WEST HILL ENERGY AND COMPUTING

CT Home Energy Solutions Impact Evaluation

Program Years 2015-2016

FINAL REPORT
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Abstract

This report presents the results of a billing analysis conducted to evaluate the impact of the Home Energy Solutions (HES) and Home Energy Solutions-Income Eligible (HES-IE) programs during 2015 and 2016.

The HES and HES-IE programs are Connecticut's largest residential energy efficiency programs, serving tens of thousands of customers per year with audits, direct installations, and rebates for a variety of energy-saving measures. The measures installed through the HES program range from easy-to-install measures, such as DHW pipe insulation, light bulbs, and faucet aerators, to larger, more technical measures, including insulation and heating, ventilation or air conditioning (HVAC) equipment replacements.

The evaluation found that, on average, utility customers saved about 11% of natural gas consumption and 6% of electricity consumption by participating in the HES and HES-IE programs, a level of savings well within the range seen across similar residential programs in the Northeast.

While these savings are substantial, they are somewhat less than reported during the 2015-2016 evaluation period. The overall realization rates for the program were 74% and 48% for natural gas and electricity, respectively, also well within the range seen for similar programs. For natural gas measures, the main contributors to the overall realization rate were insulation and air sealing measures. For electric measures, lighting measures were the primary determinant of the realization rate.

Executive Summary

The Home Energy Solutions (HES) and Home Energy Solutions – Income Eligible (HES-IE) programs are Connecticut's largest residential energy efficiency programs, serving tens of thousands of customers per year with audits, direct installations, and rebates for a variety of energy-saving measures. This impact evaluation covers program years 2015 and 2016. The previous HES/HES-IE impact evaluation was conducted for program year 2011.

The HES program serves both single-family and multifamily homes throughout market rate and low-income market segments. The measures installed through the HES program range from easy-to-install measures, such as DHW pipe insulation, light bulbs, and faucet aerators, to larger, more technical measures, including insulation and heating, ventilation or air conditioning (HVAC) equipment replacements.

Evaluated program savings were estimated from billing analysis, using cross-sectional and time-series models with customer-specific intercepts, interrupted at the time of the installation. As shown in Table ES-1, the evaluation found, on average, utility customers saved about 11% of natural gas consumption and 6% of electricity consumption by participating in the HES program. These savings are within the range seen across similar residential programs in the Northeast (see Section 4.3).

TABLE ES-1: OVERVIEW OF EVALUATED ENERGY SAVINGS PER HOUSEHOLD

	Natural Gas	Electricity
Mean Pre-Install Usage[1]	1,029 Ccf	9,157 kWh
Mean Program Reported Savings[2]	157 Ccf	1,241 kWh
Program Reported Savings as Percent of Pre-Use	15%	14%
Mean Evaluated Savings[3]	117 Ccf (+/- 9 Ccf)	591 kWh (+/- 7 kWh)
Evaluated Savings as Percent of Pre-Use	11% (+/- 1%)	6% (+/- 0.6%)

[1] For all homes included in final regression model (n=5,862 for gas; n=23,201 for electricity). See Section 3.2 for model inclusion criteria.
[2] For all single family 2015-2016 program participants (n=8,298 for gas, n=39,932 for electricity). Section 3.2 explains rationale for excluding multifamily participants.
[3] A small amount of program reported savings could not be evaluated. The realization rate for these measures was assumed to be 100%. See Section 4.

While these savings are substantial, they are somewhat less than reported during the evaluation period. The overall realization rates for the program were 74% and 48% for natural gas and electricity, respectively. Table ES-2 and Figure ES-1 present the program reported savings, evaluated savings, and realization rates by measure group. For natural gas measures, the main contributors to the overall realization rate were insulation and air sealing measures. For electric

measures, lighting measures were the primary determinant of the realization rate. Comparison to other, similar programs in the Northeast shows that the evaluated HES and HES-IE savings, as a percent of pre-install use, are within the expected range.[1]

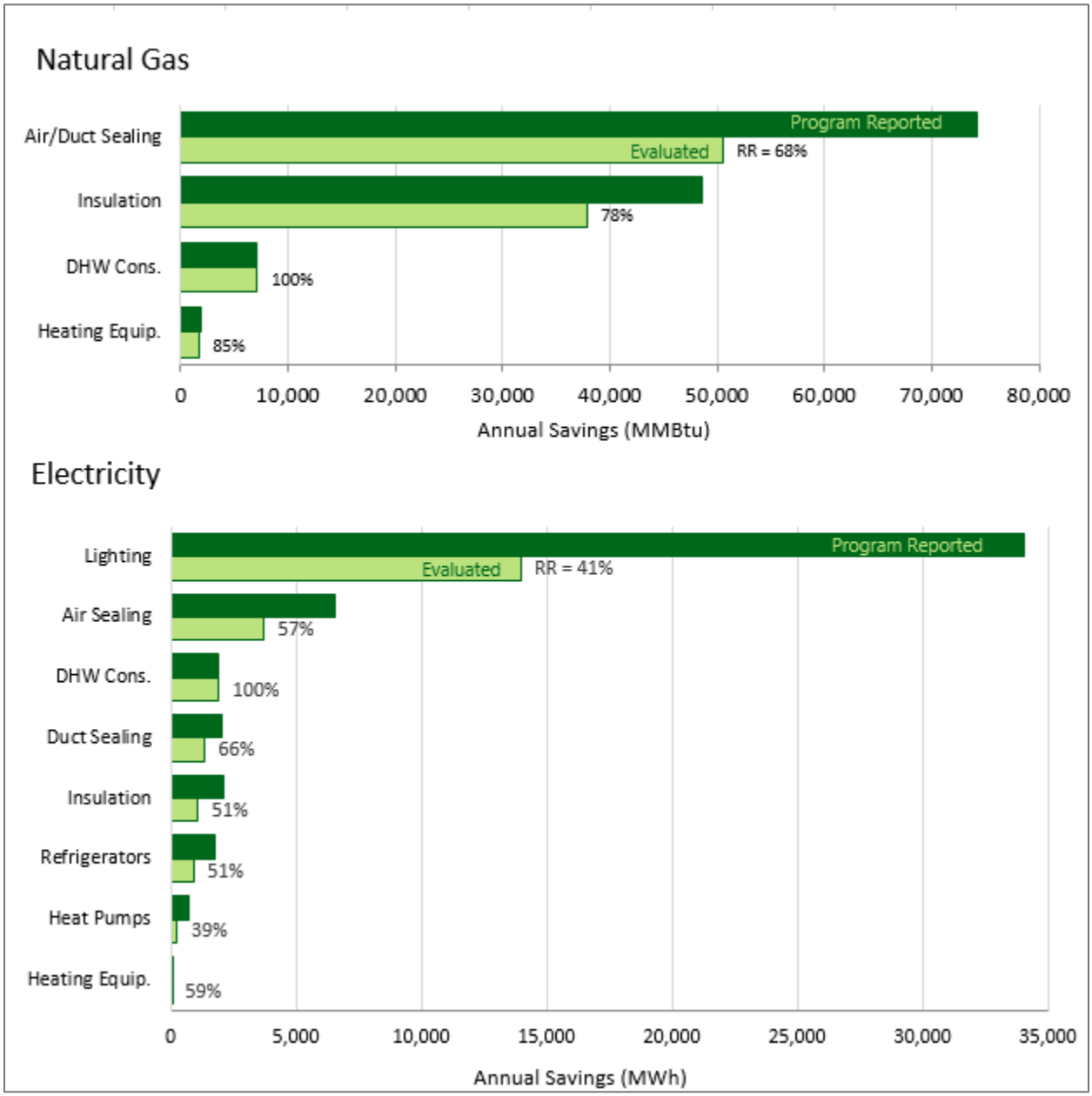
TABLE ES-2: EVALUATED ENERGY SAVINGS BY MEASURE GROUP

	Natural Gas Savings			Electricity Savings		
Measure Group	**Reported Mcf**	**Realization Rate**	**Evaluated Mcf**	**Reported MWh**	**Realization Rate**	**Evaluated MWh**
DHW Conservation[1]	68,807	100%	68,807	1,914	100%	1,914
Insulation	468,960	78%	364,895	2,139	51%	1,091
Air Sealing	646,661	68%	439,835	6,535	57%	3,725
Duct Sealing	69,650	68%	47,373	2,045	66%	1,350
Heating Equipment[1]	1,876	85%	1,601	43	59%	25
Refrigerators				1,791	51%	913
Heat Pump[1]				690	39%	269
Lighting				34,044	41%	13,958
Unevaluated[2]	30,335	100%	30,335	366	100%	366
All Groups	**1,303,175**	**74%**	**967,257**	**49,567**	**48%**	**23,611**

[1] The estimate from the regression model exhibited high variability and the realization rate was assumed to be 100%. In the case of heat pumps and heating equipment, the realization rate was computed partially from model estimates and partially from results of a separate study. See Section 4.
[2] Includes measures not evaluated because either 1) they were insufficiently represented in final billing model after attrition, or 2) the measure type could not be identified in the program data.

[1] As detailed further in Section 4.3, natural gas savings seen in similar programs and regions range from 6% to 22% of pre-install use and electricity savings range from 2% to 10%.

FIGURE ES-1: REPORTED AND EVALUATED SAVINGS WITH REALIZATION RATES



Key findings from the billing analysis and review of program reported savings are summarized in Table ES-3.

