WEST HILL ENERGY AND COMPUTING

CT Home Energy Services-Income Eligible and Home Energy Solutions Impact Evaluation

Program Years 2015-2016

FINAL REPORT
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Prepared For

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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 domestic hot water (DHW) pipe insulation, light bulbs, and faucet aerators, to larger, more technical measures, including insulation and heating, ventilation or air conditioning (HVAC) equipment replacements.

Unless stated otherwise, all savings values in this report represent gross savings. The evaluation found that, on average, utility customers saved about 11% of natural gas consumption and 6% of electricity consumption by participating in either the HES or 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 gross-savings realization rates for the combined HES and HES-IE programs, 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. The HES and HES-IE programs use different delivery models to serve single-family (1-4 units) and multifamily homes (5+ units). Both models serve both market rate (HES) and low-income market segments (HES-IE). This impact evaluation covers the single-family component of both programs (covering buildings with 1 to 4 units) for program years 2015 and 2016.[1] The previous HES/HES-IE impact evaluation was conducted for program year 2011.

The measures installed through the HES and HES-IE programs range from easy-to-install measures, such as DHW pipe insulation, light bulbs, and faucet aerators, to larger, more technical measures, including insulation, air and duct sealing, and, to a lesser degree, heating, ventilation and air conditioning (HVAC) equipment replacements. Billing analysis, a comparison of pre-treatment and post-treatment energy consumption, was the primary method used to determine the evaluated gross savings. For measures with the potential for heating and cooling savings (insulation, air sealing, duct sealing and heat pumps), electric savings were estimated separately for homes with and without a pre-period pattern of weather-dependent electric use, *i.e.*, a pattern of use consistent with space heating or air conditioning.[2]

Program Reported Savings

Tables ES-1 and ES-2 show the program reported by utility for natural gas and electric savings. Table ES-1 shows that the average natural gas savings per home for HES-IE are about double the HES savings for Southern Connecticut Gas (SCG) and Connecticut Natural Gas (CNG).[3] This difference could be partially explained by the higher installation rate of insulation in HES-IE homes. For electricity, the HES and HES-IE savings per home are reasonably close.

TABLE ES-1: PROGRAM REPORTED NATURAL GAS SAVINGS FOR SINGLE-FAMILY HOMES (1-4 UNITS) BY UTILITY AND PROGRAM

	Homes			Total Mcf			Average Mcf per Home		
Utility	HES	HES-IE	Total	HES	HES-IE	Total	HES	HES-IE	Total
Eversource	2,639	1,502	4,141	32,389	22,637	55,026	12.3	15.1	13.3
SCG/CNG	2,347	1,816	4,163	29,434	45,858	75,292	12.5	25.3	18.1
Total	4,986	3,318	8,298	61,823	68,494	130,317	12.4	20.6	15.7

[1] The terms single family and multifamily, as used in this report, refer to residences with up to 4 dwelling units and residences with 5 or more dwelling units respectively, consistent with the program definitions used by HES and HES-IE.
[2] For shell measures, savings from boiler pumps or furnace fans with lower use would be captured in the estimated savings for homes without a strong pattern of cold-temperature-dependent use.
[3] SCG and CNG are the two natural gas companies operating in United Illuminating's territory.

TABLE ES-2: PROGRAM REPORTED ELECTRIC SAVINGS FOR SINGLE-FAMILY HOMES (1-4 UNITS) BY UTILITY AND PROGRAM

	Homes			Total MWh			Average kWh		
Utility	HES	HES-IE	Total	HES	HES-IE	Total	HES	HES-IE	Total
Eversource	21,191	11,483	32,658	27,678	14,455	42,133	1,306	1,259	1,290
SCG/CNG	4,006	3,720	7,274	3,910	3,524	7,434	976	947	1,022
Total	25,197	15,203	39,932	31,589	17,979	49,567	1,254	1,183	1,241

Evaluation Results

The evaluation results from this analysis are consistent with other, similar programs in the Northeast. For natural gas savings, the HES and HES-IE program impacts were approximately 10% of pre-install use, in line with other southern New England programs, which ranged from 6% to 13%. The evaluated savings per home were substantially higher than found in the previous HES/HES-IE PY2011 impact evaluation (75% higher for HES and 40% higher for HES-IE).

For electricity, the range of evaluated savings as a percent of pre-install use was 2% to 10% for similar programs in the Northeast. Five of the eight studies are within 4% to 6%; HES and HES-IE compare favorably with 7% (HES) and 5% (HES)-IE of pre-install use for program years 2015 to 2016.

Table ES-3 shows the program reported and evaluated savings by household in relation to the pre-install annual consumption for natural gas and electricity. The programs served around 15,500 HES customers and 5,700 HES-IE customers that heated with either fuel oil or propane, collectively accounting for around 50% of all homes served by the programs during 2015 and 2016. As program implementation is the same regardless of the space heating fuel, the realization rate for delivered fuel energy savings should be the same as the natural gas realization rate

TABLE ES-3: OVERVIEW OF EVALUATED GROSS ENERGY SAVINGS PER HOUSEHOLD (1-4 UNIT BUILDINGS) BY PROGRAM AND FUEL TYPE

	Natural Gas		Electricity[1]	
	HES	**HES-IE**	**HES**	**HES-IE**
Number of Homes in the Billing Models	3,647	2,215	14,894	8,368
Mean Pre-Install Usage[2]	102.5 Mcf	103.4 Mcf	9,767 kWh	8,071 kWh
Mean Program Reported Gross Savings[3]	12.4 Mcf	20.6 Mcf	1,254 kWh	1,183 kWh
Program Reported Gross Savings as Percent of Pre-Use	12%	20%	13%	15%
Mean Evaluated Gross Savings[4]	9.8 Mcf (+/- 0.3 Mcf)	10.4 Mcf (+/- 0.5 Mcf)	683 (±23 kWh)	430 (±30 kWh)
Evaluated Gross Savings as Percent of Pre-Use	10%	10%	7%	5%
Realization Rate	79% (+/- 3%)	50% (+/- 2%)	56% (+/-2%)	36% (+/- 2%)

[1] Most homes with electric measures were heated by natural gas or delivered fuels (such as fuel oil or propane). In the program records, about 12% of participants were identified as having electric space heat, and about 55% of these homes in the regression model had electric use patterns consistent with electric space heat. The savings from heating measures were estimated separately for homes with and without a pattern of use consistent with electric space heating.
[2] For all homes in final regression model (n=5,862 for natural gas; n=23,201 for electricity). See Section 3.2 for model inclusion criteria.
[3] For all single family 2015-2016 program participants (N=8,298 for natural gas, N=39,932 for electricity). Section 3.2 explains rationale for excluding multifamily participants. Averages are computed from gross and adjusted gross values reported by utilities.
[4] A small proportion of the program reported savings could not be evaluated. The realization rate for these measures was assumed to be 100%. See Section 4.

While the savings as a percent of pre-install use are within a reasonable range, the program savings were overstated. Tables ES-4 and ES-5 summarize the evaluation results, giving the total program reported and evaluation savings and realization rates by program and by utility.

TABLE ES-4: EVALUATED NATURAL GAS SAVINGS BY UTILITY AND PROGRAM (1-4 UNIT BUILDINGS)

	Program Reported Mcf	Evaluated Mcf	Realization Rate	Relative Precision[1]
Eversource				
HES	32,389	26,705	82%	3%
HES-IE	22,637	15,803	70%	3%
CNG				
HES	26,651	20,115	75%	4%
HES-IE	45,326	18,442	41%	2%
SCG				
HES	2,783	2,137	77%	2%
HES-IE	526	237	45%	3%
Overall Program				
HES	61,823	48,957	79%	3%
HES-IE	68,489	34,482	50%	4%

[1] Relative precision of the realization rate at the 90% confidence interval. The realization rates vary due to the differences in the program savings.

TABLE ES-5: EVALUATED ELECTRIC SAVINGS BY UTILITY AND PROGRAM (1-4 UNIT BUILDINGS)

	Program Reported MWh	Evaluated MWh	Realization Rate	Relative Precision[1]
Eversource				
HES	27,678	15,132	55%	3%
HES-IE	14,455	5,282	37%	6%
United Illuminating				
HES	3,061	2,074	53%	5%
HES-IE	3,526	1,264	36%	10%
Overall Program				
HES	30,739	17,206	56%	4%
HES-IE	17,981	6,546	36%	7%

[1] Relative precision of the realization rate at the 90% confidence interval. The realization rates vary due to the differences in the program savings.

Recommended Changes to the PSD

Tables ES-6 to ES-9 summarize the realization rates (RR's) by measure group to be applied on a prospective basis. The RR's account for changes between the 2016 and 2019 Program Savings Document (PSD). The natural gas RR's should be applied to other fossil heating fuels (oil and propane). The average program reported savings for insulation were different for the Eversource and SCG/CNG, although the evaluated savings were the same. Consequently, the realization rates are different. The realization rates for air sealing and duct sealing are reported the same because the models could not separate out the individual effects.

TABLE ES-6: REALIZATION RATES FOR HES NATURAL GAS MEASURES

Measure Group		Mean Reported Mcf[1]	Mean Evaluated Mcf[1]	Realization Rate	Source/ Comments
DHW Conservation		1.6	N/A	100%	Billing analysis estimate has poor precision; no basis for adjustment
Insulation	Eversource	12.4	15.4	124%	Billing analysis included separate estimates by program component (HES and HES-IE); utilities have different program reported savings per home
	SCG & CNG	16.1		95%	
Air Sealing		9.2	6.4	70%	Billing analysis included separate estimates by program component
Duct Sealing		5.1	N/A	70%	Savings could not be independently modeled due to overlap with air sealing

TABLE ES-7: REALIZATION RATES FOR HES-IE NATURAL GAS MEASURES

Measure Group		Mean Reported Mcf	Mean Evaluated Mcf	Realization Rate	Source/ Comments
DHW Conservation		1.5	N/A	100%	Billing analysis estimate has poor precision; no basis for adjustment
Insulation	Eversource	29.6	15.8	53%	Billing analysis included separate estimates by program component (HES and HES-IE); Eversource and CNG/SCG have different program reported savings per home
	CNG & SCG	49.6		32%	
Air Sealing	Eversource	7.6	5.9	77%	Billing analysis included separate estimates by program component (HES and HES-IE); utilities have different program reported savings per home
	CNG	11.8		50%	
	SCG	9.0		66%	
Duct Sealing		6.9	N/A	61%	Savings could not be independently modeled due to overlap with air sealing; the average air sealing RR was applied
Heating Equipment Replacement and Repair		9.0	N/A	100%	For repairs, billing analysis estimate has poor precision - no basis for adjustment For replacements, 2019 PSD changed to match results from R1613/14 evaluation

Table ES-8 and ES-9 present the realization rates for electric measures. The 2019 PSD reports changes to the realization rate for refrigerators, heat pumps, furnace fans, and boiler pumps. Accordingly, the realization rates have been set to 100%.

TABLE ES-8: REALIZATION RATES FOR HES ELECTRIC MEASURES

Measure Group	Mean Reported kWh	Mean Evaluated kWh	Realization Rate	Source/ Comments
DHW Conservation	269	N/A	100%	Billing analysis estimate has poor precision; no basis for adjustment
Lighting	891	418	47%	Billing analysis included separate estimates by program component (HES and HES-IE)
Refrigerators	1,341	681	100%	2019 PSD algorithm changed, and savings are substantially lower as compared to the evaluation period (174 kWh in 2019)
Insulation	2,063	1,280	62%	Billing analysis included separate estimates by program component
Air Sealing	1,068	824	77%	Billing analysis included separate estimates by program component
Duct Sealing	809	538	66%	Billing analysis estimators not separated by program component as estimators by program had poor precision
Heat Pump Retrofit	3,057	1,790	59%	Billing analysis estimators not separated by program component, as there were two few installations in HES-IE to develop separate estimates
Heat Pump Market Opportunity	N/A	168	100%	2019 PSD changed to match results from Cadmus 2016 DHP study; evaluation used same source
Boiler Circulating Pumps	285	68	100%	2019 PSD changed to use results from R1613/14 evaluation
Furnace Fans	293	321	100%	2019 PSD changed to use results from R1613/14 evaluation

TABLE ES-9: REALIZATION RATES FOR HES-IE ELECTRIC MEASURES

Measure Group	Mean Reported kWh	Mean Evaluated kWh	Realization Rate	Source/ Comments
DHW Conservation	269	N/A	100%	Billing analysis estimate has poor precision; no basis for adjustment
Lighting	927	262	28%	Billing analysis included separate estimates by program component (HES and HES-IE)
Refrigerators	1,341	681	100%	2019 PSD algorithm changed, and savings are substantially lower as compared to the evaluation period (174 kWh in 2019)
Insulation	3,063	922	30%	Billing analysis included separate estimates by program component
Air Sealing	990	352	36%	Billing analysis included separate estimates by program component
Duct Sealing	809	538	66%	Billing analysis estimators not separated by program component as estimators by program had poor precision
Heat Pump Retrofit	3,057	1,790	59%	Billing analysis estimators not separated by program component, as there were two few installations in HES-IE to develop separate estimates
Heat Pump Market Opportunity	N/A	168	100%	2019 PSD changed to match results from Cadmus 2016 DHP study; evaluation used same source
Boiler Circulating Pumps	285	68	100%	2019 PSD changed to use results from R1613/14 evaluation
Furnace Fans	293	321	100%	2019 PSD changed to use results from R1613/14 evaluation

Key Findings

Key findings from the billing analysis and review of program reported savings are summarized in Table ES-10. In general, the evaluated savings are consistent with other, similar programs in the Northeast, but, in some cases, program reported savings are overstated. Periodic review of savings per household, comparison to pre-install bills and adjusting savings as needed may be helpful for improving realization rates.

