WEST HILL ENERGY AND COMPUTING

CT HVAC and Water Heater Process and Impact Evaluation

and

CT Heat Pump Water Heater Impact Evaluation

FINAL REPORT
R1614/R1613

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Prepared For

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Abstract

The report covers impact and process evaluation studies of the Connecticut Residential Upstream HVAC and Water Heating Program ("Upstream HVAC Program") and the impact evaluation of Heat Pump Water Heater Program. The Upstream HVAC Program offers rebates to distributors to encourage the installation of high efficiency space and water heating equipment and the Heat Pump Water Heater Program offers rebates to distributors and retailers.

This evaluation covered full analysis of five of the eight program measures, which account for over 75% or more of the program reported savings for natural gas and winter peak savings, about 60% of the electric energy savings and about 15% of the summer peak savings. The evaluated measures are boilers, furnaces, electrically commutated motor (ECM) furnace fans, heat pump water heaters (HPWH's), and boiler circulating pumps.[1] The analysis used several combinations of methods chosen to balance cost and accuracy. The analysis method and outcomes for each measure are presented in Table A-1.

Table A-1: Summary of Evaluation Activities

Evaluation Activity	Determine Baseline	Determine Efficiency	Estimate Annual Load	Estimate kW Peak Reduction	Assess Reasons for Performance	NTGR/ Decision-Making	Process
Billing or AMI analysis			● Furnaces ● Boilers ● ECM furnace fan	● ECM furnace fan			
In situ metering	● HP Water Heater	● Boilers ● Circulator pump ● HP Water Heater	● Boilers ● Circulator pump ● HP Water Heater	● Circulator pump ● HP Water Heater	● Boilers ● Circulator pump ● HP Water Heater		
Customer interviews	● HP Water Heater				● Furnaces ● Boilers ● HP Water Heater	● Furnaces ● Boilers ● HP Water Heater	● Furnaces ● Boilers ● Circulator pump ● HP Water Heater ● ECM furnace fan
Market actor interviews	● Furnaces ● Boilers ● Circulator pump ● ECM furnace fan				● Furnaces ● Boilers ● HP Water Heater	● Furnaces ● Boilers ● Circulator pump ● HP Water Heater ● ECM furnace fan	● Furnaces ● Boilers ● Circulator pump ● HP Water Heater ● ECM furnace fan
Manufacturers' data	● Furnaces ● Boilers ● Circulator pump ● HP Water Heater ● ECM furnace fan	● Furnaces ● Boilers ● Circulator pump ● HP Water Heater ● ECM furnace fan					

• Furnaces • Boilers • Circulator pump • HP Water Heater • ECM furnace fan

The approach to estimating net savings utilized the self-report method and incorporated responses to program influence questions. Both the self-report and program influence questions were tied to the program's causal mechanisms on the market actors. NTGR estimates were developed for the three markets actors, i.e., customers, contractors and distributors, and the results were combined to reflect the relative contribution of the market actors to the decision-making process. Table A-2 presents a summary of the evaluated gross and net savings

[1] Ground source heat pumps, mini-splits, air source heat pumps, air conditioners were not evaluated. In aggregate, these measures account for less than 40% of the electric energy, less than 25% of the winter peak savings, and over 80% of the summer peak electric savings. These measures were not prioritized as previous impact evaluations for ground source heat pumps and central air conditioners were completed in June of 2014 and October of 2014. Natural gas water heaters were also not evaluated as they account for less than 10% of the natural gas energy savings.

by measure. Detailed recommendations for changes to the Program Savings Document are provided in the Executive Summary and in Section 8 of the full report.

TABLE A-2: SUMMARY OF PER UNIT PSD AND EVALUATED SAVINGS BY MEASURE

Measure	2017 PSD Gross Savings	Realization Rate[1]	Evaluated Gross Savings[2]	NTGR[1,3]	Evaluated Net Savings
High Efficiency Furnace	14.1 MMBtu/year	74% +/-4%	10.4 MMBtu/year	62% +/-8%	6.4+/-0.9 MMBtu/year
High Efficiency Boiler	11.5 MMBtu/year	66%+/9%	7.6 MMBtu/year	56% +/-7%	4.3+/-0.8 MMBtu/year
ECM Boiler Circulating Pumps	285 kWh/year	24%+/-3%	68 kWh/year	69% +/-11%	47+/-9 kWh/year
	0.056 Seasonal Winter Peak kW	44%+/-5%	0.024 kW	69% +/-11%	0.017+/-0.003 kW
Furnace Fan	293 kWh/year	125%+/-7%	366 kWh/year[4]	62% +/-8%[5]	227+/-33 kWh/year
	0.090 Seasonal Winter Peak kW	131%+/-8%	0.118 kW	62% +/-8%[5]	0.073+/-0.010 kW
	0.072 Seasonal Summer Peak kW	90%+/-4%	0.065 kW	62% +/-8%[5]	0.040+/-0.006 kW
Heat Pump Water Heater[6]	2,112 kWh/year	54% +/- 6%	961 kWh/year	59% +/- 6%	567+/-85 kWh/year
	0.244 Seasonal Winter Peak kW	55% +/- 5%	0.134 kW	59% +/- 6%	0.079+/-0.012 kW
	0.185 Seasonal Summer Peak kW	95% +/- 7%	0.175 kW	59% +/- 6%	0.103+/-0.015 kW
	0 MMBtu/year	N/A	4.3 MMBtu/year	59% +/- 6%	2.5+/-0.3 MMBtu/year

[1] Confidence intervals are at the 80% confidence level and account for the sampling error at each stage of the calculation by incorporating the propagation of uncertainty.

[2] Gross evaluated savings are the PSD savings multiplied by the realization rate.

[3] NTGR = 1 – FR (Free rider rate)+SO (spillover).

[4] The furnace fan kWh savings include both winter (heating) and summer (cooling) savings. The summer savings are based on the assumption that approximately 60% of homes with furnaces also have central air conditioning. See Section 4.5 for more details.

[5] It was not possible to estimate the NTG for ECM furnace fans separately from furnaces. Only furnaces with ECM fans are eligible to receive a rebate through the program and ECM furnace fans are not a stand-alone measure. Thus, the NTGR for furnaces was applied to furnace fans.

[6]These savings reflect a blended baseline, accounting for replacements of electric and fossil fuel water heaters. Although the electric savings are lower, substantial fossil fuel MMBtu savings were added.

Recommendations

Improve Program Tracking: Issues with the data quality had substantial effects on the evaluation. In addition, it is critical to maintain a connection between the rebate and the location of the installation to allow for verification. Quality control procedures need to be strengthened to check the integrity of data required for verification and evaluation to the extent possible within the upstream program design.

Improve Communication about Rebate Processing: The satisfaction rating for distributors was substantially affected by low ratings for rebate processing, long lag time to receive the rebate and communication from the utilities. Program managers can improve communication to establish clear expectations with distributors around rebate requirements and timelines. [2]

Expand Contractor Training: Contractors expressed an interest in attending trainings offered by the utilities or third parties that increase their employees' technical knowledge of efficient products and familiarize them with program processes and requirements.

Encourage Distributors to Stock Replacement Parts: Contractors expressed concerns about equipment issues with the efficient equipment, such as problems finding replacement parts. Program staff can work with distributors to stock replacement parts and increase training to contractors on installation and maintenance concerns.

Conduct Further Research into the NTG for the Tiered Boiler Incentives: In 2017, the utilities made a change to the incentive structure for efficient boilers from a single incentive for all eligible boilers a two-tiered system depending on the level of the boiler efficiency. As this evaluation covers program years 2014 through 2016, further investigation into the effects of this tiered incentive on the NTG is warranted.

[2] The utilities reported that since developing these findings, improvements have been made to the distributor rebate process.

Executive Summary

The report covers impact and process evaluation studies of the Connecticut Residential Upstream HVAC and Water Heating Program ("Upstream HVAC Program") and the impact evaluation of Heat Pump Water Heater Program. The Upstream HVAC Program and Heat Pump Water Heater Program offer rebates to distributors to encourage the installation of high efficiency space and water heating equipment.

This evaluation covered full analysis of five of the eight program measures, which account for 75% or more of the program reported savings for natural gas and winter peak savings, about 60% of the electric energy savings, and about 15% of the summer peak savings. The evaluated measures are boilers, furnaces, electrically commutated motor (ECM) furnace fans, heat pump water heaters (HPWH's), and boiler circulating pumps.[3] The analysis used several combinations of methods chosen to balance cost and accuracy.

Research Objectives

The prioritized outcomes for this study include the following:

- Gross energy savings, peak demand reduction and realization rates for the evaluated measures
- Recommended changes to the Program Savings Document (PSD)
- Net-to-gross ratio (NTGR) for the evaluated measures
- Assessment of the effectiveness of program processes

Five evaluation activities were conducted across the five measures, as shown in Table ES-1.

Table ES-1: Summary of Evaluation Activities

Evaluation Activity	Determine Baseline	Determine Efficiency	Estimate Annual Load	Estimate kW Peak Reduction	Assess Reasons for Performance	NTGR/ Decision-Making	Process
Billing or AMI analysis			🟢🔴🔵	🔵			
In situ metering	⚫	🔴🟡⚫	🔴🟡⚫	🟡⚫	🔴🟡⚫		
Customer interviews	⚫				🟢🔴⚫	🟢🔴⚫	🟢🔴🟡⚫🔵
Market actor interviews	🟢🔴🟡🔵				🟢🔴⚫	🟢🔴🟡⚫🔵	🟢🔴🟡⚫🔵
Manufacturers' data	🟢🔴🟡⚫🔵	🟢🔴🟡⚫🔵					

🟢 *Furnaces* 🔴 *Boilers* 🟡 *Circulator pump* ⚫ *HP Water Heater* 🔵 *ECM furnace fan*

[3] Ground source heat pumps, mini-splits, air source heat pumps, air conditioners and gas water heaters were not evaluated. In aggregate, these measures account for less than about 30% of the savings energy and winter peak savings, and over 70% of the summer peak savings. These measures were not prioritized as previous impact evaluations for ground source heat pumps and central air conditioners were completed in June of 2014 and October of 2014.

Program Evaluability

The accuracy and comprehensiveness of the program tracking data is critical for effective evaluation. The Evaluation Team found substantial issues with missing data and data quality, which had direct consequences on the evaluation. Typical methods to reduce evaluation costs, such as geographic targeting for site visits, could not be employed in some cases. The data quality limited our ability to verify installations, particularly for heat pump water heaters. The location and contact information for each installation is required for verification purposes, and failure to collect this information consistently for all measures may threaten future savings claims. Table ES-2 summarizes the data issues encountered and their impact on the evaluation.

TABLE ES-2: DATA ISSUES AND PROGRAM EVALUABILITY

Issue	Measures/ Utility	Scope	Impact on Evaluation
Missing tracking data	Heat Pump Water Heaters	No site-specific data (customer/contractor) for 97% of UI rebates; no contractor for 76% of Eversource rebates	1) Lost connection between rebate & location of installation 2) Small population for site visits and could not geo-target on sites (increased evaluation costs) 3) Had to obtain supplemental data, extending evaluation time frame 4) Could not use transactional NTG approach for HPWH's[1]
	Boilers/Furnaces	Distributor field empty for 12% to 26% of rebates (both UI & Eversource)	1) Difficult to assess program (distributor) activity 2) Made transactional NTG approach difficult to implement[1]
Inaccurate tracking data	Heat Pump Water Heaters	Customer address field held distributor/retailer address for 76% of Eversource rebates	See HPWH impacts above
	Boilers/Furnaces	Contractor/distributor fields sporadically reversed & customer/contractor phones erratically placed for both utilities	1) Complicated survey solicitation process 2) Made transactional NTG approach difficult to implement
Matching Issues	Boilers/Furnaces	UI provided customer/contractor/distributor information separately from equipment model info; about 50% could not be matched	1) Reduced number of homes used to estimate evaluated savings 2) Complicated process of expanding evaluation results to the population
	Boilers/Furnaces	22% to 54% of customers with rebates could not be matched to utility accounts (both UI and Eversource)	1) Substantially reduced number of homes in the billing models
Missing program documentation	All	Some of requested program documentation was not provided	Limited scope of process evaluation

[1] The initial plan had been to try to interview the participant, contractor and distributor associated with the same site. This aspect of the evaluation was referred to as the "transactional approach."

Impact Evaluation

The analysis method and outcomes for each measure are presented in Table ES-3.

TABLE ES-3: MEASURE ANALYSIS METHODS

Measure	Analysis Method	Analysis Output
Furnace	Billing analysis (988 homes)	Full Load Hours (FLH) and Annual Consumption
	Contractor and Distributor Surveys	Baseline and NTG
	Customer Survey	NTG
Boiler	On Site Metering (37 homes)	Efficiency
	Billing analysis (1,686 homes)	FLH and Annual Consumption
	Customer survey	% of homes with integrated hot water and NTG
	Contractor and Distributor Surveys	Baseline and NTG
Circulating Pump	On Site Metering (53 pumps)	Annual Hours, CF, Efficient kW
	Contractor and Distributor Surveys	Baseline and NTG
Heat Pump Water Heater	On Site Metering (41 homes)	Annual Hours, CF, Baseline and Efficient kW
	Customer Survey	Baseline and NTG
	Contractor and Distributor Surveys	NTG
Furnace Fan	AMI analysis (111 homes)	FLH and kW
	Customer Survey	NTG
	Contractor and Distributor Surveys	Baseline and NTG

The net-to-gross ratio (NTGR) was estimated for the five measures listed in Table ES-3. The approach to estimating net savings utilized the self-report method and incorporated program influence.[4] Both the self-report and program influence questions were tied to the program's causal mechanisms on the market actors. The NTGR estimates were developed for the three markets actors, i.e., customers, contractors and distributors, and the results were combined to reflect the relative contribution of the market actors to the decision-making process.

Impact Evaluation Results

Evaluated savings for both furnaces and boilers were lower than the PSD assumptions. The primary reason is that the baseline efficiency was higher than assumed in the PSD calculations. Program reported savings were also lower than the PSD defaults. The winter and summer seasonal peak kW reductions were calculated based on the ISO-NE definitions of seasonal peak,

[4] This type of approach is also being adopted in current impact evaluations conducted in Massachusetts. These evaluations have not yet been finalized as of March, 2018.

using historical ISO-NE data.[5] The gross and net evaluated savings by measure are summarized in Table ES-4.

TABLE ES-4: SUMMARY OF PER UNIT PSD AND EVALUATED SAVINGS BY MEASURE

Measure	2017 PSD Gross Savings	Realization Rate[1]	Evaluated Gross Savings[2]	NTGR[1,3]	Evaluated Net Savings
High Efficiency Furnace	14.1 MMBtu/year	74% +/-4%	10.4 MMBtu/year	62% +/-8%	6.4+/-0.9 MMBtu/year
High Efficiency Boiler	11.5 MMBtu/year	66%+/9%	7.6 MMBtu/year	56% +/-7%	4.3+/-0.8 MMBtu/year
ECM Boiler Circulating Pumps	285 kWh/year	24%+/-3%	68 kWh/year	69% +/-11%	47+/-9 kWh/year
	0.056 Seasonal Winter Peak kW	44%+/-5%	0.024 kW	69% +/-11%	0.017+/-0.003 kW
Furnace Fan	293 kWh/year	125%+/-7%	366 kWh/year[4]	62% +/-8%[5]	227+/-33 kWh/year
	0.090 Seasonal Winter Peak kW	131%+/-8%	0.118 kW	62% +/-8%[5]	0.073+/-0.010 kW
	0.072 Seasonal Summer Peak kW	90%+/-4%	0.065 kW	62% +/-8%[5]	0.040+/-0.006 kW
Heat Pump Water Heater[6]	2,112 kWh/year	54% +/- 6%	961 kWh/year	59% +/- 6%	567+/-85 kWh/year
	0.244 Seasonal Winter Peak kW	55% +/- 5%	0.134 kW	59% +/- 6%	0.079+/-0.012 kW
	0.185 Seasonal Summer Peak kW	95% +/- 7%	0.175 kW	59% +/- 6%	0.103+/-0.015 kW
	0 MMBtu/year	N/A	4.3 MMBtu/year	59% +/- 6%	2.5+/-0.3 MMBtu/year

[1] Confidence intervals are at the 80% confidence level and account for the sampling error at each stage of the calculation by incorporating the propagation of uncertainty.
[2] Gross evaluated savings are the PSD savings multiplied by the realization rate.
[3] NTGR = 1 – FR (Free rider rate)+SO (spillover).
[4] The furnace fan kWh savings include both winter (heating) and summer (cooling) savings. The summer savings are based on the assumption that approximately 60% of homes with furnaces have central air conditioning. See Section 4.5 for more details.
[5] It was not possible to estimate the NTG for ECM furnace fans separately from furnaces. Only furnaces with ECM fans are eligible to receive a rebate through the program and ECM furnace fans are not a stand-alone measure. Thus, the NTGR for furnaces was applied to furnace fans.
[6] These savings reflect a blended baseline, accounting for replacements of electric and fossil fuel water heaters. Although the electric savings are lower, substantial fossil fuel MMBtu savings were added.