TABLE ES-3: KEY EVALUATION FINDINGS

Fuel Type	Finding	Comments
Natural Gas	Insulation and air sealing drive program savings, accounting for 80% of program reported savings.	Evaluated savings are comparable to other, similar programs.
	Duct sealing and air sealing could not be separately estimated in the billing model as they are so often installed together.	Program reported duct sealing savings seem high, at ~7% of average heating use.
Electric	Lighting is the main driver of program savings, accounting for about two-thirds of program reported savings.	Realization rate for efficient lighting was 41%.
	Program reported lighting savings per bulb were about 40% higher than cited in the 2011 evaluation.	Program reported savings per home were ~90% of the average household lighting use estimated by EIA for the Northeast. The PSD baseline is an incandescent lamp; the actual baseline is likely to be a combination of CFL, halogen, and incandescent.
	Excessive heating savings were claimed for envelope measures in homes that did not have electric space heat.	About 25% of homes with heating fuel savings from insulation and/or air sealing measures did not have usage patterns indicating electric space heat.[1]
	Air conditioning measures were infrequently installed.	About 60% of homes had usage patterns indicative of air conditioning use and the average annual air conditioning use for these homes was high (1,330 kWh), suggesting potential for improving air conditioning efficiency.
Both	Savings from DHW conservation measures could not be reliably estimated from the billing models.	These measures account for less than 6 percent of overall program reported savings

[1] The HES program does not explicitly report savings for reductions in auxiliary heating equipment use (such as boiler circulating pumps or furnace fans) for insulation, air sealing or other envelope measures. Consequently, electric savings reported from envelope measures should only represent homes with primary or secondary electric space heat. The same trend was found for air conditioning savings from insulation and air sealing measures, i.e., many homes with these measures did not have a usage pattern consistent with air conditioning use in the pre-period

There are a number of possibilities for future work that could refine or expand the findings of the billing analysis presented in this report. Table ES-4 below provides a list of the major issues encountered over the course of the evaluation that could benefit from additional study.

TABLE ES- 4: OPTIONS FOR FUTURE EVALUATION WORK

Evaluation Issue	Description	Importance to Findings	Possible Resolutions	Data Availability/ Timeframe
Multifamily Component	Only single family was included in the billing analysis MF dwelling units cannot be identified in billing data for many projects	50% of program reported natural gas savings; 30% for electricity	1. Identify the dwelling units for inclusion in a multifamily-specific billing model 2. Review modeling files and "stress test" PSD formulas with input values that best reproduce billing analysis	All data are available/ 2 months
Low Realization Rates	Billing analysis provides no insight into causes of underperformance[1]	Lighting, air and duct sealing, and insulation account most of the discrepancy between program reported and evaluation savings	"Stress test" PSD formulas with input values that best reproduce billing analysis results; modeling review and assessment of range of inputs	All data are available/ 2 months
Air Conditioning excluded from billing model	Too few installations to estimate savings in the regression model[2]	○ Less than 1% of program reported electricity savings ○ Could be more important in future	Collect AMI billing data to estimate cooling load at hourly or sub-hourly resolution; include more recent installations to estimate savings, if possible	Requires AMI data/ 3-4 months, depends on receipt of AMI data
High savings variability for DHW measures	Estimate does not meet 90/10 standard in either natural gas or electric model	○ 6% of program reported natural gas savings; 3% for electricity ○ Results are reasonable despite poor precision	Direct equipment metering, which is costly and time-consuming; PSD inputs seem to be within a reasonable range	Direct metering or bench testing/ 6 months
High savings variability for duct sealing measures	Estimate does not meet 90/10 standard in either natural gas or electric model	3% of program reported natural gas savings; also 3% for electricity.	Difficult to measure; previous study[3] included site visits and detailed analysis; unlikely that additional analysis would provide more insights	Site visits/ 9 months, to capture colder weather

[1] This limitation is inherent to billing analyses in general.
[2] Exact counts of homes cannot be given because of the multifamily participant tracking issue.
[3] "Connecticut HES Air Sealing, Duct Sealing, and Insulation Practices Report (R151)," March 24, 2016. Prepared for the Connecticut Energy Efficiency Board by NMR Group, Inc.

1 Introduction

This report presents West Hill Energy and Computing's ("West Hill Energy") impact evaluation of the Home Energy Solutions ("HES") and Home Energy Solutions-Income Eligible ("HES-IE") programs provided by the State of Connecticut's Gas and Electric utilities (collectively, "HES Program"). The evaluation covers HES Program's activity during calendar years 2015 and 2016, undertaken predominately by the Eversource and United Illuminating (UIL) companies (collectively, the "utilities").[2]

The last evaluation of the HES Program was conducted in 2014, covering program activity in calendar year 2011. The primary objective of the current evaluation was to verify program reported electricity and natural gas energy savings for as many distinct measure groups as possible, and to produce corresponding realization rates ("RR") for those measure groups. The results presented in this report are based on a statistical billing analysis that employed a cross-sectional, time-series regression model with customer-specific intercepts to estimate savings attributable to specific types of measures.

This report contains three main parts. Section 2 presents a summary of program activity during program years 2015 and 2016. Section 3 explains the methodological steps involved in conducting the analysis. Sections 4 and 5 provide detailed findings by fuel, and put the study results into a broader context. Section 6 provides a glossary of terms and abbreviations used in this report. Appendix A contains technical details about the modeling process and regression output not included in Section 4.

[2] These subsidiaries include Connecticut Natural Gas and Southern Connecticut Gas (UIL) and Yankee Gas Services (Eversource). The Connecticut Municipal Electric Energy Cooperative (CMEEC) also provides HES services but accounts for a very small fraction of 2015-16 program activity.

2 Program Description

The HES and HES-IE programs are offered by both electric and gas utilities in Connecticut. As shown in Table 2-1, the utility companies provided 2015-2016 program data showing around 350,000 Mcf of gas savings for approximately 11,000 homes, and over 72,000 MWh of electricity savings for about 54,000 homes, distributed relatively evenly between the market rate and low-income segments of the program.[3]

TABLE 2-1: PROGRAM REPORTED HES AND HES-IE ANNUAL ENERGY SAVINGS

		Eversource		United Illuminating		Combined	
		Mcf	MWh	Mcf	MWh	Mcf	MWh
HES	2015	21,418	15,917	28,543	1,976	49,961	17,893
	2016	26,503	15,776	47,230	2,552	73,733	18,328
HES-IE	2015	44,052	14,159	50,515	2,223	94,567	16,382
	2016	54,060	15,888	77,486	3,634	131,546	19,522
Total 2015-2016[1]		146,033	61,739	203,774	10,385	349,807	72,125

[1] This table was developed using the data provided by the utilities in response to a data request made in November 2017. Savings for measures that could not be matched to specific projects are not included.

Under the HES program structure, residences receive a set of core measures installed at the time of an in-home audit. In 2015-2016, the typical set of direct install core measures included efficient light bulbs, air sealing, domestic hot water (DHW) conservation measures, and to a lesser degree, duct sealing for central heating and cooling systems.

These core measures accounted for the vast majority of program reported energy savings in 2015-2016. Based on the measure descriptions provided in the program tracking data, around half of natural gas savings came from infiltration reduction measures. Lighting measures accounted for around two-thirds of all reported electricity savings, and blower-door assisted air sealing accounted for another 10%.

After receiving an initial audit, HES program customers are offered incentives on other measures, including insulation or HVAC equipment replacements, with higher incentives offered to qualifying HES-IE participants. Insulation was the most significant source of reported energy savings from the add-on measures, accounting for around 20% of all program reported Btu savings, or one-third of natural gas savings, and 5% of reported electricity savings. Heating system improvements (including replacements and heat pump installations) were the second most significant add-on measure, accounting for around 8% of total program reported Btu savings. Refrigerator replacements, while not a large proportion of the program reported

[3] Note that these totals do not precisely match those available from other public sources. Specifically, the Connecticut Statewide Energy Efficiency Dashboard reports around 353,000 Mcf and 61,000 MWh of savings for the 2015-2016 period (see https://ctenergydashboard.com/Public/PublicPerformanceReports.aspx). In addition, total participating homes could not be precisely calculated from the program data because of varying tracking conventions between single and multifamily records.

savings (around 5% of electric savings), were the biggest single share of reported electricity savings from add-on measures.

The main difference between the two utility companies was that UIL reported a significantly larger savings share from envelope measures (more than three-quarters of Btu, compared to less than 40% for Eversource), while Eversource reported relatively more savings from water and space heating improvements (around 20% of reported Btu, compared to approximately 10% for UIL). Both companies reported around two-thirds of their electricity savings from lighting measures. The total savings for both utilities by measure group are presented in Table 2-2.

TABLE 2-2: PROGRAM REPORTED HES AND HES-IE SAVINGS BY MEASURE CATEGORY, 2015-2016

	Natural Gas[1]		Electricity[1]	
Measure Category	**Annual Mcf**	**% of Mcf**	**Annual MWh**	**% of MWh**
Envelope[2]	274,377	78%	11,877	16%
Heating System[3]	50,449	14%	4,823	7%
Water Heating[4]	22,812	7%	3,476	5%
Lighting	68	0%	48,011	67%
Refrigerators	0	0%	3,684	5%
Air Conditioning	0	0%	61	0%
Appliance[5]	10	0%	134	0%
Unidentified[6]	2,091	1%	58	0%
Total	349,807	100%	72,125	100%

[1] This table was developed using the data provided by the utilities in response to a data request made in November 2017. Savings for measures that could not be matched to specific projects are not included.
[2] Includes air sealing, insulation, and window and door replacements.
[3] Includes furnaces and boiler repairs and replacements, thermostats, duct sealing, and heat pump installations
[4] Includes water heater repairs and replacements, faucet aerators and showerheads, hot water pipe insulation, and heat pump water heater installations
[5] Includes clothes washers and other unidentified appliances.
[6] Measure descriptions provided by utilities were missing or ambiguous.

