
# Final Report

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

December 31, 2014

**Connecticut Energy Efficiency Fund**

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Prepared by:
Scott Reeves
Bryan Ward
Matei Perussi
Eli Caudill
Andrew Rietz
Cadmus

Lisa Wilson-Wright
NMR Group, Inc.

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## Table of Contents

## 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*.

## Abstract

The Home Energy Services (HES) and Home Energy Services-Income Eligible (HES-IE) are major residential programs, addressing single-family, multifamily, and low-income households, and are critical to achieving the 80% Weatherization goal. The Connecticut Energy Efficiency Board (EEB) requires an impact evaluation of the HES and HES-IE programs offered by the Utilities, with critical outcomes including estimates of program impact, and factors that influence energy and demand savings. The impact evaluation was designed to provide evaluated estimates of energy and demand savings program-wide, and estimated savings associated with major measures incentivized and installed through these programs (by heating fuel type to the extent feasible) for the HES and HES-IE programs. The NMR Group and Cadmus, its subcontractor (collectively referred to as the Evaluation Team) conducted this evaluation.

The cornerstone of the analysis is a statistical billing analysis, supplemented by engineering estimates. The billing analysis used a fixed effects savings regression model to estimate household-level and measure-level saving for these programs, incorporating weather normalization, detailed measure data, and appropriate comparison groups to account for macroeconomic factors affecting the results. The engineering analysis used two engineering approaches, calibrated simulation modeling and engineering algorithms, to estimate measure-specific savings for the most common fuel types (electric, natural gas, propane, and heating oil). Both engineering approaches were informed by the same billing and program tracking data (including measure details and participant home characteristics) used in the billing analysis. While billing analysis inherently accounts for all usage changes between a period before and after measure installation (these effects can include measure interactions, energy education, behavioral/household changes, take-back, and spillover), a separate assessment was also performed to consider the specific lighting interactive effects.

***Section 1*** provides the results of a whole-house billing analysis that estimates average participant (household-level) electric and natural gas impacts. ***Section 2*** includes a measure-level impact evaluation, providing estimates of per-unit savings for measures offered through the HES and HES-IE programs, using the multi-method evaluation approach described. Methods used to assess whole-house and measure-level savings are considered industry “best practices” and both provide valuable information for Connecticut’s programs.

The report includes tables summarizing estimates of savings and realization rates for the programs, as well as for specific measures.

# Executive Summary

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.

This report provides results in different sections of this report for two separate evaluation approaches, each aimed at evaluating impacts for the program year 2011 HES and HES-IE programs:

- ***Section 1*** provides the results of a whole-house billing analysis that estimates average participant (household-level) electric and natural gas impacts.
- ***Section 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.

Both methods are considered industry “best practices” and both provide valuable information for Connecticut’s programs.

- **Whole-house billing analysis** is a statistical analysis (using fixed-effects regression models) providing household-level savings estimates, which then informs calculation of realization rates. The billing analysis uses data from participating households with sufficient billing data (prior to and after participation) to support the analysis. Statistical billing analyses are considered a best practice approach for estimating impacts associated with whole-building programs.[1] Results based on whole house billing analysis are used around the United States to provide 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 Section 1), including separate whole-house analyses of CL&P-specific HES-IE subprograms (i.e., SP1 and SP4).
- **Measure-level analysis** uses a multiple-method approach to identify the best estimates of energy savings for individual measures. The analysis uses fixed-effects 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

[1] 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)

information to refine Program Savings Documentation (PSD) savings calculations. Section 2 provides the results of the measure-level analysis for HES and HES-IE.

Table 1 presents the realization rates resulting from the different analytical approaches used in Section 1 and Section 2. Differences between section-specific realizations rates largely result from slight variations in the measure distributions between the sample of households included in the whole-house billing analysis and the program populations, as reflected in the tracking system. For HES-IE, some differences also relate to variations in the treatment of HES-IE subprograms.

Three primary factors drive the differences in realization rates for each type program (HES vs. HES-IE) and each type of savings (electric vs. gas):

1) Significant differences in energy usage in HES homes as compared to HES-IE homes (e.g., average pre-period normalized electric consumption for participants in the billing analysis sample were 11,278 kWh for HES and 7,292 kWh for HES-IE).
2) Differences in average *ex ante* savings values. *Ex ante* values are part of the realization rate equation: if they differ between HES and HES-IE, realization rates may differ for those programs, even if evaluated savings values are similar. For example, realization rates for DHW measure bundles were 82% for HES and 28% for HES-IE, calculated using evaluated savings of 395 kWh and 390 kWh, compared to *ex ante* savings of 482 kWh and 1,372 kWh, respectively.
3) Differences in the measure distributions for HES and HES-IE and for the electric and gas programs. The measure realization rates vary significantly; so, as the measure mix changes, program-level realization rates change. For example, 14% of the HES participant sample (in the whole-house analysis) received DWH measure bundles, compared to 32% of HES-IE sample.

**Table 1. Comparison of Realization Rates by Report Section***

| Program | Electric Savings | | Gas Savings | |
|---|---|---|---|---|
| | Section 1** | Section 2*** | Section 1** | Section 2*** |
| HES | 117% | 111% | 58% | 64% |
| HES-IE | 76% | 79% | 51% | 55% |

*Realization rates for oil and propane are not presented due to incomplete *ex ante* savings available in the utility tracking data and because these fuel savings are not reported in the 2013–2015 Plan.

**Section 1 realization rates for HES-IE present an average that includes model realization rates for each of the subprogram-specific analyses performed.

***Section 2 realization rates for HES-IE present an average that includes: measure-level impacts for HES-IE SP2 and SP3; and whole-house billing analysis realization rates 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, except for HES-IE SP1 and SP4, which only have whole-house billing analysis realization rates available. As discussed, billing analyses are considered an industry best practice for whole-home retrofit programs, and the whole-house billing analysis provides a robust estimate of energy savings for all measures installed, truly capturing all factors effecting savings (including measure interaction, energy education, household/behavioral changes, take-back, spillover). Higher attrition in the gas analysis samples resulted in more uncertainty as to whether the sample is representative of the population; for this reason, the Evaluation Team suggests deferring to the measure-level realization rates. This may account for possible differences in the measure mix, if the measure distribution for the population is different. From a broader context, the whole-house approach provides the best representation of the overall energy savings and realization rates for the programs. Measure level findings should be used when considering measure-level impacts.

## 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. In 2011, these measures included: 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 can 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 participants (although landlords often are subject to co-pays). Along with these core measures, 2011 HES-IE participants achieved higher rates of insulation and heating system upgrades (e.g., ductless heat pumps) than those in the HES program.

## Section 1: Whole-House Analysis

### Methodology

A statistical billing analysis was performed using fixed-effects regression models to estimate actual changes in electric and gas consumption in homes participating in the HES and HES-IE programs for 2011. The billing analysis was based on historical billing data, covering up to a year before and after participation. This study focused on 2011 because: (1) the analysis needed a complete 12-month period of post-participation billing data; and (2) at the time of evaluation planning, billing data for a complete 2013 period were unavailable (which precluded using 2012 households for the study). Weather-normalized models were used to screen for data quality and to compare the final fixed-effects model results. Additionally, a comparison group was drawn from a sample of post-2011 program participants to control for macroeconomic factors and other exogenous effects that may have affected energy consumption during the analysis period.

The tables that follow present the analysis results as "Total Evaluated Adjusted Gross Savings." This reflects the program participants' difference in energy use (which the report refers to as "model savings"), adjusted by the difference in energy use observed for the comparison group. The adjusted gross realization rates are the ratio of adjusted gross savings, calculated through the different billing analysis models, to the average reported *ex ante* savings recorded in the program tracking system for all participants in the analysis sample. The adjusted gross realization rates (specific to utility programs and types of energy) were applied to the 2011 energy savings, reported in the 2013–2015 Electric and Natural Gas Conservation and Load Management Plan (the Plan), to obtain the overall evaluated savings for 2011.[2] [3]

Due to data limitations, it was not possible to evaluate oil and propane impacts directly using billing analysis; however, evaluated gas model impacts from the billing analysis were extrapolated to the participant population with oil/propane heating and water heating.

Demand impacts were calculated from the 2011 demand savings reported in the Plan using the adjusted gross realization rates for energy savings calculated from the billing analysis models.

## Results

Table 2 through Table 5 present the evaluated adjusted gross electric and gas energy savings for each utility's HES and HES-IE programs for 2011.[4] [5] [6]

For the HES program electric savings overall, the evaluated adjusted gross savings were slightly higher than reported savings, with an adjusted gross realization rate of 117% (see Table 2). For the HES program gas savings overall, evaluated adjusted gross savings were somewhat lower than reported savings, with an adjusted gross realization rate of 58% (see Table 3).

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[2] CL&P, UI, YGS, CNG, SCG Utilities. *2013–2015 Electric and Natural Gas Conservation and Load Management Plan*. 2012. http://energizect.com/sites/default/files/2013_2015_CLM%20PLAN_11_01_12_FINAL.pdf

[3] Realization rates for oil and propane are not presented due to incomplete *ex ante* savings available in the utility tracking data and because these fuel savings are not reported in the 2013–2015 Plan.

[4] Totals may not add up to the sum of individual values due to rounding.

[5] Realization rates for "Program Overall" are calculated by taking the difference between the sum of each utility's reported savings and the sum of each utility's evaluated adjusted gross savings totals.

[6] Note that participants may have multiple fuel savings and individual households may be represented in multiple results tables.

Table 2. Total 2011 Evaluated HES Electric Savings, by Utility and Overall Program

| Utility | Reported Participation | Reported Savings (MWh) | Evaluated Adjusted Gross Savings (MWh) | Adjusted Gross Realization Rate | Relative Precision at 90% Confidence |
|---|---|---|---|---|---|
| CL&P | 15,886 | 16,403 | 18,977 | 116% | ±4% |
| UI | 5,329 | 3,588 | 4,513 | 126% | ±8% |
| **Program Overall** | **21,215** | **19,991** | **23,489** | **117%** | **±4%** |

Table 3. Total 2011 Evaluated HES Gas Savings, by Utility and Overall Program

| Utility | Reported Participation | Reported Savings (000s CCF) | Evaluated Adjusted Savings (000s CCF) | Adjusted Gross Realization Rate | Relative Precision at 90% Confidence |
|---|---|---|---|---|---|
| CNG | 1,895 | 196 | 132 | 67% | ±17% |
| SCG | 2,369 | 243 | 110 | 45% | ±27% |
| YGS | 1,811 | 172 | 112 | 65% | ±16% |
| **Program Overall** | **6,075** | **611** | **354** | **58%** | **±12%** |

For HES-IE program electric savings overall, the evaluated adjusted gross savings were slightly lower than reported savings, with an adjusted gross realization rate of 82% (see Table 4). For the HES-IE program gas savings overall, the evaluated adjusted gross savings were somewhat lower than the reported savings, with an adjusted gross realization rate of 50% (see Table 5).

The HES-IE program for CL&P is offered through four subprograms (SPs). Separate billing analyses were performed for two SPs (SP1 and SP4) due to issues related to the way data were tracked. This report presents analysis and results for SP2/SP3, SP1, and SP4 separately, and has rolled these results up to the utility level in the following summary tables for both electric and gas savings.

Table 4. Total 2011 Evaluated HES-IE Electric Savings, by Utility and Overall Program

| Utility | Reported Participation | Reported Savings (MWh) | Evaluated Adjusted Gross Savings (MWh) | Adjusted Gross Realization Rate | Relative Precision at 90% Confidence |
|---|---|---|---|---|---|
| **CL&P Overall** | **10,685** | **19,959*** | **13,600** | **68%**** | **±7%** |
| CL&P—SP1 | n/a | 2,441 | 2,052 | 84% | ±20% |
| CL&P—SP2/SP3 | | 12,157 | 8,295 | 68% | ±6% |
| CL&P—SP4 | | 5,362 | 3,253 | 61% | ±23% |
| **UI** | **5,612** | **5,173** | **5,414** | **105%** | **±6%** |

| | | | | | |
|---|---|---|---|---|---|
| **Program Overall** | **16,297** | **25,132** | **19,014** | **76%** | **±6%** |

*These totals from the reported Plan values have been disaggregated by the percentage of total CL&P HES-IE *ex ante* savings associated with SP2/SP3 (61%), SP1 (12%), and SP4 (27%).

**The realization rates for each SP-specific analysis have been applied to these Plan totals, comparing the sum of the evaluated adjusted gross savings to the reported savings total to derive an overall realization rate for CL&P's HES-IE program.

**Table 5. Total 2011 Evaluated HES-IE Gas Savings, by Utility and Overall Program**

| Utility | Reported Participation | Reported Savings (000s CCF) | Evaluated Adjusted Gross Savings (000s CCF) | Adjusted Gross Realization Rate | Relative Precision at 90% Confidence |
|---|---|---|---|---|---|
| **CNG Overall** | **1,610** | **211** | **102** | **49%** | **±20%** |
| CNG—SP1 | n/a | 24 | 20 | 83% | ±30% |
| CNG—SP2/SP3 | | 174 | 76 | 44% | ±25% |
| CNG—SP4 | | 13 | 6 | 47% | ±61% |
| **SCG** | **3,268** | **361** | **206** | **57%** | **±23%** |
| **YGS Overall** | **1,961** | **360** | **165** | **46%** | **±25%** |
| YGS—SP1 | n/a | 18 | 9 | 51% | ±38% |
| YGS—SP2/SP3 | | 283 | 132 | 47% | ±25% |
| YGS—SP4 | | 59 | 24 | 41% | ±97% |
| **Program Overall** | **6,839** | **932** | **474** | **51%** | **±14%** |

*These totals from the reported Plan values have been disaggregated by the percentage of total CL&P HES-IE *ex ante* savings associated with SP2/SP3 (82% CNG, 79% YGS), SP1 (11% CNG, 5% YGS), and SP4 (6% CNG, 16% YGS). As gas utilities territories are composed of both CL&P and UI electric customers, and the subprogram construct is specific to CL&P HES-IE delivery, the Evaluation Team used the proportion of gas savings for CL&P and UI from the program tracking data to differentiate the portion of reported HES-IE gas savings for CNG and YGS associated with each SP.

**Realization rates for each SP-specific analysis have been applied to these Plan totals, comparing the sum of the evaluated adjusted gross savings to the reported savings total to derive an overall realization rate for CNG's and YGS's respective HES-IE programs.

## *Section 2: Measure-Level Analysis*

### 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.[7] 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 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.

This impact assessment varied slightly depending on the measure in an attempt to calculate the most accurate savings values possible, given data constraints previously discussed. 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.[8] When measures fell outside of this threshold, however, the Evaluation Team derived savings for those measures using simulation modeling or engineering analysis.[9]

In regard to the results selected for this study, there are several key issues to consider:

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7 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 reasons Section 1 discusses in greater detail. This report presents separate whole-house models for SP1 and SP4.

8 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.

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.

- Savings estimates selected from the billing analysis that met the precision threshold are all statistically significant at the 99% confidence level, meaning that the observed effects are not due to random variation. Specifically, all t-statistics calculated for these estimates are at least twice as large as the critical value of 1.645 typically used at the 90% confidence level.[10]
- Precision values calculated for the billing analysis estimates represent variation in the effect that the measure has on consumption across the population (represented through high and low bounds for these savings estimates). This is different than the precision reported due to sampling uncertainty, which represents the uncertainty in an estimate due to not observing the entire population (but only a sample of it). Commonly, sampling uncertainty is referred to in sample design, using "90/10" or other targets.
- The engineering analysis draws upon a number of assumptions and relies on input estimates with unknown levels of uncertainty and unobserved data points. As such, even though precision around the engineering estimates are not quantified in this report, it is assumed that that there ***is*** uncertainty in these estimates.
- The ability to use participant-specific data from the actual participant population, rather than assumptions as in the engineering analysis, provides the best approach to achieve robust estimates of energy savings. Presenting precision around these estimates is a positive outcome of this research (e.g., ability to account for actual changes in consumption, incorporating program effects, energy education, consumer behavior), and high precision does not necessarily indicate a poor estimate.

Table 6 and Table 7 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 6. 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 |

[10] T-statistics are required to be greater than the critical value to determine statistical significance.

| Category | Measure | HES | | |
|---|---|---|---|---|
| | | Electric | Gas | Oil/Propane |
| | 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 7. 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 | – | – |

| Category | Measure | HES-IE | | |
|---|---|---|---|---|
| | | Electric | Gas | Oil/Propane |
| 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 8 presents evaluated adjusted gross electric and gas energy savings for the 2011 HES program.

**Table 8. 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 | 22,110 | 3,774 | 382 |
| Adj. Gross Realization Rate | | 111% | 64% |

*Program-level evaluated savings and realization rates for oil and propane are not presented due to incomplete *ex ante* savings available in the utility tracking data and because these fuel savings are not reported in the 2013–2015 Plan.

The HES program produced evaluated adjusted gross savings higher than reported electric savings but lower than reported gas 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 9 and Table 10 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.[11]

**Table 9. 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 | 39 | 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.

11 For measure-specific, per-unit savings estimates (outside of a program context), realization rates included in Table 9 and Table 10 should be applied without inclusion of a nonparticipant adjustment factor. From the context of evaluating program savings for a specific year, the nonparticipant adjustment factor should be applied to understand the true program-level influence (e.g., controlling for exogenous effects).

| Category | Measure | Reported *Ex Ante* Savings (kWh/ Household) * (A) | Gross Savings (kWh/ Household) (B) | Realization Rate (B/A) | Method |
|---|---|---|---|---|---|

**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 10. 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 11 presents evaluated adjusted gross electric and gas energy savings for the 2011 HES-IE program.

### Table 11. 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 | 19,950 | 1,237 | 513 |
| Adj. Gross Realization Rate** | | 79% | 55% |

*Program-level evaluated savings and realization rates for oil and propane are not presented due to incomplete *ex ante* savings available in the utility tracking data and because these fuel savings are not reported in the 2013–2015 Plan.

**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 12 and Table 13 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 12. 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 13. 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.

As this study was being completed, an additional study was also being conducted to investigate interactive effects due to the installation of residential energy efficient lighting.[12] Because the methodology in this study utilized billing analysis to determine the savings realization rate for a few measures, these realization rates may partially reflect lighting interactive effects (e.g., the measured gas savings for a heating measure may have been penalized due to the installation of energy efficient lighting, which produces less waste heat then standard efficiency lighting), along with various other effects (including measure interaction, energy education, behavioral/household changes, take-back, spillover). *Appendix L. Lighting Interactive Effect Adjustments* provides further detail regarding measure-specific adjustments that can be applied to consider these impacts independent of lighting interaction. Table 14 presents the final adjustment factors derived through this process. Note these results are presented within this appendix (and table below) and are not reincorporated in reporting overall program savings

[12] See "R67: Residential Lighting Interactive Effects Memo", NMR Group, December 20, 2014.

Table 14. HES and HES-IE Gas Measure Lighting IE Factor Adjustments

| Program | Category | Measure | Reported *Ex ante* Savings (CCF/ HH) (A) | Evaluated Gross Savings (CCF/HH) (B) | Interactive Gas (CCF/HH) Adjustment (C) | Adjusted Gross Savings (CCF/HH) (D) | Adjusted Realization Rate (D/A) |
|---|---|---|---|---|---|---|---|
| HES | Shell | Air Sealing | 62 | 57 | 14.9 | 71.9 | 116% |
| HES-IE | HVAC | Heating System Replacement | 128 | 107 | 1.4 | 108.4 | 85% |
| HES-IE | Shell | Air Sealing | 59 | 36 | 7.6 | 43.6 | 74% |
| HES-IE | Shell | Wall Insulation | 304 | 96 | 3.3 | 99.3 | 33% |

## *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

The following recommendations address improvements to data quality and 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 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 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 export program tracking data easily*** 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*

As with the 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 6 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 2 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, provided by 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 sections:

- Section 1 provides the methodology and results of performing a whole-house billing analysis of the HES and HES-IE programs.
- Section 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 measure co-payments).

Through these audits, technicians identify opportunities that allow customers to save energy through a variety of home improvements, as shown in Table 15.

**Table 15. Overview of HES and HES-IE Measure Offerings in 2011**

| 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 |
| **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 16. 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 16. 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 is organized around the two sections mentioned above: a whole-house billing analysis assessing program-level results (Section 1); and a multi-method impact approach assessing measure-level energy savings (Section 2). Each section contains the following:

- ***Methodology***, which explains the impact-evaluation tasks, data sources, and analytical approach; and
- ***Findings***, which detail key impact results from evaluation activities for the HES and HES-IE programs, at both the program and measure levels.

Subsequent to section-specific results, Recommendations and Appendices are presented for the evaluation overall.

# Section 1: Whole-House Analysis

## Methodology

Section 1 of this report provides the detailed methodology associated with performing billing analyses to estimate program-level impacts of the 2011 HES and HES-IE programs. Using this approach, electric and gas energy savings were estimated for each program overall and for each utility. Electric demand and oil/propane impacts were also estimated based on the evaluated energy savings.

### Modeling Approach: Electric and Natural Gas Impacts

To estimate actual changes in energy consumption within participating homes, the Evaluation Team used fixed-effects regression models to perform a statistical billing analysis.[13] Using historical billing data from up to a year before and after participation, program-level impacts associated with the HES and HES-IE measure installations were analyzed to estimate electric and gas savings. Weather-normalized models were used to screen the data and to provide a comparison against the final fixed-effects model results. The analysis also included the use of a comparison group based on program participants after 2011. The comparison group is used to control for macroeconomic factors and other exogenous effects that may have affected energy consumption during the timeframe that energy usage was analyzed.

For the model specifications, see *Appendix A. Billing Analysis Fixed-Effects Model* Specifications.

### Data Sources

The following data sources were used in performing the billing analysis:

- ***Program Tracking Data*** for HES and HES-IE programs, provided by CL&P and UI, for all electric and gas participants from January 2011 to October 2013.
  These data included participant names, contact information (e.g., address), 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 name or description, *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, for all electric and gas participant monthly usage history.
  These data included meter-read dates and all kWh and CCF consumption, by participant account, between January 2010 and October 2013.

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[13] Performing fixed-effects regression models with panel data is consistent with UMP protocols for evaluating whole-building retrofit. Source: UMP Whole-Building Retrofit with Consumption Data Analysis Evaluation Protocol. https://www1.eere.energy.gov/wip/pdfs/53827-8.pdf

- ***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.

  ZIP codes were used 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 (NOAA) 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 name, dates of participation, and measure installation information. These non-HES/HES-IE programs included other energy-efficiency rebate programs and the Home Energy Reports (HER) behavioral program.

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

  HER is a program that focuses on reducing energy consumption through education by increasing customers' awareness of their energy usage relative to their neighbors'. Because HER prompts behavior changes, participation in this program could be partially responsible for changes in the energy consumption observed in homes that also participated in HES and HES-IE. To control for the potential influence of HER, and ensure that any energy savings associated with that program were not attributed to HES/HES-IE, the Evaluation Team flagged all customers who participated by matching the customer account numbers between the two programs' participation tracking databases.

  Rather than excluding HER participants from the HES/HES-IE analysis, the HER participation flag was used as a dummy variable when specifying both the natural gas and electric billing analysis models. This controlled for the impact of the customers' behavior in HER and ensured that HER participation did not bias changes in energy consumption determined for HES and HES-IE.

- ***Connecticut Program Savings Documentation (PSD)***, which is 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 contained in this manual.[14]

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

- ***Connecticut 2013–2015 Electric and Natural Gas Conservation and Load Management Plan*** (the Plan), providing reported 2011 electric and gas savings by utility that were the basis for calculating total evaluated savings.
- ***Indicators of non-utility funded HES-IE projects,*** flagging those projects which leveraged state or federal funding and may not comprehensively track household-specific installations and associated energy savings.
- A CL&P HES-IE subprogram, SP1, identifies all potential program participants that leverage non-utility funding. SP2, SP3, and SP4 receive complete funding through the utility. UI provided separate data files and merged them to participant data, flagging projects that leveraged either Department of Energy (DOE) or American Recovery and Reinvestment Act (ARRA) funding for HES-IE installations.

### *Data Challenges*

The Evaluation Team addressed several issues with the participation, measure, and billing data, including:

- Delays in receipt of data;
- Lack of a data dictionary;
- Multifamily participant match to billing data;
- Receipt of data files with incorrect unique identifiers;
- Cumbersome formats and organization;
- Inconsistent information provided in repeat requests; and
- Error in mapping fields between billing and participant data files.

One utility provided electric and gas-billing data at the unit level for the majority of multifamily participants, which provided a straightforward mapping between the unit level measure data with the billing data; however, another provided billing data at the facility level. This was particularly significant in the multifamily/HES-IE SP3. In this subprogram, the *ex ante* savings estimates were aggregated to the facility level. To normalize the large usages across the complexes, the number of units needed to be determined.

To do this, the Evaluation Team checked the number of unique sequence numbers and the number of building units based on the measure data, along with Google lookups of the multifamily addresses. The usage per unit was calculated, as well as the *ex ante* estimate per unit. Then, the respective per-unit usages for these HES-IE SP3 customers and *ex ante* estimates were weighted by the number of units in the facility. Thus, a per-unit usage estimate for a 100-unit complex has more weight than a per-unit usage estimate for a 10-unit multifamily complex. This process ensured that all participant and nonparticipant data were analyzed at the unit level.

Challenges were also encountered in attempting to use unique identifiers to map participant data files to the associated billing data. One utility indicated their data management system is unable to assign unique identifiers that can map energy-efficiency projects at the customer level to billing data across different fuels savings. For example, unless program vendors collect account numbers separately for electric and gas, energy-efficiency programs can be assigned only a single fuel-specific account number, resulting in a potential disconnect between that customer ID and associated billing data. This issue contributed to high attrition in the gas participant samples due to missing and unmatched gas account numbers.

### Participant Group

For the impact analysis, data were gathered 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 because (1) the analysis sought a complete 12-month period of post-participation billing data, and (2) at the time of evaluating planning, billing data for a complete 2013 period was not available. Because of this timeline, billing data from a complete year before and after program participation was available for 2011.

The population of participants included in the analysis was maximized by using rolling specifications for assigning pre- and post-installation periods. First, the Evaluation Team identified a specific range of months during which measures were installed through the program. Then pre- and post-periods were assigned for the 12 months before and after the installation period. For the entire participant treatment group, the average pre-period of billing data ranged from June 2010 to June 2011, and the average post-period ranged from September 2011 to September 2012.

Starting with a census of participation from this period, a final participant group was identified for the analysis after screening for several criteria. The billing analysis was conducted using participants who had not moved since participating and had at least nine months of pre-period and post-period billing data. Account-level reviews of all individual participant pre- and post-period consumption were performed to identify anomalies (e.g., periods of unoccupied units) that could bias the results. Additional screening criteria were also applied, which are described in detail in the Data Screening section.

#### *HES-IE Subprogram Participation*

Differences in measure offerings, delivery, and data collection across and within the HES-IE program (and subprogram) components posed some challenges in applying the proposed impact methodology uniformly. Two SPs of CL&P's program posed these issues:

- ***SP1*** uses different funding sources to install measures, leveraging ratepayer funds against non-utility weatherization funding (often from state or federal sources). Utility data tracking did not always clearly delineate measures funded by the utilities' HES-IE program compared to non-utility funding.

- ***SP4*** is a neighborhood canvassing delivery model that focuses primarily on direct-install measures and serves as a mechanism to enroll customers in SP2.

While UI's program did not apply the same subprogram structure and definitions as CL&P's, a percentage of their HES-IE projects in 2011 also received measures installed with non-utility funding (e.g., DOE, ARRA).

For efficiency, data preparation was conducted simultaneously for the measure-level and whole building impact evaluations. The scope for performing measure-level analysis proposed removing the specific participant subpopulations that either (1) were anomalous to the standard program delivery/design, or (2) received non-utility funding (where a complete assessment of measure installations was not tracked). The entire participant analysis sample, which was cleaned and combined with billing data for the measure-specific billing analysis, was used to estimate impacts through the whole-building analysis (excluding CL&P SP1 and SP4 and UI DOE/ARRA projects). Thus, the Evaluation Team performed a completely separate analysis of HES-IE SP1 and SP4 program impacts, for a program period consistent with the HES and HES-IE SP2/SP3 analyses (i.e., 2011).