TABLE ES-10: 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.
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%. The PY2011 gave a 120% RR for lighting from a billing analysis; the 2015 PSD for lighting was increased accordingly and then increased to account for the switch from CFL/LED's to LED's only and an incandescent baseline, resulting in a substantial overstatement of savings.
	Program reported savings from heating measures were overstated for many homes.	In the electric billing model, about 45% of the homes identified as having electric space heat did not show a pattern of electric space heat during the pre-period. No savings were found for homes that did not have a clear pattern of heating-related use in the pre-period. 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.
	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
	Evaluated savings as a percent of pre-install use are consistent with other, similar programs in the Northeast	Electric program reported savings were overstated by both programs and natural gas savings were overstated by HES-IE.

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 Connecticut's natural gas and electric utilities (collectively, "HES Program(s)"). The evaluation covers the HES Programs' activity during calendar years 2015 and 2016 in the single-family customer segment administered predominately by the Eversource and United Illuminating (UIL) companies (collectively, the "utilities").[4]

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 study does not directly address energy savings from delivered fuels. However, as program implementation does not change due to the heating fuel in the home, the realization rate for delivered fuel energy savings should be the same as the natural gas realization rate.

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 (PY's) 2015 and 2016. Section 3 explains the methodological steps involved in conducting the analysis. Sections 4 and 5 provide detailed findings by fuel and program component and put the study results into a broader context. Section 6 provides a glossary of terms and abbreviations used in this report. Appendix B contains technical details about the modeling process and regression output not included in Section 4.

[4] 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 and HES-IE 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 natural gas utilities in Connecticut. As shown in Table 2-1, the utility companies provided 2015 and 2016 program data showing around 350,000 Mcf of natural 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 HES and HES-IE programs.[5] The HES and HES-IE programs also serve delivered fuels customers. This study does not include an evaluation of delivered fuels savings. However, for context, Table 2-2 shows the fuel oil and propane savings reported for HES and HES-IE in 2015 and 2016.

Program tracking data indicated that 12% of the homes had electric space heating, though only about 55% of these homes in the electric billing model showed a usage pattern consistent with electric space heat. Table 2-1 shows the program reported natural gas and electric savings for both utilities and both programs. These tables include projects in multifamily properties. Due to issues with the multifamily program tracking data, the analysis presented in the remainder of the report is limited to homes with 1 to 4 units only.

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

		Eversource		SCG/CNG	United Illuminating	Combined	
	Program Year	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 and reflects reported gross savings for both single family (1 to 4 dwelling units) and multifamily program components (5 or more dwelling units). Savings for measures that could not be matched to specific projects are not included.

[5] All program reported savings figures cited in this report are derived from the adjusted gross savings values provided by the utilities. 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.

TABLE 2-2: HES AND HES-IE PROGRAM REPORTED ANNUAL ENERGY SAVINGS OF DELIVERED FUELS

	Program Year	Eversource		United Illuminating		Combined	
		Oil (x 1000 gal)	LPG (x 1000 gal)	Oil (x 1000 gal)	LPG (x 1000 gal)	Oil (x 1000 gal)	LPG (x 1000 gal)
HES	2015	804	99	125	8	929	107
	2016	623	76	111	4	734	80
HES-IE	2015	515	27	86	1	600	28
	2016	439	39	106	2	545	41
Total 2015-2016[1]		2,380	241	428	16	2,808	257

[1] This table was developed using the data provided by the utilities in response to a data request made in November 2017 and reflects reported gross savings for both single family (1 to 4 dwelling units) and multifamily program components (5 or more dwelling units). Savings for measures that could not be matched to specific projects are not included.

Under the HES program structure, single-family 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, blower door assisted air sealing, domestic hot water (DHW) conservation measures, and to a lesser degree, instrumented 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 savings (around 5% of electric savings), were the biggest single share of reported electricity savings from add-on measures.[6]

The main difference between the savings reported by the two utility companies was that UIL reported a significantly larger share of savings from envelope measures (more than three-quarters of combined electric and natural gas MMBtu savings, compared to less than 40% for Eversource), while Eversource reported relatively more savings from water and space heating improvements (around 20% of reported MMBtu, compared to approximately 10% for UIL).

[6] UIL installed 4 refrigerators in HES homes. Eversource installed 32 refrigerators all in HES-IE homes.

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 2-3.

TABLE 2-3: HES AND HES-IE PROGRAM REPORTED SAVINGS BY MEASURE CATEGORY, PY2015-2016

	Natural Gas[1]		Electricity[1]	
Measure Category	Annual Mcf	% of Mcf	Annual MWh	% of MWh
Shell Measures[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. Both single family and multifamily projects are 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.

Tables 2-4 and 2-5 show the breakdown of program reported natural gas savings by program and utility for single family homes. Both utilities reported higher per household savings for the HES-IE program. UIL's reported HES-IE savings are particularly high.

TABLE 2-4: PROGRAM REPORTED NATURAL GAS SAVINGS FOR SINGLE FAMILY HOMES (1 TO 4 UNITS) BY UTILITY AND PROGRAM

	Homes			Total Mcf			Average Mcf per Home		
Utility	HES	HES-IE	Total	HES	HES-IE	Total	HES	HES-IE	Total
Eversource	2,639	1,502	4,141	32,389	22,637	55,026	12.3	15.1	13.3
SNG/CNG	2,347	1,816	4,163	29,434	45,858	75,292	12.5	25.3	18.1
Total	4,986	3,318	8,298	61,823	68,494	130,317	12.4	20.6	15.7

TABLE 2-5: PROGRAM REPORTED ELECTRICITY SAVINGS BY UTILITY AND PROGRAM FOR SINGLE FAMILY HOMES (1 TO 4 UNITS)

	Homes			Total MWh			Average kWh		
Utility	HES	HES-IE	Total	HES	HES-IE	Total	HES	HES-IE	Total
Eversource	21,191	11,483	32,658	27,678	14,455	42,133	1,306	1,259	1,290
SNG/CNG	4,006	3,720	7,274	3,910	3,524	7,434	976	947	1,022
Total	25,197	15,203	39,932	31,589	17,979	49,567	1,254	1,183	1,241

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

- Calculation inputs for program reported savings were not included with the project data for add-on measures. For example, the savings algorithm for insulation measures in the PSD requires project-specific inputs for the area insulated, existing and installed R-values, which were not included with the program data.
- 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.
- Some measure descriptions had to be inferred and some measures could not be identified from the information provided. This was a small issue, accounting for about 1% of the program reported savings.

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 natural gas models are provided in Appendix B.

3.1 Overview of Methods and Data Sources

Program reported savings were evaluated using pooled, cross-sectional, time-series models interrupted at the time of the installation. The program-level data provided at the household level comprise the "cross-sectional" component and the monthly billing records are the "time series" data. 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. Time-specific variables were also incorporated to address widespread changes over time. (Please refer to the Uniform Methods Projects, Chapter 8 for more information on billing analysis methods.[7])

All participants in 1-4 unit buildings with sufficient billing records were included in the final models. 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.[8] 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 PROGRAM REPORTED SAVINGS

Type of Data	Description	Purpose for Analysis
Program Data	Program 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. In this study, the data was limited to those projects in 1-4 unit homes.
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]

[1] From a base temperature of 60°F for heating degree days and 70°F f or cooling degree days. See Appendix B for more information.

[7] Agnew, K.; Goldberg, M. (2013). Chapter 8: Whole-Building Retrofit with Consumption Data Analysis Evaluation Protocol, The Uniform Methods Project: Methods for Determining Energy-Efficiency Savings for Specific Measures. Golden, CO; National Renewable Energy Laboratory. NREL/SR-7A30-53827. April 2013

[8] 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. The list covers measures installed by participants included in the final pooled billing model. Several types of measures were too infrequently installed for savings to be estimated in a regression analysis: Wi-Fi thermostats, appliances, heat pump water heaters, window and door replacements, and air conditioning.

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	Fuels Evaluated
DHW Conservation[1]	o Pipe insulation o Faucet aerators, showerheads o Water heater thermostat resets	o Electricity o Natural Gas
Insulation	o Walls, attics, ceilings, basements, etc.	o Electricity o Natural Gas
Air Sealing[12,]	o Caulking, weather stripping o Outlet gaskets, door sweeps	o Electricity o Natural Gas
Duct Sealing[12]	o Sealing and insulating forced air ductwork	o Electricity o Natural Gas
Heating Equipment[13]	o Furnace and boiler cleaning, tuning, o Repairs and replacements o Circulator pumps and furnace fan upgrades	o Electricity o Natural Gas
Lighting	o All lighting upgrades	o Electricity
Refrigeration[4]	o All refrigerator upgrades	o Electricity
Heat Pumps[5]	o All heat pump installations	o Electricity

[1] Most participants in these measure groups also simultaneously installed measures from other groups.
[2] The vast majority of air sealing was done with the assistance of a blower door test. The majority of reported air and duct sealing savings were associated with the HES program.
[3] Natural gas saving heating equipment measures were only installed by the HES-IE program.
[4] Refrigeration measures were installed predominately by the HES-IE program
[5] Installed predominately by the HES program

The comprehensive approach of the HES Programs, 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 program reported natural gas and electric energy savings, respectively. They include Wi-Fi 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. The pre-period was defined as the year prior to the installation of the first measure and the post-period was the year following the installation of the last measure.

Data cleaning 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.[9] 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.

[9] 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] Heating and cooling degree days were averaged over the 2012-2017 period and used to weather-normalize the final results.

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[10]
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:[11]

- 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.

[10] The intercept term reflects base (non-heating) consumption, primarily for water heating.
[11] 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[12]

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).[13]

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.[14] For example, about 28% of homes with

[12] 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.
[13] 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.
[14] 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.[15]

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[16]

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-

[15] 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.

[16] 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 natural gas and 54,000 electric customers.[17] Around a quarter of these were multifamily participants who were excluded from the analysis, for reasons explained in Section 3.2.2. The natural gas customer counts and reported savings totals for Eversource exclude all program data records associated with CMG and SCG. The electric customer counts and reported savings totals for UIL excluded all program data records associated with CLP. Both utilities confirmed this as the appropriate accounting early in the study.

It is typical for billing analyses to include between 40% and 60% of total eligible participants. Of the 8,298 single-family (1-4 units) natural gas participants, 71% were retained in the final model. Of the 39,932 single-family (1-4 units) 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 (5+ units). 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 natural gas model was similar to the program population.[18] Hot water and air sealing measures were by far the most often installed measures. Insulation and

[17] 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 approximate.
[18] See Tables B-1, B-2, and B-3 in the Appendix B for model and program population counts

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 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%
Unable to Match Tracking Record to a Billing Account[2]	4,670	35,262	88%
No Savings or Unidentifiable Measures[3]	1,533	33,729	84%
Insufficient Bills[4]	6,079	27,650	69%
Irregular or High/Low Usage[5]	4,449	23,201	58%
Final Model Count		23,201	58%

[1] Excludes multifamily participants. See Section 3.2.2.
[2] All of these occurrences were with Eversource records
[3] This category may include homes with savings from fuels other than electricity (such as oil or propane).
[4] Billing history had less than 4 reads, covered less than 70% of normalized, annual heating degree days, or had substantial gaps between billing cycles.
[5] 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. Few homes (388) were removed for excessively high use.

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.

1. The final models incorporated weather and measure groups as predictor (independent) variables. Flags were established for HES and HES-IE for major measures to allow the separate estimation of savings by program, where appropriate. Evaluated savings were

estimated separately by program for measures that meet the following criteria: There were a sufficient number of homes in the model for each program

2. The relative precision was less than 25% at the 90% confidence level for each program

If these criteria were not met for a specific measure, the evaluated savings for the combined HES/HES-IE programs were used.

Timing variables were also included to capture any widespread changes in energy use over time. Appendix B 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. See Appendix B for more details.

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 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 pooled, cross sectional, time series model with customer-specific intercepts, each home acts as its own control. When multiple program years are included in the analysis, the analysis period covers at least four years and time effects can be incorporated into the analysis. Thus, there is no need to include a comparison group. The model produces gross savings.

In a two-stage model where the regression is conducted only at the household level,[19] a comparison group is sometimes used to account for exogenous effects. However, because 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. it was not used in this modeling.[20] In addition, defining an equivalent comparison group can be a complicated process and it is difficult to assess the effectiveness of the selection process.

[19] 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.
[20] 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

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[21]
4. The trend line of "future participant" bills was tested for the final models[22] The trend model was not included in the final model selected.

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.[23]

[21] 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.
[22] "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.
[23] 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 B. To a large extent, the evaluated per home savings by measure were fairly consistent between HES and HES-IE. However, substantial differences in the program reported savings resulted in different realization rates for the two programs and also for the utilities.

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[24]
- heating equipment repairs and replacements

The initial modeling was conducted for the combined HES and HES-IE programs. Table 4-1 presents the results by measure group.

TABLE 4-1: ESTIMATED NATURAL GAS SAVINGS BY MEASURE GROUP FOR COMBINED HES AND HES-IE FROM BILLING ANALYSIS

Measure Group	Homes in Model (n=5,862)	Mean Gross Mcf Savings		Relative Precision at the 90% Confidence Level
		Program Reported[2]	Model Estimate	
DHW Conservation[1]	1,149	1.6	2.7	27%
Insulation	434	20.1	15.6	8%
Air & Duct Sealing[3]	3,426	9.2	6.3	9%
Heating System Improvements[1,4]	106	9.9	5.7	49%

[1] Estimator from the final model was not reliable for evaluation purposes.
[2] Computed for participants in final model. Table 4-5 gives the total program reported participant counts and savings amounts.
[3] Duct sealing savings could not be reliably estimated as an independent measure as 92% of the homes with duct sealing also had air sealing.
[4] Represents furnace and boiler replacements as well as tune-ups and repairs.

[24] 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.

In a 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 savings from the measure-specific models, indicating that the final, measure-specific model gave an accurate estimate of overall household savings.