The ISO-NE Forward Capacity Market requires that sample sizes be designed to meet the 80/10 confidence/precision target. In this evaluation, the sample was stratified by measure and the 80/10 target applies to the overall sample size.[6] The relative precision at the 80% confidence level for the gross seasonal peak kW reduction for all measures combined is 5% and 6% at the 80% confidence interval for winter and summer, respectively. Additional detail is provided in Appendix M.

[5] https://www.iso-ne.com/markets-operations/markets/demand-resources/about
[6] ISO New England Manual for Measurement and Verification of Demand Reduction Value from Demand Resources Manual M-MVDR, Revision: 6, Effective Date: June 1, 2014. Section 7.2.2 (2).

The net-to-gross ratios (NTGR) were estimated by combining the results for the three market actors and adding spillover. The NTG surveys and analysis were based on program activity in 2014 through 2016. The NTG results are summarized in Table ES-5.

TABLE ES-5: SUMMARY OF NTGR BY MEASURE

Measure	Initial NTGR[1]	Spillover	Final NTGR[2,3]
Furnaces	58%	4%	62% +/- 8%
Boilers	52%	4%	56% +/- 8%
Boiler Circulating Pumps	60%	9%	69% +/- 11%
Heat Pump Water Heaters	58%	1%	59% +/- 6%

[1] Initial NTGR = 1 – FR (Free rider rate).
[2] Final NTGR = 1 – FR (Free rider rate)+SO (spillover).
[3] Confidence intervals are at the 80% confidence level and account for the sampling error at each stage of the calculation using propagation of uncertainty.

In 2017, the utilities made a change to the incentive structure for efficient boilers from a single incentive of $750 for all boilers with an efficiency greater than 90% to a two-tiered system with an incentive of $450 for boilers with rated efficiencies from 90% to 93.9% and $750 for efficiencies of 94% or greater. Accordingly, the evaluators recommend a modified NTGR of 84% for boilers receiving the higher incentive in 2017.[7]

Process Evaluation Findings

The overall upstream program design is working, with the distributors working closely with contractors, who in turn work the customers. Some key findings are summarized below.

- Both customers and contractors gave the program high overall satisfaction ratings (88% and 80%, respectively).
- The lowest satisfaction rating was from distributors (53%). Rebate processing, the time to receive the rebate and communication from the utilities were the main factors in lowering the distributor satisfaction score.
- The vast majority of contractors (95%) reported that they are more likely to recommend high efficiency equipment due to the upstream rebate.

[7] There was a substantial increase in the percent of rebates for the higher efficiency boilers in 2017 as compared to 2016 and prior years (from about 40% to about 80%), suggesting that an adjustment to the NTGR was required. The boiler NTG was adjusted by doubling the contractor contribution to the NTGR, as the contractors are likely to be the market actor having the most impact on the increase in uptake of the high efficiency boilers.

- Contractors stated that the upstream rebates help them to sell more high efficiency equipment by reducing the price (75%), more customers asking about rebates (46%) and providing a hook to start the conversation about efficiency (37%).
- Among contractors, the most consistent theme was an opportunity for greater contractor engagement. Contractors expressed a need for increased contractor training about the program and equipment and installation issues.
- Respondents also reported a need to improve on-line information sources (the EnergizeCT website or directing contractors and customers to relevant on-line sources).
- The most commonly reported equipment concern among contractors was the lack of available replacement parts for the high-efficiency equipment, followed by more frequent customer call backs and increased maintenance needs.

Distributors mostly promote the program through one-to-one conversations with contractors. They use other tools, such as literature and in-store demos, to a lesser extent.

Recommendations

Improve Program Tracking

Issues with the data quality had substantial effects on the evaluation. It is critical to maintain a connection between the rebate and the location of the installation to allow for verification. Quality control procedures need to be strengthened to check the integrity of data required for verification and evaluation to the extent possible within the upstream program design.

Improve Communication about Rebate Processing

The overall satisfaction rating for distributors (53%) was substantially affected by low ratings for rebate processing, the time it took to receive the rebate and communication from the utilities. To sustain participation among distributors, program managers can improve communication to establish clear expectations around rebate requirements and timelines.[8]

Expand Contractor Training

Contractors expressed interest in attending trainings by the utilities or third parties that increase their employees' technical knowledge and familiarize them with program processes and requirements. Since customers may face first cost barriers despite the rebates, the utilities could also provide training on non-monetary benefits to help them upsell efficient equipment.

Encourage Distributors to Stock Replacement Parts

Contractors expressed concerns about equipment issues associated with the high efficiency equipment, including having trouble finding replacement parts. To address these equipment

[8] The utilities reported that since developing these findings, improvements have been made to the distributor rebate process.

concerns barriers, program staff can work with distributors to stock replacement parts and increase training to contractors on installation and maintenance concerns.

Conduct Further Research into the NTG for the Tiered Boiler Incentives

In 2017, the utilities made a change to the incentive structure for efficient boilers from a single incentive for all eligible boilers a two-tiered system depending on the level of the boiler efficiency. As this evaluation covers program years 2014 through 2016, further investigation into the effects of this tiered incentive on the NTG is warranted.

Recommended Changes to the PSD

The impact results indicate that the deemed savings in the PSD need to be revised. The recommended changes to heat pump water heaters depend on the baseline. The modifications shown below in Tables ES-6 and ES-7 are for either a baseline electric or fossil fuel water heater. The equations to calculate the savings using a blended baseline are given below the tables.

TABLE ES-6: SUMMARY OF RECOMMENDED CHANGES TO PSD FOR HEATING SYSTEM MEASURES

Measure	Input	2015/2017 PSD[1]	2017 PSD Alternative[2]	Recommended PSD
Furnace	Baseline AFUE	82%	85%	85%
	Heating factor (Btu/ft^2) x Average area heating by furnace (ft^2)	66.6 MMBtu/yr	55.1 MMBtu/yr	77.5 MMBtu/yr
Boiler	Baseline AFUE	82%	85%	85%
	Efficient AFUE	Rated efficiency from program tracking	Use regression to adjust installed efficiency	Adjust rated efficiency downward by 2%
	Heating factor (Btu/ft^2) x average area heated by boiler (ft^2)	66.6 MMBtu/yr	92.8 MMBtu/yr	85.2 MMBtu/yr
	Annual hot water load	11.2 MMBtu	11.2 MMBtu	No change
Circulating Pump	Annual kWh Savings	285	N/A	68
	Winter Peak kW Savings	0.056	N/A	0.024
	Summer Peak kW Savings	0.000	N/A	0.000
Furnace Fan (ECM)	Winter kWh Savings	293	N/A	321
	Summer kWh Savings	55	N/A	45
	Total Annual kWh Savings	348	N/A	366
	Winter Peak kW Savings	0.090	N/A	0.118
	Summer Peak kW Savings	0.072	N/A	0.065

[1] *Connecticut Program Savings Document*, 12th Edition for 2017 Program Year, UIL Holdings Corporation and Eversource Energy: page 181 for furnaces, 169 for boilers, 191 for boiler circulating pumps and 144 for ECM furnace fans
[2] *Connecticut Program Savings Document*, 12th Edition for 2017 Program Year, UIL Holdings Corporation and Eversource Energy: page 186 for the alternative furnace assumptions, 175 for alternative boiler assumptions

The PSD provides the deemed savings for heat pump water heaters. We recommend that the deemed savings be updated to match the evaluation results. Table 8-4 shows the recommended changes using either a baseline electric or fossil fuel water heater.

Table ES-7: Recommended Changes to the PSD for Heat Pump Water Heater Energy Savings

		Recommended Changes			
	2017 PSD[1]	Electric Baseline	Propane[2]	Oil[2]	Reason
Gallons per year (GPY)	19,839	15,415	15,415	15,415	Metering
$T_{dhw} - T_{aiw}$ (ΔT)	68	75	75	75	Metering/site visit measurement
Baseline Energy Factor (EF_b)	0.945	0.95	N/A	N/A	Manufacturer's specs
Efficient Energy Factor (EF_i)	2.68 or manufacturer specifications	2.46 or manufacturer specifications	2.46 or manufacturer specifications	2.46 or manufacturer specifications	Metering
P (heating penalty and recovery adjustment)	0.90	1.00	N/A	N/A	PSD assumption; no evidence to support
Annual kWh Savings	2,112	1,818	-1,418	-1,418	Calculated from above inputs[3]
Fossil Fuel Energy Factor (EF_{ff})	N/A	N/A	0.77a	0.65	Average of available units
Fossil Fuel Adjustment Factor (AF_{ff})	N/A	N/A	1.24	1.24	Adjustment for extra use
Annual MMBtu Savings	0	0	14.9	17.7	

[1] *Connecticut Program Savings Document*, 12th Edition for 2017 Program Year, the United Illuminating Company, page 300
[2] The calculations for the fossil fuel MMBtu savings and kWh extra use are given below.
[3] The kWh savings were estimated directly from the metering. The inputs into the PSD calculations were adjusted to match the metered energy savings as closely as possible.
a The EF for propane is a blended rate between on demand and stand-alone units.

Table ES-9 lists the recommended changes to the seasonal kW reduction for heat pump water heaters.

Table ES-8: Recommended Changes to the PSD for HPWH Seasonal Peak Demand Reduction

		Recommended Changes			
	2017 PSD[1]	Electric Baseline	Propane[2]	Oil[2]	Reason
Gallons per hour (GPH)	1.96	1.98 Winter/ 2.50 Summer	1.98 Winter/ 2.50 Summer	1.98 Winter/ 2.50 Summer	Metering/seasonal adjustment
$T_{dhw} - T_{aiw}$ (ΔT)	81 Winter/ 60 Summer	75	75	75	Metering/site visit measurement
Baseline Energy Factor (EF_b)	0.945	0.95	N/A	N/A	Manufacturer's specs
Efficient Energy Factor (EF_i)	2.68 or manufacturer specifications	2.46 or manufacturer specifications	2.46 or manufacturer specifications	2.46 or manufacturer specifications	Metering
P (heating penalty and recovery adjustment)	0.90	1.00	N/A	N/A	PSD assumption; no evidence to support
Seasonal Peak kW Reduction	.244 Winter/ .185 Summer	.234 Winter/ .296 Summer	-0.151 Winter/ -0.169 Summer	-0.151 Winter/ -0.169 Summer	Calculated from above inputs[3]
Fossil Fuel Adjustment Factor (AF_{ff})	N/A	N/A	-1.03 Winter/ -0.91 Summer	1.03 Winter/ 0.91 Summer	Adjusts for increased electric use

[1] *Connecticut Program Savings Document*, 12th Edition for 2017 Program Year, the United Illuminating Company, page 300
[2] The calculations for the fossil fuel MMBtu savings and kWh extra use are given below.
[3] The seasonal peak kW reduction was estimated directly from the metering. The inputs into the PSD calculations were adjusted to match the metered savings as closely as possible.
a The EF for propane is a blended rate between on demand and stand-alone units.

The calculations for the MMBtu savings and the extra electric use associated with installations in homes with a fossil fuel baseline are shown in Equations ES-1 through Equation ES-3 below.

Equation ES-1

$$MMBtu\ Savings = \frac{GPY\ x\ \Delta T\ x\ 8.3\frac{lbs}{gal}\ x\ 1.0\ \frac{Btu}{°F}\ /\ EF_{FF}}{3{,}412\ Btu/kWh}$$

Equation ES-2

$$kWh\ Extra\ Use_{FF} = \frac{GPY\ x\ \Delta T\ x\ 8.3\frac{lbs}{gal}\ x\ 1.0\ \frac{Btu}{°F}\ x\ AF_{ff}/\ EF_i}{3{,}412\ Btu/kWh}$$

EQUATION ES-3

$$Seasonal\ Peak\ kW\ Extra\ Use_{FF} = \frac{GPH\ x\ \Delta T\ x\ 8.3\frac{lbs}{gal}\ x\ 1.0\ \frac{Btu}{°F}\ x\ AF_{ff}/\ EF_{i}}{3{,}412\ Btu/kWh}$$

The blended baseline accounts for the incidence of baseline water heaters from the homeowner survey.[9] These equations can be used to develop deemed savings for installations where the fuel type of the baseline water heater is unknown. To calculate savings from the blended baseline, first calculate the savings from the electric and fossil fuel baselines using the inputs in Tables ES-7 and ES-8 and Equations ES-1 to ES-3, and then combine the results as shown in Equations ES-4 to ES-6.

EQUATION ES-4

$$Annual\ kWh\ Savings_{blended} = 0.74\ x\ kWhSavings_{\ electric} - 0.26\ x\ kWhExtraUse_{fossil\ fuels}$$

EQUATION ES-5

$$Annual\ Peak\ kW\ Savings_{blended} = 0.74\ x\ kWSavings_{\ electric} - 0.26\ x\ kWExtraUse_{fossil\ fuels}$$

EQUATION ES-6

$$Annual\ MMBtu\ Savings_{blended} = 0.74\ x\ 0\ MMBtuSavings_{\ electric} + 0.13\ x\ MMBtuSavings_{propane} + 0.13\ x\ MMBtuSavings_{oil}$$

Please note that there are no MMBtu savings for the electric baseline.

[9] Assuming that the prior water heater is the baseline may not be an accurate assessment of the baseline. For example, a homeowner with an oil integrated water tank that failed may well decide to replace it with an electric resistance heater. The survey investigated the different water heaters considered by the homeowners and incorporated these findings into the baseline.

1 Introduction

Impact and process evaluation studies of the Connecticut Residential Upstream HVAC and Water Heating Program ("Upstream HVAC Program") and the impact evaluation of Heat Pump Water Heater Program, completed in 2017, are documented in this report.

The Upstream HVAC Program offers rebates to distributors to encourage the installation of high efficiency space and water heating equipment. This program is implemented by Eversource and United Illuminating throughout the state of Connecticut. The rebates are paid to the distributors, and distributors and contractors are required to pass the discount on to the customer.

The Heat Pump Water Heater Program offers rebates to distributors and retailers. The distributor rebates are handled in the same way at the Upstream HVAC Program. Instant rebates of a lower value are also offered at participating retailers, coupled with a mail in rebate for the customer.

1.1 Research Objectives

The prioritized outcomes for this study include the following:

- Gross energy savings, peak demand reduction and realization rates for the evaluated measures
- Recommended changes to the PSD and "forward-looking" realization rates using the most current PSD (2017)
- Net-to-gross ratio for the evaluated measures
- Assessment of the effectiveness of the program processes

This evaluation covers program activity from January 1, 2014 through July 31, 2016. The gross impact evaluation meets or exceeds energy efficiency program evaluation industry standards, the requirements of the New England Independent System Operator (ISO) for sales into the Forward Capacity Market (FCM), and meets the Connecticut (CT) legislative intent for requiring independent impact evaluation.[10] In addition, the verification of the seasonal winter and summer peak kW reduction meets the requirement of the ISO-NE Forward Capacity Market.

This evaluation covered full analysis of five of the eight program measures, which account for more than 75% of the program reported savings for natural gas and winter peak savings, about 60% of the electric energy and about 15% of the summer peak savings. The evaluated measures are boilers, furnaces, electrically commutated motor (ECM) furnace fans, heat pump water heaters (HPWH's), and boiler circulating pumps.

Ground source heat pumps, mini-splits, air source heat pumps, air conditioners and gas water heaters were not evaluated. In aggregate, these measures account for less than 40% of the

[10] The ISO-NE FCM requires impact evaluation to be conducted by third-party independent qualified evaluators.

natural gas, energy and winter peak savings, and over 80% of the summer peak savings. These measures were not prioritized as previous impact evaluations for ground source heat pumps and central air conditioners were completed in June of 2014 and October of 2014.

