis (±30%)	Billing Analysis (±30%)
	Insulation Other**	Reported *Ex Ante*	–	–
	Windows	Engineering Algorithm	Engineering Algorithm	Engineering Algorithm
Water Heat	DHW Bundle***	Engineering Algorithm	Billing Analysis (±26%)	Billing Analysis (±26%)
	Water Heater Temp Setback	Engineering Algorithm	Engineering Algorithm	Engineering Algorithm
	Water Heater Replacement	Reported *Ex Ante*	Reported *Ex Ante*	–

*These projects consist of appliance replacements without specific detail in measure descriptions.
**These projects consist of insulation installations without locations specified in measure descriptions.
***The measure contains a mix of low-flow showerheads, faucet aerators, and pipe insulation.

Results

Table 4 presents evaluated adjusted gross electric and gas energy savings for the 2011 HES program.

Table 4. Total 2011 Evaluated HES Electric and Gas Savings

Value	Annual MWh	Annual kW	Annual CCF (000s)
Reported Savings	19,991	3,413	569
Evaluated Adjusted Savings	22,~~158~~110	3,~~783~~774	382
Realization Rate	111%		64%

The HES program produced evaluated adjusted gross savings lower than reported savings, with an adjusted gross realization rate of 111% for electric and 64% for gas. Evaluated savings were calculated using analytical methods specific to each measure, as described in more detail below

Table 5 and Table 6 present the distribution of HES electric and gas savings at the measure-level, comparing reported *ex ante* savings to estimates of evaluated gross savings. The savings estimates below reflect average household savings for participants receiving a given measure.

Table 5. Comparison of *Ex Ante* and Evaluated Gross Savings by Measure—HES Electric

Category	Measure	Reported *Ex ante* Savings (kWh/ Household) * (A)	Gross Savings (kWh/ Household) (B)	Realization Rate (B/A)	Method
Appliance	Dehumidifier	382	31	8%	Engineering Algorithm
Appliance	Freezer	705	66	9%	Engineering Algorithm
Appliance	Refrigerator	243	~~189~~39	~~78~~16%	Engineering Algorithm
Appliance	Clothes Washer	1,430	644	45%	Engineering Algorithm
HVAC	Central AC	471	386	82%	Engineering Algorithm
HVAC	Duct Sealing	309	103	33%	Simulation Modeling
HVAC	Heating System Replacement	285	380	133%	Engineering Algorithm
HVAC	Heat Pump	977	758	78%	Engineering Algorithm
HVAC	Ductless Heat Pump**	2,844	1,311	46%	Billing Analysis (±35%)
HVAC	Ground-Source Heat Pump	2,018	1,982	98%	Engineering Algorithm
Lighting	Lighting	652	782	120%	Billing Analysis (±6%)
Other	Other	259	259	100%	Reported *Ex Ante*
Shell	Air Sealing	154	269	175%	Billing Analysis (±21%)
Shell	Insulation Other	368	368	100%	Reported *Ex Ante*
Shell	Windows	3,190	3,196	100%	Engineering Algorithm
Shell	Attic Insulation	708	481	68%	Simulation Modeling
Shell	Wall Insulation	1,876	1,575	84%	Simulation Modeling
Water Heat	Heat Pump Water Heater	1,762	1,762	100%	Reported *Ex Ante*
Water Heat	DWH Bundle	482	359	82%	Billing Analysis (±21%)

*Average *ex ante* savings per household are the program population, except for measures estimated through billing analysis, which are based on the billing analysis participant sample.

**While the billing analysis estimate falls below *ex ante* savings for one of these measures, it should be noted that the billing analysis estimate assumes an existing equipment baseline and may overstate savings for these measures.

Table 6. Comparison of *Ex Ante* and Evaluated Gross Savings by Measure—HES Gas

Category	Measure	Reported *Ex ante* Savings (CCF/ Household) * (A)	Gross Savings (CCF/ Household) (B)	Realization Rate (B/A)	Method
Appliance	Clothes Washer	20	2	8%	Engineering Algorithm
HVAC	Duct Sealing	45	19	42%	Simulation Modeling
HVAC	Heating System Replacement	1,004	229	23%	Engineering Algorithm
Shell	Air Sealing	62	57	91%	Billing Analysis (±14%)
Shell	Insulation Other	175	175	100%	Reported *Ex Ante*
Shell	Windows	136	147	108%	Engineering Algorithm
Shell	Attic Insulation	179	135	76%	Simulation Modeling
Shell	Wall Insulation	449	224	50%	Simulation Modeling
Water Heat	Water Heater Replacement	56	56	100%	Reported *Ex Ante*
Water Heat	DWH Bundle	17	14	84%	Engineering Algorithm

*Average *ex ante* savings per household are based on the program population, except for measures estimated through billing analysis, which are based on the billing analysis participant sample.

Table 7 presents evaluated adjusted gross electric and gas energy savings for the 2011 HES-IE program.

Table 7. Total 2011 Evaluated HES-IE Electric and Gas Savings*

Value	Annual MWh	Annual kW	Annual CCF (000s)
Reported Savings	25,132	1,558	932
Evaluated Adjusted Savings	19,~~836~~950	1,~~230~~237	~~514~~513
Realization Rate	79%		55%

*The realization rates from the SP1 and SP4 whole-house billing analyses have been applied to the percentage of HES-IE savings attributed to each subprogram, for electric and gas, respectively.

For the HES-IE program, evaluated adjusted gross savings were lower than reported savings, with an adjusted gross realization rate of 79% for electric and 55% for gas. Evaluated savings were calculated using analytical methods specific to each measure, as described in more detail below

Table 8 and Table 9 present the distribution of HES-IE electric and gas savings at the measure-level, comparing reported *ex ante* savings to estimates of evaluated gross savings. These savings estimates reflect average household savings for participants receiving a given measure.

Table 8. Comparison of *Ex Ante* and Evaluated Gross Savings by Measure—HES-IE Electric

Category	Measure	Reported *Ex ante* Savings (kWh/ Household)* (A)	Gross Savings (kWh/ Household) (B)	Realization Rate (B/A)	Method
Appliance	Freezer	733	728	99%	Billing Analysis (±32%)
Appliance	Refrigerator	758	318	42%	Billing Analysis (±28%)
Appliance	Appliance Other	353	498	141%	Billing Analysis (±24%)
HVAC	Central AC	98	98	100%	Engineering Algorithm
HVAC	Duct Sealing	262	81	31%	Simulation Modeling
HVAC	Ductless Heat Pump	1,731	803	46%	Billing Analysis (±32%)
HVAC	Window AC	94	46	49%	Engineering Algorithm
Lighting	Lighting	467	647	138%	Billing Analysis (±6%)
Other	Other	637	637	100%	Reported *Ex Ante*
Shell	Air Sealing	342	208	61%	Simulation Modeling
Shell	Insulation Other	153	153	100%	Reported *Ex Ante*
Shell	Windows	1,295	2,253	174%	Engineering Algorithm
Shell	Attic Insulation	2,306	1,429	62%	Simulation Modeling
Shell	Wall Insulation	2,326	716	31%	Simulation Modeling
Water Heat	DWH Bundle	1,372	390	28%	Engineering Algorithm
Water Heat	Temp Setback	87	78	90%	Engineering Algorithm

*Average *ex ante* savings per household are the program population, except for measures estimated through billing analysis, which are based on the billing analysis participant sample.

Table 9. Comparison of *Ex Ante* and Evaluated Gross Savings by Measure—HES-IE Gas

Category	Measure	Reported Ex ante Savings (CCF/ Household)* (A)	Gross Savings (CCF/ Household) (B)	Realization Rate (B/A)	Method
Appliance	Appliance Other	8	8	100%	Reported *Ex Ante*
HVAC	Duct Sealing	174	28	16%	Simulation Modeling
HVAC	Heating System Replacement	128	107	84%	Billing Analysis (±14%)
Other	Other	23	23	100%	Reported *Ex Ante*
Shell	Air Sealing	59	36	61%	Billing Analysis (±31%)
Shell	Windows	25	23	93%	Engineering Algorithm
Shell	Attic Insulation	152	197	129%	Simulation Modeling
Shell	Wall Insulation	304	96	32%	Billing Analysis (±30%)
Water Heat	Temp Setback	6	4	62%	Engineering Algorithm
Water Heat	DWH Bundle	41	29	72%	Billing Analysis (±26%)

*Average *ex ante* savings per household are the program population, except for measures estimated through billing analysis, which are based on the billing analysis participant sample.

Recommendations

The Evaluation Team has developed several recommendations related to improved data management as well as several measure-specific recommendations. These recommendations address challenges that arose in working with utility billing and program tracking data throughout this study, and have been based on the impact evaluation findings and assessment of results.

Data Management

In addition to the recommendations discussed in Volume 1, some additional suggestions follow for improvements in data management. These adjustments will not only benefit the evaluation; they will provide valuable data to inform the future delivery of these programs:

- ***Measure-specific inputs require better tracking within the utility program tracking systems*** to calculate savings based on Program Savings Documentation (PSD) algorithms. In many cases, the tracking system did not provide the details used for these calculations (e.g., windows, no baseline or efficient unit descriptions or installed square footage).
  - Many challenges arose in identifying measure names/descriptions and, in some cases, disaggregating a category into specific measures for energy-savings calculations (e.g., appliances, insulation).
- ***Consistency should increase between utility tracking systems*** for programs and measures, particularly if the programs continue to be reported and evaluated jointly across gas and electric utilities.
  - Align terminologies, such as: discrete measure categories (including subcategories and descriptions, as necessary); measure input values (e.g., efficiency levels); program and subprogram names; and building/household/equipment characteristics.
  - Consistently collect household/equipment characteristics that feed into detailed savings calculations (such as building types, heating fuels, and heating and cooling equipment).
  - Integrate database QA protocols to ensure consistency within projects:
    - For example, the value of conditioned square footage from an initial home audit should match reported conditioned square footage collected in subsequent visits for follow-on measure installations; in some instances, audit data reported conflicting information for individual participants.
  - Ensure fields are populated consistently with standardized values: many differences occurred within and across utility data regarding the methods for defining or describing measures; unpopulated fields (blanks) could be appropriately replaced with values such as "n/a" or a quantity of zero.
- ***QA check information by project***. Specifically for insulation, QA checks should determine whether installed square footage quantities surpass reasonable values relative to a reported,

total, conditioned floor area. Additionally, checks could ensure fuel-specific savings calculated for a project remain consistent with information provided for that site regarding heating and water heating fuel, and the presence and/or type of cooling equipment.

- ***Improved tracking of project data for multifamily buildings.*** Reporting should be consistent at the unit level. The Evaluation Team observed that tracking data and billing data could not always be directly mapped. Billing data often were presented at the facility level, while measure data often were presented at the unit level; a unique identifier to link these data sources should help to resolve this issue. If program tracking data can maintain consistency for multifamily participants in recording information at the unit level, this unique identifier for multifamily units should be present in the billing data to facilitate integration.
- ***Improve the ability to easily export program tracking data*** for specific programs in isolation. In some cases, challenges emerged in identifying measures attributed to HES and HES-IE programs (versus other energy-efficiency programs). In several cases, lacking a program identifier, the Evaluation Team had to identify program-attributed measures using measure descriptions and rebate levels. Recommended actions include creating a data dictionary for existing variables and always adding a variable description when including new fields/values to the dataset.
- ***Ensure program tracking of both electric and gas account numbers.*** This would facilitate accessibility and connections to other databases, using account numbers as unique identifiers (e.g., billing and transaction data). Alternatively, another unique identifier currently utilized by utilities could possibly better facilitate this process.

Measure-Specific

Ductless Heat Pumps

Based on measure-level and whole-house findings, *ex ante* savings estimates for ductless heat pumps overestimated actual savings and did not account for scaled-down savings, which could relate to take-back effects or the accuracy of baseline assumptions (e.g., some level of continued baseboard heating or increased cooling loads). More detailed analysis should be performed, specific to this measure, for HES and HES-IE participants (and could include other programs offering ductless heat pumps in Connecticut). Region-specific research would help clarify discrepancies between current planning estimates and evaluated savings, refine assumptions regarding baseline conditions, and identify key inputs that the current algorithm does not account for.

Faucet Aerators

Based on the engineering review and benchmarking performed on the faucet aerator measure, the savings algorithms and inputs used for the energy-savings calculation should be adjusted to incorporate a drain factor and to use the water heater recovery efficiency rather than the energy factor.

Showerhead

Much like faucet aerators (above), the utility should use the water heater recovery efficiency rather than the energy factor when determining energy savings for showerheads.

Pipe Insulation

The Evaluation Team recommends setting a maximum linear feet of pipe insulation to be used in calculating savings for this measure (i.e., approximately six feet of pipe insulation per water heater).

Window AC

Utilities should ensure that window AC replacements installed through the program meet minimum efficiency requirements, and claimed savings should account for the installed efficiency collected through tracking data (rather than assuming a constant installed efficiency from the PSD). As discussed, the Evaluation Team found, in many cases, that installed units proved less efficient than the CEER Tier 1 or Tier 1 levels,

Introduction

This report summarizes the impact evaluation findings for the Home Energy Services (HES) and Home Energy Services—Income-Eligible (HES-IE) programs. Connecticut's Energy Efficiency Board (EEB) contracted the Evaluation Team (Cadmus and NMR) to perform an impact evaluation of the HES and HES-IE programs, which the following Connecticut electric and gas utilities provide: Connecticut Light and Power (CL&P), United Illuminating Company (UI), Southern Connecticut Gas (SCG), Connecticut Natural Gas (CNG), and Yankee Gas (Yankee).

This report consists of two volumes:

- Volume 1 provides the methodology and results of performing a whole-house billing analysis of the HES and HES-IE programs.
- Volume 2 provides the methodology and results of performing a measure-level analysis of these programs, using an evaluation approach that combines billing and engineering analyses.

The EEB Evaluation Consultant and Evaluation Team plans additional evaluation studies, focusing on: program processes; effective useful life; net-to-gross (NTG); and non-energy impacts for the HES and HES-IE programs.

Program Overview

The HES and HES-IE programs target residential customers living in single-family houses or multifamily buildings. The programs offer home energy audits by BPI-certified technicians to participating customers, regardless of their heating fuel type. Currently, the HES program requires participants to pay $75 for the initial energy audit. In the past, oil and propane heat (delivered fuels) customers had to pay larger co-payments, but American Recovery and Reinvestment Act (ARRA) funds and, more recently, other Connecticut Energy-Efficiency Fund (CEEF) funds (such as those from the Regional Greenhouse Gas Initiative), have allowed the utilities to offer the $75 co-payment to delivered-fuel households. Typically, HES-IE program participants receive audits at no cost (although property owners often must cover co-payments).

Through these audits, technicians identify opportunities that allow customers to save energy through a variety of home improvements, as shown in Table 10.

Table 10. Overview of HES and HES-IE Measure Offerings

Measure Type	Measure
Core Measures (installed on-site during audit)	Compact fluorescent light (CFL) bulbs
	Low-flow showerheads
	Low-flow faucet aerators
	Air and duct sealing

Measure Type	Measure
Additional Measures (recommended based on audit results)	**Appliance replacements** (including refrigerators, freezers, clothes washers [HES only], dehumidifiers [HES only], room air conditioning [AC]units [HES-IE only])
	Shell measures (including attic and wall; window replacements)
	HVAC equipment (including central AC units, heat pumps, ductless mini-splits)
	Water heater replacement

CL&P's HES-IE program includes four components or subprograms (SPs), as outlined in Table 11~~Table 11~~. UI's HES-IE program also collaborates with the Weatherization Assistance Program (WAP) in a manner similar to SP1 for CL&P, but UI does not utilize the same subprogram structure as CL&P.

Table 11. Overview of CL&P HES-IE Subprograms

HES-IE Component	Description
SP1: Weatherization Projects/ Department of Energy (DOE) Approved Jobs*	Utility-leveraged weatherization projects, implemented by agency networks that deliver the federally funded WAP.
SP2: Individual Customer Work Orders	Comprehensive audit and delivery of energy-efficiency and weatherization services.
SP3: Multifamily Comprehensive Projects	Comprehensive audits and delivery of energy-efficiency and weatherization services specific to multifamily buildings, in which 75% of residents meet income qualifications.
SP4: Neighborhood Canvassing	Neighborhoods with anticipated income-eligible customers receive door-to-door HES-IE marketing and direct-installation measures, leading to participation in SP2.

*Currently administered by the Connecticut Department of Energy & Environmental Protection, but previously under the jurisdiction of the Connecticut Department of Social Services.

Report Organization

This report divides into the following sections:

- ***Methodology***, which explains the impact-evaluation tasks, data sources, and analytical approach;
- ***Findings***, which detail key impact results from evaluation activities for the HES and HES-IE programs, at both program and measure levels as well as results specific to whole-house billing analysis of HES-IE SP1 and SP4;[6] and
- ***Appendices***, which provide supplemental details regarding the impact evaluation methods.

[6] Included with Volume 2 as a supplemental analysis, contracted subsequently to development of Volume 1.

Methodology

Volume 2 of this report provides the detailed methodology associated with performing a combination of analytical approaches to estimate the measure-level impacts of the 2011 HES and HES-IE programs. Using this approach, the Evaluation Team estimated electric and gas energy savings for each measure and for each program overall. The Evaluation Team also estimated electric demand and oil/propane impacts based on the evaluated energy savings. Finally, specific to HES-IE SP1 and SP4, the Evaluation Team used whole-house billing analysis to estimate electric and gas energy savings for each subprogram.

Evaluation Approach: Electric and Natural Gas Measure-Level Impacts

The Evaluation Team assessed gross per-unit savings generated by each HES and HES-IE measure. These assessments used a combination of analytical approaches: (1) a billing analysis; and (2) an engineering analysis, including calibrated simulation modeling and engineering algorithms.

Brief descriptions of each of these approach follows, with significant detail provided in this report's body and appendices:

- ***Billing Analysis.*** The Evaluation Team developed fixed-effects savings regression models to estimate measure-level savings for measures installed through the HES and HES-IE programs.[7] Weather-normalized models were developed that incorporated detailed measure information from utility tracking data. For the billing analysis, the Evaluation Team utilized a comparison group, composed of future HES and HES-IE participants (described in more detail in this report's Volume 1) to test for exogenous effects or macroeconomic factors that might have affected energy consumption between the pre- and post-periods.
- ***Engineering Analysis.*** The Evaluation Team utilized two engineering analysis approaches to estimate measure-specific savings for the most common fuel types (e.g., electric, natural gas, propane, and heating oil). Both engineering approaches relied on detailed measure information and home characteristics from utility tracking data:
  - For program measures known to generate interactive effects (e.g., those increasing or decreasing the energy consumption of another end use, such as insulation), the Evaluation Team estimated savings using a DOE-2-based simulation model, calibrated using average pre-program energy consumption of HES and HES-IE participants.
  - For measures not typically subject to interactive effects, the Evaluation Team estimated savings using standard industry engineering algorithms.

The impact assessment varied slightly per measure to calculate the most accurate savings values. A billing analysis captured participating homes' actual changes in energy consumption due to energy-

[7] For HES-IE, measure-level models only focused on SP2 and SP3 as the structures of SP1 and SP4 make it difficult to isolate measures and savings installed by the program for reasons discussed in more detail in Volume 1. This report volume presents separate whole-house models for SP1 and SP4.

efficiency and behavioral improvements. The report includes billing analysis measure- and fuel-specific results whenever these met a precision threshold set at ±35% or less at the 90% confidence level.)[8] The Evaluation Team derived savings for other measures using the engineering analysis.[9]

Table 12 and Table 13 specify the approach used for each HES and HES-IE measure, per fuel type. The tables also provide the precision associated with each billing analysis-based savings estimate.

Table 12. Methodological Approach to Calculating Savings by Measure and Primary Fuel Type—HES

Category	Measure	HES		
		Electric	Gas	Oil/Propane
Appliance	Clothes Washer	Engineering Algorithm	Engineering Algorithm	–
	Dehumidifier	Engineering Algorithm	–	–
	Freezer	Engineering Algorithm	–	–
	Refrigerator	Engineering Algorithm	–	–
	Appliance Other*	Reported *Ex Ante*	–	–
HVAC	Central AC	Engineering Algorithm	–	–
	Duct Sealing	Simulation Modeling	Simulation Modeling	Simulation Modeling
	Ductless Heat Pump	Billing Analysis (±35%)	–	–
	Ground-Source Heat Pump	Engineering Algorithm	–	–
	Heat Pump	Engineering Algorithm	–	–
	Heating System Replacement	Engineering Algorithm	Engineering Algorithm	–
Lighting	Lighting	Billing Analysis (±6%)	–	–
Other	Other	Reported *Ex Ante*	–	–
Shell	Air Sealing	Billing Analysis (±21%)	Billing Analysis (±14%)	Billing Analysis (±14%)
	Attic Insulation	Simulation Modeling	Simulation Modeling	Simulation Modeling
	Wall Insulation	Simulation Modeling	Simulation Modeling	Simulation Modeling
	Insulation Other**	Reported *Ex Ante*	Reported *Ex Ante*	Reported *Ex Ante*
	Windows	Engineering Algorithm	Engineering Algorithm	–

[8] These acceptable levels fall short of 90/10 confidence and precision for most specific measures, reflecting the relatively low incidence of these measures in the participant population. The Evaluation Team, however, sought to achieve 90/10 for specific measures whenever possible (and at the program levels). The report shows results with up to a 35% sampling error to provide the most information possible for assessing program impacts and for future program planning. However, the reader should recognize that the results with a sampling error greater than 10%–20% do not adhere to standard statistical conventions for acceptable levels of precision. In short, it is very possible that another study with similarly small sample sizes or, preferably, larger ones would draw different conclusions about the savings from measures with high sampling errors.

[9] In several instances, where tracking data did not provide sufficient measure details, the Evaluation Team accepted reported *ex ante* savings estimates without further evaluation adjustments.

Category	Measure	HES		
		Electric	Gas	Oil/Propane
Water Heat	Domestic Hot-Water (DHW) Bundle***	Billing Analysis (±21%)	Engineering Algorithm	Engineering Algorithm
	Water Heater Replacement	–	Reported *Ex Ante*	–
	Heat Pump Water Heater	Reported *Ex Ante*	–	–

*These projects consist of appliance replacements without specific detail in the measure descriptions (including refrigerators, freezers, dehumidifiers, and clothes washers).
**These projects consist of insulation installations without locations specified in the measure descriptions.
*** The measure contains a mix of low-flow showerheads, faucet aerators, and pipe insulation.

Table 13. Methodological Approach to Calculating Savings by Measure and Primary Fuel Type—HES-IE

Category	Measure	HES-IE		
		Electric	Gas	Oil/Propane
Appliance	Freezer	Billing Analysis (±32%)	–	–
	Refrigerator	Billing Analysis (±28%)	–	–
	Appliance Other*	Billing Analysis (±24%)	Reported *Ex Ante*	–
HVAC	Central AC	Engineering Algorithm	–	–
	Duct Sealing	Simulation Modeling	Simulation Modeling	Simulation Modeling
	Ductless Heat Pump	Billing Analysis (±32%)	–	–
	Heating System Replacement	–	Billing Analysis (±14%)	Billing Analysis (±14%)
	Window AC	Engineering Algorithm	–	–
Lighting	Lighting	Billing Analysis (±6%)	–	–
Other	Other	Reported *Ex Ante*	Reported *Ex Ante*	–
Shell	Air Sealing	Simulation Modeling	Billing Analysis (±31%)	Billing Analysis (±31%)
	Attic Insulation	Simulation Modeling	Simulation Modeling	Simulation Modeling
	Wall Insulation	Simulation Modeling	Billing Analysis (±30%)	Billing Analysis (±30%)
	Insulation Other**	Reported *Ex Ante*	–	–
	Windows	Engineering Algorithm	Engineering Algorithm	Engineering Algorithm
Water Heat	DHW Bundle***	Engineering Algorithm	Billing Analysis (±26%)	Billing Analysis (±26%)
	Water Heater Temp Setback	Engineering Algorithm	Engineering Algorithm	Engineering Algorithm
	Water Heater Replacement	Reported *Ex Ante*	Reported *Ex Ante*	–

*These projects consist of appliance replacements without specific detail in measure descriptions (including refrigerators and freezers).
**These projects consist of insulation installations without locations specified in measure descriptions.
***The measure contains a mix of low-flow showerheads, faucet aerators, and pipe insulation.

Data Sources

The billing and engineering analyses utilized the following data sources:[10]

- ***Program Tracking Data*** for HES and HES-IE programs, provided by CL&P and UI, and including all electric and gas participants from January 2011 to October 2013.

  These data included: participant names; contact information (e.g., addresses); unique customer identifiers (e.g., utility account numbers); participation dates; building and fuel usage characteristics (e.g., conditioned square feet, heating and water heating fuel types); and total participant *ex ante* savings estimates. The utilities also provided detailed measure data, which included: measure names or descriptions; *ex ante* per-unit measure savings; and measure-specific details used as inputs to the Connecticut Program Savings Documentation (PSD) savings algorithms, such as quantities and efficiency levels.

- ***Billing Data*** for HES and HES-IE participants, provided by CL&P and UI, and including all electric and gas participant monthly usage histories.

  These data included: meter-read dates and all kWh and CCF consumption, by participant account, between January 2010 and October 2013.

- ***Connecticut Weather Data***, including daily average temperatures, from January 2010 through October 2013, for 12 weather stations, corresponding to the nearest monitoring station locations associated with HES and HES-IE participants.

  The study used ZIP codes to match daily heating degree days (HDDs) and cooling degree days (CDDs) to respective monthly billing data read dates. TMY3 (typical meteorological year), 15-year normal weather averages from 1991–2005 were obtained from the National Oceanic and Atmospheric Administration to assess energy usage under normal weather conditions.

- ***Indicators of "Other" Energy*-Efficiency *Program Participation Data,*** composed of program tracking data for non-HES/HES-IE program participation. These data contained: program names; participation dates; and measure installation information. These non-HES/HES-IE programs included other energy-efficiency rebate programs and the Home Energy Reports (HER) behavioral program.

  The Evaluation Team used these data to identify HES participants who may have received recommendations for measures through during their audits but installed the measures through another program. Understanding whether these energy-efficiency improvements happened outside of HES or HES-IE proved important for the model to estimate savings accurately for these programs and to avoid attributing savings from other programs to HES or HES-IE.

  Rather than excluding HER participants from the HES/HES-IE analysis, the Evaluation Team used account numbers to identify HER participants and created a dummy variable for these

[10] The Volume 1 report provides detailed discussions of data challenges encountered.

households when specifying both natural gas and electric billing analysis models.[11] This controlled for impacts of customers' behaviors due to HER and ensured HER participation did not bias energy consumption changes determined for HES and HES-IE.

- ***Connecticut PSD***, a technical reference manual providing detailed documentation of energy and demand savings calculations associated with Energy Efficiency Fund programs for specific energy-savings measures. Connecticut utilities offering the HES and HES-IE programs estimate *ex ante* measure savings for these programs, based on savings calculations the manual contains.[12]
- ***Connecticut 2013–2015 Electric and Natural Gas Conservation and Load Management Plan*** (the Plan), providing reported 2011 electric and gas savings by utility; these savings served as the basis for calculating total evaluated savings.
- ***Indicators of non-utility funded HES-IE projects,*** flagging projects that leveraged state or federal funding and might not comprehensively track household-specific installations and associated energy savings.

  A CL&P HES-IE subprogram, SP1, identifies all potential program participants leveraging non-utility funding. SP2, SP3, and SP4 receive complete funding through the utility. UI provided separate data files, merged them to participant data, and flagged projects that leveraged DOE or ARRA funding for HES-IE installations.

Participant Group

For the impact analysis, the Evaluation Team gathered data from a participant (treatment) group, composed of HES and HES-IE participants from the 2011 calendar year. Measure installations for these program participants occurred between January 1, 2011, and December 31, 2011. This study focused on the 2011 program year as: the analysis sought a complete, 12-month period of post-participation billing data; and, at the time of evaluation planning, billing data for a complete 2013 period were not available. Given this timeline, billing data from a complete year before and after program participation were available for 2011.

Regarding CL&P HES-IE participation, the Evaluation Team performed measure-based analyses only for participants in SP2 and SP3, given the challenges presented with other subprograms (SP1, SP4), as discussed in this report's Volume 1 (and consistent with the project's approved scope). The Evaluation Team evaluated impacts for these subprograms separately using a whole-house billing analysis approach.