Several data quality issues were uncovered throughout the course of the evaluation, as outlined below:

- Some measure descriptions had to be inferred and some measures could not be identified from the information provided
- Calculation inputs for program reported savings were not included with the project data for add-on measures
- Multifamily buildings did not have a unique site ID that could be used to associate all treated units with a specific building
- In some cases, measures in multifamily buildings could not be matched to specific dwelling units, and, thus, could not be matched to the billing data
- Projects and measures were provided separately, and in some cases, measures were included that could not be matched to a specific project

The main implication for this evaluation was that the billing analysis was limited to single family as substantial additional analysis will be required to determine the subset of multifamily units with program and billing data.

3 Methods

This section includes an overview of the methods and data sources used to conduct the billing analysis. It covers the data cleaning process and the criteria applied to determine inclusion of households in the final regression models. Further details about the parameters of the final electric and gas models are provided in Appendix A.

3.1 Overview of Methods and Data Sources

Program reported savings were evaluated using pooled, cross-sectional, time-series models with customer-specific intercepts. All participants with sufficient billing records were included in the final models. Table 3-1 below describes the three sets of data used to build the pooled billing models.

TABLE 3-1: SOURCES OF DATA USED TO EVALUATE REPORTED SAVINGS

Type of Data	Description	Purpose for Analysis
Program Data	Reported savings, installation date and measure descriptions by home for all measures installed	Define pre- and post-installation periods and identify types of measures installed in each home
Billing Data	Monthly billing records for participating households	Merge with program data to construct the pooled model
Weather Data	Hourly temperature readings for all NOAA weather stations in CT[1]	Calculate the degree days in each billing cycle for each home

[1] Six of the seven National Oceanographic and Atmospheric Administration weather stations in Connecticut were used in the billing analysis. Customers were matched to the closest of these stations using the zip code in their billing data. The Waterbury station was not used due to the large number of missing reads.

A preliminary step in preparing the billing analysis was organizing the program data into measure group categories laid out in Table 3-2 below. Further granularity in the measure group definitions could not be supported by the underlying program data.

TABLE 3-2: DEFINITIONS OF MEASURE GROUPS

Measure Group	Measures Included in Group[1]	Fuels Evaluated
DHW Conservation[2]	○ Pipe insulation ○ Faucet aerators, showerheads ○ Water heater thermostat resets	• Electricity • Natural Gas
Insulation	○ Walls, attics, ceilings, basements, etc.	• Electricity • Natural Gas
Air Sealing[2,3]	○ Caulking, weather stripping ○ Outlet gaskets, door sweeps	• Electricity • Natural Gas
Duct Sealing[2]	○ Sealing and insulating forced air ductwork	• Electricity • Natural Gas
Heating Equipment[2]	○ Furnace and boiler cleaning, tuning, ○ Repairs and replacements ○ Circulator pumps and furnace fan upgrades	• Electricity • Natural Gas
Lighting	○ All lighting upgrades	• Electricity
Refrigeration	○ All refrigerator upgrades	• Electricity
Heat Pumps	○ All heat pump installations	• Electricity

[1] The list covers only measures installed by participants included in the final pooled billing model. Several types of measures were too infrequently installed to be estimated in a regression analysis: Wifi thermostats, appliances, heat pump water heaters, window and door replacements, natural gas conversions, and air conditioning.
[2] Most participants in these measure groups also simultaneously installed measures from other groups.
[3] The vast majority of air sealing was done with the assistance of a blower door test.

The comprehensive approach of the HES program, where multiple measures are installed in each home, adds complications to the process of specifying the model. When two or more measures are installed at the same time in the same home, it is often not possible to separate the impacts of each individual measure. In the final natural gas model, for example, the air sealing and duct sealing groups were combined, and their savings were estimated as a package, because virtually all participants who installed duct sealing also installed air sealing.

Some measures were not included in the analysis due to the small number of installations. These unevaluated measures amounted to around 4.5% and 2.0% of reported natural gas and electric energy savings, respectively. They include Wifi thermostats, appliances, heat pump water heaters, window and door replacements, and air conditioners.

Another early step in the analysis preparation was flagging homes that participated in other programs in addition to HES, specifically any non-HES rebate programs and the Home Energy

Report program. These flags were used in the process for verifying the final model results, described further in Section 3.4.

3.2 Data Cleaning

Data cleaning is a critical component of any billing analysis. Data from the three sources shown in Table 3-1 were combined and carefully reviewed to remove homes with insufficient billing data and other data issues. This was a two-stage process, comprising of the following:

1. An initial review, conducted to standardize program and billing data, and remove any households with insufficient billing history from the analysis
2. A secondary review, centered around house-by-house regressions of weather variables on energy consumption, conducted to identify homes with erratic consumption patterns and other issues

This two-stage process is described in more detail below.

3.2.1 Initial Review

In the initial review, individual projects were removed from the analysis frame for any of the following reasons:

- Project could not be matched to a specific account number in the billing data
- Project could not be matched to specific measure(s) in the program data
- Project had no associated savings reported in the program data

In the billing data, individual monthly meter reads were dropped if consumption or billing cycles overlapped or showed a pattern consistent with multiple estimated reads.[4] After these adjustments, homes with gaps between reads were reviewed and dropped if necessary. As shown in Table 3-3, participants were required to have a significant amount of billing history during heating seasons to be included in the analysis.

[4] Such idiosyncrasies are commonly associated with estimated reads. In the billing data provided for this evaluation, estimated reads were not explicitly identified.

TABLE 3-3: CRITERIA FOR INCLUSION IN THE BILLING MODELS

Fuel	Criteria for Inclusion in House-by-House Regressions
Natural Gas	○ Minimum of 180 days in both pre- and post-installation periods, including at least 2 winter months **or** ○ Sixty percent of normalized annual heating degree days[1]
Electric	○ At least 4 bills in both the pre and post-installation periods **or** ○ Seventy percent of normalized annual heating degree days[1]

[1]Normalized heating degree days were calculated using a base temperature of 60°F and averaged over 2012-2017 period.

3.2.2 Secondary Review

The first step in the second stage of data preparation was to conduct house-by-house regressions of weather on consumption for all homes that met the initial review criteria laid out above. These house-by-house regressions served different purposes in the construction of pooled models for each fuel.

The following sections cover the natural gas model, the electric model, and the treatment of multifamily homes.

Natural Gas Model

The purpose of the natural gas house-by-house regressions was to exclude any home from the pooled model without seasonal heating usage patterns. For each home, two models were tested in order to identify these cases:

1. An intercept model that assumes the home uses natural gas for both water heating and space heating[5]
2. A no-intercept model that assumes the home uses natural gas for space heating only

Based on the results from the model with the better fit, participants were excluded from the final model for any of the following reasons:[6]

- Inverse or weak relationship between usage and outdoor temperature
- Erratic consumption patterns
- Consumption levels outside of a normal residential range

Applying these screens eliminated homes that did not show a clear pattern of natural gas heating, or that could have had extended periods of vacancy or some commercial activity.

[5] The intercept term reflects base (non-heating) consumption. Water heating is generally the only base end-use large enough to be captured in an intercept term. Because the program data did not adequately identify homes' water heating fuel, it was necessary to analyze each home's data with an individualized regression model in order to flag homes that showed natural gas base use.
[6] As most homes with access to natural gas use the fuel for both space and water heating, the default assumption was that the intercept model was the best choice. The no-intercept model was used only in cases where the R^2 was substantially higher than the intercept model or if the intercept was negative.

Electric Model

All homes would be expected to show some base amount of non-weather dependent electricity consumption, reflecting lighting, plug loads, and other typical end uses. The house-by-house regressions were conducted for two reasons:

1. To identify homes with weather-dependent usage patterns (indicative of heating and cooling loads)
2. To identify homes with inconsistent usage patterns for removal from the model

These reasons are explained further in the subsections below.

Weather-Dependent Use

Understanding weather-dependent use is key to the electricity billing analysis. The house-by-house regressions were used to identify homes using electric space heat and air conditioners for two reasons:

- To identify the homes where weather-dependent savings are likely to be found.
- To ensure that heating and cooling use was captured by the model for all homes with these end uses[7]

For each home, a regression model was run for the pre-period that included an intercept term representing non-weather dependent (base) use and separate terms for heating and cooling use. Homes were defined as electric heat users by the strength and magnitude of the relationship between their electric energy consumption and cold weather temperatures (heating degree days). Similarly, homes were identified as air-conditioning users by the strength and magnitude of the relationship between their consumption and warm weather temperatures (cooling degree days).[8]

If appropriate, two parameters were created for the same measure to account for weather-dependent savings. For example, heat pumps would be expected to save electricity in homes with electric space heat and use extra electricity in homes with central fossil fuel heating systems. To reflect this reality, the final model had one parameter for homes with electric space heat in the pre-period, and another for homes without electric space heat in the pre-period.