Estimating measure-level savings from a billing regression model often gives variable results. The precision of the estimated savings for DHW conservation and heating system savings was poor, likely a consequence of two limitations of the analysis:

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[25]
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

This result indicates that the DHW conservation and heating system savings cannot be reliably estimated from the regression model and alternative strategies were used for these measures, as described below in Table 4-2.

TABLE 4-2: SOURCE OF REALIZATION RATES FOR NATURAL GAS MEASURES NOT EVALUATED BY BILLING ANALYSIS

Measure Group	Savings per Home	Source of Realization Rate
Heating System Improvements	11 Mcf (Replace) 7 Mcf (Repair)	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	1 Mcf	Assumed RR of 100% because measures are a small percent of overall program reported savings (5% for natural gas, 4% for electricity)
Unevaluated Measures	15 Mcf	Assumed RR of 100% because measures are a small percent of overall program reported savings (2% for natural gas, 1% for electricity)

[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.

As air sealing was installed in the vast majority of homes, it was not possible to isolate duct and air sealing savings in the regression model and develop reliable estimates of savings for duct sealing. Of the 493 homes with duct sealing, only 39 (8%) did not also receive air sealing. The

[25] DHW use was incorporated into the model through the use of customer-specific intercepts which estimated the non-heating use in each home. 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.

regression model was run with two variables, one for air sealing only and one for air and duct sealing combined, with the following results:

1. The savings for the two measure groups were not statistically different
2. The estimated savings were very close (6.2 Mcf for air sealing and 6.5 Mcf for combined duct and air sealing)

These results suggest that the duct sealing savings are small.

For insulation and air sealing, additional modeling was conducted to assess whether there were differences between the HES and HES-IE programs. Tables 4-3 and 4-4 show the results for HES and HES-IE participants within each measure group. The precision of the estimated savings is generally lower than the modeled savings with the combined programs as the number of homes in each measure group is smaller. These tables show that the evaluated Mcf savings per home for the two program subcomponents are quite close (within 3% to 8%).

The most notable difference between the programs is the much higher reported insulation savings for HES-IE. The program reported savings per home for HES-IE was 46 Mcf for homes in the model, more than 3.5 times that for HES. This difference resulted in realization rates of 119% for HES and 31% for HES-IE.

TABLE 4-3: HES NATURAL GAS GROSS SAVINGS BY MEASURE GROUP FROM THE BILLING ANALYSIS FOR 1-4 UNIT HOMES

Measure Group	Homes in Model (n=3,647)	Mean Gross Mcf Savings		Relative Precision[2]	Realization Rate
		Program Reported[1]	Model Estimate		
Insulation					
Eversource	133	12.4	15.4	12%	124%
CNG/SCG[3]	20	16.1			95%
Air Sealing	1,877	9.2	6.4	9%	70%

[1] Computed for participants in the model.
[2] At the 90% confidence level.
[3] There were too few SCG homes with insulation in model to develop separate RR's by utility.

TABLE 4-4: HES-IE NATURAL GAS GROSS SAVINGS BY MEASURE GROUP FROM THE BILLING ANALYSIS FOR 1-4 UNIT HOMES

Measure Group	Homes in Model (n=2,215)	Mean Gross Mcf Savings		Relative Precision[2]	Realization Rate
		Program Reported[1]	Model Estimate		
Insulation					
Eversource	50	29.6	15.8	10%	53%
CNG/SCG[3]	231	49.6			32%
Air Sealing	1,056	9.6	5.9	14%	61%

[1] Computed for participants in the model.
[2] At the 90% confidence level.
[3] There were too few SCG homes with insulation in model to develop separate RR's by utility.

TABLE 4-5: HES PROGRAM REPORTED AND EVALUATED NATURAL GAS GROSS SAVINGS BY MEASURE GROUP FOR 1-4 UNIT HOMES

Measure Group	Utility	Homes with Measure[1]	Total Gross Program Reported Mcf[1]	Realization Rate	Total Gross Evaluated Mcf
Air Sealing	All[2]	4,249	41,593	70%	29,115
Insulation	Eversource	420	5,649	124%	7,005
	CNG[3]	871	2,966	95%	2,818
	SCG[3]	107	467	95%	444
Duct Sealing[4]	All	715	5,239	70%	3,667
DHW Conservation[5]	All	3,854	4,298	100%	4,298
Unevaluated[6]	All	109	1,611	100%	1,611
Total		4,986a	61,823	79%	48,958

[1] 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 (5 or more residential units), so will differ from those presented here.
[2] The program reported savings per home for air sealing were highly consistent among the utilities and the RR was the same for all three utilities.
[3] For CNG and SCG, the vast majority of these installations were attic hatch insulation with low savings. As the evaluated savings reflect a larger scale installation, the realization rate was applied rather than the evaluated per home savings.
[4] Savings from duct sealing could not be estimated from the regression model due to the overlap with air sealing measures; the RR for air sealing was applied.
[4] The regression coefficient from the final model was not reliable for evaluation purposes. Realization rate was assumed to be 100%.
[5] Category represents all measures not evaluated because either 1) they were insufficiently represented in final model after attrition (Wi-Fi 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.
a Count of homes by measure add up to more than the total as more than one measure was installed in some homes. Six homes were recorded as participating in both HES and HES-IE.

TABLE 4-6: HES-IE PROGRAM REPORTED AND EVALUATED NATURAL GAS GROSS SAVINGS BY MEASURE GROUP FOR 1-4 UNIT HOMES

Measure Group	Utility	Homes with Measure[1]	Total Program Reported Mcf[1]	Realization Rate	Total Evaluated Mcf
Air Sealing[2]	Eversource	1,048	7,993	77%	6,183
	CNG	1,272	14,954	50%	7,505
	SCG	14	126	66%	83
Insulation	Eversource	323	9,302	53%	4,930
	CNG	588	28,167	32%	9,014
	SCG	7	344	32%	110
DHW Conservation[3]	All	2,480	2,583	100%	2,583
Heating System	Repair/Tune[3]	127	940	100%	940
	Replacement[4]	61	936	71%	664
Duct Sealing[5]	All	219	1,726	61%	1,053
Unevaluated[6]	All	73	1,417	100%	1,417
Total		3,318a	68,489	50%	34,482

[1] 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 (5 or more residential units), so will differ from those presented here.
[2] The program reported savings per home for air sealing varied substantially by utility and separate RR's were calculated for each utility.
[3] The regression coefficient from the final model was not reliable for evaluation purposes. Realization rate was assumed to be 100%.
[4] Realization rate was adopted from results of the 2018 CT Upstream HVAC Program Impact Evaluation.
[5] Savings from duct sealing could not be estimated from the regression model due to the overlap with air sealing measures; due to the small savings associated with duct sealing, the average HES-IE RR for air sealing was applied.
[6] Category represents all measures not evaluated because either 1) they were insufficiently represented in final model after attrition (Wi-Fi 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.
a Count of homes by measure add up to more than the total as more than one measure was installed in some homes. Six homes were recorded as participating in both HES and HES-IE.

Table 4-7 shows the realization rates by utility and program, incorporating all measures.

TABLE 4-7: SUMMARY OF PROGRAM REPORTED AND EVALUATED NATURAL GAS GROSS SAVINGS BY UTILITY AND PROGRAM FOR 1-4 UNIT HOMES

	Gross Program Reported Mcf	Gross Evaluated Mcf	Realization Rate	Relative Precision[1]
Eversource				
HES	32,389	26,705	82%	3%
HES-IE	22,637	15,803	70%	3%
CNG				
HES	26,651	20,115	75%	4%
HES-IE	45,326	18,442	41%	2%
SCG				
HES	2,783	2,137	77%	2%
HES-IE	526	237	45%	3%
Overall Program				
HES	61,823	48,957	79%	3%
HES-IE	68,489	34,482	50%	4%

[1] Relative precision of the realization rate at the 90% confidence interval. The realization rates vary due to the differences in the program savings.

Table 4-8 presents the average natural gas savings per home for the current PY2015-2016 evaluation as compared to the PY2011 evaluation for HES and HES-IE. The evaluated savings as a percent of pre-install use for both programs compares favorably to the previous evaluation for 2011. One reason for the increase in savings could be the greater share of insulation in the 2015-16 measure mix as compared to 2011 (36% in 2015-2016 compared to 28% in 2011 for HES[26]).

[26] *Op. cit.*, Cadmus, 2014, p. 185

TABLE 4-8: SUMMARY OF NATURAL GAS HOUSEHOLD GROSS SAVINGS AND COMPARISON TO PY2011 EVALUATION

	PY 2015/2016 Evaluation		PY 2011 Evaluation	
	HES	**HES-IE**	**HES**	**HES-IE**
Mean Pre-Install Usage (Mcf)[1]	102.5	103.4	105.1	84.0
Mean Program Reported Gross Savings (Mcf)[2]	12.4	20.6	9.1	14.9
Program Reported Gross Savings as Percent of Pre-Use	12%	20%	9%	18%
Mean Evaluated Gross Savings (Mcf)[3]	9.8 (+/- 0.3)	10.4 (+/- 0.5)	5.5 (+/- 0.3)	7.3 (+/- 1.2)
Evaluated Gross Savings as Percent of Pre-Use	10%	10%	5%	9%
Realization Rate	79% (+/- 3%)	50% (+/- 2%)	60% (+/-3%)	79% (+/- 8%)

[1] For all homes in final regression model (n=5,862 for natural gas). See Section 3.2 for model inclusion criteria.
[2] For all single family 2015-2016 program participants (N=8,298 for natural gas). Section 3.2 explains rationale for excluding multifamily participants. Averages are computed from gross and adjusted gross values reported by utilities.
[3] A small proportion of the program reported savings could not be evaluated. The realization rate for these measures was assumed to be 100%. See Section 4.

Figures 4-1 and 4-2 summarize how each measure group contributes to the overall realization rates for HES and HES-IE. Air sealing is the primary driver of the realization rate for HES and insulation had the largest impact on the HES-IE realization rate.

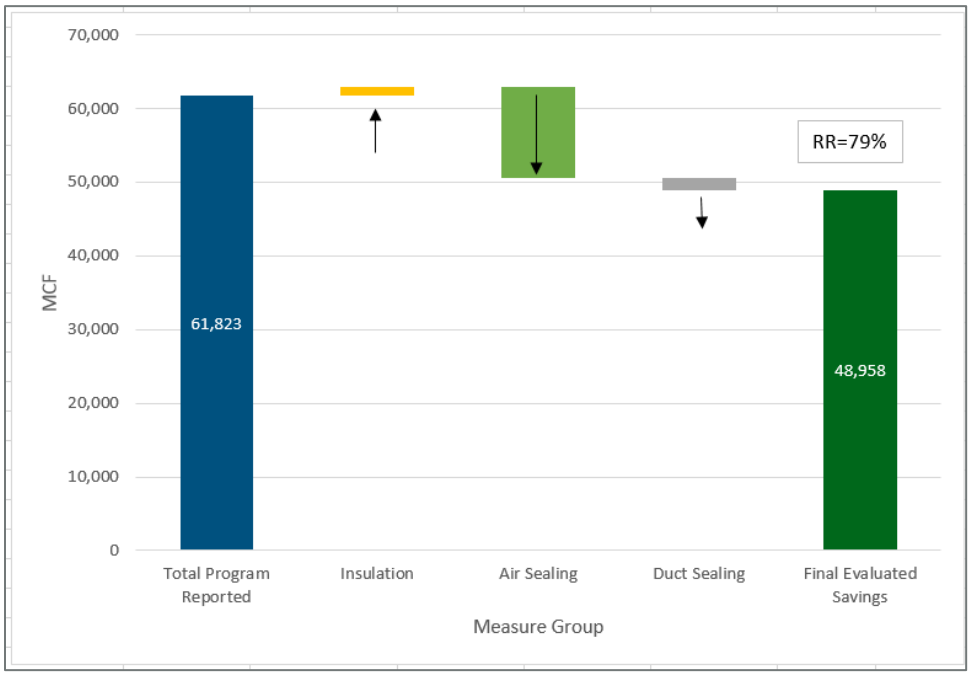

FIGURE 4-1: WATERFALL GRAPH OF HES NATURAL GAS PROGRAM REPORTED AND EVALUATED SAVINGS

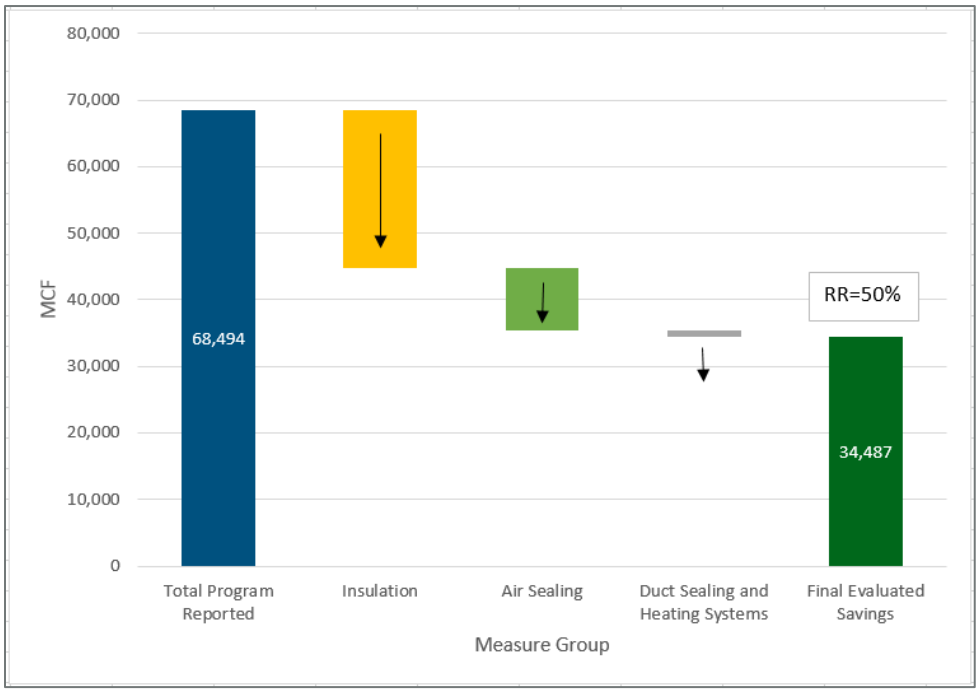

FIGURE 4-2: WATERFALL GRAPH OF NATURAL GAS PROGRAM REPORTED AND EVALUATED SAVINGS FOR HES-IE

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[27] groups:

- DHW conservation
- insulation
- air sealing
- duct sealing
- refrigerators
- heat pumps[28]
- lighting

Table 4-9 presents the savings estimates produced by the final model for these measure groups for the combined HES and HES-IE programs.