### *Control for Non-HES/HES-IE Program Effects*

In an effort to isolate the program effect specifically on the measures installed through HES and HES-IE, several steps were taken to control for non-program energy-efficiency installations. This accounted for (1) overlapping HER program participation; (2) non-utility funded installations occurring under HES-IE (e.g., DOE); and (3) overlapping participation in other energy-efficiency programs aside from HES and HES-IE.

In regard to overlapping participation, only about 0.2% of the gas participant population for HES and HES-IE were participating in some other energy-efficiency program during the pre- to post-period of this analysis. For the electric participants, 4% participated in other programs, and 3% participated in HER.

### *Final Participant Group Analysis Samples*

Application of these various filters reduced the size of the participant group available for the billing analysis, for which Table 17 shows final sample sizes. Additional details specific to the screening process are provided in the Data Screening section.

**Table 17. Billing Analysis Participant Groups, by Program and Fuel**

| Participant Group | Electric | Natural Gas |
|---|---|---|
| HES | 11,110 | 1,862 |
| HES-IE | 5,481 | 1,250 |

## Comparison Group

As an important aspect of the billing analysis quasi-experimental design, the analysis used a comparison group of "nonparticipants" to account for exogenous factors that may have occurred simultaneous to program activity. These factors can include macroeconomic effects, increases or decreases in energy rates, or other interactions that may have affected energy consumption outside of the program influence. For both HES and HES-IE programs, comparison groups were identified using samples of future program participants who participated after the analysis period, for HES and HES-IE respectively. For this analysis, the comparison group was selected from program participants between approximately October 2012 and September 2013. This group is referred to as nonparticipants or the comparison group. [15]

Using future participants as a comparison group for similar analyses has several advantages, compared to selecting randomly from the customer population. First, the future participants are more representative of the participant treatment group than a random sample of residential customers because they are more likely to closely resemble participants from previous years in terms of energy awareness and pre-program building characteristics. Second, because this population has received program measures, the Evaluation Team was able to control and isolate the installation period of the comparison group to ensure that no program impacts would influence the analysis period.

To maximize the available comparison group sample and to maintain complete separation from the treatment group of 2011 participants, this sample was selected from customers that participated from October 2012 through September 2013. The approach ensured that the comparison group had sufficient billing data (using two complete years for comparison occurring before actual participation) and with both the pre- and post-periods consistent with the average participant pre- and post-participation periods. The comparison group pre-period of billing data ranged from June 2010 to June 2011, and the post-period ranged from September 2011 to September 2012, each period reflecting the average participant ranges.

### *Final Comparison Group Analysis Samples*

The comparison group was similar to the participant group in that the application of several data screens reduced the size of the group that was available for the billing analysis. Table 18 shows the final sample sizes. The Data Screening section provides more details specific to the screening process.

**Table 18. Billing Analysis Comparison Group, by Program and Fuel**

| Comparison Group | Electric | Natural Gas |
|---|---|---|
| HES | 8,547 | 1,192 |
| HES-IE | 5,430 | 644 |

[15] Changes in energy use for these comparison groups between the pre and post periods of this study are relatively small. These estimates reflected high relative precision, as changes in consumption would likely be more random than for customers engaged in utility DSM programs. The whole-house analysis Findings sections provide greater detail.

### Savings Calculation

The Evaluation Team is reporting adjusted gross savings as the final estimate of program impacts. Adjusted gross savings is derived from "adjusting" evaluated participant savings based on changes in energy usage of a comparison group. As savings are being adjusted based on a comparison group of "future" program participants and not on a true control group (i.e., a randomized controlled trial experimental design), the adjusted gross savings should not account for freeridership and spillover.[16] For these reasons, these savings are defined as *adjusted gross savings* for this analysis.[17]

#### *Model-Specific (Average Participant) Evaluated Savings*

Since comparison group pre-period usage may not be identical to the participant pre-usage, a "percent of pre" approach was used to obtain the adjusted gross participant savings. The following formula depicts this specific calculation for adjusted gross participant savings:

$$Adj. Gross\ Savings = (Pre\ Part\ Usage)\left(\frac{Part\ Change\ In\ Usage}{Pre\ Part\ Usage} - \frac{NonPart\ Change\ In\ Usage}{Pre\ NonPart\ Usage}\right)$$

Through this process, instead of taking the difference between the participant savings delta and the nonparticipant savings delta (i.e., a difference-of-differences approach), the percentage reduction of both the participant and the nonparticipant groups (specifically, savings as a percentage of weather-normalized pre-period energy consumption) were obtained. The percentage reduction representative of adjusted gross savings is the participant percentage-change reduction minus the nonparticipant percentage reduction. This adjusted gross percentage reduction can then be multiplied by the participant pre-period usage to obtain the adjusted gross participant savings, thus effectively accounting for the differences in pre-period usage between participants and nonparticipants.

#### *Overall Program-Year Evaluated Savings*

Given discrepancies between the total savings in the program-tracking data received compared to those savings reported in the Plan, the Evaluation Team relied on the adjust gross realization rates that were calculated via billing analysis (for specific analysis samples) to calculate evaluated total program-year savings. First, estimates of adjust gross savings were developed through the billing analysis and compared these average model savings estimates to average *ex ante* participant savings (reported in the utility tracking data) to calculate the adjusted gross realization rate. Then these adjusted gross savings

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

17 As noted, the EEB Evaluation Consultant and Evaluation Team are engaged in planning an additional evaluation study focused on NTG for these programs, primarily for HES. It is common best practice within the energy efficiency EM&V community to assume that the NTG ratio for low-income programs is 1.0, since these participants are unlikely to install these measures on their own due to significant affordability barriers.

realization rates, by utility program and fuel, were applied to the overall 2011 program-year reported savings from the Plan to derive the evaluated adjusted gross savings for the 2011 program year.[18] [19]

Table 19 provides the percentage assumptions used for disaggregating reported HES-IE savings reported in the Plan. These percentages were calculated based on the participant tracking data provided by the utilities.

**Table 19. Percentage of HES-IE Savings Attributed to Subprograms or DOE/ARRA Projects**

| Fuel | Utility | Percentage of HES-IE Savings | | |
|---|---|---|---|---|
| | | SP1 | SP4 | DOE/ARRA Projects |
| Electric | CL&P | 12% | 27% | n/a |
| | UI | n/a | n/a | 1% |
| Gas | CNG | 11% | 6% | n/a |
| | SCG | n/a | n/a | 5% |
| | YGS | 5% | 16% | n/a |

*Since gas utilities territories are composed of both CL&P and UI electric customers, and the subprogram construct is specific to CL&P HES-IE delivery, the proportion of gas savings for CL&P and UI from the program tracking data was used to differentiate the portion of reported HES-IE gas savings for CNG and YGS associated with specific SPs.

## Demand Impact Approach

The study's primary focus is evaluating energy savings through billing analysis; program-level demand impacts is also provided by applying the realization rates based on the energy impact analysis to the 2011 demand savings reported in the Plan.[20]

## Estimating Oil/Propane Impacts

Because oil and propane are not metered, and the fuel sales data are often difficult to access, are not always reliable, or are not available in electronic format, a direct calibrated analysis of oil and propane households was not performed. Instead, to develop an estimate of oil and propane savings based on the program-level billing analysis, conversion factors were used to extrapolate impacts in relation to those

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18 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.

19 As noted in the Participant Group section, CL&P's HES-IE SP1 and SP4 were assessed separately through billing analysis models distinct from the HES-IE SP2 and SP3. As CL&P's HES-IE SP1 participants received non-utility funded installations, a portion of the modeled energy savings are attributed to non-utility funded measures.

20 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 (seasonal versus on peak) to estimate demand associated with program measure activity for a specific program period.

savings occurring in natural-gas homes. This approach assumes that homes using propane or oil heat have similar construction features and base loads as those heated with natural gas.

The conversion factors and equations provided in the PSD were used for these conversions. For thermal enclosure, duct sealing, and water-consumption savings measures, the PSD provided the following general equation for fuel savings conversion:

$$Fuel\ Savings = \frac{Btu\ Savings}{System\ Efficiency \times Fuel\ Conversion}$$

In this equation, Btu Savings refers to the reduced amount of heat transfer from the improvement in envelop or duct measures, or the reduced amount of heated water used at the faucet or showerhead. The following fuel conversions, provided in the PSD, were used as inputs into this equation for fuel conversion:

- Natural gas: 100,000 Btu/therm
- Natural gas: 102,900 Btu/CCF
- Oil: 138,690 Btu/gallon
- Propane: 91,330 Btu/gallon

The assumed system efficiencies in the PSD are equivalent for each fuel type for the thermal enclosure, duct sealing, and water-consumption reduction measures. This simplifies the savings conversion from natural gas to oil or propane, as shown in the following equation:

$$Fuel\ Savings\ (Gallons) = \frac{Natural\ Gas\ Fuel\ Savings\ (CCF) \times 102{,}900\ (\frac{Btu}{CCF})}{Fuel\ Conversion\ (\frac{Btu}{Gallon})}$$

Specifically, the following conversion factors are used:

- CCF to gallons of oil: 0.7419
- CCF to gallons of propane: 1.1267

To ensure that savings are comparable, the measure distribution of gas-savings homes from the analysis sample was compared to the measure distribution of oil- and propane-heated households. Similar proportions of energy-savings measures occurred in each.

The whole-house analysis in Section 1 is based on the associated impacts for program participants included in the gas billing analysis, assuming that the savings associated with a typical mix of measures that drive gas impacts can be extrapolated to the population of oil- and propane-savings participants.

Section 2 of this analysis explores the impacts of oil and propane associated with the specific participant population and the energy-savings measures for which they occur.[21]

## Data Screening

### *General Screens*

The following screens removed anomalies, incomplete records, and outlier accounts that could have biased savings estimations:

- Inability to merge the participant and measure data with the billing data, including instances of customers for which different addresses are listed between the participant data, measure data, and billing data files;
- Insufficient billing data for accounts with fewer than nine months (270 days) of billing data in the pre- or post-period;
- Accounts that change electric or gas usage from the pre- or post- period by more than 70%;[22]
- Accounts with low annual usage in the pre- or post-period (e.g., less than 1,000 kWh for electric, or less than 200 CCF for gas);[23]
- Customers for which the *ex ante* savings estimate exceeds the pre-period usage, or where the *ex ante* savings estimate is less than 1% of the pre-period usage;[24]
- For the comparison group, any nonparticipants with higher per-unit usage compared to the maximum participant per-unit usage;[25] and
- Other extreme values, including vacancies in the billing data (outliers); heating or cooling system changes (e.g., adding or removing heating or cooling loads); base-load equipment changes; or changes in occupancy.[26]

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[21] Both Section 1 and 2 analyses only focus on HES-IE fuel and propane impacts associated with SP2 and SP3.

[22] Changes in usage of this magnitude are probably due to vacancies, home remodeling or addition, seasonal occupation, or fuel switching. Changes of usage over a certain threshold are not anticipated to be attributed to program effects and can confound the analysis of consumption for this purpose.

[23] As a reference point, the average CL&P household uses approximately 800 kWh each *month*; therefore, *annual* usage less than 1,000 is very low for residential households in Connecticut.

[24] That is, if the program estimated that the household would save more energy than it actually used in the first place. If the *ex ante* savings exceed the pre-period usage, a high probability exists of either vacancies in the pre-period or potential inconsistencies in matching measure and billing data. In instances where *ex ante* savings are less than 1% of the pre-period usage, the impact will be too insignificant to capture through a billing analysis.

[25] Nonparticipants with larger usage than the maximum participant usage are removed to ensure that the comparison group more closely resembles the participant group in terms of energy consumption.

[26] Base-load changes could include adding or removing appliances (such as a refrigerator or water heater) or changes in occupancy; in either case, this may convolute the analysis for distinguishing program effects.

### Weather Normalization Model Screens

The primary models used for obtaining energy savings were pooled fixed-effects models; additional models were run for initial data processing, additional screening, and comparison to the final energy model savings. Specifically, models similar to Princeton Scorekeeping Method (PRISM) were used to weather-normalize pre- and post-billing data for each account, and to provide an alternate check on measure savings obtained from the pooled fixed-effects model.

For each participant home, three models in both the pre- and post-periods were run to weather-normalize the raw billing data:

- Heating and cooling
- Heating only
- Cooling only

See *Appendix B. PRISM Model* Specifications for more detail.

Through this process, the Evaluation Team removed gas customers from the analysis where the model heating parameters were negative, indicating an inconsistency in heating energy-usage trends that corresponded to increases or decreases in HDDs. Specifically for the electric billing analyses, customers were removed when all models (e.g., heating and cooling, heating only, cooling only) yielded negative heating, cooling, and base-load parameters.

### Model Attrition

Application of these screens resulted in final cleaned, matched analytic HES samples consisting of 11,110 participants and 8,547 nonparticipants in the electric analysis, and 1,862 participants and 1,192 nonparticipants in the gas analysis.

For more detail on HES model attrition, reference *Appendix C. Model* Attrition.

Main sources of attrition in the HES participant electric models included insufficient pre- and post-period months of billing data and outlier removal, for which the latter involved detailed review of individual participant pre- and post-period consumption. Due to the level of rigor involved in the outlier review process, this review was performed only on the participant groups for both gas and electric analyses.

The primary driver of attrition in the HES gas models was the inability to match the program tracking data (including participant and measure data files) to the billing data. As mentioned in the Data Challenges section, a key contributor to this issue is that the utility customer data-tracking system has limited ability to assign unique identifiers that can map energy-efficiency projects to billing data across different fuels' saving participants.

Application of these screens resulted in overall cleaned, matched HES-IE samples consisting of 5,481 participants and 5,430 nonparticipants in the electric analysis, and 1,250 participants and 644 nonparticipants in the gas analysis.

Similar to HES, the main sources of attrition in the HES-IE participant electric models included insufficient pre- and post-period months of billing data and outlier removal. Challenges for HES-IE gas participants are comparable to those for HES, with attrition in the HES-IE gas models primarily driven by the inability to match the program tracking data (including participant and measure data files) to the billing data.

For more detail on HES-IE model attrition, reference *Appendix C. Model* Attrition.

# Section 1: HES Findings

## Overall Results

This section presents evaluated savings estimates for the HES program, covering electric, natural gas, and oil/propane fuel types. The results are grouped by fuel savings. Specific to the electric and gas findings, several detailed tables are presented to help contextualize the evaluated impacts as a result of the billing analysis, including measure distributions and findings specific to distinct analysis samples included through modeling (e.g., by utility, by building type).

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

## *Electric Savings*

### Billing Analysis Results

Table 20 compares changes in energy consumption from the pre- to post-program periods for the participant and comparison groups. Estimated adjusted gross savings are included, calculated based on the “percent of pre” approach discussed in the Savings Calculation section of the methodology.

**Table 20. HES Electric Billing Analysis: Savings Summary, Overall**

| Group | n | PRENAC | Model Savings (kWh) | Savings as Percentage of Pre-Usage | Relative Precision at 90% | Savings Lower 90% (kWh) | Savings Upper 90% (kWh) |
|---|---|---|---|---|---|---|---|
| Participant | 11,110 | 11,278 | 1,096 | 10% | ±2% | 1,071 | 1,122 |
| Comparison | 8,547 | 10,666 | 28 | 0% | ±112% | -3 | 60 |
| Adjusted gross | 11,110 | 11,278 | 1,067 | 9% | ±4% | 1,026 | 1,107 |

*Overall model average base-65 HDD (5,716) and CDD (617).

Participants achieved estimated gross energy savings of 1,096 kWh. A slight decrease in electric usage detected in the comparison group resulted in an adjusted gross savings estimate of 1,067 kWh.

Table 21 shows additional utility-specific models, which disaggregate the overall HES program results shown above for the participant, comparison group, and adjusted gross savings estimates.

**Table 21. HES Electric Billing Analysis: Savings Summary, by Utility**

| Group | Utility | n | PRENAC | Model Savings (kWh) | Savings as Percentage of Pre-Usage | Relative Precision at 90% |
|---|---|---|---|---|---|---|
| Participant | CL&P | 8,695 | 11,878 | 1,146 | 10% | ±3% |
| | UI | 2,415 | 9,159 | 972 | 11% | ±5% |
| | **Overall** | **11,110** | **11,278** | **1,096** | **10%** | **±2%** |
| Comparison | CL&P | 7,043 | 11,061 | 59 | 1% | ±61% |
| | UI | 1,504 | 8,896 | -79 | -1% | ±85% |
| | **Overall** | **8,547** | **10,666** | **28** | **0%** | **±112%** |
| Adjusted gross | CL&P | 8,695 | 11,878 | 1,082 | 9% | ±4% |
| | UI | 2,415 | 9,159 | 1,053 | 12% | ±8% |
| | **Overall** | **11,110** | **11,278** | **1,067** | **9%** | **±4%** |

Savings as a percentage of pre-usage are quite similar among HES participants across utilities. CL&P participants demonstrate slightly higher electric savings, though higher pre-period usage results in percentage savings approximately 1% less than that of UI participants.

Changes in comparison group usage reveal slight increases in consumption for UI nonparticipants, while CL&P nonparticipants are showing minor decreases in consumption. These effects result in nearly equivalent adjusted gross electric savings across the utility programs: approximately 1,082 kWh for CL&P and 1,053 kWh for UI.

Table 22 shows the frequency distribution of measure installations occurring in the analysis sample of participants, by electric utility, along with the average reported savings per measure type. The Evaluation Team stresses that the measures did not serve as model inputs. Instead, the listing of measures and their *ex ante* per-unit savings estimates provides context for understanding the model results.

**Table 22. HES Electric Analysis: Measure Distribution of Final Model Sample**

| Category | Measure | Percent of Sample | | Average *Ex Ante* Savings by Measure (kWh per Participant) | |
|---|---|---|---|---|---|
| | | CL&P | UI | CL&P | UI |
| Lighting | Lighting | 97% | 97% | 661 | 622 |
| Water Heat | DWH Bundle* | 16% | 9% | 483 | 477 |
| | Heat Pump Water Heater | <1% | <1% | 1,762 | 1,762 |
| Shell | Air Sealing | 76% | 67% | 163 | 117 |
| | Attic Insulation | n/a | <1% | n/a | 110 |
| | Wall Insulation | n/a | <1% | n/a | 90 |
| | Windows | <1% | n/a | 482 | n/a |

| Category | Measure | Percent of Sample | | Average *Ex Ante* Savings by Measure (kWh per Participant) | |
|---|---|---|---|---|---|
| | | CL&P | UI | CL&P | UI |
| | Insulation Other** | 4% | n/a | 368 | n/a |
| HVAC | Duct Sealing | 15% | 30% | 310 | 292 |
| | Central AC | 1% | 4% | 230 | 173 |
| | Heating System Replacement | <1% | <1% | 288 | 293 |
| | Heat Pump | <1% | <1% | 1,136 | 728 |
| | Ductless Heat Pump | <1% | <1% | 2,969 | 2,152 |
| | Ground-Source Heat Pump | <1% | n/a | 2,630 | n/a |
| Appliance | Refrigerator | <1% | 1% | 247 | 234 |
| | Dehumidifier | <1% | <1% | 398 | 172 |
| | Clothes Washer | <1% | <1% | 364 | 102 |
| | Freezer | <1% | n/a | 638 | n/a |
| Other | Other | n/a | <1% | n/a | 259 |
| **Sample (n)** | | **8,695** | **2,415** | | |

*Contains a mix of low-flow showerheads, faucet aerators, and pipe insulation.

**Projects consist of insulation installations without location description.

In general, installation activity for both utility HES programs (and the associated electric impacts) is characterized by high frequencies of energy-efficient lighting (97% for CL&P, 97% for UI) and air sealing (76%, 67%), along with duct sealing (15%, 30%) and hot-water savings measures (12%, 9%). This mix of measures composes the "core" installations that occur during the initial in-home visit, in which an HES program technician performs an audit to assess home energy performance. Based on the recommendations for deeper energy-saving measures, participants can opt to use HES-specific rebates for subsequent measure installations such as insulation or replacement of appliance or HVAC systems.

Installations for the participant analysis sample reveal lower levels of these "add-on" rebated measure options. In part, this may be due to higher saturations of non-electric heating or water, which would mean that the measures such as insulation would result in natural gas, fuel oil, or propane savings, not electric savings.[27] However, appliance installations are also infrequent relative to the total participant sample (for most, occurring in less than 1% of the participants).

The majority of average per-participant *ex ante* measure savings estimates are similar across utility program participants. The only exceptions occur for heat pumps, dehumidifiers, and clothes washers, where CL&P average per-unit savings is noticeably higher than the UI estimates. Given such low

[27] Approximately 9% of the HES participant sample in the electric models was identified as electrically heated.

frequencies of these measure installations, deviations in these *ex ante* savings are unlikely to produce a significant effect in consideration of realized savings.

A key implication of this measure mix—which despite being skewed towards small measures rather than big savings ones is still producing reliable electricity savings—is that these impacts will primarily affect electric base load, with slight effects on heating and cooling.

To provide some additional context around the program-specific impacts, Table 23 and Table 24 show the HES adjusted gross energy savings by heating type (electric versus non-electric) and building type (single-family versus multifamily).

Table 23 provides transparency around the larger absolute energy savings that are associated with electrically heated homes, over 70% higher than non-electrically heated homes. Yet, the electric heat homes are a small part of the sample, which is why overall savings, percent savings, and precision more closely resemble non-electric homes than electric ones. Consideration of savings as a percentage of PRENAC indicates that these are relatively similar and consistent with the overall model results.

**Table 23. HES Electric Billing Analysis: Savings Summary, by Participant Heating Fuel (Adjusted Gross)**

| Participant Heating Type | n | PRENAC | Model Savings (kWh) | Savings as Percentage of Pre-Usage | Relative Precision at 90% |
|---|---|---|---|---|---|
| Electric | 1,042 | 17,642 | 1,720 | 10% | ±10% |
| Non-electric | 10,068 | 10,621 | 999 | 9% | ±4% |
| **Overall** | **11,110** | **11,278** | **1,067** | **9%** | **±4%** |

Table 24 shows that the bulk of HES electric-savings participants occur in single-family homes, demonstrating slightly higher savings than in multifamily units. However, it is important to note that while there is a savings discrepancy of about 300 kWh on average between these participant types, lower pre-period usage for multifamily participants' results in a higher savings as a percentage of PRENAC.

**Table 24. HES Electric Billing Analysis: Savings Summary, by Building Type (Adjusted Gross)**

| Building Type | n | PRENAC | Model Savings (kWh) | Savings as Percentage of Pre-Usage | Relative Precision at 90% |
|---|---|---|---|---|---|
| Single-family | 10,589 | 11,552 | 1,084 | 9% | ±4% |
| Multifamily | 521 | 6,177 | 761 | 12% | ±16% |
| **Overall** | **11,110** | **11,278** | **1,067** | **9%** | **±4%** |

### Realization Rate

Table 25 provides realization rates based on the participant gross and adjusted gross savings for the billing analysis sample.

**Table 25. HES Electric Billing Analysis: Realization Rate Summary**

| Group | Utility | 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 |
|---|---|---|---|---|---|---|
| Gross savings | CL&P | 1,146 | 936 | 122% | 10% | 8% |
| | UI | 972 | 837 | 116% | 11% | 9% |
| | **Overall** | **1,096** | **914** | **120%** | **10%** | **8%** |
| Adjusted gross savings | CL&P | 1,082 | 936 | 116% | 9% | 8% |
| | UI | 1,053 | 837 | 126% | 12% | 9% |
| | **Overall** | **1,067** | **914** | **117%** | **9%** | **8%** |

Participants of both CL&P and UI programs are observing realization rates higher than 100%. Average *ex ante* savings for participants are similar across utility-programs (these vary by approximately 100 kWh). For each utility program, evaluated per participant savings estimated through the billing analysis are higher than the *ex ante* estimates. Even accounting for the nonparticipant adjustment, realization rates for both HES electric impacts are over 100%, averaging approximately 117% for the program statewide.

## *Natural Gas Savings*

### Billing Analysis Results

Table 26 compares changes in energy consumption from the pre- to post-program periods for the participant and comparison groups. Estimated adjusted gross savings are included, calculated based on the "percent of pre" approach discussed in the Savings Calculation section of the methodology

**Table 26. HES Natural Gas Billing Analysis: Savings Summary, Overall**

| Group | n | PRENAC | Model Savings (CCF) | Savings as Percentage of Pre-Usage | Relative Precision at 90% | Savings Lower 90% (CCF) | Savings Upper 90% (CCF) |
|---|---|---|---|---|---|---|---|
| Participants | 1,862 | 1,051 | 72 | 7% | ±6% | 68 | 76 |
| Comparison | 1,192 | 999 | 17 | 2% | ±25% | 12 | 21 |
| Adjusted gross | 1,862 | 1,051 | 55 | 5% | ±12% | 48 | 61 |

*Overall model average base-65 HDD (5,626).

Participants achieved estimated gross energy savings of 72 CCF. A slight decrease in gas usage detected in the comparison group resulted in an adjusted gross savings estimate of 55 CCF.

Table 27 presents additional utility-specific models that disaggregate the overall HES program results shown above for the participant, comparison group, and adjusted gross savings estimates.

**Table 27. HES Natural Gas Billing Analysis: Savings Summary, by Utility**

| Group | Utility | n | PRENAC | Model Savings (CCF) | Savings as Percentage of Pre-Usage | Relative Precision at 90% |
|---|---|---|---|---|---|---|
| Participants | CNG | 649 | 1,160 | 76 | 7% | ±10% |
| | SCG | 461 | 1,053 | 61 | 6% | ±13% |
| | YGS | 752 | 957 | 76 | 8% | ±8% |
| | **Overall** | **1,862** | **1,051** | **72** | **7%** | **±6%** |
| Comparison | CNG | 508 | 1,041 | 15 | 1% | ±43% |
| | SCG | 243 | 1,052 | 14 | 1% | ±68% |
| | YGS | 441 | 922 | 19 | 2% | ±33% |
| | **Overall** | **1,192** | **999** | **17** | **2%** | **±25%** |
| Adjusted gross | CNG | 649 | 1,160 | 59 | 5% | ±17% |
| | SCG | 461 | 1,053 | 46 | 4% | ±27% |
| | YGS | 752 | 957 | 55 | 6% | ±16% |
| | **Overall** | **1,862** | **1,051** | **55** | **5%** | **±12%** |

Average participant savings for CNG and YGS appear to be similar, at 76 CCF each, while average gross participant savings for SCG are approximately 20% lower (61 CCF). Comparison groups for each gas utility are saving a roughly consistent amount of energy during the analysis period (1 to 2% of PRENAC). Adjusted gross savings by utility program are similar in proportion to the participant gross savings, with comparable gas savings between CNG and YGS, and slightly lower SCG impacts.

Table 28 shows the frequency distribution of measure installations occurring in the analysis sample of participants, along with the average reported savings per measure type. Upon review of the utility program tracking data, the Evaluation Team determined UI insulation formulas are based on changes in R-value and are not constant *ex ante* savings per square foot (like CL&P). For SCG, the median wall R-value is 0, for which 0.28 CCF per square foot is assigned; the median attic R-value is 19, for which 0.047 CCF per square foot is assigned. This infers that average SCG participant homes have higher levels of baseline insulation in attics, resulting in larger incremental savings for wall insulation projects (most often relative to no pre-existing levels of insulation).

**Table 28. HES Natural Gas Analysis: Measure Distribution of Final Model Sample**

| Category | Measure | Percentage of Sample | | | Average *Ex Ante* Savings by Measure (CCF per Participant) | | |
|---|---|---|---|---|---|---|---|
| | | CNG | SCG | YGS | CNG | SCG | YGS |
| Shell | Air sealing | 90% | 97% | 91% | 62 | 64 | 61 |
| | Attic insulation | n/a | 3% | n/a | n/a | 114 | n/a |
| | Wall insulation | n/a | 1% | n/a | n/a | 287 | n/a |
| | Insulation other | <1% | n/a | <1% | 228 | n/a | 69 |
| | Windows | n/a | n/a | <1% | n/a | n/a | 19 |
| Water heating | DWH bundle* | 81% | 78% | 76% | 30 | 26 | 27 |
| HVAC | Duct sealing | 12% | 26% | 15% | 42 | 48 | 53 |
| | Heating system replacement | <1% | <1% | <1% | 304 | 282 | 171 |
| Appliance | Clothes washer | n/a | <1% | n/a | n/a | 8 | n/a |
| **Sample (n)** | | **649** | **461** | **752** | | | |

*Contains a mix of low-flow showerheads, faucet aerators, and pipe insulation.