[11] The current HER program only targets electric customers and measures, but the behavioral changes adopted by HERs households could generate gas savings or lead them to adopt gas-saving measures.

[12] http://www.ctenergyinfo.com/sites/default/files/2012%20CT%20Program%20Savings%20Documentation%20FINAL.pdf

Comparison Group

The Evaluation Team used a comparison group in conducting a billing analysis consistent with the discussion from Volume 1. Specific to the measure-level billing analyses, the Evaluation Team used the nonparticipation adjustment factor from the whole-house models (the percentage difference between gross model savings and adjusted gross model savings) to scale total evaluated savings consistently to account for exogenous effects.

Savings Calculation

Because whole-house retrofit programs install multiple measures, the estimation of the total savings requires a comprehensive method for capturing the combined effect of all of the installed measures. The Evaluation Team has already presented the results of a whole house billing analysis. In this section of the report, the Evaluation Team assesses savings at the measure level to provide further insights into drivers of the realization rates observed in the whole house billing analysis. The Evaluation Team first developed the best estimate of annual energy savings for each measure installed through the program, based on billing analysis, building simulation modeling, or engineering analysis.

Billing analysis results took first priority and were applied for measures that produced results meeting a specified precision level. Billing analysis was the basis for the initial whole-house estimates and is also used, where possible, to obtain savings estimates at the measure level. However, billing analysis will not provide results at the measure level when almost all of the homes received the measure, when very few homes received the measure, or when the savings for the measure are a relatively small component of the total program savings.

Building simulation modeling results were applied for measures that have significant interactive effects with other measures, and the billing analysis did not provide definitive results.

Engineering analysis results were applied for measures not addressed through the billing analysis or the building simulation.

~~The Evaluation Team first developed the best estimate of annual energy savings for each measure installed through the program, based either on billing analysis, building simulation modeling, or engineering analysis. Billing analysis results applied for measures that produced results meeting a specified precision level. Building simulation modeling results applied for measures exhibiting significant interactive effects with other measures, but not meeting the minimum precision level established for billing analysis results. Engineering analysis results applied for measures not addressed through the billing analysis or the building simulation. The Findings sections present these best estimates as evaluated gross savings.~~

The Findings sections present these best estimates at the measure level as evaluated gross savings and compares those savings The Findings sections also compare evaluated gross savings to average *ex ante* savings for each measure captured in the utility tracking data to derive a measure-level realization rate (i.e., the percentage of difference between "expected" and evaluated savings).). The measure-level realization rates are presented below in Table 15 and Table 16 for HES, and Table 46Table 47 and Table 47Table 48 for HES-IE.

To develop program-level realization rates, the Evaluation Team applied measure-level realization rates to total savings for a measure, as captured in the utility program tracking data. Appendix F. Detailed Distribution of Total Savings provides the total gross evaluated savings as compared to the total reported *ex ante* savings for each measure, along with gross program-level realization rates.

Nonparticipation adjustment factors were applied to the program-level gross realization rate to derive the final program-level realization rates and adjusted gross savings, as reported in Table 14 and Table 45Table 44, below.

As savings have been adjusted based on a comparison group and not on a true control group (i.e., a randomized, controlled trial experimental design), adjusted gross savings accounted for some NTG elements (e.g., take-back effects), but likely did not fully account for them.[13]

Given the method used, analysis defined the resulting savings as adjusted gross savings.

Demand Impacts

The study primarily focused on evaluating energy savings through billing analysis. In addition, it determined program-level demand impacts by applying the realization rates, based on the energy impact analysis to the 2011 demand savings reported in the Plan.[14]

Overall Program-Year Evaluated Savings

The overall program-level realization rate for each program and fuel were adjusted (using the nonparticipant adjustment factor) based on the comparison group to derive the final (adjusted gross) realization rate. The Evaluation Team then applied this realization rate to the savings reported in the Plan for the 2011 program year to derive the *evaluated adjusted gross savings* presented in Table 14 and Table 45Table 46 for HES and HES-IE, respectively.[15] The nonparticipant adjustment based on the

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13 UMP Whole-Building Retrofit with Consumption Data Analysis Evaluation Protocol. Available online at: https://www1.eere.energy.gov/wip/pdfs/53827-8.pdf

14 As a supplemental analysis, the Evaluation Team has proposed performing a more detailed demand-impact modeling approach for evaluating demand savings. This approach would use end-use load shapes and several peak period definitions (e.g., seasonal versus on peak) to estimate demand associated with program measure activities for a specific program period.

15 The savings reported in the Plan for the 2011 program year have been adjusted by net realization rates, outlined in the 2011 PSD (Chapter 7, Table 1.3C, p.232) for both HES and HES-IE programs. For this study,

comparison group is used to account for exogenous factors or impacts on energy use not related to the program. Because the adjustment is based on a comparison group and not on a true control group (i.e., a randomized, controlled trial experimental design), adjusted gross savings accounted for some net-to-gross elements (e.g., take-back effects), but likely do not fully account for them.[16]

The program-level "reported" savings presented in Table 14 and Table 45Table 46 do not match the "ex ante" savings presented in the tables in Appendix F due to discrepancies between savings totals from the program-tracking data received and the savings reported in the Plan.

Given discrepancies between total savings reported in the program-tracking data received and the savings reported in the Plan, the Evaluation Team relied on adjusted gross realization rates, calculated using different analytical methods, and adjusted for exogenous/nonparticipant effects. Adjusted gross savings realization rates, by utility program and fuel, were applied to savings reported in the Plan for the overall 2011 program year to derive evaluated adjusted gross savings for the 2011 program year.[17]

As noted in the Participant Group sectionIt should be noted that, neither CL&P's HES-IE SP1 nor SP4 were included in the analysis sample used in the measure-specific billing analysis. The Evaluation Team did perform a separate billing analysis to calculate whole-house adjusted gross savings estimates for these
discrete SPs. These subprograms have been included in the estimation of total program savings, through applying adjusted gross realization rates from this whole-house analysis to the percentage of reported HES-IE savings attributed to each SP, for gas and electric savings, respectively.

Demand Impacts

The study primarily focused on evaluating energy savings through billing analysis. In addition, it determined program-level demand impacts by applying the realization rates, based on the energy impact analysis to the 2011 demand savings reported in the Plan.[18]

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these net realization rates have been backed out of the Plan-reported savings to ensure adjusted gross realization rates from this study have been applied to "unadjusted," gross *ex ante* results.

16 UMP Whole-Building Retrofit with Consumption Data Analysis Evaluation Protocol. Available online at: https://www1.eere.energy.gov/wip/pdfs/53827-8.pdf

17 The savings reported in the Plan for the 2011 program year have been adjusted by net realization rates, outlined in the 2011 PSD (Chapter 7, Table 1.3C, p.232) for both HES and HES-IE programs. For this study, these net realization rates have been backed out of the Plan-reported savings to ensure adjusted gross realization rates from this study have been applied to "unadjusted," gross *ex ante* results.

18 As a supplemental analysis, the Evaluation Team has proposed performing a more detailed demand-impact modeling approach for evaluating demand savings. This approach would use end-use load shapes and several peak period definitions (e.g., seasonal versus on peak) to estimate demand associated with program measure activities for a specific program period.

Billing Analysis

The Evaluation Team developed measure-level models using the same participant and comparison groups employed in determining the whole-house savings estimates. Volume 1 provides a detailed discussion of model selection, analysis periods, and participant/nonparticipant groups.

Separate whole-house billing analyses calculated impacts on consumption for HES-IE SP1 and SP4, as analyses for these programs had not been completed for the Volume 1 delivery. The Evaluation Team followed the same modeling approach and method for screening billing data for the SP1 and SP4 analysis, which Volume 1 discusses in detail.

Model Attrition

As noted, attrition associated with measure-level analysis matches the discussion of participant and nonparticipant group model attrition presented in Volume 1.

Appendix D. Billing Analysis Model Attrition for HES-IE SP1 and SP4 provides more detail on HES-IE SP1 and SP4 model attrition.

Engineering Analysis

Simulation Modeling

Program measures that generate interactive effects, such as insulation and air sealing, required use of simulation models to determine energy savings values. For such measures, the Evaluation Team estimated savings using a DOE-2 based simulation model, calibrated to pre-measure installation energy consumption. This approach improved the accuracy of modeled consumption for pre-measure installation cases, thus increasing the accuracy of calculated savings. Compared to separate engineering calculations, the calibrated modeling approach improved accuracy by accounting for the following:

- Internal and solar gains;
- Monthly variations in energy use due to occupant behaviors;
- The thermal mass of building assemblies and other internal components; and
- Locations of infiltration (rather than assuming all infiltration occurs directly to or from the outside).

The Evaluation Team developed individual simulation models for each building, heating fuel (natural gas and electric), and program type. This process relied on program and participant information from the utility tracking system, such as heated floor areas, to determine conditioned floor areas of each building type (i.e., single-family, multifamily), heating fuel (i.e., electric, gas), and program type (i.e., HES, HES-IE). Following development of the model for each building, heating fuel, and program type, each baseline model could be calibrated to the end uses described in Appendix C. Simulation Modeling Details

Following development of the calibrated baseline models (e.g., building prototypes), the Evaluation Team incorporated inputs to simulate changes to baseline conditions, allowing calculation of energy savings for weatherization and duct-sealing measures. For insulation measures, post-measure installation R-values—derived from utility tracking data—were input into the models. For air and duct-sealing measures, the Evaluation Team similarly relied on program tracking data for average leakage estimates.

An initial attempt to incorporate installed surface areas of insulation measures produced outputs that could not be confirmed as total surface areas of that building component. The Evaluation Team identified anomalies in the process, such as a project where the square footage of installed wall insulation exceeded realistic conditions, given the conditioned floor area from the tracking data.

Due to this limitation, the Evaluation Team used models to determine percentages of savings for each measure, relative to the weather-sensitive heating and cooling loads for each prototype. Savings percentages by measure from simulation models were applied to weather-normalized energy consumption available from the participant sample used in the billing analysis. The Evaluation Team used this approach to calculate average measure savings for each building type, heating fuel, and program type. Savings percentages of weather-sensitive loads (and underlying equipment efficiencies) were assumed to be the same for oil and propane-heat homes as for gas-heated homes—a technique consistent with the PSD's methodology for estimating oil and propane savings.

Engineering Algorithms

The Evaluation Team used engineering algorithms to supplement the billing analysis and simulation modeling for measures not typically subject to interactive effects. The engineering algorithms primarily derived from the most recent PSD (2013). In some cases, the utility tracking data proved insufficient to evaluate measures adequately using only the 2013 PSD, so the Evaluation Team incorporated supplemental sources, such as regional technical resource manuals (TRMs) and current evaluation research.

Savings within the PSD were broken into two main components: lost opportunity savings and retirement savings. Lost opportunity savings were awarded where an installed unit proved more efficient than a defined baseline or standard; retirement savings were awarded for installed units meeting a defined baseline or standard and resulting in the replacement or retirement of a less efficient unit.

When both savings could be claimed for a given installation, savings could be deemed "retrofit" savings; this approximated what is commonly called an "early replacement" measure, accounting for existing baselines or equipment, in comparison to the new/installed measure (rather than using a baseline associated with the current standard).

The PSD also states: "When the retirement life is approximately zero, savings are reduced to lost opportunity savings only. Retirement savings are acknowledged to exist but are ignored because they are assumed to be short lived." This statement implies that retirement and retrofit savings can only be procured for measures where the program significantly affects the behavior of customers in the service territory.

This evaluation assumed: HES participants received only lost opportunity savings (commonly called "replace on burnout"); and HES-IE participants received retrofit savings (accounting for existing baseline conditions, and assuming, in the program's absence, HES-IE participants would continue using equipment beyond its expected useful life).

The Evaluation Team calculated evaluated savings on a per-household basis, primarily relying on program tracking data for PSD algorithm inputs. Additional sources (including TRMs and recent evaluation studies) were used to supplement the analysis as needed, and, in some cases, to provide a more detailed comparison of measure-specific algorithms and inputs. Appendix B. Engineering Algorithms and the Findings section provide further discussions of algorithm-based calculations and assumptions.

The Evaluation Team acknowledges that code changes have occurred since the 2011 PSD, and, in some cases, evaluated savings reflect current conditions rather than conditions at the time of measure installation. This has resulted in lower savings for measures affected by the updated code. These measures, however, accounted for a small proportion of overall savings for HES and HES-IE and did not materially affect overall results.

Estimating Oil/Propane Impacts

To develop estimates of oil and propane savings, the Evaluation Team used conversion factors to extrapolate evaluated impacts in relation to savings occurring in natural-gas homes. This approach assumed that homes using propane or oil heat would have similar construction features and base loads as those heated with natural gas. The PSD provided the conversion factors and equations used for these conversions. Volume 1 of this report presents further details regarding this approach.

~~*Billing Analysis*~~

~~The Evaluation Team developed measure-level models using the same participant and comparison groups employed in determining the whole-house savings estimates. Volume 1 provides a detailed discussion of model selection, analysis periods, and participant/nonparticipant groups.~~

~~Separate whole-house billing analyses calculated impacts on consumption for HES-IE SP1 and SP4, as analyses for these programs had not been completed for the Volume 1 delivery. The Evaluation Team followed the same modeling approach and method for screening billing data for the SP1 and SP4 analysis, which Volume 1 discusses in detail.~~

~~Model Attrition~~

~~As noted, attrition associated with measure-level analysis matches the discussion of participant and nonparticipant group model attrition presented in Volume 1.~~

~~Appendix D. Billing Analysis Model Attrition for HES-IE SP1 and SP4 provides more detail on HES-IE SP1 and SP4 model attrition.~~

HES Findings

This section presents evaluated savings estimates for all HES measures, covering electric, natural gas, oil, and propane fuel types. The results are presented first at the program level, followed by measure-specific findings, grouped by measure type and primary heating fuel type.

Program-Level Results

Table 14 presents the evaluated adjusted gross electric and gas energy savings for the 2011 HES program.

Table 14. Total 2011 Evaluated HES Electric and Gas Savings

Value	Annual MWh	Annual kW	Annual CCF (000s)
Reported Savings	19,991	3,413	596
Evaluated Adjusted Gross Savings	22,~~158~~110	3,~~783~~774	382
Realization Rate	111%		64%

For the HES program electric savings overall, evaluated adjusted gross savings were slightly higher than reported savings, with an adjusted gross realization rate of 111%. For the HES program gas savings overall, evaluated adjusted gross savings were lower than reported savings, with an adjusted gross realization rate of 64%. Evaluated savings have been estimated for each measure (based on either a billing analysis, building simulation modeling or engineering analysis. Program level savings are then calculated by rolling up the measure level savings, as described in more detail below.

Figure 1 and Figure 2 show the distribution of evaluated energy savings by measure, for electric and gas, respectively. For this program, the majority of savings occurred through the following measures:

- For electric savings: lighting and air sealing account for 76% of reported savings and 86% of evaluated savings.
- For gas savings: air sealing, DHW bundle, and insulation account for 86% of reported savings and 93% of evaluated savings.

Figure 1. Measure Distribution of 2011 HES Electric Savings, *Ex Ante* and Evaluated

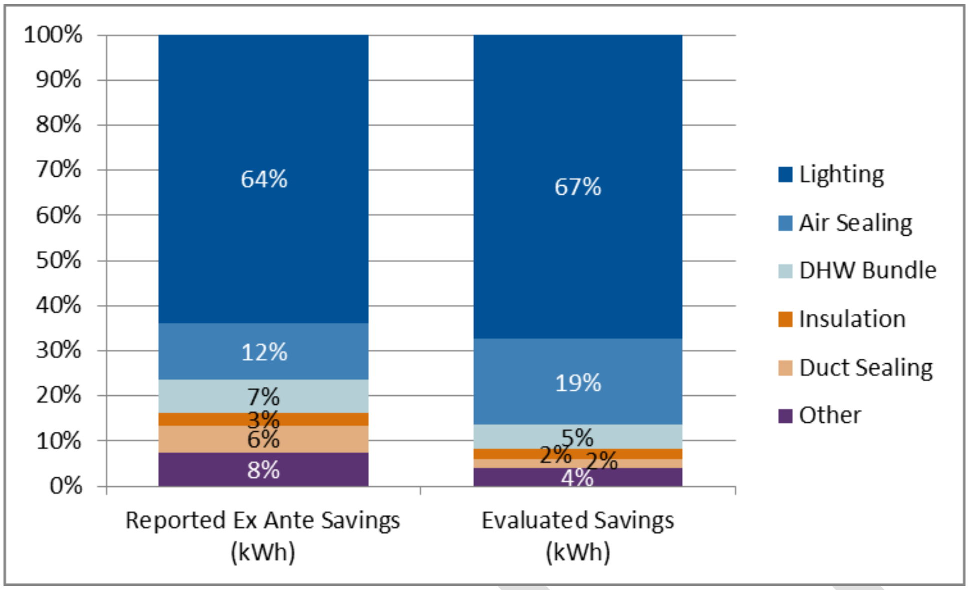


Figure 2. Measure Distribution of 2011 HES Gas Savings, *Ex Ante* and Evaluated

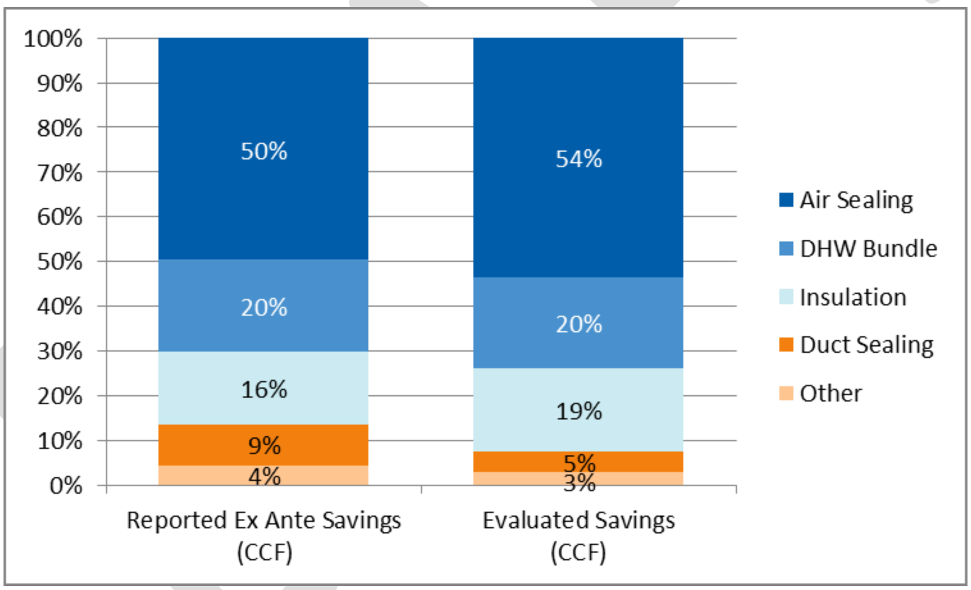


Table 15 and Table 16 present the distribution of HES electric and gas savings at the measure-level, comparing reported *ex ante* savings to estimates of evaluated gross savings. The savings estimates below reflect average household savings for participants receiving a given measure.

Table 15. Comparison of *Ex Ante* and Evaluated Gross Savings by Measure—HES Electric

Category	Measure	Reported *Ex ante* Savings (kWh/ Household) * (A)	Gross Savings (kWh/ Household) (B)	Realization Rate (B/A)	Method
Appliance	Dehumidifier	382	31	8%	Engineering Algorithm
Appliance	Freezer	705	66	9%	Engineering Algorithm
Appliance	Refrigerator	243	~~189~~39	~~78~~16%	Engineering Algorithm
Appliance	Clothes Washer	1,430	644	45%	Engineering Algorithm
HVAC	Central AC	471	386	82%	Engineering Algorithm
HVAC	Duct Sealing	309	103	33%	Simulation Modeling
HVAC	Heating System Replacement	285	380	133%	Engineering Algorithm
HVAC	Heat Pump	997	758	78%	Engineering Algorithm
HVAC	Ductless Heat Pump**	2,844	1,311	46%	Billing Analysis (±35%)
HVAC	Ground-Source Heat Pump	2,018	1,982	98%	Engineering Algorithm
Lighting	Lighting	652	782	120%	Billing Analysis (±6%)
Other	Other	259	259	100%	Reported *Ex Ante*
Shell	Air Sealing	154	269	175%	Billing Analysis (±21%)
Shell	Insulation Other	368	368	100%	Reported *Ex Ante*
Shell	Windows	3,190	3,196	100%	Engineering Algorithm
Shell	Attic Insulation	708	481	68%	Simulation Modeling
Shell	Wall Insulation	1,876	1,575	84%	Simulation Modeling
Water Heat	Heat Pump Water Heater	1,762	1,762	100%	Reported *Ex Ante*
Water Heat	DWH Bundle	482	359	82%	Billing Analysis (±21%)

*Average *ex ante* savings per household are the program population, except for measures estimated through billing analysis, which are based on the billing analysis participant sample.

**While the billing analysis estimate falls below *ex ante* savings for one of these measures, it should be noted that the billing analysis estimate assumes an existing equipment baseline and may overstate savings for these measures.

Table 16. Comparison of *Ex Ante* and Evaluated Gross Savings by Measure—HES Gas

Category	Measure	Reported *Ex ante* Savings (CCF / Household) * (A)	Gross Savings (CCF/ Household) (B)	Realization Rate (B/A)	Method
Appliance	Clothes Washer	20	2	8%	Engineering Algorithm
HVAC	Duct Sealing	45	19	42%	Simulation Modeling
HVAC	Heating System Replacement	1,004	229	23%	Engineering Algorithm
Shell	Air Sealing	62	57	91%	Billing Analysis (±14%)
Shell	Insulation Other	175	175	100%	Reported *Ex Ante*
Shell	Windows	136	147	108%	Engineering Algorithm
Shell	Attic Insulation	179	135	76%	Simulation Modeling
Shell	Wall Insulation	449	224	50%	Simulation Modeling
Water Heat	Water Heater Replacement	56	56	100%	Reported *Ex Ante*
Water Heat	DWH Bundle	17	14	84%	Engineering Algorithm

*Average *ex ante* savings per household are based on the program population, except for measures estimated through billing analysis, which are based on the billing analysis participant sample.

For those measures attributed to more than 5% of program savings, Table 17 and Table 18 provide notes regarding considerations or implications for the PSD.

Table 17. PSD Considerations—HES Electric

Measure	Percent of Total Evaluated Savings	Consideration
Lighting	67%	Consider revisions to lighting calculation assumptions (e.g., HOU, in service rate), perhaps in consideration of total number of bulbs installed per household
Air Sealing	19%	Consider incorporating evaluated realization rates in the savings calculation and/or developing deemed savings values (by heating system) using evaluation results. In regard simulation modeling assumptions used in PSD, consider reviewing input assumptions, building prototypes, and calibration process to customer usage to assess whether these align with the current program participation.

DWH Bundle	5%	Consider incorporating evaluated realization rates in the savings calculation and review input assumptions used in the current algorithm (given significant changes in assumed water savings for showerheads and aerators between the 2011 and 2013 PSDs). In addition, consider several revisions to current algorithms, including: a drain factor for aerators, maximum feet of pipe wrap (i.e., 6 ft.), and use of water heater recovery efficiency rather than energy factor for showerhead/aerator savings calculation.
General		Consider performing ongoing whole-house billing analysis to assess annual savings, including home characteristic stratifications when sufficient data are available to support the analysis (e.g., heating equipment).

Table 18. PSD Considerations —HES Gas

Measure	Percent of Total Evaluated Savings	Consideration
Air Sealing	54%	Consider incorporating evaluated realization rates in the savings calculation and/or developing deemed savings values (by heating system) using evaluation results. In regard simulation modeling assumptions used in PSD, consider reviewing input assumptions, building prototypes, and calibration process to customer usage to assess whether these are aligned with the current program participation.
DWH Bundle	20%	Consider incorporating evaluated realization rates in the savings calculation and review input assumptions used in the current algorithm (given significant changes in assumed water savings for showerheads and aerators between the 2011 and 2013 PSDs). In addition, consider several revisions to current algorithms, including: a drain factor for aerators, maximum feet of pipe wrap (i.e., 6 ft.), and use of water heater recovery efficiency rather than energy factor for showerhead/aerator savings calculation.
Insulation	19%	Consider revisions to insulation calculation assumptions (e.g., HDD, ASHRAE adjustment factor) to account for realization rate differences. Review baseline R value data collection and entry protocols, to ensure correct baseline is tracked (e.g., no zero or missing values).
General		Consider performing ongoing whole-house billing analysis to assess annual savings, including home characteristic stratifications when sufficient data are available to support the analysis (e.g., heating equipment).

Measure-Level Savings

This section addresses evaluated gross savings estimates for all HES measures, covering electric, natural gas, and oil/propane fuel types. The results are grouped by fuel savings and are presented for distinct measures and/or measure categories.

HES Electric Savings

The billing analysis provided estimates of electric savings for several HES measure categories: lighting, ductless heat pumps, air sealing, insulation other (containing a mix of attic and wall installations), and the DHW bundle (containing showerheads, pipe insulation, and aerators). All other estimates of electric savings presented in this section were determined using engineering algorithms and simulation modeling.

Lighting

The Evaluation Team estimated impacts for a combined lighting bundle (primarily composed of CFLs, along with a few installations of fixtures and light emitting diodes [LEDs]) through the billing analysis.[19] Table 19~~Table 17~~ presents the billing analysis model results for lighting measures, which achieved a precision (±6%) estimate of below the study threshold of 35%, as well as below the industry standard of 10%.

Table 19. HES Billing Analysis Electric Savings Results for Lighting

Measure	n	PRENAC	Model Savings (kWh)	Savings as Percent of Pre-Usage	Relative Precision at 90%
Lighting	10,797	11,220	782	7%	±6%

On average, the program installed 18.6 CFLs per household, based on participants in the billing analysis sample. Given average household-level CFL savings of 782 kWh annually, this equates to about 42 kWh per bulb—results slightly higher than average gross *ex ante* savings (652 kWh) from the utility tracking system data, based on PSD calculations.

Table 20~~Table 18~~ provides the realization rate, based on comparing the gross savings estimate from the billing analysis to the average *ex ante* savings per household.

Table 20. HES Billing Analysis Realization Rate Summary for Lighting

Measure	Gross Model Savings (kWh)	Reported *Ex Ante* Savings (kWh)	Realization Rate	Model Savings as Percent of Pre-Usage	Reported *Ex Ante* Savings as Percent of Pre-Usage
Lighting	782	652	120%	7%	6%

Typical energy savings drivers drawn from CFL engineering algorithms include assumptions for average hours of use (HOU), the change in wattage between existing and replaced bulbs, and installation or in-service rates. HES field implementation protocols require auditors to install all bulbs delivered to participants (i.e., leaving no bulbs behind uninstalled), up to a maximum of 25 bulbs per home. No specific guidance exists regarding installation only in high-use sockets (e.g., protocols indicate: “CFLs should be installed throughout the house in any suitable fixture”);[20] some similar programs restrict installation to high-use sockets (e.g., three hours or more), ensuring higher savings associated with

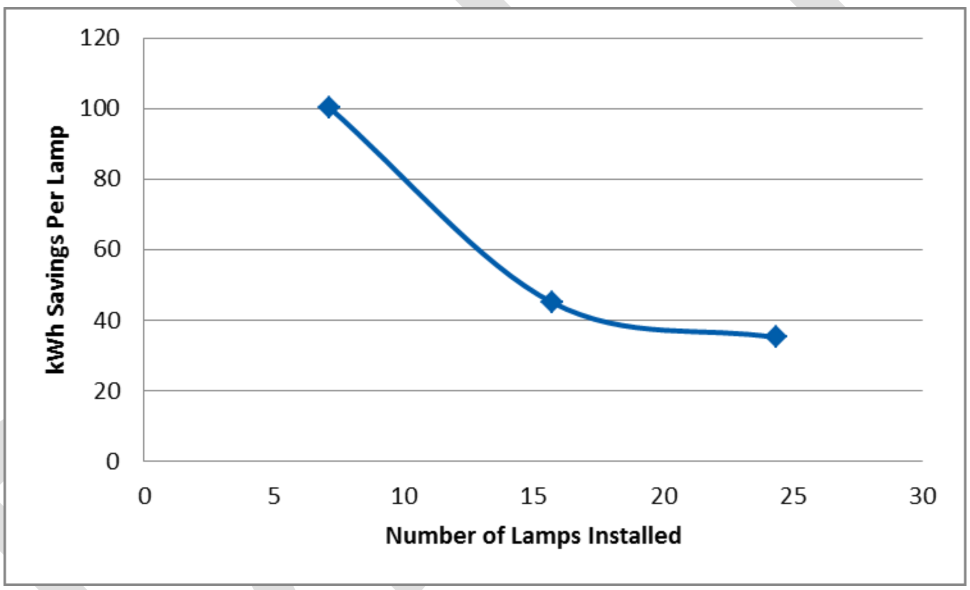
19 As CFLs represent approximately 99.9% of total *ex ante* reported savings for the lighting category, analysis findings can be considered largely in the context of CFL bulb installation.