[27] 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.

[28] Heat pump savings were estimated separately for homes that had electric space heating prior to installation and homes that did not.

TABLE 4-9: ESTIMATED ELECTRIC SAVINGS BY MEASURE GROUP FOR COMBINED HES AND HES-IE FROM THE BILLING ANALYSIS FOR 1-4 UNIT HOMES

Measure Group	Homes in Model (n=23,201)	Mean Gross kWh Savings per Home			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. Tables 4-11 and 4-12 give 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 4-10.

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, and air sealing measure groups. As found in the natural gas analysis, the household savings from the electric model shown in **Error! R eference source not found.** were comparable to the results from a simpler, household level model, suggesting that the final model gave an accurate estimate of overall household savings.

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 4-10.

TABLE 4-10: SOURCE OF REALIZATION RATES FOR ELECTRIC MEASURES NOT EVALUATED BY BILLING ANALYSIS

Measure Group	Savings Per House	Source of Realization Rate
Heat Pumps (Homes without electric space heat)	168 kWh	2016 MA/RI impact evaluation of heat pumps[1]
Boiler Circulating Pumps	68 kWh	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	366 kWh	
DHW Conservation Measures	235 kWh	Assumed RR of 100% (Measures are a small percent of overall program savings.)
Unevaluated Measures	523 kWh	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.

Heating-related measures (insulation, air sealing and duct sealing) show substantially lower savings than estimated by the program. The magnitude of the program reported savings suggests that the savings are claimed for homes with electric space heat (ESH). However, almost half (45%) of the homes in the regression model that were identified as having ESH in the program records did not show a pattern of use consistent with ESH during the pre-period.

The modeling was conducted with separate variables for homes with and without a pattern of ESH use for these heating-related measures. Savings were only found in homes with ESH use during the pre-install period. Variables were added to estimate savings for homes without ESH or AC in the pre-period, and no savings were found for air sealing, duct sealing or insulation.

Heating and air conditionings savings attributable to heat pumps were estimated by the electric model. The process was to compare pre- and post-period usage in only those homes with electricity consumption patterns indicative of air conditioning or electric heating use in the pre period. Only homes with pre-existing electric heating were included in the estimate of electric heating savings from heat pumps, and only homes with pre-existing mechanical cooling were included in the estimate of cooling savings from heat pumps.

Homes that did not have air conditioning or electric space heating signatures in the pre-installation period were not used to estimate heat pump savings. These installations were assumed to be market opportunity and savings were estimated from the 2016 Massachusetts/Rhode Island evaluation of heat pumps, as shown in Table 4-10.

Additional modeling was conducted to assess whether there were differences between the HES and HES-IE programs. Tables 4-11 and 4-12 show the results of this analysis for each measure group. Program-specific DHW savings were not modeled because the precision of the estimate

in the model with the programs combined was already unacceptably low and would only be lower if the measure group was split by program component.

Evaluated savings were estimated separately by program for measures that meet the following criteria:

1. There are a sufficient number of homes in the model for each program. Heat pumps and refrigerators do not meet this criterion.
2. The relative precision is less than 25% at the 90% confidence level for each program. Duct sealing does not meet this criterion.

The precision of the savings estimates by program component is generally lower than the modeled savings of the combined programs due to the smaller number of homes used to estimate the savings. Table 4-11 below shows the program reported and evaluated savings by program component for lighting, air sealing and insulation, the three measures that meet the above criteria.

TABLE 4-11: ELECTRIC MEASURE GROUP REALIZATION RATES BY PROGRAM

Measure Group	Program	Homes with Measure	Total Gross Program Reported MWh	Realization Rate	Total Gross Evaluated MWh
Lighting	HES	24,049	22,750	47%	10,693
	HES-IE	14,052	11,294	28%	3,162
	Overall	38,101	34,044	41%	13,855
Air Sealing	HES	15,778	4,240	77%	3,265
	HES-IE	6,539	2,295	36%	826
	Overall	22,317	6,535	63%	10,693
Insulation	HES	2,941	1,015	62%	630
	HES-IE	819	1,124	30%	337
	Overall	3,760	2,139	45%	967

Tables 4-12 and 4-13 show how the measure group realization rates from the electric model and the other sources cited in Table 4-10 were applied to the program reported savings to compute an overall realization rate for each program. This result was driven largely by the performance of lighting, by far the most widely installed electric measure.

TABLE 4-12: HES PROGRAM REPORTED AND EVALUATED ELECTRIC SAVINGS BY MEASURE GROUP

Measure Group	Homes With Measure[1,2]	Total Gross Program Reported MWh[2]	Realization Rate	Total Gross Evaluated MWh
Lighting	24,049	22,750	47%	10,693
Air Sealing[5]	15,778	4,240	77%	3,265
Duct Sealing[4,5]	4,272	1,599	66%	1,055
DHW Conservation[3]	4,845	1,137	100%	1,137
Insulation[4.5]	2,941	1,015	62%	630
Heat Pumps[5]	256	657	39%	256
Unevaluated[7]	273	143	100%	143
Heating Equipment[6]	2	43	59%	25
Refrigerators	24	4	51%	2
Total	25,197	31,589	54%	17,206

[1] This column reflects all PY2015 and 2016 homes in the HES program and does not add to the total as some participants installed more than one measure.
[2] 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.
[3]Estimator from the final model was not reliable for evaluation purposes. Realization rate was assumed to be 100%.
[4]Air sealing was installed in almost all homes, which made it more difficult to estimate savings from other heating-related measures. For insulation, homes with air sealing and insulation were included in the variable, and the estimates were adjusted based on the air sealing only results. The same approach was used for duct sealing.
[5] Both heating and air conditioning savings were modeled for these measures.
[6] This measure group includes boiler circulation pumps and furnace fans; the majority of these installations were in MF homes. These two single family homes were not included in final model and the realization rate was adopted from 2018 CT Upstream HVAC impact evaluation.[29]
[7] Category represents all measures not evaluated because either 1) they were insufficiently represented in final model after attrition (Wi-Fi 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%.

[29] "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 4-13: HES-IE PROGRAM REPORTED AND EVALUATED ELECTRIC SAVINGS BY MEASURE GROUP

Measure Group	Homes With Measure[1,2]	Total Gross Program Reported MWh[2]	Realization Rate	Total Gross Evaluated MWh
Lighting	14,052	11,294	28%	3,162
Air Sealing[5]	6,539	2,295	36%	826
Refrigerators	1,346	1,787	51%	912
Insulation[4,5]	819	1,124	30%	337
DHW Conservation[3]	3,322	776	100%	776
Duct Sealing[4,5]	1,169	447	66%	295
Unevaluated[7]	269	223	100%	223
Heat Pumps[5]	10	32	39%	13
Heating Equipment[6]	2	<1	59%	<0
Total	15,203	17,979	36%	6,544

[1] This column reflects all PY2015 and 2016 homes in the HES program and does not add to the total as some participants installed more than one measure.
[2] 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.
[3]Estimator from the final model was not reliable for evaluation purposes. Realization rate was assumed to be 100%.
[4]Air sealing was installed in almost all homes, which made it more difficult to estimate savings from other heating-related measures. For insulation, homes with air sealing and insulation were included in the variable, and the estimates were adjusted based on the air sealing only results. The same approach was used for duct sealing.
[5] Both heating and air conditioning savings were modeled for these measures.
[6] This measure group includes boiler circulation pumps and furnace fans; the majority of these installations were in MF homes. These two single family homes were not included in final model and the realization rate was adopted from 2018 CT Upstream HVAC impact evaluation.[30]
[7] Category represents all measures not evaluated because either 1) they were insufficiently represented in final model after attrition (Wi-Fi 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%.

The overall program reported and evaluated savings and realization rates by program are presented in Table 4-14 below.

[30] "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 4-14: SUMMARY OF PROGRAM REPORTED AND EVALUATED ELECTRIC SAVINGS BY PROGRAM

	Gross Program Reported MWh	Gross Evaluated MWh	Realization Rate	Relative Precision[1]
Eversource				
HES	27,678	15,132	55%	3%
HES-IE	14,455	5,282	37%	6%
United Illuminating				
HES	3,061	2,074	53%	5%
HES-IE	3,526	1,264	36%	10%
Overall Program				
HES	30,739	17,206	56%	4%
HES-IE	17,981	6,546	36%	7%

1 The realization rates vary due to the differences in the program savings. The standard errors come from the program-specific model. Small changes in precision among the utilities is primarily due to differences in the mix of measures.

Table 4-14 presents the average electricity savings calculated from the measure group realization rates discussed above. Average annual savings were 683 kWh per household for HES and 430 for HES-IE, amounting to around 5% to 7% of average household electricity consumption. This is lower than the previous evaluation for 2011, which found a 10% reduction in usage.

TABLE 4-15: SUMMARY OF ELECTRIC HOUSEHOLD SAVINGS AND COMPARISON TO PY2011 EVALUATION

	PY 2015/2016 Evaluation[1]		PY 2011 Evaluation	
	HES	HES-IE	HES	HES-IE
Mean Pre-Install Usage (kWh)[2]	9,767	8,071	11,278	7,292
Mean Program Reported Gross Savings (kWh)	1,254	1,183	914	1,281
Program Reported Gross Savings as Percent of Pre-Use	13%	15%	8%	18%
Mean Evaluated Gross Savings (kWh)[4]	683 (+/- 23)	430 (+/- 30)	1,067 (+/- 40)	1,005 (+/- 46)
Evaluated Gross Savings as Percent of Pre-Use	7%	5%	9%	14%
Realization Rate	56% (+/-2%)	36% (+/- 2%)	117% (+/-4%)	78% (+/- 4%)

[1] Most homes with electric measures were heated by natural gas or delivered fuels (such as fuel oil or propane). In the program records, about 12% of participants were identified as having electric space heat, and about 55% of these homes in the regression model had electric use patterns consistent with electric space heat. The savings from heating measures were estimated separately for homes with and without a pattern of use consistent with electric space heating.
[2] For all homes in final regression model (n=23,201 for electricity). See Section 3.2 for model inclusion criteria.
[3] For all single family 2015-2016 program participants (n=39,932 for electricity). Section 3.2 explains rationale for excluding multifamily participants. Averages are computed from gross and adjusted gross values reported by utilities.
[4] A small proportion of the program reported savings could not be evaluated. The realization rate for these measures was assumed to be 100%. See Section 4.

Figures 4-3 and 4-4 summarize how each measure group contributes to the overall realization rates for HES and HES-IE. Lighting is the primary driver of the realization rate for both programs.