In general, installation activity for each of the utility HES programs (and the associated gas impacts) is characterized by high frequencies of air sealing (90% for CNG, 97% for SCG, and 91% for YGS), hot-water savings measures (67%, 75%, 63%), and pipe insulation for CNG (50%) and YGS (48%). In addition to air sealing, duct sealing represents another high gas-saving measure, occurring for 12% of CNG, 26% of SCG, and 15% of YGS participants.

As discussed in the Data Challenges section, high attrition of gas participants occurred due to lack of available account numbers and ability to merge these customers with billing data. As a result, frequencies of certain measures may be underrepresented in cases where higher proportions of accounts that received these measures are screened out of the analysis. For example, CL&P provided a dataset of nearly 400 participants receiving various types of insulation; only seven of these participants had gas account numbers listed, which are requisite for matching to billing data for performing this analysis. While these accounts represent only approximately 8% of the total HES gas accounts prior to screening, it is not possible to be certain that the attrition is entirely random and the results are not biased, since they are based on data where the billing records could be matched.

Table 29 shows that the majority of HES gas-savings participants occur in single-family homes, which is consistent with the HES electric participant distribution.

Table 29. HES Natural Gas Billing Analysis: Savings Summary, by Building Type (Adjusted Gross)

| Building Type | n | PRENAC | Model Savings (CCF) | Savings as Percentage of Pre-Usage | Relative Precision at 90% |
|---|---|---|---|---|---|
| Single-family | 1,784 | 1,063 | 56 | 5% | ±10% |
| Multifamily | 78 | 786 | 21 | 3% | ±128% |
| **Overall** | **1,862** | **1,051** | **55** | **5%** | **±12%** |

### Realization Rate

Table 30 provides realization rates based on the participant gross and adjusted gross savings for the billing analysis sample.

Table 30. HES Natural Gas Billing Analysis: Realization Rate Summary

| Group | Utility | Model Savings (CCF) | Reported *Ex Ante* Savings (CCF) | Realization Rate | Model Savings as Percentage of Pre-Usage | Reported *Ex Ante* Savings as Percentage of Pre-Usage |
|---|---|---|---|---|---|---|
| Gross savings | CNG | 76 | 88 | 86% | 7% | 8% |
| | SCG | 61 | 103 | 59% | 6% | 10% |
| | YGS | 76 | 85 | 89% | 8% | 9% |
| | **Overall** | **72** | **91** | **80%** | **7%** | **9%** |
| Adjusted gross savings | CNG | 59 | 88 | 67% | 5% | 8% |
| | SCG | 46 | 103 | 45% | 4% | 10% |
| | YGS | 55 | 85 | 65% | 6% | 9% |
| | **Overall** | **55** | **91** | **60%** | **5%** | **9%** |

Average expected gas savings for HES participants are higher in each case than savings estimated through the model. In accounting for the nonparticipant savings, adjusted gross realization rates are reduced slightly from those reported for gross savings.

## *Oil/Propane Savings*

Table 31 provides extrapolated oil and propane savings based on: (1) the participant population reporting oil/propane savings tracked in the utility data, (2) the distribution of these participants by heating and water heating types, and (3) the application of evaluated adjusted gross savings from the gas billing analysis models.

Table 31. HES Total Evaluated Oil and Propane Savings, by Heating and Water Heating Fuel Type

| Fuel Type | Configuration | n | Gas Model Savings (CCF per participant) | Conversion Factor (gallons/CCF) | Converted Oil/Propane Savings (gallons per participant) | Total Oil/Propane Savings (gallons) |
|---|---|---|---|---|---|---|
| Oil | Heating Only | 3,693 | 41 | 0.7419 | 30 | 112,506 |
| | Water Heating Only | 187 | 14 | 0.7419 | 10 | 1,899 |
| | Combo | 8,196 | 55 | 0.7419 | 41 | 332,918 |
| | **Overall** | **12,076** | **n/a** | **n/a** | **n/a** | **447,323** |
| Propane | Heating Only | 238 | 41 | 1.1267 | 46 | 11,011 |
| | Water Heating Only | 166 | 14 | 1.1267 | 15 | 2,560 |
| | Combo | 365 | 55 | 1.1267 | 62 | 22,516 |
| | **Overall** | **769** | **n/a** | **n/a** | **n/a** | **36,087** |

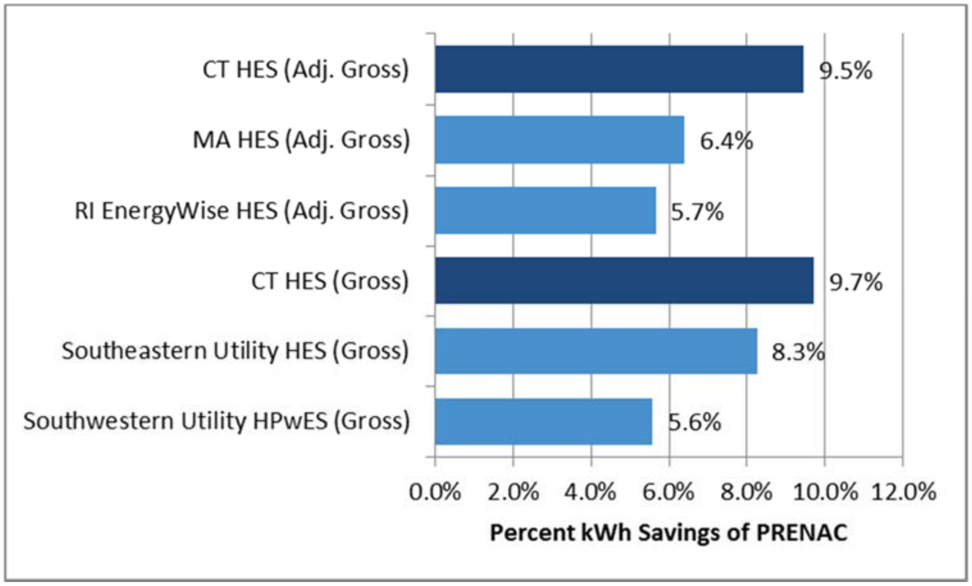
## Benchmarking

### *Benchmarking: HES Electric*

To provide context for the program’s savings estimates, Figure 1 compares results from other similar energy-efficiency programs that offered an initial home audit with direct-installation and options for add-on measures (e.g., equipment, insulation).[28] The first three bars compare programs with evaluated adjusted gross savings, while the remaining bars compare only gross estimates of savings (i.e., no adjustment for nonparticipants).

[28] The comparables are Massachusetts HES, Rhode Island EnergyWise HES, and two similar utility programs from the Southeast and Southwest. See *Appendix K. References* for source information.

**Figure 1. Evaluated HES Electric Impact Comparison: Savings Percentage of Pre-Installation Period Consumption**




As shown in the figure, the Connecticut HES program's electric savings percentages were slightly higher than the range of estimates observed through other programs. However, to provide a meaningful comparison, it is important to consider the primary electric-savings measures that drive the impacts of each of these programs.

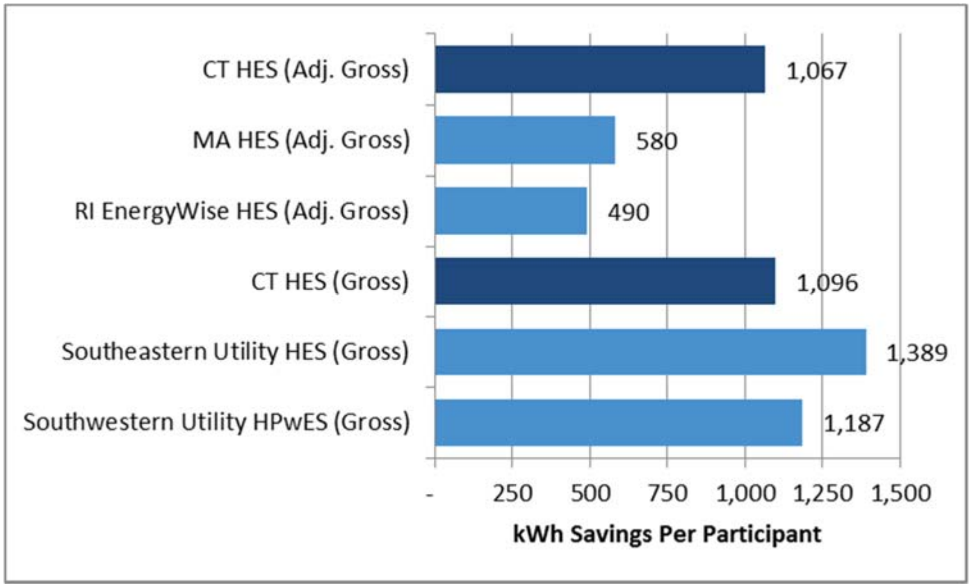
The CT HES electric impacts were characterized primarily by installations of CFLs, hot-water savings measures, and air sealing, but the mix of measures varied in the other programs. These programs' savings were composed primarily of the following measures:

- CT HES: lighting (97%), air sealing (74%), duct sealing (19%), hot-water saving (12%)
- MA HES: lighting (99%), refrigerators (5%), fan savings (32%), (only base-load measures; did not include electric heating participants or shell measures)
- RI EnergyWise HES: lighting (96%), with low frequencies of appliances (e.g., 3% refrigerators)
- Southeastern utility HES: attic insulation (95%), HVAC (10%), air sealing (10%), lighting (2%)
- Southwestern utility HPwES: lighting (92%), insulation and duct sealing (42%), hot-water saving (53%)

Despite variation in the types of electric-saving measures installed through these programs, Connecticut's HES program savings of approximately 9.5 to 9.7% of pre-installation period usage appeared relatively high by comparison.

Figure 2 compares average per-participant kWh savings from the comparable studies.

**Figure 2. Evaluated HES Electric Impact Comparison: Average Per-Participant Savings**



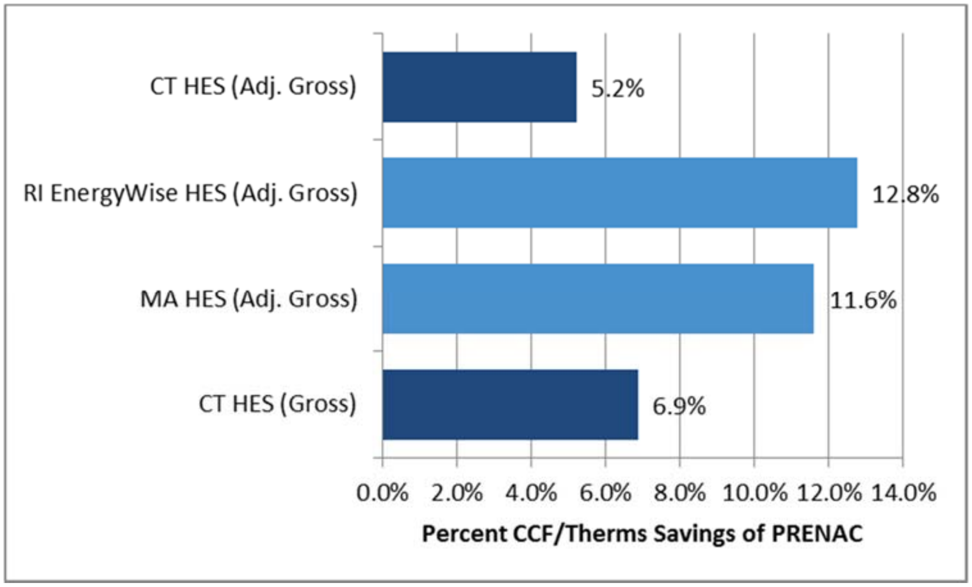

As shown, average kWh for Connecticut's HES program participants was less than the average for several other programs; compared to approximately 11,278 kWh in Connecticut, the average participants' pre-installation period consumption of these other programs ranged between 16,000 kWh and 22,000 kWh. In the higher kWh-saving programs, more electric heating (and cooling) and more installations of shell measures (e.g., insulation) appeared to drive these differences. Compared to the Massachusetts HES, higher installations of air sealing, duct sealing, and hot-water savings probably contributed to increased electric savings in Connecticut.

### *Benchmarking: HES Gas*

To provide context for the program's savings estimates, Figure 3 compares results from other similar energy-efficiency programs that offered an initial home audit with direct-installation and options for add-on measures (e.g., equipment, insulation).[29] The first three bars compare programs with evaluated adjusted gross savings, while the remaining bar provides the Connecticut HES gross estimates of savings (i.e., no adjustment for nonparticipants).

[29] The comparables are Massachusetts HES and Rhode Island EnergyWise HES. See *Appendix K. References* for source information.

**Figure 3. Evaluated HES Gas Impact Comparison: Savings Percentage of Pre-Period Consumption**




As shown in the figure, the Connecticut HES program's gas savings percentages were below the range of estimates observed in similar programs. It seems likely this disparity was attributed to the primary gas-savings measure mix driving each of these programs' impacts. While the CT HES gas impacts were characterized primarily by projects receiving air sealing, duct sealing, and hot-water savings measures, each of the other programs had higher installations of shell measures, such as attic, wall, and floor insulation.

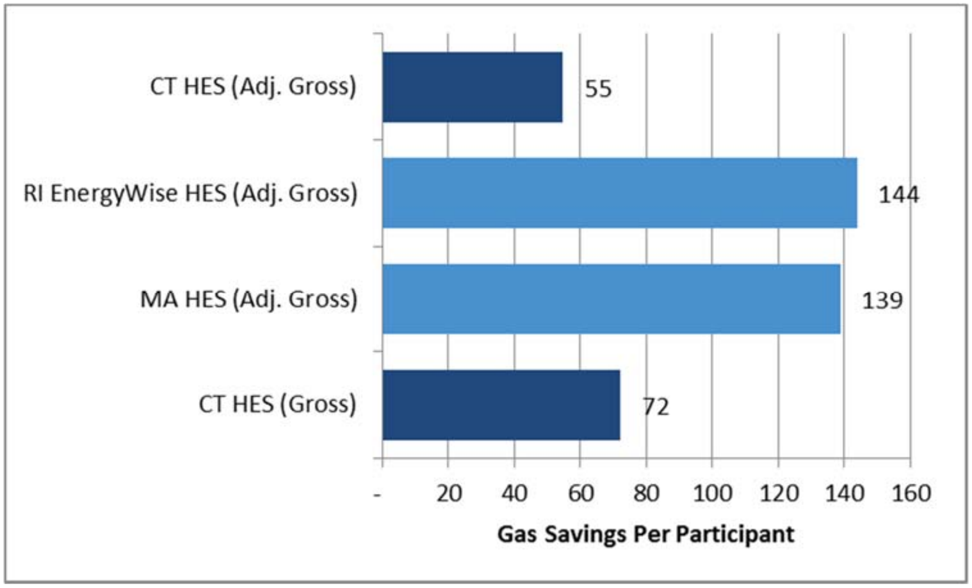
Under Connecticut's HES program, insulation and equipment replacements are part of the add-on measures recommended through the audit, which the participant decides whether to install, and appeared to differ from comparable programs.

The comparable programs' savings primarily comprised the following mixture of measures:

- CT HES: air sealing (92%), hot-water saving (67%), pipe insulation (39%), duct sealing (17%)
- RI EnergyWise HES: air sealing (55%), attic/wall/floor insulation (47%, 23%, 20%), showerheads (17%)
- MA HES: air sealing (80%), attic/wall/floor insulation (36%, 20%, 12%), some water-savings measures

A comparison of absolute estimates of savings presented a similar story. While Figure 4 shows average gas savings (including CCF and therms), regardless of the normalized pre-installation period consumption, Connecticut's HES program showed lower estimates of savings by comparison.

Figure 4. Evaluated HES Gas Impact Comparison: Average Per-Participant Savings



## *Section 1: HES-IE Findings—Whole House (SP2/SP3)*

### Overall Results

This section presents evaluated savings estimates for the HES-IE program, covering electric, natural gas, and oil/propane fuel types. The results are grouped by fuel savings. Specific to the electric and gas findings, several detailed tables are presented to help contextualize the evaluated impacts as a result of the billing analysis, including measure distributions and findings specific to distinct analysis samples included through modeling (e.g., by utility, by building type).

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

As discussed under the Methodology section for whole-house analysis, the CL&P HES-IE SP1 and SP4 have been omitted from this billing analysis and are assessed separately in the following section: Section 1: HES-IE Findings—Whole-House (SP1/SP4). The subsequent findings derived through the billing analyses are based on analysis samples that exclude both SP1 and SP4 participants.

### *Electric Savings*

#### Billing Analysis Results—Whole-House (SP2/SP3 Only)

Table 32 compares changes in energy consumption from the pre- to post-program periods for the participant and comparison groups. Estimates of adjusted gross savings are included, calculated based on the “percent of pre” approach discussed in the Savings Calculation section of the methodology.

**Table 32. HES-IE Electric Billing Analysis: Savings Summary, Overall**

| Group | n | PRENAC | Model Savings (kWh) | Savings as Percentage of Pre-Usage | Relative Precision at 90% | Savings Lower 90% (kWh) | Savings Upper 90% (kWh) |
|---|---|---|---|---|---|---|---|
| Participants | 5,481 | 7,292 | 885 | 12% | ±4% | 848 | 922 |
| Comparison | 5,430 | 6,091 | -100 | -2% | ±29% | -129 | -72 |
| Adjusted gross | 5,481 | 7,292 | 1,005 | 14% | ±5% | 958 | 1,051 |

*Overall model average base-65 HDD (5,665) and CDD (632).

Participants achieved estimated gross energy savings of 885 kWh. A slight increase in electric usage detected in the comparison group resulted in an adjusted gross savings estimate of 1,005 kWh. Despite slightly lower adjusted gross savings when compared to the overall HES program (1,067 kWh), percentage savings are actually 5% higher in HES-IE due to lower pre-period participant consumption.

Table 33 presents additional utility-specific models that disaggregate the overall HES-IE program results shown above for the participant, comparison group, and adjusted gross savings estimates.

**Table 33. HES-IE Electric Billing Analysis: Savings Summary, by Utility**

| Group | Utility | n | PRENAC | Model Savings (kWh) | Savings as Percentage of Pre-Usage | Relative Precision at 90% |
|---|---|---|---|---|---|---|
| Participants | CL&P | 3,196 | 7,408 | 917 | 12% | ±6% |
| | UI | 2,285 | 7,111 | 864 | 12% | ±5% |
| | **Overall** | **5,481** | **7,292** | **885** | **12%** | **±4%** |
| Comparison | CL&P | 4,016 | 6,367 | -80 | -1% | ±43% |
| | UI | 1,414 | 5,204 | -108 | -2% | ±46% |
| | **Overall** | **5,430** | **6,091** | **-100** | **-2%** | **±29%** |
| Adjusted gross | CL&P | 3,196 | 7,408 | 1,011 | 14% | ±6% |
| | UI | 2,285 | 7,111 | 1,011 | 14% | ±6% |
| | **Overall** | **5,481** | **7,292** | **1,005** | **14%** | **±5%** |

Both kWh savings and savings as a percentage of pre-usage are quite similar among HES-IE participants across utilities. While CL&P participants demonstrate slightly higher electric savings, higher pre-period usage results in percentage savings approximately identical to UI participants.

Both utility programs observe an increase in electric usage of the comparison group participants. These effects result in nearly equivalent adjusted gross electric savings across the utility programs: approximately 1,011 kWh for both CL&P and UI.

Table 34 shows the frequency distribution of measure installations occurring in the analysis sample of participants, by electric utility, along with the average reported savings per measure type. The Evaluation Team stresses that the measures did not serve as model inputs. Instead, the listing of measures and their *ex ante* savings estimates provides context for understanding the model results.

**Table 34. HES-IE Electric Analysis: Measure Distribution of Final Model Sample**

| Category | Measure | Percentage of Sample | | Average *Ex Ante* Savings by Measure (kWh per Participant) | |
|---|---|---|---|---|---|
| | | CL&P | UI | CL&P | UI |
| Lighting | Lighting | 84% | 96% | 503 | 419 |
| Water heat | DWH bundle * | 40% | 21% | 565 | 697 |
| | Water heater replacement | 3% | n/a | 55 | n/a |
| Shell | Air sealing | 32% | 53% | 514 | 380 |
| | Attic insulation | 9% | 2% | 433 | 2,565 |
| | Wall insulation | 2% | <1% | 1,493 | 1,440 |
| | Insulation other ** | 2% | n/a | 153 | n/a |
| | Windows | 2% | n/a | 532 | n/a |
| HVAC | Ductless heat pump | 21% | 7% | 1,717 | 1,805 |
| | Duct sealing | <1% | 4% | 284 | 255 |
| | Window AC | 4% | n/a | 98 | n/a |
| | Central AC | n/a | <1% | n/a | 98 |
| Appliance | Refrigerator | 26% | n/a | 758 | n/a |
| | Appliance other *** | n/a | 13% | n/a | 353 |
| | Freezer | 3% | n/a | 733 | n/a |
| Other | Other | <1% | n/a | 637 | n/a |
| **Sample (n)** | | **3,196** | **2,285** | | |

*Contains a mix of low-flow showerheads, faucet aerators, and pipe insulation.

**Projects that consist of insulation installations without available detail on location.

***Projects composed of appliance installations with specific category details.

In general, installation activity for both utility HES-IE programs (and the associated electric impacts) is characterized by high frequencies of energy-efficient lighting (84% for CL&P, 96% for UI), air sealing (32%, 53%), hot-water savings measures (39%, 21%), along with ductless heat pumps (19%, 7%) and appliances (29%, 13%). Many of these measures compose a similar mix of HES "core" installations (i.e., CFLs, air sealing, water-saving measures), though certainly higher frequencies of appliance, insulation, and HVAC equipment installations are occurring under HES-IE. Similar to HES, the HES-IE program technician performs a home energy assessment to identify deeper energy-savings measures for installation; the key difference is that these "add-on" measures are usually free of charge to HES-IE participants (although landlords often are subject to co-pays), contingent only upon whether they are eligible for efficiency upgrade or replacement based on the audit. Thus, when comparing HES to HES-IE, one should keep in mind that a larger proportion of HES-IE households installed deep savings measures because they received them for free; the fact that HES households need to buy these measures—even with sizable rebates and opportunities for financing—reduces the prevalence of their adoption.

Overall, a higher saturation of electric heating occurs for HES-IE participants compared to HES.[30] This would indicate a higher frequency of opportunities for measures that target electric heating loads.

The majority of average per-participant *ex ante* measure savings estimates are similar across utility program participants. The only noticeable exception occurs for attic insulation, where UI average per-unit savings is nearly six times higher than the CL&P estimate. Upon review of the utility program tracking data, CL&P applies a constant 1.3 kWh *ex ante* savings per square foot of insulation, while UI employs a formula that is dependent on R-value (ranging from 0.71 kWh per square foot to 8.25 kWh per square foot).

To provide some additional context around the program-specific impacts, Table 35 and Table 36 show the HES-IE adjusted gross energy savings by heating type (electric versus non-electric) and building type (single-family versus multifamily).

Nearly a third of the HES-IE participant sample homes are electrically heated, demonstrating approximately 36% higher kWh savings on average than non-electrically heated homes, as shown in Table 35. However, consideration of savings as a percentage of PRENAC indicates that these are relatively similar and consistent with the overall model results.

**Table 35. HES-IE Electric Billing Analysis: Savings Summary, by Participant Heating Fuel (Adj. Gross)**

| Participant Heating Type | n | PRENAC | Model Savings (kWh) | Savings as Percentage of Pre-Usage | Relative Precision at 90% |
|---|---|---|---|---|---|
| Electric | 1,741 | 8,918 | 1,231 | 14% | ±8% |
| Non-electric | 3,740 | 6,485 | 905 | 14% | ±5% |
| **Overall** | **5,481** | **7,292** | **1,005** | **14%** | **±5%** |

Table 36 shows that approximately 56% of HES-IE electric-savings participants occur in multifamily homes. While there is a savings discrepancy of about 312 kWh on average between these participant types, lower pre-period usage for multifamily participants results in a slightly higher savings as a percentage of PRENAC.

**Table 36. HES-IE Electric Billing Analysis: Savings Summary, by Building Type (Adjusted Gross)**

| Participant Heating Type | n | PRENAC | Model Savings (kWh) | Savings as Percentage of Pre-Usage | Relative Precision at 90% |
|---|---|---|---|---|---|
| Single-family | 2,389 | 9,048 | 1,193 | 13% | ±7% |
| Multifamily | 3,092 | 6,143 | 880 | 14% | ±7% |
| **Overall** | **5,481** | **7,292** | **1,005** | **14%** | **±5%** |

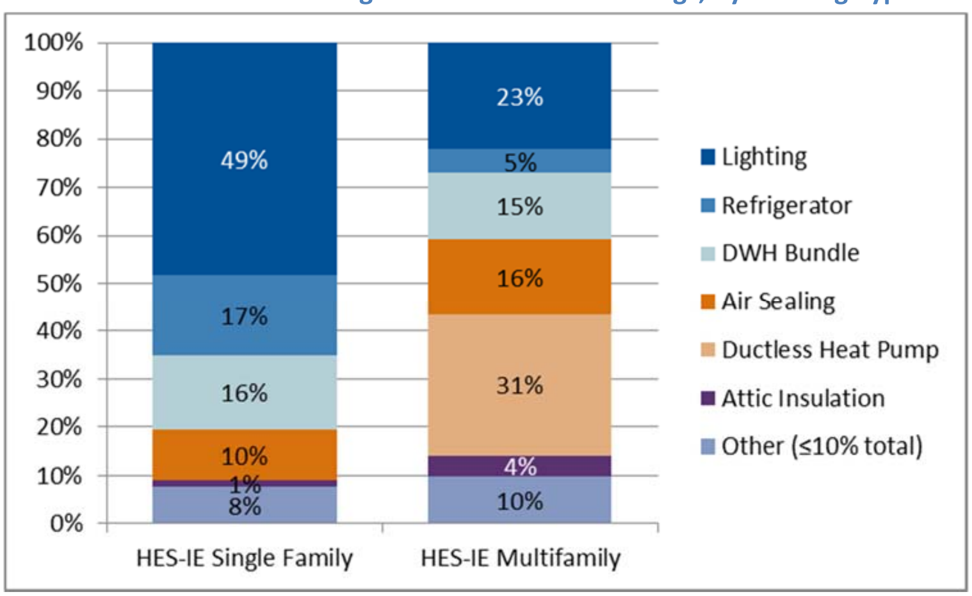
30 Approximately 32% of the HES-IE participant sample in the electric models was identified as electrically heated, compare to only 9% for HES.

A deeper analysis of the distribution of HES-IE measure installations by building type and associated *ex ante* savings reveals some key distinctions; specifically:

- A higher frequency of ductless heat pump installations occurred in multifamily (24%) versus single-family participants (<1%) in the analysis sample.
- Average *ex ante* savings for ductless heat pumps represent the highest portion of expected electric savings for multifamily HES-IE participants (a function of the number installed and the average *ex ante* savings).
- Average *ex ante* ductless heat pumps savings represent a high percentage compared to average pre-period usage for the HES-IE analysis sample (approximately 15% of PRENAC for single-family participants and 29% for multifamily).[31]

Related to the first and second point, Figure 5 illustrates the distribution of average *ex ante* savings for measures installed for the HES-IE participant analysis sample, taking into account the frequency of installation (installation rate) and average *ex ante* savings per measure; essentially, this depicts the expected savings by building type, weighted by the *ex ante* savings and frequency of installation. Measures accounting for less than 10% of these *ex ante* savings were combined into the category "Other."

**Figure 5. Distribution of *Ex Ante* HES-IE Electric Savings, Weighted by Frequency of Installation and Average *Ex Ante* Measure Savings, by Building Type**




Ductless heat pumps are the expected source of nearly a third of HES-IE multifamily participant savings. As shown above in Table 34, average expected savings for ductless heat pumps are among the largest

[31] Averaged *ex ante* savings for ductless heat pumps also represents a high percentage savings for HES as well (savings of 25% of PRENAC for single-family participants; none were installed for multifamily participants).

per-unit kWh estimates under HES-IE (averaging 1,394 kWh for single-family and 1,751 kWh for the analysis sample, across utilities). Given the higher frequency of these installations in multifamily buildings, it is likely that a large portion of the overall savings derived from installing ductless heat pumps will be attributable to multifamily homes rather than single-family homes.