Some homes with program reported electricity savings from heating-related measures did not show a pattern of electric space heat usage, and some homes with program reported cooling savings did not show a pattern of air-conditioning use.[9] For example, about 28% of homes with

[7] This approach reduces the error in the model and avoids the possibility of biasing the savings estimates due to changes in space heating and/or cooling use.
[8] Equipment other than air conditioning may also exhibit weather-dependent usage, such as whole house fans or dehumidifiers. However, the threshold for defining air conditioning users was set high enough to preclude mistaking these less intensive end uses for direct cooling.
[9] While some electricity savings is to be expected in homes not heating with electricity, for example from reduced fan motor and circulating pump run times, the amount of savings reported for these homes was high enough to suggest electricity was the primary heating fuel. Note also that the PSD does not explicitly prescribe envelope savings for motor fans and circulating pumps so it is not clear why electricity savings would be reported for any home not heating with electricity.

electric savings from air sealing measures and 60% of homes with electric savings from duct sealing measures showed no signs of electric heating.[10]

Measure group variables for heating-related measures were defined by home as follows:

- The home had electric space heating in the pre-period
- The program reported savings for the measures were 100 kWh per year or higher[11]

The same approach was used for cooling-related savings. For measures that could have both heating and cooling savings, such as insulation and duct sealing, both heating and cooling parameters were included. The evaluated savings for heating and cooling measures were calculated from the model output in a two-step process:

1. Savings were calculated from the model coefficient for homes with electric heat (or air conditioning)
2. These savings were adjusted proportionally to account for the homes with the measure but no electric space heat (or air conditioning) signature in the billing data

Accounting for the weather-dependent patterns of use reduces the error in the model and improves the ability to estimate savings from weather-dependent measures.

Exclusion from the Model

The house-by-house regression results were also used to exclude homes from the final model for the following reasons:

- Negative intercept (representing non-weather-dependent use)
- Erratic consumption patterns
- Consumption levels outside of a normal residential range

Applying these screens eliminated homes with extended periods of vacancy or some commercial activity.

Multifamily Buildings

The secondary review also included assessing the variability of participant usage. The cross-sectional component in a pooled model, *i.e.*, the home, should be reasonably homogenous. Generally, single or double dwelling units, whether in detached single family, attached single family, or multifamily buildings, fit this description.

However, the program tracking data for multifamily projects was not comprehensive enough to enable accurate matching of multifamily dwelling units to their billing data for a substantial portion of the analysis period. For this reason, the analysis was conducted using only single-

[10] The Connecticut PSD does not prescribe electric savings from central fossil fuel systems (such as reduced furnace fan or boiler circulating pump use). In addition, the measure group flag was only set to 1 if the savings were greater than 100 kWh. Thus, homes with program reported, heating savings from insulation, duct sealing or air sealing would be expected to have some type of electric space heat.

[11] This restriction was added as measures with small savings are difficult to estimate from monthly billing models. Other cut-off values were tested and found to have comparable impacts on the results.

family homes. Additional review is currently in progress to assess the scope of this issue and decide whether multifamily modeling can be conducted with available data.

3.2.3 Attrition Summary

Tables 3-4 and 3-5 present summaries of the data attrition resulting from the initial and secondary stages of data preparation described above. The utilities provided program data for approximately 11,000 gas and 54,000 electric customers.[12] Around a quarter of these were multifamily participants who were excluded from the analysis, as explained in Section 3.2.2.

It is typical for billing analyses to include between 40% and 60% of total eligible participants. Of the 8,298 single family natural gas participants, 71% were retained in the final model. Of the 39,932 single family electric participants, 58% were retained.

TABLE 3-4: NATURAL GAS MODEL SUMMARY OF ATTRITION

Reason for Removal	Number Removed	Participants Remaining	Percent Remaining
Total Participants[1]	-	8,298	100%
No Bills	149	8,149	98%
No Savings or Unidentifiable Measures[2]	295	7,854	95%
Insufficient Bills[3]	1,328	6,512	78%
Irregular or High/Low Usage[4]	505	6,007	72%
Final Model Count	**-**	**5,862**	**71%**

[1] Excludes multifamily participants. See Section 3.2.2.
[2] Home had no measure(s) associated with it, or measure(s) could not be identified in program data.
[3] Billing history did not cover:
- a minimum of 180 days and at least two winter months in both pre- and post-installation periods, or
- sixty percent of normalized annual heating degree days
[5] The regression model exhibited poor fit (R^2 less than 0.70 or t-statistic with absolute value less than 2) or annualized usage in either the pre- or post-installation period was greater than 2,750 Ccf or less than 250 Ccf; criteria was applied on results of house-by-house regression.

The measure mix in the final model was similar to the program population.[13] Hot water and air sealing measures were by far the most often installed measures. Insulation and duct sealing measures were the second most often installed measures, though less than half as many homes in the final model installed an insulation or duct sealing measure, as did a hot water or air

[12] Because the number of multifamily participants cannot be comprehensively counted (see Section 3.2.2) these figures and any that depend on them—denoted in *italics*—are necessarily approximate.
[13] See Tables A-1, A-2, and A-3 in the appendix for model and program population counts

sealing measure. Few households in the final model or the program population installed heating equipment.

TABLE 3-5: ELECTRIC MODEL SUMMARY OF ATTRITION

Reason for Removal	Number Removed	Participants Remaining	Percent Remaining
Total Participants[1]	-	39,932	100%
No Bills	4,670	35,262	88%
No Savings or Unidentifiable Measures	1,533	33,729	84%
Insufficient Bills[2]	6,079	27,650	69%
Irregular or High/Low Usage[3]	4,449	23,201	58%
Final Model Count		**23,201**	**58%**

[1] Excludes multifamily participants. See Section 3.2.2.
[2] Billing history had less than 4 reads, covered less than 70% of normalized, annual heating degree days, or had substantial gaps between billing cycles.
[3] Regression model had negative intercept or steep negative cooling slope, average consumption over a billing period was more than 100 kWh per day in April, May, Sept, or Oct, or more than 150 kWh per day over the entire period, average consumption over a billing period was less than 5 kWh per day, or home had reads with zero usage.

As with the natural gas model, the measure mix in the final electric model was similar to the program population. Lighting was by far the best represented measure, followed by domestic hot water and air sealing measures. Few homes in the final model had installed efficient air-conditioning or heating equipment, so savings could not be reliably estimated for these groups. Heat pumps were also rarely installed through the program.

3.3 Billing Models

The final models were cross-sectional, time series, interrupted at the time of the installation. The models included customer-specific intercepts (fixed effects). A fixed effects model estimates the overall influence of a predictor (or independent) variable on a response (or dependent) variable, while controlling for factors that do not change over time within each individual household (the cross-section), such as size of the home, presence of major appliances and lifestyle.

The final models incorporated weather and measure groups as predictor (independent) variables. Timing variables were also included to capture any widespread changes in energy use over time. Appendix A provides the model equations and additional details about the different model specifications tested and selection criteria used to settle on the final parameters.

In addition to the final model, several alternative model specifications were tested to verify results and analyze differences in savings between subgroups of program participants. Table 3-6 below documents the main purposes of the alternative models used in the analysis. These

models were designed to estimate savings at the household level and did not attempt to disaggregate savings estimates into different measure groups.

TABLE 3-6: DESCRIPTION OF SUPPLEMENTAL MODELS

Models Tested	Model Description
Alternative Models	***Model Tests for...[1]***
Household Level[2]	○ Reductions in base usage among participants with base measures AND ○ Reductions in heating/cooling usage among participants with heating/cooling measures
Household Level with utility company differentiation	○ Differences in base and weather-dependent usage reductions between Eversource and United Illuminating
Household Level with program segment differentiation	○ Differences in base and weather-dependent usage reductions between HES and HES-IE
Household Level with non-HES participants identified	○ Differences in base and weather-dependent usage reductions for HES participants who also participated in non-HES programs[2]
Household Level with HER participants identified	○ Differences in base and weather-dependent usage reductions for HES participants that received Home Energy Reports

[1] All significance tests assumed a 90% confidence interval.
[2] The results of the household level configuration provide a reasonableness check on the program-wide realization rate calculations developed from the final model results. Comparable results indicate that the more complex measure level model was appropriately specified.

3.4 Model Selection

An important aspect of the modeling process was comparing alternative models to determine the best fit and to assess the relative importance of specific variables. Alternative models were developed with differing configurations of measure groups. The general process was to start with the simplest model and add granularity.

One of the key issues with modeling HES program savings is the combination of measures installed in each home. Attempting to estimate the savings from each measure individually, without accounting for the range of measures installed in the home, introduces multicollinearity into the model, which can result in estimators that are of a substantially different magnitude or

of the wrong sign. To address this issue, the alternative models included various configurations of measures commonly installed together.

A combination of strategies was used to identify the best model. Standard statistics, such as R^2 and t-values for specific parameters, and changes in the magnitude of the key estimators were reviewed. In addition, the information-theoretic approach to model selection was employed, which relies on the Akaike Information Criteria (AIC) statistic to compare models. In conjunction, these methods ensured the selection of the final model was based on objective, statistical standards and the final model improves the ability to estimate the parameters of interest.

3.5 Exogenous Effects

A billing analysis is based on the assumption that overall changes in household consumption can be used to calculate the savings from participation in efficiency programs. Energy use may be affected by widespread economic changes, or other factors outside the influence of the program. In a two-stage model where the regression is conducted only at the household level,[14] a comparison group is sometimes used to account for exogenous effects. However, a comparison group may introduce additional uncertainty in the model, as it includes naturally-occurring efficiency and the end result cannot be clearly interpreted as either gross or net savings.[15] In addition, defining an equivalent comparison group can be a complicated process.