20 *2012 Home Energy Solutions: Field Implementation Manual*. p. 48.

higher HOU. It is likely that the directive to install CFLs in all available sockets stemmed from Connecticut's goal of achieving high socket saturations at the state level.

A closer look at average savings based on the number of lighting installations per home reveals a decrease in average savings, given an increase in installations. This trend may relate to HOU effects, with few installations made into higher-use sockets (resulting in higher average savings), for an average decrease in HOU as the number of installations per home increase.[21] Figure 3 illustrates this trend, showing a decrease in lighting savings based on the quantity installed (thus increasing the number of lower-use sockets in the overall average). Given that the realization rate is greater than 100% suggests that the strategy of getting bulbs into as many sockets as possible did not reduce savings overall, but it does suggest the need to update the savings assumptions or how the values are applied. The Evaluation Team's understands that this update may already be underway, given the recent completion of the Regional Hours of Use study.[22]

Figure 3. HES—Per Unit Lighting Savings Based on Number of Installations



[21] Upon first appearances, the trend showing HOU decreasing with installations of more energy-efficient bulbs may seem to contradict the *Northeast Regional Hours of Use Study*. That study found: 1) HOU was higher for energy-efficient vs. inefficient bulbs; and 2) this relationship did not change with socket saturations (i.e., the percentage of sockets filled with energy-efficient bulbs). The two studies, however, really could not be directly compared. The current study focuses on bulbs an auditor directly installed in every socket in a home, up to the program limit (i.e., 25). In contrast, the regional HOU study primarily focused on bulbs obtained from retail stores, with the home occupants deciding where to install bulbs, and even homes with the highest energy-efficient socket saturations having many (sometimes 50% or more) of their sockets filled with inefficient bulbs. Thus, though the studies do not contradict one another, they simply cannot be directly compared.

[22] NMR Group, Inc. and DNV GL. 2014. *Northeast Regional Hours of Use Study.* Final delivered on May 5, 2014. https://app.box.com/s/o1f3bhbunib2av2wiblu

Table 21~~Table 19~~ presents additional details regarding lighting installations by the quantity received (binned in categories of 1 to 10, 11 to 20, and greater than 20 lighting installations). As shown, average savings per bulb decrease within each category as more bulbs are installed per home.

Table 21. HES Energy Savings Based on Lighting Quantity Installed

CFLs Received	Percent of Sample	Average CFLs Installed	Gross Model Savings		*Ex Ante* Savings		Realization Rate
			kWh/unit	kWh/ household	kWh/unit	kWh/ household	
1-10	16%	7.1	100.3	716	34.7	248	289%
11-20	35%	15.8	45.0	708	34.5	544	130%
>20	50%	24.4	35.1	855	35.3	860	99%
Overall	100%	18.6	42.0	782	35.0	652	120%

Shell Measures and Duct Sealing

The Evaluation Team estimated impacts for shell measures (including insulation and air sealing) and duct-sealing measures primarily using a combination of billing analysis and building simulation models. Specifically, estimates for air sealing have been estimated using billing analysis, given precision estimates meeting the study's threshold. Impacts associated with window replacements have been assessed using engineering algorithms due to limited information provided in the program tracking data.

Electric savings for these measures are associated with heating savings from electric heat sources, in addition to reductions in cooling and fan energy consumption (associated with reduced run times in homes with gas, oil, or propane heating).

Billing Analysis Results

The Evaluation Team estimated air sealing impacts through the billing analysis, as this measure achieved a precision estimate of less than the study threshold. Table 22~~Table 20~~ presents the corresponding billing analysis model results.

Table 22. HES Billing Analysis Electric Savings Results for Air Sealing

Measure	n	PRENAC	Model Savings (kWh)	Savings as Percent of Pre-Usage	Relative Precision at 90%
Air Sealing	8,201	11,987	269	2%	±21%

Table 23~~Table 21~~ provides the realization rate, based on comparing the gross savings estimate from the billing analysis to the average *ex ante* savings per household, demonstrating that electric savings associated with this measure are much higher than the *ex ante* savings would suggest.

Table 23. HES Billing Analysis Realization Rate Summary for Air Sealing

Measure	Gross Model Savings	Reported *Ex Ante* Savings	Realization Rate	Model Savings as	Reported *Ex Ante* Savings

	(kWh)	(kWh)*		Percent of Pre-Usage	as Percent of Pre-Usage
Air Sealing	269	154	175%	2%	1%

*Average *ex ante* savings is based on the participant sample used in the billing analysis and may vary from averages based on the program population.

Simulation Modeling Results

The Evaluation Team used detail provided in the utility tracking data (for each building type and heating fuel combination) to assess corresponding pre- and post-installation information for each measure analyzed using the calibrated simulation approach. Table 24~~Table 22~~ presents these details, including average pre- and post-installation insulation levels (weighted by square footage installed) and changes in air and duct-sealing levels (i.e., cubic feet per minute [CFM]).

Table 24. HES Electric—Shell and Duct Sealing Measure Distribution and Installation Details

Measure	Participants*	Pre-Condition	Post-Condition	Average % Leakage Reduction	Units
Duct Sealing	3,468	410	331	19%	CFM 25
Attic Insulation	522	R8	R34	n/a	R-Value
Wall Insulation	55	R0.5	R14	n/a	R-Value

*Count of participants reflects the number with *ex ante* savings reported for a given measure.

The Evaluation Team used the energy models to calculate the percent savings for each weather-sensitive measure. These percentages were then applied to the pre-period weather-sensitive usage for each model to calculate evaluated energy savings. Table 25~~Table 23~~ presents: weighted, household-level electric savings for each measure; and realization rates compared to average *ex ante* savings, along with the savings percentages of weather-sensitive loads.

Table 25. HES Electric—Weighted Household Savings for Shell and Duct Measures

Measures	Average *Ex Ante* Savings (kWh)	Average Pre-Installation Weather-Sensitive Consumption (kWh)	Savings as % of Weather-Sensitive Load	Average Evaluated Gross Savings (kWh)	Realization Rate
Duct Sealing	309	3,942	2.6%	103	33%
Attic Insulation	708	3,395	14.2%	481	68%
Wall Insulation	1,876	7,243	21.7%	1,575	84%

Differences in calculation approaches (including specific simulation modeling assumptions and algorithm inputs) likely drove differences in evaluated savings, compared to *ex ante* savings. For example, REM/Rate models from 2008 were used to estimate savings for air- and duct-sealing in the PSD (performed by C&LM Planning team, Northeast Utilities). Differences that could account for such variations include the following:

- Differences in building prototypes modeled, specific assumptions associated with existing conditions (e.g., duct locations), and square footage (for each prototype and measure to be modeled); and
- Whether the simulation models were calibrated to pre-period billing data, and, if so, whether these models were based on average customer usage, average participant-specific usage, or usage associated with specific participants for each prototype.

Using a modeling approach that calculated savings as a percentage of energy use limited the potential to overestimate savings on a per-measure basis. For example, evaluated estimates of air-sealing and duct-sealing measures accounted for the overall, feasible reduction in air leakage, ensuring these estimates remained relative to overall consumption (and did not overestimate the combined impact).

Engineering Algorithm Results

For window replacements, pre- and post-installation data were not available to incorporate into the modeling. Consequently, the Evaluation Team made assumptions regarding window efficiencies and square footage installed.[23] Table 26~~Table 24~~ lists the participation, average installed units, average household savings, and realization rates of window measure installations.

Table 26. HES Electric—Evaluated Window Savings

Measure	Total Participants	Average Installed Units	Evaluated Gross Unit Savings (kWh)	Ex-Ante Household Savings (kWh)	Evaluated Gross Household Savings (kWh)	Realization Rate
Windows	14	13.71	233	3,190	3,196	100%

Domestic Hot Water

The Evaluation Team used the billing analysis to estimate impacts for a combined DHW measure bundle (including showerheads, faucet aerators, and pipe insulation). Table 27~~Table 25~~ presents the billing analysis model results for the DHW measure bundle, which achieved a precision estimate below the study threshold.

Table 27. HES Billing Analysis Electric Savings Results for Electric DHW Measures

Measure	n	PRENAC	Model Savings (kWh)	Savings as Percent of Pre-Usage	Relative Precision at 90%
DHW Bundle	1,578	14,669	395	3%	±21%

[23] Evaluated savings estimates assume installation of ENERGY STAR windows from a single-pane baseline, with typical window size of 3 feet by 4 feet (a 2011 PSD assumption). Annual electric heating (*AEH*) and cooling (*AEC*) usage are provided in the PSD: 5.66 kWh/ft^2 (AEH_{es}) and 1.49 kWh/ft^2 (AEC_{es}) for the ENERGY STAR unit, and 22.02 kWh/ft^2 (AEH_b) and 2.57 kWh/ft^2 (AEC_b) for the single pane baseline. Average savings for windows include cooling savings for 30% of homes with central AC units (indicated in the utility tracking system).

Table 28~~Table 26~~ provides the realization rate for this measure, based on comparing the gross savings estimate from the billing analysis to average *ex ante* savings per household.

Table 28. HES Billing Analysis Realization Rate Summary for Electric DHW Measures

Measure	Gross Model Savings (kWh)	Reported *Ex Ante* Savings (kWh)	Realization Rate	Model Savings as Percent of Pre-Usage	Reported *Ex Ante* Savings as Percent of Pre-Usage
DHW Bundle	395	482	82%	3%	3%

For specific measures within the DHW bundle, the Evaluation Team performed an engineering review and comparison against a range of other sources (including evaluation studies and TRMs). Appendix B. Engineering Algorithms presents these detailed findings.

HVAC

The Evaluation Team estimated impacts for several HVAC measures using a combination of billing analysis and engineering algorithms. Table 29~~Table 27~~ provides details for each of these measures, including: the total number of participants, the capacity and efficiency of installed units (each based on average installed units from utility program tracking data), and the method of analysis used.

Table 29. HES Electric HVAC Measure Distribution and Evaluated Savings

Measure	Total Participants	Average Capacity of Installed Unit (Tons)	Average Efficiency of Installed Unit	Method
Heat Pump	132	2.4	9 HSPF, 12 EER	Engineering Algorithm
Ductless Heat Pump	269	1.5	10 HSPF, 20.1 SEER	Billing Analysis
Geothermal Heat Pump	77	4.2	17.3 EER, 3.8 COP	Engineering Algorithm
Heating System Replacement*	15	n/a	n/a	Engineering Algorithm
Central AC	219	2.7	12.8 EER	Engineering Algorithm

*Corresponding electric savings primarily are attributed to ECM fans, included as part of new fossil fuel heating systems. ECM fans save electricity over standard furnace fans when operating in a circulation mode. As the fan operates more efficiently, it produces less waste heat than a normal fan, resulting in a slight reduction in electric savings realized by the fossil fuel system.

The Evaluation Team estimated impacts for ductless heat pumps through the billing analysis, as this measure achieved a precision estimate within the study threshold. Table 30~~Table 28~~ presents the corresponding billing analysis model results.

Table 30. HES Billing Analysis Electric Savings Results for Heat Pumps

Measure	n	PRENAC	Model Savings (kWh)	Savings as Percent of Pre-Usage	Relative Precision at 90%
Ductless Heat Pump	59	15,051	1,311	9%	±35%

Table 31~~Table 29~~ provides realization rates, based on comparing evaluated savings to average *ex ante* savings per household.

Table 31. HES Realization Rate Summary for HVAC Measures

Measure	*Ex Ante* Household Savings (kWh)	Evaluated Gross Household Savings (kWh)	Realization Rate
Heat Pump	977	758	78%
Ductless Heat Pump*	2,844	1,311	46%
Geothermal Heat Pump	2,018	1,982	98%
Heating System Replacement**	285	380	133%
Central AC	471	386	82%

*These savings estimates were determined through billing analysis and based on the analysis sample. All other savings values were determined through engineering algorithms and based on the program population.

**Average savings for ECMs include heating savings (293 kWh) and cooling savings (92 kWh) for homes with central AC units (indicated in the utility tracking system).

For ductless heat pump measures, the Evaluation Team performed an engineering review and comparison against a range of other sources (including evaluation studies and TRMs). Appendix B. Engineering Algorithms presents these detailed findings.

primary factor driving the clothes washer realization rate was that evaluated savings used the lost opportunity savings calculation approach (assuming a standard baseline) as opposed to calculating savings based on early retirement (assuming an existing baseline).

The primary driver of realizations for central AC and heat pump installations resulted from evaluated savings using the lost opportunity calculation approach (assuming a standard baseline), rather than calculating savings based on early retirement (assuming an existing baseline).[24] While the HES program authorizes an option for contractors to offer increased incentives for encouraging early retirement of existing units, the program tracking data did not clearly differentiate between units that were lost opportunities and those that were early retirements.

The primary driver of realizations for electric savings attributed to heating system replacements resulted from the change in algorithms from the 2011 PSD to the 2013 PSD. In 2011, claimed savings of 285 kWh were used, while in 2013 claimed savings of 293 kWh were used for heating, with additional claimed savings of 92 kWh used for homes with central air conditioning. A large majority of homes had existing central air conditioners (93.3%), which resulted in increased electric savings and reflected a higher realization rate using this updated approach.

[24] The PSD lost-opportunity savings calculations assume baseline efficiency for central AC savings (EER_b) of 11 Btu/Watt-hr and baseline heating system performance for heat pump installations ($HSPF_b$) of 7.7 Btu/Watt-hr. Average installed heating and cooling capacity ($CAP_{H,}$ and $CAP_{C,i}$) for heat pump and central AC measures are based on average installed units from the utility tracking database.

The primary driver of realizations for geothermal heat pump installations resulted from the 2011 and 2013 PSDs using the same algorithms, with a very slight changes in inputs between the two years.[25] Though both PSD algorithms were based on the same source, the 2013 PSD cites a value of 17.2 EER (EER_{CDH}), while the 2011 PSD cites a value of 17.1 EER (EER_{CDH}). These EER_{CDH} values were used to normalize savings determined through the study to account for the efficiency of units installed through the CT program. As the 2013 PSD used a higher-efficiency value for normalization, savings realized using the 2013 algorithm and inputs were lower than savings realized using the 2011 algorithm and inputs.

Appliances

The Evaluation Team used engineering algorithms to estimate savings for appliances measures, including replacements of refrigerators, freezers, clothes washers, and dehumidifiers. Savings calculations were based on a combination of utility tracking data, the 2013 PSD, and other researched assumptions. Table 32~~Table 30~~ provides the distribution of participants, average *ex ante* and evaluated savings, and a realization for HES appliance measures.

Table 32. HES Electric Appliance Measure Distribution and Evaluated Savings

Measure	Total Participants	*Ex Ante* Household Savings (kWh)	Evaluated Gross Household Savings (kWh)	Realization Rate
Refrigerator	293	243	~~189~~39	~~78~~16%
Freezer	18	705	66	9%
Clothes Washer	46	1,430	664	45%
Dehumidifier	174	382	31	8%

Refrigerators and Freezers

The Evaluation Team evaluated refrigerator and freezer replacements as lost opportunity measures.[26] ~~For refrigerator and freezer replacements, t~~The utility tracking data provided installed unit sizes and equipment model numbers for many installations. These inputs allowed the Evaluation Team to determine average energy consumption of the installed units (E_i) through the ENERGY STAR database. For the HES program, average annual energy consumption was ~~452.7~~463 kWh for installed refrigerators and 567 kWh for installed freezers.

The Evaluation Team used the ~~unit~~ make and model number of the new equipment provided in the utility tracking system to research product size (adjusted volume) and unit configuration in the ENERGY STAR database to determine baseline energy usage (based on the 2001 Federal Standard). The

[25] The Evaluation Team calculated savings for geothermal heat pumps assuming baseline efficiencies associated with the "Closed Loop Water to Water" system types, which assume 15.1 EER (EER_b) and 3.0 coefficient of performance (COP_b).

[26] For refrigerators, the lost opportunity savings calculation assumed a baseline of a 2004 ENERGY STAR unit, rather than the 2001 Federal Standard, while the calculation for freezers assumed a baseline of the 2001 Federal Standard.

algorithms for estimating the 2001 Federal Standard were based on the adjusted volume (AV)[27] of the installed unit. Table 33Table 31 and Table 34Table 32 provide these details for baseline and new unit consumption for freezers and refrigerators.

Table 33. Average Baseline Electric Usage for Freezers*

Configuration	Algorithm for Determining Baseline Consumption* ($E_{fed\ std}$)	Average Baseline kWh Consumption ($E_{b,\ lostopp}$)	Average New Unit kWh Consumption (E_i)
Upright freezers with manual defrost	(7.55 * AV) + 258.3	n/a	n/a
Upright freezers with automatic defrost	(12.43 * AV) + 326.1	1.60716.5	642
Chest freezers and all other freezers except compacts	(9.88 * AV) + 143.7	1.18415.2	342
Overall Average Baseline Usage		633	567

*Lookup table provided in the PSD, based on 2001 Federal Standard.Federal Register Part IX, 10 CFR Part 430, Vol. 63, No. 81, *Energy Conservation Program for Consumer Products: Energy Conservation Standards for Refrigerators, Refrigerator-Freezers and Freezers*; Final Rule. Published Monday, April 28, 1997. Effective July 1, 2001.

27 This value accounts for the fresh volume (refrigerator portion) and frozen volume (freezer portion) of a given unit. The method of calculating adjusted volume is: AV = Fresh Volume + (1.63 * Frozen Volume). ENERGY STAR uses this metric to help calculate savings and account for increased energy consumed by freezers in a given configuration.

Table 34. Average ~~Baseline~~ Electric Usage for Refrigerators*

Configuration	Defrost	Through -the- Door Ice	Algorithm for Determining Baseline Consumption* ($E_{fed\ std}$ *0.85)**	Average Baseline kWh Consumption ($E_{b,\ lostopp}$)	Average New Unit kWh Consumption (E_i)
Any	Manual	Any	(8.82*AV+248.4)*0.85	n/a	n/a
Any	Partial Automatic	Any	(8.82*AV+248.4) *0.85	n/a	n/a
All-Refrigerator (No Frozen Compartment)	Automatic	Any	(9.8*AV+276) *0.85	n/a	n/a
Top Mount Freezer	Automatic	No	(9.8*AV+276) *0.85	492.93	379.57
Side Mount Freezer	Automatic	No	(4.91*AV+507.5) *0.85	n/a	n/a
Bottom Mount Freezer	Automatic	No	(4.6*AV+459) *0.85	580.24	452.39
Top Mount Freezer	Automatic	Yes	(10.2*AV+356) *0.85	n/a	n/a
Side Mount Freezer	Automatic	Yes	(10.1*AV+406) *0.85	715.20	553.22
Bottom Mount Freezer	Automatic	Yes	(5.0*AV+539.0) *0.85	689.85	535.80
Overall Average Baseline Usage				597	463

* Lookup table provided in the PSD, based on 2001 Federal Standard.
** PSD used constant factor 0.85 to calculate baseline energy usage at the ENERGY STAR 2004 level using the electric usage of the 2001 Federal Standard ($E_{fed\ std}$). ~~Federal Register Part IX, 10 CFR Part 430, Vol. 63, No. 81, *Energy Conservation Program for Consumer Products: Energy Conservation Standards for Refrigerators, Refrigerator-Freezers and Freezers*; Final Rule. Published Monday, April 28, 1997. Effective July 1, 2001.~~

The Evaluation Team also assumed adjust volume is consistent between new and existing units ~~newly installed units would have the same adjusted volume as existing units.~~.[28]

~~The primary driver of the realization rate for the freezer measures related to 2011 *ex ante* savings claimed in the program-tracking database. Average *ex ante* savings reported in the utility tracking data appeared closer to estimates of lifetime savings,[29] rather than first-year savings for freezer replacements.~~

~~The Evaluation Team evaluated refrigerators and freezer replacements as lost opportunity measures, which assumed the replacement of a standard efficiency unit, rather than an existing baseline, with an~~

[28] The PSD refrigerator savings calculation includes a constant assumption for a DOE test lab performance adjustment factor of 0.881, also included in this calculation for evaluated savings.

[29] ~~According to the 2011 PSD, lifetime savings were calculated assuming the typical retired unit should claim: (1) approximately 72 kWh of savings for the first four years (accounting for replacements of an older unit with a unit meeting the federal standard); and then (2) 40 kWh for 11 years (accounting for a unit meeting the federal standard replaced by an ENERGY STAR unit). This resulted in approximately 728 kWh.~~

ENERGY STAR unit. Savings were evaluated and reported on a per-annum basis, meaning *evaluated gross* savings only accounted for one year of savings (rather than four (and/or 11) years of savings).

For refrigerators and freezers, the primary factors driving the realization rates were the evaluated energy consumption of the installed and baseline (federal standard) units. The Evaluation Team relied on the tracking data to identify the installed unit's energy consumption, based on the ENERGY STAR database, and then assumed the existing unit was the same size (i.e., the adjusted volume) and configuration as the installed unit.

Clothes Washers

The Evaluation Team calculated savings for clothes washer installations using the 2013 PSD algorithms and the assumption that if a dryer fuel was not listed, the dryer savings would be accounted for using the algorithm for an unknown fuel type outlined in the PSD. The Evaluation Team matched the program tracked units to the ENERGY STAR database, using the unit make and model number recorded in the utility tracking data, to determineing the unit capacity and modified energy factor (MEF). In some instances, the Evaluation Team found tracked savings were allocated incorrectly, such as when a residence was classified as having a gas washer/dryer setup, but recorded savings in kWh.

The average capacity (Cap_i)and MEF (MEF_i) for installed units were evaluated at 3.7 cubic feet and 2.5 cubic feet/kWh per cycle, respectively. The PSD outlined defined baseline MEF (MEF_b) as was 1.8 cubic feet/kWh per cycle for units with unknown fuel type. ; tThe evaluated electric realization rate was 45%, with per-unit and per-household savings of 1,285 664 kWh.[30]

The primary factor driving the clothes washer realization rate was that evaluated savings used the lost opportunity savings calculation approach (assuming a standard baseline) as opposed to calculating savings based on early retirement (assuming an existing baseline).

Dehumidifiers

Dehumidifiers were evaluated as a lost opportunity measure using the 2013 PSD, based on savings realized by installing a new, high-efficiency unit rather than installing a unit meeting the minimum federal standard.[31] The utility tracking data provide make and model of the installed units, and the Using the 2012 Federal Standard represents the baseline unit efficiency, the Evaluation Team assessed baseline efficiency, as shown in Table 35Table 33.

[30] The PSD equation for annual electric savings ($AKWH_{LostOpp}$) also included a constant value (321.3 for unknown fuel types) applied to capacity, used consistently in calculating evaluated savings.

[31] The PSD dehumidifier savings calculation includes factors in their equation converting liters to pints (0.473) and 1,620 hours to annual days (67.6), also included in this calculation for evaluated savings.

Table 35. Average ~~Baseline~~ Dehumidifier ~~Electric~~ Efficiency and Installations ~~for Dehumidifiers~~

Capacity (Pints/day)	Baseline ~~2012 Federal Standard for Dehumidifier~~ Energy Factor ($EF_{b, lostopp}$)	Average Installed Unit Energy Factor (EF_i)	Number of Units
≤ 25	1.35	1.20	11
> 25 to ≤ 35		1.40	25
> 35 to ≤ 45	1.5	1.50	15
> 45 to ≤ 54	1.6	1.60	66
> 54 to < 75	1.7	1.80	57
≥ 75 to ≤ 185	2.5	n/a	n/a

The average energy factor of newly installed units (EF_i) was determined by matching unit model numbers from the utility tracking data against the ENERGY STAR database. The majority of installed units occurred within higher-capacity bins. Units in the lower-capacity bins actually realized negative savings, as the units installed were below the efficiency level outlined in the 2012 Federal Standard. Consequently, although the unit was considered efficient during the 2011 program year, when evaluated using the 2013 PSD, the unit would be less efficient than the baseline outlined by the PSD. As a result, some units installed in 2011 actually consumed more energy than baseline units, resulting in negative savings.

~~**Table 36. Average Dehumidifier Energy Factor**~~

~~Capacity (Pints/day)~~	~~Average Energy Factor from Utility Tracking Data~~	~~Number of Units~~
~~≤ 25~~	~~1.20~~	~~11.00~~
~~> 25 to ≤ 35~~	~~1.40~~	~~25.00~~
~~> 35 to ≤ 45~~	~~1.50~~	~~15.00~~
~~> 45 to ≤ 54~~	~~1.60~~	~~66.00~~
~~> 54 to < 75~~	~~1.80~~	~~57.00~~
~~≥ 75 to ≤ 185~~	~~-~~	~~-~~

The key realization rate driver for the dehumidifier measure resulted from the shift in baseline and efficient conditions. The 2011 PSD used the 2008 ENERGY STAR standard as the efficient condition. In 2012, a new federal standard was introduced that was as efficient–if not more so–than the 2008 ENERGY STAR standards. The 2013 PSD used the 2012 Federal Standard as the *baseline* efficiency; so what was considered an efficient unit in 2011 then operated at or below the baseline efficiency level. Thus, evaluated savings and realization rate for this measure were very low, given only the most efficient units installed in 2011 received savings after the baseline shifted.

HES Natural Gas Savings

The billing analysis provided estimates of gas savings for HES air sealing. All other estimates of gas savings presented in this section derived from engineering algorithms and simulation modeling.

Shell Measures and Duct Sealing

The Evaluation Team estimated natural gas impacts for shell measures (including air sealing, attic and wall insulation) and duct sealing primarily using a combination of billing analysis and calibrated building simulation models. Specifically, air sealing savings were estimated using billing analysis, given precision estimates meeting the threshold for this study. Impacts associated with window replacements were assessed using engineering algorithms due to limited information provided in the program tracking data.

Billing Analysis Results

The Evaluation Team estimated air sealing impacts through billing analysis, as this measure achieved a precision estimate within than the study threshold. Table 36~~Table 35~~ presents the billing analysis model results.

Table 36~~37~~. HES Billing Analysis Gas Savings Results for Air Sealing and Insulation Other

Measure	n	PRENAC	Model Savings (CCF)	Savings as Percent of Pre-Usage	Relative Precision at 90%
Air Sealing	1,713	1,059	57	5%	±14%

Table 37~~Table 36~~ provides the realization rate based on comparing the gross savings estimate from the billing analysis to average *ex ante* savings per household.

Table 37~~38~~. HES Billing Analysis Realization Rate Summary for Air Sealing and Insulation Other

Measure	Gross Model Savings (CCF)	Reported *Ex Ante* Savings (CCF)*	Realization Rate	Model Savings as Percent of Pre-Usage	Reported *Ex Ante* Savings as Percent of Pre-Usage
Air Sealing	57	62	91%	5%	6%

*Average *ex ante* savings is based on the participant sample used in the billing analysis and may vary from averages based on the program population.

Simulation Modeling Results

The Evaluation Team used detail provided in the utility tracking data (for each building type and heating fuel combination) to assess corresponding pre- and post-installation information for each measure analyzed using the calibrated simulation approach. Table 38~~Table 37~~ presents these details, including average pre- and post-installation insulation levels (weighted by square footage installed) and changes in air and duct-sealing levels.

Table 38~~39~~. HES Gas—Shell and Duct-Sealing Measure Distribution and Installation Details

Measure	Participants*	Pre-Condition	Post-Condition	Average % Leakage Reduction	Units
Duct Sealing	1,192	522	393	25%	CFM 25
Attic Insulation	383	R5	R32	n/a	R-Value
Wall Insulation	54	R0.5	R15.5	n/a	R-Value

*Count of participants reflects the number with *ex ante* savings reported for a given measure.