In Table 37, this difference is apparent in comparing HES-IE realization rates by building type (based on adjusted gross savings compared to average *ex ante* savings for the analysis sample).

**Table 37. HES-IE Electric Billing Analysis: Realization Rate by Building Type**

| Building Type | PRENAC | 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 |
|---|---|---|---|---|---|---|
| Single-family | 9,048 | 1,193 | 1,138 | 105% | 13% | 13% |
| Multifamily | 6,143 | 880 | 1,374 | 64% | 14% | 22% |
| **Overall** | **7,292** | **1,005** | **1,281** | **78%** | **14%** | **18%** |

Despite similarities in percentage savings compared to pre-period usage, average expected participant *ex ante* savings is slightly higher for multifamily participants due in large part to the high frequency of ductless heat pumps. Accounting for pre-period usage, the estimate of expected savings for multifamily participants assumed savings of 22% of pre-period usage, approximately 7% higher than for single-family homes. Given the measure mix by building type, the assumed savings appear more aggressive for multifamily participants compared to single-family.

Furthermore, given the prevalence of ductless heat pumps for multifamily participants and the associated lower realization rate, there is a need to review the *ex ante* assumptions used in the savings calculation for this measure. For example, it is possible that the *ex ante* calculation did not account for pre-installation usage levels for this customer segment. In comparing average expected savings to analysis sample participants, approximately 29% of average multifamily participant usage would be saved through ductless heat pumps (while only 15% for single-family participants).

A recent study of ductless heat pump retrofits in multifamily buildings identified high levels of take back occurring for participants through an increase in average temperature settings during the heating season.[32] Take-back or rebound effects typically refer to the behavioral responses to the installation of new energy-efficiency technology, which may result in lower expected savings due to an increase in participant usage. For example, the installation of a new energy-efficient heating system may prompt a participant to increase the temperature settings, anticipating the increase in cost-savings for operating

32 Larson, et al. *Ductless Heat Pump Retrofits in Multifamily and Small Commercial Buildings: A Report of BPA Energy Efficiency's Emerging Technologies Initiative.* 2012. http://www.bpa.gov/energy/n/emerging_technology/pdf/DHPx_Multifamily%20_Small_Commercial_Report_02-08-13.pdf

an efficient unit. Through an analysis of 12 submetered sites, the study identified increased heating levels for participants receiving ductless heat pumps ranging from 39% (1,416 kWh) to 78% (2,603 kWh) relative to pre-installation usage.

### Realization Rate

Table 38 provides realization rates based on the participant gross and adjusted gross savings for the billing analysis sample.

**Table 38. HES-IE Electric Billing Analysis: Realization Rate Summary**

| Group | Utility | 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 |
|---|---|---|---|---|---|---|
| Gross savings | CL&P | 917 | 1,481 | 62% | 12% | 20% |
| | UI | 864 | 966 | 89% | 12% | 14% |
| | **Overall** | **885** | **1,281** | **69%** | **12%** | **18%** |
| Adjusted gross savings | CL&P | 1,011 | 1,481 | 68% | 14% | 20% |
| | UI | 1,011 | 966 | 105% | 14% | 14% |
| | **Overall** | **1,005** | **1,281** | **78%** | **14%** | **18%** |

Averaged expected electric savings for UI and CL&P participants vary by approximately 515 kWh, each of which are lower than the evaluated gross savings estimated through the billing analysis. When accounting for the nonparticipant adjustment, both realization rates increase from the gross estimate, with UI achieving 105% and CL&P achieving 68%.

## *Natural Gas Savings*

### Billing Analysis Results—Whole-House (SP2/SP3 Only)

Table 39 compares changes in energy consumption from the pre- to post-program periods for the participant and comparison groups. Estimated adjusted gross savings are included, calculated based on the "percent of pre" approach discussed in the Savings Calculation section of the methodology.

**Table 39. HES-IE Natural Gas Billing Analysis: Savings Summary, Overall**

| Group | n | PRENAC | Model Savings (CCF) | Savings as Percentage of Pre-Usage | Relative Precision at 90% | Savings Lower 90% (CCF) | Savings Upper 90% (CCF) |
|---|---|---|---|---|---|---|---|
| Participant | 1,250 | 840 | 85 | 10% | ±10% | 77 | 94 |
| Comparison | 644 | 873 | 13 | 1% | ±62% | 5 | 21 |
| Adjusted gross | 1,250 | 840 | 73 | 9% | ±16% | 61 | 84 |

*Overall model average base-65 HDD (5,665).

Participants achieved estimated gross energy savings of 85 CCF. A slight reduction in gas usage detected in the comparison group resulted in an adjusted gross savings estimate of 73 CCF, approximately 15% of gross participant savings.

Table 40 presents additional utility-specific models that disaggregate the overall HES program results shown above for the participant, comparison group, and adjust gross savings estimates.

**Table 40. HES-IE Natural Gas Billing Analysis: Savings Summary, by Utility**

| Group | Utility | n | PRENAC | Model Savings (CCF) | Savings as Percentage of Pre-Usage | Relative Precision at 90% |
|---|---|---|---|---|---|---|
| Participant | CNG | 460 | 976 | 90 | 9% | ±10% |
| | SCG | 340 | 903 | 68 | 7% | ±17% |
| | YGS | 450 | 713 | 92 | 13% | ±14% |
| | **Overall** | **1,250** | **840** | **85** | **10%** | **±10%** |
| Comparison | CNG | 223 | 981 | 23 | 2% | ±62% |
| | SCG | 233 | 928 | -3 | 0% | ±366% |
| | YGS | 188 | 756 | 18 | 2% | ±76% |
| | **Overall** | **644** | **873** | **13** | **1%** | **±62%** |
| Adjusted gross | CNG | 460 | 976 | 67 | 7% | ±25% |
| | SCG | 340 | 903 | 71 | 8% | ±23% |
| | YGS | 450 | 713 | 75 | 11% | ±25% |
| | **Overall** | **1,250** | **840** | **73** | **9%** | **±16%** |

Average participant savings for CNG and YGS appear fairly similar, at 90 CCF and 92 CCF respectively. While SCG average gross participant savings are lower, the comparison-group adjustment results in an increase in adjusted gross savings, while CNG and YGS each decrease. Adjusted gross impact estimates are ultimately quite similar across gas utilities; however, lower pre-period usage for YGS reflects a higher savings percent (11%) than either CNG or SCG (at 7% and 8%, respectively).

Table 41 shows the frequency distribution of measure installations that occur in the analysis sample of participants, along with the average reported savings per measure type.

**Table 41. HES-IE Natural Gas Analysis: Measure Distribution of Final Model Sample**

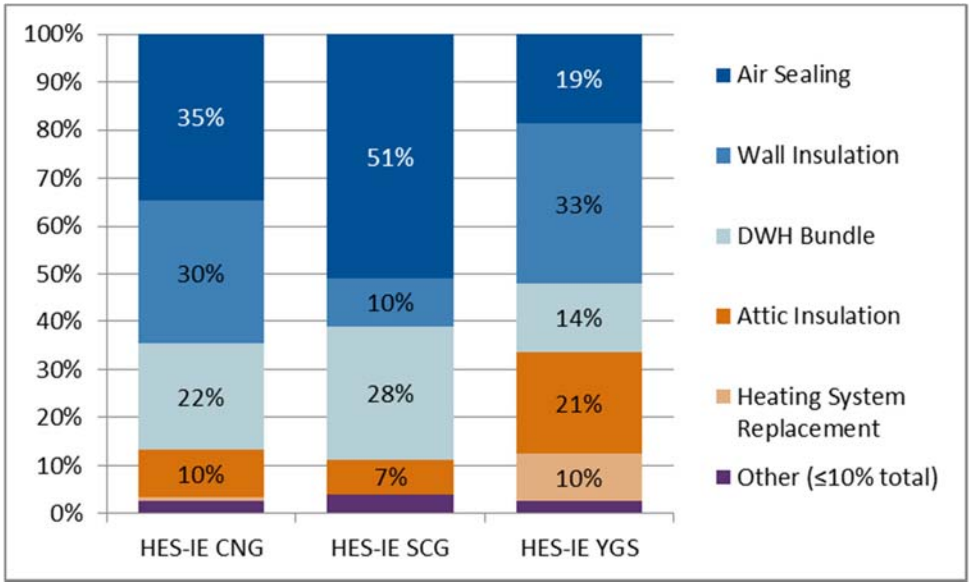
| Category | Measure | Percentage of Sample | | | Average *Ex Ante* Savings by Measure (CCF per Participant) | | |
|---|---|---|---|---|---|---|---|
| | | CNG | SCG | YGS | CNG | SCG | YGS |
| Shell | Air sealing | 77% | 96% | 68% | 69 | 66 | 45 |
| | Attic insulation | 5% | 4% | 26% | 287 | 204 | 135 |
| | Wall insulation | 12% | 3% | 22% | 373 | 477 | 251 |
| | Windows | 2% | n/a | 5% | 4 | n/a | 63 |
| Water heating | DWH bundle* | 82% | 90% | 63% | 43 | 38 | 37 |
| | Water heater temp setback | 32% | <1% | 5% | 6 | 6 | 6 |
| HVAC | Duct sealing | n/a | 10% | <1% | n/a | 49 | 29 |
| | Heating system replacement | <1% | n/a | 12% | 267 | n/a | 127 |
| Appliance | Appliance other | n/a | 1% | n/a | n/a | 8 | n/a |
| Other | Other | <1% | n/a | 1% | 130 | n/a | 8 |
| **Sample (n)** | | **460** | **340** | **450** | | | |

*Contains a mix of low-flow showerheads, faucet aerators, and pipe insulation.

In general, installation activity for each of the HES-IE utility programs (and associated gas impacts) is characterized by high frequencies of air sealing (77% for CNG, 96% for SCG, 68% for YGS) and hot-water savings measures (80%, 90%, 61%). Attic and wall insulation are each installed at a lower frequency of participant homes; however, the average *ex ante* savings are among the higher gas-savings measures, in addition to heating system replacements.

To characterize the weight of the expected energy savings relative to the frequency of installation, Figure 6 provides a summary by utility program that shows the measures that account for over 90% of the expected savings. Measures accounting for less than 10% of these *ex ante* savings were combined into the category “Other.”

**Figure 6. Distribution of *Ex Ante* HES-IE Gas Savings, Weighted by Frequency of Installation and Average *Ex Ante* Measure Savings, by Utility**




The summary of weighted expected savings by frequency of installation helps to illustrate how certain measures characterize and differentiate the program delivery across utility programs. The measure mix and associated savings for each of these participant analysis samples provides perspective on how utility-specific evaluated savings may differ. For example, heating system replacements occurred only under the YGS program. Additionally, slightly higher participant model savings occurred under the CNG and YGS programs (90 and 92 CCF, respectively, compared to 68 CCF for SCG), which each have a higher portion of expected savings derived from attic and wall insulation.

Table 42 provides a comparison of HES-IE adjusted gross gas savings by building type.

**Table 42. HES-IE Natural Gas Billing Analysis: Savings Summary, by Building Type (Adjusted Gross)**

| Building Type | n | PRENAC | Model Savings (CCF) | Savings as Percentage of Pre-Usage | Relative Precision at 90% |
|---|---|---|---|---|---|
| Single-family | 594 | 995 | 54 | 5% | ±21% |
| Multifamily | 656 | 735 | 85 | 12% | ±19% |
| **Overall** | **1,250** | **840** | **73** | **9%** | **±16%** |

Similar to HES-IE electric, over half of HES-IE gas savings participants occur within multifamily homes.

### Realization Rate

Table 43 provides overall 2011 HES-IE gas energy savings, by utility and overall. In this table, realization rates based on the specific billing-analysis model groups by utility are applied to the 2011 *ex ante* savings as reported in the Plan.

Table 43. HES-IE Natural Gas Billing Analysis: Realization Rate Summary

| Group | Utility | Model Savings (CCF) | Reported *Ex Ante* Savings (CCF) | Realization Rate | Model Savings as Percentage of Pre-Usage | Reported *Ex Ante* Savings as Percentage of Pre-Usage |
|---|---|---|---|---|---|---|
| Gross savings | CNG | 90 | 152 | 59% | 9% | 16% |
| | SCG | 68 | 124 | 55% | 7% | 14% |
| | YGS | 92 | 161 | 57% | 13% | 23% |
| | **Overall** | **85** | **149** | **57%** | **10%** | **18%** |
| Adjusted gross savings | CNG | 67 | 152 | 44% | 7% | 16% |
| | SCG | 71 | 124 | 57% | 8% | 14% |
| | YGS | 75 | 161 | 47% | 11% | 23% |
| | **Overall** | **73** | **149** | **49%** | **9%** | **18%** |

### *Oil/Propane Savings*

Table 44 provides extrapolated oil and propane savings based on: (1) the participant population reporting oil/propane savings tracked in the utility data, (2) the distribution of these participants by heating and water heating types, and (3) the application of evaluated adjusted gross savings from the gas billing analysis models.

Table 44. HES-IE Total Evaluated Oil and Propane Savings, by Heating and Water Heating Fuel Type

| Fuel Type | Configuration | n* | Gas Model Savings (CCF per participant) | Conversion Factor (gallons/CCF) | Converted Oil/Propane Savings (gallons per participant) | Total Oil/Propane Savings (gallons) |
|---|---|---|---|---|---|---|
| Oil | Heating Only | 1,531 | 55 | 0.7419 | 40 | 61,962 |
| | Water Heating Only | 117 | 18 | 0.7419 | 13 | 1,578 |
| | Combo | 2,859 | 73 | 0.7419 | 54 | 154,279 |
| | **Overall** | **4,507** | **n/a** | **n/a** | **n/a** | **217,820** |
| Propane | Heating Only | 63 | 55 | 1.1267 | 61 | 3,872 |
| | Water Heating Only | 66 | 18 | 1.1267 | 20 | 1,352 |
| | Combo | 66 | 73 | 1.1267 | 82 | 5,409 |
| | **Overall** | **195** | **n/a** | **n/a** | **n/a** | **10,633** |

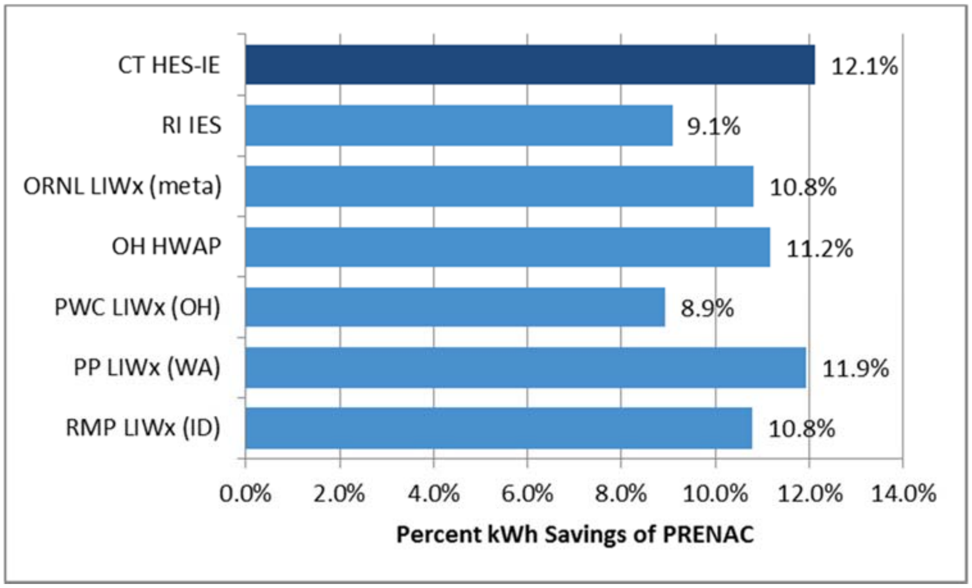
*CL&P HES-IE SP4 participants have been removed from these totals.

## Benchmarking—Whole-House (SP2/SP3 Only)

### *Benchmarking: HES-IE Electric*

To provide context for the program's savings estimates, Figure 7 compares results from other whole-house low-income energy-efficiency programs similar to HES-IE.[33] This comparison comprises studies for which gross savings are available (i.e., no adjustment for nonparticipants included).

**Figure 7. Evaluated HES-IE Electric Impact Comparison: Gross Savings Percentage of Pre-Installation Period Consumption**




As shown in Figure 7, the Connecticut HES-IE program's electric savings percentage was slightly higher than the range of estimates observed through the other programs. The 2005 Oak Ridge National Laboratory metaevaluation of six states' low-income weatherization programs reported savings percentages (relative to pre-installation weatherization usage) ranging from 6.6% to 11.5% for electric-heat participants (average 9%) and -2.9% to 17.8% for non-electric-heat participants (average 7.5%).[34] Estimated impacts for the Connecticut HES-IE program were above these ranges for both electric- and non-electric-heat homes.

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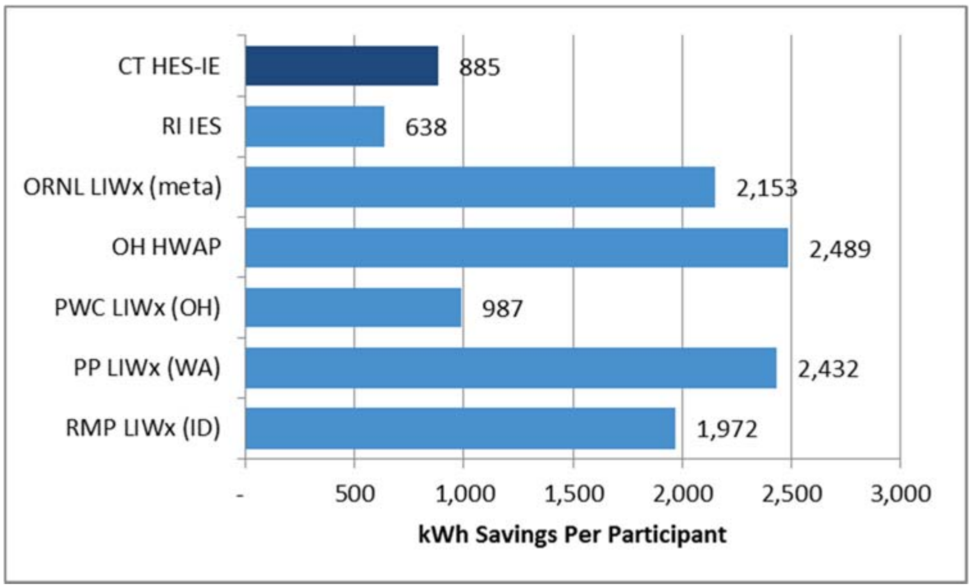
33 The comparables are Rhode Island Income-Eligible Services, Oak Ridge National Laboratory Metaevaluation of low-income weatherization programs, Ohio Home Weatherization Assistance Program, People Working Cooperative Low-Income Weatherization Program in Ohio, Pacific Power Low-Income Weatherization Program in Washington, and Rocky Mountain Power Low-Income Weatherization Program in Idaho. See *Appendix K. References* for sources information.

34 Schweitzer, Martin. Estimating the National Effects of the U.S. Department of Energy's Weatherization Assistance Program with State-Level Data: A Metaevaluation Using Studies from 1993 to 2005. 2005. http://weatherization.ornl.gov/pdfs/ORNL_CON-493.pdf

Higher savings for the Connecticut HES-IE program may be characterized by the mix of electric-saving measures installed;[35] however, these program participants are also unique because, on average, they used less electric heat than similar programs. Connecticut HES-IE participant pre-installation usage was 7,292 kWh for the average participant; the other studies ranged from 11,000 kWh to 22,000 kWh, indicating higher levels of electrically heated participant homes.

Absolute estimates of savings should also be considered. The Evaluation Team normalized the above percentage comparison to the average level of pre-installation period consumption, which accounted for variation in participation across different geographies, climates, and levels of electric heating and cooling saturations. Figure 8 compares average per participant kWh savings from the Connecticut HES-IE and the comparable studies.

**Figure 8. Evaluated HES-IE Electric Impact Comparison: Average Per-Participant Savings**




As shown, average kWh for Connecticut's HES-IE program participants was less than most other programs, which is a function of higher saturations of non-electric heat and lower associated pre-installation period electric usage. In these higher kWh-saving programs, more electric heating (and cooling for SRP) and more installations of shell measures (e.g., insulation) appeared to drive these differences.

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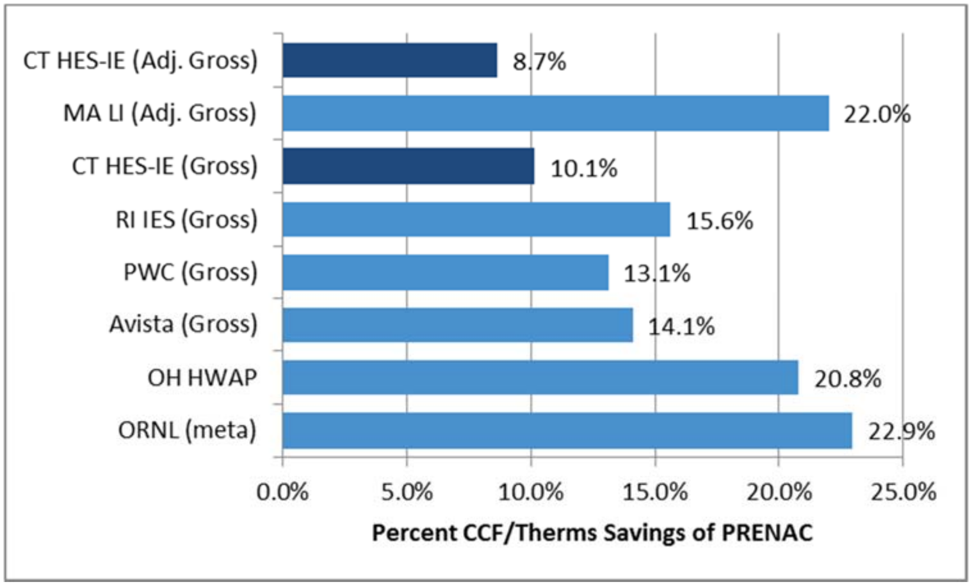
35 Nearly all of the comparison studies are programs that leverage the DOE Weatherization Assistance Program infrastructure and the associated delivery and installation protocols, which offer a mix of measures including low-cost direct installations (e.g., CFLs, aerators, low-flow showerheads), appliance replacement, HVAC equipment repair and replacement, and weatherization measures (e.g., insulation, air sealing, duct sealing). The measure mix associated with the Rhode Island IES program impacts is atypical by comparison, composed primarily of lighting (98%) and refrigerator replacement (38%).

### *Benchmarking: HES-IE Gas*

To provide context for the program's savings estimates, Figure 9 compares results from other whole-house low-income energy-efficiency programs similar to HES-IE.[36] This comparison comprises studies for which gross savings are available (i.e., no adjustment for nonparticipants included).

**Figure 9. Evaluated HES-IE Gas Impact Comparison: Savings Percentage of Pre-Period Consumption**




As shown in the figure, the Connecticut HES-IE program's gas savings percentages were below the range of estimates observed in other programs. It seems likely that this disparity was attributed to the primary gas-savings measure mix driving each of these programs' impacts.

Specifically, the high percentage of savings for Massachusetts' low-income program reflected the high frequencies of insulation measures (75% of participants) and heating equipment replacement (48%), along with some water-heating measures (20%). Additionally, Rhode Island's Income-Eligible Services program reflected installations of insulation (77%), air sealing (68%), heating system replacement (16%), and duct sealing (5%).

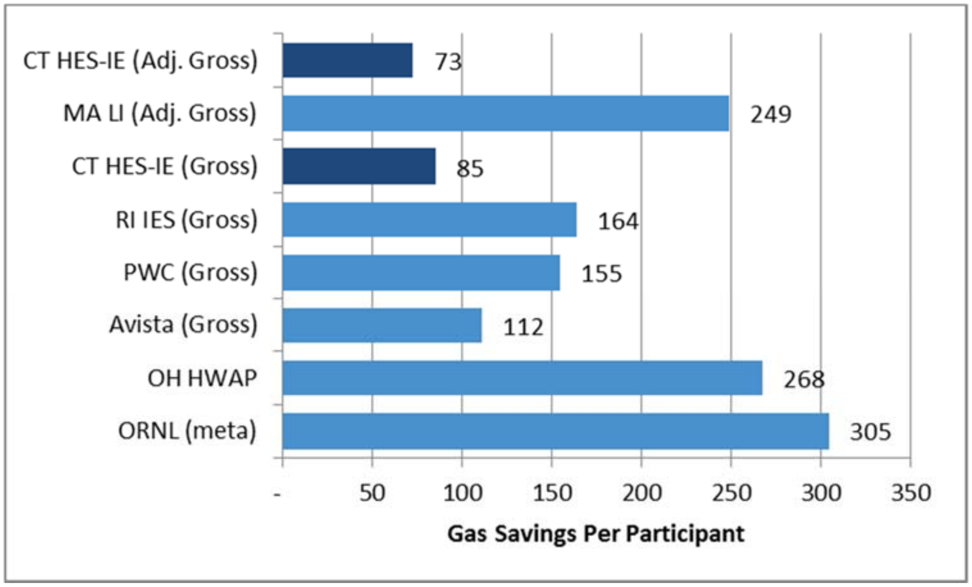
In Connecticut's HES-IE program, while there were high levels of air sealing (79%) and hot water saving measures (76%), there were lower levels of attic insulation (12%), wall insulation (13%), and heating

[36] The comparables are Massachusetts Low-Income Program, Rhode Island Income-Eligible Services, Oak Ridge National Laboratory Metaevaluation of low-income weatherization programs, Ohio Home Weatherization Assistance Program, People Working Cooperative Low-Income Weatherization Program in Ohio, Avista Utilities Low-Income Weatherization Program in Idaho and Washington. See *Appendix K. References* for source information.

system replacements (5%), all of which represented high gas-savings measures like the comparison programs.

A comparison of absolute estimates of savings presents a similar story. Figure 10 shows the average CCF or therms savings, regardless of the normalized per-installation period consumption levels, but Connecticut's HES-IE program showed lower savings estimates by comparison.

**Figure 10. Evaluated HES-IE Gas Impact Comparison: Average Per-Participant Savings**




A comparison of total 2011 program expenditures to the total reported savings (from the Plan) reveals an expected $/CCF ranging from $4.91 per therm to $5.69 per therm across the Connecticut HES-IE gas utility programs. These metrics provide some context around the anticipated program cost-effectiveness associated with *ex ante* savings and costs associated with the measure mix, delivery, and program administration. Low-income retrofit programs for six Massachusetts utilities showed a range between $11.24 per therm to $30.07 per therm for program activity in 2011, reflecting significantly higher cost per therm saved.[37] While the Massachusetts low-income retrofit programs demonstrate higher savings based on evaluation results, higher costs per unit of gas savings suggest differences in program cost-effectiveness by comparison to Connecticut HES-IE.

37 Massachusetts Utility Mid-Term Modifications to Three-Year Plans for 2011(Exhibit G (08-50 Tables)). Massachusetts Energy Efficiency Advisory Council. http://www.ma-eeac.org/Mid-Term%20Modifications.html

## Section 1: HES-IE Findings—Whole-House (SP1/SP4)

### 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—Whole-House (SP1/SP4 Only)

Table 45 compares changes in energy consumption from the pre- to post-program periods for the participant and comparison groups, by HES-IE subprogram.

**Table 45. 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 46 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 46. 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 47 and Table 48 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 47 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 47. 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 48 shows the bulk of HES-IE SP1 and SP4 electric-savings participation occurred in single-family homes, producing higher savings than multifamily, and the SPs 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 48. 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 49 provides realization rates for HES-IE SP1 and SP4, based on the participant gross and adjusted gross savings for the billing analysis sample.

Table 49. 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—Whole-House (SP1/SP4 Only)

Table 50 compares changes in energy consumption for HES-IE SP1 and SP4 from the pre- to post-program periods for the participant and comparison groups.[38]

Table 50. 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.

[38] 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 51 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 51. 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 52 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 52. 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 53 only shows model results for SP1 by building type.

**Table 53. 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 54 provides realization rates, based on participant gross and adjusted gross savings for the billing analysis sample.

Table 54. 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% |

## Section 1: Overall Whole-House Analysis Results

### HES Program Results

#### *Overall HES Electric Program Results*

Table 55 provides overall 2011 HES electric energy savings, by utility and overall. In this table, realization rates based on the specific billing-analysis model groups by utility are applied to the 2011 *ex ante* savings as reported in the Plan.