1.1.1 Impact Evaluation

Table 1-1 summarizes the evaluation activities for this study.[11]

TABLE 1-1: SUMMARY OF EVALUATION ACTIVITIES

Evaluation Activity	Determine Baseline	Determine Efficiency	Estimate Annual Load	Estimate kW Peak Reduction	Assess Reasons for Performance	NTGR/ Decision-Making	Process
Billing or AMI analysis			● Furnaces, ● Boilers, ● ECM furnace fan	● ECM furnace fan			
In situ metering	● HP Water Heater	● Boilers, ● Circulator pump, ● HP Water Heater	● Boilers, ● Circulator pump, ● HP Water Heater	● Circulator pump, ● HP Water Heater	● Boilers, ● Circulator pump, ● HP Water Heater		
Customer interviews	● HP Water Heater				● Furnaces, ● Boilers, ● HP Water Heater	● Furnaces, ● Boilers, ● HP Water Heater	● Furnaces, ● Boilers, ● Circulator pump, ● HP Water Heater, ● ECM furnace fan
Market actor interviews	● Furnaces, ● Boilers, ● Circulator pump, ● ECM furnace fan				● Furnaces, ● Boilers, ● HP Water Heater	● Furnaces, ● Boilers, ● Circulator pump, ● HP Water Heater, ● ECM furnace fan	● Furnaces, ● Boilers, ● Circulator pump, ● HP Water Heater, ● ECM furnace fan
Manufacturers' data	● Furnaces, ● Boilers, ● Circulator pump, ● HP Water Heater, ● ECM furnace fan	● Furnaces, ● Boilers, ● Circulator pump, ● HP Water Heater, ● ECM furnace fan					

• *Furnaces* • *Boilers* • *Circulator pump* • *HP Water Heater* • *ECM furnace fan*

1.1.2 Process Evaluation

The Evaluation Team conducted a process evaluation the Upstream HVAC and Water Heating Program. The purpose of the process evaluation was to address the following research objectives:

- Document program activities
- Assess program management and administrative experiences
- Assess program experiences from customers, contractors, distributors/retailers[12]

Table 1-2 summarizes the Evaluation Team's approach to the process evaluation.

[11] UI provided 15-minute AMI data for over 500 customer accounts, requiring substantial effort on their part. The AMI data were critical for the impact evaluation of the furnace fans.

[12] The evaluation team originally had an objective to assess links in the program logic model; however, there was no program logic model so this objective was removed from the evaluation.

TABLE 1-2: PROCESS EVALUATION APPROACH SUMMARY

Objective	Research Questions	Method
Document Program Activities	Who participated? What type of measures did customers install? What market efforts occurred? What communication efforts occurred?	Review program documents; Interview program staff
Assess Program Management and Administration Experiences	What are staff experiences with program administration, data management, marketing and outreach, internal communications, and external communications	Interview program staff
Assess Program Experiences by Customers, Contractors, Distributors/Retailers	How do market actors learn about the program? Are market actors satisfied with the program? How do distributors/retailers/contractors sell the program to their customers? How do distributors/retailers track data and experience program participation processes?	Incorporate questions into interviews with customers, contractors, distributors/ retailers

1.1.3 Previous Evaluations

The last impact evaluations for ground source heat pumps and central air conditioners were completed in June of 2014 and October of 2014. Ductless heat pumps and non-heat pump DHW replacements were evaluated as part of the PY 2011 Home Energy Services Program completed in December of 2014.

2 Program Description

In 2014, Eversource and United Illuminating launched the Upstream HVAC Program. Program administrators began transitioning most of the residential HVAC and water heating rebates into an upstream rebate model, allowing customers to receive an instant discount on installed qualifying equipment. Historically, CEEB provided residential customers rebates for HVAC and water heating equipment through the Home Energy Solutions program. The upstream natural gas boiler rebate and the natural gas water heater rebate were piloted in October 2013-March 2014 and became fully upstream in April 2014. Furnaces and boiler circulator pump rebates became fully upstream in April 2014. Upstream heat pump water heater rebates became available in January 2014.[13]

This section is based primarily on findings from program staff interviews and program documentation available on-line or from program staff, and includes the following subsections:

- Program overview
- Program budgets
- Implementation
- Program savings
- Summary of participation levels in 2014 - 2015

2.1 Program Overview

The goal of the Upstream HVAC program is to "create market transformation toward the stocking, sale, and distribution of high efficiency equipment."[14] The Upstream HVAC Program provides rebates to distributors for qualified HVAC and hot water equipment that are sold and installed at residential sites.[15] For heat pumps water heaters, the program also provides retailers with a rebate; the retailer rebate is lower than the distributor rebate.[16] In all cases, the discount is to be provided directly to the customer by the contractor or retailer through an instant rebate clearly identified on the invoice or receipt.

The Upstream HVAC Program is designed to overcome a number of customer barriers to the installation of high efficiency HVAC and water heating equipment:[17]

- Higher first costs of high efficiency equipment for customers
- Availability of high efficiency equipment for emergency installations as HVAC equipment is often purchased when older equipment fails or is about to fail

[13] Program staff reported these dates during the interview with the Evaluation Team.
[14] Connecticut Energy Efficiency Fund. Energy Efficiency Board 2014 Programs and Operations Report (March 1, 2015), p6.
[15] Distributors are only given the rebate if the rebate processor can confirm that the site is an eligible residential customer.
[16] In these cases, customers are also given an opportunity to mail in a rebate for the difference in rebate value if they provide the utility with the installation address.
[17] "First cost" is the only barrier identified in the Eversource Energy Residential Energy Efficiency Residential Heat Pump and Central Air Conditioning Energy Efficiency Rebates 2016 Implementation Manual; however, the Evaluation Team concluded the program is also designed to address the increased availability for emergency installations based on conversations with program staff.

Requirements for eligible equipment and rebate amounts are summarized in Table 2-1.

TABLE 2-1: HIGH EFFICIENCY STANDARDS (2016 ENERGIZE CT REBATE SUMMARY TABLE)

Measure	Qualification Criteria	Incentive Amount*
Boiler	ENERGY STAR 90% AFUE or Greater and AHRI Rated with boiler reset control	$750[a]
Natural Gas Furnace	ENERGY STAR 95% AFUE or greater and AHRI Rated with ECM air handler motor	$600
Boiler Circulator Pump	Approved models only: some Grundfos Alpha models, BumbleBee, some Wilo models, etc.	$100
Heat Pump Water Heater	ENERGY STAR with COP of 2.0 or greater	$400[b] or $300 instant + $100 mail-in at retailers

a $1000 incentive is offered to electric resistance heat customers with an audit prior to installation.
b With the exception of heat pump water heaters, measures are only eligible if sold to a licensed contractor at a participating distributor.

Appendix B provides the theoretical reasoning underlying this type of program.

2.2 Program Budgets

Annual budgets for the program are allocated based on a 3-year planning cycle, with annual updates that allow for budget reallocations.[18] The utilities provided the Upstream HVAC program budget and goal within the 2016-2018 Electric and Natural Gas Conservation and Load Management Plan (C&LM).[19] This budget encompasses the downstream and upstream rebates and reflects the scope of this program moving forward. As shown in Tables 2-2 and Table 2-3, this program generates roughly 20% of residential gas savings and less than 5% of residential electric savings.

[18] The program budgets are structured by territory. There are five utilities in the state, and each one has a separate budget. Eversource (electric) also encompasses Yankee Gas (gas utility), and United Illuminating (electric) manages the budgets for Southern Connecticut Gas and Connecticut Natural Gas. Budgets are allocated based on rate payer contribution estimates (which takes into consideration weather and previous billing data). Prior to 2016, the utilities did not report a separate budget and goal for the Upstream HVAC program, as it was incorporated into the HES Program budget and goals.
[19] Program staff reported they do not have any goals based on measure type, but rather all goals are rolled together at the Program level. (Source: utility staff email to evaluation team)

TABLE 2-2: 2016-2018 UPSTREAM HVAC NATURAL GAS BUDGET AND SAVINGS GOALS

Year	Annual CCF Budget (x$1000)	% of Residential CCF Budget	Annual CCF Savings	% of Residential CCF Savings
2016	4,848	18%	643,556	21%
2017	5,289	17%	749,907	21%
2018	5,439	17%	779,059	20%

Source: 2016-2018 C&LM, Table B4 (pp46-48) and Table A1 (p137). Percentages calculated based only on the residential sub-total, which does not include items such as administration, education programs, and loan programs.
(http://www.ct.gov/deep/lib/deep/energy/conserloadmgmt/2016_2018_CLM_PLAN_FINAL.pdf)

TABLE 2-3: 2016-2018 UPSTREAM HVAC ELECTRIC BUDGET AND SAVINGS GOALS

Year	Annual MWh Budget (x$1000)	% of Residential MWh Budget	Annual MWh Savings	% of Res MWh Savings	Peak kW Impact	% of Res kW Impact
2016	2,868	4%	4,802	3%	367	2%
2017	3,416	5%	5,763	4%	591	3%
2018	3,398	5%	5,797	4%	591	2%

Source: 2016-2018 C&LM, Table A1 (p41), Table B4 (pp 46-48). Percentages calculated based only on the residential sub-total, which does not include items such as administration, education programs, and loan programs.
(http://www.ct.gov/deep/lib/deep/energy/conserloadmgmt/2016_2018_CLM_PLAN_FINAL.pdf)

2.3 Implementation

Program staff conducts four major activities: enrolling distributors, marketing and outreach, overseeing rebate processing, and following-up with participating customers. These activities are described in Table 2-4.

TABLE 2-4: IMPLEMENTATION ACTIVITIES

Program Activity	Description	Comments
Enrolling Distributors	Utilities have a standard memorandum of understanding (MOU) with each participating distributor to document agreement	Staff conducted many activities including attending trade ally events, one-on-one visits to distributors, program annual roll-out event
Marketing and Outreach	Program staff and implementers collaborate with manufacturers to promote eligible equipment	Activities include communicating with distributors and contractors about rebate offerings, general marketing efforts aimed at customers, and providing access to HPWH mail-in rebate forms
Rebate Processing	1) Distributors send monthly reports to the rebate vendor 2) Utilities reimburse vendor for the rebate costs 3) Program staff enter data into their tracking systems for internal monthly reports of rebate spending and savings	The rebate vendor checks to ensure equipment was eligible, installed within the utility territory by a qualified contractor at an eligible customer site
Follow up with Customers	1) The utilities perform a post installation inspection on roughly 5% of the equipment purchases 2) Program staff sends a postcard to customers to raise awareness of the rebate	Inspections verify that the equipment reported was actually installed

2.4 Program Savings

The analysis of program data shows that Eversource's program activity was between 5 and 6 times larger than United Illuminating's activity in 2014 and 2015 for the evaluated measures, which can be expected due to the difference in size of the service territories. As shown in Figures 2-1 and 2-2, Eversource saw a slight decrease in claimed savings for evaluated measures between 2014 and 2015 (from roughly 6.6 million kWh to 6.0 million kWh) while United Illuminating achieved a slight increase in claimed savings (from roughly 1.4 million kWh to 1.7 million kWh).

Peak demand savings remained relatively stable over the period 2014-2015. Eversource saw a slight decrease in peak demand savings and United Illuminating achieved a slight increase. Both utilities achieved an increase in gas savings from 2014 to 2015.

Savings by year are depicted graphically for Eversource and United Illuminating in Figures 2-1 and 2-2, respectively.

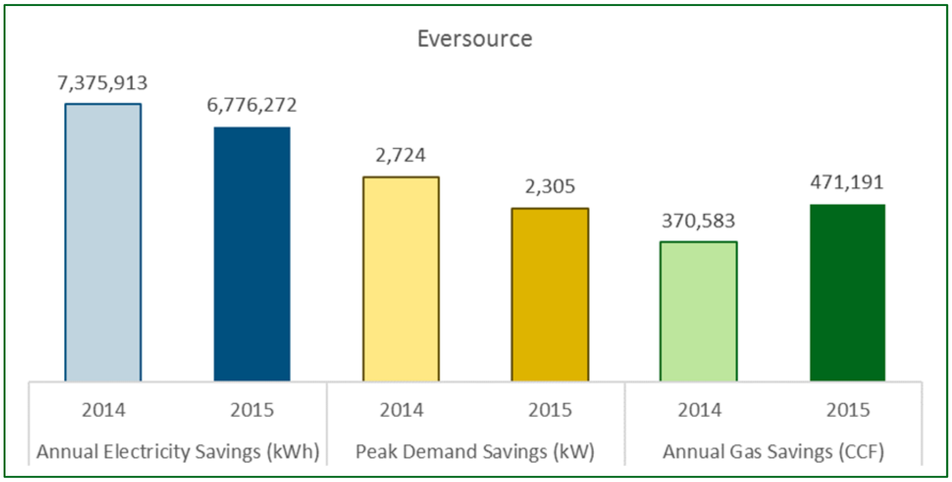

FIGURE 2-1: EVERSOURCE PROGRAM SAVINGS BY YEAR

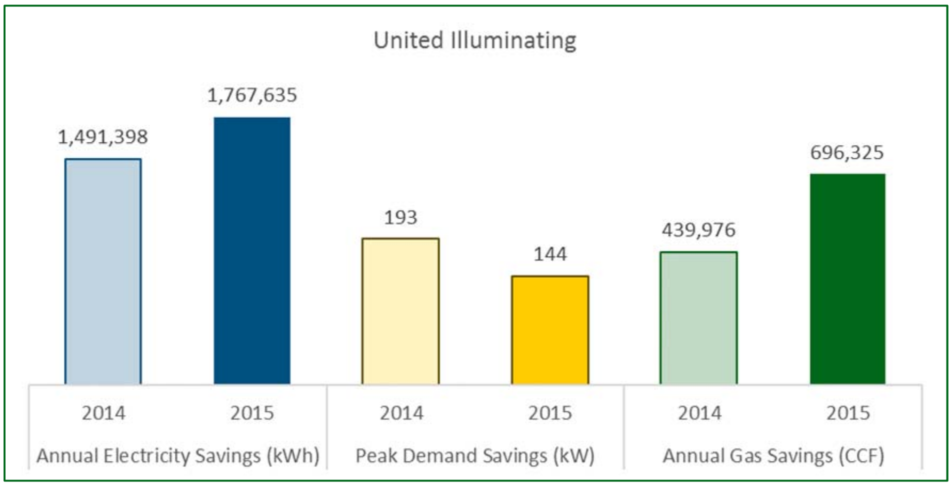

FIGURE 2-2: UI PROGRAM SAVINGS BY YEAR

2.5 Summary of Participation Levels in 2014-2015

For measures included in this evaluation, Eversource rebates accounted for nearly three-quarters (73%, or 27,753 rebates) of all rebates issued in the period 2014-2015, as shown in Figure 2-3.[20]

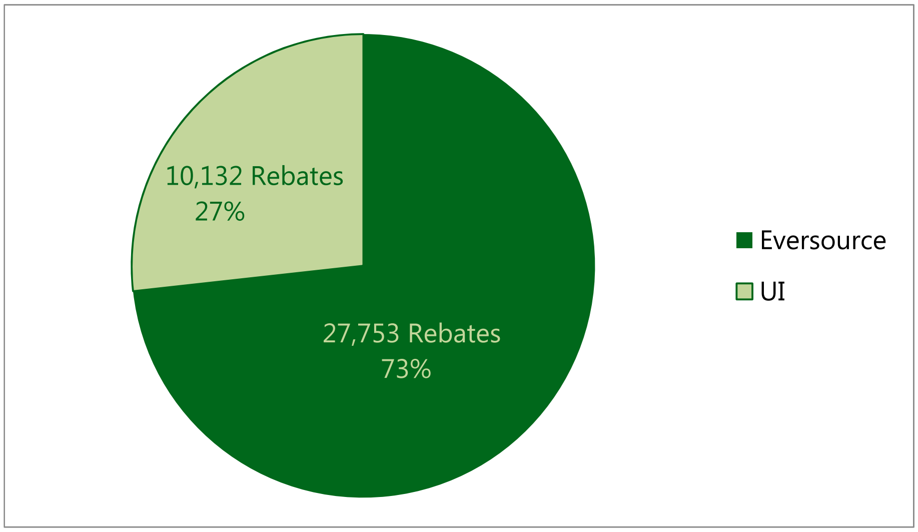

FIGURE 2-3: NUMBER OF REBATES BY UTILITY, 2014-2015

Figure 2-4 shows that both Eversource and United Illuminating exhibited an increase in the number of rebates from 2014-2015, though United Illuminating's increase was greater on both a relative and an absolute scale (an increase of 32.7%, or 1,426 rebates for United Illuminating versus an increase of 4.3%, or 585 rebates for Eversource).

[20] This is expected as Eversource's service territory has many more customers than UI's.