The Evaluation Team used the energy models to calculate the savings percentage of weather-sensitive loads for each measure, which were then applied to pre-period, weather-sensitive usage for each model to calculate evaluated energy savings. Table 39~~Table 38~~ presents the weighted household-level gas savings for each measure and the realization rates compared to average *ex ante* savings, along with savings percentages of weather-sensitive loads.

Table 39~~40~~. HES Gas—Weighted Household Savings for Shell and Duct Measures

Measures	Average *Ex Ante* Savings (CCF)	Average Pre-Installation Weather-Sensitive Consumption (CCF)	Savings as % of Weather-Sensitive Load	Average Evaluated Gross Savings (CCF)	Realization Rate
Duct Sealing	45	790	2.3%	19	42%
Attic Insulation	179	964	14.0%	135	76%
Wall Insulation	449	801	27.9%	224	50%

Differences between *ex ante* and evaluated savings for shell and duct sealing measures estimated using building simulation models are presented above in the HES Electric Savings section.

Engineering Algorithm Results

For window replacements, pre- and post-installation data were not available to incorporate into the modeling. Consequently, the Evaluation Team made assumptions regarding window efficiencies and square footage installed.[32] Table 40~~Table 39~~ lists: participation; average installed units; average household savings; and realization rates of window measure installations.

Table 40~~41~~. HES Gas—Evaluated Window Savings

Measure	Total Participants	Average Installed Units	Evaluated Gross Unit Savings (CCF)	*Ex-Ante* Household Savings (CCF)	Evaluated Gross Household Savings (CCF)	Realization Rate
Windows	42	15	10	136	147	108%

Domestic Hot Water

The Evaluation Team used engineering algorithms to estimate HES gas savings for each DHW measure: showerheads, faucet aerators, and pipe insulation. Savings calculations were based on a combination of utility tracking data, the 2013 PSD, and other researched assumptions. For each measure, the Evaluation Team performed in-depth benchmarking against a range of other sources (including evaluation studies and TRMs). Appendix B. Engineering Algorithms presents these detailed findings.

32 Evaluated savings estimates assume installation of ENERGY STAR windows from a single pane baseline, with typical window size of 3 feet by 4 feet (2011 PSD assumption). Annual gas usage (*AGU*) is provided in the PSD: 0.28 CCF/ft^2 (AGU_{es}) for the ENERGY STAR unit, and 1.08 CCF/ft^2 (AGU_b) for the single pane baseline.

Table 41Table 40 lists the participation, average installed units, average household savings, and realization rates of DHW measure installations.

Table 4142. HES Gas DHW Measure Distribution and Evaluated Savings

Measure	Total Participants	Average Installed Units	Evaluated Gross Unit Savings (CCF)	*Ex Ante* Household Savings (CCF)	Evaluated Gross Household Savings (CCF)	Realization Rate
Showerhead	4,138	1.3 units	7.3	14.5	9.4	65%
Faucet Aerators	3,111	1.3 units	3.0	1.2	3.8	321%
Pipe Insulation*	2,454	5.6 ft.	0.7	3.4	3.9	114%

*Only the water-heating application of this measure was evaluated (not space-heating impacts).

The primary factor driving realizations for showerheads and aerators was the change in input assumptions used in the 2011 PSD to the 2013 PSD. In the 2011 PSD, the average annual water savings were 3,650 gallons per showerhead and 255.5 gallons per aerator. In the 2013 PSD, average annual water savings were 1,212.3 gallons per showerhead and 1,238 gallons per aerator. On its own, these changes reduce showerhead realization rates to 33% of the 2011 value and increase aerator realization rates to 454% of the 2011 value. However, additional differences in the PSD versions, including algorithm refinements and changes in input values (e.g., number of showerheads and faucets per home), resulted in the overall realization rate adjustments presented in Table 41Table 40.

Though not outlined in the PSD, a drain factor adjustment is common in TRMs to account for water usage not dependent on the length of time a faucet remains on, but rather on a specific quantity of water (such as filling a vessel). The Evaluation Team used a value of 79.5% for the drain factor, consistent with other TRMs from the region.[33] Future primary research would allow determination of a more accurate value for this input

The Evaluation Team felt the pipe insulation savings set forth in the PSD proved reasonable, though the savings should be capped at six feet of insulation. Currently, the PSD allows the same savings level for each foot of installation, without a cap. However, as savings decrease as distance increases away from the water heater, incremental savings are negligible beyond approximately six feet. Consequently, installations with more than six feet of insulation installed only received evaluated gross savings for the first six feet, and thus resulted in a realization rate lower than 100%.

HVAC: Heating System Replacement

The Evaluation Team used an engineering algorithm to estimate savings for heating system replacement measures. As the HES program targets early retirement for heating system replacements (offering participants an increased incentive) and utility data tracked baseline efficiencies, the Evaluation Team

33 This factor is included in TRMs for the following states: Illinois, Indiana, Massachusetts, Pennsylvania, and the Mid-Atlantic region.

calculated evaluated savings using the retrofit method outline in the PSD (allowing for early retirement savings) for qualifying measures, and the lost opportunity calculation for those that did not. ~~Savings calculations were based on a combination of utility tracking data, the 2013 PSD, and other researched assumptions.~~ While ~~The~~ the measure category “heating system replacement” in the utility tracking data can include installations of new energy-efficient boilers and furnaces, ~~though~~ only efficient furnaces occurred under the 2011 HES program.

Based on the utility tracking data, the average efficiency of installed units ~~is~~ was 96% AFUE ($AFUE_E$), average baseline efficiency was 76.5 AFUE ($AFUE_B$), and average heated area (*A*) was 2,325 square feet.[34] Table 42~~Table 41~~ provides the distribution of participants, average *ex ante* and evaluated savings, and a realization for HES appliance measures.

Table 42~~43~~. HES Gas Heating System Replacement Distribution and Evaluated Savings

Measure	Total Participants	*Ex Ante* Household Savings (CCF)	Evaluated Gross Household Savings (CCF)	Realization Rate
Heating System Replacement	14	1,005	229	23%

~~As the HES program targets early retirement for heating system replacements (offering participants an increased incentive) and utility data tracked baseline efficiencies, the Evaluation Team calculated evaluated savings using the retrofit method outline in the PSD (allowing for early retirement savings).~~ While using the retrofit savings calculation, ~~Only~~ only a few installations had baseline efficiencies that qualified for early retirement savings, while *ex ante* savings were based on a PSD-deemed value that assumed early retirement for all installations; this provided the key factor influencing the realization rate for heating system replacement measures.

Appliances: Clothes Washer

The Evaluation Team used engineering algorithms to estimate gas savings for clothes washers. Savings calculations were based on a combination of utility tracking data, the 2013 PSD, and other researched assumptions. Table 43~~Table 42~~ provides the distribution of participants, average *ex ante* and evaluated savings, and the realization rate for HES appliance measures.

Table 43~~44~~. HES Gas Clothes Washer Distribution and Evaluated Savings

Measure	Total Participants	*Ex Ante* Household Savings (CCF)	Evaluated Gross Household Savings (CCF)	Realization Rate
Clothes Washer	61	20	1.54	8%

Details regarding the assumption and calculations used for evaluating clothes washers are similar to those discussed in the HES Electric Savings section above. As discussed, the primary factor driving the

[34] This savings calculation included a heating factor (*HF*) based on the age of the home, which the Evaluation Team looked up in the PSD reference table (average age of home was 36 years, based on utility tracking data, corresponding to an average HF of 38,800).

clothes washer realization rate was that evaluated savings used the lost opportunity savings calculation approach (assuming a standard baseline) as opposed to calculating savings based on early retirement (assuming an existing baseline).

HES Oil/Propane Savings

Table 44Table 43 presents estimates for oil and propane savings associated with shell, duct sealing, and DHW measures. As discussed in the Methodology, evaluated gross savings derived through the gas analyses were scaled using conversion factors consistent with the PSD to estimate oil and propane impacts by measure. The previous section discusses the analytical methods used to calculate the gas savings specific to each measure.

Table 4445. HES Oil and Propane—Evaluated Savings for Shell, Duct, and DHW Measures

Category	Measures	Average Evaluated Gross Savings (CCF)	Oil		Propane	
			Conversion Factor (gallons/CCF)	Oil Savings per Participant (Gallons)**	Conversion Factor (gallons/CCF)	Propane Savings per Participant (Gallons)
Shell and Duct*	Air Sealing	57	0.7419	41	1.1267	64
	Attic Insulation	126		91		142
	Wall Insulation	237		171		267
	Duct Sealing	18		13		21
DHW	Showerhead	9.4		6.9		10.5
	Faucet Aerators	3.8		2.9		4.3
	Pipe Insulation	3.9		2.9		4.4

*Measure savings estimated using simulation models have been reweighted based on the average distribution of building types for oil and propane-heated populations, respectively.
**Due to differences in standard efficiencies between oil and natural gas heating systems (assuming baseline AFUE of 80 and 78, respectively), converted oil savings for shell and duct measures have been adjusted accordingly.

HES-IE Findings

This section presents evaluated savings estimates for all HES-IE measures, covering electric, natural gas, and oil fuel types. The results are presented first at the program level, followed by measure-specific findings, grouped by measure type and primary heating fuel type.

Program-Level Results

Table 45~~Table 44~~ presents evaluated adjusted gross electric and gas energy savings for the 2011 HES-IE program.

Table 45~~46~~. Total 2011 Evaluated HES-IE Electric and Gas Savings

Value	Annual MWh	Annual kW	Annual CCF (000s)
Reported Savings	25,132	1,558	932
Evaluated Adjusted Savings	19,~~836~~950	1,~~230~~237	~~514~~513
Realization Rate	79%		55%

*The realization rates from the SP1 and SP4 whole-house billing analyses have been applied to the percentage of HES-IE savings attributed to each subprogram, for electric and gas, respectively.

For the HES-IE program, evaluated adjusted gross savings were lower than reported savings, with an adjusted gross realization rate of 79% for electric and 55% for gas. Evaluated savings have been calculated using analytical methods specific to each measure, as described in more detail below.

Figure 4 and Figure 5 show the distribution of evaluated energy savings by measure, for electric and gas, respectively. For this program, the majority of savings occurred through the following measures:

- For electric savings: lighting, ductless heat pumps, and air sealing accounted for 69% of reported savings and 79% of evaluated savings.
- For gas savings: insulation, air sealing, and DHW bundle accounted for 90% of reported savings and 89% of evaluated savings.

Figure 4. Measure Distribution of 2011 HES-IE Electric Savings, *Ex Ante* and Evaluated

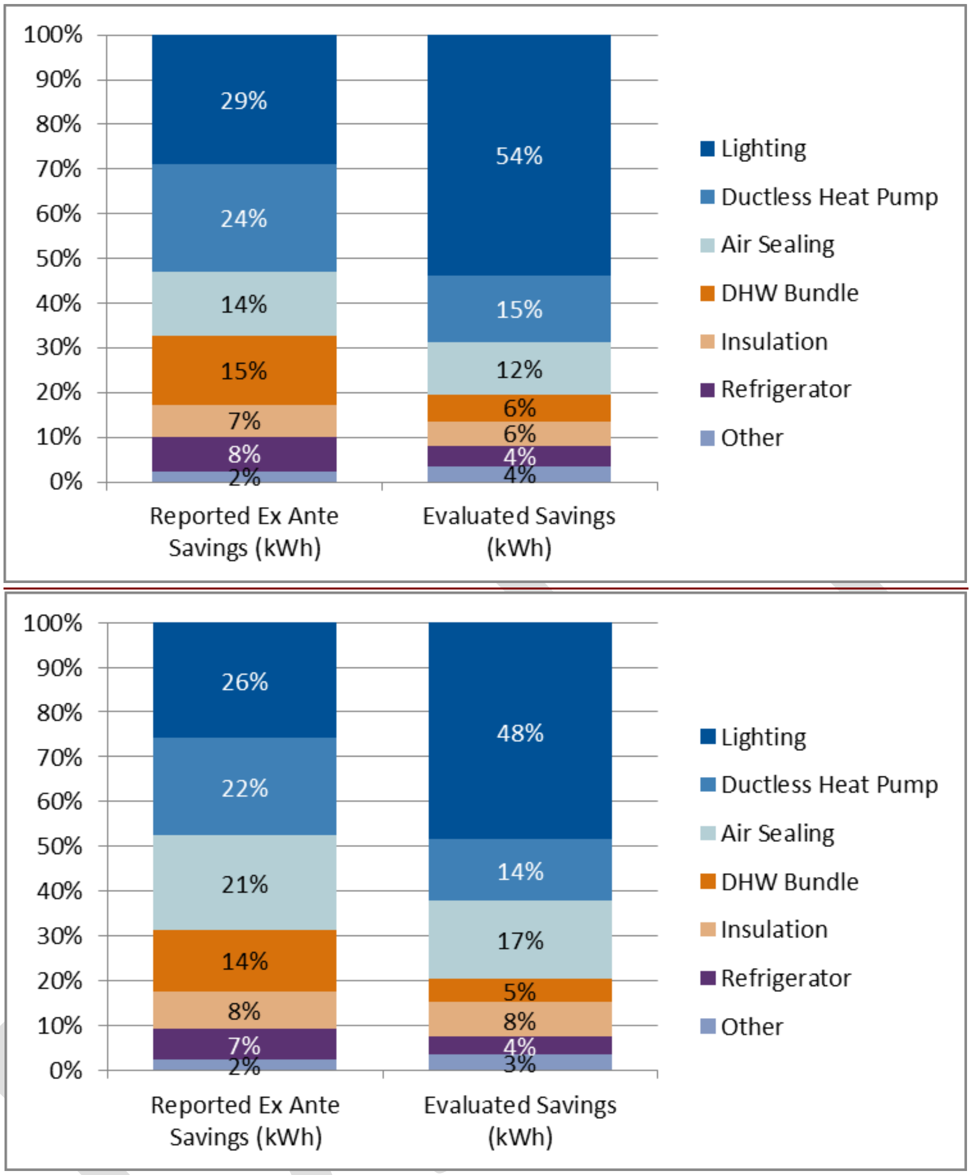
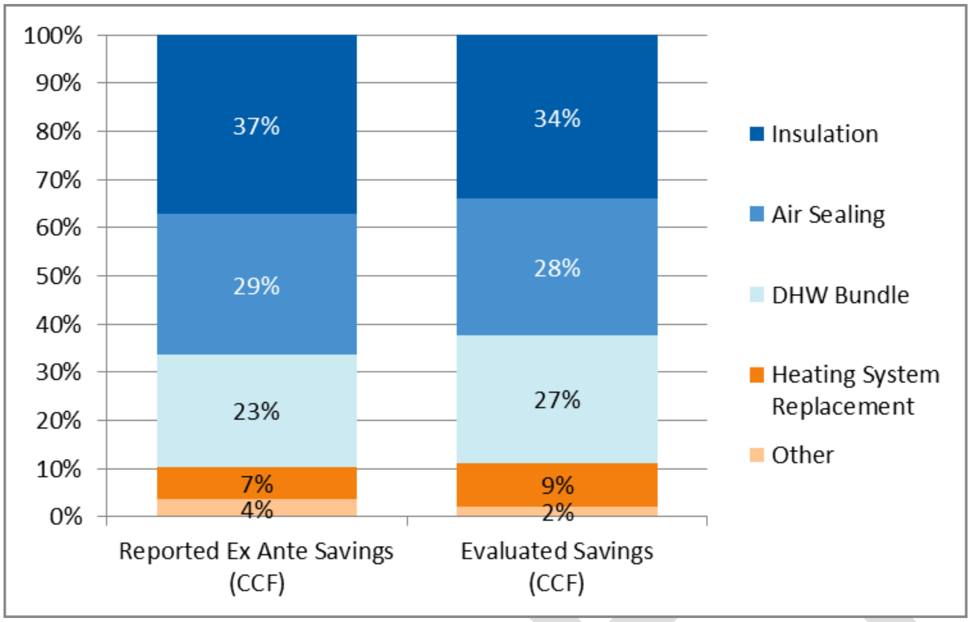


Figure 5. Measure Distribution of 2011 HES-IE Gas Savings, *Ex Ante* and Evaluated



As shown, variation occurred in the percent of totals savings attributed to specific measure categories, which was a function of measure-specific realization rates. For electric savings, air sealing, ductless heat pumps, refrigerator replacement, and the DHW bundle represented a high proportion of program *ex ante* savings (60% in total), and each received lower realization rates. For gas savings, insulation, air sealing, and wall insulation also accounted for a high proportion of *ex ante* savings (90%) and had lower measure-specific realization rates.

Table 46~~Table 45~~ and Table 47~~Table 46~~ present the distribution of HES-IE electric and gas savings at the measure-level, comparing reported *ex ante* savings to estimates of evaluated gross savings. The savings estimates below reflect average household savings for participants receiving a given measure.

Table 46~~47~~. Comparison of *Ex Ante* and Evaluated Gross Savings by Measure—HES-IE Electric

Category	Measure	Reported *Ex ante* Savings (kWh/ Household)* (A)	Gross Savings (kWh/ Household) (B)	Realization Rate (B/A)	Method
Appliance	Freezer	733	728	99%	Billing Analysis (±32%)
Appliance	Refrigerator	758	318	42%	Billing Analysis (±28%)
Appliance	Appliance Other	353	498	141%	Billing Analysis (±24%)
HVAC	Central AC	98	98	100%	Engineering Algorithm
HVAC	Duct Sealing	262	81	31%	Simulation Modeling
HVAC	Ductless Heat Pump	1,731	803	46%	Billing Analysis (±32%)
HVAC	Window AC	94	46	49%	Engineering Algorithm

Category	Measure	Reported *Ex ante* Savings (kWh/ Household)* (A)	Gross Savings (kWh/ Household) (B)	Realization Rate (B/A)	Method
Lighting	Lighting	467	647	138%	Billing Analysis (±6%)
Other	Other	637	637	100%	Reported *Ex Ante*
Shell	Air Sealing	342	208	61%	Simulation Modeling
Shell	Insulation Other	153	153	100%	Reported *Ex Ante*
Shell	Windows	1,295	2,253	174%	Engineering Algorithm
Shell	Attic Insulation	2,306	1,429	62%	Simulation Modeling
Shell	Wall Insulation	2,326	716	31%	Simulation Modeling
Water Heat	DWH Bundle	1,372	390	28%	Engineering Algorithm
Water Heat	Temp Setback	87	78	90%	Engineering Algorithm

*Average *ex ante* savings per household are the program population, except for measures estimated through billing analysis, which are based on the billing analysis participant sample.

Table 4748. Comparison of *Ex Ante* and Evaluated Gross Savings by Measure—HES-IE Gas

Category	Measure	Reported *Ex ante* Savings (CCF/ Household)* (A)	Gross Savings (CCF/ Household) (B)	Realization rate (B/A)	Method
Appliance	Appliance Other	8	8	100%	Reported *Ex Ante*
HVAC	Duct Sealing	174	28	16%	Simulation Modeling
HVAC	Heating System Replacement	128	107	84%	Billing Analysis (±14%)
Other	Other	23	23	100%	Reported *Ex Ante*
Shell	Air Sealing	59	36	61%	Billing Analysis (±31%)
Shell	Windows	25	23	93%	Engineering Algorithm
Shell	Attic Insulation	152	197	129%	Simulation Modeling
Shell	Wall Insulation	304	96	32%	Billing Analysis (±30%)
Water Heat	Temp Setback	6	4	62%	Engineering Algorithm
Water Heat	DWH Bundle	41	29	72%	Billing Analysis (±26%)

*Average *ex ante* savings per household are the program population, except for measures estimated through billing analysis, which are based on the billing analysis participant sample.

For those measures attributed to more than 5% of program savings, Table 48Table 49 and Table 49Table 50 provide notes regarding implications for the PSD.

Table 48~~49~~. PSD Considerations —HES-IE Electric

Measure	Percent of Total Evaluated Savings	Consideration
Lighting	54%	Consider revisions to lighting calculation assumptions (e.g., HOU, in service rate), perhaps in consideration of total number of bulbs installed per household.
Ductless Heat Pump	15%	Consider revisions to insulation calculation assumptions (e.g., baseline equipment, takeback effect) to account for realization rate differences. Review baseline data collection and entry protocols, to ensure correct baseline is tracked for both heating and cooling. Consider specifying distinct savings calculations by building type (e.g., single family vs. multifamily) and equipment configuration (e.g., room AC + baseboard heating, no AC + forced-air furnace).
Air Sealing	12%	Consider incorporating evaluated realization rates in the savings calculation and/or developing deemed savings values (by heating system) using evaluation results. In regard simulation modeling assumptions used in PSD, consider reviewing input assumptions, building prototypes, and calibration process to customer usage to assess whether these align with the current program participation.
Insulation	6%	Consider revisions to insulation calculation assumptions (e.g., HDD, ASHRAE adjustment factor) to account for realization rate differences. Review baseline R value data collection and entry protocols, to ensure correct baseline is tracked (e.g., no zero or missing values).
DWH Bundle	6%	Consider incorporating evaluated realization rates in the savings calculation and review input assumptions used in the current algorithm (given significant changes in assumed water savings for showerheads and aerators between the 2011 and 2013 PSDs). In addition, consider several revisions to current algorithms, including: a drain factor for aerators, maximum feet of pipe wrap (i.e., 6 ft.), and use of water heater recovery efficiency rather than energy factor for showerhead/aerator savings calculation.
General		Consider performing ongoing whole-house billing analysis to assess annual savings, including home characteristic stratifications when sufficient data are available to support the analysis (e.g., heating equipment).

Table 49~~50~~. PSD Considerations —HES-IE Gas

Measure	Percent of Total Evaluated Savings	Consideration
Insulation	34%	Consider revisions to insulation calculation assumptions (e.g., HDD, ASHRAE adjustment factor) to account for realization rate differences. Review baseline R value data collection and entry protocols, to ensure correct baseline is tracked (e.g., no zero or missing values).
Air Sealing	28%	Consider incorporating evaluated realization rates in the savings calculation and/or developing deemed savings values (by heating system) using evaluation results. In regard simulation modeling assumptions used in PSD, consider reviewing input assumptions, building prototypes, and calibration process to customer usage to assess whether these align with the current program participation.

DWH Bundle	27%	Consider incorporating evaluated realization rates in the savings calculation and review input assumptions used in the current algorithm (given significant changes in assumed water savings for showerheads and aerators between the 2011 and 2013 PSDs). In addition, consider several revisions to current algorithms, including: a drain factor for aerators, maximum feet of pipe wrap (i.e., 6 ft.), and use of water heater recovery efficiency rather than energy factor for showerhead/aerator savings calculation.
Heating System Replacement	9%	Consider revisions to heating system replacement calculation assumptions (e.g., baseline efficiency) to account for realization rate differences. Review baseline equipment data collection and entry protocols, to ensure correct baseline is tracked and accurately account for existing conditions.
General		Consider performing ongoing whole-house billing analysis to assess annual savings, including home characteristic stratifications when sufficient data are available to support the analysis (e.g., heating equipment).

Measure-Level Savings

This section presents evaluated gross savings estimates for all HES-IE measures, covering electric, natural gas, and oil/propane fuel types. The report groups results by fuel savings and presents them for distinct measures and/or measure categories.

HES-IE Electric Savings

The billing analysis provided estimates of electric savings for several HES-IE measure categories: lighting, ductless heat pumps, and refrigerator and freezer replacement (including the "appliance other" category). The Evaluation Team determined all other electric savings estimates presented in this section through engineering algorithms and simulation modeling.

Lighting

The Evaluation Team estimated impacts for a combined lighting bundle (primarily including CFLs, along with fixtures and LEDs) through the billing analysis.[35] Table 50~~Table 47~~ presents the billing analysis model results for lighting measures, which achieved a precision estimate within the study threshold.

Table 50~~49~~. HES-IE Billing Analysis Electric Savings Results for Lighting

Measure	n	PRENAC	Gross Model Savings (kWh)	Savings as Percent of Pre-Usage	Relative Precision at 90%
Lighting	4,876	7,271	647	9%	±6%

On average, 13.7 CFLs were installed per household. This equates to about 47 kWh per bulb. These results were slightly higher than average gross *ex ante* savings from the utility tracking system data, based on PSD calculations.

35 As CFLs represent approximately 95% of total *ex ante* reported savings for the lighting category, analysis findings can be considered largely in the context of CFL bulb installations.

Table 51Table 48 provides realization rates, based on comparing the gross savings estimate from the billing analysis to the average *ex ante* savings per household.

Table 5150. HES-IE Billing Analysis Realization Rate Summary for Lighting

Measure	Gross Model Savings (kWh)	Reported *Ex Ante* Savings (kWh)	Realization Rate	Model Savings as Percent of Pre-Usage	Reported *Ex Ante* Savings as Percent of Pre-Usage
Lighting	647	467	138%	9%	6%

Typical drivers of energy savings included: assumptions for average HOU; and the change in wattage between the existing and replaced bulbs. HES-IE field implementation protocols required auditors to install all bulbs delivered to participants (i.e., no bulbs were left behind uninstalled), up to a maximum of 25 bulbs per home.[36] Specific guidance did not address installations only in high-use sockets. Similar programs sometimes use such instruction to restrict installation only to high-use sockets (e.g., three hours or more) to ensure the higher savings associated with higher HOU.

A closer examination of average savings, based on the number of lighting installations per home, revealed a decrease in average savings, given an increase in installations. This trend could relate to the HOU effect, with few installations made into higher-use sockets (resulting in higher average savings), with an average decrease in HOU as the number of installations per home increase.[37] Figure 6 illustrates this trend, with a decrease in lighting savings based on the quantity installed (increasing the number of lower-use sockets in the overall average).

36 *2013 Home Energy Solutions –Income Eligible: Field Training Manual*. p. 8 and p. 40.

37 Upon first appearances, the trend showing HOU decreasing with installations of more energy-efficient bulbs may seem to contradict the *Northeast Regional Hours of Use Study*. That study found: 1) HOU was higher for energy-efficient vs. inefficient bulbs; and 2) this relationship did not change with socket saturations (i.e., the percentage of sockets filled with energy-efficient bulbs). The two studies, however, really could not be directly compared. The current study focuses on bulbs an auditor directly installed in every socket in a home, up to the program limit (i.e., 25). In contrast, the regional HOU study primarily focused on bulbs obtained from retail stores, with the home occupants deciding where to install bulbs, and even homes with the highest energy-efficient socket saturations having many (sometimes 50% or more) of their sockets filled with inefficient bulbs. Thus, though the studies do not contradict one another, they simply cannot be directly compared.

Figure 6. HES-IE—Per-Unit Lighting Savings, Based on Number of Installations

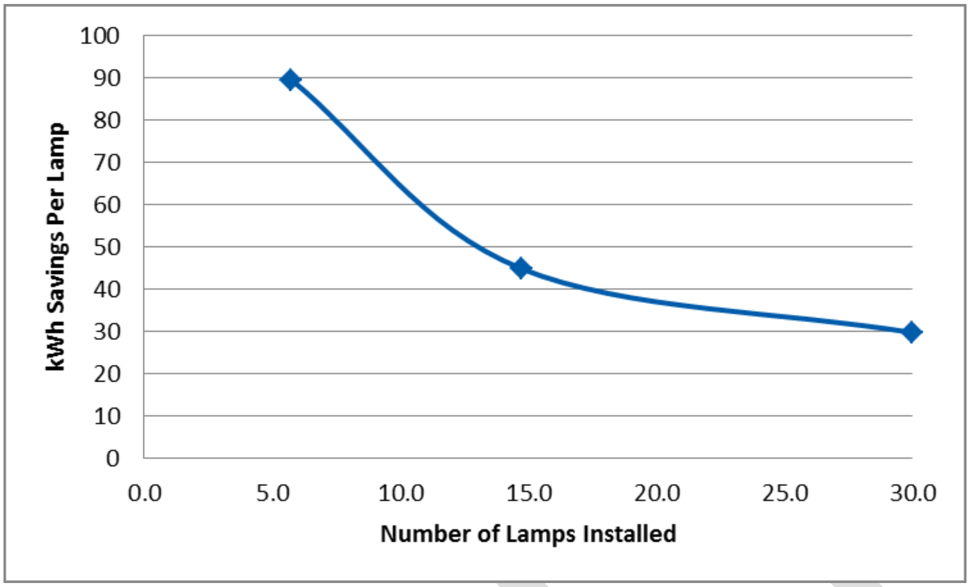


Table 52~~Table 49~~ presents additional details regarding lighting installations by the quantity received (binned in categories of 1 to 10, 11 to 20, and greater than 20 lighting installations). As shown, average savings per bulb decrease within each category as more bulbs are installed per home.