**Table 55. Total 2011 Evaluated HES Electric Savings, by Utility and Overall Program***

| Utility | Reported Participation | Reported Savings (MWh) | Evaluated Adjusted Gross Savings (MWh) | Adjusted Gross Realization Rate |
|---|---|---|---|---|
| CL&P | 15,886 | 16,403 | 18,977 | 116% |
| UI | 5,329 | 3,588 | 4,513 | 126% |
| **Program Overall**** | **21,215** | **19,991** | **23,489** | **117%** |

*Totals may not add up to the sum of individual values due to rounding.

**The realization rate for "Program Overall" is calculated by taking the difference between the sum of each utility's reported savings and the sum of each utility's evaluated adjusted gross savings totals.

Table 56 provides evaluated adjustments to the reported demand impacts from the Plan. Realization rates developed through the electric HES billing analysis were applied to reported demand savings by utility.

**Table 56. Total 2011 Evaluated HES Demand Savings, by Utility and Overall Program***

| Utility | Reported Participation | Reported Demand Savings (kW) | Evaluated Adjusted Gross Demand Savings (kW) | Adjusted Gross Realization Rate |
|---|---|---|---|---|
| CL&P | 15,886 | 2,633 | 3,046 | 116% |
| UI | 5,329 | 780 | 981 | 126% |
| **Program Overall**** | **21,215** | **3,413** | **4,027** | **118%** |

*Totals may not add up to the sum of individual values due to rounding.

**The realization rate for "Program Overall" is calculated by taking the difference between the sum of each utility's reported savings and the sum of each utility's evaluated adjusted gross savings totals.

#### *Overall HES Gas Program Results*

Table 57 provides overall 2011 HES gas energy savings, by utility and overall. In this table, realization rates based on the specific billing-analysis model groups by utility are applied to the 2011 *ex ante* savings as reported in the Plan.

**Table 57. Total 2011 Evaluated HES Gas Savings, by Utility and Overall Program***

| Utility | Reported Participation | Reported Savings (000s CCF) | Evaluated Adjust Gross Savings (000s CCF) | Adjusted Gross Realization Rate |
|---|---|---|---|---|
| CNG | 1,895 | 196 | 132 | 67% |
| SCG | 2,369 | 243 | 110 | 45% |
| YGS | 1,811 | 172 | 112 | 65% |
| **Program Overall**** | **6,075** | **611** | **354** | **58%** |

*Totals may not add up to the sum of individual values due to rounding.

**The realization rate for "Program Overall" is calculated by taking the difference between the sum of each utility's reported savings and the sum of each utility's evaluated adjusted gross savings totals.

The Evaluation Team explores the discrepancies driving the differences in realization for specific measures in Section 2. A thorough understanding of *ex ante* calculations and the high-frequency measures that characterize program savings will be important in assessing whether measure-specific *ex ante* assumptions may deviate from the actual population, or whether other impacts to consumption (e.g., take-back, behavior change) or installation are driving these differences in savings from the planning estimates.

## HES-IE Program Results

### *Overall HES-IE Electric Program Results*

Table 58 provides overall 2011 HES-IE electric energy savings, by utility and overall. In this table, realization rates based on the specific billing-analysis model groups by utility are applied to the 2011 *ex ante* savings as reported in the Plan.

**Table 58. Total 2011 Evaluated HES-IE Electric Savings, by Utility, Subprogram, and Overall Program***

| Utility | Reported Participation | Reported Savings (MWh) | Evaluated Adjusted Gross Savings (MWh) | Adjusted Gross Realization Rate |
|---|---|---|---|---|
| CL&P Overall | 10,685 | 19,959*** | 13,600 | 68%**** |
| CL&P—SP1 | n/a | 2,441 | 2,052 | 84% |
| CL&P—SP2/SP3 | | 12,157 | 8,295 | 68% |
| CL&P—SP4 | | 5,362 | 3,253 | 61% |
| UI | 5,612 | 5,173 | 5,414 | 105% |
| **Program Overall**** | **16,297** | **25,132** | **19,014** | **76%** |

*Totals may not add up to the sum of individual values due to rounding.

**The realization rate for "Program Overall" is calculated by taking the difference between the sum of each utility's reported savings and the sum of each utility's evaluated adjusted gross savings totals.

***These totals from the reported Plan values have been disaggregated by the percentage of total CL&P HES-IE *ex ante* savings associated with SP2/SP3 (61%), SP1 (12%), and SP4 (27%).

****The realization rates for each SP-specific analysis have been applied to these Plan totals, comparing the sum of the evaluated adjusted gross savings to the reported savings total to derive an overall realization rate for CL&P's HES-IE program.

Table 59 provides evaluated adjustments to the reported demand impacts from the Plan. Realization rates developed through the electric HES-IE billing analysis were applied to reported demand savings by utility.

**Table 59. Total 2011 Evaluated HES-IE Demand Savings, by Utility and Overall Program**

| Utility | Reported Participation | Reported Demand Savings (kW) | Evaluated Adjusted Gross Demand Savings (kW) | Adjusted Gross Realization Rate |
|---|---|---|---|---|
| CL&P | 10,685 | 901** | 614 | 68%*** |
| UI | 5,612 | 325 | 341 | 105% |
| **Program Overall*** | **16,297** | **1,227** | **955** | **78%** |

*The realization rate for "Program Overall" has been calculated by taking the difference between the sum of each utility's reported savings and the sum of each utility's evaluated adjusted gross savings totals.

**These totals from the reported Plan values have been disaggregated by the percentage of total CL&P HES-IE *ex ante* savings associated with SP2/SP3 (61%), SP1 (12%), and SP4 (27%).

***The realization rates for each SP-specific analysis have been applied to these Plan totals, comparing the sum of the evaluated adjusted gross savings to the reported savings total to derive an overall realization rate for CL&P's HES-IE program.

### *Overall HES-IE Gas Program Results*

Table 60 provides overall 2011 HES-IE gas energy savings, by utility and overall. In this table, realization rates based on the specific billing-analysis model groups by utility are applied to the 2011 *ex ante* savings as reported in the Plan.

Table 60. Total 2011 Evaluated HES-IE Gas Savings, by Utility, Subprogram, and Overall Program*

| Utility | Reported Participation | Reported Savings (000s CCF) | Evaluated Adjusted Gross Savings (000s CCF) | Adjusted Gross Realization Rate |
|---|---|---|---|---|
| CNG Overall | 1,610 | 211*** | 102 | 49%**** |
| CNG—SP1 | n/a | 24 | 20 | 83% |
| CNG—SP2/SP3 | | 174 | 76 | 44% |
| CNG—SP4 | | 13 | 6 | 47% |
| SCG | 3,268 | 361 | 206 | 57% |
| YGS Overall | 1,961 | 360*** | 165 | 46%**** |
| YGS—SP1 | n/a | 18 | 9 | 51% |
| YGS—SP2/SP3 | | 283 | 132 | 47% |
| YGS—SP4 | | 59 | 24 | 41% |
| **Program Overall**** | **6,839** | **932** | **474** | **51%** |

*Totals may not add up to the sum of individual values due to rounding.

**The realization rate for "Program Overall" is calculated by taking the difference between the sum of each utility's reported savings and the sum of each utility's evaluated adjusted gross savings totals.

***These totals from the reported Plan values have been disaggregated by the percentage of total CL&P HES-IE *ex ante* savings associated with SP2/SP3 (82% CNG, 79% YGS), SP1 (11% CNG, 5% YGS), and SP4 (6% CNG, 16% YGS). As gas utilities territories are composed of both CL&P and UI electric customers, and the subprogram construct is specific to CL&P HES-IE delivery, the Evaluation Team used the proportion of gas savings for CL&P and UI from the program tracking data to differentiate the portion of reported HES-IE gas savings for CNG and YGS associated with each SP.

****Realization rates for each SP-specific analysis have been applied to these Plan totals, comparing the sum of the evaluated adjusted gross savings to the reported savings total to derive an overall realization rate for CNG's and YGS's respective HES-IE programs.

## Section 2: Measure-Level Analysis

Section 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 (SP2/SP3 only). 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.

### *Methodology*

#### 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.[39] 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 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.

This impact assessment varied slightly depending on the measure in an attempt to calculate the most accurate savings values possible, given data constraints previously discussed. A billing analysis captured

[39] 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 under the whole-house analysis Methodology section.

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.[40] When measures fell outside of this threshold, however, the Evaluation Team derived savings for those measures using simulation modeling or engineering analysis.[41]

In regard to the results selected for this study, there are several key issues to consider:

- Savings estimates selected from the billing analysis that met the precision threshold are all statistically significant at the 99% confidence level, meaning that the observed effects are not due to random variation. Specifically, all t-statistics calculated for these estimates are at least twice as large as the critical value of 1.645 typically used at the 90% confidence level.[42]
- Precision values calculated for the billing analysis estimates represent variation in the effect that the measure has on consumption across the population (represented through high and low bounds for these savings estimates). This is different than the precision reported due to sampling uncertainty, which represents the uncertainty in an estimate due to not observing the entire population (but only a sample of it). Commonly, sampling uncertainty is referred to in sample design, using "90/10" or other targets.
- The engineering analysis draws upon a number of assumptions and relies on input estimates with unknown levels of uncertainty and unobserved data points. As such, even though precision around the engineering estimates are not quantified in this report, it is assumed that that there ***is*** uncertainty in these estimates.
- The ability to use participant-specific data from the actual participant population, rather than assumptions as in the engineering analysis, provides the best approach to achieve robust estimates of energy savings. Presenting precision around these estimates is a positive outcome of this research (e.g., ability to account for actual changes in consumption, incorporating program effects, energy education, consumer behavior), and high precision does not necessarily indicate a poor estimate.

40 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.

41 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.

42 T-statistics are required to be greater than the critical value to determine statistical significance.

Table 61 and Table 62 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 61. 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 (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 62. 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:[43]

- ***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

[43] The whole-house analysis Data Sources section provides detailed discussions of data challenges encountered.

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. The Evaluation Team calculated degree days for all cooling degree and heating degree bases, ranging from 45 to 85. Variable bases were required from PRISM-analysis models to most accurately disaggregate usage into the base load, heating, and cooling (electric only) components.

- ***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 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 households when specifying both natural gas and electric billing analysis models.[44] 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

[44] 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.

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.[45]

- ***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 Section 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.

### Comparison Group

The Evaluation Team used a comparison group in conducting a billing analysis consistent with the discussion from Section 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.

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

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 if these effects cannot be discerned, such as 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 Findings sections present these best estimates at the measure level as evaluated gross savings and compares those 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 65 and Table 66 for HES, and Table 96 and Table 97 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 J. 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 64 and Table 95, below. Given the method used, analysis defined the resulting savings as adjusted gross savings.

### *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 64 and

Table 95 for HES and HES-IE, respectively.[46] The nonparticipant adjustment based on the comparison group is used to account for exogenous factors or impacts on energy use not related to the program. Since savings are being adjusted based on a comparison group of "future" program participants and not a true control group (i.e., randomized controlled trial experimental design), the adjusted gross savings should not account for freeridership and spillover.[47] For these reasons, these savings are defined as *adjusted gross savings* for this analysis.[48]

The program-level "reported" savings presented in Table 64 and Table 95 do not match the "*ex ante*" savings presented in the tables in *Appendix J. Detailed Distribution of Total Savings* due to discrepancies between savings totals from the program-tracking data received and the savings reported in the Plan.

It 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.[49]

## Billing Analysis

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

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46 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.

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

48 The EEB Evaluation Consultant and Evaluation Team are engaged in planning an additional evaluation study focused on NTG for these programs, primarily for HES. It is common best practice within the energy efficiency EM&V community to assume that the NTG ratio for low-income programs is 1.0, since these participants are unlikely to install these measures on their own due to significant affordability barriers.

49 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.

The measure-level models estimate savings by comparing the change in usage for each measure, accounting for interactions with the other measures installed. First, measure-specific model terms and their interactions with HDDs and CCDs (electric only) were included to reference pre-period baseline usage levels for each measure. Next, the models obtained the total weather-normalized incremental savings for each measure in three components (e.g., base load, heating, and cooling [in electric only]) by including interactions with measure installations and HDDs and CDDs with the post-period indicator.

For the heating and cooling terms, the measure-specific TMY3 normal averages were multiplied by the measure-specific heating and cooling degree averages. Savings from the three components were summed up to obtain the savings delta from each measure. The models corrected for differences in pre- and post-period weather and to normalize the weather to TMY3 weather conditions, as the weather in the analysis period might not be the same as normal weather conditions.

### *Model Attrition*

As noted, attrition associated with measure-level analysis matches the discussion of participant and nonparticipant group model attrition presented in Section 1. *Appendix C. Model* Attrition provides more detail on model attrition for HES and HES-IE analyses.

## 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 I. 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 algorithms were used where an installed unit proved more efficient than a defined baseline or standard; retirement savings algorithms were used 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 H. Engineering Review* and the Findings sections provide further discussions of algorithm-based calculations and assumptions.

The Evaluation Team acknowledges that code and standard 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 codes and standards. 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. Section 1 of this report presents further details regarding this approach.

### Lighting Interactive Effects

As this study was being completed, an additional study was also being conducted to investigate interactive effects due to the installation of residential energy efficient lighting.[50] Because the methodology in this study utilized billing analysis to determine the savings realization rate for a few measures, these realization rates may partially reflect lighting interactive effects (e.g., the measured gas savings for a heating measure may have been penalized due to the installation of energy efficient lighting, which produces less waste heat then standard efficiency lighting), along with various other effects (including measure interaction, energy education, behavioral/household changes, take-back, spillover). *Appendix L. Lighting Interactive Effect Adjustments* provides further detail regarding measure-specific adjustments that can be applied to consider these impacts independent of lighting interaction. Table 63 presents the final adjustment factors derived through this process. Note these results are

[50] See "R67: Residential Lighting Interactive Effects Memo", NMR Group, December 20, 2014.

presented within this appendix (and table below) and are not reincorporated in reporting overall program savings

**Table 63. HES and HES-IE Gas Measure Lighting IE Factor Adjustments**

| Program | Category | Measure | Reported *Ex ante* Savings (CCF/ HH) (A) | Evaluated Gross Savings (CCF/HH) (B) | Interactive Gas (CCF/HH) Adjustment (C) | Adjusted Gross Savings (CCF/HH) (D) | Adjusted Realization Rate (D/A) |
|---|---|---|---|---|---|---|---|
| HES | Shell | Air Sealing | 62 | 57 | 14.9 | 71.9 | 116% |
| HES-IE | HVAC | Heating System Replacement | 128 | 107 | 1.4 | 108.4 | 85% |
| HES-IE | Shell | Air Sealing | 59 | 36 | 7.6 | 43.6 | 74% |
| HES-IE | Shell | Wall Insulation | 304 | 96 | 3.3 | 99.3 | 33% |

## Section 2: 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 64 presents the evaluated adjusted gross electric and gas energy savings for the 2011 HES program.

**Table 64. 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 | 22,110 | 3,774 | 382 |
| Realization Rate | 111% | | 64% |

*Program-level evaluated savings and realization rates for oil and propane are not presented due to incomplete *ex ante* savings available in the utility tracking data and because these fuel savings are not reported in the 2013–2015 Plan.

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 11 and Figure 12 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 11. Measure Distribution of 2011 HES Electric Savings, *Ex Ante* and Evaluated

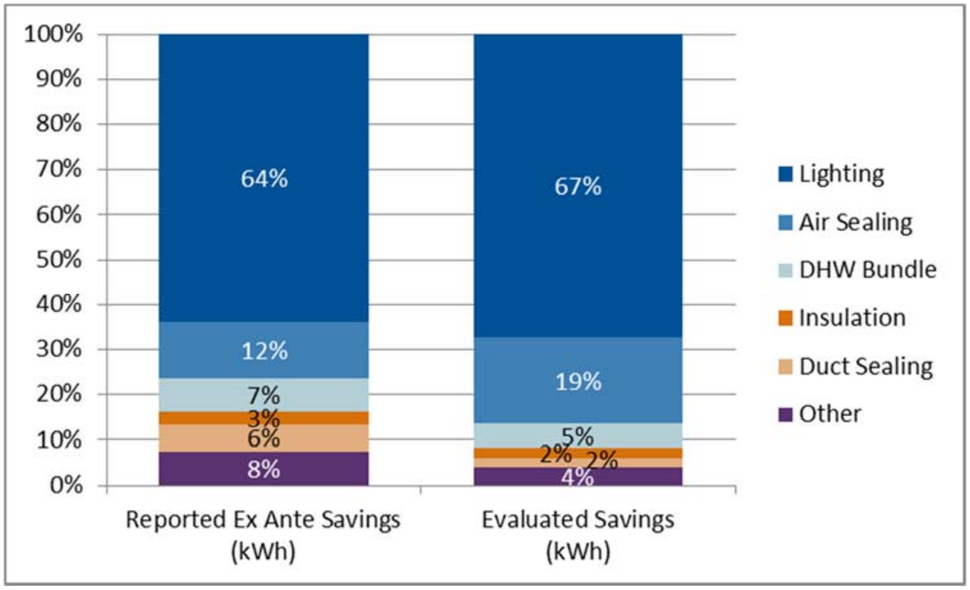


Figure 12. Measure Distribution of 2011 HES Gas Savings, *Ex Ante* and Evaluated

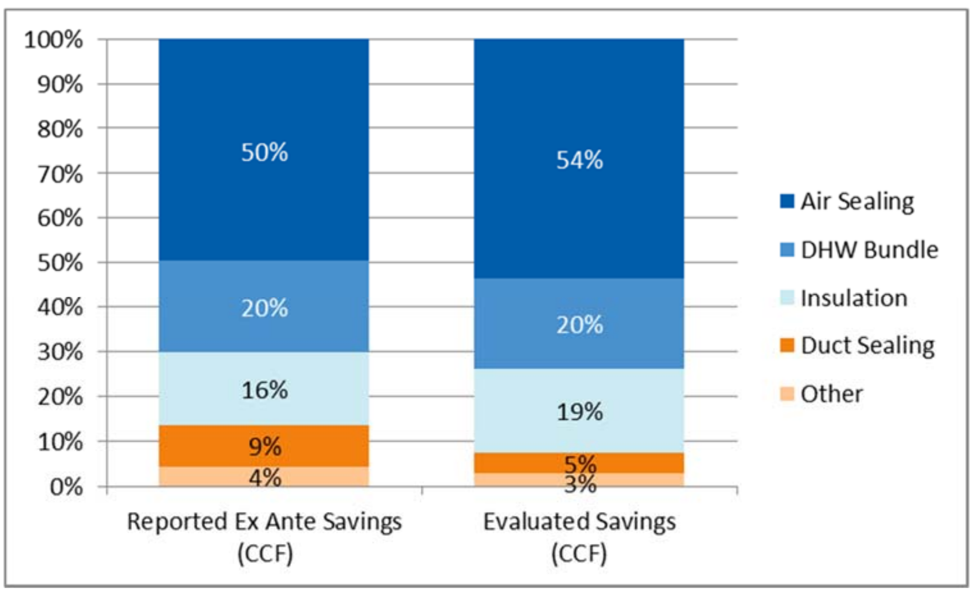

Table 65 and Table 66 present the distribution of HES electric and gas savings at the measure-level, comparing reported *ex ante* savings to estimates of evaluated gross savings. The savings estimates below reflect average household savings for participants receiving a given measure.[51]

**Table 65. 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 | 39 | 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.

[51] For measure-specific per-unit savings estimates (outside of a program context), realization rates included in Table 65 and Table 66 should be applied without inclusion of a nonparticipant adjustment factor. From the context of evaluating program savings for a specific year, the nonparticipant adjustment factor should be applied to understand the true program-level influence (e.g., controlling for exogenous effects).

**While the billing analysis estimate falls below *ex ante* savings, it should be noted that the billing analysis estimate implicitly assumes an existing equipment baseline rather than replacement with a standard baseline unit.

**Table 66. 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 67 and Table 68 provide notes regarding considerations or implications for the PSD.

**Table 67. 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 regards to the 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. |

| Measure | Percent of Total Evaluated Savings | Consideration |
| --- | --- | --- |
| 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 68. 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.[52] Table 69 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 69. 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 70 provides the realization rate, based on comparing the gross savings estimate from the billing analysis to the average *ex ante* savings per household.[53]

**Table 70. 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% |

52 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.

53 Findings appear consistent with the realization rates calculated using the *Northeast Residential Lighting Hours-of-Use Study* (R3) (Source: Glenn Reed e-mail “RE: PSD update: HES/HES-IE Realization Rates.” September 22, 2014.)

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");[54] some similar programs restrict installation to high-use sockets (e.g., three hours or more), ensuring higher savings associated with 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.[55] Figure 13 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.[56]

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54 *2012 Home Energy Solutions: Field Implementation Manual*. p. 48.

55 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.

56 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

Figure 13. HES—Per Unit Lighting Savings Based on Number of Installations

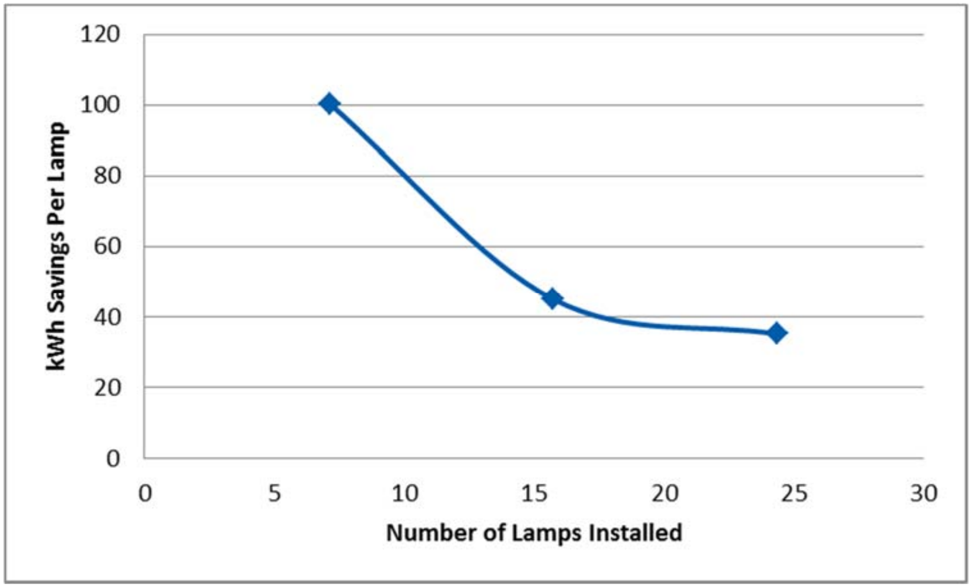


Table 71 presents additional details regarding lighting installations by the quantity received (binned in categories of 1 to 10, 11 to 20, and greater than 20 lighting installations). As shown, average savings per bulb decrease within each category as more bulbs are installed per home.

Table 71. 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 72 presents the corresponding billing analysis model results.

**Table 72. 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 73 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 73. HES Billing Analysis Realization Rate Summary for Air Sealing**

| 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 |
|---|---|---|---|---|---|
| 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 74 presents these details, including average pre- and post-installation insulation levels (weighted by square footage installed) and changes in duct-sealing levels (i.e., cubic feet per minute [CFM]).

**Table 74. 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 75 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 75. 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.[57] Table 76 lists the participation, average installed units, average household savings, and realization rates of window measure installations.

[57] 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 76. 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 77 presents the billing analysis model results for the DHW measure bundle, which achieved a precision estimate below the study threshold.

Table 77. 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% |

Table 78 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 78. 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 H. Engineering Review* presents these detailed findings.

### HVAC

The Evaluation Team estimated impacts for several HVAC measures using a combination of billing analysis and engineering algorithms. Table 79 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 79. 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 80 presents the corresponding billing analysis model results.

**Table 80. 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 81 provides realization rates, based on comparing evaluated savings to average *ex ante* savings per household.

**Table 81. 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 H. Engineering* presents these detailed findings.

As a point of comparison, the Evaluation Team benchmarked the current model savings against a recent ductless heat pump on-site metering study, performed by KEMA. This provided the source of the PSD estimate. A statistically significant difference appears to occur between these estimates, with the current billing analysis estimates showing slightly better precision. While both studies rely on primary data, different program years and participant types (e.g., variations in customer usage, building types, baselines, and HES participant vs. standalone equipment replacement) may contribute to differences in evaluated savings. *Appendix H. Engineering Review* presents these detailed findings.

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).[58] 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.

The primary driver of realizations for geothermal heat pump installations resulted from the 2011 and 2013 PSDs using the same algorithms, with very slight changes in inputs between the two years.[59] 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.

58 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.

59 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 ($COP_b$).

### 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 82 provides the distribution of participants, average *ex ante* and evaluated savings, and a realization for HES appliance measures.

**Table 82. 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 | 39 | 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.[60] 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 463 kWh for installed refrigerators and 567 kWh for installed freezers.

The Evaluation Team used the 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 algorithms for estimating the 2001 Federal Standard were based on the adjusted volume (AV)[61] of the installed unit. Table 83 and Table 84 provide these details for baseline and new unit consumption for freezers and refrigerators.

60 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.

61 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 83. Average 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 | 716.5 | 642 |
| Chest freezers and all other freezers except compacts | (9.88 * AV) + 143.7 | 415.2 | 342 |
| Overall Average Baseline Usage | | 633 | 567 |

*Lookup table provided in the PSD, based on 2001 Federal Standard.

### Table 84. Average 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 ($E_{fed\ std}$).

The Evaluation Team also assumed adjust volume is consistent between new and existing units.[62]

[62] 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.

For refrigerators and freezers, the primary factors driving the realization rates were the evaluated energy consumption of the installed and baseline units, compared to *ex ante* savings assumptions. 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., 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 determine 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 defined baseline MEF ($MEF_b$) as 1.8 cubic feet/kWh per cycle for units with unknown fuel type. The evaluated electric realization rate was 45%, with per-unit and per-household savings of 664 kWh.[63]

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.[64] The utility tracking data provide make and model of the installed units, and the 2012 Federal Standard represents the baseline unit efficiency, as shown in Table 85.

63 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.

64 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 85. Average Dehumidifier Efficiency and Installations**

| Capacity (Pints/day) | Baseline 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.

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 86 presents the billing analysis model results.

**Table 86. 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 87 provides the realization rate based on comparing the gross savings estimate from the billing analysis to average *ex ante* savings per household.

**Table 87. 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 88 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 88. 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 89 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 89. 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.[65] Table 90 lists: participation; average installed units; average household savings; and realization rates of window measure installations.

**Table 90. 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 H. Engineering Review* presents these detailed findings.

Table 91 lists the participation, average installed units, average household savings, and realization rates of DHW measure installations.

[65] 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 91. 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.[66] 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 91.

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.[67] 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. This realization rate is higher than 100% due to instances in the program tracking data where *ex ante* savings were not claimed.

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66 Based on the input comparison for aerator and showerhead savings algorithms (cited in *Appendix H. Engineering Review*), changes made to average annual water savings appeared to move in the right direction compared to the 2011 assumptions; however, these inputs may have been overly adjusted in comparison to other studies.

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

### 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 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. While the measure category "heating system replacement" in the utility tracking data can include installations of new energy-efficient boilers and furnaces, only efficient furnaces occurred under the 2011 HES program.

Based on the utility tracking data, the average efficiency of installed units was 96% AFUE ($AFUE_E$), average baseline efficiency was 76.5 AFUE ($AFUE_B$), and average heated area ($A$) was 2,325 square feet.[68] Table 92 provides the distribution of participants, average *ex ante* and evaluated savings, and a realization for HES appliance measures.

**Table 92. 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% |

While using the retrofit savings calculation, 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 93 provides the distribution of participants, average *ex ante* and evaluated savings, and the realization rate for HES appliance measures.

**Table 93. 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

[68] 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 94 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 94. 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.

## *Section 2: 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 95 presents evaluated adjusted gross electric and gas energy savings for the 2011 HES-IE program.