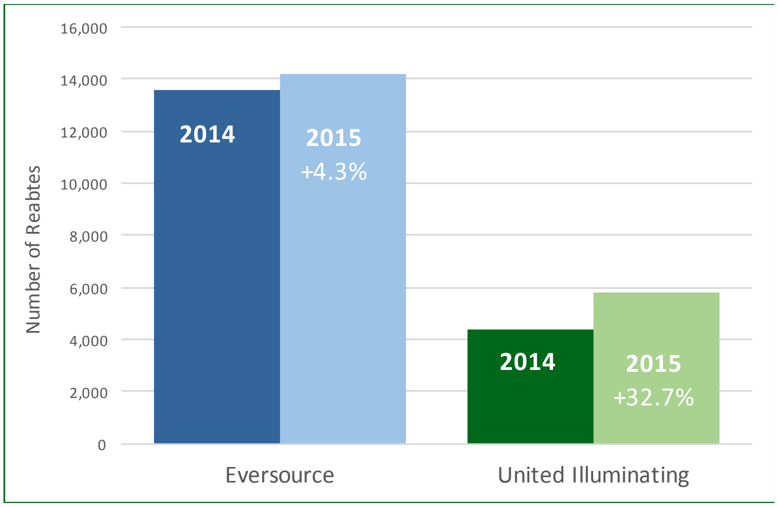

FIGURE 2-4: NUMBER OF REBATES BY UTILITY BY YEAR

Boilers, circulating pumps, and furnaces experienced strong year-over-year growth from 2014 to 2015 across both utilities. At the same time, rebates for heat pump water heaters remained relatively static. These trends are shown below in Figure 2-5 for Eversource and in Figure 2-6 for United Illuminating.

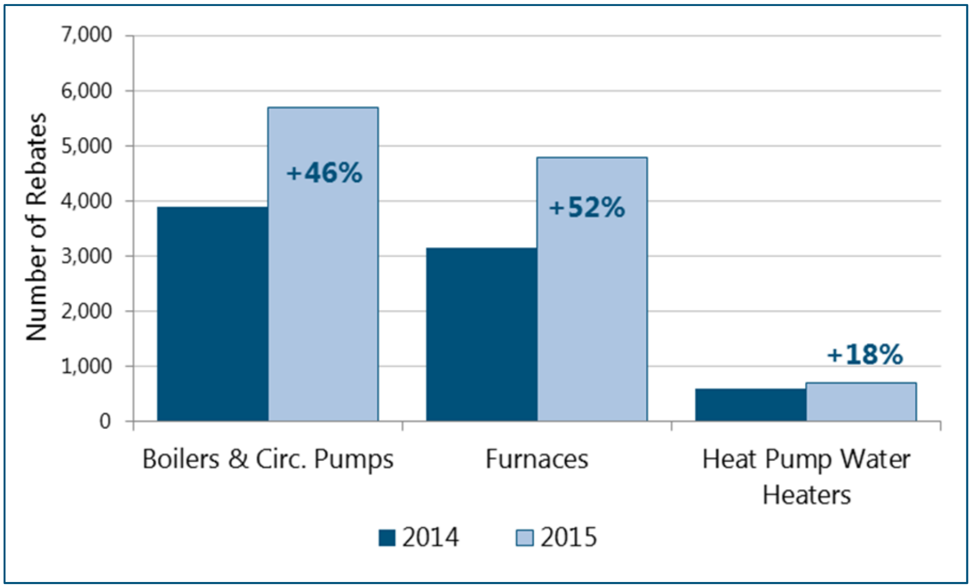

FIGURE 2-5: NUMBER OF REBATES BY MEASURE BY UTILITY BY YEAR - EVERSOURCE

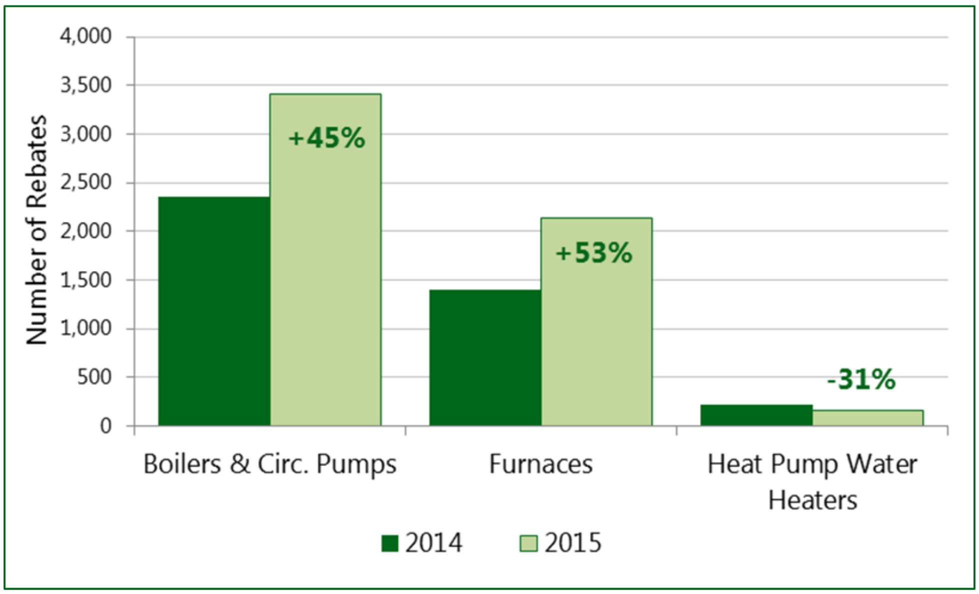

FIGURE 2-6: NUMBER OF REBATES BY MEASURE BY UTILITY BY YEAR – UNITED ILLUMINATING

3 Program Evaluability

The accuracy and comprehensiveness of the program tracking data is a critical component to effective evaluation. There are several aspects of the evaluation design and implementation that are particularly dependent on accurate program tracking data:

- Assessing program activity and processes
- Obtaining contact information for customers, contractors and distributors for surveys
- Planning site visits to minimize travel costs
- Calculating evaluated savings using the efficiency and capacity of the installed equipment (boilers and furnaces)
- Conducting billing analysis, which requires matching program tracking and utility account data
- Applying evaluation results to the program as a whole

When key information is missing, the evaluation can be compromised. The research team encountered serious data deficiencies for this program. While collecting all of this data may not be feasible in an upstream program, it limits the scope of the evaluation research. The data issues fall into four broad categories:

1. Missing tracking data – key fields are not populated
2. Inaccurate tracking data – fields are populated but the data are not consistent with the field definition
3. Matching issues – there was no unique key for matching customers between files (customers to accounts or customer contact to model information)
4. Missing program documentation – critical documentation was not provided

Table 3-1 summarizes the data issues and their impact on the evaluation.

Table 3-1: Data Issues and Program Evaluability

Issue	Measures/ Utility	Scope	Impact on Evaluation
Missing tracking data	Heat Pump Water Heaters	No site-specific data (customer/contractor) for 97% of UI rebates; no contractor for 76% of Eversource rebates	1) Lost connection between rebate & location of installation 2) Small population for site visits and could not geo-target site visits (increased evaluation costs) 3) Had to obtain supplemental data, extending evaluation time frame 4) Could not use transactional NTG approach for HPWH's
	Boilers/Furnaces	Distributor field empty, varying from about 12% to 26% of rebates by measure (both UI & Eversource)	1) Difficult to assess program (distributor) activity 2) Made transactional NTG approach difficult to implement
Inaccurate tracking data	Heat Pump Water Heaters	Customer address field held distributor/retailer address for 76% of Eversource rebates	See HPWH impacts above
	Boilers/Furnaces	Contractor/distributor fields sporadically reversed & customer/contractor phones erratically placed for both utilities	1) Complicated survey solicitation process 2) Made transactional NTG approach difficult to implement
Matching Issues	Boilers/Furnaces	UI provided customer/contractor/distributor information separately from equipment model info; about 50% could not be matched	1) Reduced number of homes used to estimate evaluated savings 2) Complicated process of expanding evaluation results to the population
	Boilers/Furnaces	22% and 54% of customers with rebates could not be matched to utility accounts (both UI and Eversource)	1) Substantially reduced number of homes in the billing models
Missing program documentation	All	Some of requested program documentation was not provided	Limited scope of process evaluation

The following sections provide additional information about the data quality and impacts on the evaluation results.

3.1 Missing and Inaccurate Data

The program data had issues with missing data and data quality. Possibly due to the upstream nature of the program, it appears some information is not always being collected or is not accurate. Figures 3-1 and 3-2 below show the scale of the data issues across the evaluated measures. The furnace and furnace fan are entered as the same measure in the database and thus have identical data issues. The categories used in the graphs are defined as follows:

- **Issue** - field is populated but a systematic issue was identified with the field, such as the use of defaults in the account number fields
- **No issues** - field is population with no obvious, systematic error
- **Missing** - field is not populated

Fields in the "no issues" category are not verified to be accurate as the Evaluation Team did not have sufficient information to verify all fields.[21] Table 3-2 defines the data fields types used in Figures 3-1 and 3-2 below.

TABLE 3-2: DATA FIELD TYPE DEFINITIONS

Data Field Type	Description	Importance for Evaluation
Model	Model numbers of the efficient equipment	Used to calculate savings
Address	Address where the equipment was installed	Required for site visits and for verification of the installation
Contractor	contractor associated with the installation	Assessing program activity Conducting contractor surveys
Distributor	distributor that processed the rebate	Assessing program activity Conducting distributor surveys
Account	utility account number for the location of the installation	Billing analysis for boilers, furnaces and ECM furnace fans

Figures 3-1 and 3-2 show the percent of records in these categories for key fields in the tracking databases. For heat pump water heaters, the utilities began requiring the distributors to collect customer data in the latter half of 2016, which postdated most of the evaluation period shown in Figures 3-1 and 3-2 below.[22]

[21] For example, in the account number field, the Evaluation Team could identify records with missing information or those with default account numbers, but it was not possible to verify the accuracy of the account numbers in the other records.
[22] Prior to this requirement, distributors who did not provide customer data were given a lower rebate ($300 as opposed to $400.)

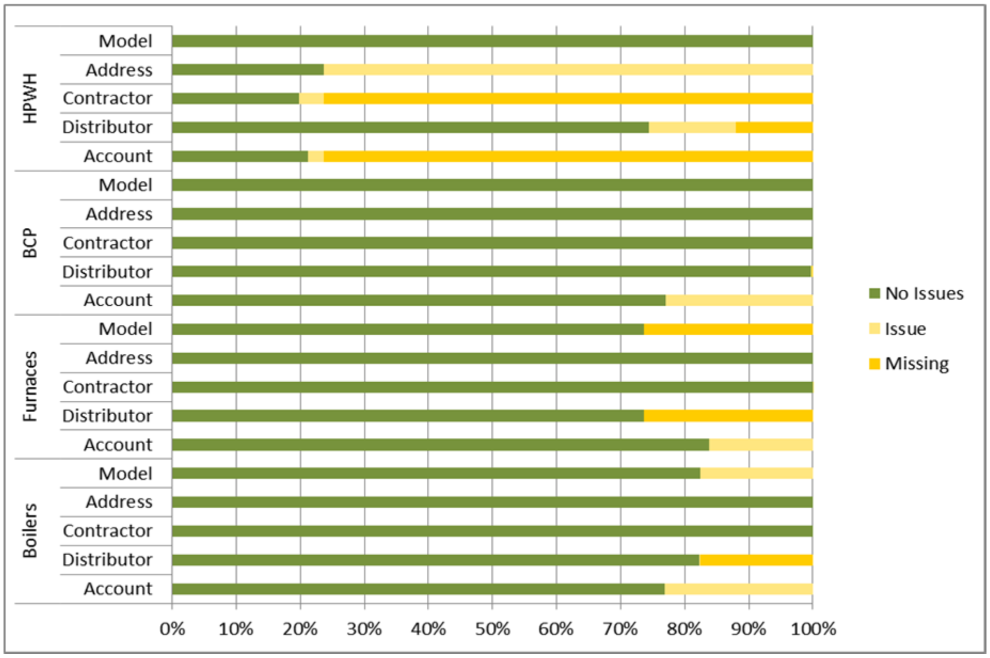

FIGURE 3-1: EVERSOURCE DATA ISSUES BY MEASURE AND DATA FIELD

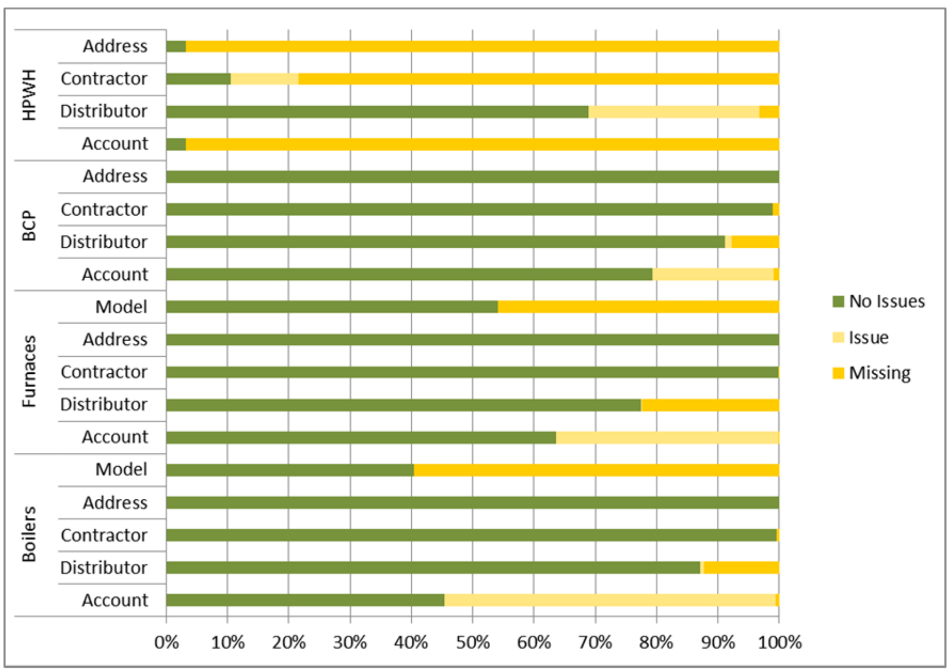

FIGURE 3-2: UI DATA ISSUES BY MEASURE AND DATA FIELD

The largest portion of missing data was in the heat pump water heater measures; distributors were not required to collect customer information until 2016 and a large portion of the population was missing accurate customer contact information. This lack of contact information effectively eliminated the option of using geographic clustering to minimize the costs of the site visits and generally made it more difficult to complete required number of site visits and customer surveys.

Distributor and contractor contact information was also often missing or incorrect, making it more difficult to solicit for the customer, contractor and distributor surveys. Some of the issues are as follows:

- Customer addresses were actually contractor or distributor addresses
- Contractor addresses matched distributor or retailer contact information.
- Customer phone numbers and e-mails were found to be the contractor's or distributor's

While contacting contractors for surveys, the Evaluation Team found that at least 10% of the phone numbers with no other apparent issues were inaccurate.

Equipment model information was sometimes just a string of numbers, some of which were AHRI reference numbers, but some were an unknown number (Eversource only). While the data set also included the efficiency and capacity of the unit, it was not possible to verify this information.

3.2 Matching Issues

In some cases, data were provided from multiple sources and could not be matched to the original tracking data set. Two examples are discussed below.

1. UI provided the detailed measure information (model information, efficiency, and emails) separately. However, this supplemental data set did not include a unique ID number to match to the original program data. Only about 50% of the projects could be matched using account numbers, address, or phone numbers.
2. Due the large number of homes missing a reliable account number, both utilities were able to only partially fulfill the request for billing records, which substantially reduced the number of homes included in the billing models used to estimate savings for boilers, furnaces and ECM furnace fans.

3.2 Data Tracking Considerations

While the Evaluation Team did not find definitive evidence of double counting of measures, the current data tracking system makes it difficult to rule out the possibility that this occurs at some level. Our analysis showed that approximately 100 customers listed in program data had received a rebate from both Eversource and United Illuminating.[23] It is likely that many of these customers live in overlapping service territories, and thus may have their electricity provided by one utility and their gas service provided by another. However, without an ongoing comparison across the two utilities' datasets, the possibility of double counting of measures remains a concern.

[23] Customers with the same first and last name, street address, and town/city were considered to be the same customer. This is complicated in some cases by the fact that the utilities' track system mixes end-use customer information with contractor information in the same field.

3.3 Program Documentation

The Evaluation Team did not receive documentation on a number of program aspects, which impeded the Evaluation Team's ability to fully assess program achievements. Table 3-3 presents the missing documentation.