Table 52~~51~~. HES-IE Energy Savings Based on Lighting Quantity Installed

CFLs Received	Percent of Sample	Average CFLs Installed	Gross Model Savings		*Ex Ante* Savings		Realization Rate
			kWh / unit	kWh / household	kWh / unit	kWh / household	
1-10	43%	5.7	89.4	514	36.3	209	246%
11-20	35%	14.7	44.8	661	35.4	522	127%
>20	21%	30.0	29.7	892	32.1	964	92%
Overall	100%	13.7	47.1	647	34.0	467	138%

Shell Measures and Duct Sealing

The Evaluation Team primarily used calibrated building simulation models to estimate impacts for shell measures (including air sealing, attic and wall insulation) and duct-sealing measures. Impacts associated with window replacements have been assessed using engineering algorithms due to limited information provided in the program tracking data.

Electric savings for these measures are associated with heating savings from electric heat sources, along with reductions in cooling and fan energy consumption (associated with reduced run times in homes with gas, oil, or propane heating).

The Evaluation Team used details provided in the utility tracking data (for each building type and heating fuel combination) to assess corresponding pre- and post-installation information for each measure analyzed using the calibrated simulation approach. Table 53~~Table 50~~ presents these details, including average pre- and post-installation insulation levels (weighted by square footage installed) and changes in air and duct-sealing levels.

Table 53~~52~~. HES-IE Electric—Shell and Duct-Sealing Measure Distribution and Installation Details

Measure	Participants*	Pre-Condition	Post-Condition	Average % Leakage Reduction	Units
Air Sealing	2,116	2,098	1,754	16%	CFM 50
Duct Sealing	166	517	310	40%	CFM 25
Attic Insulation	106	R3	R37	n/a	R-Value
Wall Insulation	259	R0.5	R15	n/a	R-Value

*Count of participants reflects the number with *ex ante* savings reported for a given measure.

The Evaluation Team used the energy models to calculate the savings percentage of weather-sensitive loads for each measure, which then could be applied to the pre-period, weather-sensitive usage for each model to calculate evaluated energy savings. Table 54~~Table 51~~ presents weighted, household-level, electric savings for each measure and realization rates compared to average *ex ante* savings, along with the savings percentages of weather-sensitive loads.

Table 54~~53~~. HES-IE Electric—Weighted Household Savings for Shell and Duct Measures

Measures	Average *Ex Ante* Savings (kWh)	Average Pre-Installation Weather-Sensitive Consumption (kWh)	Savings as % of Weather-Sensitive Load	Average Evaluated Gross Savings (kWh)	Realization Rate
Air Sealing	342	4,227	4.9%	208	61%
Duct Sealing	262	2,040	4.0%	81	31%
Attic Insulation	2,306	4,408	32.4%	1,429	62%
Wall Insulation	2,326	3,555	20.2%	716	31%

Differences between *ex ante* and evaluated savings for shell and duct sealing measures estimated using building simulation models are presented above in the HES Electric Savings section.

Engineering Algorithm Results

For window replacements, pre- and post-installation data were unavailable to incorporate into the modeling. Consequently, the Evaluation Team made assumptions regarding window efficiencies and square footage installed.[38] Table 55~~Table 52~~ lists the participation, average installed units, average household savings, and realization rates of window measure installations.

[38] Evaluated savings estimates assume installation of ENERGY STAR windows from a single-pane baseline, with typical window size of 3 feet by 4 feet (2011 PSD assumption). Annual electric heating usage (*AEH*) is provided in the PSD: 5.66 kWh/ft^2 (AEH_{es}) for the ENERGY STAR unit and 22.02 kWh/ft^2 (AEH_b) for the single pane baseline. Average savings for windows includes only heating savings, as cooling equipment type was not provided in the utility tracking data.

Table 5554. HES-IE Electric—Evaluated Window Savings

Measure	Total Participants	Average Installed Units	Evaluated Gross Unit Savings (kWh)	*Ex Ante* Household Savings (kWh)	Evaluated Gross Household Savings (kWh)	Realization Rate
Windows	42	11	196	1,295	2,253	174%

Domestic Hot Water

Using engineering algorithms, the Evaluation Team estimated impacts for a combined DHW measure bundle (including showerheads, faucet aerators, and pipe insulation) and water heater temperature setback. Savings calculations were based on a combination of utility tracking data, the 2013 PSD, and other researched assumptions. For each of these measures, the Evaluation Team performed in-depth benchmarking against a range of other sources (including evaluation studies and TRMs). Appendix B. Engineering Algorithms presents these detailed findings.

Table 56Table 53 lists the participation, average installed units, average household savings, and realization rates of DHW measure installations.

Table 5655. HES-IE Electric DHW Measure Distribution and Evaluated Savings

Measure	Total Participants	Average Installed Units	Evaluated Gross Unit Savings (kWh)	*Ex Ante* Household Savings (kWh)	Evaluated Gross Household Savings (kWh)	Realization Rate
Showerhead	6,532	1.1 units	151	769	152	20%
Faucet Aerators	7,616	1.1 units	61	25	61	243%
Pipe Wrap*	598	4.6 ft.	11	53	52	99%
Temp Setback**	330	1 unit	78	87	78	90%

*The evaluation only addressed the water-heating application of this measure (not space heating impacts).
**Savings for water heater thermostat setback is based on the PSD calculation, which uses constant assumptions for EF and hot water usage for clothes washers and dishwashers. As utility tracking data did not include information on the presence of clothes washers and dishwashers, the Evaluation Team used the assumption that all homes include both.

As discussed under the HES Natural Gas Savings section, the primary factor driving realization rates for showerheads and aerators was the change in input assumptions used in the savings calculations from

the 2011 PSD to the 2013 PSD.[39] Additionally, the Evaluation Team applied a drain factor (79.5%) to the evaluated savings calculation for aerators, and evaluated pipe insulation savings, based on only the first six feet of insulation installed. For more detail, see the Domestic Hot Water discussion for HES.

HVAC

The Evaluation Team estimated impacts for several HES-IE HVAC measures using a combination of billing analysis and engineering algorithms. Table 57~~Table 54~~ provides details for each of these measures, including the total number of participants, the capacity and efficiency of installed units (based on utility tracking data), and the analysis methods used.

Table 57~~56~~. HES-IE Electric HVAC Measure Distribution and Evaluated Savings

Measure	Total Participants	Average Capacity of Installed Unit (tons)	Average Efficiency of Installed Unit	Method
Ductless Heat Pump	1,919	1.46	9.8 HSPF, 17.3 SEER	Billing Analysis
Window AC	246	0.68	10.4 EER	Engineering Algorithm
Central AC	1	2.0	12.5 EER	Engineering Algorithm

The Evaluation Team estimated impacts for ductless heat pumps using billing analysis as this measure achieved a precision estimate of less than the study threshold. Table 58~~Table 55~~ presents the corresponding billing analysis model results.

Table 58~~57~~. HES-IE—Billing Analysis Electric Savings Results for Heat Pumps

Measure	n	PRENAC	Model Savings (kWh)	Savings as Percent of Pre-Usage	Relative Precision at 90%
Ductless Heat Pump	815	7,488	803	11%	±32%

Table 59~~Table 56~~ provides realization rates based on comparing the evaluated savings to the average *ex ante* savings per household.

Table 59~~58~~. HES-IE—Realization Rate Summary for HVAC Measures

Measure	*Ex Ante* Household Savings (kWh)	Evaluated Gross Household Savings (kWh)	Realization Rate
Ductless Heat Pump*	1,731	803	46%
Window AC	93.9	46.4	49%

[39] In the 2011 PSD, it was assumed average annual water savings were 6,160 gallons per showerhead and 332 per aerator. In the 2013 PSD, average annual water savings were assumed to be 1,212 gallons per showerhead and 1,238 gallons per aerator. On their own, these changes could affect realization rate adjustments of 20% for showerheads and 372% for aerators. However, other changes from 2011 to 2013—such as algorithm refinement and changes in input values (e.g., the number of showerheads or faucets per home)— had more minor impacts, particularly for showerheads, leading to evaluated gross realization rates of 20% for showerheads and 243% for aerators.

Central AC	98.0	97.58	100%

*Savings estimates were determined through billing analysis and based on the analysis sample; all other savings values were determined through engineering algorithms and were based on the program population.

For ductless measures, the Evaluation Team performed an engineering review and a comparison against a range of other sources (including evaluation studies and TRMs). Appendix B. Engineering Algorithms presents these detailed findings. While *ex ante* savings estimates were consistent with several other studies, evaluated savings more closely resembled a ductless heat pump study and billing analysis performed by Ecotope for the Bonneville Power Administration (BPA).[40] This study focused on ductless heat pump installations in multifamily buildings and identified increased take-back effects, which likely resulted in lower evaluated savings compared to planning estimates. These findings were similar to those estimated through the current billing analysis and reflected the Evaluation Team's whole-house billing analysis results, suggesting lower realization rates for ductless heat pumps in multifamily buildings likely played a key role in the overall program realization rate for HES-IE electric savings.

The primary driver of realizations rates for window AC installations reflected the significantly lower efficiency of installed units than the assumed efficiency of new unit installations outlined in the 2011 PSD. The PSD assumed newly installed units would be CEE Tier 1 or Tier 2 efficiencies.

The Evaluation Team found many cases where installed units were actually less efficient than the PSD assumption. Program tracked data indicated an average, evaluated EER_i value of 10.4, falling roughly halfway between the Federal Standard baseline and the efficient condition of CEE Tier 1. The algorithm did not change from the 2011 PSD to the 2013 PSD, and baseline units were evaluated at the same level, meaning only the efficiency of the newly installed unit presented a difference between *ex ante* and evaluated gross savings.[41]

Appliances

The Evaluation Team used the billing analysis to estimate impacts for refrigerator and freezer replacements. Table 60Table 57 presents the billing analysis model results for these appliances, which achieved a precision estimate within the study threshold.

Table 6059. HES-IE Billing Analysis Electric Savings Results for Appliances

Measure	n	PRENAC	Model Savings (kWh)	Savings as Percent of Pre-Usage	Relative Precision at 90%
Refrigerator	845	7,117	318	4%	±28%

40 Bonneville Power Administration. *Ductless Heat Pump Retrofits in Multifamily and Small Commercial Buildings*. Prepared by Ecotope, Inc. December 2012.

41 The savings calculation for window AC units included PSD constant input assumptions for 272 annual equivalent full load hours (EFLH). The Evaluation Team used utility tracking data for cooling capacity of new units (*$CAP_{C,i}$*), and assumed this to be equal to capacity of the existing unit (*$CAP_{C,e}$*), averaging 0.7 tons. Baseline EER (*ERR_e*) was assigned relative to the efficient unit configuration using a PSD lookup table, which averaged 9.4 EER.

Freezer	84	8,970	728	8%	±32%
Appliance Other	299	7,479	498	7%	±24%

*Represents a mix of appliance replacements (e.g., refrigerator, freezer) bundled in the program tracking data.

Table 61~~Table 58~~ provides realization rates based on comparing the gross savings estimate (from the billing analysis) to the average *ex ante* savings per household.

Table 61~~60~~. HES-IE Billing Analysis Realization Rate Summary for Appliances

Measure	Gross Model Savings (kWh)	Reported *Ex Ante* Savings (kWh)	Realization Rate	Model Savings as Percent of Pre-Usage	Reported *Ex Ante* Savings as Percent of Pre-Usage
Refrigerator	318	758	42%	4%	11%
Freezer	728	733	99%	8%	8%
Appliance Other	498	353	141%	7%	5%

HES-IE model estimates for refrigerators and freezers are higher than savings estimated for these measures under HES (using engineering algorithms). This variation, however, was expected, as HES-IE replacements capture the existing baseline for these measures and should reflect a more significant change in consumption than replacements under HES (i.e., going from standard to high-efficiency units).

HES-IE Natural Gas Savings

The billing analysis provided estimates of gas savings for several HES-IE measure categories: heating system replacement; air sealing; wall insulation; and the DHW bundle. All other gas savings estimates presented in this section were determined through engineering algorithms and simulation modeling.

Shell Measures and Duct Sealing

The Evaluation Team estimated impacts for shell measures (including insulation and air sealing) and duct-sealing measures, primarily using a combination of billing analysis and building simulation models. Specifically, estimates for air sealing and wall insulation were estimated using billing analysis, given precision estimates meeting the study's threshold. Impacts associated with window replacements were assessed using engineering algorithms due to limited information provided in the program tracking data.

While duct-sealing impacts exhibited a greater association to savings occurring through reduced energy losses from heating and cooling, the report presents these together with shell measures, given the similarities in evaluation methods and the discussion of results.

Billing Analysis Results

The Evaluation Team estimated impacts for air sealing and wall insulation using the billing analysis, given this measure achieved a precision estimate of less than the study threshold. Table 62~~Table 59~~ presents the corresponding billing analysis model results.

Table 62~~61~~. HES-IE Billing Analysis Gas Savings Results for Air Sealing and Wall Insulation

Measure	n	PRENAC	Model Savings	Savings as Percent of	Relative Precision at

			(CCF)	Pre-Usage	90%
Air Sealing	984	932	36	4%	±31%
Wall Insulation	162	975	96	10%	±30%

Table 63~~Table 60~~ provides realization rates, based on comparing the gross savings estimate (from the billing analysis) to average *ex ante* savings per household.

Table 63~~62~~. HES-IE Billing Analysis Realization Rate Summary for Air Sealing and Wall Insulation

Measure	Gross Model Savings (CCF)	Reported *Ex Ante* Savings (CCF)*	Realization Rate	Model Savings as Percent of Pre-Usage	Reported *Ex Ante* Savings as Percent of Pre-Usage
Air Sealing	36	59	61%	4%	6%
Wall Insulation	96	304	32%	10%	31%

*Average *ex ante* savings are based on the participant sample used in the billing analysis and may vary from averages based on the program population.

Simulation Modeling Results

The Evaluation Team used details provided in the utility tracking data (for each building type and heating fuel combination) to assess corresponding pre- and post-installation information for each measure analyzed using the calibrated simulation approach. Table 64~~Table 61~~ presents these details, including average pre- and post-installation insulation levels (weighted by square footage installed) and changes in air and duct-sealing levels.

Table 64~~63~~. HES-IE Gas—Shell and Duct Sealing Measure Distribution and Installation Details

Measure	Participants*	Pre-Condition	Post-Condition	Average % Leakage Reduction	Units
Duct Sealing	109	786	625	20%	CFM 25
Attic Insulation	106	R3	R37	n/a	R-Value

*Count of participants reflects the number with *ex ante* savings reported for a given measure.

The Evaluation Team used the energy models to calculate the savings percentage of weather-sensitive loads for each measure, which were then applied to pre-period, weather-sensitive usage for each model to calculate evaluated energy savings. Table 65~~Table 62~~ presents the weighted, household-level gas savings for measures and realization rates, compared to average *ex ante* savings, along with savings percentages of weather-sensitive loads.

Table 65~~64~~. HES-IE Gas—Weighted Household Savings for Shell and Duct Measures

Measures	Average *Ex Ante* Savings (CCF)	Average Pre-Installation Weather Sensitive Consumption (CCF)	Savings as % of Weather-Sensitive Load	Average Evaluated Gross Savings (CCF)	Realization Rate

Duct Sealing	174	681	4.2%	28	16%
Attic Insulation	152	767	25.7%	197	129%

Differences between *ex ante* and evaluated savings for shell and duct sealing measures estimated using building simulation models are presented above in the HES Electric Savings section.

Engineering Algorithm Results

For window replacements, pre- and post-installation data were not available to incorporate into the modeling. Consequently, the Evaluation Team made assumptions regarding window efficiencies and square footage installed.[42] Table 66~~Table 63~~ lists the participation, average installed units, average household savings, and realization rates of window measure installations.

Table 66~~65~~. HES-IE Gas—Evaluated Window Savings

Measure	Total Participants	Average Installed Units	Evaluated Gross Unit Savings (CCF)	Ex-Ante Household Savings (CCF)	Evaluated Gross Household Savings (CCF)	Realization Rate
Windows	33	2	10	25	23	93%

Domestic Hot Water

The Evaluation Team estimated impacts for a combined DHW measure bundle through billing analysis, while impacts associated with water heater temperature setback were estimated using engineering algorithms.

Table 67~~Table 64~~ presents the billing analysis model results for the DHW measure bundle, which achieved a precision estimate within the study threshold.

Table 67~~66~~. HES-IE Billing Analysis Gas Savings Results for DHW Bundle

Measure	n	PRENAC	Model Savings (CCF)	Savings as Percent of Pre-Usage	Relative Precision at 90%
DHW Bundle	965	901	29	3%	±26%

Table 68~~Table 65~~ provides realization rates, based on comparing the gross savings estimate from the billing analysis to the average *ex ante* savings per household.

Table 68~~67~~. HES-IE Billing Analysis Realization Rate Summary for DHW Bundle

Measure	Gross Model Savings (CCF)	Reported *Ex Ante* Savings (CCF)	Realization Rate	Model Savings as Percent of Pre-Usage	Reported *Ex Ante* Savings as Percent of Pre-Usage

42 Evaluated savings estimates assume installation of ENERGY STAR windows from a single pane baseline, with typical window size of 3 feet by 4 feet (2011 PSD assumption). Annual gas usage (*AGU*) is provided in the PSD: 0.28 CCF/ft^2 (AGU_{es}) for the ENERGY STAR unit, and 1.08 CCF/ft^2 (AGU_b) for the single pane baseline.

DHW Bundle	29	41	72%	3%	5%

Table 69~~Table 66~~ lists the participation, average household savings, and realization rate for water heater temperature setback.[43]

Table 69~~68~~. HES Gas Water Temperature Set Back Evaluated Savings

Measure	Total Participants	*Evaluated Gross* Savings Per Unit (CCF)	*Ex Ante* Household Savings (CCF)	*Evaluated Gross* Household Savings (CCF)	Realization Rate
Temp Setback	465	4	6	4	62%

HVAC: Heating System Replacement

The Evaluation Team estimated impacts for heating system replacements through the billing analysis. Table 70~~Table 67~~ presents the billing analysis model results for these measures, which achieved a precision estimate within the study threshold.

Table 70~~69~~. HES-IE Billing Analysis Gas Savings Results for Heating System Replacement

Measure	n	PRENAC	Gross Model Savings (CCF)	Savings as Percent of Pre-Usage	Relative Precision at 90%
Heating System Replacement	58	686	107	16%	±14%

Table 71~~Table 68~~ provides realization rates, based on comparing the gross savings estimate from the billing analysis to the average *ex ante* savings per household.

Table 71~~70~~. HES-IE Billing Analysis Realization Rate Summary for Heating System Replacement

Measure	Gross Model Savings (CCF)	Reported *Ex Ante* Savings (CCF)	Realization Rate	Model Savings as Percent of Pre-Usage	Reported *Ex Ante* Savings as Percent of Pre-Usage
Heating System Replacement	107	128	84%	16%	19%

Energy Savings: Oil/Propane

Table 72~~Table 69~~ presents estimates for oil and propane savings associated with shell, duct sealing, and DHW measures. As discussed in the Methodology, evaluated gross savings derived through the gas analyses were scaled using conversion factors consistent with the PSD to estimate oil and propane

[43] Savings for water heater thermostat setback is based on the PSD calculation which uses constant assumptions for energy factors and hot water usage for clothes washers and dishwashers. As utility tracking data did not include information on the presence of clothes washers and dishwashers, the Evaluation Team used the assumption that all homes include both.

impacts by measure. The previous section discussed the analytical methods used to calculate gas savings specific to each measure.

Table 72~~71~~. HES-IE Oil and Propane—Evaluated Savings for Shell and Duct Measures

Category	Measures	Average Evaluated Gross Savings (CCF)	Oil		Propane	
			Conversion Factor (gallons/CCF)	Oil Savings per Participant (Gallons)**	Conversion Factor (gallons/CCF)	Propane Savings per Participant (Gallons)
Shell and Duct*	Air Sealing	36		26		41
	Attic Insulation	139		100		156
	Wall Insulation	96		70		109
	Duct Sealing	24		17		27
	Windows	23		17		26
DHW	Showerhead	7.4		5.5		8.4
	Faucet Aerators	3.0	0.7419	2.2	1.1267	3.4
	Pipe Insulation	3.0		2.2		3.4
	Water Heater Temp Setback	4.0		2.9		4.5
HVAC	Heating System Replacement	107		78		121

*Measure savings estimated using simulation models have been reweighted, based on the average distribution of building types for oil and propane-heated populations, respectively.

**Due to differences in standard efficiencies between oil and natural gas heating systems (assuming baseline AFUE of 80 and 78, respectively), converted oil savings for shell, duct, and heating system replacement measures have been adjusted accordingly.

HES-IE Subprograms 1 and 4 Analysis Findings

Overall Results

This section presents evaluated savings estimates for the HES-IE SP1 and SP4, covering electric and natural gas impacts estimated using a whole-house billing analysis. The report groups results by fuel savings. Several detailed tables help present the evaluated impacts resulting from the billing analysis, including measure distributions and findings specific to distinct analysis samples included through modeling (e.g., by household type, by building type).

These results include weather-normalized annual consumption in the pre-program period (PRENAC) to characterize average energy consumption of participant and comparison groups prior to program treatment. Additionally, consideration of program impacts in terms of savings as a percentage of pre-period usage (i.e., PRENAC) provides a helpful metric for comparison purposes and for assessing the magnitude of program impacts as this ratio normalizes these savings relative to consumption levels.

Electric Savings

Billing Analysis Results

Table 73~~Table 70~~ compares changes in energy consumption from the pre- to post-program periods for the participant and comparison groups, by HES-IE subprogram. The table includes estimated adjusted gross savings, calculated based on the "percent of pre" approach discussed in the Methodology section in Volume 1 of this report.

Table 73~~72~~. HES-IE SP1 and SP4 Electric Billing Analysis: Savings Summary, Overall

HES-IE Subprogram	Group	n	PRENAC	Model Savings (kWh)	Savings as Percentage of Pre-Usage	Relative Precision at 90%	Savings Lower 90% (kWh)	Savings Upper 90% (kWh)
SP1*	Participant	1,348	8,708	765	9%	±7%	711	819
	Comparison	197	8,841	-314	-4%	±-66%	-522	-107
	Adjusted gross	1,348	8,708	1,074	12%	±20%	860	1,289
SP4	Participant	2,670	6,617	458	7%	±7%	426	491
	Comparison	256	6,181	-160	-3%	±-87%	-298	-21
	Adjusted gross	2,670	6,617	629	10%	±23%	487	772

*Savings estimated for SP1 include impacts associated with measure installations funded through non-utility sources (e.g., DOE), as part of WAP.

Participants achieved estimated gross energy savings of 765 kWh for SP1 and 458 kWh for SP4. An increase in electric usage, detected in the comparison groups, resulted in an adjusted gross savings estimate of 1,074 kWh for SP1 and 629 kWh for SP4.

Table 74~~Table 71~~ shows the frequency distribution of measure installations from the analysis sample of participants, by HES-IE subprogram, along with the average reported savings per measure type. The Evaluation Team stresses that the measures did not serve as model inputs. Rather, the listing of measures and their *ex ante* per-unit savings estimates provided a context for understanding the model results.

Table 74~~73~~. HES-IE SP1 and SP4 Electric Analysis: Measure Distribution of Final Model Sample

Category	Measure	Percentage of Sample		Average *Ex Ante* Savings by Measure (kWh per Participant)	
		SP1	SP4**	SP1	SP4**
Lighting	Lighting	93%	96%	712	403
Water Heat	DHW Bundle*	26%	77%	793	812
	Pipe Insulation	4%	<1%	115	62
	Water Heater Setback	5%	<1%	86	86
Shell	Air Sealing	7%	5%	1,635	604
	Attic Insulation	2%	n/a	638	n/a
	Wall Insulation	<1%	n/a	2,339	n/a
	Windows	<1%	n/a	231	n/a
HVAC	Window AC	<1%	<1%	56	29
Appliances	Freezer	5%	n/a	877	n/a
	Refrigerator	23%	4%	985	806
Other	Other	<1%	n/a	554	n/a
Sample (n)		**1,348**	**2,670**		

*Contains a mix of low-flow showerheads, faucet aerators, and pipe insulation.
**SP4 participation is defined using the tracking system and may include instances of crossover participation into other HES-IE SPs—a desired outcome in that SP4 is designed to feed into SP1 and SP2—resulting in additional measure installations for this sample. To avoid double counting, the analysis captures these savings in SP4 but not SP1 or SP2.

Generally, SP1 and SP4 installation activities (and the associated electric impacts) were characterized by high frequencies of energy-efficient lighting (93% for SP1, 96% for SP4) and hot-water saving measures (26%, 77%), with SP1 also indicating high installation rates for refrigerator replacements (23%).

To provide additional context regarding the program-specific impacts, Table 75~~Table 72~~ and Table 76~~Table 73~~ show the HES-IE SP1 and SP4 adjusted gross energy savings by heating type (electric versus non-electric) and building type (single-family versus multifamily).

Table 75~~Table 72~~ illustrates the larger, absolute energy savings associated with electrically heated homes for HES-IE SP1 and SP4. Electric-heat homes make up a small part of the sample, especially in SP1; consequently overall savings, percent savings, and precision more closely resemble non-electric homes than electric ones.

Table ~~74~~75. HES-IE SP1 and SP4 Electric Billing Analysis: Savings Summary, by Participant Heating Fuel (Adjusted Gross)

HES-IE Subgroup	Participant Heating Type	n	PRENAC	Model Savings (kWh)	Savings as Percentage of Pre-Usage	Relative Precision at 90%
SP1	Electric	130	15,277	1,279	8%	±73%
	Non-electric	1,218	8,007	1,051	13%	±21%
	Overall	**1,348**	**8,708**	**1,074**	**12%**	**±20%**
SP4	Electric	698	9,162	1,155	13%	±24%
	Non-electric	1,972	5,794	441	8%	±26%
	Overall	**2,670**	**6,617**	**629**	**10%**	**±23%**

Table 76~~Table 73~~ shows the bulk of HES-IE SP1 and SP4 electric-savings participation occurred in single-family homes, producing higher savings than multifamily, and the subprograms exhibited similar pre-period usage between the participant types. This resulted in higher savings as a percentage of pre-period usage for single-family homes.

Table ~~75~~76. HES-IE SP1 and SP4 Electric Billing Analysis: Savings Summary, by Building Type (Adjusted Gross)

HES-IE Subgroup	Participant Heating Type	n	PRENAC	Model Savings (kWh)	Savings as Percentage of Pre-Usage	Relative Precision at 90%
SP1	Single family	1,266	8,747	1,119	13%	±19%
	Multifamily	82	8,106	584	7%	±159%
	Overall	**1,348**	**8,708**	**1,074**	**12%**	**±20%**
SP4	Single family	2,665	6,543	647	10%	±22%
	Multifamily	5	7,661	213	3%	±41%
	Overall	**2,670**	**6,617**	**629**	**10%**	**±23%**

Realization Rate

Table 77~~Table 74~~ provides realization rates for HES-IE SP1 and SP4, based on the participant gross and adjusted gross savings for the billing analysis sample.

Table 7776. HES-IE SP1 and SP4 Electric Billing Analysis: Realization Rate Summary

HES-IE Subgroup	Group	Model Savings (kWh)	Reported *Ex Ante* Savings (kWh)	Realization Rate	Model Savings as Percentage of Pre-Usage	Reported *Ex Ante* Savings as Percentage of Pre-Usage
SP1	Gross Savings	765	1,278	60%	9%	15%
	Adjusted Gross Savings	1,074	1,278	84%	12%	15%
SP4	Gross Savings	458	1,037	44%	7%	16%
	Adjusted Gross Savings	629	1,037	61%	10%	16%

Natural Gas Savings

Billing Analysis Results

Table 78Table 75 compares changes in energy consumption for HES-IE SP1 and SP4 from the pre- to post-program periods for the participant and comparison groups. Analysis included estimated, adjusted, gross savings, calculated based on the "percent of pre" approach, as discussed in the Methodology section of Volume 1.[44]

Table 7877. HES-IE SP1 and SP4 Natural Gas Billing Analysis: Savings Summary, Overall*

HES-IE Subprogram	Group	n	PRENAC	Model Savings (CCF)	Savings as Percentage of Pre-Usage	Relative Precision at 90%	Savings Lower 90% (CCF)	Savings Upper 90% (CCF)
SP1	Participants	231	1,006	97	10%	±15%	83	111
	Comparison**	664	873	13	1%	±62%	5	21
	Adjusted gross	231	1,006	82	8%	±20%	66	99
SP4	Participants	114	723	43	6%	±39%	26	59
	Comparison**	664	873	13	1%	±62%	5	21
	Adjusted gross	114	723	32	4%	±58%	13	51

*Smaller SP1/SP4 participant samples resulted in decreased model precision.