Non-program changes, both internal (such as changes in occupancy) and external (such as changes in energy prices), were addressed in the pooled billing analysis as follows:

1. The fixed effects model accounts for the factors in each home that remain stable over time
2. The timing variables account for widespread changes in energy use across all homes in the model
3. The model includes all homes meeting the criteria for inclusion and the models were quite large, indicating random changes internal to the household will not bias the results[16]
4. The trend line of "future participant" bills was tested for the final models[17]

[14] While household regressions were conducted in this evaluation as part of the data cleaning process, the final results were estimated from pooled models including all eligible homes.
[15] Randazzo, K.; Ridge, R.; and Wayland, S. (2017, in revision). Observations on Chapter 8 of the Uniform Methods Project: A Discussion of Comparison Groups for Net and Gross Impacts. Opinion Dynamics, submitted to PG&E
[16] In a large model, for example, some houses will experience an increase in occupancy and others a decrease. As these changes are random, they will cancel each other out.
[17] "Future" participants are often used as a comparison group, as these customers are likely to be the most similar to participants during the evaluated period.

In addition, previous research indicates the large, pooled models do not produce biased estimators when compared to a model incorporating detailed survey data regarding changes in household composition and energy use.[18]

[18] Megdal & Associates, LLC, West Hill Energy & Computing, Inc. NYSERDA 2007-2008 Empower New York Program Impact Evaluation Report. April 2012

4 Results

This section describes the results of the natural gas and electric billing analyses. Details from the regression output are provided in Appendix A.

4.1 Natural Gas Results

Several different measure group configurations were tested and compared before finalizing a model estimating savings for four measure groups:

- DHW conservation
- insulation
- air sealing/duct sealing[19]
- heating equipment repairs and replacements

Table 4-1 presents the savings estimates produced by the final model for these measure groups.

TABLE 4-1: ESTIMATED NATURAL GAS SAVINGS BY MEASURE GROUP

Measure Group	Homes in Model (n=5,862)	Mean Ccf Savings		Relative Precision at the 90% Confidence Level
		Program Reported[2]	Model Estimate	
DHW Conservation[1]	1,149	16	27	+/-27%
Insulation	434	201	156	+/-8%
Air & Duct Sealing	3,426	92	63	+/-9%
Heating System Improvements[1,3]	106	99	57	+/-49%

[1] Estimator from the final model was not reliable for evaluation purposes.
[2] Computed for participants in final model. Table 4-3 gives the total program reported participant counts and savings amounts.
[3] Represents furnace and boiler replacements as well as tune-ups and repairs.

Regression models produce accurate estimates of savings when comparing overall household energy consumption between periods. Estimating measure-level savings however, often gives variable results. Savings for insulation and air/duct sealing measure groups were both estimated within the 90/10 standard of confidence/precision level. The estimates for DHW conservation and heating system savings did not meet this standard, likely a consequence of two limitations of the analysis:

[19] It was not possible to isolate duct sealing savings because virtually all homes in the final model that installed duct sealing also installed air sealing measures.

1. Separating weather-dependent and non-weather dependent use in a regression model is inexact; Unlike heating savings estimates which are generally stable, modeled DHW savings can be highly variable[20]
2. The heating system measure group was small and included a wide range of measures with highly variable savings, from tune-ups to boiler or furnace replacements

The evaluation approach for the measure groups that could not be estimated with the regression model are described in Table 4-2.

TABLE 4-2: SOURCE OF REALIZATION RATES FOR NATURAL GAS MEASURES NOT EVALUATED THROUGH THE REGRESSION ANALYSIS

Measure Group	Source of Realization Rate
Heating System Improvements	Program reported savings for heating system replacements were separated from maintenance/repair measures. o Furnace/boiler replacements: 2018 CT Upstream HVAC Program Impact Evaluation.[1] o Maintenance/repair: Assumed RR of 100%
DHW Conservation Measures	Assumed RR of 100% (Measures are a small percent of overall program savings.)
Unevaluated Measures	Assumed RR of 100% (Measures are a small percent of overall program savings.)

[1] CT HVAC and Water Heater Process and Impact Evaluation and CT Heat Pump Water Heater Impact Evaluation Report, July 19, 2018, Prepared for the CT EEB Evaluation Team by West Hill Energy and Computing. This study involved direct metering of 40 participants of an upstream program.

Table 4-3 shows how the measure group realization rates were calculated from the final natural gas model and the other sources cited in Table 4-3, to produce an overall natural gas realization rate of 74%. This result was driven largely by the performance of air sealing measures, the most widely installed natural gas measure, and insulation, the highest impact measure.

[20] While DHW use is largely non-weather dependent, it has some characteristics similar to weather-dependent measures since the water inlet temperatures in the winter are lower during the heating season. In addition, non-weather-dependent use tends to be substantially smaller than heating use, making it more difficult to develop an accurate estimate.

TABLE 4-3: TOTAL EVALUATED GAS SAVINGS BY MEASURE GROUP

Measure Group	Homes with Measure[1]	Total Program Reported Mcf[1]	Realization Rate	Total Evaluated Mcf
DHW Conservation[1]	6,328	68,807	100%	68,807
Insulation	2,293	468,960	78%	364,895
Air Sealing	6,549	646,661	68%	439,835
Duct Sealing	928	69,650	68%	47,373
Heating Equipment				
Repair/Tune[1]	127	9,403	100%	9,403
Replacements[2]	61	9,358	71%	6,608
Unevaluated[3]	182	30,335	100%	30,335
Total	**8,298**	**1,303,175**	**74%**	**967,257**

[1] The regression coefficient from the final model was not reliable for evaluation purposes. Realization rate was assumed to be 100%.
[2] Realization rate was adopted from results of the 2018 CT Upstream HVAC Program Impact Evaluation.
[3] Category represents all measures not evaluated because either 1) they were insufficiently represented in final model after attrition (Wifi thermostats, window and door replacements, heat pump water heaters, and appliances), or 2) the measure type could not be identified from descriptions in program data. Realization rate was assumed to be 100 per cent.
[4] Participant counts and savings totals exclude multifamily projects, consistent with the composition of the final model. Totals in Table 2-1 and Table 2-2 include multifamily projects, so will differ from those presented here.

There were also small, but statistically significant differences found between savings estimates for the separate utilities and between market rate and low-income program segments. These differences appear to be driven by the penetration of insulation measures. In both cases, the better performing participant group installed significantly more insulation than their counterpart.

Table 4-4 presents the average natural gas savings calculated from the measure group realization rates discussed above. Average annual savings were 117 Ccf per household, amounting to around 11% of annual consumption. This compares favorably to the previous evaluation for 2011, which found only a 6% reduction in usage. One reason for the increase in savings could be the greater share of insulation in the 2015-16 measure mix as compared to 2011.

TABLE 4-4: SUMMARY OF NATURAL GAS HOUSEHOLD SAVINGS

	Energy Use or Savings
Mean Pre-Install Usage[1]	1,029 Ccf
Mean Program Reported Savings[2]	157 Ccf
Program Reported Savings as Percent of Pre-Use	15%
Mean Evaluated Savings[3]	117 Ccf (+/- 9 Ccf)
Evaluated Savings as Percent of Pre-Use	11% (+/- 1%)

[1] For all homes included in final model (n=5,862).
[2] For all single family 2015-16 participants (n=8,298). Value for homes in final model was 160 Ccf.
[3] A small amount of program reported savings could not be evaluated and were assigned a default realization rate of 100 per cent.

In the regression analysis, savings from the pooled models estimated at the household level tend to be more accurate than measure level estimates and can provide a useful verification of findings from the more complicated models. In this case, the household level results were comparable to the results in Table 4-4, suggesting that the final, measure-specific model gave an accurate estimate of overall household savings.

4.2 Electric Results

As with the natural gas model, several configurations of measure groups were tested and compared before finalizing a model. The final configuration estimated savings for seven[21] groups:

- DHW conservation
- insulation
- air sealing
- duct sealing
- refrigerators
- heat pumps[22]
- lighting

[21] Air conditioners could not be included as a measure group in the final model because they were predominantly installed in multifamily buildings excluded from the analysis. Similarly both boiler circulating pumps and furnace fans were installed too infrequently to be modeled.
[22] Heat pump savings were estimated separately for homes that had electric space heating prior to installation and homes that did not.

Table 4-5 presents the savings estimates produced by the final model for these measure groups.

TABLE 4-5: ESTIMATED ELECTRIC SAVINGS BY MEASURE GROUP

Measure Group	Homes in Model (n=23,201)	Mean kWh Savings			Relative Precision at the 90% Confidence Level
		Program Reported[1]	Model Estimate[2]	Adjusted Model Estimate[3]	
DHW Conservation[4]	1,981	269	144	144	+/-53%
Insulation[5]	322	2,352	1,842	1,204	+/-10%
Air Sealing[5]	1,582	1,032	822	586	+/-10%
Duct Sealing[5]	648	538	809	357	+/-19%
Refrigerators	1,041	1,341	681	681	+/-8%
Heat Pumps[6]	162	2,748	N/A	1,657	+/-18%
Lighting	13,584	903	N/A	367	+/-6%

[1] Calculated for participants in final model. Table 4-7 gives the total program reported participant counts and savings amounts.
[2] Estimated only for homes showing a pattern of electric weather-dependent space heat and/or air-conditioning during the pre-install period.
[3] Regression coefficients were adjusted for heating to represent all homes in the model with the measure, including those without a consumption pattern of weather-dependent use. For example, the model estimate of insulation savings was reduced to account for the 34% percent of homes with the measure that did not show weather-dependent electric use during the pre-install period. For measures with no weather-dependent savings, the adjusted model estimate is the same as the model estimate.
[4] Estimator from the final model was not reliable for evaluation purposes.
[5] The savings for these measures include both heating and air conditioning savings.
[6] Includes only homes with a pattern of electric space heat use in the pre-installation period (retrofit homes). Savings for homes without pre-installation period electric space heat (lost opportunity) were not estimated from the billing analysis. See Table 4-6.