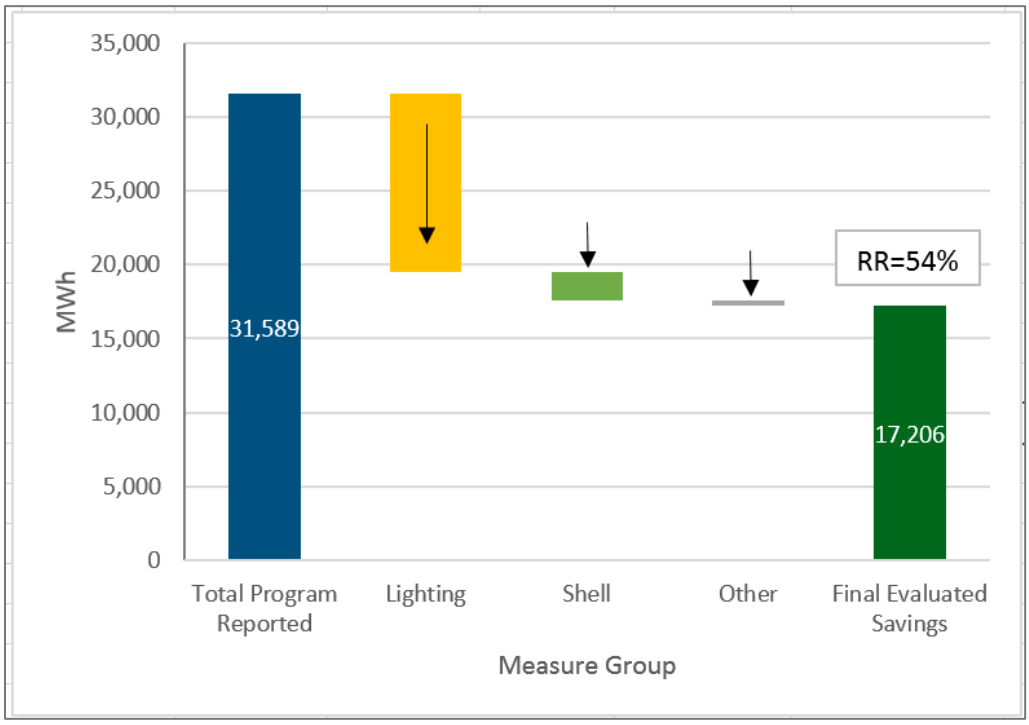

FIGURE 4-3: WATERFALL GRAPH OF ELECTRIC PROGRAM REPORTED AND EVALUATED SAVINGS FOR HES

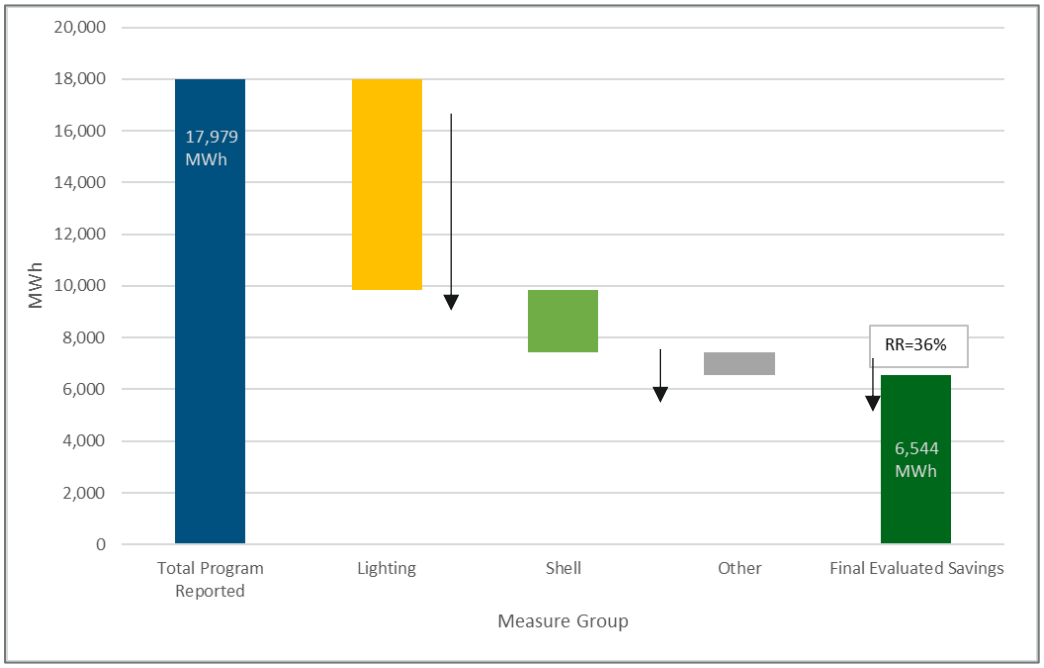

FIGURE 4-4: WATERFALL GRAPH OF ELECTRIC PROGRAM REPORTED AND EVALUATED SAVINGS FOR HES-IE

The utilities used the following formula for calculating the reported energy savings from lighting. They calculated the savings from each LEDs at 54 kWh/bulb. This is an increase over the PY2011 PSD for CFLs of 35 kWh/bulb ex ante, adjusted to 42 kWh/bulb to reflect the 120% RR from the previous study.

These estimates correctly note that LEDs have a wattage of the LEDs are lower than the CFLs, however, it disregards a number of factors that drove down the wattages and/or the hours of use estimates that also figure in the savings calculation. Additional investigation was conducted into the low realization rate for lighting, yielding the following findings:

- The PY2011 HES/HES-IE impact evaluation concluded that the lighting savings were substantially understated. The benchmarking section also indicated that the HES/HES-IE savings per home as a percent of pre-install use were higher than the other comparison programs.[31] The PY2015 raised the savings estimates to reflect this earlier underestimation.
- Between PY2011 and PY2015, the program moved from installing one LED and several CFL's to installing all LED's; Eversource program rules in 2015-16 required replacement of incandescents only. PSD savings were increased to assume an incandescent baseline and LED replacement.
- The average annual lighting consumption for all residential dwellings in the Northeast estimated by the Energy Information Administration (EIA) in 2015 is 992 kWh per home.[32] The recent NMR lighting study estimated that annual residential lighting use in Connecticut was about 2,005 kWh in 2015.[33] A US Department of Energy study in 2012 estimated residential lighting load at 1,578 kWh per year. [34]
- On average, 22 lamps per home were installed through HES and 19 lamps per home through HES-IE in PY2015 and PY2016. The NRM lighting study estimated that an average of about 26 sockets per home in non-low-income homes and 6 sockets in low income homes contained incandescents in 2015.[35]
- Beginning in 2013, EISA regulations no longer permitted the manufacture and sale of incandescents at or above 75W. A year later this became true for 40W and 60W incandescents. By 2015, half the incandescent bulbs in lamps used more than 3 hours a day would be expected to have burnt out and most likely replaced with bulbs of a lower wattage. The more hours a lamp was used, the likelier the lamp would have been

[31] The impact evaluation for PY2011 found that the realization rate for lighting was 120% for HES and 138% for HES-IE. Cadmus, 2014, pages 11, 13 and 42.
[32] 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.
[33] NRM Group, 2016. Connecticut LED Lighting Study Report (R154). Prepared for the Connecticut EEB. See Figure 20.
[34] DNV KEMA, 2012. Residential Lighting End-Use Consumption Study: Estimation Framework and Initial Estimates Prepared for the U.S. Department of Energy under Contract DE-AC05-76RL01830.
[35] *Op. cit.*, NMR, 2016. See Table 3.

replaced by a lower wattage halogen or an LED indicating that the remaining incandescents in an audited home would be in sockets with lower hours of use.

- The program reported savings for HES and HES-IE are 13% and 15% of pre-install use, respectively.

Using the range of residential lighting use from the EIA, DOE and NRM studies, the HES and HES-IE program reported lighting savings per home in PY2015/PY2016 range from 40% to over 100% of annual lighting use. The program reported savings as a percent of pre-install use are substantially higher than found in any of the eight other impact evaluations of similar programs identified in the PY2011 and PY2015/PY2016 impact evaluations, as discussed further in the following section.

There are several other ways that lighting savings could have been overreported, such as the following:

- A recent study of a similar program in Massachusetts shows that participants reported frequent replacement of CFLs even though that practice was prohibited.[36] It is also possible that customers who knew program rules, swapped their CFLs for incandescents before the audit, so that they could receive LEDs.
- The prescribed hours of use for some install locations could be overstated, or installers could be inaccurately reporting installations in locations with higher hours of use.
- West Hill Energy had no way to verify whether light bulb locations were accurately reported but it is logical that most of the remaining incandescents in a home would be found in the locations with lower hours of use, since the most used incandescent lamps are more likely to have burned out and replaced by an LED or CFL.
- It is also possible that the default watt ratio used when existing bulb wattage is unknown could overstate savings. The 75% Energy Information Security Act (EISA) discount to the watt ratio may not have been systematically applied where appropriate.

The evaluated savings are reasonable in the context of the pre-install use and estimated annual lighting loads from various sources.

For insulation, air and duct sealing, 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.[37] This outcome is not unique to this evaluation[38] and may be partially related to difficulties in attributing program reported savings to a specific fuel in homes with multiple heating fuels.

[36] Navigant et al., 2018. Massachusetts Home Energy Services Process Evaluation (Res 35). See Table 16.
[37] Approximately 25% of the homes in the model with air sealing and insulation savings had usage patterns that did not indicate the presence of weather-dependent electric heating load. About 60% of the homes with duct sealing also showed no sign of electric heating.
[38] The same pattern was found in the NYSERDA HPwES program evaluations. See References section for the report details.

Additional models were run as checks to ensure that the modeled savings were not biased downward due to homes with changes in AC use between the pre- and post-periods and possible impacts of heat pump installations on other measures. The results of this process indicate that the savings from the final model are not biased downward. Please refer to Appendix B, Section B2.2 and Table B-7.

4.3 Comparison to Other Studies

The results from the HES/HES-IE PY2015/PY2016 impact evaluation were compared to impact evaluations conducted for other, similar programs in the Northeast. The comparison was conducted for gross or adjusted gross savings, rather than net savings. Both low income and market rate programs were included in the comparison: the NY Empower Program, VGS Low Income Program and CT HES-IE PY2011 are low income; the remainder of the comparison programs are market rate. The results are presented separately for natural gas and electric savings. Appendix C has additional detail about the comparison programs.

4.3.1 Natural Gas

Evaluated savings for programs in the Northeast similar to HES/HES-IE are shown in Figures 4-5 and 4-6. All of the natural gas programs shown in Figure 4-5 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 16%. The HES and HES-IE program impacts were 10% of pre-install use, in line with other southern New England programs, which range from 6% to 12%. 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 (10%) compared to the previous impact evaluation (6%).

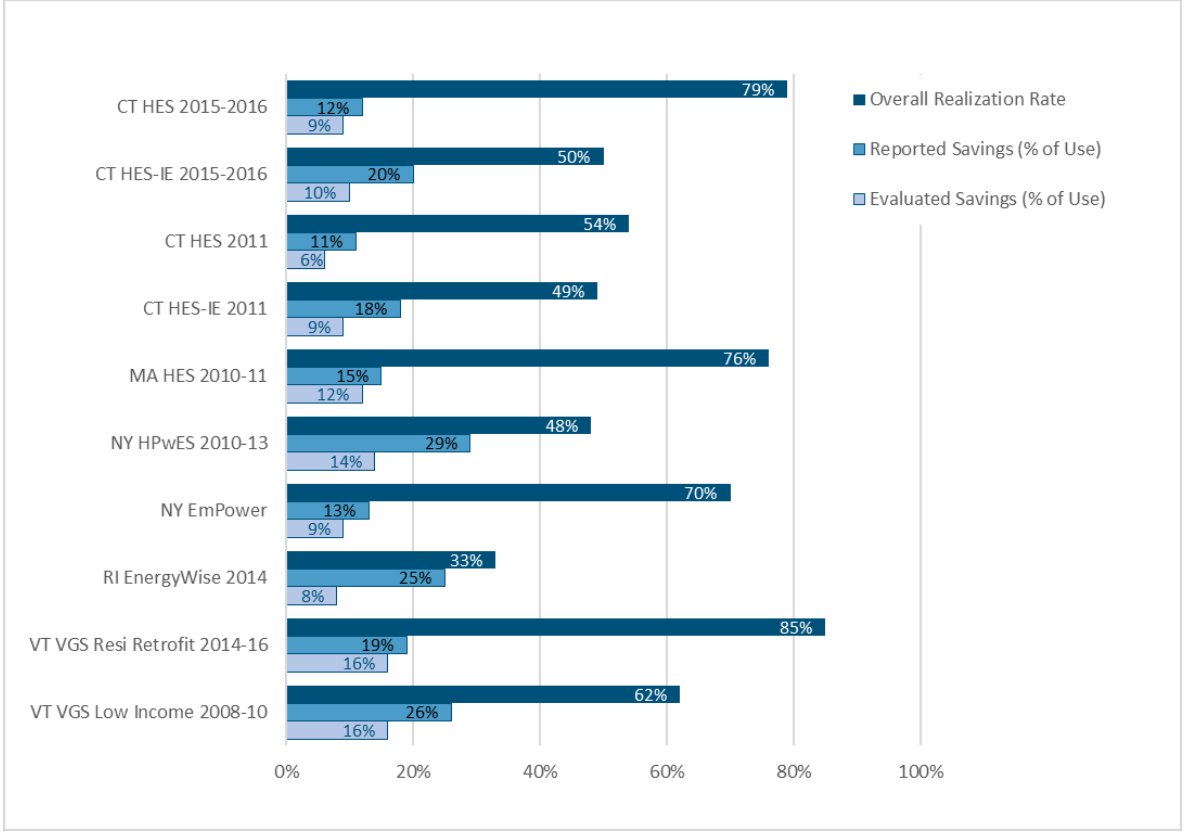

FIGURE 4-5: COMPARISON OF NATURAL GAS IMPACTS FOR SIMILAR PROGRAMS

While the savings as a percent of pre-install use fall within a fairly narrow band, Figure 4-5 shows a wide spread of realization rates for natural gas, ranging from 33% to 85% with a median of 58%. The CT HES and HES-IE PY2015/2016 program realization rates at 79% 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. The CT HES and HES-IE programs follow the methods and inputs prescribes in the CT PSD.[39] However, the realization rates in Figure 4-5 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 (85%), 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.

[39] For most of the heating measures, including insulation and air sealing, the PSD requires inserting site-specific inputs into the PSD algorithms. Other measures, such as lighting, have a more prescriptive approach.

4.3.2 Electricity

For electric savings, the range of evaluated savings as a percent of pre-install use is 2% to 18%. Four of the eight studies are within 4% to 6%; HES and HES-IE are in this range with 7% and 5% for PY 2015/2016, respectively. The previous CT HES/HES-IE impact evaluation has the highest savings at 10% for HES and 18% for HES-IE, mostly likely due to the high savings for lighting found in that evaluation. Only one of the other seven studies shows savings of a similar magnitude (NY EmPower at 9%).