**Table 95. 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 | 19,950 | 1,237 | 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 14 and Figure 15 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 14. Measure Distribution of 2011 HES-IE Electric Savings, *Ex Ante* and Evaluated**

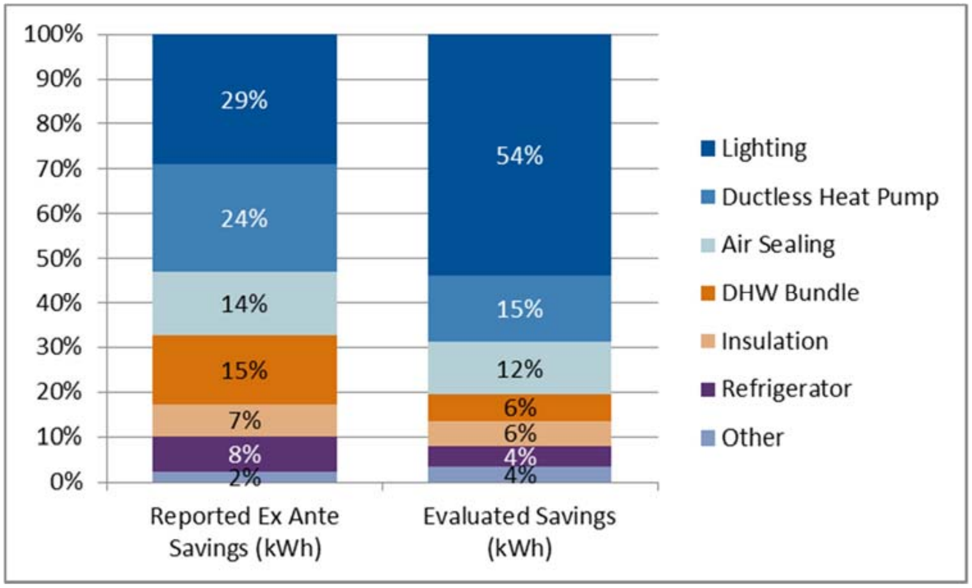
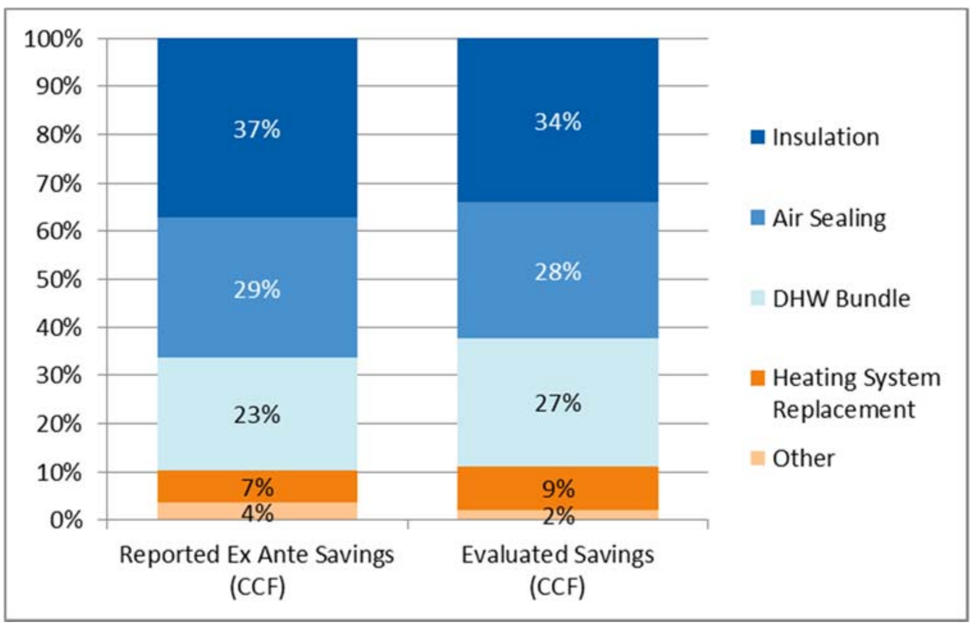



**Figure 15. Measure Distribution of 2011 HES-IE Gas Savings, *Ex Ante* and Evaluated**




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 DHW measures also accounted for a high proportion of *ex ante* savings (90%) and had lower measure-specific realization rates.

Table 96 and Table 97 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.[69]

**Table 96. 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.

69 For measure-specific per-unit savings estimates (outside of a program context), realization rates included in Table 96 and Table 97 should be applied without inclusion of a nonparticipant adjustment factor. From the context of evaluating program savings for a specific year, the nonparticipant adjustment factor should be applied to understand the true program-level influence (e.g., controlling for exogenous effects).

Table 97. 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 98 and Table 99 provide notes regarding implications for the PSD.

Table 98. 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. |

| Measure | Percent of Total Evaluated Savings | Consideration |
|---|---|---|
| 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 99. 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. |

| Measure | Percent of Total Evaluated Savings | Consideration |
|---|---|---|
| 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.[70] Table 100 presents the billing analysis model results for lighting measures, which achieved a precision estimate within the study threshold.

**Table 100. 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.

70 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 101 provides realization rates, based on comparing the gross savings estimate from the billing analysis to the average *ex ante* savings per household.

**Table 101. 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.[71] 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.[72] Figure 16 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).

[71] *2013 Home Energy Solutions –Income Eligible: Field Training Manual*. p. 8 and p. 40.

[72] 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 16. HES-IE—Per-Unit Lighting Savings, Based on Number of Installations

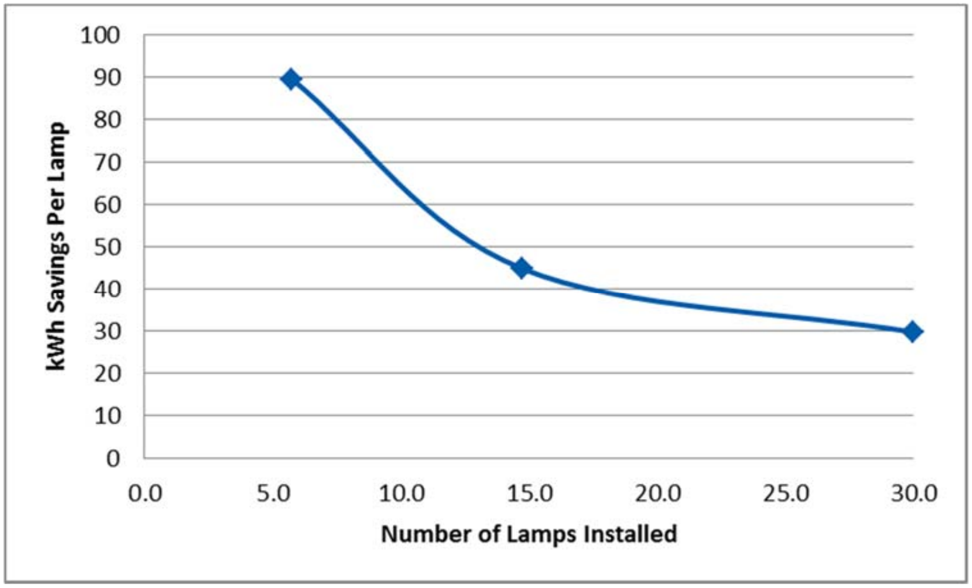



Table 102 presents additional details regarding lighting installations by the quantity received (binned in categories of 1 to 10, 11 to 20, and greater than 20 lighting installations). As shown, average savings per bulb decrease within each category as more bulbs are installed per home.

Table 102. 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 103 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 103. 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 104 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 104. 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.[73] Table 105 lists the participation, average installed units, average household savings, and realization rates of window measure installations.

Table 105. 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 H. Engineering Review* presents these detailed findings.

Table 106 lists the participation, average installed units, average household savings, and realization rates of DHW measure installations.

Table 106. 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.

73 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.

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.[74] 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 107 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 107. 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 108 presents the corresponding billing analysis model results.

**Table 108. 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 109 provides realization rates based on comparing the evaluated savings to the average *ex ante* savings per household.

[74] 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.

**Table 109. 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% |
| Central AC | 98 | 98 | 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 H. Engineering Review* 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).[75] 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.

Similar to HES, the Evaluation Team benchmarked current model savings against a recent ductless heat pump on-site metering study performed by KEMA, providing the PSD estimate source. A statistically significant difference appeared to occur between these estimates, with the current billing analysis estimates showing slightly better precision. While both studies relied on primary data, different program years and participant types (e.g., variations in customer usage, building types, baselines, HES-IE participant vs. standalone equipment replacement) may contribute to differences in evaluated savings. *Appendix H. Engineering Review* presents these detailed findings.

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,

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

meaning only the efficiency of the newly installed unit presented a difference between *ex ante* and evaluated gross savings.[76]

### Appliances

The Evaluation Team used the billing analysis to estimate impacts for refrigerator and freezer replacements. Table 110 presents the billing analysis model results for these appliances, which achieved a precision estimate within the study threshold.

**Table 110. 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% |
| 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 111 provides realization rates based on comparing the gross savings estimate (from the billing analysis) to the average *ex ante* savings per household.

**Table 111. 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).

76 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.

### *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 112 presents the corresponding billing analysis model results.

**Table 112. HES-IE Billing Analysis Gas Savings Results for Air Sealing and Wall Insulation**

| Measure | n | PRENAC | Model Savings (CCF) | Savings as Percent of Pre-Usage | Relative Precision at 90% |
|---|---|---|---|---|---|
| Air Sealing | 984 | 932 | 36 | 4% | ±31% |
| Wall Insulation | 162 | 975 | 96 | 10% | ±30% |

Table 113 provides realization rates, based on comparing the gross savings estimate (from the billing analysis) to average *ex ante* savings per household.

**Table 113. 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 114 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 114. 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 115 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 115. 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.[77] Table 116 lists the participation, average installed units, average household savings, and realization rates of window measure installations.

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77 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 116. 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 117 presents the billing analysis model results for the DHW measure bundle, which achieved a precision estimate within the study threshold.

Table 117. 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 118 provides realization rates, based on comparing the gross savings estimate from the billing analysis to the average *ex ante* savings per household.

Table 118. 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 |
|---|---|---|---|---|---|
| DHW Bundle | 29 | 41 | 72% | 3% | 5% |

Table 119 lists the participation, average household savings, and realization rate for water heater temperature setback.[78]

[78] 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.

**Table 119. 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 120 presents the billing analysis model results for these measures, which achieved a precision estimate within the study threshold.

**Table 120. 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 121 provides realization rates, based on comparing the gross savings estimate from the billing analysis to the average *ex ante* savings per household.

**Table 121. 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 122 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 discussed the analytical methods used to calculate gas savings specific to each measure.

**Table 122. 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 | 0.7419 | 26 | 1.1267 | 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 | | 2.2 | | 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.

## Recommendations

### General

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. 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 2 levels.

# Appendix A. Billing Analysis Fixed-Effects Model Specifications—Whole House

## Model Specification: Gas Whole House

To estimate gas energy savings from the HES and HES-IE programs, a pre- and post-installation savings analysis fixed-effects modeling method was used, which used 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 following model specification determined overall savings:[79]

$$ADC_{it} = \alpha_i + \Phi_i AVGHDD_{it} + \beta_1 POST_i + \beta_2 POST_i * AVGHDD_{it} + \varepsilon_{it}$$

Where for each participant or nonparticipant customer “i” and monthly billing period “t”:

| | | |
|---|---|---|
| $ADC_{it}$ | = | the average daily CCF consumption during the pre- or post-installation program period. |
| $\alpha_i$ | = | the average daily CCF base-load intercept for each customer. (This is part of the fixed-effects specification.) |
| $\Phi_i$ | = | the baseline usage per HDD for each customer. |
| $AVGHDD_{it}$ | = | the average daily base 65 HDDs, based on home location. |
| $\beta_1$ | = | the average daily whole-house base-load CCF savings. |
| $POST_i$ | = | an indicator variable that is 1 in the post-period (after the latest measure installation) and 0 in the pre-period (prior to participation). |
| $\beta_2$ | = | the whole-house heating CCF savings per heating degree-day. |
| $POST_i * AVGHDD_{it}$ | = | an interaction between the *POST* indicator variable and the heating degree-days (*AVGHDD*). |
| $\varepsilon_{it}$ | = | the modeling estimation error. |

## Model Specification: Electric Whole House

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

79 Indicator variables for non-HES/HES-IE program participation were not included in the gas modeling, given a participation rate of 0.2% for these other energy-efficiency programs. There was only other-program participation during the pre-period. The models that incorporated these indicators of non-HES/HES-IE program participation yielded identical savings estimates to the models without these variables.

- 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 model estimates savings after accounting for other non-HES/HES-IE program participation and HER participation. The following model specification determined overall savings:

$$
\begin{aligned}
ADC_{it} = {} & \alpha_i + \beta_1 AVGHDD_{it} + \beta_2 AVGCDD_{it} + \beta_3 OTHERPROG_i * \ AVGHDD_{it} \\
& + \beta_4 OTHERPROG_i * \ AVGCDD_{it} + \beta_5 HER_i * \ AVGHDD_{it} + \beta_6 HER_i * \ AVGCDD_{it} \\
& + \beta_7 POST_i \ + \beta_8 POST_i * AVGHDD_{it} + \beta_9 POST_i * AVGCDD_{it} \ + \beta_{10} OTHERPROG_i \\
& * POST_i + \beta_{11} HER_i * POST_i + \varepsilon_{it}
\end{aligned}
$$

Where for each participant or nonparticipant customer "i" and monthly billing period "t":

| | | |
|---|---|---|
| $ADC_{it}$ | = | the average daily kWh consumption during the pre- or post-installation program period. |
| $\alpha_i$ | = | the average daily kWh base-load intercept for each customer. (This is part of the fixed effects specification.) |
| $\beta_1$ | = | the average daily per heating degree-day usage in the pre-period. |
| $AVGHDD_{it}$ | = | the average daily base 65 HDDs, based on home location. |
| $\beta_2$ | = | the average daily per cooling degree-day usage in the pre-period |
| $AVGCDD_{it}$ | = | the average daily base 65 CDDs, based on home location. |
| $OTHERPROG_i$ | = | an indicator variable for other program participation (other than HER). |
| $HER_i$ | = | an indicator variable for HER program participation. |
| $\beta_3$ | = | the incremental per heating degree-day usage in the pre-period from other program participation. |
| $OTHERPROG_i *AVGHDD_{it}$ = | | interaction of other program participation and AVGHDD. |
| $\beta_4$ | = | the incremental per cooling degree-day usage in the pre-period from other program participation. |
| $OTHERPROG_i *AVGCDD_{it}$ = | | interaction of other program participation and AVGHDD. |
| $B_5$ | = | the incremental per heating degree-day usage in the pre-period from HER program participation. |
| $HER_i *AVGHDD_{it}$= | | interaction of HER program participation and AVGHDD. |
| $\beta_{\backslash 6}$ | = | the incremental per cooling degree-day usage in the pre-period from HER program participation. |
| $HER_i *AVGCDD_{it}$ = | | interaction of HER program participation and AVGHDD. |
| $\beta_7$ | = | the average daily whole-house program base-load kWh savings. |
| $POST_i$ | = | an indicator variable that is 1 in the post-period (after the latest measure installation) and 0 in the pre-weatherization period. |

| | | |
|---|---|---|
| $\beta_8$ | = | the whole-house heating kWh savings per heating degree-day. |
| $POST_i * AVGHDD_{it}$ | = | an interaction between the *POST* indicator variable and the heating degree-days (*AVGHDD*). |
| $\beta_9$ | = | the whole-house cooling kWh savings per cooling degree-day |
| $POST_i * AVGCDD_{it}$ | = | an interaction between the *POST* indicator variable and the cooling degree-days (*AVGCDD*). |
| $\beta_{10}$ | = | the average daily other program kWh savings. |
| $OTHERPROG_i * POST_i$ | = | an interaction of OTHERPROG and an indicator variable that is 1 in the post-period (after the other program participation date) and 0 in the pre-other participation program period. |
| $\beta_{11}$ | = | the average daily HER program kWh savings. |
| $HER_i * POST_i$ | = | an interaction of HER and an indicator variable that is 1 in the post-period (after the HER program participation date) and 0 in the pre-HER participation program period. |
| $\varepsilon_{it}$ | = | the modeling estimation error. |

# Appendix B. PRISM Model Specifications

The heating and cooling PRISM model was estimated in both the pre- and post-period for each customer using the following specification:[80]

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

Where for each customer “i” and calendar month “t”:

$ADC_{it}$ = average daily CCF or kWh consumption in the pre- or post-program period.

$\alpha_i$ = the participant intercept, representing the average daily CCF or kWh base load.

$\beta_1$ = the model space heating slope (used only in the heating only, heating + cooling model).

$AVGHDD_{it}$ = the base 65 average daily HDDs for the specific location (used only in the heating only, heating + cooling model).

$\beta_2$ = the model space cooling slope (used only in the cooling only, heating + cooling model).

$AVGCDD_{it}$ = the base 65 average daily CDDs for the specific location (used only in the cooling only, heating + cooling model).

$\varepsilon_{it}$ = the error term.

Using the above model, weather-NAC could be computed as:[81]

$$NAC_i = \alpha_i * 365 + \beta_1 LRHDD_{it} + \beta_2 LRCDD_{it} + \varepsilon_{it}$$

Where, for each customer “i”:

$NAC_i$ = normalized annual CCF or kWh consumption.

$\alpha_I$ = the intercept equaling the average daily or base load for each participant, representing the average daily base load from the model.

$\alpha_i * 365$ = annual base-load CCF or kWh usage (non-weather sensitive).

$\beta_1$ = the heating slope (in effect, usage per heating degree from the model above).

$LRHDD_i$ = the annual, long-term HDDs of a TMY3 in the 1991–2005 series from NOAA, based on home location

$\beta_1 * LRHDD_i$ = weather-normalized, annual weather-sensitive (heating) usage (i.e., HEATNAC)

---

[80] For gas savings models, cooling data and parameters are omitted (i.e., $\beta_2$, $AVGCDD_{it}$).

[81] For gas savings models, cooling data and parameters are omitted (i.e., $\beta_2$, $LRCDD_i$).

| | | |
|---|---|---|
| $\beta_2$ | = | the cooling slope; in effect, usage per cooling degree from the model above |
| $LRCDD_i$ | = | the annual, long-term CDDs of a TMY3 in the 1991–2005 series from NOAA, based on home location |
| $\beta_2 * LRCDD_i$ | = | weather-normalized, annual weather-sensitive (cooling) usage (i.e., COOLNAC) |
| $\varepsilon_i$ | = | the error term |

# Appendix C. Model Attrition

## *HES Program*

**Table 123. Participant Attrition: Electric Analysis (HES)**

| Screen | Participants Remaining | Percent Remaining | Number Dropped | Percent Dropped |
|---|---|---|---|---|
| Original electric accounts | 19,320 | 100% | 0 | 0% |
| Matched to billing data provided | 17,348 | 90% | 1,972 | 10% |
| Insufficient pre- and post-period months | 15,308 | 79% | 2,040 | 11% |
| Changed usage from the pre to post (> 70%) | 15,240 | 79% | 68 | 0% |
| *Ex ante* savings higher than pre-usage, or *ex ante* savings <1% of pre-usage | 14,946 | 77% | 294 | 2% |
| Pre- or post-period usage less than 1000 kWh | 14,937 | 77% | 9 | 0% |
| PRISM screen: wrong signs on PRISM parameters | 14,872 | 77% | 65 | 0% |
| Account-level inspection of pre/post 12-month usage (e.g., vacancies, anomalies) | 11,110 | 58% | 3,762 | 19% |
| **Final analysis group** | **11,110** | **58%** | **8,210** | **42%** |

**Table 124. Comparison Group Attrition: Electric Analysis (HES)**

| Screen | Participants Remaining | Percent Remaining | Number Dropped | Percent Dropped |
|---|---|---|---|---|
| Original electric accounts | 12,391 | 100% | 0 | 0% |
| Matched to billing data provided | 12,077 | 97% | 314 | 3% |
| Insufficient pre- and post-period months | 8,677 | 70% | 3,400 | 27% |
| Changed usage from the pre to post (> 70%) | 8,602 | 69% | 75 | 1% |
| Pre- or post-period usage less than 1000 kWh or more than maximum participant usage | 8,593 | 69% | 9 | 0% |
| PRISM screen: wrong signs on PRISM parameters | 8,547 | 69% | 46 | 0% |
| **Final analysis group** | **8,547** | **69%** | **3,844** | **31%** |

Table 125. Participant Attrition: Gas Analysis (HES)

| Screen | Participants Remaining | Percent Remaining | Number Dropped | Percent Dropped |
|---|---|---|---|---|
| Original gas accounts | 4,922 | 100% | 0 | 0% |
| Matched to billing data provided | 2,718 | 55% | 2,204 | 45% |
| Insufficient pre- and post-period months | 2,369 | 48% | 349 | 7% |
| Changed usage from the pre to post (> 70%) | 2,346 | 48% | 23 | 0% |
| *Ex ante* savings higher than pre-usage, or *ex ante* savings <1% of pre-usage | 2,145 | 44% | 201 | 4% |
| Pre- or post-period usage less than 200 therms | 2,071 | 42% | 74 | 2% |
| PRISM screen: wrong signs on PRISM parameters | 2,028 | 41% | 43 | 1% |
| Account-level inspection of pre/post 12-month usage (e.g., vacancies, anomalies) | 1,862 | 38% | 166 | 3% |
| **Final analysis group** | **1,862** | **38%** | **3,060** | **62%** |

Table 126. Comparison Group Attrition: Gas Analysis (HES)

| Screen | Participants Remaining | Percent Remaining | Number Dropped | Percent Dropped |
|---|---|---|---|---|
| Original gas accounts | 3,290 | 100% | 0 | 0% |
| Matched to billing data provided | 2,039 | 62% | 1,251 | 38% |
| Insufficient pre- and post-period months | 1,312 | 40% | 727 | 22% |
| Changed usage from the pre to post (> 70%) | 1,288 | 39% | 24 | 1% |
| Pre- or post-period usage less than 200 therms or more than max part usage | 1,221 | 37% | 67 | 2% |
| PRISM screen: wrong signs on PRISM parameters | 1,192 | 36% | 29 | 1% |
| **Final analysis group** | **1,192** | **36%** | **2,098** | **64%** |

## *HES-IE Program (SP2/SP3)*

**Table 127. Participant Attrition: Electric Analysis (HES-IE)**

| Screen | Participants Remaining | Percent Remaining | Number Dropped | Percent Dropped |
|---|---|---|---|---|
| Original electric accounts | 11,577 | 100% | 0 | 0% |
| Matched to billing data provided | 11,395 | 98% | 182 | 2% |
| Insufficient pre- and post-period months | 8,378 | 72% | 3,017 | 26% |
| Changed usage from the pre to post (> 70%) | 8,325 | 72% | 53 | 0% |
| *Ex ante* savings higher than pre-usage, or *ex ante* savings <1% of pre-usage | 7,815 | 68% | 510 | 4% |
| Pre- or post-period usage less than 1000 kWh | 7,782 | 67% | 33 | 0% |
| PRISM screen: wrong signs on PRISM parameters | 7,705 | 67% | 77 | 1% |
| Account-level inspection of pre/post 12-month usage (e.g., vacancies, anomalies) | 5,481 | 47% | 2,224 | 19% |
| **Final analysis group** | **5,481** | **47%** | **6,096** | **53%** |

**Table 128. Comparison Group Attrition: Electric Analysis (HES-IE)**

| Screen | Participants Remaining | Percent Remaining | Number Dropped | Percent Dropped |
|---|---|---|---|---|
| Original electric accounts | 9,103 | 100% | 0 | 0% |
| Matched to billing data provided | 8,721 | 96% | 382 | 4% |
| Insufficient pre- and post-period months | 5,690 | 63% | 3,031 | 33% |
| Changed usage from the pre to post (> 70%) | 5,599 | 62% | 91 | 1% |
| Pre- or post-period usage less than 1000 kWh or more than maximum participant usage | 5,497 | 60% | 102 | 1% |
| PRISM screen: wrong signs on PRISM parameters | 5,430 | 60% | 67 | 1% |
| **Final analysis group** | **5,430** | **60%** | **3,673** | **40%** |

Table 129. Participant Attrition: Gas Analysis (HES-IE)

| Screen | Participants Remaining | Percent Remaining | Number Dropped | Percent Dropped |
|---|---|---|---|---|
| Original gas accounts | 5,120 | 100% | 0 | 0% |
| Matched to billing data provided | 2,374 | 46% | 2,746 | 54% |
| Insufficient pre- and post-period months | 1,872 | 37% | 502 | 10% |
| Changed usage from the pre to post (> 70%) | 1,864 | 36% | 8 | 0% |
| *Ex ante* savings higher than pre-usage, or *ex ante* savings <1% of pre-usage | 1,529 | 30% | 335 | 7% |
| Pre; or post-period usage less than 200 therms | 1,480 | 29% | 49 | 1% |
| PRISM screen: wrong signs on PRISM parameters | 1,446 | 28% | 34 | 1% |
| Account-level inspection of pre/post 12-month usage (e.g., vacancies, anomalies) | 1,250 | 24% | 196 | 4% |
| **Final analysis group** | **1,250** | **24%** | **3,870** | **76%** |

Table 130. Comparison Group Attrition: Gas Analysis (HES-IE)

| Screen | Participants Remaining | Percent Remaining | Number Dropped | Percent Dropped |
|---|---|---|---|---|
| Original gas accounts | 3,738 | 100% | 0 | 0% |
| Matched to billing data provided | 1,759 | 47% | 1,979 | 53% |
| Insufficient pre- and post-period months | 846 | 23% | 913 | 24% |
| Changed usage from the pre to post (> 70%) | 831 | 22% | 15 | 0% |
| Pre- or post-period usage less than 200 therms or more than max part usage | 668 | 18% | 163 | 4% |
| PRISM screen: wrong signs on PRISM parameters | 644 | 17% | 24 | 1% |
| **Final analysis group** | **644** | **17%** | **3,094** | **83%** |

## *HES-IE Program (SP1 and SP4)*

**Table 131. 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 132. 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 133. 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 134. 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 135. 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 136. 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 D. Frequency Distribution of Measure Installations from Participant Analysis Samples—Whole House

Table 137. Frequency Distribution of Electric Measures for HES and HES-IE Participant Samples, by Utility Program and Overall

| Category | Measure | HES | | | HESIE (SP2/SP3) | | |
|---|---|---|---|---|---|---|---|
| | | CLP | UI | Overall | CLP | UI | Overall |
| Lighting | Lighting | 97% | 97% | 97% | 84% | 96% | 89% |
| Shell | Air sealing | 76% | 67% | 74% | 32% | 53% | 41% |
| | Attic insulation | n/a | <1% | <1% | 9% | 2% | 6% |
| | Wall insulation | n/a | <1% | <1% | 2% | <1% | 1% |
| | Insulation other* | 4% | n/a | 3% | 2% | n/a | 1% |
| | Windows | <1% | n/a | <1% | 2% | n/a | 1% |
| Water heat | DWH bundle** | 16% | 9% | 14% | 40% | 21% | 32% |
| | Water heater Replacement | n/a | n/a | n/a | 3% | n/a | 2% |
| | Heat pump water heater | <1% | <1% | <1% | n/a | n/a | n/a |
| HVAC | Duct sealing | 15% | 30% | 19% | <1% | 4% | 2% |
| | Heating system replacement | <1% | <1% | <1% | n/a | n/a | n/a |
| | Heat pump | <1% | <1% | <1% | 2% | n/a | 1% |
| | Ductless heat pump | <1% | <1% | <1% | 21% | 7% | 15% |
| | Ground-source heat pump | <1% | n/a | <1% | n/a | n/a | n/a |
| | Window AC | n/a | n/a | n/a | 4% | n/a | 2% |
| | Central AC | 1% | 4% | 2% | n/a | <1% | <1% |
| Appliance | Clothes washer | <1% | <1% | <1% | n/a | n/a | n/a |
| | Dehumidifier | <1% | <1% | <1% | n/a | n/a | n/a |
| | Freezer | <1% | n/a | <1% | 3% | n/a | 2% |
| | Refrigerator | <1% | 1% | <1% | 26% | n/a | 15% |
| | Appliance other*** | n/a | n/a | n/a | n/a | 13% | 5% |
| Other | Other | n/a | <1% | <1% | <1% | n/a | <1% |
| **Sample (n)** | | **8,695** | **2,415** | **11,110** | **3,196** | **2,285** | **5,481** |

*Projects that consist of insulation installations without available detail on location

**Contains a mix of low-flow showerheads, faucet aerators, and pipe insulation

***Projects composed of appliance installations with specific category details

**Table 138. Frequency Distribution of Gas Measures for HES and HES-IE Participant Samples, by Utility Program and Overall**

| Category | Measure | HES | | | | HESIE (SP2/SP3) | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | CNG | SCG | YGS | Overall | CNG | SCG | YGS | Overall |
| Shell | Air sealing | 90% | 97% | 91% | 92% | 77% | 96% | 68% | 79% |
| | Attic insulation | n/a | 3% | n/a | <1% | 5% | 4% | 26% | 12% |
| | Wall insulation | n/a | 1% | n/a | <1% | 12% | 3% | 22% | 13% |
| | Insulation other* | <1% | n/a | <1% | <1% | n/a | n/a | n/a | n/a |
| | Windows | n/a | n/a | <1% | <1% | 2% | n/a | 5% | 3% |
| Water heat | DWH bundle** | 81% | 78% | 76% | 78% | 82% | 90% | 63% | 77% |
| | Water heater replacement | n/a | n/a | n/a | n/a | 32% | <1% | 5% | 14% |
| HVAC | Duct sealing | 12% | 26% | 15% | 17% | n/a | 10% | <1% | 3% |
| | Heating system replacement | <1% | <1% | <1% | <1% | <1% | n/a | 12% | 5% |
| Appliance | Clothes washer | n/a | <1% | n/a | <1% | n/a | n/a | n/a | n/a |
| | Appliance other*** | n/a | n/a | n/a | n/a | n/a | 1% | n/a | <1% |
| Other | Other | n/a | n/a | n/a | n/a | <1% | n/a | 1% | <1% |
| **Sample (n)** | | **649** | **461** | **752** | **1,862** | **460** | **340** | **450** | **1,250** |

*Projects that consist of insulation installations without available detail on location
**Contains a mix of low-flow showerheads, faucet aerators, and pipe insulation
***Projects composed of appliance installations with specific category details

**Table 139. Frequency Distribution of Measure Installed for HES and HES-IE Participants with Oil / Propane Heating or Water Heating***

| Category | Measure | HES | | HES-IE (SP2/SP3) | |
|---|---|---|---|---|---|
| | | Oil | Propane | Oil | Propane |
| Shell | Air sealing | 94% | 95% | 77% | 91% |
| | Attic insulation | <1% | n/a | 9% | 9% |
| | Wall insulation | <1% | n/a | 6% | 5% |
| | Insulation other** | n/a | n/a | <1% | <1% |
| | Windows | n/a | n/a | 7% | 8% |
| Water heat | DWH bundle*** | 12% | 4% | 16% | 6% |
| | Low-flow showerhead | 34% | 36% | 48% | 57% |
| | Pipe insulation | 39% | 37% | 15% | 19% |
| | Faucet aerator | 37% | 39% | 55% | 76% |
| | Water heater set back | n/a | n/a | 6% | 14% |
| | Water heater replacement | <1% | n/a | <1% | <1% |
| | Heat pump water heater | <1% | n/a | <1% | <1% |
| HVAC | Duct sealing | 17% | 20% | 1% | <1% |
| | Heating system repair | n/a | n/a | <1% | <1% |
| | Heating system replacement | n/a | n/a | 3% | 3% |

| Category | Measure | HES | | HES-IE (SP2/SP3) | |
|---|---|---|---|---|---|
| | | Oil | Propane | Oil | Propane |
| Appliance | Clothes washer | <1% | n/a | <1% | <1% |
| Other | Other | 14% | 15% | n/a | n/a |
| **Sample (n)** | | **12,076** | **769** | **4,507** | **195** |

*CL&P HES-IE SP4 participants are not included in these frequencies.