Estimating savings at the measure-level with regression models often yields variable results. The final electric model produced stable results within the 90/10 standard of confidence/precision for the insulation, lighting, air sealing and duct sealing measure groups, as well as for heat pumps installed in homes previously using electric space heat.

The precision of the estimates for the DHW conservation and duct sealing, and for heat pump installations in homes with prior electric space heat, was somewhat worse than the 90/10 confidence/precision standard. These three measure groups collectively account for less than 10% of the program reported savings.

The evaluation approach for the measure groups that could not be estimated with the regression model, including those that could not be included at all (boiler circulating pumps and furnace fans), are described in

Table 4-6.

TABLE 4-6: SOURCE OF REALIZATION RATES FOR ELECTRIC MEASURES NOT EVALUATED THROUGH THE BILLING ANALYSIS

Measure Group	Source of Realization Rate
Heat Pumps (Homes without electric space heat)	2016 MA/RI impact evaluation of heat pumps[1]
Boiler Circulating Pumps	2018 CT Upstream HVAC impact evaluation;[2] included *in situ* metering of boiler circulating pumps and an AMI billing analysis of furnace fans
Furnace Fans	
DHW Conservation Measures	Assumed RR of 100% (Measures are a small percent of overall program savings.)
Unevaluated Measures	Assumed RR of 100% (Measures are a small percent of overall program savings.)

[1] "Ductless Mini-Split Heat Pump Impact Evaluation," December 30, 2016, Prepared for the Electric and Gas Program Administrators of Massachusetts and Rhode Island, by the Cadmus Group. This characterization is a better estimate of the savings from this lost opportunity measure as the regression model savings reflect the extra use from the heat pump rather than a lost opportunity baseline (standard efficiency heat pump).
[2] "CT HVAC and Water Heater Process and Impact Evaluation and CT Heat Pump Water Heater Impact Evaluation Report," July 19, 2018, Prepared for the CT EEB Evaluation Team by West Hill Energy and Computing.

Table 4-7 shows how the measure group realization rates from the final electric model, and the other sources cited in Table 4-6, were applied to the program reported savings to compute an overall realization rate of 48%. This result was driven largely by the performance of lighting, by far the most widely installed electric measure, and to a lesser extent by the heating measures (air sealing, insulation, and duct sealing).

TABLE 4-7: TOTAL EVALUATED ELECTRICITY SAVINGS BY MEASURE GROUP

Measure Group	Homes With Measure[4]	Total Program Reported MWh[4]	Realization Rate	Total Evaluated MWh
DHW Conservation[1]	8,167	1,914	100%	1,914
Insulation	3,760	2,139	51%	1,091
Air Sealing	22,313	6,535	57%	3,725
Duct Sealing	5,441	2,045	66%	1,350
Heating Equipment[2]	4	43	59%	25
Refrigerators	1,370	1,791	51%	913
Heat Pumps	266	690	39%	269
Lighting	38,088	34,044	41%	13,958
Unevaluated[3]	542	366	100%	366
Total	**39,932**	**49,567**	**48%**	**23,611**

[1] Estimator from the final model was not reliable for evaluation purposes. Realization rate was assumed to be 100%.
[2] This measure group includes boiler circulation pumps and furnace fans; these measures were not represented in final model. The realization Rate was adopted from 2018 CT Upstream HVAC impact evaluation.[23]
[3] Category represents all measures not evaluated because either 1) they were insufficiently represented in final model after attrition (Wifi thermostats, window and door replacements, heat pump water heaters, air conditioners and appliances), or 2) the measure type could not be identified from descriptions in program data. Realization rate was assumed to be 100%.
[4] Participant counts and savings totals exclude multifamily projects, consistent with the composition of the final model. Savings totals in Table 2-1 and Table 2-2 are inclusive of multifamily projects.

Table 4-8 presents the average electricity savings calculated from the measure group realization rates discussed above. Average annual savings were 591 kWh per household, amounting to around 6% of average household electricity consumption. This is lower than the previous evaluation for 2011, which found a 10% reduction in usage.

[23] "CT HVAC and Water Heater Process and Impact Evaluation and CT Heat Pump Water Heater Impact Evaluation Report," July 19, 2018, Prepared for the CT EEB Evaluation Team by West Hill Energy and Computing. The realization rate was calculated by comparing the evaluated kWh savings per unit in this study to the HES program reported kWh per unit.

TABLE 4-8: SUMMARY OF ELECTRIC HOUSEHOLD SAVINGS

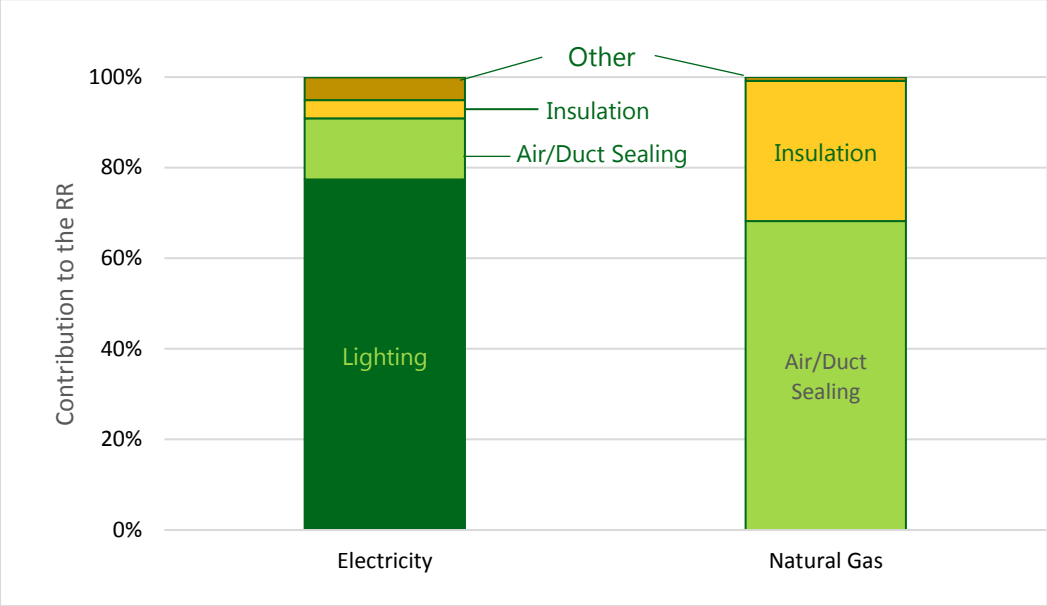
	Energy Use or Savings
Mean Pre-Install Usage[1]	9,157 kWh
Mean Program Reported Savings[2]	1,241 kWh
Program Reported Savings as Percent of Pre-Use	14%
Mean Evaluated Savings[3]	591 kWh (+/- 7 kWh)
Evaluated Savings as Percent of Pre-Use	6% (+/- 0.6%)

[1] For all homes included in final model.
[2] For all single family 2015-16 program participants. For homes in the model the mean-reported savings is 1,180 kWh
[3] A small percent of program reported savings could not be evaluated. The RR for these measures was assumed to be 100%.

As found in the natural gas analysis, the electric results in Table 4-8 were comparable to the results from a simpler, household level model, suggesting that the final model gave an accurate estimate of overall household savings. In the electric analysis, no statistically significant differences in performance between utilities or program segments were found.

Figure 4-9 below summarizes the contribution of each measure type to the overall realization rates for natural gas and electricity. Air sealing and insulation together explain 99% of the natural gas realization rate. Lighting explains nearly 80% of the electricity realization rate.

TABLE 4-9: CONTRIBUTION OF SPECIFIC MEASURES TO OVERALL REALIZATION RATE



Additional investigation was conducted into the low realization rate for lighting, yielding the following findings:

- According to the previous HES evaluation, the average program reported lighting savings in program year 2011 was 653 kWh per home.[24] This is about 40% lower than the 903 kWh per home found by this study for program years 2015 to 2016.
- The average program reported savings per bulb in 2015 to 2016 was 54 kWh, an increase of 19 kWh (or 55%) from the 35 kWh per bulb cited in the 2011 evaluation.[25]
- The average annual lighting consumption for all residential dwellings in the Northeast estimated by the EIA is 992 kWh per home.[26] The evaluated savings were 367 kWh per home, which would equate to about a 37% reduction assuming the EIA's figure for average lighting use.
- Applying the 2015-2016 program reported lighting savings to the EIA estimate of average lighting use implies a 90% reduction in lighting usage, suggesting a substantial overstatement of savings.

[24] Cadmus Group, Inc., 2014. Impact Evaluation: 2011 Connecticut Home Energy Services.
[25] The impact evaluation for PY2011 found that the realization rate for lighting was 120%. If the results of this evaluation were applied, the program reported savings would have been about 42 kWh per bulb.
[26] U.S Energy Information Administration. 2015 Residential Energy Consumption Survey: Energy Consumption and Expenditure Tables. This is the average for all residential dwellings, both single and multi-family. For CT, the average is likely to be higher because of the higher share of larger homes.