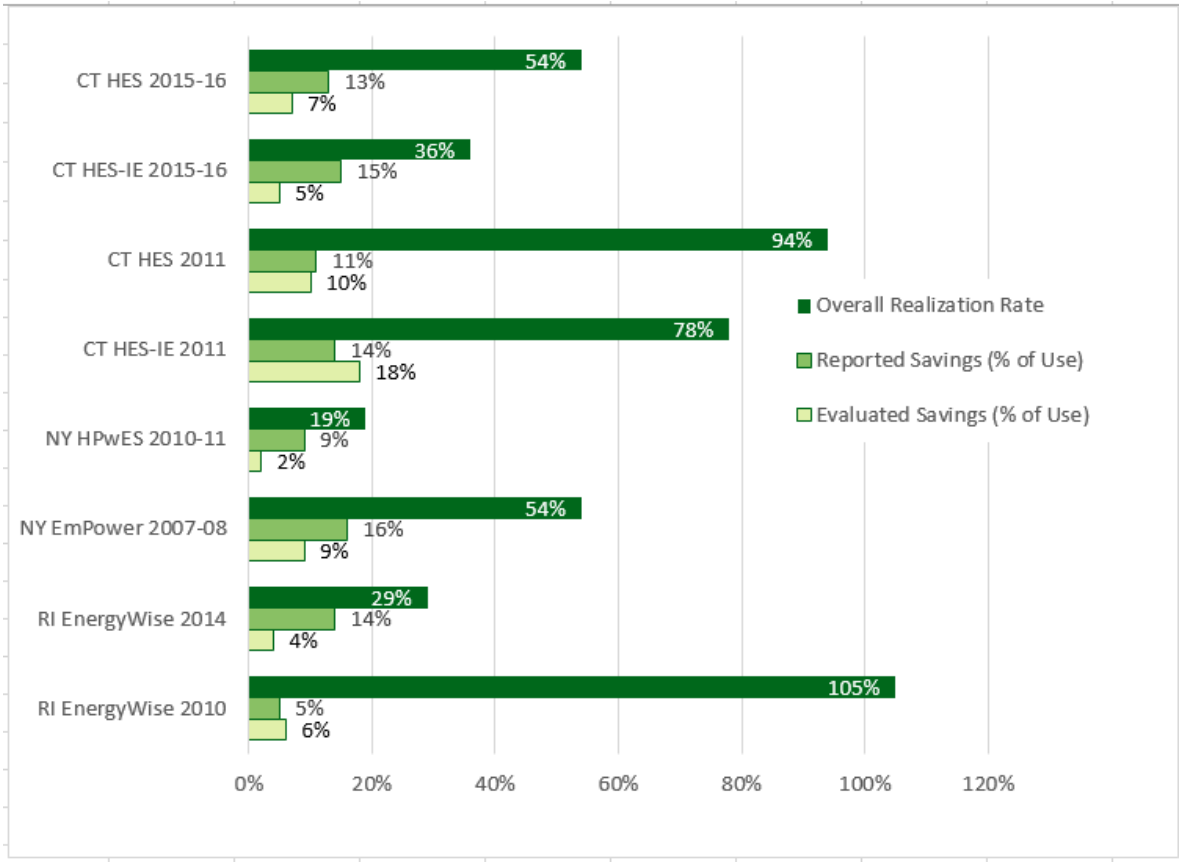

FIGURE 4-6: COMPARISON OF ELECTRIC IMPACTS FOR SIMILAR PROGRAMS

As with natural gas, Figure 4-6 shows a wide spread of realization rates for electric measures, ranging from 19% to 105%, with a median of 54%. The CT HES program RR of 54% is at the median, and HES-IE is below at 36%. The high realization rate from the previous HES/HES-IE impact evaluation was primarily due to higher-than-expected savings from lighting. 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 realization rates, evaluation activities and program improvements.

5.1 Summary of Results

Table 5-1 summarizes the evaluated performance of the combined HES programs during the PY's 2015-2016. HES and HES-IE participants saw substantial reductions in energy consumption during the evaluation period.

TABLE 5-1: OVERVIEW OF EVALUATED GROSS ENERGY SAVINGS PER HOUSEHOLD (1-4 UNIT BUILDINGS) BY PROGRAM AND FUEL TYPE

	Natural Gas		Electricity[1]	
	HES	HES-IE	HES	HES-IE
Number of Homes in the Billing Models	3,647	2,215	14,894	8,368
Mean Pre-Install Usage[2]	102.5 Mcf	103.4 Mcf	9,767 kWh	8,071 kWh
Mean Program Reported Gross Savings[3]	12.4 Mcf	20.6 Mcf	1,254 kWh	1,183 kWh
Program Reported Gross Savings as Percent of Pre-Use	12%	20%	13%	15%
Mean Evaluated Gross Savings[4]	9.8 Mcf (+/- 0.3 Mcf)	10.4 Mcf (+/- 0.5 Mcf)	683 (±23 kWh)	430 (±30 kWh)
Evaluated Gross Savings as Percent of Pre-Use	10%	10%	7%	5%
Realization Rate	79% (+/- 3%)	50% (+/- 2%)	56% (+/-2%)	36% (+/- 2%)

[1] Most homes with electric measures were heated by natural gas or delivered fuels (such as fuel oil or propane). In the program records, about 12% of participants were identified as having electric space heat, and about 55% of these homes in the regression model had electric use patterns consistent with electric space heat. The savings from heating measures were estimated separately for homes with and without a pattern of use consistent with electric space heating.
[2] For all homes in final regression model (n=5,862 for natural gas; n=23,201 for electricity). See Section 3.2 for model inclusion criteria.
[3] For all single family 2015-2016 program participants (N=8,298 for natural gas, N=39,932 for electricity). Section 3.2 explains rationale for excluding multifamily participants. Averages are computed from gross and adjusted gross values reported by utilities.
[4] A small proportion of the program reported savings could not be evaluated. The realization rate for these measures was assumed to be 100%. See Section 4.

The savings as a percent of pre-install use are in the range of other, similar programs in the Northeast. 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 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.
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%. The PY2011 gave a 120% RR for lighting from a billing analysis; the 2015 PSD for lighting was increased accordingly and then increased to account for the switch from CFL/LED's to LED's only and an incandescent baseline, resulting in a substantial overstatement of savings.
	Program reported savings from heating measures were overstated for many homes.	In the electric billing model, about 45% of the homes identified as having electric space heat did not show a pattern of electric space heat during the pre-period. No savings were found for homes that did not have a clear pattern of heating-related use in the pre-period.[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
	Evaluated savings as a percent of pre-install use are consistent with other, similar programs in the Northeast	Electric program reported savings were overstated by both programs and natural gas savings were overstated by HES-IE.

[1] 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

Recommendation realization rates and suggestions for improving program implementation are described below.

5.2.1 Realization Rates

The billing analysis indicates that the realization rates are different for HES and HES-IE. For one measure, insulation, the RR's also vary by utility due to the differences in program reported savings. Tables 5-3 to 5-6 summarize the realization rates by measure group to be applied on a prospective basis. West Hill Energy recommends that the natural gas realization rates also be applied to other fossil fuels.

TABLE 5-3: REALIZATION RATES FOR HES NATURAL GAS MEASURES

Measure Group		Mean Gross Program Reported Mcf[1]	Mean Gross Evaluated Mcf[1]	Realization Rate	Source/ Comments
DHW Conservation		1.6	N/A	100%	Billing analysis estimate has poor precision; no basis for adjustment
Insulation[1]	Eversource	12.4	15.4	124%	Billing analysis included separate estimates by program component (HES and HES-IE); utilities have different program reported savings per home
	SCG & CNG	16.1		95%	
Air Sealing		9.2	6.4	70%	Billing analysis included separate estimates by program component
Duct Sealing[2]		5.1	N/A	70%	Savings could not be independently modeled due to overlap with air sealing

[1] The average program reported savings were different for the Eversource and SCG/CNG, although the evaluated savings were the same. Consequently, the realization rates are different.
[2] The realization rate for air sealing was applied.

TABLE 5-4: REALIZATION RATES FOR HES-IE NATURAL GAS MEASURES

Measure Group		Mean Gross Program Reported Mcf	Mean Gross Evaluated Mcf	Realization Rate	Source/ Comments
DHW Conservation		1.5	N/A	100%	Billing analysis estimate has poor precision; no basis for adjustment
Insulation[1]	Eversource	29.6	15.8	53%	Billing analysis included separate estimates by program component (HES and HES-IE); Eversource and CNG/SCG have different program reported savings per home
	CNG & SCG	49.6		32%	
Air Sealing	Eversource	7.6	5.9	77%	Billing analysis included separate estimates by program component (HES and HES-IE); utilities have different program reported savings per home
	CNG	11.8		50%	
	SCG	9.0		66%	
Duct Sealing[2]		6.9	N/A	61%	Savings could not be independently modeled due to overlap with air sealing; average air sealing RR was applied
Heating Equipment Replacement and Repair		9.0	N/A	100%	For repairs, billing analysis estimate has poor precision - no basis for adjustment For replacements, 2019 PSD changed to match results from R1613/14 evaluation

[1] The average program reported savings were different for the Eversource and SCG/CNG, although the evaluated savings were the same. Consequently, the realization rates are different.
[2] The realization rate for air sealing was applied.

TABLE 5-5: REALIZATION RATES FOR HES ELECTRIC MEASURES

Measure Group	Mean Gross Program Reported kWh	Mean Gross Evaluated kWh	Realization Rate	Source/ Comments
DHW Conservation	269	N/A	100%	Billing analysis estimate has poor precision; no basis for adjustment
Lighting	891	418	47%	Billing analysis included separate estimates by program component (HES and HES-IE)
Refrigerators[1]	1,341	681	100%	2019 PSD algorithm changed, and savings are substantially lower as compared to the evaluation period (174 kWh in 2019)
Insulation	2,063	1,280	62%	Billing analysis included separate estimates by program component
Air Sealing	1,068	824	77%	Billing analysis included separate estimates by program component
Duct Sealing	809	538	66%	Billing analysis estimators not separated by program component as estimators by program had poor precision
Heat Pump Retrofit[1]	3,057	1,790	59%	Billing analysis estimators not separated by program component, as there were two few installations in HES-IE to develop separate estimates
Heat Pump Market Opportunity[1]	N/A	168	100%	2019 PSD changed to match results from Cadmus 2016 DHP study; evaluation used same source
Boiler Circulating Pumps[1]	285	68	100%	2019 PSD changed to use results from R1613/14 evaluation
Furnace Fans	293	321	100%	2019 PSD changed to use results from R1613/14 evaluation

[1] For these measures, the RR was not calculated from the program reported and evaluated savings due to changes made to the 2019 PSD.

TABLE 5-6: REALIZATION RATES FOR HES-IE ELECTRIC MEASURES

Measure Group	Mean Gross Program Reported kWh	Mean Gross Evaluated kWh	Realization Rate	Source/ Comments
DHW Conservation	269	N/A	100%	Billing analysis estimate has poor precision; no basis for adjustment
Lighting	927	262	28%	Billing analysis included separate estimates by program component (HES and HES-IE)
Refrigerators[1]	1,341	681	100%	2019 PSD algorithm changed, and savings are substantially lower as compared to the evaluation period (174 kWh in 2019)
Insulation	3,063	922	30%	Billing analysis included separate estimates by program component
Air Sealing	990	352	36%	Billing analysis included separate estimates by program component
Duct Sealing	809	538	66%	Billing analysis estimators not separated by program component as estimators by program had poor precision
Heat Pump Retrofit	3,057	1,790	59%	Billing analysis estimators not separated by program component, as there were two few installations in HES-IE to develop separate estimates
Heat Pump Market Opportunity[1]	N/A	168	100%	2019 PSD changed to match results from Cadmus 2016 DHP study; evaluation used same source
Boiler Circulating Pumps[1]	285	68	100%	2019 PSD changed to use results from R1613/14 evaluation
Furnace Fans[1]	293	321	100%	2019 PSD changed to use results from R1613/14 evaluation

[1] For these measures, the RR was not calculated from the program reported and evaluated savings due to changes made to the 2019 PSD.

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. This problem was more present with the Eversource program tracking data.

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.[40]

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 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.

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

Recommendation #5: Conduct mid-year reviews of program savings by home to assess whether the average savings appear to be within a reasonable range in comparison to pre-install use. If the natural gas savings are more than 14% of pre-install use or the electric savings are more than 7% of pre-install use, adjustments may be warranted to brings program savings into the range with historical performance in CT and other states in the Northeast.

Reason: Savings as a percent of pre-install use is a good indicator of whether savings can be achieved and verifying savings to pre-install use may be a mechanism to improve RR's. Average annual heating use in southern New England is consistently in the vicinity of 100 Mcf in numerous studies and the annual average electric use from the PY2011 and PY2016/2016 evaluations is also reasonably consistent. Consequently, the average pre-install use per home from this evaluation could be used rather than collecting the pre-install consumption data for each home. This approach should work as long as there are many homes in the analysis.

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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Appendix A

Program Savings

Appendix A: Program Savings

This appendix provides additional detail about the program savings provided from the utility tracking system files. The tables below include all annual program savings for single family (one to four units) and multifamily (5+ units) homes. Tables A-1 and A-2 show the natural gas savings by measure group for HES and HES-IE.

TABLE A-1: HES PROGRAM REPORTED NATURAL GAS SAVINGS BY MEASURE CATEGORY

Measure Category	Eversource[1]		CNG/SCG[1]	
	Annual Mcf	% of Mcf	Annual Mcf	% of Mcf
Air Sealing	20,587	64%	21,005	71%
Insulation	5,649	17%	3,434	12%
Duct Sealing	2,877	9%	2,361	8%
DHW Conservation	2,264	7%	2,034	7%
Unevaluated[2]	1,012	3%	599	2%
Heating System	0	0%	0	0%
Total	32,389	100%	29,434	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] Measure descriptions provided by utilities were missing or ambiguous.

TABLE A-2: HES-IE PROGRAM REPORTED NATURAL GAS SAVINGS BY MEASURE CATEGORY

	Eversource[1]		CNG/SCG[1]	
Measure Category	**Annual Mcf**	**% of Mcf**	**Annual Mcf**	**% of Mcf**
Insulation	9,302	41%	28,511	62%
Air Sealing	7,993	35%	15,080	33%
Heating System	1,702	8%	174	0%
Unevaluated[2]	1,367	6%	56	0%
DHW Conservation	1,233	5%	1,350	3%
Duct Sealing	1,039	5%	687	1%
Total	22,637	100%	45,858	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] Measure descriptions provided by utilities were missing or ambiguous.

Tables A-3 and A-4 show the electric savings by measure group for HES and HES-IE.