TABLE 3-3: MISSING PROGRAM DOCUMENTATION FOR EVALUATION PURPOSES

Missing Documentation	Evaluation Need	Program Management Need
Program-specific goals and budget (including by measure type)	Evaluate whether goals were met; provide understanding of how program was budgeted and funds were spent	Understand progress to date- both with regards to funding and goals, and further understand measure specific issues
Program-specific implementation plan	Complete reference for program design, planned activities, program requirements, program theory and logic, budgets, and goals	Communication tool for third parties, managers, regulators, evaluators, and new staff
Data on marketing, outreach, and training activities that occurred (including a list of activities, attendees, topics) and any related materials presented at events	Evaluate the extent to which marketing activities occurred	Reference to understand prior and current activities and can be used to better understand future marketing, outreach, and training needs
Program theory and logic model	Understanding of program theory and logic; tool for evaluators to assess whether linkages led to desired outcome	Communication tool for third parties, managers, regulators, evaluators, and new staff to better understand and focus on the purpose of program and certain program activities

4 Impact Evaluation Findings

This section covers the gross evaluated savings for furnaces, boilers, boiler circulating pumps, heat pump water heaters and ECM furnace fans. The final subsection discusses the baseline survey and results for all measures.

4.1 Furnaces

The overall realization rate for the furnace natural gas savings is 81%, comparing the evaluated to the program reported savings. The primary reason is an adjustment to the baseline furnace efficiency, as shown in Figure 4-1. The baseline efficiency used in the PSD is the minimum federal standard; however the market baseline from the contractor and distributor surveys was higher. The billing analysis showed a slight increase in average consumption which partially offset the reduction in savings due to the baseline efficiency adjustment.

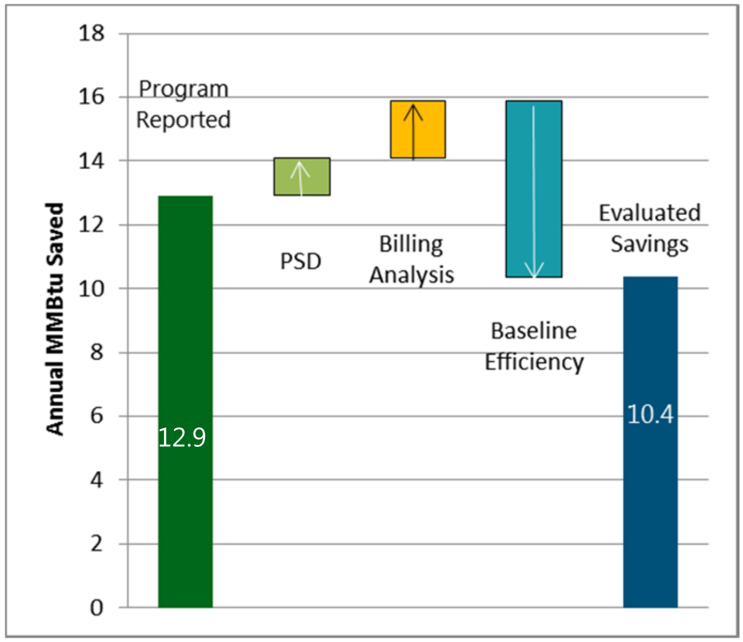

FIGURE 4-1: FURNACE MMBTU SAVINGS PER UNIT

An overview of the adjustments to the furnace MMBtu savings is provided in Table 4-1.

TABLE 4-1: OVERVIEW OF ADJUSTMENTS TO FURNACE MMBTU SAVINGS

Reason for Adjustment	Annual MMBtu		Adjustment (MMBtu)		Discussion
	Eversource	UI	Eversource	UI	
Average Program Reported Savings	12.8	12.9			Average savings per unit; UI and Eversource program reported savings were very close
2017 PSD Savings	14.1	13.9	+1.3	+1	PSD deemed savings, as estimated from the program data provided by the utility
Billing Analysis	15.9	15.9	+1.8	+2	Adjusted full load hours from billing analysis using rated efficiencies
Evaluated Savings after Baseline Adjustment	10.4	10.4	-5.2	-5.2	Baseline as determined from contractor and distributor surveys
Realization Rate	81%	81%			

The 2017 PSD offers an alternative method of calculating savings resulting in lower savings by using a baseline efficiency of 85% and a slightly lower average heat load. The savings from this alternative method are close to the evaluated gross savings.

This program targets lost opportunity measures, *i.e.*, the efficient equipment is assumed to replace existing equipment at the end of its useful life. Consequently, the baseline is a standard furnace operating under the same, post-install conditions. To address this issue, savings were estimated using a hybrid approach combining billing analysis and engineering algorithms.[24] Billing analysis was employed to estimate the annual heating consumption during the post-install period and this value was used in the engineering algorithm to estimate savings. The baseline efficiency was adjusted based on contractor and distributor surveys.

A recent metering study conducted in Massachusetts concluded that furnaces operate at, or very close to, the rated efficiency.[25] Thus, the Evaluation Team did not conduct metering of furnaces.

The following sections describe the program reported savings, PSD savings, adjustments from the billing analysis and the baseline research and recommendations for updates to the PSD.

4.1.1 Program Reported Savings

Program reported savings are slightly below the PSD deemed savings for both utilities on average. In the case of United Illuminating the average savings *per* unit is 12.9 MMBtu, as compared to the deemed PSD value of 13.9 MMBtu. Eversource claimed an average of 12.8 MMBtu while the deemed savings are 14.1 MMBtu. The program savings are based on the increase in the efficiency rating of the equipment over federal standards.

4.1.2 PSD Savings

The 2015 PSD savings incorporates numerous house-specific inputs, including the heated area of the home, the heating factor based on the age of the home, and the efficiencies of the baseline and efficient furnaces. For the most part, this information was not collected as part of the program implementation. Consequently, default values for heating factor and heated area were used to estimate the PSD MMBTU savings.[26]

The default 2015 PSD annual MMBtu savings per unit are 14.1.[27] The PSD value is higher than the program reported savings by 1.2 MMBtu. This only includes the savings from the furnace, not any additional savings for efficient furnace fans.

[24] Parlin, K, Brooks, N., Buhr, T., Flanders, A., Mysholowsky, S., Jimenez, R. "Baseline or Bust: Calculating Savings for a Residential Heating Equipment Program," Broadening our Horizons, Long Beach, CA: : International Energy Program Evaluation Conference, August 2015.

[25] "High Efficiency Heating Equipment Impact Evaluation Final Report," prepared for the Electric and Gas Program Administrators of Massachusetts by The Cadmus Group, et. al. March,015

[26] UI provided customer-specific information, including the efficiency of the installed unit, in a separate file from the program savings; however, the customer-specific file did not have a unique key to match it to the program savings file and the evaluators were unable to match the two files for most of the installed units.

[27] Connecticut Program Savings Document, 10th Edition for 2015 Program Year, the United Illuminating Company, page 165

4.1.3 Billing Analysis

To calculate annual heating consumption, we conducted separate linear regression models for each home using only post-install billing data. The post-install period was used for the following reasons:

1. It reflects the actual operating conditions of the equipment
2. As this measure is replaced on failure, the post-install period (rather than the pre-install period) is the correct baseline

The models regressed the average-daily natural gas consumption on the average-daily heating degree days (HDD) for each billing period (monthly for almost all bills). The HDD were calculated at a base degree of 60°F based on our previous experience with residential billing analyses.

Models were tested with and without intercepts for each home. We recorded three results from each model:

1. The R^2, which reflects the strength of the relationship between heating degree days and consumption
2. The heating slope coefficient (therms/HDD), which reflects the magnitude of the relationship between heating degree-days (HDD) and consumption
3. The intercept, which reflects therms of base use, such as water heating or cooking

The R^2 from each model and the sign of the heating slope and intercept were used to determine which model was a better fit. In the evaluated savings, the heating slope was used to calculate annual heating consumption, as shown in Equation 4-1 below.

EQUATION 4-1

$$NAHC = \beta \times HDD$$

Where

NAHC = Normalized Annual Heating Consumption, *i.e.*, the normalized therms per year used for space heating

β = Heating slope, *i.e.*, the regression estimator for the HDD (therms/HDD)

HDD = 6-year normalized HDD at a base temperature of 60°F for the nearest weather station

The PSD calculation for estimating savings is presented in Equation 4-2. The total savings in Btus ($ABTU_H$) are calculated using the area (A), heating factor (HF), and baseline ($AFUE_B$) and installed ($AFUE_I$) rated efficiencies. The area times the heating factor is the equivalent of the normalized annual heating consumption (NAHC) for the building.

Equation 4-2

$$ABTU_H = A \times HF \times \left(\frac{1}{AFUE_B} - \frac{1}{AFUE_I}\right) = NAHC\ x\ \left(\frac{1}{AFUE_B} - \frac{1}{AFUE_I}\right)$$

The NAHC can also be calculated by multiplying the input capacity of the heating system (kBtu/h) and the full load hours (FLH). Equation 4-3 shows the modified formula.

Equation 4-3

$$ABTU_H = NAHC\ x\ \left(\frac{1}{AFUE_B} - \frac{1}{AFUE_I}\right) = FLH \times Capacity_{Input} \times \left(\frac{1}{AFUE_B} - \frac{1}{AFUE_I}\right)$$

Using the NAHC from the billing analysis (Equation 4-1), the FLH was calculated by dividing the NAHC by the input capacity of the installed furnace.

Homes were removed from the analysis for the following reasons:

1. Key information about the model of the efficient equipment was missing from the utility data set
2. Insufficient billing data (less than one full heating season in the post period)
3. R^2 below 0.70, suggesting that natural gas use is not linear with temperature and the method described above is not effective for estimating heating consumption
4. Very low or very high consumption, outside the expected range of residential use

The number of homes removed for each of these reasons is provided in the Table 4-2.

Table 4-2: Attrition in the Furnace Billing Model

	Number of Furnaces	% Remaining in Model
Total Requested	5,196	
Total Received	1,905	100%
Accounts with 12 months post installation data	1,218	64%
Removed for other reasons	230	12%
Accounts in final model	988	52%

Homes in the latter two categories (R^2 and high or low use) were eliminated as they are not expected to be representative of typical residential use and may reflect transition periods (such as the property changing hands or non-representative periods of vacancy). A sensitivity analysis was conducted to assess whether excluding these homes had a substantial effect on the analysis. The results suggest that the impacts are quite small: annual consumption may be slightly overstated (by about 2%). The actual impact on the evaluated savings is much smaller than 2% due to the baseline adjustment.

This analysis showed slightly higher consumption than the default values used in the PSD. The results from the billing analysis are summarized in Table 4-3 below.

TABLE 4-3: BILLING ANALYSIS RESULTS FOR FURNACES

	Full Load Hours (Annual Hours) n=988	Annual Consumption (MMBtu) n=988
Default PSD 2015/2017	N/A	66.6
Mean Full Load Hours	995	77.5
Median Full Load Hours	879	67.9
80% Confidence Interval[1]	+/-22	+/-1.5
Relative Precision at 80%[1]	2.2%	1.9%

[1] As sampling was not conducted, the confidence interval reflects variability in the model, not sampling error.

4.1.4 Baseline Adjustment

In the PSD, the efficiency of the baseline heating equipment was assumed to be the federal standard (80%). However, the market baseline as determined through the surveys of contractors and distributors suggests the baseline efficiency is higher. The survey questions asked respondents to estimate the percent of installations or sales by efficiency category for units that did not receive the rebate. The method for determining the baseline is described in Section 5.6.

The percent of furnaces or installed sold outside of the program by efficiency category is shown in Table 4-4. To calculate the average efficiency, the midpoint of each efficiency bin was used. The results of the survey were weighted based on the number of units sold through the program by the contractors and distributors who responded to the survey. Based on these results, the baseline efficiency was adjusted to 85%.

TABLE 4-4: BASELINE SURVEY RESULTS FOR FURNACES

	Number of Respondents	Efficiency Category			Average Efficiency
		80-84%	85-89%	90-94%	
Contractors	33	54%	21%	25%	85.5%
Weighted Contractors	33	74%	11%	15%	84.1%
Distributors	17	34%	30%	36%	87.1%
Weighted Distributors	17	36%	22%	26%	86.4%

4.1.5 Recommended Changes to the PSD

The PSD has two sets of inputs for this measure, one for retrofit and one for lost opportunity measures. We agree with this approach and note that the utilities correctly used the lost opportunity inputs. As this program is an upstream program and it is not always possible to collect the detailed information about the homes required for the PSD calculations, we recommend using default values for the PSD inputs.

In addition, the 2017 PSD has an alternative method to calculate savings using a baseline efficiency of 85%. We also agree with this adjustment, as it is consistent with the findings of this evaluation.

The efficiency of the installed equipment was often missing from UI's program tracking data as provided to the evaluators. This input is critical to the calculation of savings and needs to be recorded. Table 4-5 below shows the recommended adjustments to the PSD.

TABLE 4-5: RECOMMENDED CHANGES TO THE PSD FOR FURNACES

Input	2015/2017 PSD[1]	2017 PSD Alternative[2]	Recommended PSD	Discussion
Baseline AFUE	82%	85%	85%	Market baseline rather than federal minimum; updated in alternative method in the 2017 PSD
Heating factor (Btu/ft^2) x Average area heating by furnace (ft^2)	66.6 MMBtu/yr	55.1 MMBtu/yr	77.5 MMBtu/yr	Using billing analysis annual consumption results rather than default inputs

[1] *Connecticut Program Savings Document*, 12th Edition for 2017 Program Year, UIL Holdings Corporation and Eversource Energy: page 181 for furnaces

[2] *Connecticut Program Savings Document*, 12th Edition for 2017 Program Year, UIL Holdings Corporation and Eversource Energy: page 186 for the alternative furnace assumptions

4.2 Boilers

The overall realization rate for the boiler natural gas savings is 69% for United Illuminating and 68% for Eversource, when comparing the evaluated results to the program reported savings for program years 2014 through July, 2016. The primary reason for the low realization rate is an adjustment to the baseline efficiency as shown in Figure 4-2 and Figure 4-3. The baseline efficiency used in the 2015 PSD is the minimum federal standard as of 2012, while the evaluation used a market baseline from a survey of contractors and distributors.

The billing analysis showed an increase in average consumption which was mostly offset by the reduction in savings due to the installed efficiency adjustment. The PSD savings adjustment for UI savings is larger than the Eversource adjustment due to the missing efficiencies in the UI dataset. The final evaluated savings values also include the adjusted savings from integrated DHW heating. Table 4-6 below summarizes the average claimed savings per boiler for both utilities as well as all adjustments. On average, Eversource slightly understated the energy savings in comparison to the 2015 PSD and UI overstated the savings in comparison to the 2015 PSD.

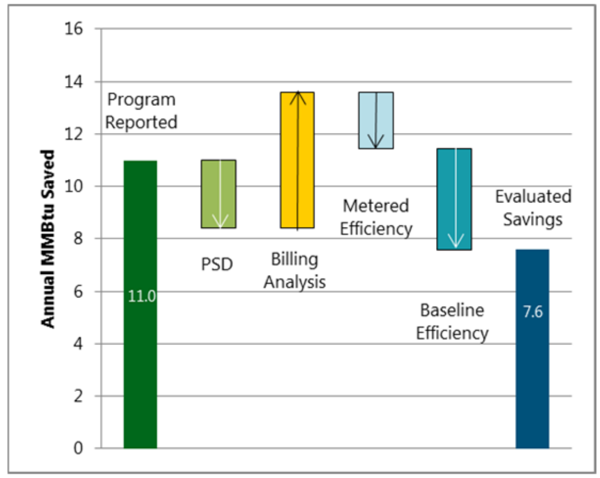

FIGURE 4-2: UI BOILER UNIT MMBTU SAVINGS

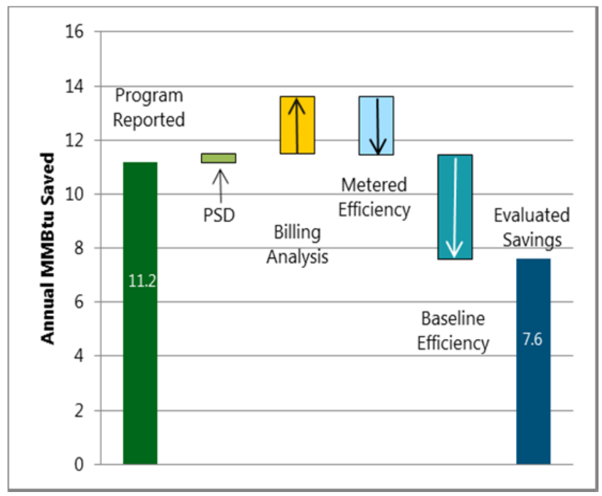

FIGURE 4-3: EVERSOURCE BOILER UNIT MMBTU SAVINGS

The 2017 PSD offers an alternative method of calculating savings that uses a baseline efficiency of 85%, which is the same baseline efficiency as found in this evaluation. This alternative method also includes an adjustment to the efficiency of the installed equipment, which is supported by the results of this evaluation. The PSD 2017 alternative method for estimating savings for efficient boilers produces results that are reasonably close to the evaluated savings.