**Projects that consist of insulation installations without available detail on location

***Contains a mix of low-flow showerheads and faucet aerators

**Table 140. Frequency Distribution of Electric Measures for HES and HES-IE Participant Samples, by HER Participation**

| Category | Measure | HES | | HES-IE (SP2/SP3) | |
|---|---|---|---|---|---|
| | | Non-HER | HER | Non-HER | HER |
| Lighting | Lighting | 97% | 98% | 89% | 89% |
| Shell | Air Sealing | 73% | 85% | 41% | 37% |
| | Attic Insulation | <1% | n/a | 6% | n/a |
| | Wall Insulation | <1% | n/a | 1% | 2% |
| | Insulation Other | 3% | 5% | 1% | n/a |
| | Windows | <1% | <1% | 1% | 2% |
| Water heat | DWH Bundle | 14% | 28% | 32% | 54% |
| | Water Heater Replacement | n/a | n/a | 1% | 6% |
| | Heat Pump Water Heater | <1% | n/a | n/a | n/a |
| HVAC | Duct Sealing | 18% | 21% | 2% | n/a |
| | Heat Pump | <1% | <1% | n/a | n/a |
| | Heating System Replacement | <1% | <1% | n/a | n/a |
| | Ductless Heat Pump | <1% | 1% | 15% | n/a |
| | Ground-Source Heat Pump | <1% | n/a | n/a | n/a |
| | Window AC | n/a | n/a | 2% | 9% |
| | Central AC | 2% | <1% | <1% | n/a |
| Appliance | Clothes Washer | <1% | <1% | n/a | n/a |
| | Dehumidifier | <1% | <1% | n/a | n/a |
| | Freezer | <1% | n/a | 1% | 7% |
| | Refrigerator | <1% | <1% | 15% | 35% |
| | Appliance Other | n/a | n/a | 6% | n/a |
| Other | Other | <1% | n/a | <1% | n/a |
| **Sample (n)** | | **10,668** | **442** | **5,427** | **54** |

**Table 141. Frequency Distribution of Gas Measures for HES and HES-IE Participant Samples, by HER Participation**

| Category | Measure | HES | | HES-IE (SP2/SP3) | |
|---|---|---|---|---|---|
| | | Non-HER | HER | Non-HER | HER |
| Shell | Air Sealing | 92% | 92% | 79% | 50% |
| | Attic Insulation | <1% | n/a | 12% | n/a |
| | Wall Insulation | <1% | n/a | 13% | n/a |
| | Insulation Other | <1% | n/a | n/a | n/a |
| | Windows | <1% | n/a | 3% | n/a |
| Water Heating | DWH Bundle | 79% | 54% | 77% | 100% |
| | Water Heater Replacement | n/a | n/a | 14% | n/a |
| HVAC | Duct Sealing | 17% | 31% | 3% | n/a |
| | Heating System Replacement | <1% | n/a | 5% | n/a |
| Appliance | Clothes Washer | <1% | n/a | n/a | n/a |
| | Appliance Other | n/a | n/a | <1% | n/a |
| | Other | n/a | n/a | <1% | n/a |
| **Sample (n)** | | **1,849** | **13** | **1,246** | **4** |

# Appendix E. Billing Analysis Model Outputs – Whole House

## HES Electric Models

Table 142. Overall HES Electric Savings Model Output After Screening
(n=11,110 participants, n=8,547 nonparticipants)

| Group | Variable | Parameter Estimate | Standard Error | Z-Score | p-Value |
|---|---|---|---|---|---|
| Participant | AvgHDD | 0.4126 | 0.0078 | 52.93 | <.0001 |
| | AvgCDD | 1.9841 | 0.0201 | 98.68 | <.0001 |
| | Other program * HDD | 0.0462 | 0.0316 | 1.46 | 0.1432 |
| | HER *HDD | 0.5380 | 0.0507 | 10.61 | <.0001 |
| | Other program *CDD | 0.0727 | 0.0733 | 0.99 | 0.3214 |
| | HER * CDD | 1.5933 | 0.1236 | 12.89 | <.0001 |
| | Post | -1.2443 | 0.0728 | -17.1 | <.0001 |
| | Post*HDD | -0.0960 | 0.0040 | -24.1 | <.0001 |
| | Post*CDD | -0.1516 | 0.0107 | -14.12 | <.0001 |
| | HER * post | -2.2197 | 0.4392 | -5.05 | <.0001 |
| | Other program * Post | -1.9197 | 0.5492 | -3.5 | 0.0005 |
| Comparison | AvgHDD | 0.3457 | 0.0072 | 48.14 | <.0001 |
| | AvgCDD | 1.8572 | 0.0205 | 90.67 | <.0001 |
| | Other program * HDD | 0.0527 | 0.0357 | 1.48 | 0.1398 |
| | HER *HDD | 0.3924 | 0.0619 | 6.34 | <.0001 |
| | Other program *CDD | 0.0786 | 0.0863 | 0.91 | 0.3626 |
| | HER * CDD | 1.5995 | 0.1413 | 11.32 | <.0001 |
| | Post | -0.2562 | 0.0718 | -3.57 | 0.0004 |
| | Post*HDD | -0.0074 | 0.0034 | -2.15 | 0.0312 |
| | Post*CDD | 0.1742 | 0.0116 | 14.96 | <.0001 |
| | HER * Post | -1.2313 | 0.4405 | -2.8 | 0.0052 |
| | Other program * Post | 0.0139 | 0.5945 | 0.02 | 0.9813 |

**Table 143. CL&P HES Electric Savings Model Output After Screening (n=8,695 participants, n=7,043 nonparticipants)**

| Group | Variable | Parameter Estimate | Standard Error | Z-Score | p-Value |
|---|---|---|---|---|---|
| Participant | AvgHDD | 0.4541 | 0.0095 | 47.64 | <.0001 |
| | AvgCDD | 2.0614 | 0.0246 | 83.73 | <.0001 |
| | Other program * HDD | 0.0061 | 0.0320 | 0.19 | 0.8493 |
| | HER *HDD | 0.4995 | 0.0509 | 9.81 | <.0001 |
| | Other program *CDD | -0.0226 | 0.0745 | -0.3 | 0.7621 |
| | HER * CDD | 1.5004 | 0.1242 | 12.08 | <.0001 |
| | Post | -1.4336 | 0.0876 | -16.36 | <.0001 |
| | Post*HDD | -0.0965 | 0.0047 | -20.43 | <.0001 |
| | Post*CDD | -0.1080 | 0.0128 | -8.42 | <.0001 |
| | HER * post | -2.1322 | 0.4416 | -4.83 | <.0001 |
| | Other program * post | -1.8589 | 0.5508 | -3.37 | 0.0007 |
| Comparison | AvgHDD | 0.3610 | 0.0084 | 43.21 | <.0001 |
| | AvgCDD | 1.8792 | 0.0234 | 80.28 | <.0001 |
| | Other program * HDD | 0.0357 | 0.0360 | 0.99 | 0.3213 |
| | HER *HDD | 0.3764 | 0.0621 | 6.06 | <.0001 |
| | Other program *CDD | 0.0342 | 0.0871 | 0.39 | 0.6949 |
| | HER * CDD | 1.5581 | 0.1418 | 10.99 | <.0001 |
| | Post | -0.4852 | 0.0825 | -5.88 | <.0001 |
| | Post*HDD | -0.0028 | 0.0039 | -0.71 | 0.4759 |
| | Post*CDD | 0.2255 | 0.0132 | 17.04 | <.0001 |
| | HER * post | -1.2050 | 0.4411 | -2.73 | 0.0063 |
| | Other program * post | -0.0050 | 0.5953 | -0.01 | 0.9933 |

Table 144. UI HES Gas Savings Model Output After Screening
(n=2,415 participants, n=1,504 nonparticipants)

| Group | Variable | Parameter Estimate | Standard Error | Z-Score | p-Value |
|---|---|---|---|---|---|
| Participant | AvgHDD | 0.2715 | 0.0101 | 26.89 | <.0001 |
| | AvgCDD | 1.7407 | 0.0314 | 55.41 | <.0001 |
| | Other program * HDD | 0.0000 | 0.0000 | . | . |
| | HER *HDD | 0.0000 | 0.0000 | . | . |
| | Other program *CDD | 0.0000 | 0.0000 | . | . |
| | HER * CDD | 0.0000 | 0.0000 | . | . |
| | Post | -0.7386 | 0.1112 | -6.64 | <.0001 |
| | Post*HDD | -0.0948 | 0.0064 | -14.85 | <.0001 |
| | Post*CDD | -0.2644 | 0.0180 | -14.67 | <.0001 |
| | HER * post | 0.0000 | 0.0000 | . | . |
| | Other program * post | 0.0000 | 0.0000 | . | . |
| Comparison | AvgHDD | 0.2757 | 0.0111 | 24.88 | <.0001 |
| | AvgCDD | 1.7627 | 0.0413 | 42.72 | <.0001 |
| | Other program * HDD | 0.0000 | 0.0000 | . | . |
| | HER *HDD | 0.0000 | 0.0000 | . | . |
| | Other program *CDD | 0.0000 | 0.0000 | . | . |
| | HER * CDD | 0.0000 | 0.0000 | . | . |
| | Post | 0.4417 | 0.1294 | 3.41 | 0.0006 |
| | Post*HDD | -0.0156 | 0.0068 | -2.3 | 0.0217 |
| | Post*CDD | 0.0039 | 0.0228 | 0.17 | 0.8631 |
| | HER * post | 0.0000 | 0.0000 | . | . |
| | Other program * post | 0.0000 | 0.0000 | . | . |

## HES Gas Models

Table 145. Overall HES Gas Savings Model Output After Screening
(n=1,862 participants, n=1,192 nonparticipants)

| Group | Variable | Parameter Estimate | Standard Error | t-value | P-value |
|---|---|---|---|---|---|
| Participant | Post | -0.0121 | 0.0074 | -1.64 | 0.1013 |
| | Post * AvgHDD | -0.0120 | 0.0004 | -30.63 | <.0001 |
| Comparison | Post | -0.0453 | 0.0060 | -7.49 | <.0001 |
| | Post* Participation | 0.0332 | 0.0094 | 3.55 | 0.0004 |
| | Post * AvgHDD | -0.0120 | 0.0004 | -31.55 | <.0001 |

**Table 146. CNG HES Gas Savings Model Output After Screening (n=649 participants, n=508 nonparticipants)**

| Group | Variable | Parameter Estimate | Standard Error | t-value | P-value |
|---|---|---|---|---|---|
| Participant | Post | -0.0499 | 0.0140 | -3.56 | 0.0004 |
| | Post * AvgHDD | -0.0104 | 0.0008 | -13.81 | <.0001 |
| Comparison | Post | -0.0412 | 0.0098 | -4.2 | <.0001 |
| | Post* Participation | -0.0087 | 0.0160 | -0.54 | 0.5869 |
| | Post * AvgHDD | -0.0104 | 0.0007 | -15.3 | <.0001 |

**Table 147. SCG HES Gas Savings Model Output After Screening (n=461 participants, n=243 nonparticipants)**

| Group | Variable | Parameter Estimate | Standard Error | t-value | P-value |
|---|---|---|---|---|---|
| Participant | Post | 0.0296 | 0.0145 | 2.03 | 0.0419 |
| | Post * AvgHDD | -0.0131 | 0.0008 | -16.22 | <.0001 |
| Comparison | Post | -0.0392 | 0.0141 | -2.78 | 0.0055 |
| | Post* Participation | 0.0688 | 0.0208 | 3.31 | 0.0009 |
| | Post * AvgHDD | -0.0131 | 0.0008 | -15.45 | <.0001 |

**Table 148. YGS HES Gas Savings Model Output After Screening (n=752 participants, n=441 nonparticipants)**

| Group | Variable | Parameter Estimate | Standard Error | t-value | P-value |
|---|---|---|---|---|---|
| Participant | Post | -0.0045 | 0.0103 | -0.44 | 0.6626 |
| | Post * AvgHDD | -0.0128 | 0.0005 | -23.99 | <.0001 |
| Comparison | Post | -0.0532 | 0.0090 | -5.92 | <.0001 |
| | Post* Participation | 0.0487 | 0.0136 | 3.57 | 0.0004 |
| | Post * AvgHDD | -0.0128 | 0.0005 | -24.03 | <.0001 |

## HES-IE Electric Models (SP2/SP3)

Table 149. Overall HES-IE Electric Savings Model Output After Screening (n=5,481 participants, n=5,430 nonparticipants)

| Group | Variable | Parameter Estimate | Standard Error | Z-Score | p-Value |
|---|---|---|---|---|---|
| Participant | AvgHDD | 0.4642 | 0.0111 | 41.72 | <.0001 |
| | AvgCDD | 1.0193 | 0.0193 | 52.87 | <.0001 |
| | Other Program * HDD | -0.2873 | 0.0579 | -4.96 | <.0001 |
| | HER *HDD | 0.4919 | 0.1349 | 3.65 | 0.0003 |
| | Other Program *CDD | 0.5328 | 0.3422 | 1.56 | 0.1194 |
| | HER * CDD | 0.8754 | 0.2286 | 3.83 | 0.0001 |
| | Post | -0.6586 | 0.0760 | -8.67 | <.0001 |
| | Post*HDD | -0.0996 | 0.0054 | -18.34 | <.0001 |
| | Post*CDD | -0.1269 | 0.0116 | -10.91 | <.0001 |
| | HER * Post | -1.2591 | 1.1810 | -1.07 | 0.2864 |
| | Other Program * Post | -5.7085 | 0.3880 | -14.71 | <.0001 |
| Comparison | AvgHDD | 0.3230 | 0.0086 | 37.41 | <.0001 |
| | AvgCDD | 0.8151 | 0.0197 | 41.29 | <.0001 |
| | Other Program * HDD | 0.1531 | 0.1120 | 1.37 | 0.1715 |
| | HER *HDD | 0.5924 | 0.1328 | 4.46 | <.0001 |
| | Other Program *CDD | 0.2211 | 0.2261 | 0.98 | 0.3283 |
| | HER * CDD | 0.8338 | 0.2871 | 2.9 | 0.0037 |
| | Post | 0.0240 | 0.0610 | 0.39 | 0.6938 |
| | Post*HDD | 0.0080 | 0.0036 | 2.24 | 0.025 |
| | Post*CDD | 0.0759 | 0.0093 | 8.18 | <.0001 |
| | HER * Post | -1.7963 | 0.8507 | -2.11 | 0.0347 |
| | Other Program * Post | 1.4996 | 0.9916 | 1.51 | 0.1304 |

**Table 150. CL&P HES-IE Electric Savings Model Output After Screening (n=3,196 participants, n=4,016 nonparticipants)**

| Group | Variable | Parameter Estimate | Standard Error | Z-Score | p-Value |
|---|---|---|---|---|---|
| Participant | AvgHDD | 0.4982 | 0.0160 | 31.16 | <.0001 |
| | AvgCDD | 0.9867 | 0.0273 | 36.12 | <.0001 |
| | Other Program * HDD | -0.3190 | 0.0590 | -5.4 | <.0001 |
| | HER *HDD | 0.4618 | 0.1353 | 3.41 | 0.0006 |
| | Other Program *CDD | 0.5488 | 0.3434 | 1.6 | 0.11 |
| | HER * CDD | 0.8959 | 0.2292 | 3.91 | <.0001 |
| | Post | -0.6047 | 0.1019 | -5.93 | <.0001 |
| | Post*HDD | -0.1096 | 0.0076 | -14.4 | <.0001 |
| | Post*CDD | -0.1050 | 0.0163 | -6.43 | <.0001 |
| | HER * Post | -1.2001 | 1.1842 | -1.01 | 0.3109 |
| | Other Program * Post | -5.7615 | 0.3879 | -14.85 | <.0001 |
| Comparison | AvgHDD | 0.3497 | 0.0107 | 32.53 | <.0001 |
| | AvgCDD | 0.8048 | 0.0248 | 32.5 | <.0001 |
| | Other Program * HDD | 0.1287 | 0.1132 | 1.14 | 0.2557 |
| | HER *HDD | 0.5662 | 0.1331 | 4.25 | <.0001 |
| | Other Program *CDD | 0.2167 | 0.2267 | 0.96 | 0.3392 |
| | HER * CDD | 0.8290 | 0.2876 | 2.88 | 0.0039 |
| | Post | -0.0840 | 0.0745 | -1.13 | 0.2595 |
| | Post*HDD | 0.0087 | 0.0042 | 2.06 | 0.0396 |
| | Post*CDD | 0.1060 | 0.0121 | 8.79 | <.0001 |
| | HER * Post | -1.7783 | 0.8511 | -2.09 | 0.0367 |
| | Other Program * Post | 1.5086 | 0.9956 | 1.52 | 0.1297 |

Table 151. UI HES-IE Gas Savings Model Output After Screening
(n=2,285 participants, n=1,414 nonparticipants)

| Group | Variable | Parameter Estimate | Standard Error | Z-Score | p-Value |
|---|---|---|---|---|---|
| Participant | AvgHDD | 0.3973 | 0.0120 | 33.17 | <.0001 |
| | AvgCDD | 1.0256 | 0.0214 | 47.94 | <.0001 |
| | Other Program * HDD | 0.0000 | 0.0000 | . | . |
| | HER *HDD | 0.0000 | 0.0000 | . | . |
| | Other Program *CDD | 0.0000 | 0.0000 | . | . |
| | HER * CDD | 0.0000 | 0.0000 | . | . |
| | Post | -0.7738 | 0.1052 | -7.36 | <.0001 |
| | Post*HDD | -0.0863 | 0.0066 | -13.04 | <.0001 |
| | Post*CDD | -0.1563 | 0.0141 | -11.06 | <.0001 |
| | HER * Post | 0.0000 | 0.0000 | . | . |
| | Other Program * Post | 0.0000 | 0.0000 | . | . |
| Comparison | AvgHDD | 0.2120 | 0.0111 | 19.02 | <.0001 |
| | AvgCDD | 0.7859 | 0.0202 | 38.9 | <.0001 |
| | Other Program * HDD | 0.0000 | 0.0000 | . | . |
| | HER *HDD | 0.0000 | 0.0000 | . | . |
| | Other Program *CDD | 0.0000 | 0.0000 | . | . |
| | HER * CDD | 0.0000 | 0.0000 | . | . |
| | Post | 0.2700 | 0.0945 | 2.86 | 0.0043 |
| | Post*HDD | 0.0030 | 0.0061 | 0.49 | 0.6225 |
| | Post*CDD | -0.0105 | 0.0137 | -0.77 | 0.4439 |
| | HER * Post | 0.0000 | 0.0000 | . | . |
| | Other Program * Post | 0.0000 | 0.0000 | . | . |

## HES-IE Gas Models (SP2/SP3)

Table 152. Overall HES-IE Gas Savings Model Output After Screening
(n=1,250 participants, n=644 nonparticipants)

| Group | Variable | Parameter Estimate | Standard Error | t-value | P-value |
|---|---|---|---|---|---|
| Participant | Post | -0.0383 | 0.0068 | -5.63 | <.0001 |
| | Post * AvgHDD | -0.0126 | 0.0004 | -34.43 | <.0001 |
| Comparison | Post | -0.0354 | 0.0067 | -5.32 | <.0001 |
| | Post* Participation | -0.0028 | 0.0098 | -0.29 | 0.7727 |
| | Post * AvgHDD | -0.0126 | 0.0004 | -32.79 | <.0001 |

**Table 153. CNG HES-IE Gas Savings Model Output After Screening (n=460 participants, n=223 nonparticipants)**

| Group | Variable | Parameter Estimate | Standard Error | t-value | P-value |
|---|---|---|---|---|---|
| Participant | Post | -0.0483 | 0.0124 | -3.9 | <.0001 |
| | Post * AvgHDD | -0.0131 | 0.0007 | -19.62 | <.0001 |
| Comparison | Post | -0.0628 | 0.0121 | -5.17 | <.0001 |
| | Post* Participation | 0.0145 | 0.0173 | 0.84 | 0.4021 |
| | Post * AvgHDD | -0.0131 | 0.0007 | -19.61 | <.0001 |

**Table 154. SCG HES-IE Gas Savings Model Output After Screening (n=340 participants, n=233 nonparticipants)**

| Group | Variable | Parameter Estimate | Standard Error | t-value | P-value |
|---|---|---|---|---|---|
| Participant | Post | 0.0249 | 0.0149 | 1.67 | 0.0946 |
| | Post * AvgHDD | -0.0139 | 0.0008 | -16.52 | <.0001 |
| Comparison | Post | 0.0086 | 0.0126 | 0.68 | 0.4969 |
| | Post* Participation | 0.0164 | 0.0198 | 0.83 | 0.4078 |
| | Post * AvgHDD | -0.0139 | 0.0009 | -16.15 | <.0001 |

**Table 155. YGS HES-IE Gas Savings Model Output After Screening (n=450 participants, n=188 nonparticipants)**

| Group | Variable | Parameter Estimate | Standard Error | t-value | P-value |
|---|---|---|---|---|---|
| Participant | Post | -0.0657 | 0.0093 | -7.03 | <.0001 |
| | Post * AvgHDD | -0.0115 | 0.0005 | -23.52 | <.0001 |
| Comparison | Post | -0.0485 | 0.0103 | -4.73 | <.0001 |
| | Post* Participation | -0.0171 | 0.0147 | -1.16 | 0.2452 |
| | Post * AvgHDD | -0.0115 | 0.0006 | -20.82 | <.0001 |

## HES-IE Electric Models (SP1/SP4)

Table 156. 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 157.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 Gas Models (SP1 and SP4)

### Table 158. 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 159. 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. Supplemental Whole-House Billing Analysis Summaries

## By Utility and Building Type

**Table 160. HES Electric Billing Analysis: Savings Summary, by Building Type and Utility (Adjusted Gross)**

| Group | Utility | n | PRENAC | Model Savings (kWh) | Savings as Percentage of Pre-Usage | Relative Precision at 90% |
|---|---|---|---|---|---|---|
| CL&P | SF | 8,680 | 11,880 | 1,084 | 9% | ±4% |
| | MF | 15 | 10,957 | 1,016 | 9% | ±60% |
| | **Overall** | **8,695** | **11,878** | **1,082** | **9%** | **±4%** |
| UI | SF | 1,909 | 10,060 | 1,130 | 11% | ±11% |
| | MF | 506 | 6,047 | 762 | 13% | ±15% |
| | **Overall** | **2,415** | **9,159** | **1,053** | **12%** | **±8%** |
| Overall | SF | 10,589 | 11,552 | 1,084 | 9% | ±4% |
| | MF | 521 | 6,177 | 761 | 12% | ±16% |
| | **Overall** | **11,110** | **11,278** | **1,067** | **9%** | **±4%** |

**Table 161. HES Natural Gas Billing Analysis: Savings Summary, by Building Type and Utility (Adjusted Gross)**

| Group | Utility | n | PRENAC | Model Savings (CCF) | Savings as Percentage of Pre-Usage | Relative Precision at 90% |
|---|---|---|---|---|---|---|
| CNG | SF | 645 | 1,161 | 64 | 5% | 17% |
| | MF | 4 | 881 | -134 | -15% | -103% |
| | **Overall** | **649** | **1,160** | **59** | **5%** | **17%** |
| SCG | SF | 391 | 1,101 | 45 | 4% | 36% |
| | MF | 70 | 784 | 21 | 3% | 147% |
| | **Overall** | **461** | **1,053** | **46** | **4%** | **27%** |
| YGS | SF | 748 | 958 | 48 | 5% | 20% |
| | MF | 4 | 734 | 66 | 9% | 61% |
| | **Overall** | **752** | **957** | **55** | **6%** | **16%** |
| Overall | SF | 1,784 | 1,063 | 56 | 5% | 10% |
| | MF | 78 | 786 | 21 | 3% | 128% |
| | **Overall** | **1,862** | **1,051** | **55** | **5%** | **12%** |

**Table 162. HES-IE Electric Billing Analysis: Savings Summary, by Building Type and Utility (Adjusted Gross)—SP2/SP3**

| Group | Utility | n | PRENAC | Model Savings (kWh) | Savings as Percentage of Pre-Usage | Relative Precision at 90% |
|---|---|---|---|---|---|---|
| CL&P | SF | 1,481 | 9,330 | 1,233 | 13% | ±8% |
| | MF | 1,715 | 6,117 | 863 | 14% | ±10% |
| | **Overall** | **3,196** | **7,408** | **1,011** | **14%** | **±6%** |
| UI | SF | 908 | 8,586 | 1,113 | 13% | ±11% |
| | MF | 1,377 | 6,183 | 917 | 15% | ±8% |
| | **Overall** | **2,285** | **7,111** | **1,011** | **14%** | **±6%** |
| Overall | SF | 2,389 | 9,048 | 1,193 | 13% | ±7% |
| | MF | 3,092 | 6,143 | 880 | 14% | ±7% |
| | **Overall** | **5,481** | **7,292** | **1,005** | **14%** | **±5%** |