TABLE A-3: HES PROGRAM REPORTED ELECTRIC SAVINGS BY MEASURE CATEGORY

	Eversource[1]		United Illuminating[1]	
Measure Category	**Annual MWh**	**% of MWh**	**Annual MWh**	**% of MWh**
Lighting	19,689	71%	3,061	78%
Air Sealing	3,921	14%	319	8%
Duct Sealing	1,311	5%	288	7%
DHW Conservation	1,022	4%	116	3%
Insulation	907	3%	108	3%
Heat Pumps	657	2%	0	0%
Unevaluated[2]	128	0%	15	0%
Refrigerators	0	0%	4	0%
Heating System	43	0%	0	0%
Total	27,678	100%	3,910	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] Measure descriptions provided by utilities were missing or ambiguous.

TABLE A-4: HES-IE PROGRAM REPORTED ELECTRIC SAVINGS BY MEASURE CATEGORY

	Eversource[1]		United Illuminating[1]	
Measure Category	**Annual MWh**	**% of MWh**	**Annual MWh**	**% of MWh**
Lighting	8,973	62%	2,321	66%
Air Sealing	1,877	13%	418	12%
Duct Sealing	1,771	12%	17	0%
DHW Conservation	740	5%	383	11%
Insulation	663	5%	114	3%
Heat Pumps	310	2%	137	4%
Unevaluated[2]	89	1%	134	4%
Refrigerators	32	0%	0	0%
Heating System	0	0%	0	0%
Total	14,455	100%	3,524	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] Measure descriptions provided by utilities were missing or ambiguous.

Appendix B

Analysis Details

Appendix B: Analysis Details

This appendix provides additional detail about the billing regression models and output. The first section covers the regression models; the second section gives the regression output; the third section is a discussion of the comparison group trend line and the fourth section covers the diagnostics.

B.1 Regression Model Details

The pooled model is a cross-sectional, time series, fixed effects model, interrupted at the time of the installation. The program-level data provided at the household level comprise the "cross-sectional" component and the monthly billing records are the "time series" data. The "fixed effects" component of the regression model includes customer-specific intercepts to take into account the characteristics of the home that do not vary over time, e.g., size of home, housing stock and household patterns of energy use. Time-specific variables are also incorporated to address widespread changes over time.

With a pooled model, all billing records are included in the model and only one model is used. The model may include parameters to estimate measure-level savings. The savings are calculated from the regression output. The participants included in the model effective act as their own control, as each home is compared to itself.

The generalized model equations with customer specific intercepts are shown in Equations 1 and 2 below, for both the natural gas and electric models.

EQUATION 1: NATURAL GAS MODEL REGRESSION EQUATION

$$C_{it} = \alpha_i + \tau_t + \beta_b x_{b,it} P_{it} + \beta_h x_{h,it} P_{it} HDD_{it} + \gamma_{i,h} HDD_{it} + \varepsilon_{it}$$

EQUATION 2: ELECTRIC MODEL REGRESSION EQUATION

$$C_{it} = \alpha_i + \tau_t + \beta_b x_{b,it} P_{it} + \beta_h x_{h,it} P_{it} HDD_{it} + \beta_c x_{c,it} P_{it} CDD_{it} + \gamma_h HDD_{it} + \gamma_c CDD_{it} + \varepsilon_{it}$$

where

C_{it} is the monthly consumption for the household *i* in period *t*, in kWh or Ccf per day

α_i is the "customer-specific" intercept for household *i*, accounting for unexplained difference in use between households associated with the number of occupants, appliance holdings, lifestyle, etc.

τ_t is the "time-specific" error for period t, reflecting the unexplained difference in use between time periods

$x_{b,it}$ and $x_{h,it}$ are the dummy variables indicating the base measures (water heating, refrigeration), heating measures (envelope, heating system repair/replacement) and

cooling measures (air-conditioning, etc.) that were installed at household *i* (1 if measure was installed, 0 if not)

P_{it} is the dummy variable to designate the post-period for home *i* in time period *t* (0 in the pre-period and 1 in the post-period)

β_b, β_h and β_c are the regression estimators for the base, heating measures and cooling measures, representing the Ccf or kWh saved from base measures, Ccf or kWh per HDD for heating measures, and Ccf or kWh per CDD for cooling measures

$\gamma_{i,h}$ and $\gamma_{i,c}$ are the heating and cooling slopes

HDD_{it} and CDD_{it} are the heating and cooling degree days for household *i* in period *t*

ε_{it} is the error term that accounts for the difference between the model estimate and actual consumption for household *i* in period *t*

All billing records are included in the model and only one model is used. The model may include parameters to estimate measure-level savings. The savings are calculated from the regression output.

B2. Regression Output

The regression results for the final natural gas and electric models are presented in the tables below. For both the natural gas and electric models an initial model with all program segments was run first, then more granular models were tested and used if the estimators show statistically different results. The model outputs for each model are shown below.

B2.1. Natural Gas Regression

Two versions of the natural gas model were run: 1) a model with all homes and no differentiation between HES and HES-IE and 2) a model with two estimators for major measures designating the participant was in HES or HES-IE. The R^2 for both the combined HES and HES-IE gas model and the program-specific gas model was 0.96.

The initial modeling included all measures in all homes. However, the estimators were unstable due to multicollinearity caused by the installation of multiple measures in a single home.

As air sealing was in most homes even when no other measures were installed, it was the only measure that could be completed isolated from other measures, i.e., the air sealing coefficients were restricted to homes with air sealing only. To avoid multicollinearity for the other measures, efforts were made to develop the savings estimates from homes with air sealing plus one other heating-related measure. The insulation measure group included homes with air

sealing and a small number of homes with duct sealing. The vast majority of homes with duct sealing also installed air sealing.

Many homes simply had too many different types of measures installed to be included in any specific measure group. The frequency of installation of both air sealing and duct sealing measures in the same homes made it difficult to attribute savings estimates for these measure groups exclusively to one or the other measure. These homes were grouped together in two parameters, one for homes with multiple measures plus a heating equipment measure and a second one for homes with multiple measures without a heating equipment measure.

TABLE B- 1: NATURAL GAS REGRESSION OUTPUT OF COMBINED HES & HES-IE MODEL

Parameter	Estimator[1]	t-value[2]	Unit of Estimator	Homes in Model
Hot Water	-0.0738	-6.21	Ccf/Day	1,149
Insulation	-0.0274	-21.32	Ccf/HDD	434
Air Sealing	-0.0109	-21.73	Ccf/HDD	2,933
Duct Sealing/Air Sealing[3]	-0.0113	-9.80	Ccf/HDD	493
Heating Equipment	-0.0100	-5.11	Ccf/HDD	106
Multiple Measures with Heating Equipment[4]	-.03818	-3.36	Ccf/HDD	19
Multiple Measures without Heating Equipment[4]	-.02162	-29.15	Ccf/HDD	1,330
Heating Slope[5]	0.1505	936.68	Ccf/HDD	5,862
Intercept[5]	0.0950	15.07	Ccf/Day	5,862

[1] For heating and cooling measures, the estimator represents the average change in use per degree day for homes in that measure group. For base use measures (Hot Water Conservation), it represents the average change in use per day.
[2] The t-value measures whether the value of the coefficient is statistically different from zero. It is calculated as the estimator divided by its standard error. A t-value with an absolute value of 1.64 or higher indicates the coefficient is statistically different from zero at the 90% confidence level.
[3] Duct sealing could not be effectively separated from air sealing as only 38 homes had duct sealing only.
[4] Homes with too many different measures to be placed into any one measure group. These groups were separated into homes with heating system equipment measures and those that did not have heating system equipment measures.
[5] Represents the average for all homes in model. The full regression output includes a heating slope and intercept estimate for each individual home in the model.

TABLE B- 2: NATURAL GAS REGRESSION OUTPUT OF PROGRAM-SPECIFIC MODEL

Parameter	Estimator[1]	t-value[2]	Unit of Estimator	Homes in Model
HES Hot Water	-0.0792	-5.64	Ccf/Day	684
HES-IE Hot Water	-0.0616	-3.09	Ccf/Day	465
HES Insulation	-0.0269	-13.30	Ccf/HDD	153
HES-IE Insulation	-0.0276	-16.82	Ccf/HDD	281
HES Air Sealing	-0.0113	-19.14	Ccf/HDD	1,877
HES-IE Air Sealing	-0.0102	-11.48	Ccf/HDD	1056
HES Duct Sealing[3]	-0.0103	-8.70	Ccf/HDD	392
HES-IE Duct Sealing[3]	-0.0153	-4.71	Ccf/HDD	101
HES-IE Heating Equipment	-0.0170	-5.14	Ccf/HDD	106
HES-IE Multiple Measures with Heating Equipment[4]	-0.0383	-3.36	Ccf/HDD	19
HES Multiple Measures without Heating Equipment[4]	-.01987	-22.71	Ccf/HDD	927
HES-IE Multiple Measures without Heating Equipment[4]	-0.0258	-19.05	Ccf/HDD	403
Heating Slope[5]	0.1505	936.68	Ccf/HDD	5,862
Intercept[%]	0.0947	15.04	Ccf/Day	5,862

[1] For heating and cooling measures, the estimator represents the average change in use per degree day for homes in that measure group. For base use measures (Hot Water Conservation), it represents the average change in use per day.
[2] The t-value measures whether the value of the coefficient is statistically different from zero. It is calculated as the estimator divided by its standard error. A t-value with an absolute value of 1.64 or higher indicates the coefficient is statistically different from zero at the 90% confidence level.
[3] Duct sealing could not be effectively separated from air sealing as only 38 homes in the HES/HES-IE combined programs had duct sealing only.
[4] Homes with too many different measures to be placed into any one measure group. These groups were separated into homes with heating system equipment measures and those that did not have heating system equipment measures.
[5] Represents the average for all homes in model. The full regression output includes a heating slope and intercept estimate for each individual home in the model.

B2.2. Electric Regression

Three versions of the electric model were run: 1) a model with all homes and no differentiation between HES and HES-IE and 2) a model with HES homes only and 3) a model with HES-IE homes only. This approach was adopted due to the large number of homes in the models (over 23,000 for the combined model). The R^2 for the combined HES and HES-IE electric model was 0.81, 0.81 for HES only, and 0.83 for HES-IE only.

For homes with electric savings for insulation, air sealing and duct sealing, the measure flag was set to one only if the electric program reported savings were 100 kWh or more. This approach avoided inclusion of homes with small savings that are unlikely to be able to be estimated through a billing model. It also avoided inadvertently the inclusion of homes with insulation that saved fuels other than electricity.

The initial modeling included all measures in all homes. As with the natural gas model, the estimators were unstable due to multicollinearity caused by the installation of multiple measures in a single home. To avoid multicollinearity, homes with heating measures were isolated by restricting the savings estimates to homes with air sealing plus only one other shell measure. As air sealing was in most homes, it was not possible to isolate the estimates to homes with a single heating measure. The insulation and duct sealing measure estimators were then adjusted to remove the portion due to air sealing and allow separate estimates for each measure group. Similarly, for the lighting estimator, only homes with exclusively lighting measures were included to limit collinearity in the model as the majority of homes received lighting measures.

House-by-house regression models were run for the pre-period that included an intercept term representing non-weather dependent (base) use and separate terms for heating and/or cooling use for all homes individually. The purpose of this step was to identify homes with a signal consistent with electric space heating (ESH) or air conditioning (AC) use in the pre-period.

In the final, pooled model, the regression coefficients for shell measures (insulation, air sealing, and duct sealing) were applied only to homes that showed weather dependent heating use in the pre-installation period that indicated some level of electric space heating. The cooling portion of the savings was similarly calculated only for homes that showed weather dependent AC use in the pre-installation period.

For air sealing, duct sealing and insulation, the modeling was conducted with separate variables for homes with and without a pattern of ESH use and AC use in the pre-period. No heating savings were found for homes without a signal of ESH and no cooling savings were found in homes without the AC signal in the pre-period. Consequently, the variables for homes without heating and/or cooling usage were dropped. The savings estimates are based on homes with ESH and/or AC use during the pre-install period and adjusted for the percent of homes with ESH and/or AC.

The heat pump measure used a similar method, with separate variables for homes with and without an ESH signal during the pre-period. For AC, savings were estimated only for homes with a signal of AC during the pre-period. A variable was added to estimate additional AC savings in homes that did not have signal of AC in the pre-period. This variable was added to ensure that additional use for new AC load did not bias the estimated savings from other measures; this extra use was not included the calculation of the heat pump retrofit savings. For homes without pre-period ESH, market opportunity savings were adopted from the Massachusetts study, as noted in the body of the report. Savings for homes with ESH were estimated from the model.

TABLE B-3: ELECTRIC REGRESSION HES AND HES-IE COMBINED OUTPUT

Parameter	Estimator[1]	t-value[2]	Unit of Estimator	Homes in Model[3]
Lighting	-1.0051	-26.51	kWh/Day	13,584
Hot Water Conservation	-1.2959	-16.06	kWh/Day	1,981
Refrigerator	-1.8651	-19.35	kWh/Day	1,041
Insulation Heating	-0.3464	-15.13	kWh/HDD	322
Insulation Cooling[4]	-0.7147	-6.27	kWh/CDD	277
Air Sealing Heating	-0.1340	-13.98	kWh/HDD	1,582
Air Sealing Cooling[4]	-0.5851	-12.09	kWh/CDD	1,384
Duct Sealing Heating	-0.2191	-17.09	kWh/HDD	648
Duct Sealing Cooling[4]	-0.5132	-12.45	kWh/CDD	1,610
Heat Pumps	-0.3702	-9.35	kWh/HDD	99
Other Base Measures[5]	-0.7475	-3.70	kWh/Day	174
Multiple Heating Measures[6]	-0.2159	-9.11	kWh/HDD	173
Heating Slope[7]	1.2077	163.59	kWh/HDD	23,262
Cooling Slope[7]	2.0769	211.79	kWh/CDD	23,262
Intercept	25.6076	134.88	kWh/Day	23,262

[1] For heating and cooling measures, the estimator represents the average change in use per degree day for homes in that measure group. For base use measures, such as Hot Water Conservation, it represents the average change in use per day.
[2] The t-value measures whether the value of the coefficient is statistically different from zero. It is calculated as the estimator value divided by its standard error. A t-value with an absolute value of 1.64 or higher indicates the coefficient is statistically different from zero at the 90% confidence level.
[3] Population encompasses single family homes only.
[4] The cooling and heating portions of the envelope measures were combined to estimate the final measure group savings.
[5] Group includes appliances and other unidentifiable measures.
[6] Homes with too many different measures to be placed into any measure group.
[7] Represents the average for all homes in model. The full regression output includes a heating/cooling slope and intercept estimate for each individual home in the model.