**Due to insufficient sample sizes, the HES-IE SP2/SP3 comparison group was used to control for exogenous effects and should represent an appropriate sample of nonparticipants for SP1 and SP4.

[44] Gas savings were only specifically reported for CNG and YGS participants through the billing analysis of HES-IE SP1 and SP4. Billing analysis samples only included one SCG participant for SP1 and no SCG participants for SP4.

Participants achieved estimated gross energy savings of 97 CCF for SP1 and 43 CCF for SP4. A decrease in gas usage in the comparison group resulted in an adjusted gross savings estimate of 82 CCF for SP1 and 32 CCF for SP4.

Table 79~~Table 76~~ presents additional, utility-specific models that disaggregate the overall HES-IE SP1 and SP4 results (shown above) for the participant, comparison group, and adjusted gross savings estimates.

Table 79~~78~~. HES-IE SP1 and SP4 Natural Gas Billing Analysis: Savings Summary, by Utility

HES-IE Subprogram	Group	Utility	n	PRENAC	Model Savings (CCF)	Savings as Percentage of Pre-Usage	Relative Precision at 90%
SP1	Participant	CNG	130	1,060	108	10%	±19%
		YGS	101	943	82	9%	±22%
		Overall	**231**	**1,006**	**97**	**10%**	**±15%**
	Comparison	CNG	223	981	23	2%	±62%
		YGS	188	756	18	2%	±76%
		Overall*	**642**	**873**	**13**	**1%**	**±62%**
	Adjusted Gross	CNG	130	1,060	84	8%	±30%
		YGS	101	943	60	6%	±38%
		Overall	**231**	**1,006**	**82**	**8%**	**±20%**
SP4	Participant	CNG	25	1,031	54	5%	±22%
		YGS	89	652	40	6%	±49%
		Overall	**114**	**723**	**43**	**6%**	**±39%**
	Comparison	CNG	223	981	23	2%	±62%
		YGS	188	756	18	2%	±76%
		Overall*	**644**	**873**	**13**	**1%**	**±62%**
	Adjusted Gross	CNG	25	1,031	30	3%	±61%
		YGS	89	652	25	4%	±97%
		Overall	**114**	**723**	**32**	**4%**	**±58%**

*Overall comparison group for SP2/SP3 includes some nonparticipants from the SCG territory, providing increased sample sizes for this comparison.

Table 80~~Table 77~~ shows the frequency distribution of measure installations from the analysis sample of participants, by HES-IE subprogram, along with average reported savings per measure type.

Table 80~~79~~. HES-IE SP1 and SP4 Natural Gas Analysis: Measure Distribution of Final Model Sample

Category	Measure	Percentage of Sample		Average *Ex Ante* Savings by Measure (CCF per Participant)	
		SP1	SP4**	SP1	SP4**
Shell	Air Sealing	63%	42%	57	40
	Attic Insulation	11%	n/a	41	n/a
	Wall Insulation	6%	n/a	127	n/a
	Windows	4%	n/a	7	n/a
Water Heat	DHW Bundle*	77%	96%	41	41
	Pipe Insulation	18%	3%	5	10
	Water Heater Setback	12%	n/a	6	n/a
HVAC	Heating System Replacement	3%	n/a	318	n/a
Other	Other	3%	n/a	35	n/a
Sample (n)		**231**	**114**		

*Contains a mix of low-flow showerheads, faucet aerators, and pipe insulation.
**SP4 participation is defined using the tracking system and may include instances of crossover participation into other HES-IE SPs, resulting in additional measure installations for this sample.

In general, installation activities for each utility HES-IE SP1 and SP4 (and associated gas impacts) were characterized by high frequencies for: air sealing (63% for SP1, 42% for SP4); hot-water savings measures, including the DHW bundle (77%, 96%); and, specific to SP1, pipe insulation (18%) and water heater temperature setback (12%). Attic and wall insulation also were present for 6% and 4% of SP1 participants, respectively.

The majority of HES-IE SP1 and SP4 gas-savings participation occurred in single-family homes, a finding consistent with the HES-IE SP1 and SP4 electric participant distribution. As just one SP4 participant was listed as multifamily, Table 81~~Table 78~~ only shows model results for SP1 by building type.

Table 81~~80~~. HES-IE SP1 and SP4 Natural Gas Billing Analysis: Savings Summary, by Building Type (Adjusted Gross)

HES-IE Subprogram	Participant Heating Type	n	PRENAC	Model Savings (CCF)	Savings as Percentage of Pre-Usage	Relative Precision at 90%
SP1	Single-family	195	1,030	83	8%	±22%
	Multifamily	36	880	64	7%	±36%
	Overall	**231**	**1,006**	**82**	**8%**	**±20%**

Realization Rate

Table 82Table 79 provides realization rates, based on participant gross and adjusted gross savings for the billing analysis sample.

Table 8281. HES-IE SP1 and SP4 Natural Gas Billing Analysis: Realization Rate Summary

HES-IE Subprogram	Group	Model Savings (CCF)	Reported *Ex Ante* Savings (CCF)	Realization Rate	Model Savings as Percent of Pre-Usage	Reported *Ex Ante* Savings as Percent of Pre-Usage
SP1	Gross	97	110	89%	10%	11%
	Adjusted Gross	82	110	75%	8%	11%
SP4	Gross	43	60	71%	6%	8%
	Adjusted Gross	32	60	53%	4%	8%

Recommendations

General

As discussed in the Volume 1 report, the Evaluation Team has developed several recommendations related to improved data management. These recommendations address challenges that arose in working with utility billing and program tracking data throughout this study. In addition to recommendations discussed in Volume 1, some additional suggestions follow for improvements in data management. These adjustments will not only benefit the evaluation, but will provide valuable data to inform the future delivery of these programs:

- ***Measure-specific inputs require better tracking within the utility program tracking systems*** to calculate savings based on PSD algorithms. In many cases, the tracking system did not provide the details used for these calculations (e.g., windows, no baseline or efficient unit descriptions or installed square footage).
    - Many challenges arose in identifying measure names/descriptions and, in some cases, disaggregating a category into specific measures for energy-savings calculations (e.g., appliances, insulation).
- ***Consistency should increase between utility tracking systems*** for programs and measures, particularly if the programs continue to be reported and evaluated jointly across gas and electric utilities.
    - Align terminologies, such as: discrete measure categories (including subcategories and descriptions, as necessary); measure input values (e.g., efficiency levels); program and subprogram names; and building/household/equipment characteristics.
    - Consistently collect household/equipment characteristics that feed into detailed savings calculations (such as building types, heating fuels, and heating and cooling equipment).
    - Integrate database QA protocols to ensure consistencies within projects:
        - For example, the value of conditioned square footage from an initial home audit should match reported condition square footage collected in subsequent visits for follow-on measure installations; in some instances, audit data reported conflicting information for individual participants.
    - Ensure fields are populated consistently with standardized values: many differences occurred within and across utility data regarding how measures were defined or described; unpopulated fields (blanks) could be appropriately replaced with values such "n/a" or a quantity of zero.
- ***QA check information by project***. Specifically for insulation, QA checks should determine whether installed square footage quantities surpass reasonable values relative to a reported, total, conditioned floor area. Additionally, QA checks could ensure fuel-specific savings calculated for a project remain consistent with the information provided for a site regarding heating and water heating fuels and the presence and/or type of cooling equipment.

- ***Improved tracking of project data for multifamily buildings.*** Reporting should be consistent at the unit level. The Evaluation Team observed that tracking data and billing data could not always be directly mapped. Billing data often were presented at the facility level, while measure data often were presented at the unit level; a unique identifier to link these data sources should help to resolve this issue. If program tracking data can maintain consistency for multifamily participants in recording information at the unit level, this unique identifier for multifamily units should be present in the billing data to facilitate integration.
- ***Improve ability to easily export program tracking data*** for specific programs in isolation. In some cases, challenges emerged in identifying measures attributed to HES and HES-IE programs (versus other energy-efficiency programs). In several cases, lacking a program identifier, the Evaluation Team had to identify program-attributed measures using measure descriptions and rebate levels. Recommended actions include creating a data dictionary for existing variables and always adding a variable description when adding new fields/values to the dataset.
- ***Ensure program tracking of both electric and gas account numbers.*** This would facilitate accessibility and connections to other databases, using account numbers as unique identifiers (e.g., billing and transaction data). Alternatively, perhaps another unique identifier currently utilized by utilities could better facilitate this process.

Measure Specific

Ductless Heat Pumps

Based on measure-level and whole-house findings, *ex ante* savings estimates for ductless heat pumps overestimate actual savings and do not account for scaled-down savings, which potentially relates to take-back effects or the accuracy of baseline assumptions (e.g., some level of continued baseboard heating or increased cooling loads). More detailed analysis should be performed, specific to this measure, for HES and HES-IE participants (and could include other programs offering ductless heat pumps in Connecticut). Region-specific research will help clarify the discrepancies between current planning estimates and evaluated savings, refine assumptions regarding baseline conditions, and identify key inputs that the current algorithm does not account for.

Faucet Aerators

Based on the engineering review and benchmarking performed on the faucet aerator measure, the savings algorithms and inputs used for the energy-savings calculation should be adjusted.

First, a drain factor should be included. This would account for non-time-dependent water usage and, therefore, would not be impacted by flow rates. For example, filling a vessel requires the same amount of water, whether or not using an aerator. As a result, installation of a low-flow faucet aerators only increase the time required to complete this task and does not reduce the amount of water used.

Second, the utility should use the water heater recovery efficiency rather than the energy factor when determining energy savings for faucet aerators. The energy factor accounts for the total amount of hot

water produced relative to energy consumed for a given day, which includes: the recovery efficiency, standby losses, and cycling losses. Installation of an aerator does not impact standby or cycling losses in a water heater; rather, energy savings are realized due to a smaller volume of cold water entering the water heater. Consequently, recovery efficiency is the true efficiency that should be used for energy-savings calculations.

Showerhead

Much like faucet aerators (above), the utility should use the water heater recovery efficiency rather than the energy factor when determining energy savings for showerheads. The energy factor accounts for the total amount of hot water produced relative to energy consumed for a given day, which includes: the recovery efficiency, standby losses, and cycling losses. Installation of a showerhead does not impact standby or cycling losses in a water heater; rather, energy savings are realized due to a smaller volume of cold water entering the water heater. Consequently, recovery efficiency is the true efficiency that should be used for energy-savings calculations.

Pipe Insulation

Based on the Evaluation Team's review of the pipe insulation measure, the PSD does not limit the amount of insulation that can be installed and receive savings. Through a review of supplemental resources, the Evaluation Team found the maximum savings achievable through pipe insulation should not exceed the savings achieved through installation of a heat trap in a water heater. Based on the PSD value of 10.4 kWh per linear foot of pipe insulation, this results in a maximum installation of approximately six feet of pipe insulation per water heater. The Evaluation Team finds that savings for hot water pipe insulation should only be received for the installation of six feet of pipe insulation. Additional insulation provides negligible savings, and the installation of less insulation proves ineffective in reducing energy consumption.

Furthermore, the Evaluation Team considers it worthwhile for the utility to revisit the savings estimates used for installations of pipe insulation. The model used by the utility calculates energy savings in systems where water continuously circulates at a raised temperature—a common occurrence in many commercial applications. In a residential hot water system, however, hot water primarily is located in hot water tanks and does not constantly circulate through piping systems. Consequently, water in the pipes cools relatively quickly, and energy savings drop off dramatically.

Window AC

Utilities should ensure that window AC replacements installed through the program meet minimum efficiency requirements, and claimed savings should account for the installed efficiency collected through tracking data (rather than assuming a constant installed efficiency from the PSD). As discussed, the Evaluation Team found that, in many cases, the installed units proved less efficient than the CEER Tier 1 or Tier 1 levels,

Appendix A. Billing Analysis Fixed-Effects Model Specifications

Measure-Level Model Results

To estimate gas and electric energy savings from the HES and HES-IE programs, the Evaluation Team used a pre- and post-installation savings analysis fixed-effects modeling method, which utilized pooled monthly time-series (panel) billing data. The fixed-effects modeling approach corrected for the following:

- Differences between pre- and post-installation weather conditions; and
- Differences in usage consumption between participants, through inclusion of a separate intercept for each participant.

This modeling approach ensured that model savings estimates would not be skewed by unusually high-usage or low-usage participants. The measure-level analysis used the same analysis samples and a similar model specification to that used for whole-house billing analysis, while adding measure-specific indicators as parameters (interacting with POST, AVGHDD, and AVGCDD variables). Due to the model's complexity and the extent of parameters used, the following tables present key parameter estimates that represent total energy savings for measures.

Table 83~~82~~. HES Electric Complex Measures Model Specification

Variable	Parameter Estimate	Standard Error	t-statistic	p-Value
Air Sealing	-271.88	33.83	-8.04	0.0000
Lighting	-780.93	26.78	-29.16	0.0000
Dehumidifier	256.72	172.46	1.49	0.1366
Freezer	-124.23	736.21	-0.17	0.8660
Refrigerator	-323.81	130.35	-2.48	0.0130
Central Air Conditioner	-142.95	123.29	-1.16	0.2463
Duct Sealing	-131.04	45.14	-2.90	0.0037
Pipe Insulation	-271.58	77.81	-3.49	0.0005
Clothes Washer	-361.38	249.59	-1.45	0.1477
Insulation Other	-626.65	137.28	-4.56	0.0000
Heat Pump Water Heater	-318.82	313.23	-1.02	0.3088
Windows	-422.61	490.15	-0.86	0.3886
Heating System Replacement	-276.70	331.75	-0.83	0.4043
Heat Pump	-1778.58	495.49	-3.59	0.0003
Ductless Heat Pump	-1315.14	281.67	-4.67	0.0000
Geothermal Heat Pump	-1404.01	753.93	-1.86	0.0626
Other	-338.16	393.35	-0.86	0.3900
DHW Bundle	-316.57	60.47	-5.23	0.0000
Attic Insulation	-126.38	517.34	-0.24	0.8070
Wall Insulation	-3081.42	3022.96	-1.02	0.3081

Table 84~~83~~. HESIE Electric Complex Measure Model Specification

Variable	Parameter Estimate	Standard Error	t-statistic	p-Value
Air Sealing	-66.52	49.18	-1.35	0.1763
Lighting	-645.49	23.91	-27.00	0.0000
Freezer	-725.40	139.50	-5.20	0.0000
Refrigerator	-316.90	53.99	-5.87	0.0000
Central Air Conditioner	294.13	119.15	2.47	0.0136
Duct Sealing	-9.65	124.80	-0.08	0.9384
Pipe Insulation	-77.48	165.19	-0.47	0.6391
Insulation Other	737.12	172.36	4.28	0.0000
Windows	-257.96	204.34	-1.26	0.2069
Heat Pump	-1583.91	132.61	-11.94	0.0000
Ductless Heat Pump	-696.03	138.13	-5.04	0.0000
Other	-922.59	268.75	-3.43	0.0006
DHW Bundle	-93.18	58.04	-1.61	0.1085
Attic Insulation	-330.35	108.19	-3.05	0.0023
Wall Insulation	923.85	178.14	5.19	0.0000
Appliance Other	-493.26	71.17	-6.93	0.0000
Window AC	-631.27	107.90	-5.85	0.0000
Water Heater Temp Setback	56.52	255.66	0.22	0.8250

Table 85~~84~~. HES Gas Complex Model Specification

Variable	Parameter Estimate	Standard Error	t-statistic	p-Value
Air Sealing	-55.93	4.34	-12.88	0.0000
Duct Sealing	-19.30	8.01	-2.41	0.0161
Pipe Insulation	-11.85	4.76	-2.49	0.0128
Clothes Washer	-346.55	4.24	-81.74	0.0000
Insulation Other	-149.19	34.93	-4.27	0.0000
Water Heater	-98.92	54.31	-1.82	0.0687
Heating System Replacement	-132.85	37.43	-3.55	0.0004
Windows	-75.02	5.49	-13.66	0.0000
DHW Bundle	-12.99	4.86	-2.67	0.0076
Attic Insulation	-51.68	26.36	-1.96	0.0501
Wall Insulation	-102.17	68.10	-1.50	0.1337

Table 8685. HESIE Gas Complex Model Specification

Variable	Parameter Estimate	Standard Error	t-statistic	p-Value
Air Sealing	-30.32	5.29	-5.74	0.0000
Duct Sealing	-13.07	16.00	-0.82	0.4141
Pipe Insulation	3.14	7.66	0.41	0.6815
Water Heater Temp Setback	-9.64	7.86	-1.23	0.2201
Heating System Replacement	-103.42	8.81	-11.73	0.0000
Windows	-64.64	21.66	-2.98	0.0029
Other	33.28	13.30	2.50	0.0124
DHW Bundle	-36.08	5.66	-6.38	0.0000
Attic Insulation	-44.00	14.88	-2.96	0.0032
Wall Insulation	-90.95	16.81	-5.41	0.0000
Appliance Other	-52.88	48.70	-1.09	0.2778

SP1 and SP4 Model Specification

The Volume 1 report provides whole-house model specifications for the HES and HES-IE programs.

Appendix B. Engineering Algorithms

This section presents a more detailed engineering review for several program measures. The review references the sources shown in Table 87~~Table 84~~.

Table 87~~86~~. Sources used in Engineering Algorithm Review

Source	Reference
Indiana TRM	Indiana Technical Reference Manual, Version 1.0. Prepared by TecMarket Works. January 10, 2013.
Illinois TRM	Illinois Statewide Technical Reference Manual for Energy Efficiency, Version 2.0. Created by the Illinois Energy Efficiency Stakeholder Advisory Group. June 7, 2013.
Massachusetts TRM	Massachusetts Technical Reference Manual for Estimating Savings from Energy Efficiency Measures. 2012 Program Year – Report Version. August 2013.
Pennsylvania TRM	Technical Reference Manual for the State of Pennsylvania. June 2014.
Mid Atlantic TRM	Mid-Atlantic Technical Reference Manual, Version 3.0 Prepared by Shelter Analytics. March 2013.
MA HES Evaluation Report, 2011	Massachusetts Home Energy Services Impact Evaluation. Prepared by Cadmus. August 2012.
MA Low-Income Evaluation Report, 2011	Massachusetts Low Income Single Family Program Impact Evaluation. Prepared by Cadmus. June 2012.
NEEA DHP Study / Report	Ductless Heat Pump Impact & Process Evaluation: Billing Analysis Report. Prepared by Ecotope, Inc. August 2013. Report #13-262.
Regional Technical Forum	Single Family Residential Ductless Heat Pump Program Savings Workbook. April 2013.
EmPOWER Maryland Report, 2011	Residential Retrofits Report, Cadmus. October 2011.
BPA DHP Study / Report	Bonneville Power Administration, Ductless Heat Pump Retrofits in Multifamily and Small Commercial Buildings. Prepared by Ecotope, Inc. December 2012.
KEMA Ductless Mini Pilot Study	Ductless Mini Pilot Study, Final Report. Prepared by KEMA, Inc. June 2009. Prepared for NSTAR Electric and Gas Corporation, National Grid, Connecticut Light and Power, United Illuminating, Western Massachusetts Electric Company, Connecticut Energy Conservation Management Board.

Pipe Insulation

The literature review for this measure identified seven sources, based on regional and program similarities. Table 88~~Table 85~~ shows per-measure, energy savings estimates. Due to the variability in per-unit savings, evaluation methodologies, and the availability of current evaluation research, the Evaluation Team performed a more in-depth analysis for this measure.

Table 8887. Results of the Pipe Insulation Literature Review

Source	Additional Information	Energy Savings per Six Feet of Installed Insulation (kWh)
Connecticut Program Savings Document, Eighth Edition, 2013	2013 PSD	62.40
Connecticut Program Savings Document, 2011	2011 PSD	62.40
Illinois Statewide Technical Reference Manual, Version 2.0, 2013	Illinois	148.00
Massachusetts Home Energy Services Impact Evaluation	MA Report	383.50
Massachusetts Technical Reference Manual—2012 Program Year	MA TRM	330.00
Efficiency Maine Residential Technical Reference Manual, Version 2014.1, 2013	Maine	61.80
Pennsylvania PUC Technical Reference Manual, 2014	PA 2014	60.10
Indiana Technical Resource Manual, Version 1.0, 2013	Indiana	160.20
Mid-Atlantic Technical Reference Manual, Version 3.0, 2013	Mid-Atlantic 2013	155.70

Pipe insulations' full impact on water heater savings can be difficult to define due to the different thermodynamic and heat transfer processes at work in a system. The DHW energy loss scenarios within the system include the following:

1. Conductive and convective heat transfer from water flowing through the piping system.

   Water flowing through a piping system loses energy due to heat transfers from piping to the air surrounding the piping system.

2. Conductive heat transfer from the water heater tank to the piping.

   Due to its lower temperature and direct contact (through couplings) with the hot water stored within the water heater tank, the piping transfers energy from the tank through the length of piping. This energy transfer occurs from the start of the piping system to a point on the piping system equal to the ambient air.

3. Natural convection (thermosyphoning).

   Due to cold water's higher density than warm water, piping systems containing water at temperatures lower than water within the water heater tank could potentially displace water within the tank with water from the piping system—a phenomenon often called natural convection or thermosyphoning. Natural convection presents a problem when water stored within a tank is forced into the piping system, while water from the piping system enters the tank, causing the water heater to use additional energy to raise water temperatures.

Recent evaluation research indicates scenarios 1 and 3 present the two primary energy-loss scenarios. Energy loss scenario 1 only applies when hot water actually flows from the water heater to the point of use. Based on an average household water consumption of 69.3 gallons, the Evaluation Team found hot water pipe wrap reduced the heat transfer from water flowing through the piping system by 4.94 kWh over the course of a year.

For energy loss scenario 3—natural convection—the maximum possible energy savings would be realized through a heat trap: mechanical devices that prevent water in a piping system from flowing back into the water heater, thus eliminating losses associated with natural convection. The EmPOWER study found that energy savings from heat traps amounted to 58 kWh annually. A U.S. Department of Energy water heater standard mandated inclusion of heat traps in all water heaters manufactured after 2004.[45]

Sources evaluated for this comparison used a mix of approaches to target energy savings from scenarios 1 and 3, but, based on the Evaluation Team's review, none of the following sources captured the true energy savings from water heater pipe insulation. In many cases, savings claimed by reviewed sources greatly overestimated savings associated with this measure. Table 89~~Table 86~~ presents the various inputs for each savings value with published inputs and algorithms.

[45] *EmPOWER Maryland: 2011 Engineering Review: Residential Retrofits*. P 75–88.

Table 8988. Summary of Pipe Insulation Assumptions and Values

Inputs Description	2013 PSD	2011 PSD	Illinois	MA Report	MA TRM	Maine	PA 2014	Indiana	Mid-Atlantic 2013
R Exist (Btu/hr-°F-ft)			1.00	1.00				1.00	1.00
R New (Btu/hr-°F-ft)			5.00	5.00				5.00	4.50
Length of Insulation (ft)	1.00	10.00	1.00	6.00	1.00	10.00	10.00	1.00	1.00
Circumference of Pipe (ft)	0.13	0.13	0.20	0.13			0.20	0.20	0.20
Hot Water Temp (°F)	90.00	90.00		120.00		125.00			
Ambient Air Temp (°F)	60.00	60.00		65.00		50.80			
Delta T (°F)	30.00	30.00	60.00	55.00		74.20		65.00	65.00
HOU (hours)			8,766.00	8,760.00		8,760.00		8,760.00	8,760.00
RE of Water Heater (%)			0.98	0.97		0.98		0.98	0.98
Gallons per Day (Gal / Day)				0.02		51.10			
Savings Factor (%)						0.03	0.03		
Density of Water						8.30			
Water Heater Energy Consumption (kWh)				4,261.00			3,338.00		
Water Heater Energy Factor (%)							0.94		
Pipe Diameter (in.)	0.50	0.50	0.75	0.50			0.75	0.75	0.75
Thermal Regain Factor (%)				0.33					
Energy Savings per six feet of Pipe Insulation Installation (kWh)	62.40	62.40	148.00	383.50	330.00	61.80	60.10	160.20	155.70

*Shaded cells indicate a calculated value.

Based on the EmPOWER report, pipe insulation installation can achieve maximum savings of roughly 62 kWh. The Evaluation Team allocated 10.4 kWh per linear foot of insulation installed, up to a maximum of six feet of insulation. For a 0.5 inch diameter pipe, this provided average savings of 62.4 kWh per installation.

Faucet Aerators

The engineering review for faucet aerators by examining published reports and TRMs deemed relevant to the evaluation due to their regional similarities, low-income specific recommendations, or separate inputs for multifamily savings. The review identified eight sources. Table 90~~Table 87~~ shows the per-measure energy savings estimates. Due to the variability in per-unit savings, the Evaluation Team performed a more in-depth analysis of the savings algorithms.

Table 90~~89~~. Results of the Faucet Aerator Literature Review

Source	Additional Information	Annual Energy Savings per Faucet (kWh)
Connecticut Program Savings Document, Eight Edition, 2013	2013 PSD	79.38
Connecticut Program Savings Document, 2011	2011 PSD (HES)	17.26
	2011 PSD (HES-IE)	22.42
Illinois Statewide Technical Reference Manual, Version 2.0, 2013	Illinois (Single-Family)	44.44
	Illinois (Multifamily)	55.87
Massachusetts Home Energy Services Impact Evaluation	MA (Kitchen)	71.15
	MA (Bath)	33.26
Massachusetts Low Income Single Family Program Impact Evaluation, 2012	MA LI (Kitchen)	58.45
	MA LI (Bath)	27.32
Efficiency Maine Residential Technical Reference Manual, Version 2014.1, 2013	Maine (Kitchen)	283.39
	Maine (Bathroom)	29.22
Maine (Kitchen)	PA 2014	69.27
Indiana Technical Resource Manual, Version 1.0, 2013	Indiana (Kitchen)	37.45
	Indiana (Bathroom)	38.84
Mid-Atlantic Technical Reference Manual, Version 3.0, 2013	Mid-Atlantic 2013	12.11

Table 91~~Table 88~~ presents the various inputs for each savings value with published inputs and algorithms. This research revealed a great many approaches used to arrive at the energy savings values. Consequently, the Evaluation Team normalized savings values for studies providing sufficient published data. This process involved reviewing key components for energy-saving equations and normalizing inputs for comparison. For example, the Evaluation Team assessed annual water savings per year (gallons) and energy savings per gallon. In total, six studies supplied enough detail to inform the normalized savings calculation. Table 92~~Table 89~~ shows the normalization results.