TABLE 4-6: OVERVIEW OF ADJUSTMENTS TO BOILER SAVINGS

Reason for Adjustment	Annual MMBtu per Unit		Adjustment (MMBtu)		
	Eversource	UI	Eversource	UI	Reason for Adjustment
Average Program Reported Savings	11.2	11.0			Average claimed savings per unit
PSD Savings	11.5	8.4	+0.3	-2.6	PSD deemed savings based on inputs from program tracking
Billing Analysis	13.6	13.6	+2.1	+5.2	Adjusted full load hours from billing analysis using rated efficiencies
Metered Efficiency	11.4	11.4	-2.2	-2.2	Adjusted rated efficiency based on metering
Baseline Efficiency	7.6	7.6	-3.9	-3.9	Baseline as determined from contractor and distributor surveys
Realization Rates	69%	68%			

As with furnaces, boilers installations are lost opportunity measures and the baseline is a standard furnace operating under the same, post-install conditions. To address this issue, savings were estimated using a hybrid approach combining billing analysis and engineering algorithms.[28] Billing analysis was employed to estimate the annual heating consumption during the post-install period and this value was inserted into the engineering algorithm to estimate savings. The baseline efficiency was adjusted based on contractor and distributor surveys.

A recent metering study conducted in Massachusetts concluded that condensing boilers often operate below the rated efficiency.[29] Consequently, the Evaluation Team also conducted metering of boilers to establish the actual efficiency under common operating conditions.

The following sections describe the program reported savings, PSD savings, adjustments from the billing analysis, metering results, and the baseline research and recommendations for updates to the PSD.

[28] *Op. cit.*, Parlin, 2015
[29] *Op. cit.*, Cadmus, 2015

4.2.1 Program Reported Savings

Table 4-6 above summarizes the average claimed savings per boiler for both utilities as well as all adjustments. On average, Eversource slightly understated the energy savings in comparison to the 2015 PSD and UI overstated the savings.

A large part of the reason the UI savings are understated is that the efficiency of the installed unit was not recorded, so our calculation assumed the minimum eligible efficiency. The other difference between the two utilities is the program reported savings for the integrated domestic hot water (DHW). Eversource claimed DHW savings for all purchased boilers, while UI appears to have only claimed DHW savings for about half of the boilers installed.[30]

4.2.2 PSD Savings

The PSD savings for boilers incorporates numerous house-specific inputs, including the heated area of the home, the heating factor based on the age of the home, and the efficiencies of the baseline and installed boilers. For the most part, this information was not available in the program tracking files provided to the evaluators.[31] The inputs and defaults used to estimate the PSD savings are shown in Table 4-7.

Table 4-7: PSD Boiler Inputs

PSD Inputs	Eversource	UI	Assumptions for Units with No Data
Heated area of home	Missing for over 90% of units sold	Missing for all units sold	PSD default value of 2,000 square feet
Heating factor (based on age of home)	Missing for over 90%	Missing for all units sold	PSD default value of 33,300
Baseline efficiency	Used federal minimum of 82%		Federal minimum for PSD comparison
Efficiency of installed unit	Entered for all units	Missing for about 65%	Minimum eligible efficiency
Integrated Hot Water savings	Claimed savings for all units sold	Claimed savings for about 15% of units; unknown for most of remaining units	Assumed no integrated hot water

4.2.3 Billing Analysis

The billing analysis method for boilers is same as was used for furnaces and is described in Section 4.1.3. The formula for calculating the savings is copied here and shown as Equation 4-4.

[30] The exact number of homes is unclear due to the missing efficiency data.

[31] UI provided customer-specific information, including the efficiency of the installed unit, in a separate file from the program savings; however, the customer-specific file did not have a unique key to match it to the program savings file and the evaluators were unable to match the two files for most of the installed units.

Equation 4-4

$$ABTU_H = FLH \times Capacity_{Input} \times \left(\frac{1}{AFUE_B} - \frac{1}{AFUE_I}\right)$$

Table 4-8 shows the source of inputs for calculating the savings for boilers.

Table 4-8: Source of Inputs for Calculating Savings for Boilers

Input	Description	Source
FLH	Full Load Hours	Gas Billing Analysis
Output Capacity	Heating system output capacity	Program data
$AFUE_B$	AFUE of baseline heating system	Contractor and distributor surveys
$AFUE_I$	AFUE of installed heating system	Program data and metering

This analysis showed slightly higher consumption than the default values used in the PSD. The PSD default value for the heating factor is 66.6 MMBtu, as compared to 79.5 MMBtu from the billing analysis. The results from the billing analysis are summarized in Table 4-9 below.

Table 4-9: Boiler Full Load Hours and Normalized Annual Heating Consumption

	Full Load Hours (n=1,686)	NAHC (MMBtu) (n=1,686)
Mean	689	85.2[1]
Median	643	76.9
80% Confidence Interval[2]	+/-9	+/-1.2
Relative Precision at 80%[2]	1.3%	1.3%

[1]The heating factor is calculated by multiplying the consumption and the average installed efficiency (93.5%) from the program data.[32]
[2]The relative precision and confidence interval are due to variation in the model, not sampling error as no sampling was conducted.

4.2.4 Metered Efficiency

Metering was completed in 41 homes. At the time of meter installation, combustion efficiency tests were completed with the boiler responding to each of the heating zones and each combination of zones using a combustion analyzer. Flow measurements were taken for each zone and zone combination. Longer term metering for a 4 to 6 week period was also completed

[32] The heating factor is calculated by multiplying the consumption and the average installed efficiency (93.5%) from the program data.

at each home, with the metering occurring from January, 2017 through April, 2017. Details about the sampling are provided in Appendix J.

Two adjustments were made based on metering results:

1. Rated efficiency was adjusted to reflect the actual, achieved efficiency
2. The percent of homes with integrated hot water was adjusted based on the site visit sample and the boiler survey results

Complete data was obtained for 36 of the 41 homes.

Efficiency Adjustment

The program savings used the manufacturer specified AFUE as the installed efficiency. High efficiency boilers achieve their rated efficiencies when the flue gas temperature is lowered in the heat exchanger to the point where condensate forms. Depending on the setup or location, condensing may occur less often than expected. A recent study in Massachusetts indicated that the actual installed efficiency achieved tended to be lower on average than the rated efficiency.[33]

Key features of the metering and analysis are as follows:

- The flue and water temperatures were collected during the site visits as well as boiler runtime and spot measurements of the boiler efficiency and flow rates through the distribution system.
- The analysis was done on a house by house basis, calculating the run time and efficiency from the collected data.
- The flue temperature was the primary data point used as it is directly related to the combustion efficiency and was correlated to the spot measurements of efficiency taken during the site visits.
- The results from the meter period were normalized to the average temperature from the last 6 years.

The analysis showed that the metered efficiency was better than rated in some homes and worse in others. A minority of the boilers were not condensing properly, resulting in a net downward adjustment of about 2%, as shown in Table 4-10.

TABLE 4-10: BOILER METERING RESULTS

Average Rated Efficiency	Average Metered Efficiency	Efficiency Adjustment	Relative Precision of Metered Efficiency at 80%	Confidence Interval at 80%
94.0%	92.1%	-1.9%	1%	+/- 0.7%

[33] *Op. cit.*, Cadmus, 2015

Condensing varies with temperature. The average percent of time that the boilers were condensing is compared by outdoor temperature bin in Figure 4-4. The data show condensing topping out at about 80% of the hours around 45°F, reducing from 80% to around 60% between 45°F and 30°F, and leveling off from 30°F to 10°F. The large drop below 10°F is based on very few data points. The distribution of the metering hours by temperature bin is discussed below.

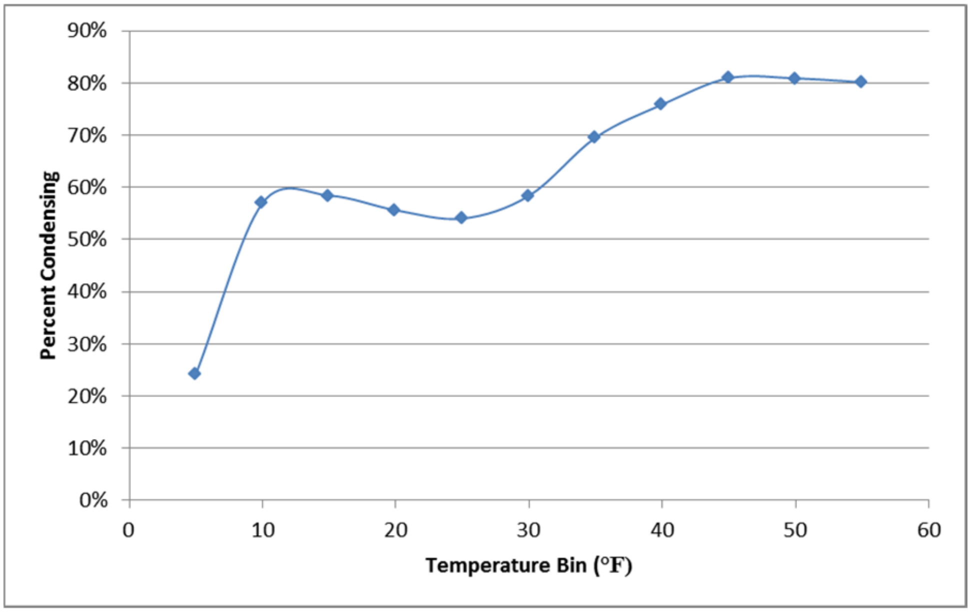

FIGURE 4-4: CONDENSING PERCENT OF HOURS BY TEMPERATURE BIN FOR BOILERS

Table 4-11 compares the Massachusetts boiler study to the Connecticut study described in this report. The Massachusetts study found a larger reduction in efficiency overall driven by a substantially larger decrease in efficiency in the 90%+ AFUE group.[34]

[34] *Ibid.*

TABLE 4-11: COMPARISON OF MA AND CT BOILER STUDIES

	MA Study	CT Study	Comments
Results: 90-94% AFUE	80% with limited condensing; 5% average drop in AFUE	40% with limited condensing; no average drop in AFUE	CT study showed some units were operating above the rated efficiency, which partially mitigated the effects of those with limited condensing; Could be variety of reasons for differences, such as climate differences or installation practices
Sample size in final analysis	38	36	About the same
Length of metering	Most of the heating season	4-6 weeks	CT metering period had few data points during very cold temperatures (<10°F); see discussion below
Method	Compared supply/return water temperatures	Compared supply/return water temperatures	Measuring water temperature has higher measurement error; Water temperature less reliable indicator of condensing
		Measured flue gas temperature	Fewer measurements and less error; Flue gas temperature gives clearer signal of condensing

The Evaluation Team collected sufficient information to use two methods to measure condensing boilers, i.e., by measuring supply and return temperature and measuring the flue gas temperature. We were unable to produce meaningful results using the method from the Massachusetts study, possibly due to the small temperature differences between the supply and return temperatures and the potential measurement error.[35]

Measuring flue gas temperature produced more reliable results. The dew point of combusted natural gas is 134° F assuming 15% excess air. Condensate occurs when the flue gas temperature is below the dew point. As the flue gas method provides a direct measurement of when condensing occurring, it was more straightforward, required fewer measurements, and the results are more reliable.

A key part of boiler metering is ensuring that a wide range of outdoor temperatures is covered. In the Massachusetts study, the metering was conducted over longer time period, whereas time frame for our study was more compressed. To investigate the possible impacts of this difference, we analyzed the time period by number of hours in the temperature bins and number of homes included in the analysis with hours in the temperature bin. This information was compared to the normalized percent of annual hours in these temperature bins, as shown in Table 4-12.

[35] The measurement error has two components. First, it is necessary to measure the temperature of the outside of the pipe by an attached sensor that relies on a thermal bond. It is not a direct measurement of the return water itself. Second, the reaction time of the sensor is dependent on both the sensor itself and the effectiveness of the thermal bond. In addition, the return water temperature is an indirect indicator of condensing occurring in the system.

This analysis indicates that the shorter term metering adequately covered a wide range of temperatures, as shown the following:

- At temperatures between 15°F and 50°F (accounting for over 75% of the annual heating hours), a large majority of homes (as least 30) are in the analysis and there are a substantial number of hours in each temperature bin
- Only 3 homes had hours at temperatures of 10°F and below, but less than 1% of the winter hours fall into this category
- At the warmest temperatures (60°F and above), there are also few homes with metering, but the boilers do not run much at these temperatures (4% of the hours)

As the results presented in the report are weather-normalized, the analysis takes into account the changes in condensing over a wide range of temperatures.

TABLE 4-12: METERED HOURS BY TEMPERATURE BIN FOR BOILERS

Temperature Bin (°F)	Total Hours	Hours Boiler On	Percent of Hours Boiler On	Number of Homes	Percent of Winter Hours in Temperature Bin[1]
< 10°F	18	10	54%	3	0.8%
10°F	322	194	60%	24	1.3%
15°F	867	464	54%	33	2.6%
20°F	1554	695	45%	33	4.6%
25°F	2527	1025	41%	35	7.0%
30°F	2879	971	34%	36	11.1%
35°F	2838	862	30%	36	15.1%
40°F	2012	524	26%	34	13.4%
45°F	1290	242	19%	30	12.4%
50°F	1064	196	18%	30	10.7%
55°F	506	67	13%	24	8.7%
60°F	102	9	9%	16	6.2%
>60°F	36	2	4%	6	5.9%

[1]Based on the average of the temperature data for 2011-2016 from the Hartford weather station.

Incidence of Integrated Hot Water

Savings from integrated hot water were incorporated into the program reported savings for boilers, as eligible boilers can also provide domestic hot water. Eversource appears to assume that all boilers have integrated hot water. The evaluators were unable to determine the assumption used by UI for a large majority of the purchases.

The Evaluation Team collected information about the incidence of integrated hot water during the site visits and through the detailed customer survey. The results from these sources indicate that approximately 90% of boilers have integrated hot water. The integrated hot water portion of the boiler savings were multiplied by a factor of 0.9 to account for the homes without integrated hot water.

4.2.5 Baseline Adjustment

For the program claimed savings, the efficiency of the baseline heating equipment was assumed to be the federal minimum standard (82%). However, the market baseline as determined through the surveys of contractors and distributors suggests the baseline efficiency is higher.

The method for determining the baseline is described in Section 4.6. Table 4-13 shows the reported sales of boilers that were not part of the program, by efficiency level. To calculate the average efficiency, the midpoint of each efficiency bin was used.[36] The survey results were weighted based on the number of rebates for each respondent. The average of the contractor and distributor responses indicates a baseline AFUE of 85%.

TABLE 4-13: BOILER BASELINE SURVEY RESULTS

	Number of Respondents	Percent in each Efficiency Category		Average Efficiency
		82-84%	85-89%	
Contractors	37	57%	43%	84.5%
Weighted Contractors	37	58%	42%	84.5%
Distributors	19	40%	60%	85.0%
Weighted Distributors	19	28%	72%	85.6%

4.2.6 Recommended Changes to the PSD

As this program is an upstream program and it is not always possible to collect the detailed information about the homes required for the PSD calculations, we recommend using default values for the PSD inputs. The 2017 PSD has an alternative method to calculate savings using a baseline efficiency of 85% and making an adjustment to the efficiency (AFUE) of the installed equipment. These adjustments are consistent with the findings of this evaluation and this alternative PSD method is likely to produce savings that are close to the evaluated savings. Table 4-14 below shows the recommended adjustments to the PSD.

[36] Due to the limited number of models available in the 86% to 89% range, the midpoint for the 86-89% bin was set at 86%.

TABLE 4-14: RECOMMENDED CHANGES TO THE PSD FOR BOILERS

Input	2017 PSD Standard Method[1]	2017 PSD Alternative Method[2]	Recommended Inputs	Discussion
Baseline AFUE	82%	85%	85%	Market baseline rather than federal minimum; updated in alternative method in the 2017 PSD
Efficient AFUE[3]	Rated efficiency from program tracking	Use regression to adjust installed efficiency	Adjust rated efficiency downward by 2%	UI's tracking needs to be improved to ensure this critical input is available for all purchases Efficiency adjustment from site visit metering; adjustment made in PSD 2017 alternative method
Heating factor (Btu/ft^2) x average area heated by boiler (ft^2)	66.6 MMBtu/yr	92.8 MMBtu/yr	85.2 MMBtu/yr	Using billing analysis annual consumption results rather than default inputs.
Annual hot water load	11.2 MMBtu	11.2 MMBtu	No change	Verified by the metering of heat pump water heaters

[1] *Connecticut Program Savings Document*, 12th Edition for 2017 Program Year, UIL Holdings Corporation and Eversource Energy: page 169 for boilers

[2] *Connecticut Program Savings Document*, 12th Edition for 2017 Program Year, UIL Holdings Corporation and Eversource Energy: page 175 for alternative boiler assumptions

[3]The efficiency of the installed equipment was often missing from UI's program tracking data as provided to the evaluators. This input is critical to the calculation of savings and needs to be recorded.