One potential explanation for overstated lighting savings is that the PSD prescribes screw-base incandescent bulbs as the baseline for program years 2015 to 2017. The actual baseline for these years is most likely a mix of CFL's, halogens, and incandescent.

The performance of heating measures (insulation, air and duct sealing) accounted for about 15% of the discrepancy between the program reported and evaluated savings. The main reason for the lower evaluated savings is that electric savings were claimed in homes that did not show a pattern of electric space heat and/or air conditioning during the pre-installation period.[27] This outcome is not unique to this evaluation[28] and may be partially related to difficulties in attributing savings to a specific fuel in homes with multiple heating fuels.

4.3 Comparison to Other Studies

Evaluated savings for programs in the Northeast similar to HES/HES-IE are shown in Tables 4-10 and 4-11. All of the natural gas programs shown in Table 4-10 included insulation and air sealing; however, the penetration of insulation, which has high savings, and other measures with smaller savings is likely to vary from program to program. For electricity, lighting was the primary source of savings for most of the programs, with the exception of the NYSERDA programs, where a substantial portion of the program reported savings were associated with heating-related measures.

The findings from this analysis are within the general range found in previous studies. For natural gas savings, evaluated savings as a percentage of pre-install use runs from 6% to 22%. The HES/HES-IE program impact was 11% of pre-install use, in line with other southern New England programs, which range from 6% to 13%. The Vermont and New York program impacts are higher, within the 14% to 16% range, possibly due to a greater emphasis on comprehensive envelope projects. The current HES natural gas analysis shows substantially higher savings as percent of pre-install use (11%) compared to the previous impact evaluation (6%), probably driven by increased penetration of insulation and air sealing measures.

[27] Approximately 25% of the homes in the model with air sealing and insulation savings had usage patterns that did not indicate the presence of electric space heating. About 60% of the homes with duct sealing also showed no sign of electric space heating. As the PSD does not prescribe envelope savings for motor fans and circulating pumps, it is not clear why electricity savings would be reported for any envelope measures in home not heating with electricity.

[28] The same pattern was found in the NYSERDA HPwES program evaluations. See References section for the report details.

TABLE 4-10: COMPARISON OF NATURAL GAS IMPACTS FOR SIMILAR PROGRAMS

State	Program	Program Year(s)	Mean Home Use (MMBtu/yr)	Reported Savings (% of Use)	Evaluated Savings (% of Use)	Overall Realization Rate
CT	Home Energy Services	2015-2016	103	15%	11%	74%
CT	Home Energy Services[1]	2011	105	11%	6%	54%
MA	Home Energy Services[2]	2010-2011	120	15%	12%	76%
RI	EnergyWise[3]	2010	117	13%	13%	99%
RI	EnergyWise[4]	2014	110	25%	8%	33%
NY	Home Performance with Energy Star[5]	2007-2008	106	25%	16%	65%
NY	Home Performance with Energy Star[6]	2010-2013	96	29%	14%	48%
NY	EmPower[7]	2007-2008	109	13%	9%	70%
VT	VGS Residential Retrofit[8]	2014-2016	102	19%	16%	85%
VT	VGS Residential High Use[9]	2008-2010	126	26%	22%	89%
VT	VGS Low Income[10]	2008-2010	88	26%	16%	62%

[1] The Cadmus Group, Inc. Impact Evaluation: Home Energy Services. December 2014.
[2] The Cadmus Group, Inc. Home Energy Services Impact Evaluation. August 2012
[3] The Cadmus Group, Inc. Rhode Island EnergyWise Single Family Impact Evaluation. October 2012
[4] DNV GL (KEMA, Inc.). Impact Evaluation of 2014 EnergyWise Single Family Program. August 2016
[5] Megdal & Associates, LLC, West Hill Energy & Computing, Inc. NYSERDA 2007-2008 Home Performance with Energy Star Program Impact Evaluation Report. September 2012
[6] Energy & Resource Solutions, West Hill Energy, Inc. Home Performance with Energy Star Program Impact Evaluation Report (PY2010-2013). November 2016.
[7] Megdal & Associates, LLC, West Hill Energy & Computing, Inc. NYSERDA 2007-2008 Empower New York Program Impact Evaluation Report. April 2012
[8] West Hill Energy & Computing, Inc. Impact Evaluation of Vermont Gas System's Residential Retrofit Program. September 2018.
[9] West Hill Energy & Computing, Inc., GDS Associates, Inc. VGS Residential Program Impact Evaluation. March 2013.
[10] West Hill Energy & Computing, Inc., GDS Associates, Inc. VGS Residential Program Impact Evaluation. April 2013. VGS's low income program is delivered by Champlain Valley Office of Economic Opportunity.

While the savings as a percent of pre-install use fall within a fairly narrow band, Table 4-10 shows a wide spread of realization rates for natural gas, ranging from 33% to 99% with a median of 70%. The CT HES/HES-IE program realization rate (74%) is close to the MA HES realization rate (76%), and above the median.

Differences in methods of reporting savings are one possible explanation for the variation in realization rates. Some programs estimate the program reported savings by constructing

engineering models for each home; others use deemed savings in various ways. However, the realization rates in Tables 4-10 do not seem to be related to the method of estimating savings for reporting purposes, as programs using engineering models are found near both the top and the bottom of the spread.

The Vermont Gas System High Use Program, with a high relative realization rate (89%), has a practice of calibrating the program reported savings to actual changes in customer use. While reconciling pre and post-period billing may not be an option for all programs, calibrating the savings to pre-install use is likely to be more feasible. Average savings of more than 20% of pre-install use is higher than found in most evaluations.

TABLE 4-11: COMPARISON OF ELECTRIC IMPACTS FOR SIMILAR PROGRAMS

State	Program	Program Year(s)	Mean Home Use (kWh/yr)	Reported Savings (% of Use)	Evaluated Savings (% of Use)	Overall Realization Rate
CT	Home Energy Solutions	2015-2016	9,157	14%	6%	48%
CT	Home Energy Services[1]	2011	11,278	11%	10%	94%
MA	Home Energy Services[2]	2011	not given	not given	6%	not given
RI	EnergyWise[3]	2010	8,912	5%	6%	105%
RI	EnergyWise[4]	2014	9,274	14%	4%	29%
NY	Home Performance with Energy Star[5]	2007-08	8,700	10%	4%	35%
NY	Home Performance with Energy Star[6]	2010-11	9,310	9%	2%	19%
NY	EmPower[7]	2007-2008	7,792	16%	9%	54%

[1] The Cadmus Group, Inc. Impact Evaluation: Home Energy Services. December 2014
[2] The Cadmus Group, Inc. Home Energy Services Impact Evaluation. August 2012
[3] The Cadmus Group, Inc. Rhode Island EnergyWise Single Family Impact Evaluation. October 2012
[4] DNV GL (KEMA, Inc.). Impact Evaluation of 2014 EnergyWise Single Family Program. August 2016
[5] Megdal & Associates, LLC, West Hill Energy & Computing, Inc. NYSERDA 2007-2008 Home Performance with Energy Star Program Impact Evaluation Report
[6] Energy & Resource Solutions, West Hill Energy, Inc. Home Performance with Energy Star Program Impact Evaluation Report (PY2010-2013). November 2016
[7] Megdal & Associates, LLC, West Hill Energy & Computing, Inc. NYSERDA 2007-2008 Empower New York Program Impact Evaluation Report

For electric savings, the range of evaluated savings as a percent of pre-install use is 2% to 10%. Five of the eight studies are within 4% to 6%; HES/HES-IE is at the high end with 6% for program years 2015 to 2016. The previous HES/HES-IE evaluation has the highest savings at

10%, mostly likely due to the high savings for lighting found in that evaluation. Only one of the other eight studies shows savings of a similar magnitude (EmPower at 9%).

As with natural gas, Table 4-11 shows a wide spread of realization rates for electric measures, ranging from 19% to 105%, with a median of 48%. The CT HES/HES-IE program RR (48%) is the median. The high realization rate from the previous HES/HES-IE impact evaluation was primarily due to higher-than-expected savings from lighting. However, as discussed in Section 4.2, the program reported lighting savings for PY2015-2016 were substantially higher than the evaluated savings from the previous HES/HES-IE impact evaluation. The low realization rate for the NYSERDA HPwES Program (19%) was largely related to high program reported electric savings for heating-related measures, which were not discernable in the billing data.

5 Conclusions

This section summarizes the results of the billing analysis and provides recommendations for evaluation activities and program improvements.

5.1 Summary of Results

Table 5-1 summarizes the evaluated performance of the HES programs during the 2015-2016 program years. HES participants saw substantial reductions in energy consumption during the evaluation period.

TABLE 5-1: EVALUATED ENERGY SAVINGS AS PERCENT OF ANNUAL CONSUMPTION

	Natural Gas	Electricity
Mean Pre-Installation Use[1]	1,029 Ccf	9,157 kWh
Mean Program Reported Savings[2]	157 Ccf	1,241 kWh
Program Reported Savings as Percent of Pre-Use	15%	14%
Mean Evaluated Savings[3]	117 Ccf (+/- 9 Ccf)	591 kWh (+/- 7 kWh)
Evaluated Savings as Percent of Pre-Use	11% (+/- 1%)	6% (+/- 0.6%)

[1] For all homes included in final regression model (n=5,862 for gas; n=23,201 for electricity)
[2] For all single family 2015-16 participants (n=8,298 for gas, n=39,932 for electricity)
[3] A small amount of program reported savings could not be evaluated and were assigned a default realization rate of 100%.