Table 91~~90~~. Summary of Faucet Aerator Assumptions and Values*

Inputs Description	2013 PSD	2011 PSD (HES)	2011 PSD (HES-IE)	IL (SF)	IL (MF)	MA (Kit.)	MA (Bath)	MA LI (Kit.)	MA LI (Bath)	ME (Kit.)	ME (Bath)	PA 2014	IN (Kit.)	IN (Bath)	Mid-Atlantic 2013
Average Duration per Event (Min) (d_e)	0.62	1.00	1.00	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	3.00	2.00	n/a
Energy Factor of Electric Water Heater (%) (EF_E)	0.95	0.90	0.90	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Faucet Flow Rate, Base (Gal/Min) (gpm)	2.20	2.20	2.20	1.20	1.20	1.30	1.30	1.30	1.30	2.20	2.20	2.20	2.40	2.40	2.20
Faucet Flow Rate, Low-Flow (Gal/Min) (gpm)	1.50	1.50	1.50	0.94	0.94	1.00	1.00	1.00	1.00	1.50	1.50	1.50	1.50	1.00	1.50
Faucets per Home (faucets/Home) (n_a)	5.10	3.00	3.00	3.83	2.50	1.03	2.42	1.03	2.42	1.00	2.96	3.80	n/a	n/a	3.50
Median Number of Faucet Events per Day (Events/Day) (n_e)	42.90	3.00	3.00	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	1.00	1.00	n/a
Water Savings per Year per Faucet (Gal/Year/Faucet)	1,239	256	332	497	625	836	391	686	321	2,696	333	848	621	644	1,620
Temperature of Water from Faucet (˚F) (T_{faucet})	80.00	80.00	80.00	90.00	90.00	90.00	90.00	90.00	90.00	93.00	86.00	87.80	80.00	80.00	80.00
Temperature of Water into House (˚F) (T_{supply})	55.00	55.00	55.00	54.10	54.10	56.04	56.04	56.04	56.04	50.80	50.80	55.00	55.70	55.70	55.00
Minutes of Faucet Use per Day per Person (Min/day/Person)	n/a	n/a	n/a	9.85	9.85	5.45	2.93	5.45	2.93	4.50	1.70	6.10	3.00	2.00	4.95
Average People per Home (Person/Home)	n/a	n/a	n/a	2.56	2.10	2.80	2.80	2.30	2.30	2.34	2.34	2.60	n/a	n/a	2.56
Drain Factor (%)	n/a	n/a	n/a	0.80	0.80	0.50	0.70	0.50	0.70	n/a	n/a	0.80	0.63	0.63	0.50
Electric Water Heater Recovery Efficiency (%)	n/a	n/a	n/a	0.98	0.98	0.97	0.97	0.97	0.97	0.98	0.98	0.98	0.98	0.98	0.98
Energy Savings per Gallon (kWh/Gal)	0.06	0.07	0.07	0.09	0.09	0.09	0.09	0.09	0.09	0.11	0.09	0.08	0.06	0.06	0.01
Gallons/Person/Day	n/a	n/a	n/a	n/a	n/a	10.90	10.90	10.90	10.90	n/a	n/a	n/a	n/a	n/a	10.90

*Shaded cells indicate a calculated value.

Table 9291. Normalized Assumptions for Faucet Aerator Energy Savings Calculations*

Inputs Description	2013 PSD	2011 PSD (HES)	2011 PSD (HES-IE)	Illinois (SF)	Illinois (MF)	MA (Kit)	MA (Bath)	MA LI (Kit)	MA LI (Bath)	Maine (Kit)	Maine (Bath)	PA 2014	Indiana (Kit)	Indiana (Bath)	Mid-Atlantic 2013
Faucet Flow Rate, Base (Gal/Min) (gpm)	2.20	2.20	2.20	1.20	1.20	1.30	1.30	1.30	1.30	2.20	2.20	2.20	2.40	2.40	2.20
Faucet Flow Rate, Low-Flow (Gal/Min) (gpm)	1.50	1.50	1.50	0.94	0.94	1.00	1.00	1.00	1.00	1.50	1.50	1.50	1.50	1.00	1.50
Days of Faucet Use (Days/Year)	365	365	365	365.25	365.25	365	365	365	365	365	365	365	365	365	365
Faucets per Home (faucets/Home) (n_a)	5.10	3.00	3.00	3.83	2.50	1.03	2.42	1.03	2.42	1.00	2.96	3.80	n/a	n/a	3.50
Average People per Home (Person/Home)	n/a	n/a	n/a	2.56	2.10	2.80	2.80	2.30	2.30	2.34	2.34	2.60	n/a	n/a	2.56
Pct. of Water Used as Flowing Water as Opposed to Filling the Sink (%)	n/a	n/a	n/a	0.80	0.80	0.50	0.70	0.50	0.70	n/a	n/a	0.80	0.63	0.63	0.50
Minutes of Faucet Use per Day per Person (Min/day/Person)	n/a	n/a	n/a	9.85	9.85	5.45	2.93	5.45	2.93	4.51	1.65	6.10	3.00	2.00	4.95
Water Savings per Year per Faucet (Gal/Year/Faucet)	1,239	256	332	497	625	836	391	686	321	2,696	333	848	621	644	1,620
Energy Savings per Gallon (kWh/Gal)	0.06	0.07	0.07	0.09	0.09	0.09	0.09	0.09	0.09	0.11	0.09	0.08	0.06	0.06	0.01
Energy Savings per Faucet per Year (kWh)	79.38	17.26	22.42	44.45	55.87	71.15	33.26	58.45	27.32	283.39	29.22	69.27	37.45	38.84	12.11
Hours of Faucet Use per Year per Faucet (Hours/Year/Faucet)	n/a	n/a	n/a	40.10	50.50	90.10	20.70	74.20	17.10	64.20	7.90	25.40	n/a	n/a	22.00

*Shaded cells indicate a calculated value.

While the PSD-specific equation is:[46]

$$AKWH = \frac{\sqrt{n} * (T_{Faucet} - T_{Supply}) * d_W * SH_W * S_W / 10^6\ {}^{Btu}/_{MMBtu}}{.003412\ {}^{MMBtu}/_{kWh} *\ EF_E}$$

With S_W representing:Thus,

$$S_W = n_e * d_e * 365 * r_g * (gpm_{federal\ std} - gpm_{WaterSense})/n_a$$

-the normalized equation for faucet aerator savings became:

$$kWh_{FA} = \frac{(Flow_{Base} - Flow_{EE}) * Time_{Fauc} * Days_{Year} * R_g * \%Flow}{Fauc_{House}} * Savings_{Gal}$$

Where:

$Flow_{Base}$ = The flow rate in gallons per minute of the base faucet (GPM)

$Flow_{EE}$ = The flow rate in gallons per minute of the faucet aerator (GPM)

The PSD outlined flow rates of 2.2 gallons per minute and 1.5 gallons per minute—values also used in several sources identified for comparison.

$Time_{Fauc}$ = Average household faucet usage (Min)

The 2013 PSD indicated average household faucet usage of 26.5 minutes per day, a value comparable to other sources reviewed.

$Days_{Year}$ = The number of days per year that faucets are used (Days)

The number of days per year were assumed to be 365 for this calculation.

R_g= Ratio to adjust usage for a cooler climate

The case study PSD used to estimate water usage indicated a difference in water usage for northern sites than for southern sites. A 0.9344 value was used to adjust water usage for Connecticut.

$\%Flow$ = Percentage of water flowing down a drain (if water is collected in a sink, a faucet aerator will not result in saved water) (%)

Several resources reviewed used a de-rating factor to account for water usage not affected by installation of a faucet aerator. This usage occurs when the end user seeks a certain volume of water rather than use of flowing water. Such users are not necessarily concerned with time, but rather with an amount of water; so the aerator does not affect water consumption, only the time required to produce

46 The equation for calculating gas savings (ACCF) differs only in use of the constant 0.102900 MMBtu/CCF in place of the constant 0.003412 MMBtu/kWh. Values specific to EF will also be fuel-specific.

a given water quantity. The Evaluation Team agrees with this concept, and accepts the 79.5% value used by Pennsylvania and Illinois, pending further research to refine this estimate.

$Fauc_{House}$ = The number of faucets per house (Faucets)

The average number of faucets per home, including kitchens and bathrooms, was determined to be 5.1 faucets.

$Savings_{Gal}$ = The energy savings in kWh per gallon of water flow reduced (kWh/Gal)

The Evaluation Team arrived at 0.06206 kWh per gallon using the following equation:

$$8.3\frac{lb}{gal} * \frac{(Temp_{Fauc} - Temp_{Entrance})}{WH_{Eff} * 1000000 * 0.003412\, kWh/MMBtu} = 0.06206\ \mathrm{kWh/Gal}$$

Where:

$Temp_{Fauc}$ = The temperature of water at the exit of the faucet (°F)

$Temp_{Entrance}$ = The temperature of water entering the home (°F)

Values of 80 and 55, respectively, were chosen, as outlined in the PSD and offering the most predominantly used values. Furthermore, these values provided a more conservative estimate of water savings, compared to the other sources with higher faucet temperatures or lower entering temperatures.

WH_{Eff} = The recovery efficiency of the electric water heater (%)

The efficiency used in the PSD equals the water heater's energy factor. The energy factor represents the efficiency of heating and storing water; however, the energy savings calculation for low-flow aerators should not consider water heater standby losses. Consequently, the Evaluation Team recommends using 98% as the value for water heater efficiency. The recovery efficiency for fossil fuel water heaters was evaluated as 67%.

The overall equation became:

$$Energy\ Savings\ =* \frac{(2.2 - 1.5) * 26.5 * 0.9344 * 365 * 0.65}{5.1} * 0.06206 = 61.2\, kWh$$

Showerheads

The engineering review for showerheads began with a review of published reports and TRMs deemed relevant to the evaluation due to their regional similarities, low-income specific recommendations, or separate inputs for multifamily savings. A total of seven sources were identified. Table 93~~Table 90~~ shows the per-measure energy savings estimates. Due to variability in per-unit savings, the Evaluation Team performed a more in-depth analysis of the savings algorithms and their inputs.

Table 93~~92~~. Results of the Showerhead Literature Review

Source	Additional Information	Annual Energy Savings per Faucet (kWh)
Connecticut Program Savings Document, Eight Edition, 2013	2013 PSD	155.40
Connecticut Program Savings Document, 2011	2011 PSD (HES)	493.30
	2011 PSD (HES-IE)	832.50
Illinois Statewide Technical Reference Manual, Version 2.0, 2013	Illinois (SF)	272.90
	Illinois (MF)	308.30
Massachusetts Home Energy Services Impact Evaluation	MA (HES)	328.60
Massachusetts Low Income Single Family Program Impact Evaluation, 2012	MA (LI)	260.60
Efficiency Maine Residential Technical Reference Manual, Version 2014.1, 2013	Maine (LI)*	150.00
Pennsylvania PUC Technical Reference Manual, 2014	PA 2014 (SF)	310.90
	PA 2014 (MF)	271.00
Indiana Technical Resource Manual, Version 1.0, 2013	Indiana	427.80
Mid-Atlantic Technical Reference Manual, Version 3.0, 2013	Mid-Atlantic 2013	168.80

*Specific to low-income electric heat multifamily program.

Table 94~~Table 91~~ presents the various inputs for each savings value with published inputs and algorithms. This research revealed many different approaches used to determine energy savings values. As a result, the Evaluation Team chose to normalize savings values for studies providing sufficient published data. All seven sources provided enough detail to inform the normalized savings calculation. Table 95~~Table 92~~ shows the normalization results.

Table 94~~93~~. Summary of Showerhead Assumptions and Values*

Inputs Description	2013 PSD	2011 PSD (HES)	2011 PSD (HES-IE)	Illinois (SF)	Illinois (MF)	MA (HES)	MA (LI)	Maine (LI)	PA 2014 (SF)	PA 2014 (MF)	Indiana	Mid-Atlantic 2013
Density of Water (d_W)	8.31	8.30	8.30	8.33	8.33	8.31	8.31	8.33	8.33	8.33	8.33	8.33
Energy Factor - Electric Water Heater (EF_E)	0.95	0.90	0.90									
GPM Base (Gal/min) (gpm)	2.50	2.50	2.50	2.67	2.67	2.05	2.05	2.50	2.50	2.50	2.80	2.50
GPM Low (Gal/min) (gpm)	2.00	2.00	2.00	2.00	2.00	1.61	1.61	2.00	1.50	1.50	2.00	2.00
Average Total Number Showerheads per Household (n_a)	2.30	2.00	1.10	1.80	1.30	1.00	1.00	1.70	1.70	1.30		1.60
Average Number of Shower Events per Day per Household (n_e)	1.97			1.92	1.58	2.03	1.61	1.43	1.62	1.08	1.43	2.56
Annual Water Savings per Showerhead (Gal) (S_W)	1,212.30	3,650.00	6,160.00									
Temp. of Water from Shower (˚F) (T_{shower})	105.00	105.00	105.00	105.00	105.00	105.00	105.00	101.00	101.00	101.00	105.00	105.00
Temp. of Water into House (˚F) (T_{supply})	55.00	55.00	55.00	54.10	54.10	56.00	56.00	50.80	55.00	55.00	55.70	55.00
Days/Year	365.00	365.00	365.00	365.25	365.25	365.00	365.00	365.00	365.00	365.00	365.00	365.00
RE of Electric Water Heater (%)				0.98	0.98	0.97	0.97	0.98	0.98	0.98	0.98	0.98
Electric Energy per Gallon of Water (kW/Gal)	0.13	0.14	0.14	0.13	0.13	0.12	0.12	0.13	0.12	0.12	0.12	0.13
Showers per Person per Day				0.75	0.75	0.70	0.70	0.61	0.60	0.60	0.58	1.00
Number of People per Home				2.56	2.10	2.90	2.30	2.34	2.70	1.80	2.46	2.56
Average Length of Shower (Minutes)				8.20	8.20	8.20	8.20	7.83	7.80	7.80	8.36	4.64
Average Gallons per Shower (Gal)												11.60
Usage per Household per Day (Minutes)		40.00	35.00									
Annual Household Water Consumption (Gal)	14,920	36,500	32,303	15,354	12,595	12,455	9,878	10,199	11,530	7,687	12,190	10,839
Annual Water Savings per Showerhead (Gal)	1,212	3,650	6,160	2,152	2,431	2,673	2,120	1,200	2,713	2,365	3,483	1,355

*Shaded cells represent a calculated value.

Table 9594. Normalized Assumptions for Showerhead Energy Savings Calculations

Inputs Description	2013 PSD	2011 PSD (HES)	2011 PSD (HES-IE)	Illinois (SF)	Illinois (MF)	MA (HES)	MA (LI)	Maine (LI)	PA 2014 (SF)	PA 2014 (MF)	Indiana	Mid-Atlantic 2013
Showerhead Flow Rate, Base (Gal/Min) (gpm)	2.50	2.50	2.50	2.67	2.67	2.05	2.05	2.50	2.50	2.50	2.80	2.50
Showerhead Flow Rate, Low-Flow (Gal/Min) (gpm)	2.00	2.00	2.00	2.00	2.00	1.61	1.61	2.00	1.50	1.50	2.00	2.00
Days of Shower Use (Days/Year)	365	365	365	365.25	365.25	365	365	365	365	365	365	365
Showerheads per Home (Showers/Home) (n_a)	2.30	2.00	1.10	1.79	1.30	1.00	1.00	1.70	1.70	1.30		1.60
Average People per Home (Person/Home)				2.56	2.10	2.90	2.30	2.30	2.70	1.80	2.46	2.56
Minutes of Shower Use per Day per Person (Min/day/Person)				8.20	8.20	8.20	8.20	7.80	7.80	7.80	8.40	4.60
Average Showers / Person / Day				0.75	0.75	0.70	0.70	0.61	0.60	0.60	0.58	1.00
Temp. from the Shower (T_{shower})	105	105	105	105	105	105	105	101	101	101	105	105
Temp. of Water in the Sewer Mains (T_{supply})	55.00	55.00	55.00	54.10	54.10	56.00	56.00	50.80	55.00	55.00	55.70	55.00
Water Heater Recovery Efficiency				0.98	0.98	0.97	0.97	0.98	0.98	0.98	0.98	0.98
Water Savings per Year per Shower (Gal/Year/Shower)	1,212	3,650	6,160	2,152	2,431	2,673	2,120	1,200	2,713	2,365	3,483	1,355
Energy Savings per Gallon (kWh/Gal)	0.13	0.14	0.14	0.13	0.13	0.12	0.12	0.13	0.12	0.12	0.12	0.13
Energy Savings per Shower per Year (kWh)	155.40	493.30	832.50	272.90	308.30	328.60	260.60	150.00	310.90	271.00	427.80	168.80

*Shaded cells represent a calculated value.

While the PSD-specific equation is:[47]

$$AKWH = \frac{\sqrt{n} * (T_{Shower} - T_{Supply}) * d_W * SH_W * S_W / 10^6 \,{}^{Btu}/_{MMBtu}}{.003412 \,{}^{MMBtu}/_{kWh} * EF_E}$$

With S_W representing:~~Thus,~~

$$S_W = n_e * d_e * 365 * r_g * (gpm_{federal\ std} - gpm_{WaterSense})/n_a$$

~~The~~ the normalized equation for showerhead savings became:

$$kWh_{Shower} = \frac{(Flow_{Base} - Flow_{EE}) * Time_{Shower} * R_g * \#Showers * Days_{Year}}{Shower_{House}} * Savings_{Gal}$$

Where:

$Flow_{Base}$ = The flow rate in gallons per minute of the base showerhead (GPM)

$Flow_{EE}$ = The flow rate in gallons per minute of the low-flow showerhead (GPM)

The study selected flow rates of 2.5 and 2.0, used by PSD and the most common rates across all savings sources. These flow rates provided savings of 0.5 gallons-per-minute, a slightly conservative figured compared to sources used for benchmarking, but in line with EPA WaterSense guidelines.

$Time_{Shower}$ = The amount of time in minutes that a person uses a home shower (Min)

The per-person shower usage time varied from 4.6 to 8.4 minutes per day. The majority of these values fell within a range of 7.8 to 8.4 minutes, with 4.6 minutes as a distinct outlier. The Evaluation Team found the PSD's estimate of 8.3 minutes per shower reasonable and used this value to evaluate savings.

$Days_{Year}$ = The number of days per year that showers are used (Days)

For this calculation, 365 days were assumed per year.

R_g= Ratio to adjust usage for a cooler climate

The case study the PSD used to estimate water usage showed a difference in water usage for northern sites compared to southern sites. A value of 0.9344 was used to adjust water usage for Connecticut.

$\#Showers$ = The number of showers taken each day

The Evaluation Team used the PSD value of 1.97 for this input, a reasonable value based on the average number of people in a Connecticut home (2.61) and the typical number of showers per person, per day, indicated from the other sources.

[47] The equation for calculating gas savings (ACCF) differs only in use of the constant 0.1029 MMBtu/CCF in place of the constant 0.003412 MMBtu/kWh. Values specific to EF will also be fuel-specific.

$Shower_{House}$ = The number of showers per house (Showers)

The Evaluation Team used the PSD value of 2.3.

$Savings_{Gal}$ = The energy savings in kWh per gallon of water flow reduced (kWh/Gal)

The Evaluation Team arrived at 0.1245 kWh per gallon using the following equation:

$$8.3\,\frac{lb}{gal} * \frac{(Temp_{Fauc} - Temp_{Entrance})}{WH_{Eff} * 1{,}000{,}000 * 0.003412\; kWh/MMBtu} = 0.1245 \text{ kWh/Gal}$$

Where:

$Temp_{Fauc}$ = The temperature of water at the exit of the shower (°F)

$Temp_{Entrance}$ = The temperature of water entering the home (°F)

Values of 105 and 55, respectively, were chosen as the most predominantly used values. Furthermore, these values provided a more conservative estimate of water savings compared to other sources with higher shower temperatures or lower entering temperatures.

WH_{Eff} = The recovery efficiency of the electric water heater (%)

Presently, the efficiency used in the PSD equals the water heater's energy factor. The energy factor represents the efficiency of heating and storing water; however, the energy savings calculation for low-flow aerators should not consider water heater standby losses. Consequently, the Evaluation Team recommends using 98% as the value for water heater efficiency. The recovery efficiency for fossil fuel water heaters was evaluated as 67%.

The overall equation then became:

$$Energy\ Savings \ = * \frac{(2.5 - 2.0) * 8.3 * 1.97 * 365 * 0.9344}{2.3} * 0.1245 = 150.7\ kWh$$

Though the evaluated savings of 150.7 kWh per showerhead is on the same order of magnitude as the 2013 PSD deemed value of 155.4 kWh, the Evaluation Team recommends adopting the approach outlined in this report.

Ductless Heat Pumps

The Evaluation Team estimated impacts for ductless heat pumps through billing analyses, calculating 1,331 kWh for HES and 803 kWh for HES-IE and resulting in realization rates of 46.1% and 46.4%, respectively.

To provide context around these results, a review was performed of recently published reports and TRMs. The review identified some trends in savings calculations from recent studies, though it also identified studies citing lower estimates, which align more with the billing analysis results from this study. Table 96~~Table 93~~ shows the per-measure energy savings estimates.

Table 96~~95~~. Results of the Ductless Heat Pump Literature Review

Source	Electric Replacement (kWh)	Fossil Fuel Replacement (kWh)	Take-back Reduction (kWh)	Average Replacement (kWh)
Connecticut Program Savings Document, 2013	3,091	438		2,050
Connecticut Program Savings Document, 2011	3,091	438		2,050
Massachusetts Home Energy Services Impact Evaluation		535		535
Regional Technical Forum	2,926			2,926
NEEA Report	3,120		1,014	2,106
BPA – Ductless Heat Pump Retrofits Study – unit savings, average of two MF complexes	1,368		544	824
KEMA Ductless Mini Pilot Study	2,329 to 2,764			

The KEMA evaluation of a ductless mini-split pilot study in Connecticut identified approximately 2,500 kWh in average savings, reflecting about a 30% reduction in heating usage. The PSD algorithm was based on savings factors from this pilot study, though it also authorized custom analyses based on simulation modeling or billing analysis (capping total savings at 50% of heating usage). The KEMA study and a recent NEEA evaluation by Ecotope (of ductless heat pump installations in the northwest) each estimated impacts using billing and metering analyses, finding savings estimates between 2,100 kWh and 2,700 kWh.

Another recent Ecotope evaluation for BPA estimated impacts of ductless heat pumps in multifamily buildings between 700 kWh and 900 kWh per unit. This study identified take-back occurring for participants through an increase in average temperature settings during the heating season, ranging from 418 kWh to 800 kWh. Take-back or rebound effects typically refer to behavioral responses to the installation of new energy-efficiency technologies, which may result in lower expected savings due to increased participant usage. For example, installation of a new energy-efficient heating system may prompt a participant to increase temperature settings, anticipating increases in cost-savings for operating an efficient unit. Ecotope also cites larger take-backs of this magnitude for these multifamily buildings than for those observed in previous single-family building studies.

Specific to CT HES-IE, a higher frequency of ductless heat pump installations occurred in multifamily (24%) versus single-family participants (<1%) in this study's billing analysis sample. The study's estimated savings for HES-IE (804 kWh), weighted more heavily to reflect multifamily building installations, remained the most consistent with findings from the BPA/Ecotope study. Despite climate differences between CT and the Northwest, this similarity may reflect multifamily occupant consumption and relate to take-back effects.

Based on an assessment of reported *ex ante* savings of ductless heat pumps from Volume 1 of this report, the Evaluation Team identified claimed savings that represented a high percentage of pre-period usage for the HES-IE analysis sample (approximately 15% of PRENAC for single-family participants and 29% for multifamily).[48]

Given the variability in recent studies, future evaluation research should focus on refining savings assessments to account for specific baselines and building types, in addition to assessing take-back levels. This research should provide the precision of savings estimates to allow comparison of results across evaluation studies.

~~Refrigerators and Freezers~~

~~Evaluation of the PY2011 refrigerator and freezer replacement measures could not be conducted using program data due to limited utility tracking data information regarding replaced units. The 2013 PSD outlined a savings methodology based on knowing specific information about existing and replacement units, including rated consumption, size, and orientation. Based on the lack of information, the Evaluation Team reviewed published reports and TRMs deemed relevant to the program. Six sources were identified for the refrigerator replacement measure, and five sources were identified for the freezer replacement measure. Table 94 shows the per-measure energy savings estimates. Due to variability in per-unit savings, the Evaluation Team performed a more in-depth analysis of the savings algorithms and their inputs.~~

~~Table 96. Results of the Refrigerator and Freezer Literature Review~~

~~Source~~	~~Refrigerator Savings (kWh)~~	~~Freezer Savings (kWh)~~
~~Connecticut Program Savings Document, Eight Edition, 2013~~	~~Varies~~	~~Varies~~
~~Connecticut Program Savings Document, 2011~~	~~247~~	~~112~~
~~Illinois Statewide Technical Reference Manual, Version 2.0, 2013*~~	~~806~~	~~1,097~~
~~Massachusetts Home Energy Services Impact Evaluation~~	~~762~~	~~238~~
~~Pennsylvania PUC Technical Reference Manual, 2014~~	~~586~~	~~714~~
~~Indiana Technical Resource Manual, Version 1.0, 2013~~	~~1,251~~	~~942~~
~~Mid-Atlantic Technical Reference Manual, Version 3.0, 2013~~	~~678~~	~~N/A~~

~~*These values are for a recycling program and not a replacement program, but provide a reference point for the unit energy consumption of a replaced unit.~~

~~Of the six sources identified for the refrigerator measure, only five were for measures with retired units actively replaced by newer, more efficient units, as set forth in the PSD. The sixth source, the Illinois TRM, included a refrigerator recycling program. Though these data were not directly comparable to the~~

48 Averaged *ex ante* savings for ductless heat pumps also represent a high percentage of savings for HES savings of 25% of PRENAC for single-family participants; none were installed for multifamily participants).

measure in question, the retired unit energy consumption proved helpful in identifying an input for use in the Connecticut evaluation.

Similarly to the refrigerator measure, only three of five sources identified for the freezer replacement measure had measures that included replacing the retired unit with a newer, more efficient unit. Other data collected from these sources included retired unit energy consumption, which proved helpful in evaluating missing inputs for the Connecticut evaluation. Table 95 and Table 96 show inputs used to evaluate these measures.

Table 97. Refrigerator Inputs

Input	2013 PSD	2011 PSD	Illinois	MA	PA 2014	Indiana	Mid-Atlantic 2013
UEC Replaced Unit (kWh)	-	-	806	1,180	1,018	1,696	1,146
UEC New Unit (kWh)	-	-	-	418	431	445	468
Site-Lab Factor (%)	0.88	0.88	-	-	-	-	-
Claimed Savings (kWh)	-	247	806	762	586	1,251	678

Table 98. Freezer Inputs

Input	2013 PSD	2011 PSD	Illinois	MA	PA 2014	Indiana
UEC Replaced Unit (kWh)	-	-	1,097	696	1,065	942
UEC New Unit (kWh)	-	-	-	458	351	-
Claimed Savings (kWh)	-	112	1,097	238	714	942

The PSD outlined the following equation for each of these measures:

$$kWh_{Refrgerator} = E_{replaced} - SLF * E_{installed}$$

$$kWh_{Freezer} = E_{replaced} - E_{installed}$$

Where:

$E_{replaced}$ = The rated energy consumption of the replaced unit

These data the replaced wereas not available provided for the majority (99%) of units. in the tracking data (nearly 99% of the reported measures lacked this information). As a result, the Evaluation Team used the benchmarked sources to estimate unit energy consumption of the replaced units. Energy consumption for replaced refrigerators was 1,180 kWh and consumption for replaced freezers was 696 kWh.

$E_{installed}$ = The rated energy consumption of the replacement unit

The program data effectively tracked data for the replacement new units. Equipment model numbers were matched against the ENERGY STAR database to determine the rated energy consumption for each unit. The average energy consumption of the installed units was determined as 462.7 kWh for refrigerators and 567.0 kWh for freezers.

SLF = An adjustment factor to account for differences in unit operations between the laboratory test setting and the actual in-home setting

This site-lab factor proved unique to the Connecticut PSD and was not found in any benchmarking sources. However, the same interaction was found in two separate metering studies: one performed in 2004 and another performed in 2009. These studies found the actual energy consumption of ENERGY STAR refrigerators was 88.1% of the rated energy consumption on the label. Overall energy savings equations then became:

$$kWh_{Refrigerator} = 1180.0 - 0.881 * 461.8 = 773.1kWh$$

$$kWh_{Freezer} = 696.0 - 452.0 = 244.0kWh$$

Appendix C. Simulation Modeling Details

Simulation modeling consisted of the following tasks:

- Analyzing participant data for each heating fuel, building, and program type;
- Disaggregating billing data into end uses;
- Calibrating the model using participant data to inform building characteristics; and
- Determining measure-level savings by running DOE-2 models, calibrated to baseline consumption values.

Analysis of Participant Data

Billing data were used to determine energy use for annual heating, cooling, and base loads for each house type, fuel, and program through a variable degree day analysis. The analysis determined average monthly consumption for each fuel and annual consumption for heating, cooling, and base loads. For this analysis, base loads refer to all non-heating and cooling end uses. The analysis did not provide monthly consumption by end use.

As only total monthly consumption values were available for natural gas and electricity but not for end use, annual end-use data were distributed to each month when an informed value of monthly consumption could be calculated.

To determine monthly heating consumption, the annual heating consumption value developed through variable degree day analysis was applied to each month, based on the proportion of HDDs for each month. For gas-heated homes, the remaining monthly natural gas consumption was assigned to water heating and gas appliances.

The Evaluation Team weather-normalized the raw monthly billing data for each account using a customer-specific methodology, comparable to the Princeton Scorekeeping Method (PRISM). This methodology conformed to the approach described in *Chapter 8: Whole-Building Retrofit with Consumption Data Analysis Evaluation Protocol* of *The Uniform Methods Project.*[49] These models provided monthly weather-normalized usage for each account.