TABLE B-4: ELECTRIC REGRESSION HES ONLY OUTPUT

Parameter	Estimator[1]	t-value[2]	Unit of Estimator	Homes in Model[3]
Lighting	-1.1462	-24.01	kWh/Day	8,831
Hot Water Conservation	-1.2057	-10.70	kWh/Day	1,062
Refrigerator	-1.1436	-2.05	kWh/Day	30
Insulation Heating	-0.3795	-13.93	kWh/HDD	229
Insulation Cooling[4]	-0.6600	-5.26	kWh/CDD	223
Air Sealing Heating	-0.2185	-15.17	kWh/HDD	850
Air Sealing Cooling[4]	-0.5330	-8.78	kWh/CDD	963
Duct Sealing Heating	-0.2274	-15.84	kWh/HDD	533
Duct Sealing Cooling[4]	-0.4397	-9.66	kWh/CDD	1,393
Heat Pumps	-0.2932	-7.18	kWh/HDD	95
Other Base Measures[5]	-0.7601	-3.93	kWh/Day	167
Multiple Heating Measures[6]	-0.2230	-9.75	kWh/HDD	151
Heating Slope[7]	1.1689	119.99	kWh/HDD	14,894
Cooling Slope[7]	2.1531	166.68	kWh/CDD	14,894
Intercept	27.1991	96.85	kWh/Day	14,894

[1] For heating and cooling measures, the estimator represents the average change in use per degree day for homes in that measure group. For base use measures, such as Hot Water Conservation, it represents the average change in use per day.
[2] The t-value measures whether the value of the coefficient is statistically different from zero. It is calculated as the estimator value divided by its standard error. A t-value with an absolute value of 1.64 or higher indicates the coefficient is statistically different from zero at the 90% confidence level.
[3] Population encompasses single family homes only.
[4] The cooling and heating portions of the envelope measures were combined to estimate the final measure group savings.
[5] Group includes appliances and other unidentifiable measures.
[6] Homes with too many different measures to be placed into any measure group.
[7] Represents the average for all homes in model. The full regression output includes a heating/cooling slope and intercept estimate for each individual home in the model.

TABLE B-5: ELECTRIC REGRESSION HES-IE ONLY OUTPUT

Parameter	Estimator[1]	t-value[2]	Unit of Estimator	Homes in Model[3]
Lighting	-0.7184	-11.80	kWh/Day	4,753
Hot Water Conservation	-1.3926	-12.21	kWh/Day	919
Refrigerator	-2.0959	-19.69	kWh/Day	1,011
Insulation Heating	-0.2484	-5.87	kWh/HDD	93
Insulation Cooling[4]	-0.6676	-2.47	kWh/CDD	54
Air Sealing Heating	-0.0561	-4.49	kWh/HDD	732
Air Sealing Cooling[4]	-0.5457	-7.86	kWh/CDD	421
Duct Sealing Heating	-0.1900	-6.86	kWh/HDD	115
Duct Sealing Cooling[4]	-0.5423	-6.70	kWh/CDD	217
Heat Pumps	-1.1805	-7.29	kWh/HDD	4
Other Base Measures[5]	2.5210	1.15	kWh/Day	7
Multiple Heating Measures[6]	-0.1446	-1.54	kWh/HDD	22
Heating Slope[7]	1.2522	111.17	kWh/HDD	8,368
Cooling Slope[7]	1.7281	119.04	kWh/CDD	8,368
Intercept	22.7969	91.91	kWh/Day	8,368

[1] For heating and cooling measures, the estimator represents the average change in use per degree day for homes in that measure group. For base use measures, such as Hot Water Conservation, it represents the average change in use per day.
[2] The t-value measures whether the value of the coefficient is statistically different from zero. It is calculated as the estimator value divided by its standard error. A t-value with an absolute value of 1.64 or higher indicates the coefficient is statistically different from zero at the 90% confidence level.
[3] Population encompasses single family homes only.
[4] The cooling and heating portions of the envelope measures were combined to estimate the final measure group savings.
[5] Group includes appliances and other unidentifiable measures.
[6] Homes with too many different measures to be placed into any measure group.
[7] Represents the average for all homes in model. The full regression output includes a heating/cooling slope and intercept estimate for each individual home in the model.

TABLE B-6: HOMES IN SINGLE FAMILY PROGRAM POPULATION BY MEASURE TYPE

	Number of Homes in Model		Number of Homes in Program	
Measure Type	**Natural Gas**	**Electric**	**Natural Gas**	**Electricity**
Hot Water Conservation	1,149	1,981	6,328	8,167
Insulation	434	599	2,293	3,760
Air Sealing	2,933	2,966	6,549	22,313
Duct Sealing	493	2,258	928	5,441
Heating Equipment	106	0	168	4a
Lighting	NA	13,584	NA	38,088
Refrigerator	NA	1,041	NA	1,370
Heat Pumps	NA	99	NA	266
Miscellaneous[1]	0	0	182	534
Total Homes	5,862	23,201	8,298	39,932

[a] "Heating equipment" measures include furnace fans and boiler circulating pumps. The vast majority of the installations were in the multifamily component of the program.
[1] Includes windows and doors, thermostats, natural gas water heaters, electric appliances, and heat pump water heaters.

Additional models were run as checks to ensure that the modeled savings were not biased downward due to homes with changes in AC use between the pre- and post-periods and possible impacts of heat pump installations on other measures. These two final checks are described in Table B-7 below. The results of this process indicate that the savings from the final model are not biased downward.

TABLE B-7: DESCRIPTION OF FINAL CHECKS ON THE ELECTRIC MODEL

Purpose	Reason	Description	Result
Assess impacts of variable AC use between pre- and post-period	If homes in the model have no AC in pre-period and add AC during the study period, savings from shell measures could be understated.	1. Added two variables, one for homes with AC in pre only, one for AC in post only	Savings from shell measures remained stable; lighting savings were lower
	-10% in model had signs of AC use in the pre-period only -14% showed signs of AC use in the post-period only	2. Excluded heat pumps from new variables, as heat pump variable was already defined correctly	
Determine whether heat pump installations affect other heating measures	Extra use from heat pumps in homes heated with fossil fuels could be resulting in lower savings from shell measures.[1]	Redefined all heating-related measures to be mutually exclusive, i.e., every home was assigned to only one measure, even if multiple measures were installed.	Savings from shell measures remained stable; retrofit heat pump savings increased due to inclusion of savings from shell measures

[1] The final model included a variable to capture the extra use for the heat pump installations, which addressed this issue. This additional check was conducted to verify that the results were not biased.

B3. Comparison Group Trend Line

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,[1] 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.[2] In addition, defining an equivalent comparison group can be a complicated process.

[1] 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.

[2] 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

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, *i.e.*, each home acts as its own control
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, indicating random changes internal to the household should not bias the results
4. The model included two years of program participants and four years of bills, thus incorporating a substantial period to address changes over time

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.[3]

In this study, we also tested a comparison group trend line in the final models to assess possible impacts of non-program effects. The trend line has a less direct impact than explicitly incorporating the comparison group into the model, which may mitigate some of the disadvantages of using a comparison group.

Future participants were used as the comparison group to address self-selection bias. The bills for future participants were limited to the period ***prior*** to participation in the program. Thus, their consumption would not be affected by program activity and they are known to have participated in the program.

The trend line was developed by averaging the comparison group use by day, adding the average use for all days in each billing cycle, and then entering this trend variable into the billing model.

For natural gas, the modeled results with the trend line gave program savings that were about 20% lower than the final model (without the trend line). When the final model was run with the trend line and excluding the timing variable, the results were very close the original output (used to estimate the evaluated program savings). This result suggests that the trend line and the timing variable were having the same impact and including both variables double counts the non-program effects.

For the electric model, the program savings decreased about 12% when the trend line was included. Due to the complexity of the electric model, the reasons for the decrease in savings were not as clear.

Given these results, the final models without the trend line were used to estimate savings for both fuel types.

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

B4. Regression Diagnostics

After the savings were estimated, several diagnostics were checked for additional information. The model was tested for the following violations of assumptions:

- Autocorrelation (observations are not completely independent)
- Influential data points
- Heteroscedasticity (unequal variances)

Autocorrelation of errors is most common in time-series due to the intrinsic relationship between the most recent prior period and the present measurement, while unspecified variables are missing that would explain the underlying mechanisms for these changes. If the model exhibits autocorrelation, the estimators are unbiased, but the variance in the model tends to be artificially low.

Influential data points could occur when a small number of homes have a substantial upward or downward impact on the result.

If a data set exhibits heteroscedasticity, the estimator should be unbiased, but the variance is larger than may actually be the case. However, a high degree of heteroscedasticity may also be a sign that the model is misspecified, which could affect the results.

In addition, multicollinearity occurs when predictor variables are correlated with one another, which can happen if measures are installed as a group. If multicollinearity is present, the estimators are sometimes of the wrong sign or not statistically significant.

The table below outlines the additional analyses used to verify the results and the findings we obtained.

TABLE B- 8: DIAGNOSTICS OVERVIEW

Step	Result		Finding	Implications
	Gas	Electric		
Durbin-Watson statistic	0.85	2.09	This statistic indicates the presence of autocorrelation.	Autocorrelation is common in billing models; the estimators are unbiased, but the variance may be understated.
Influential Data Points	3 Identified	None	Homes with potential influential impacts were identified using a pooled DFFITS by household.[1]	The natural gas model was tested with and without the potential influential homes; these three homes had little impact on the final results (less than 1% change in the RR).
Goldfeld-Quandt test	3.32	2.88	This indicator measures heteroscedasticity in the data set.	A GQ statistic of 1.0 indicates no heteroscedasticity; 3.32 suggests a low level of heteroscedasticity that would not be expected to impact the results.

[1] Belsley, D.A., Kuh, E., and Welsch, R.E. Regression Diagnostics, New York: John Wiley & Sons, Inc., 1980.

Appendix C

Comparison to Other Studies

Appendix C: Comparison to Other Studies

The results from the HES/HES-IE PY2015/PY2016 impact evaluation were compared to impact evaluations conducted for other, similar programs in the Northeast as shown in Tables C-1 and C-2. The comparison was conducted for gross or adjusted gross savings, rather than net savings. Both low income and market rate programs were included in the comparison: the NY Empower Program, VGS Low Income Program and CT HES-IE PY2011 are low income; the remainder of the comparison programs are market rate. The results are presented separately for natural gas and electric savings.

All of the natural gas programs shown in Table C-1 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.

TABLE C-1: COMPARISON OF NATURAL GAS IMPACTS FOR SIMILAR PROGRAMS

State	Program	Program Type	Program Year(s)	Mean Home Use (MMBtu/yr)	Reported Savings (% of Use)	Evaluated Savings (% of Use)	Overall Realization Rate
CT	Home Energy Services - IE	Low Income	2015-2016	103	20%	10%	50%
CT	Home Energy Services	Market-based	2015-2016	103	12%	9%	79%
CT	Home Energy Services - IE[1]	Low Income	2011	84	18%	9%	49%
CT	Home Energy Services[1]	Market-based	2011	105	9%	5%	60%
MA	Home Energy Services[2]	Direct and Market	2010-2011	120	15%	12%	76%
RI	EnergyWise[3]	Market-based	2010	117	13%	13%	99%
RI	EnergyWise[4]	Market-based	2014	110	25%	8%	33%
NY	Home Performance with Energy Star[5]	Market-based	2007-2008	106	25%	16%	65%
NY	Home Performance with Energy Star[6]	Market-based	2010-2013	96	29%	14%	48%
NY	EmPower[7]	Low Income	2007-2008	109	13%	9%	70%
VT	VGS Residential Retrofit[8]	Direct	2014-2016	102	19%	16%	85%
VT	VGS Low Income[10]	Low Income	2008-2010	88	26%	16%	62%
VT	VGS Residential High Use[9]	Market-based	2008-2010	126	26%	22%	89%

[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.

TABLE C-2: COMPARISON OF ELECTRIC IMPACTS FOR SIMILAR PROGRAMS

State	Program	Program Type	Program Year(s)	Mean Home Use (kWh/yr)	Reported Savings (% of Use)	Evaluated Savings (% of Use)	Overall Realization Rate
CT	Home Energy Solutions - IE	Low Income	2015-2016	9,157	15%	5%	36%
CT	Home Energy Solutions	Market-based	2015-2016	9,157	13%	7%	54%
CT	Home Energy Services - IE[1]	Low Income	2011	7,292	18%	14%	78%
CT	Home Energy Services[1]	Market-based	2011	11,278	8%	9%	117%
MA	Home Energy Services[2]	Direct and Market	2011	not given	not given	6%	not given
RI	EnergyWise[3]	Market-based	2010	8,912	5%	6%	105%
RI	EnergyWise[4]	Market-based	2014	9,274	14%	4%	29%
NY	Home Performance with Energy Star[5]	Market-based	2007-08	8,700	10%	4%	35%
NY	Home Performance with Energy Star[6]	Market-based	2010-11	9,310	9%	2%	19%
NY	EmPower[7]	Low Income	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