4.3 ECM Circulating Pumps

The realization rate for the annual kWh savings is 24%, comparing the evaluated savings (68 kWh per year) to the program reported savings (285 kWh). The large reduction in savings is almost entirely due to a decrease in annual hours based on the metering results. The metering results also greatly decreased the winter peak coincidence factor as shown in Figure 4-5, decreasing the winter peak kW savings from 0.056 to 0.024 and resulting in a realization rate of 44%. Table 4-15 shows an overview of ECM circulating pump kWh and kW savings.

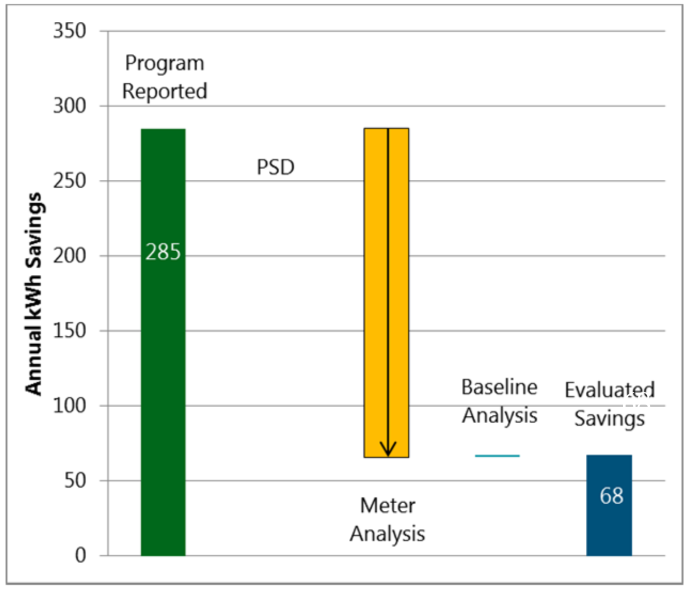

FIGURE 4-5: CIRCULATING PUMP KWH SAVINGS PER UNIT

Table 4-15 summarizes the adjustments to the savings for boiler circulating pumps.

TABLE 4-15: OVERVIEW OF ADJUSTMENTS TO BOILER CIRCULATING PUMP SAVINGS

	Annual kWh	Adjustment (kWh)	Peak kW	Adjustment (kW)	Discussion
Program Reported Savings	285		0.056		Average savings per unit
2015 PSD Savings	285	0	0.056	0	PSD deemed savings
Metered Runtime	66	-219	0.024	-0.032	Calculated from metering and weather normalized
Baseline and Efficient Pump kW	68	2	0.024	0.000	Baseline kW from distributor and contractor surveys. Efficient kW from measurement of installed pumps
Realization Rate	24%		44%		

The relative precision of the seasonal winter peak kW reduction is 12% at the 80% confidence level. For all three measures with seasonal winter peak kW reduction, the relative precision is 6%, which meets the ISO-NE Forward Capacity requirement for stratified samples. Details on the calculation of the seasonal peak kW are provided in Appendix M.

Each adjustment is described in the sections below.

4.3.1 Program Reported and PSD Savings

The program reported savings match the 2015 PSD savings for boiler circulating pumps. The PSD energy and peak demand savings are deemed based on a prior evaluation of circulator pumps conducted in Massachusetts.[37]

4.3.2 Metered Savings

The Impact Evaluation Team conducted site inspection and metering of 53 boiler circulator pumps to calculate the average annual run time and winter coincidence factor.[38] The metering occurred at 29 homes and included 53 pumps (1.8 pumps per home).[39] The sample design is described in Appendix J.

Two methods of data collection were employed to calculate the annual hours of the pumps:

1. on/off data using mag loggers that measure change in magnetic fields (30 pumps)
2. temperature sensors on the pipes to determine when water was flowing (23 pumps)

For the pumps with temperature sensors only, criteria were established to determine when the pump was running using 11 homes with both on/off and temperature sensor data, as explained below.

- If the water temperature is high (over 90 °F), the pump is running.
- If the water temperature is increasing, the pump is running.
- If the water temperature is decreasing slightly (by less 1.25 °F), the pump is running, as the boiler cycles off or modulates down periodically but the pump will run as long as the thermostat is still calling for heat

The above criteria, on average, provided runtime that was less than 2% different than the on/off metering of the 11 of the pumps with both sets of data. Numerous other criteria were tested and these criteria provided the best match between the two data sets.

The runtime results for both of these methods were normalized to typical winter temperatures using the temperature data from the last 6 years. Table 4-16 presents the annual run hours and seasonal peak kW below[40] Details regarding the calculation of the seasonal peak kW are provided in Appendix M.

[37] The Cadmus Group, Inc. (2012) Impact Evaluation of the 2011-2012 ECM Circulator Pump Pilot Program. Prepared for the electric and Gas Program Administrators of Massachusetts. This is the reference provided in the 2015 CT Program Savings Documentation, page 171.

[38] In some homes, both the boilers and boiler circulating pumps were metered. To meet the target sample size, additional metering of boiler circulating pumps was conducted. More information is provided in Appendix J.

[39] The sample was stratified by homes with one pump and homes with multiple pumps. As the sample matched the population well on this key metric (1.8 pumps per home in the sample as compared to about 2 pumps per home in the population), it was not necessary to weight the results.

[40] Two pumps that were used for the domestic hot water loop were excluded from the analysis, which has little impact on the evaluated savings.

TABLE 4-16: BOILER CIRCULATING PUMP METERING RESULTS

	Annual Hours	Seasonal Winter Peak kW
Mean	1172	0.024
Median	1169	0.024
80% Confidence Interval	+/-143 hours	+/-0.003
Relative Precision at 80%	12%	12%

The annual hours from this analysis are comparable to the average of about 700 FLH for the boilers, as shown in Table 4-8 above. The annual operating hours of the circulator pumps are expected to be higher than the FLH of the boilers, as boilers cycle off at a high temperature setting and back on when a low temperature setting is reached, while the pumps continue to run until the call for heat is satisfied. For most of the heating season, on/off cycling or modulating during heat calls is frequent as the boilers have ample excess capacity.

These results are much lower than the implied annual hours of 5,089 based on the kWh and kW savings claimed in the PSD. The PSD values appear to be based on continuous runtime during the winter months, which does not match what was found at any of the metered locations.

4.3.3 Baseline and Efficient kW

In the PSD, the connected load kW savings are specified at 0.056 kW, but the baseline and efficient kW values are not explicitly stated. The evaluated connected load kW savings are approximately the same at 0.058.

As is consistent with lost opportunity measures, the baseline is a standard efficiency, new circulating pump. The evaluated baseline is a market baseline as determined through the surveys of contractors and distributors.

The method for determining the baseline is described in Section 4.6. The baseline approach for the circulating pumps varied from other measures in that the contractors and distributors were asked to both specify the percent of circulating pumps by efficiency category *and also to provide the three most commonly sold models*. The Evaluation Team used the specifications of the provided models to determine the average baseline kW for each category of pump.

The weighted average baseline kW is 0.077. More detail is provided in Table 4-17.

Table 4-17: Baseline Survey Results for Boiler Circulating Pumps

	Percent in each Category	
	Single Speed Pump	Multi-Speed Pump
Contractors[1]	76%	24%
Weighted Contractors	59%	41%
Distributors[1]	71%	29%
Weighted Distributors	90%	10%
Average Weighted Contractors & Distributors	83%	17%
Baseline kW	0.077	0.074
Efficient kW	0.019	0.019
kW Savings	0.058	0.055

The efficient kW was calculated based on spot measurements of the power draw of 41 ECM circulator pumps. For pumps with adjustable speed and multiple zones, multiple measurements were taken while running with each different combination of zones. These different spot measurements were averaged for any pump with multiple operation modes to calculate an average kW for each ECM pump. The kW per pump was averaged to obtain the ECM circulator pump power of 0.019 kW.

In the PSD, this measure is characterized this measure as retrofit. The Evaluation Team did not find evidence that contractors are replacing circulating pumps prior to the time of failure.[41] However, the evaluated baseline is close to the PSD baseline, suggesting that the distinction between retrofit and lost opportunity measures does not have a major impact on the savings.

4.3.4 Recommended Changes to the PSD

The 2017 PSD provides deemed savings for this measure. No changes to this measure characterization were made between the 2015 and 2017 PSDs. The PSD specifies that boiler circulating pumps are a retrofit measure. The Evaluation Team did not find evidence to support this assumption, as discussed in Section 4.3.3 above. We recommend that the deemed savings be updated to match the evaluation results, as shown in Table 4-18.

[41] The only possible retrofit application could be replacing pumps when a new boiler is installed. However, in our 40 site visits to meter boilers, 24 homes did not have new circulating pumps, suggesting that pump retrofits are not consistently installed with a new boiler.

TABLE 4-18: RECOMMENDED CHANGES TO THE PSD FOR BOILER CIRCULATING PUMPS

	Annual kWh	Seasonal Winter Peak kW	Seasonal Summer Peak kW
2017 PSD	285	0.056	0.000
Evaluated	68	0.024	0.000

4.4 Heat Pump Water Heaters

The realization rate for the annual overall energy savings is 106%, as the savings from metering are slightly higher than the deemed energy savings from the 2015 PSD as shown in Figure 4-6. However, the PSD savings assume the baseline is an electric water heater, while the customer survey indicated that the baseline is a mix of electric resistance and fossil fuels. Thus, some of the electric savings have been converted to fossil fuel MMBtu savings. Table 4-19 provides an overview of adjustments to the heat pump water heater kWh and kW savings.

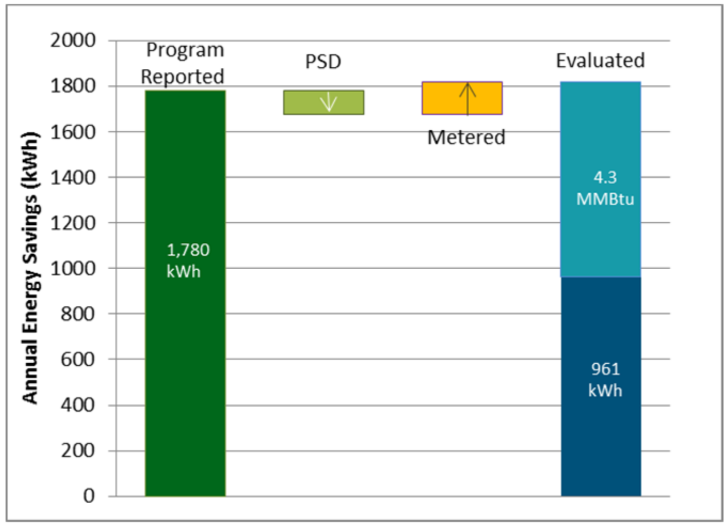

FIGURE 4-6: HPWH KWH SAVINGS PER UNIT

TABLE 4-19: OVERVIEW OF ADJUSTMENTS TO HEAT PUMP WATER HEATER SAVINGS

	Annual kWh	Adjustment (kWh)	Fossil Fuel Savings (MMBtu)	Discussion
Average Program Reported Savings	1,780		0.0	Average savings per unit; UI and Eversource program reported savings were very close No fossil fuel savings were claimed
PSD Savings	1,675	-105	0.0	PSD deemed savings
Metered Savings	1,818	+143	0.0	Estimated from metering, adjusted for occupancy and use of modes
Evaluated Savings after Baseline Adjustment	961	-857	+4.3	Baseline as determined from customer survey, taking into account the fossil fuel alternatives considered

The realization rates for the winter and summer peak kW reduction are 77% and 100% respectively. The verification of the seasonal winter and summer peak kW reduction meets the ISO-NE Forward Capacity Market standards. Additional detail on the calculation of the seasonal peak kW reduction is provided in Appendix M.

Table 4-20 compares heat pump water reported and evaluated savings, and the adjustments are described in the following sections.

TABLE 4-20: COMPARISON OF SAVINGS FOR HEAT PUMP WATER HEATERS

	Annual kWh	Seasonal Winter Peak kW	Seasonal Summer kW	MMBtu Savings
Program Reported	1,780	0.210	0.174	0.0
2015 PSD[1]	1,675	0.201	0.171	0.0
Metered	1,818	0.243	0.296	N/A
Evaluated	961	0.134	0.175	4.3
RR	54% +/- 6%	77% +/- 7%	100% +/- 7%	N/A
Relative Precision at 80% Confidence Level	11%	9%	7%	6%

[1]*Connecticut Program Savings Document*, 10th Edition for 2015 Program Year, the United Illuminating Company, page 275

The verification of the seasonal winter and summer peak kW reduction meets the ISO-NE Forward Capacity standards. Additional detail on the calculation of the seasonal peak kW reduction is provided in Appendix M.

4.4.1 Program Reported Savings

The average annual program reported savings from January 2014 through July 2016 are shown in Table 4-21 below. On average, Eversource overstated the energy savings by 6% in comparison to the 2015 PSD and UI overstated the savings by 5%.

TABLE 4-21: PROGRAM REPORTED SAVINGS FOR HEAT PUMP WATER HEATERS

	Eversource			United Illuminating		
	Program Reported (MWh)	PSD (MWh)	Percent Difference	Program Reported (MWh)	PSD (MWh)	Percent Difference
Heat Pump Water Heater	5,486	5,152	**6%**	1,025	973	**5%**

4.4.2 PSD Savings

The PSD deemed savings for residential heat pump water heaters are provided in Table 4-20. The values are calculated in the PSD and the same values are applied to every water heater. No MMBtu savings for fossil fuels were claimed. The 2017 PSD values were also provided in Table 4-22 for comparison purposes.

TABLE 4-22: PSD SAVINGS FOR HEAT PUMP WATER HEATERS

	Annual kWh	Winter Peak kW	Summer kW	Fossil Fuel MMBtu Savings
2015 Heat Pump Water Heaters[1]	1,675	0.203	0.171	0.0
2017 Heat Pump Water Heaters[2]	2,112	0.244	0.185	0.0

[1]*Connecticut Program Savings Document*, 10th Edition for 2015 Program Year, the United Illuminating Company, page 275
[2]*Connecticut Program Savings Document*, 12th Edition for 2017 Program Year, the United Illuminating Company, page 299

4.4.3 Metered Savings

The Evaluation Team conducted metering during the site visit of 41 heat pump water heaters to estimate the savings in the field. Metering was conducted from November 2016 through April 2017. Details on the sampling are provided in Appendix J.

The kW of the heat pump water heaters was directly metered in the home in two stages:

1. In **efficient mode** (typically hybrid[42] or heat pump), as found when we arrived at the site, for three to four weeks
2. Switched to **electric resistance** mode for two weeks

The savings were calculated by comparing the operation of the heat pump in the two modes (efficient and electric resistance). After switching to electric resistance mode, some models were designed to return automatically to hybrid mode after two days. When this issue was identified, homeowners were alerted and requested to switch the mode again. However, a consequence was that metering was collected for a few homes in three modes: heat pump, hybrid and electric resistance. A second consequence was that four homes had a very short duration of metering in electric resistance modes (two days), and these homes were eliminated. The final analysis was based on 36 homes with three homes metered in both hybrid and heat pump modes, for a total of 39.

Occupancy and the mode (hybrid and heat pump) were the two most critical factors affecting the savings. *Post hoc* stratification using the customer survey data was conducted to expand the results from the site visits to the larger population.[43] The key components of the calculation of metered savings are summarized in Table 4-23.

[42] In heat pump mode, the electric resistance unit does not turn on at any time and the water heater runs only on the heat pump. In hybrid mode, the water heater runs in heat pump mode except if the tank is depleted.
[43] The Web-based survey was open to all customers with a heat pump water heater and contact information, resulting in 100 completed surveys.