For each participant home, the Evaluation Team estimated a heating and cooling model to weather-normalize raw electric billing data, with a fixed heating reference temperature of 65 °F and a fixed cooling reference temperature of 65 °F for the fixed 65-degree method. The study also estimated variable degree day PRISM models allowing heating and cooling reference temperatures to vary from 45 °F to 85 °F .

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[49] Agnew, Ken and M. Goldberg. *Uniform Methods Project: Methods for Determining Energy Efficiency Savings for Specific Measures*, Chapter 8: Whole-Building Retrofit with Consumption Data Analysis Evaluation Protocol. U.S. Department of Energy, National Renewable Energy Laboratory. April 2013. (NREL/SR-7A30-53827) Available online: http://www1.eere.energy.gov/office_eere/de_ump_protocols.html.

The model used the following specification:

$$ADC_{it} = \alpha_i + \beta_1 AVGHDD_{it} + \beta_2 AVGCDD_{it} + \varepsilon_{it}$$

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

ADC_{it}	=	the average daily kWh consumption in the program period
α_i	=	the participant intercept; represents the average daily kWh base load
β_1	=	the model space heating slope
β_2	=	the model cooling slope
$AVGHDD_{it}$	=	the 65 °F reference temperature average daily HDDs for the specific location for the fixed reference models, or the best heating reference temperature in the 45 °F to 85 °F range for the variable degree day models
$AVGCDD_{it}$	=	the 65 °F reference temperature average daily CDDs for the specific location for the fixed reference models, or the best cooling reference temperature in the 45 °F to 85 °F range for the variable degree day models
ε_{it}	=	the error term

Using the model, the Evaluation Team computed monthly, weather-normalized consumption for each customer and month (t), as follows:

$$NMC_{it} = (\alpha_i * 365)/12 + \beta_1 LRHDD_{it} + \beta_2 LRCDD_{it}$$

Where for each customer 'i' and calendar month 't':

NMC_{it}	=	the normalized monthly kWh consumption in month t
α_i	=	the intercept is the average daily base load kWh for each participant from the model above
$(\alpha_i * 365)/12$	=	the monthly base load kWh usage (non-weather-sensitive)
β_1	=	the heating slope; in effect, usage per heating degree day from the model above
$LRHDD_{it}$	=	monthly base 65 long-term HDDs of a typical month year (TMY3) in the 1991–2005 series from NOAA, based on home locations[50]
$\beta_1 * LRHDD_{it}$	=	the weather-normalized monthly weather-sensitive heating usage
β_2	=	the cooling slope; in effect, usage per cooling degree day from the model above

[50] Due to the complexity of obtaining the TMY3 normal HDDs and CDDs for each of the bases from 45 °F to 85 °F, monthly usages were only estimated using the heating and cooling model parameters from the fixed base 65 PRISM models. The variable base models, however, were used to more accurately disaggregate total, weather-normalized annual consumption into three components: base load, heating load, and cooling load.

$LRCDD_{it}$ = monthly base 65 long-term CDDs of a typical month year (TMY3) in the 1991–2005 series from NOAA, based on home locations

$\beta_2 * LRCDD_{it}$ = the weather-normalized monthly weather-sensitive cooling usage

Where the heating and cooling models described above yielded negative intercepts, negative heating slopes, or negative cooling slopes, the Evaluation Team estimated additional models to separate only the cooling usage (Cooling-Only Models) or the heating usage (Heating-Only Models). From these models with correct signs on all parameters, the best model for each participant could be selected, based on the model with the highest R-square among its options.

The Evaluation Team used a similar modeling process to weather-normalize gas consumption data, using heating-only models.

The 65 degree day PRISM-like billing analysis method was performed in addition to the variable degree day analysis to provide an estimate of monthly end-use consumption. These values did not agree on an annual basis to the more refined variable degree day analysis results. The results from the 65 degree day billing analysis were used to estimate the percent of air conditioning load for each month and were then used in conjunction with annual cooling consumption, developed through the variable degree day analysis, to assign air conditioning loads for each month.

For gas heated homes, the monthly cooling load was subtracted from the total monthly electrical load to determine the baseline electric consumption. For electric heated homes, the monthly base load was determined by subtracting monthly heating and cooling consumption from the total monthly electric consumption.

Participant data were reviewed to determine building component attributes that most accurately portrayed the baseline participant building, typically consisting of: conditioned floor areas, blower door and duct leakage test results, and installed insulation values for walls and ceilings. The baseline values for wall and ceiling insulation levels were reviewed to confirm changes between program types, heating fuels, and building types. As baseline insulation levels significantly affected potential energy savings for additional installation of insulation, average pre-installation R-values were determined through component U-value calculations, weighted by installed surface areas. Appropriate pre-installation levels of R0–R0.5 for wall insulation and R4.5–R5.5 for attic insulation were determined through reviews of the program data.

Model Calibration Process

Following disaggregation of billing data into annual end uses by fuel type, the values could be applied to develop calibrated energy models through use of DOE2. The models were developed based on program data, such as conditioned floor areas, baseline insulation levels, and numbers of stories, to compare modeled energy consumption to participant billing data.

Models developed represented average participant homes or units for each program, housing type, and heating type to match pre-measure billing data. The models used for this process assumed the presence of air conditioning in all homes or units. This allowed calculation of energy savings due to reduced air conditioning loads on a program-wide basis, in case data showing the presence of air conditioning did not prove accurate in all cases.

As participant billing data were not based in a single location, multiple locations were used in the billing analysis to determine annual consumption. The multiple locations required models built in multiple weather locations to match data from the billing analysis. Two weather locations (Bridgeport and Hartford) were selected to agree with locations from the billing data.

For homes with gas heat, data showed an approximately equal participant split between locations that best represented the program participants. For electric heating, 62.5% of participants were assumed from Hartford and 37.5% from Bridgeport. The combination of housing types, heating fuels, programs, and weather locations required development of 16 separate calibrated baseline models (8 building configurations for each weather location). Table 97 provides a list of the different baseline building models developed for the analysis.

Table 97. Calibrated Baseline Models by Building Prototype

Program	Building Type	Heating Fuel	Weather Location
HES	Single Family	Electric	Hartford
HES	Single Family	Gas	Hartford
HES	Multifamily	Electric	Hartford
HES	Multifamily	Gas	Hartford
HES	Single Family	Electric	Bridgeport
HES	Single Family	Gas	Bridgeport
HES	Multifamily	Electric	Bridgeport
HES	Multifamily	Gas	Bridgeport
HES-IE	Single Family	Electric	Hartford
HES-IE	Single Family	Gas	Hartford
HES-IE	Multifamily	Electric	Hartford
HES-IE	Multifamily	Gas	Hartford
HES-IE	Single Family	Electric	Bridgeport
HES-IE	Single Family	Gas	Bridgeport
HES-IE	Multifamily	Electric	Bridgeport
HES-IE	Multifamily	Gas	Bridgeport

The calibration process consisted of developing models and updates until each model could be considered fully calibrated. Each model was calibrated to match the annual heating, cooling, and base load electric consumption within 1% of the amount provided through variable degree billing analysis for a sample of program participants. Models also were calibrated to agree with monthly electric base loads and heating consumption, within 1% of the amounts provided through billing analysis.

Each model in each climate location was individually calibrated through an iterative process, requiring manual updates for each of the 16 baseline models. Most ~~updates~~ adjustments consisted of changes to temperature setpoints, equipment efficiencies, and use schedules to align the monthly modeled consumption to the pre-installation billing data usage. Minimal changes from reported component insulation levels were made in the calibration process to avoid significant changes to baseline energy consumption when performing measure savings analysis.

Initial development of models provided insights into the amount of updates required. All models initially were developed to utilize built-in features of the modeling program, assigning U.S. Department of Energy Building America benchmark consumption loads and profiles for baseline end uses.

Upon comparing modeled electric base load consumption to billing data, the Evaluation Team found the values varied significantly, requiring updates to baseline electric loads and schedules in the calibration process. Figure 7 and Figure 8 show examples comparing end-use targets and calibrated baseline model results.

Figure 7. Comparison of Gas Heating End-Use Profile Targets to the Calibrated DOE-2 Model

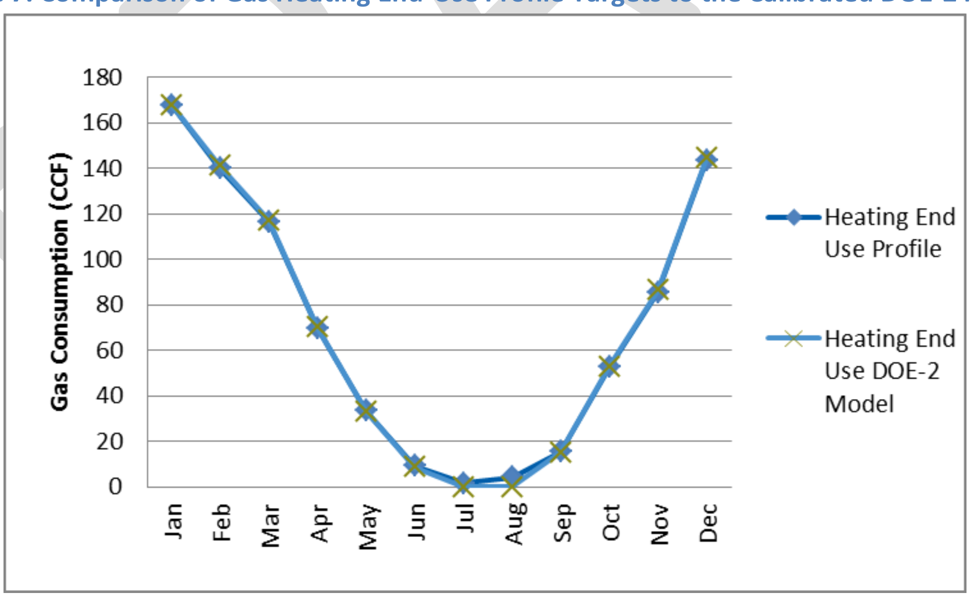
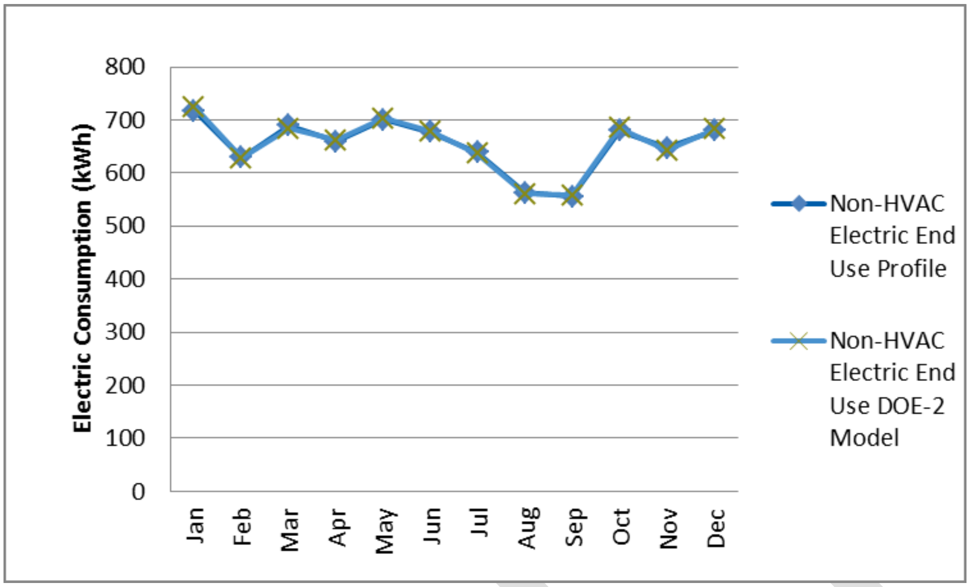


Figure 8. Comparison of Non-HVAC Electric End-Use Profile Targets to the Calibrated DOE-2 Model



Calculate Measure-Level Savings

Following model calibration, the Evaluation Team updated measure inputs in each model to represent the pre- and post-measure installation. This consisted of four steps:

1. Calculating measure-level savings through modeling.
2. Calculating the modeled percentage of savings for each measure, as compared to the measure-weighted, weather-sensitive consumption for each building, heating fuel, and program type.
3. Calculating program savings for each measure using measure-specific, weather-sensitive consumption.
4. Determining weighted savings for each measure and each fuel by program type.

For each calibrated building prototype, the Evaluation Team developed measure-specific models to calculate savings for the measures. Table 98 provides an example of all model iterations developed for a single prototype (i.e., HES single family electrically-heated homes).

Table 98. Example of Savings Models (HES Single Family Electrically-Heated Homes)

Program	Building Type	Heating Fuel	Weather Region	Measure Iteration
HES	Single Family	Electric	Hartford	Calibrated Baseline
HES	Single Family	Electric	Hartford	Duct Sealing*
HES	Single Family	Electric	Hartford	Air Sealing
HES	Single Family	Electric	Hartford	Wall Insulation
HES	Single Family	Electric	Hartford	Attic Insulation

HES	Single Family	Electric	Bridgeport	Calibrated Baseline
HES	Single Family	Electric	Bridgeport	Duct Sealing*
HES	Single Family	Electric	Bridgeport	Air Sealing
HES	Single Family	Electric	Bridgeport	Wall Insulation
HES	Single Family	Electric	Bridgeport	Attic Insulation

*For duct sealing, separate models were developed for attic and basement duct location.

Program data were used to determine post-installation insulation, blower door, and duct leakage values, and then were applied to the calibrated models. Although for many installations, only a portion of each surface area was treated, each model was developed assuming the entire surface area received treatment. Calculating the difference in consumption between baseline and improved models determined the savings for each measure.

Electric savings values were compared to pre-installation, weather-sensitive electric consumption to determine the percent of savings for each measure in each building, heating fuel, and program type. Gas savings values were compared to pre-installation, weather-sensitive gas consumption to determine the percent of savings for each measure in each building, heating fuel, and program type. The pre-installation, weather-sensitive consumption used to determine percent savings for each measure was weighted by building heating fuel and program type, and did not depend on the measure.

To calculate program savings per measure, the Evaluation Team applied the percent savings of the weather-sensitive load, as determined through use of calibrated models to the weather-sensitive load for each building, heating fuel, and program type. In these calculations, pre-installation, weather-sensitive consumption was specific to households where the measure was installed and sufficient billing data were available, compared to weighted values used to calculate the percent savings value. These savings were then weighted, based on the sample of households with sufficient billing data to determine measure savings for the HES and HES-IE programs.

Appendix D. Billing Analysis Model Attrition for HES-IE SP1 and SP4

Table 99. Participant Attrition: Electric Analysis (HES-IE SP1)

Screen	Participants Remaining	Percent Remaining	Number Dropped	Percent Dropped
Original electric accounts	2,135	100%	0	0%
Matched to billing data provided	2,080	97%	55	3%
Insufficient pre- and post-period months	1,734	81%	346	16%
Changed usage from the pre to post (> 70%)	1,714	80%	20	1%
Ex ante savings higher than pre-usage, or *ex ante* savings <1% of pre-usage	1,676	79%	38	2%
Pre- or post-period usage less than 1000 kWh	1,672	78%	4	0%
PRISM screen: wrong signs on PRISM parameters	1,662	78%	10	0%
Account-level inspection of pre/post 12-month usage (e.g., vacancies, anomalies)	1,348	63%	314	15%
Final analysis group	**1,348**	**63%**	**787**	**37%**

Table 100. Comparison Group Attrition: Electric Analysis (HES-IE SP1)

Screen	Participants Remaining	Percent Remaining	Number Dropped	Percent Dropped
Original electric accounts	317	100%	0	0%
Matched to billing data provided	294	93%	23	7%
Insufficient pre- and post-period months	209	66%	85	27%
Changed usage from the pre to post (> 70%)	204	64%	5	2%
Pre- or post-period usage less than 1000 kWh or more than maximum participant usage	203	64%	1	0%
PRISM screen: wrong signs on PRISM parameters	197	62%	6	2%
Account-level inspection of pre/post 12-month usage (e.g., vacancies, anomalies)	197	62%	0	0%
Final Analysis Group	**197**	**62%**	**120**	**38%**

Table 101. Participant Attrition: Gas Analysis (HES-IE SP1)

Screen	Participants Remaining	Percent Remaining	Number Dropped	Percent Dropped
Original gas accounts	358	100%	0	0%
Matched to billing data provided	289	81%	69	19%
Insufficient pre- and post-period months	254	71%	35	10%
Changed usage from the pre to post (> 70%)	253	71%	1	0%
Ex ante savings higher than pre-usage, or *ex ante* savings <1% of pre-usage	248	69%	5	1%
Pre- or post-period usage less than 200 therms	240	67%	8	2%
PRISM screen: wrong signs on PRISM parameters	240	67%	0	0%
Account-level inspection of pre/post 12-month usage (e.g., vacancies, anomalies)	232	65%	8	2%
Final Analysis Group	**232**	**65%**	**126**	**35%**

Table 102. Participant Attrition: Electric Analysis (HES-IE SP4)

Screen	Participants Remaining	Percent Remaining	Number Dropped	Percent Dropped
Original electric accounts	5,014	100%	0	0%
Matched to billing data provided	4,938	98%	76	2%
Insufficient pre- and post-period months	3,658	73%	1,280	26%
Changed usage from the pre to post (> 70%)	3,625	72%	33	1%
Ex ante savings higher than pre-usage, or *ex ante* savings <1% of pre-usage	3,445	69%	180	4%
Pre- or post-period usage less than 1000 kWh	3,422	68%	23	0%
PRISM screen: wrong signs on PRISM parameters	3,384	67%	38	1%
Account-level inspection of pre/post 12-month usage (e.g., vacancies, anomalies)	2,670	53%	714	14%
Final Analysis Group	**2,670**	**53%**	**2,344**	**47%**

Table 103. Comparison Group Attrition: Electric Analysis (HES-IE SP4)

Screen	Participants Remaining	Percent Remaining	Number Dropped	Percent Dropped
Original electric accounts	418	100%	0	0%
Matched to billing data provided	412	99%	6	1%
Insufficient pre- and post-period months	269	64%	143	34%
Changed usage from the pre to post (> 70%)	265	63%	4	1%
Pre- or post-period usage less than 1000 kWh or more than maximum participant usage	260	62%	5	1%
PRISM screen: wrong signs on PRISM parameters	256	61%	4	1%
Account-level inspection of pre/post 12-month usage (e.g., vacancies, anomalies)	256	61%	0	0%
Final Analysis Group	**256**	**61%**	**162**	**39%**

Table 104. Participant Attrition: Gas Analysis (HES-IE SP4)

Screen	Participants Remaining	Percent Remaining	Number Dropped	Percent Dropped
Original gas accounts	266	100%	0	0%
Matched to billing data provided	215	81%	51	19%
Insufficient pre- and post-period months	156	59%	59	22%
Changed usage from the pre to post (> 70%)	156	59%	0	0%
Ex ante savings higher than pre-usage, or *ex ante* savings <1% of pre-usage	147	55%	9	3%
Pre; or post-period usage less than 200 therms	145	55%	2	1%
PRISM screen: wrong signs on PRISM parameters	145	55%	0	0%
Account-level inspection of pre/post 12-month usage (e.g., vacancies, anomalies)	114	43%	31	12%
Final Analysis Group	**114**	**43%**	**152**	**57%**

Appendix E. Billing Analysis Model Outputs for HES-IE SP1 & SP4

HES-IE Subprogram Electric Models

Table 105. Overall HES-IE SP1 Electric Savings Model Output After Screening (n=1,348 participants; n=197 nonparticipants)

Group	Variable	Parameter Estimate	Standard Error	Z-Score	p-Value
Participant	AvgHDD	0.3489	0.0183	19.05	<.0001
	AvgCDD	1.2102	0.0369	32.82	<.0001
	Other Program * HDD	0.1565	0.1274	1.23	0.2193
	HER *HDD	0.7026	0.1593	4.41	<.0001
	Other Program *CDD	-0.3204	0.2618	-1.22	0.2211
	HER * CDD	1.1216	0.3008	3.73	0.0002
	Post	-1.3003	0.1583	-8.21	<.0001
	Post*HDD	-0.0476	0.0085	-5.6	<.0001
	Post*CDD	-0.027	0.0243	-1.11	0.2659
	HER * Post	-0.4009	0.9844	-0.41	0.6839
	Other Program * Post	-9.499	5.2006	-1.83	0.0678
Comparison	AvgHDD	0.3909	0.0483	8.09	<.0001
	AvgCDD	1.2219	0.0951	12.85	<.0001
	Other Program * HDD	-0.3019	0.057	-5.29	<.0001
	HER *HDD	0.9481	0.0479	19.8	<.0001
	Other Program *CDD	-0.2041	0.2586	-0.79	0.4299
	HER * CDD	1.6066	0.0934	17.21	<.0001
	Post	-0.1223	0.4639	-0.26	0.792
	Post*HDD	0.0457	0.0193	2.37	0.0177
	Post*CDD	0.1703	0.0722	2.36	0.0183
	HER * Post	-1.9488	0.3352	-5.81	<.0001
	Other Program * Post	-5.601	1.8904	-2.96	0.003

Table 106.Overall HES-IE SP4 Electric Savings Model Output After Screening (n=2,670 participant; n=256 nonparticipant)

Group	Variable	Parameter Estimate	Standard Error	Z-Score	p-Value
Participant	AvgHDD	0.2082	0.0075	27.93	<.0001
	AvgCDD	0.8216	0.0269	30.58	<.0001
	Other Program * HDD	0	0	.	.
	HER *HDD	0.5185	0.2197	2.36	0.0183
	Other Program *CDD	0	0	.	.
	HER * CDD	1.2637	0.484	2.61	0.009
	Post	-1.3963	0.1089	-12.82	<.0001
	Post*HDD	-0.0043	0.0046	-0.92	0.3589
	Post*CDD	0.1221	0.0121	10.1	<.0001
	HER * Post	-3.3507	2.9051	-1.15	0.2488
	Other Program * Post	0	0	.	.
Comparison	AvgHDD	0.3291	0.03	10.96	<.0001
	AvgCDD	0.8241	0.0486	16.94	<.0001
	Other Program * HDD	0	0	.	.
	HER *HDD	0.9318	0.3993	2.33	0.0196
	Other Program *CDD	0	0	.	.
	HER * CDD	1.0014	0.1167	8.58	<.0001
	Post	0.2847	0.24	1.19	0.2356
	Post*HDD	-0.0079	0.0136	-0.58	0.5599
	Post*CDD	0.1688	0.0402	4.2	<.0001
	HER * Post	-5.4305	1.2168	-4.46	<.0001
	Other Program * Post	0	0	.	.

HES-IE Subprogram Gas Models

Table 107. Overall HES-IE SP1 Gas Savings Model Output After Screening (n=231 participants)

Group	Variable	Parameter Estimate	Standard Error	Z-Score	p-Value
Participant	Post	0.0084	0.0115	0.73	0.4629
	Post*HDD	-0.0176	0.0015	-11.43	<.0001

Table 108. Overall HES-IE SP4 Gas Savings Model Output After Screening (n=114 participants)

Group	Variable	Parameter Estimate	Standard Error	Z-Score	p-Value
Participant	Post	-0.0182	0.0181	-1.01	0.3145
	Post*HDD	-0.006	0.0013	-4.55	<.0001

Appendix F. Detailed Distribution of Total Savings

The following tables present detailed summaries of total *ex ante* savings (base on the utility tracking system) and evaluated savings by program and measure category.

Table 109. Distribution of Total *Ex Ante* and Gross Evaluated Savings by Measure – HES Electric

Category	Measures	Reported *Ex Ante* Savings (kWh)	Gross Evaluated Savings (kWh)
Appliance	Appliance Unknown	989	989
Appliance	Clothes Washer	66,596	30,003
Appliance	Dehumidifier	66,496	5,380
Appliance	Freezer	12,686	1,184
Appliance	Refrigerator	71,332	11,448
HVAC	Central AC	154,922	127,005
HVAC	Duct Sealing	1,070,773	358,369
HVAC	Ductless Heat Pump	568,404	261,946
HVAC	Ground-Source Heat Pump	155,395	152,616
HVAC	Heat Pump	180,562	140,180
HVAC	Heating System Replacement	4,275	5,697
Lighting	Lighting	11,423,871	13,700,120
Other	Other	1,091	1,091
Shell	Air Sealing	2,232,231	3,902,406
Shell	Insulation Unknown	470,693	470,693
Shell	Attic Insulation	1,892	1,286
Shell	Wall Insulation	222	186
Shell	Windows	44,656	44,739
Water Heat	DHW Bundle	1,326,459	1,086,839
Water Heat	Heat Pump Water Heater	19,382	19,382
Program Total		**17,872,926**	**20,321,560**
Gross Program Realization Rate		**114%**	
Adjust Gross Program Realization Rate*		**111%**	

*Incorporates the nonparticipant adjustment factor of 97%.

Table 110. Distribution of Total *Ex Ante* and Gross Evaluated Savings by Measure – HES Gas

Category	Measures	Reported *Ex Ante* Savings (CCF)	Gross Evaluated Savings (CCF)
Appliance	Clothes Washer	1,225	94

HVAC	Duct Sealing	53,675	22,301
HVAC	Heating System Replacement	14,147	3,225
Shell	Air Sealing	289,669	263,851
Shell	Insulation Other	86,554	86,554
Shell	Windows	5,712	6,173
Shell	Attic Insulation	4,930	3,733
Shell	Wall Insulation	3,392	1,690
Water Heat	Water Heater Replacement	1,736	1,736
Water Heat	DHW Bundle	119,470	99,983
Other	Other	3,308	3,308
Program Total		**583,818**	**492,648**
Gross Program Realization Rate		**84%**	
Adjust Gross Program Realization Rate*		**64%**	

*Incorporates the nonparticipant adjustment factor of 76%.

Table 111. Distribution of Total *Ex Ante* and Gross Evaluated Savings by Measure – HES-IE Electric*

Category	Measures	Reported Ex Ante Savings (kWh)	Gross Evaluated Savings (kWh)
Appliance	Appliance Unknown	146,155	206,373
Appliance	Freezer	72,326	71,853
Appliance	Refrigerator	1,284,248	539,355
HVAC	Central AC	98	98
HVAC	Duct Sealing	43,351	13,406
HVAC	Ductless Heat Pump	3,956,200	1,835,668
HVAC	Heat Pump	n/a	n/a
HVAC	Window AC	21,759	10,751
Lighting	Lighting	4,729,820	6,550,510
Other	Other	27,128	27,128
Shell	Air Sealing	2,341,386	1,425,734
Shell	Insulation Unknown	355,249	355,249
Shell	Attic Insulation	244,451	151,448
Shell	Wall Insulation	571,800	176,139
Shell	Windows	53,335	92,774
Water Heat	DHW Bundle	2,516,118	714,855
Water Heat	Water Heater Temp Setback	18,222	16,457
Water Heat	Water Heater Replacement	10,116	10,116
Program Total		**16,391,761**	**12,197,914**

Gross Program Realization Rate	**74%**
Adjust Gross Program Realization Rate**	**85%**

*Savings from measure-level analysis of HES-IE exclude SP1 and SP4
**Incorporates the nonparticipant adjustment factor of 114%.

Table 112. Distribution of Total *Ex Ante* and Gross Evaluated Savings by Measure – HES-IE Gas*

Category	Measures	Reported Ex Ante Savings (CCF)	Gross Evaluated Savings (CCF)
Appliance	Appliance Other	219	219
HVAC	Duct Sealing	18,886	3,098
HVAC	Heating System Replacement	51,189	42,787
Shell	Air Sealing	216,247	132,047
Shell	Windows	685	636
Shell	Attic Insulation	16,094	20,792
Shell	Wall Insulation	180,042	57,126
Shell	Insulation Other	80,003	80,003
Water Heat	Water Heater Temp Setback	2,560	1,580
Water Heat	Water Heater Replacement	56	56
Water Heat	DHW Bundle	174,149	124,958
Other	Other	682	682
Lighting	Lighting	3,502	3,502
Program Total		**744,314**	**467,486**
Gross Program Realization Rate		**63%**	
Adjust Gross Program Realization Rate**		**54%**	

*Savings from measure-level analysis of HES-IE exclude SP1 and SP4
**Incorporates the nonparticipant adjustment factor of 85%.