**Table 163. HES-IE Natural Gas Billing Analysis: Savings Summary, by Building Type and Utility (Adjusted Gross)—SP2/SP3**

| Group | Utility | n | PRENAC | Model Savings (CCF) | Savings as Percentage of Pre-Usage | Relative Precision at 90% |
|---|---|---|---|---|---|---|
| CNG | SF | 228 | 1,060 | 52 | 5% | ±35% |
| | MF | 232 | 892 | 75 | 8% | ±53% |
| | **Overall** | **460** | **976** | **67** | **7%** | **±25%** |
| SCG | SF | 182 | 961 | 53 | 5% | ±48% |
| | MF | 158 | 840 | 86 | 10% | ±32% |
| | **Overall** | **340** | **903** | **71** | **8%** | **±23%** |
| YGS | SF | 184 | 950 | 48 | 5% | ±37% |
| | MF | 266 | 621 | 74 | 12% | ±34% |
| | **Overall** | **450** | **713** | **75** | **11%** | **±25%** |
| Overall | SF | 594 | 995 | 54 | 5% | ±21% |
| | MF | 656 | 735 | 85 | 12% | ±19% |
| | **Overall** | **1,250** | **840** | **73** | **9%** | **±16%** |

## By Implementer/Delivery Agency

Table 164. HES Electric Billing Analysis: Savings Summary, by Agency (Gross)

| Agency | n | PRENAC | Model Savings (kWh) | Savings as Percentage of Pre-Usage | Relative Precision at 90% |
|---|---|---|---|---|---|
| **Overall—Gross Participant** | **11,110** | **11,278** | **1,096** | **10%** | **±2%** |
| COMPETITIVE RESOURCES INC. (CRT) | 1,380 | 10,183 | 963 | 9% | ±7% |
| Wesson Energy, Inc. | 1,193 | 11,690 | 1,083 | 9% | ±7% |
| New England Conservation Services, LLC | 1,115 | 9,845 | 980 | 10% | ±7% |
| EcoSmart by R Pelton Builders, Inc. | 988 | 10,433 | 1,043 | 10% | ±8% |
| New England Smart Energy Group, LLC | 905 | 15,031 | 1,508 | 10% | ±7% |
| Lantern Energy, LLC | 801 | 9,400 | 951 | 10% | ±9% |
| VICTORY ENERGY SOLUTIONS | 734 | 9,997 | 963 | 10% | ±8% |
| Green Star Energy Solutions, LLC | 529 | 13,025 | 1,300 | 10% | ±11% |
| Save Home Energy, Inc. | 507 | 10,636 | 995 | 9% | ±10% |
| Energy Resource Group | 428 | 11,176 | 936 | 8% | ±13% |
| EnergyPRZ, LLC | 335 | 12,313 | 1,119 | 9% | ±14% |
| Gulick Building & Development, LLC | 303 | 11,241 | 1,137 | 10% | ±12% |
| HOFFMAN FUEL | 254 | 13,442 | 1,270 | 9% | ±16% |
| Santa Fuel, Inc. | 248 | 13,438 | 1,487 | 11% | ±14% |
| Tri City Home Energy Services | 228 | 9,739 | 914 | 9% | ±14% |
| Handyman Express Energy Solutions LLC | 227 | 13,673 | 1,631 | 12% | ±19% |
| Climate Partners, LLC | 195 | 12,998 | 1,065 | 8% | ±22% |
| Alternative Global Energy, Inc. | 145 | 12,207 | 1,103 | 9% | ±16% |
| CLIMATE PARTNERS | 115 | 10,149 | 873 | 9% | ±20% |
| Unknown | 83 | 12,993 | 1,424 | 11% | ±23% |
| Energy Efficiencies Solutions, LLC | 71 | 9,369 | 882 | 9% | ±22% |
| PELTON BUILDERS INC | 66 | 11,518 | 1,158 | 10% | ±18% |
| Zerodraft of Connecticut | 58 | 10,024 | 995 | 10% | ±30% |
| MASTER CARPENTERS LLC | 55 | 10,118 | 781 | 8% | ±36% |
| Mr. Handyman of Upper Fairfield County | 50 | 14,044 | 1,501 | 11% | ±31% |
| EAGLE EYE ENERGY (MOLINA & ASSOC) | 35 | 8,680 | 772 | 9% | ±36% |
| RPM Energy Solutions | 17 | 9,151 | 1,390 | 15% | ±35% |
| GREEN BUILT CONNECTICUT LLC | 16 | 19,762 | 1,492 | 8% | ±43% |
| POSSIDENTO THERRIEN ELECTRICAL CONTR., LLC | 16 | 12,389 | 1,285 | 10% | ±52% |
| Meadows RE Management Development Corp. | 9 | 10,199 | 1,452 | 14% | ±72% |
| Molina & Associates, Inc. | 4 | 12,138 | 916 | 8% | ±83% |

**Table 165. HES Natural Gas Billing Analysis: Savings Summary, by Agency (Gross)**

| Agency | n | PRENAC | Model Savings (CCF) | Savings as Percentage of Pre-Usage | Relative Precision at 90% |
|---|---|---|---|---|---|
| **Overall—Gross Participant** | **1,862** | **1,051** | **72** | **7%** | **±6%** |
| COMPETITIVE RESOURCES INC. (CRT) | 322 | 909 | 61 | 7% | ±12% |
| EcoSmart by R Pelton Builders, Inc. | 257 | 1,041 | 74 | 7% | ±15% |
| New England Conservation Services, LLC | 198 | 1,006 | 60 | 6% | ±18% |
| VICTORY ENERGY SOLUTIONS | 175 | 1,087 | 83 | 8% | ±17% |
| Wesson Energy, Inc. | 152 | 991 | 54 | 5% | ±22% |
| Lantern Energy, LLC | 120 | 1,114 | 108 | 10% | ±21% |
| Save Home Energy, Inc. | 112 | 1,065 | 82 | 8% | ±18% |
| New England Smart Energy Group, LLC | 100 | 1,554 | 103 | 7% | ±26% |
| Gulick Building & Development, LLC | 54 | 1,122 | 51 | 5% | ±47% |
| Tri City Home Energy Services | 52 | 848 | 66 | 8% | ±31% |
| Green Star Energy Solutions, LLC | 43 | 1,148 | 80 | 7% | ±38% |
| Energy Resource Group | 42 | 947 | 83 | 9% | ±34% |
| EnergyPRZ, LLC | 40 | 1,115 | 68 | 6% | ±45% |
| Climate Partners, LLC | 38 | 1,198 | 66 | 6% | ±45% |
| Handyman Express Energy Solutions LLC | 27 | 1,100 | 69 | 6% | ±47% |
| CLIMATE PARTNERS | 23 | 850 | 47 | 6% | ±70% |
| HOFFMAN FUEL | 23 | 1,022 | 103 | 10% | ±28% |
| Santa Fuel, Inc. | 19 | 993 | 98 | 10% | ±53% |
| Energy Efficiencies Solutions, LLC | 12 | 1,050 | 90 | 9% | ±27% |
| MASTER CARPENTERS LLC | 12 | 1,046 | 78 | 7% | ±45% |
| PELTON BUILDERS INC | 10 | 1,208 | 66 | 5% | ±48% |
| EAGLE EYE ENERGY (MOLINA & ASSOC) | 9 | 798 | 4 | 1% | ±412% |
| Zerodraft of Connecticut | 7 | 1,108 | 24 | 2% | ±300% |
| Mr. Handyman of Upper Fairfield County | 5 | 1,420 | 90 | 6% | ±35% |
| Alternative Global Energy, Inc. | 3 | 1,034 | 67 | 6% | ±9% |
| GREEN BUILT CONNECTICUT LLC | 3 | 1,992 | 60 | 3% | ±249% |
| POSSIDENTO THERRIEN ELECTRICAL CONTR., LLC | 3 | 1,380 | 9 | 1% | ±1789% |
| Unknown | 1 | 1,038 | 16 | 2% | 0% |

Table 166. HES-IE Electric Billing Analysis: Savings Summary, by Agency (Gross)—SP2/SP3

| Agency | n | PRENAC | Model Savings (kWh) | Savings as Percentage of Pre-Usage | Relative Precision at 90% |
|---|---|---|---|---|---|
| **Overall—Gross Participant** | **5,481** | **7,292** | **885** | **12%** | **±4%** |
| COMPETITIVE RESOURCES INC. (CRT) | 1,781 | 6,457 | 801 | 12% | ±7% |
| New Opportunities, Inc. | 935 | 8,430 | 1,090 | 13% | ±8% |
| Zerodraft of Connecticut | 679 | 8,199 | 980 | 12% | ±10% |
| ACCESS | 483 | 8,406 | 1,134 | 13% | ±9% |
| New England Conservation Services, LLC | 440 | 7,224 | 757 | 10% | ±11% |
| LANTERN ENERGY | 355 | 4,656 | 614 | 13% | ±15% |
| WRAP | 214 | 6,126 | 843 | 14% | ±39% |
| GULICK BUILDING AND DEVELOPMENT LLC | 156 | 8,488 | 1,036 | 12% | ±22% |
| SAVE HOME ENERGY LLC | 101 | 7,628 | 774 | 10% | ±17% |
| ENERGY PRZ | 100 | 8,771 | 927 | 11% | ±24% |
| COMMUNITY ACTION AGENCY | 90 | 7,685 | 958 | 12% | ±24% |
| ACTION FOR BRIDGEPORT COMMUNITY DEVELOPMENT | 72 | 7,055 | 699 | 10% | ±30% |
| Handyman Express Energy Solutions LLC | 56 | 8,390 | 1,201 | 14% | ±24% |
| Unknown | 11 | 7,995 | 741 | 9% | ±56% |
| MR HANDYMAN (LBO LLC) | 4 | 8,466 | 2,117 | 25% | ±52% |
| HESHP | 3 | 10,820 | 1,915 | 18% | ±44% |
| Energy Resource Group | 1 | 5,663 | 502 | 9% | 0% |

**Table 167. HES-IE Natural Gas Billing Analysis: Savings Summary, by Agency (Gross)—SP2/SP3**

| Agency | n | PRENAC | Model Savings (CCF) | Savings as Percentage of Pre-Usage | Relative Precision at 90% |
|---|---|---|---|---|---|
| **Overall—Gross Participant** | **1,250** | **840** | **85** | **10%** | **±10%** |
| COMPETITIVE RESOURCES INC. (CRT) | 606 | 899 | 73 | 8% | ±11% |
| Zerodraft of Connecticut | 203 | 911 | 81 | 9% | ±18% |
| New Opportunities, Inc. | 132 | 877 | 67 | 8% | ±22% |
| New England Conservation Services, LLC | 100 | 841 | 72 | 9% | ±25% |
| HESHP | 56 | 487 | 110 | 23% | ±21% |
| ACCESS | 35 | 769 | 147 | 19% | ±24% |
| GULICK BUILDING AND DEVELOPMENT LLC | 29 | 928 | 92 | 10% | ±33% |
| SAVE HOME ENERGY LLC | 23 | 872 | 65 | 7% | ±47% |
| COMMUNITY ACTION AGENCY | 17 | 856 | 82 | 10% | ±57% |
| LANTERN ENERGY | 15 | 887 | 65 | 7% | ±65% |
| Unknown | 15 | 895 | 33 | 4% | ±111% |
| ENERGY PRZ | 11 | 761 | 26 | 3% | ±127% |
| WRAP | 5 | 937 | 104 | 11% | ±83% |
| ACTION FOR BRIDGEPORT COMMUNITY DEVELOPMENT | 2 | 1,060 | 165 | 16% | ±14% |
| Handyman Express Energy Solutions LLC | 1 | 974 | 129 | 13% | 0% |

# Appendix G. Measure-Level Billing Analysis Models

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 168. 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 169. HESIE Electric (SP2/SP3) 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 170. 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 171. HESIE Gas (SP2/SP3) 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 |

## Appendix H. Engineering Review

This section presents a more detailed engineering review for several program measures. The review references the sources shown in Table 172.

**Table 172. 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. |

*See *Appendix K. References* for additional source information

### *Pipe Insulation*

The literature review for this measure identified seven sources, based on regional and program similarities. Table 173 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 173. 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.[82]

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 174 presents the various inputs for each savings value with published inputs and algorithms.

82 *EmPOWER Maryland: 2011 Engineering Review: Residential Retrofits*. P 75–88.

**Table 174. 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 175 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 175. 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 176 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 177 shows the normalization results.

**Table 176. 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 177. 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:[83]

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

With $S_W$ representing:

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

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

83 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.

amount of water; so the aerator does not affect water consumption, only the time required to produce 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 178 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 178. 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 179 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 180 shows the normalization results.

**Table 179. 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 180. 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:[84]

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

With $S_W$ representing:

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

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

[84] 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.

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.

$Shower_{House}$ = 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 181 shows the per-measure energy savings estimates.

**Table 181. 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 |
| 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 Section 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).[85]

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, equipment operation, and integration with existing systems. This research should provide the precision of savings estimates to allow comparison of results across evaluation studies.

As another point of comparison, the Evaluation Team benchmarked the current model savings against a recent ductless heat pump on-site metering study performed by KEMA, which provides the source of the PSD estimate. There appears to be a statistically significant difference between these estimates, with the current billing analysis estimates showing slightly better precision. While both studies rely on primary data, different program years and participant types (e.g., variations in customer usage, building types, baselines, HES participant vs. standalone equipment replacement) may contribute to differences in evaluated savings. Table 182 provides this comparison of precision between evaluated savings from billing analysis and average *ex ante* savings and precision derived from the KEMA study.

**Table 182. Ductless Mini-Split Savings Comparison**

| Program | Cadmus | | | *Ex Ante* (kWh)* | KEMA** | | Difference | | |
|---|---|---|---|---|---|---|---|---|---|
| | Model Savings (kWh) | SE | Relative Precision | | SE | Relative Precision | Savings Value (kWh) | SE | p-value |
| HES | 1,311 | 283 | ±35% | 2,844 | 664 | ±38% | 1,533 | 721 | 0.034 |
| HES-IE | 803 | 157 | ±32% | 1,731 | 404 | ±38% | 928 | 434 | 0.032 |

*Average *ex ante* savings from program tracking data.

**Standard error (for combined heating and cooling) calculated from relative precision and savings estimates for Hartford.

85 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).

# Appendix I. 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.*[86] 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

86 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.

variable degree day PRISM models allowing heating and cooling reference temperatures to vary from 45 °F to 85 °F .

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 |
| $\alpha_i$ | = | the participant intercept; represents the average daily kWh base load |
| $\beta_1$ | = | the model space heating slope |
| $\beta_2$ | = | 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 |
| $\varepsilon_{it}$ | = | 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 |
| $\alpha_i$ | = | 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) |
| $\beta_1$ | = | 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[87] |
| $\beta_1 * LRHDD_{it}$ | = | the weather-normalized monthly weather-sensitive heating usage |

[87] 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.

$\beta_2$ = the cooling slope; in effect, usage per cooling degree day from the model above

$LRCDD_{it}$ = 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 183 provides a list of the different baseline building models developed for the analysis.

**Table 183. 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 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 17 and Figure 18 show examples comparing end-use targets and calibrated baseline model results.

**Figure 17. Comparison of Gas Heating End-Use Profile Targets to the Calibrated DOE-2 Model**

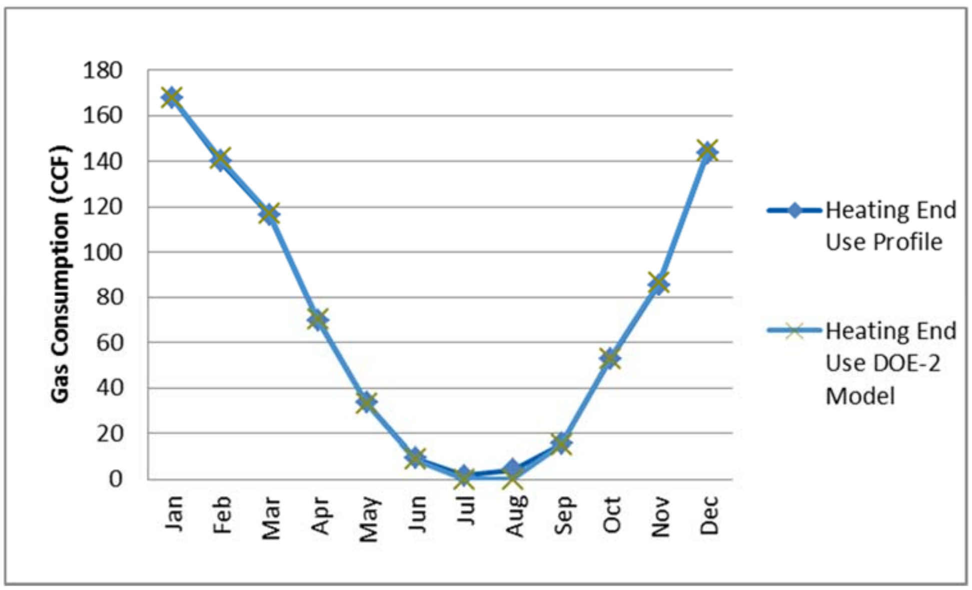
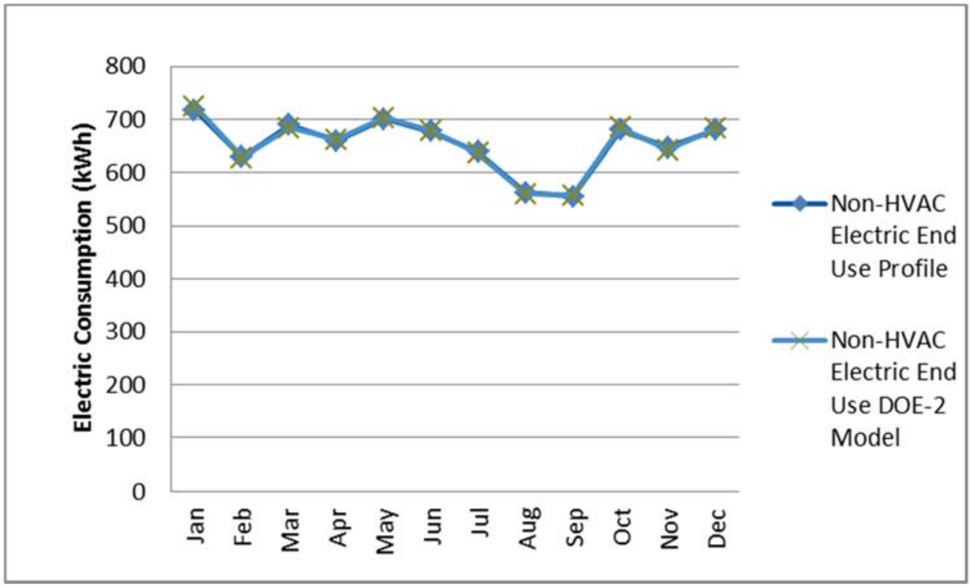


Figure 18. Comparison of Non-HVAC Electric End-Use Profile Targets to the Calibrated DOE-2 Model




## *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 184 provides an example of all model iterations developed for a single prototype (i.e., HES single-family electrically-heated homes).

**Table 184. 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.[88]

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.

[88] As an example, average R-values were based on area-weighted U-values, specific to each of the different building prototypes. U-values were calculated based on the R-values of installed insulation and building materials. Reported surface area for each participant was used to calculate area-weighted U-values for each building type and heat source to estimate average R-values.

# Appendix J. Detailed Distribution of Total Savings—Measure-Level

The following tables present detailed measure-level analysis summaries of total *ex ante* savings (base on the utility tracking system) and evaluated savings by program and measure category.[89]

**Table 185. 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%** | |

*Program totals based on utility tracking system data and are different than overall results presented in Table 8 (calculated by applying program-level adjusted gross realization rates to those program-level savings reported in the Plan)

**Incorporates the nonparticipant adjustment factor of 97%.

[89] Measure-specific realization rates are presented in the executive summary and body of the report, such as in Table 9 and Table 10 for HES, and Table 11 and Table 12 for HES-IE.

**Table 186. 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%** | |

*Program totals based on utility tracking system data and are different than overall results presented in Table 8 (calculated by applying program-level adjusted gross realization rates to those program-level savings reported in the Plan)

**Incorporates the nonparticipant adjustment factor of 76%.

**Table 187. 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 |

| Category | Measures | Reported *Ex Ante* Savings (kWh) | Gross Evaluated Savings (kWh) |
|---|---|---|---|
| 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

**Program totals based on utility tracking system data and are different than overall results presented in Table 11 (calculated by applying program-level adjusted gross realization rates to those program-level savings reported in the Plan)

***Incorporates the nonparticipant adjustment factor of 114%.

**Table 188. 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

**Program totals based on utility tracking system data and are different than overall results presented in Table 11 (calculated by applying program-level adjusted gross realization rates to those program-level savings reported in the Plan)

***Incorporates the nonparticipant adjustment factor of 85%.

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# Appendix L. Lighting Interactive Effect Adjustments

As this study was being completed, an additional study was also being conducted to investigate interactive effects due to the installation of residential energy efficient lighting.[90] Because the methodology in this study utilized billing analysis to determine the savings realization rate for a few measures, these realization rates may partially reflect lighting interactive effects (e.g., the measured gas savings for a heating measure may have been penalized due to the installation of energy efficient lighting, which produces less waste heat then standard efficiency lighting), along with various other effects (including measure interaction, energy education, behavioral/household changes, take-back, spillover).

The companies, both UI and CL&P, expressed concern that the R16 HES study did not fully account for the results of the R67 lighting interactive effects study and requested that the realization rates in the final R16 report should be adjusted to correctly account for lighting interactive effects.[91] This appendix seeks to address these concerns and provide guidance to make adjustments to the measure-level findings where appropriate by taking the following steps:

1) Identify the applicable measures that are affected,
2) Estimate the average household gas (ccf), energy (kWh), and demand (kW) adjustments,
3) Apply this adjustment to the identified measures, and
4) Describe how and where these adjustments should be made.

The EEB consultant has reviewed both studies and determined that the only instances where the realization rates may not properly reflect true savings are those gas-saving measures whose savings were determined through a billing analysis.[92] According to the evaluation consultant, any measure that received either engineering or simulation analysis did not have lighting retrofit interactivity as a component of the analysis (i.e., the estimated savings would not be impacted by the installation of efficient lighting). Furthermore, as shown in *Appendix D. Frequency Distribution of Measure Installations from Participant Analysis Samples—Whole House*, there were a number of measures that were infrequently installed, so this analysis focused only those measures that were installed by more than 1% of the homes. Finally, only the shell of HVAC-based gas measures should be included in this adjustment since the lighting interactivity of appliance or water heat-based measures is not deemed significant for this adjustment.

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90 See "R67: Residential Lighting Interactive Effects Memo", NMR Group, December 20, 2014.

91 See utility responses to R67: Lighting Interactive Effects Memo (http://www.energizect.com/about/eeboard/evaluationreports

92 While there would also be electric interactive effects, because billing analysis was used to determine the realization rates for both lighting and other electric HVAC and shell measures, these realization rates would fully account for these interactive effects (i.e., the heating penalty and cooling benefits would be reflected in the billing analysis).

The only measures that meet the above criteria are air sealing (for both HES and HES-IE) and heating system replacement and wall insulation (for HES-IE only). Detailed evaluation results from this R16 study are included below in Table 189.

**Table 189. Gas Measures to Receive Lighting Interactive Effect Adjustment**

| Program | Category | Measure | Reported *Ex ante* Savings (CCF/ Household) * (A) | Gross Savings (CCF/ Household) (B) | Realization Rate (B/A) | Method | % of Homes Installed |
|---|---|---|---|---|---|---|---|
| HES | Shell | Air Sealing | 62 | 57 | 91% | Billing Analysis (±14%) | 92% |
| HES-IE | HVAC | Heating System Replacement | 128 | 107 | 84% | Billing Analysis (±14%) | 5% |
| HES-IE | Shell | Air Sealing | 59 | 36 | 61% | Billing Analysis (±31%) | 79% |
| HES-IE | Shell | Wall Insulation | 304 | 96 | 32% | Billing Analysis (±30%) | 13% |

The next step is to estimate the average household gas (ccf) adjustment attributable to the lighting retrofit. To estimate this gas adjustment, both the heating fuel interactive effects (IE) factor and the total lighting savings associated with the HES retrofits are needed. Table 9 in the R67 study documents the heating fuel IE factors (see Table 190 below). These values represent the estimated increased heating fuel usage due to the installation of energy efficient lighting (i.e., for every kWh saved due to efficient lighting, an additional 0.019 ccf of natural gas is needed for heating).

**Table 190. Heating Fuel IE Factors – Units of Fuel/kWh**

| Heating fuel | Number of Homes | Heating IE Factor in Fuel Units/kWh |
|---|---|---|
| Oil (gallons) | 112 | 0.014 |
| Natural gas (ccf) | 46 | 0.019 |
| LP (gallons) | 3 | 0.019 |
| Biomass (MMBtu) | 3 | 0.002 |
| *Overall (MMBtu)* | *166* | *0.002* |

The total savings associated with the lighting retrofit is reported in this R16 report in Table 9 (for HES) and Table 12 (for HES-IE). The total gross model kWh per household for the HES program is 782 kWh and is based on a retrofit of 18.6 bulbs per home. The total gross model kWh per household for the HES-

IE program is 647 kWh and is based on a retrofit of 13.7 bulbs per home. Therefore the total gas (ccf) adjustment required for this exercise is 14.9 ccf for the HES program (782 kWh * 0.019 ccf/kWh) and 12.3 ccf for the HES-IE program (647 kWh * 0.019 ccf/kWh).

The next step in this process is to then apply the gas (ccf) adjustment to the impacted measures. The gas adjustment is applied proportionally based on both the gross realized gas savings and the proportion of homes that received the measure. Since this adjustment only needs to be applied to the air sealing measure for the HES program, all of the gas adjustment is applied to this measure. For the HES-IE program, however, this adjustment needs to be applied across three measures, which was applied based on savings and saturation-weighted estimates as shown below in Table 191. The final savings adjustments are summarized below in Table 192.

**Table 191. HES-IE Allocation of Interactive Effects Adjustment**

| Program | Category | Measure | Ex Post Gross Savings (CCF/ Household) | % of Homes Installed | Avg Savings/ Home | % Allocation | Gas (ccf) Adjustment |
|---|---|---|---|---|---|---|---|
| HES-IE | HVAC | Heating System Replacement | 107 | 5% | 5.4 | 12% | 1.4 |
| HES-IE | Shell | Air Sealing | 36 | 79% | 28.4 | 61% | 7.6 |
| HES-IE | Shell | Wall Insulation | 96 | 13% | 12.5 | 27% | 3.3 |
| ***Total*** | | | | | | ***100%*** | ***12.3*** |

**Table 192. HES and HES-IE Gas Measure Lighting IE Factor Adjustments**

| Program | Category | Measure | Reported *Ex ante* Savings (CCF/ HH) (A) | Evaluated Gross Savings (CCF/HH) (B) | Interactive Gas (CCF/HH) Adjustment (C) | Adjusted Gross Savings (CCF/HH) (D) | Adjusted Realization Rate (D/A) |
|---|---|---|---|---|---|---|---|
| HES | Shell | Air Sealing | 62 | 57 | 14.9 | 71.9 | 116% |
| HES-IE | HVAC | Heating System Replacement | 128 | 107 | 1.4 | 108.4 | 85% |
| HES-IE | Shell | Air Sealing | 59 | 36 | 7.6 | 43.6 | 74% |
| HES-IE | Shell | Wall Insulation | 304 | 96 | 3.3 | 99.3 | 33% |

As noted in the introduction, the final step is to describe how and where these adjustments should be made. These adjustments can be made for the above measures for updating the PSD, but the PSD should report the savings with and without the interactive effects, as the actual gas savings realized will be lower when bundled with lighting retrofits.

Additionally, the cost-effectiveness analysis for the HES and HES-IE lighting measures should be adjusted to reflect these heating impacts. This can be done by treating the lighting interactive effects as a negative non-electric (fossil fuel) benefit. For example, the avoided gas cost for HES would be calculated based on 14.9 ccf/year, taking the net present value over the lifetime of the lighting measures (since these penalties would only occur during the lifetime of the lighting measures, and not the heating measures which may have a longer lifetime).[93]

[93] Note the interactive adjustments presented here are based on first year annual savings for the lighting savings. If the expected savings due to lighting changes (e.g., due to a change in the mix of lighting products, such as LEDs, or adjustments due to the 2007 Energy Independence and Security Act) the interactive effects should be adjusted accordingly.