The savings as a percent of pre-install use are in the range of other, similar programs in the Northeast, as are the realization rates of 74% and 48%, for natural gas and electric savings respectively.

For natural gas, the main contributors to the overall realization rate were insulation and air sealing measures. For electricity, lighting was the primary determinant of the overall realization rate. The key findings from the billing analysis and review of program reported savings are summarized in below

Table 5-2 below

TABLE 5-2: KEY EVALUATION FINDINGS

Fuel Type	Finding	Comments
Natural Gas	Insulation and air sealing drive program savings, accounting for 80% of program reported savings.	Evaluated savings are comparable to other, similar programs.
	Duct sealing and air sealing could not be separately estimated in the billing model as they are so often installed together.	Program reported duct sealing savings seem high, at ~7% of average heating use.
Electric	Lighting is the main driver of program savings, accounting for about two-thirds of program reported savings.	Realization rate for efficient lighting was 41%.
	Program reported lighting savings per bulb were about 40% higher than cited in the 2011 evaluation.	Program reported savings per home were ~90% of the average household lighting use estimated by EIA for the Northeast. The PSD baseline is an incandescent lamp; the actual baseline is likely to be a combination of CFL, halogen, and incandescent.
	Excessive heating savings were claimed for envelope measures in homes that did not have electric space heat.	About 25% of homes with heating fuel savings from insulation and/or air sealing measures did not have usage patterns indicating electric space heat.[1]
	Air conditioning measures were infrequently installed.	About 60% of homes had usage patterns indicative of air conditioning use and the average annual air conditioning use for these homes was high (1,330 kWh), suggesting potential for improving air conditioning efficiency.
Both	Savings from DHW conservation measures could not be reliably estimated from the billing models.	These measures account for less than 6 percent of overall program reported savings

[1] The HES program does not explicitly report savings for reductions in auxiliary heating equipment use (such as boiler circulating pumps or furnace fans) for insulation, air sealing or other envelope measures. Consequently, electric savings reported from envelope measures should only represent homes with primary or secondary electric space heat. The same trend was found for air conditioning savings from insulation and air sealing measures, i.e., many homes with these measures did not have a usage pattern consistent with air conditioning use in the pre-period

5.2 Recommendations

5.2.1 Evaluation Activities

There are many reasons why evaluated savings can differ from program reported savings. While a billing analyses cannot explain why savings were overstated, it can provide clues for where to focus such an investigation. This evaluation was designed to be completed sequentially, with the billing analysis first, to be followed by further investigation into a specific measure or component of the program.

West Hill Energy has identified options for further work that could refine or expand the findings of the billing analysis presented in this report and help improve the alignment between actual and reported savings in the future. These options vary in depth, length of time to complete, and requirements for additional data collection.

Options for future study are presented in Table 5-3.

TABLE 5-3: OPTIONS FOR FUTURE EVALUATION WORK

Evaluation Issue	Description	Importance to Findings	Possible Resolutions	Data Availability/ Timeframe
Multifamily Component	Only single family was included in the billing analysis MF dwelling units cannot be identified in billing data for many projects	50% of program reported natural gas savings; 30% for electricity	1. Identify the dwelling units for inclusion in a multifamily-specific billing model 2. Review modeling files and "stress test" PSD formulas with input values that best reproduce billing analysis	All data are available/ 2 months
Low Realization Rates	Billing analysis provides no insight into causes of underperformance[1]	Lighting, air and duct sealing, and insulation account most of the discrepancy between program reported and evaluation savings	"Stress test" PSD formulas with input values that best reproduce billing analysis results; modeling review and assessment of range of inputs	All data are available/ 2 months
Air Conditioning excluded from billing model	Too few installations to estimate savings in the regression model[2]	○ Less than 1% of program reported electricity savings ○ Could be more important in future	Collect AMI billing data to estimate cooling load at hourly or sub-hourly resolution; include more recent installations to estimate savings, if possible	Requires AMI data/ 3-4 months, depends on receipt of AMI data
High savings variability for DHW measures	Estimate does not meet 90/10 standard in either natural gas or electric model	○ 6% of program reported natural gas savings; 3% for electricity ○ Results are reasonable despite poor precision	Direct equipment metering, which is costly and time-consuming; PSD inputs seem to be within a reasonable range	Direct metering or bench testing/ 6 months
High savings variability for duct sealing measures	Estimate does not meet 90/10 standard in either natural gas or electric model	3% of program reported natural gas savings; also 3% for electricity.	Difficult to measure; previous study[3] included site visits and detailed analysis; unlikely that additional analysis would provide more insights	Site visits/ 9 months, to capture colder weather

[1] This limitation is inherent to billing analyses in general.
[2] Exact counts of homes cannot be given because of the multifamily participant tracking issue.
[3] "Connecticut HES Air Sealing, Duct Sealing, and Insulation Practices Report (R151)," March 24, 2016. Prepared for the Connecticut Energy Efficiency Board by NMR Group, Inc.

5.2.2 Program Improvements

The accuracy and comprehensiveness of program tracking data is critical to effective evaluation. Several significant data quality issues were encountered in the data cleaning process that should be addressed by the utilities, as outlined in the following recommendations:

Recommendation #1: Standardize measure categories and measure descriptions, including links to identifiers in the PSD.

Reason: Some measure descriptions had to be inferred and some measures could not be identified at all from the information provided by the utilities.

Recommendation #2: Incorporate *ex ante* savings calculation inputs into program tracking database at the measure level.

Reason: This information is needed to verify that the savings were calculated in accordance with the PSD. In general, this information was available for the core measures, but not for add-on measures such as insulation.[29]

Recommendation #3: Track project details for all dwelling units within multifamily buildings such that in-unit meter data (where available) can be accurately matched to the specific measures installed in that residence and that all dwelling units in a specific building can be identified.

Reason: A substantial number of multifamily projects could not be matched to the billing data by dwelling unit. To work around this obstacle, multifamily projects were separated from the program population. In addition, a clear method of identifying common areas and master-metered multifamily buildings would be useful.

Recommendation #4: Enforce referential integrity on program tracking database to assign unique site IDs, unique project IDs, and unique measure IDs as follows:

1. A unique site ID represents the residential building where work was done, whether single family or multifamily.
2. Each project ID represents a distinct job where one or more measures of a single type were installed at the given site. In multifamily buildings, projects may span multiple residences.
3. Each measure ID should represent a specific measure installed and be associated with a specific project and site

Reason: This issue affected the evaluation in multiple ways. In the multifamily component, the evaluators were not consistently able to match units to buildings or identify common areas. In many cases, this had to be inferred from the address information, which was not

[29] The utilities provided more detailed information for a substantial sample of projects, and the evaluators verified the PSD savings for the sample.

always standardized by building. In addition, some measures were not associated with a project that was included in the program data; these measures were not included in the evaluation.

6 Glossary

Attrition – Percent of homes eliminated from the pooled regression models due to insufficient billing history, erratic bills, or other reasons.

Autocorrelation - Autocorrelation occurs when observations in a regression model are not independent; the consequence of uncorrected autocorrelation is typically higher calculated statistical precision than is actually the case.

Billing Analysis - Estimation of program savings through the analysis of utility billing records comparing consumption prior to program participants and following program participation. This term encompasses a variety of types of analysis, from simple pre-/post- to complex regressions.

Building Shell/Envelope - The assembly of exterior components of a building which enclose conditioned spaces, through which thermal energy may be transferred to or from the exterior, unconditioned spaces, or the ground. Shell/envelope measures in HES/HES-IE include insulation (attic and wall insulation), window and door replacement, and air sealing.

Coefficient of Determination (R^2, R-squared) - Proportion of variability in a regression data set that can be explained by the model.

Collinearity - Collinearity refers to the situation where two or more independent variables in a model are highly correlated, such as when two measures tend to be installed together. Collinearity results in higher variances for both predicted and explanatory variables and creates difficulty in partitioning variance among the competing explanatory variables.

Confidence Level– Specifies the success rate associated with the methods used to estimate the mean value.

Confidence Interval – Interval of plausible values for the variable of interest; 90% confidence interval indicates that repeated sampling of the same population would produce a mean value within the confidence interval in 90% of the samples.

DHW - Domestic hot water, also water heater or water heating.

Estimator – The value of the regression coefficient from the model output.

Evaluated Gross Savings – The verified change in energy consumption and/or demand that results directly from program-related actions taken by participants in the program, regardless of why they participated.

Heteroscedasticity - Heteroscedasticity occurs in a regression model when there are subpopulations within the model with unequal variances. Heteroscedasticity does not bias the regression coefficients but can bias the standard errors and standard statistical tests.

Model Misspecification – This term covers large areas of regression misapplication in which the model chosen omits relevant explanatory variables, includes irrelevant explanatory variables, ignores qualitative changes in explanatory variables, or accepts regression equations with incorrect mathematical form.

Program Reported Savings – The savings contained in the program tracking databases provided by the utilities to the evaluators for this study.

Program Year, PY – The calendar year when a HES/HES-IE project was completed.

Realization rate (RR) – The ratio of the evaluated gross (*ex post*) savings to the program reported (*ex ante*) savings.

Relative Precision – error bound (one half of the confidence interval) divided by the mean value; this statistic provides a relative assessment of the precision of the estimator

t-value – the t-value of a regression coefficient measures whether the value of the coefficient is statistically different from zero. The statistic is the coefficient over its standard error.

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