TABLE 4-23: COMPONENTS OF CALCULATING THE HEAT PUMP WATER SAVINGS

Input	Source	Comments
Annual load in electric resistance mode	Meter data	Metering of the heat pump in electric resistance mode, extrapolated to a year[1]
Annual load in efficient mode	Meter data	Metering of the heat pump using the mode set by the homeowner, extrapolated to a year
Occupancy Adjustment	Customer survey	Incidence of homes with 1 to 2 occupants and with 3 or more occupants from customer survey; *post hoc* stratification to adjust metered savings
Mode Adjustment	Customer survey	Determine number of weeks in each mode from customer survey; *post hoc* stratification to adjust metered savings

1 The savings were annualized by calculating the savings per day for the metering period and multiplying it by 365 days.

Heat pump water heaters can be operated in heat pump, hybrid, high-demand, electric and vacation modes. As some customers with heat pump water heaters change the mode during the year, survey respondents were asked to estimate the number of weeks per year in each of the modes. Figure 4-7 provides a summary of the weeks in each mode as reported by the survey respondents. Approximately 50% of the respondents reported running their heat pump water in a single mode, which is typically either heat pump or hybrid mode.

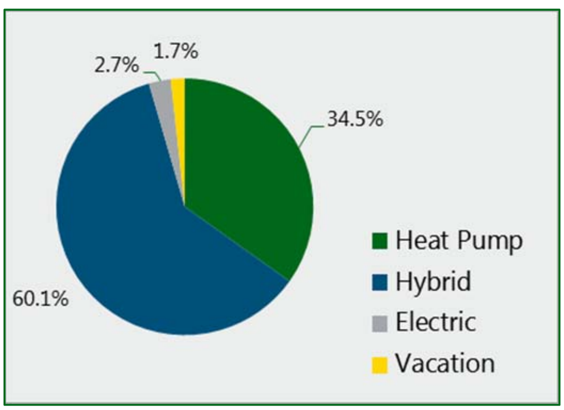

FIGURE 4-7: MODES USED BY HEAT PUMP WATER HEATER SURVEY RESPONDENTS[44]

Savings from heat pump water heaters vary with the amount of hot water used. Occupancy was used as a proxy for hot water consumption. The savings from the metered homes were adjusted to reflect the population by using the survey results. Table 4-24 provides a summary of the occupancy levels reported by the site visit respondents compared to the surveyed population.[45]

[44] High demand mode was such a small percent of the weeks per year (less than 1%) that was not included in this graph.
[45] Site visit respondents are included in the survey respondents.

TABLE 4-24: OCCUPANCY SURVEY RESPONSES FOR HEAT PUMP WATER HEATERS

Occupancy Group	Definition	Metered Homes (n=40)	Survey Respondents (n=100)[1]
Small	1-2 occupants	55%	60%
Large	3 or more occupants	45%	40%

[1] Site visit respondents are included in the survey respondents.

The location of the heat pump water heater in heated or unheated space, as well as the size of the room, could affect performance. A large majority of the installations were in unheated or semi-conditioned spaces, mostly in the basement. Some of the findings from the metering are discussed below.

- The average coefficient of performance (COP), as determined from the metered data and weighted to the population, is 2.54.
- Of the metered homes, six (6) heat pump water heaters were installed in heated areas and the remaining 33 were installed in unheated or semi-conditioned space (unheated basements).
- The average COP for the water heaters located in heated spaces was 3.3, as compared to 2.6 for heaters in the unheated/semi-conditioned spaces; this difference is statistically significant at the 90% confidence interval.
- Five (5) of the metered units were installed in rooms smaller than the recommendation 100 square feet; the difference in the average COP was not statistically significant.

As metering was conducted from November, 2016 to April, 2017, the estimation of savings does not account for potential seasonal effects of improved performance during the warmest part of the year.

One concern about heat pump water heaters is that the temperature of the ambient air around the heat pump water heaters will be lower due to the operation of the heat pump, which may require replacement heat from the central heating system. Thus, there may be an interactive effect and some of the savings from the heat pump water heater could be offset by the increased heating system use. These interactive effects are less likely to occur when the heat pump water heater is located in an unheated basement, and over 75% of the survey respondents identified an unheated basement as the location of the heat pump water heater.

As part of the metering process, the kW draw of the central heating system was also metered. Additional analysis was conducted to assess changes in use of the central heating system for the units installed in unheated areas.[46] As the efficient and baseline (electric resistance) metering periods were consecutive rather than concurrent, the weather conditions were different between the two periods. Given the small sample size and variability of weather conditions

[46] A similar analysis was not conducted for the units in heating areas due to the small sample size (6 homes).

during the two metering periods, these results are suggestive rather than definitive. The issues with the analytical approach and resolutions are explained in Table 4-25 below.

TABLE 4-25: ANALYTICAL APPROACH TO ASSESS HPWH/HEATING SYSTEM INTERACTIVE EFFECTS

Issue	Explanation	Effect on Analysis	Resolution
Differences in temperatures during metering periods	The temperatures during the metering in baseline mode were colder than the efficient mode in most cases	Expect higher heating system use in efficient mode, but baseline period is colder	Assume 10% of extra use is due to colder temperatures
Warmer temperatures during metering	A few homes were completed in the Spring and average temperatures were above 50°F	Heating system would not be expected to operate during the metering period	Removed 3 homes from analysis
Heat system not used	Metering indicated heating system was not used in some homes	No heating use in metering period	Removed 2 homes from analysis

The approach was to determine the proportion of homes with additional heating system use that could be associated with replacement heat required due to the operation of the heat pump water heater. This analysis was based on two components:

1. The relationship between the average outdoor air temperature and average ambient air temperature near the water heater
2. The percent of time the heating system was running during the two metering periods

This strategy provides an estimate of the proportion of homes with the potential for extra heating use due to the heat pump water heater. It does not provide an estimate of the magnitude of the additional heating system use.

If the average outdoor air temperature between the two metering periods (efficient and baseline) was within 3°F, the metering periods were considered to be similar and any increase in the period of time the heating system was operating was assumed to be due to the need to replace the heat removed by the heat pump water heater. If the average outdoor air temperature during the baseline metering was more than 3°F, 10% extra heating system use during the baseline period was allowed to account for the colder weather. Table 4-26 provides a summary of heat pump water heater and heating system interactive effects.

TABLE 4-26: SUMMARY OF HPWH/HEATING SYSTEM INTERACTIVE EFFECTS

Average Outdoor Air Temperature	Threshold for Assuming Heat was Replaced	Number of Homes		Percent of Homes
		Total	Require Extra Heating[1]	
Efficient & baseline metering periods **within 3°F**	% heating system on: Efficient > Baseline	16	9	56%
Baseline more than **3°F colder** than efficient	% heating system on: Efficient > (Baseline + 10%)	11	6	55%

[1] The difference in ambient temperature between the baseline and efficiency periods remained within a 3°F range or increased for all of these homes, suggesting that the heating system could be operating to replace the heat.

This result suggests that about half the homes have additional heating system use to replace the heat displaced by the heat pump water heater. Additional research is needed to develop a more accurate estimate.

In addition, there is some evidence that there could be additional savings from lower dehumidifier use, as investigated through the customer survey:

- 57% of the surveyed customers reported that they have a dehumidifier
- 61% of those with dehumidifiers reported that they use the dehumidifier a lot less or somewhat less since the HPWH was installed
- Only 1% (one respondent) reported that s/he uses the dehumidifier more since the HPWH was installed

Metering of the dehumidifiers would be required to develop an estimate of these savings and additional research is needed to quantify these savings.

4.4.4 Baseline Adjustment

The baseline fuel and water heater type were determined from the customer survey, according to the systems the customer considered and the availability of certain fuels. Figure 4-8 illustrates how the baseline was determined. If the customer did not identify any alternative systems considered, the default was defined as follows:

- natural gas water heater (if natural gas is available)[47]
- previous water heater and fuel types (replacement and no natural gas)
- electric resistance (new installation and no natural gas)

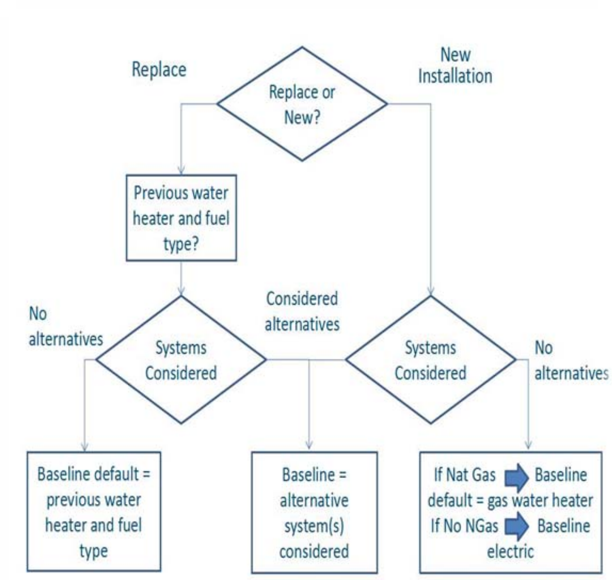

FIGURE 4-8: HPWH BASELINE APPROACH

The results of this analysis show that electric resistance or on demand constitute the largest part of the baseline (74%) and fossil fuel options account for the remainder (26%) as shown in Table 4-27. The fossil fuel savings were estimated using average efficiencies for the type of unit based on a review of available units.

TABLE 4-27: CUSTOMER BASELINE FUEL TYPES FOR HEAT PUMP WATER HEATERS

Fuel[1]	Water Heater	Baseline Percent (n=100)	Baseline Efficiency
Electricity	Stand Alone/On Demand	74%	98%
Oil	Stand Alone/Integrated	13%	65%
Propane	On Demand	7%	87%
Propane	Stand Alone	6%	65%

[1]A few respondents reported that they considered installing solar hot water systems with electric or gas back up. Due to the high initial cost of these systems, these responses were excluded from the analysis.

The baseline-adjusted savings were calculated using two inputs: the savings in comparison to electric resistance heat and the electric use associated with installing a heat pump water heater instead of a fossil fuel heater. Table 4-28 provides the baseline adjustments.

[47] Less than 3% of survey respondents had natural gas available. This result may not properly reflect the UI service territory. UI was not able to provide us with contact information for the survey, so all responses reflect the Eversource service territory. As Eversource has more territory without access to natural gas than UI, these results may be underestimating natural gas in the baseline.

Table 4-28: Baseline Adjustments for Heat Pump Water Heaters

Baseline Fuel Type	Percent of Homes	kWh Savings	Fossil Fuel MMBtu	Notes
Electric	74%	1,818	0	Electric resistance and on demand
Fossil Fuel	26%	(1,418)	16.4	Extra electric use from installation of HPWH instead of fossil fuel unit Efficiencies for MMBtu savings based on types of units considered and manufacturers' data
Weighted Average		961	4.3	

4.4.5 Recommended Changes to the PSD

The PSD provides the deemed savings for this measure. We recommend that the deemed savings be updated to match the evaluation results. Table 4-29 shows the recommended changes using either a baseline electric or fossil fuel water heater.

Table 4-29: Recommended Changes to the PSD for HPWH Energy Savings

		Recommended Changes			
	2017 PSD[1]	Electric Baseline	Propane[2]	Oil[2]	Reason
Gallons per year(GPY)	19,839	15,415	15,415	15,415	Metering
$T_{dhw} – T_{aiw}$ (ΔT)	68	75	75	75	Metering/site visit measurement
Baseline Energy Factor (EF_b)	0.945	0.95	N/A	N/A	Manufacturer's specs
Efficient Energy Factor (EF_i)	2.68 or manufacturer specifications	2.46 or manufacturer specifications	2.46 or manufacturer specifications	2.46 or manufacturer specifications	Metering
P (heating penalty and recovery adjustment)	0.90	1.00	N/A	N/A	PSD assumption; no evidence to support
Annual kWh Savings	2,112	1,818	-1,418	-1,418	Calculated from above inputs[3]
Fossil Fuel Energy Factor (EF_{ff})	N/A	N/A	0.77a	0.65	Average of available units
Fossil Fuel Adjustment Factor (AF_{ff})	N/A	N/A	1.24	1.24	Adjustment for extra use
Annual MMBtu Savings	0	0	14.9	17.7	

[1]*Connecticut Program Savings Document*, 12th Edition for 2017 Program Year, the United Illuminating Company, page 300
[2] The calculations for the fossil fuel MMBtu savings and kWh extra use are given below.
[3] The kWh savings were estimated directly from the metering. The inputs into the PSD calculations were adjusted to match the metered energy savings as closely as possible.
a The EF for propane is a blended rate between on demand and stand-alone units.

Table 4-30 lists the recommended changes for the winter and summer kW peak reduction.[48]

TABLE 4-30: RECOMMENDED CHANGES TO THE PSD FOR HPWH SEASONAL PEAK DEMAND REDUCTION

		Recommended Changes			
	2017 PSD[1]	Electric Baseline	Propane[2]	Oil[2]	Reason
Gallons per hour (GPH)	1.96	1.98 Winter/ 2.50 Summer	1.98 Winter/ 2.50 Summer	1.98 Winter/ 2.50 Summer	Metering/seasonal adjustment
$T_{dhw} - T_{aiw}$ (ΔT)	81 Winter/ 60 Summer	75	75	75	Metering/site visit measurement
Baseline Energy Factor (EF_b)	0.945	0.95	N/A	N/A	Manufacturer's specs
Efficient Energy Factor (EF_i)	2.68 or manufacturer specifications	2.46 or manufacturer specifications	2.46 or manufacturer specifications	2.46 or manufacturer specifications	Metering
P (heating penalty and recovery adjustment)	0.90	1.00	N/A	N/A	PSD assumption; no evidence to support
Seasonal Peak kW Reduction	.244 Winter/ .185 Summer	.234 Winter/ .296 Summer	-0.151 Winter/ -0.169 Summer	-0.151 Winter/ -0.169 Summer	Calculated from above inputs[3]
Fossil Fuel Adjustment Factor (AF_{ff})	N/A	N/A	-1.03 Winter/ -0.91 Summer	1.03 Winter/ 0.91 Summer	Adjusts for increased electric use

[1]*Connecticut Program Savings Document*, 12th Edition for 2017 Program Year, the United Illuminating Company, page 300
[2] The calculations for the fossil fuel MMBtu savings and kWh extra use are given below.
[3] The seasonal peak kW reduction was estimated directly from the metering. The inputs into the PSD calculations were adjusted to match the metered savings as closely as possible.
a The EF for propane is a blended rate between on demand and stand-alone units.

The calculations for the MMBtu savings and the extra electric use associated with installations in homes with a fossil fuel baseline are shown in Equations 4-5 through Equation 4-7 below.

EQUATION 4-5

$$MMBtu\ Savings = \frac{GPY\ x\ \Delta T\ x\ 8.3\,\frac{lbs}{gal}\ x\ 1.0\ \frac{Btu}{°F}\ /\ EF_{FF}}{3{,}412\ Btu/kWh}$$

[48] The ISO-NE Forward Capacity Market winter peak period is from 5:00 PM to 7:00 PM in December and January and the summer peak period is from 1:00 PM to 5:00 PM in June, July and August. The FCM also has the option of bidding in savings for the seasonal peak, which is based on kW that can be removed from the grid at specific hours when the grid is most constrained. This value was not calculated as there are currently no provisions in the program to control the heat pump water heater loads.

EQUATION 4-6

$$kWh\ Extra\ Use_{FF} = \frac{GPY\ x\ \Delta T\ x\ 8.3\frac{lbs}{gal}\ x\ 1.0\ \frac{Btu}{°F}\ x\ AF_{ff} /\ EF_i}{3{,}412\ Btu/kWh}$$

EQUATION 4-7

$$Seasonal\ Peak\ kW\ Extra\ Use_{FF} = \frac{GPH\ x\ \Delta T\ x\ 8.3\frac{lbs}{gal}\ x\ 1.0\ \frac{Btu}{°F}\ x\ AF_{ff} /\ EF_i}{3{,}412\ Btu/kWh}$$

The blended baseline accounts for the incidence of baseline water heaters from the homeowner survey.[49] The blended baseline can be used when the fuel type of the baseline water heater is unknown. To calculate savings from the blended baseline, first calculate the savings from the electric and fossil fuel baselines using the inputs in Tables 4-28 and 4-29 and Equations 4-5 to 4-7, and then combine the results as shown in Equations 4-8 to 4-10.

EQUATION 4-8

$$Annual\ kWh\ Savings_{blended} = 0.74\ x\ kWhSavings\ _{electric} - 0.26\ x\ kWhExtraUse_{fossil\ fuels}$$

EQUATION 4-9

$$Annual\ Peak\ kW\ Savings_{blended} = 0.74\ x\ kWSavings\ _{electric} - 0.26\ x\ kWExtraUse_{fossil\ fuels}$$

EQUATION 4-10

$$\begin{aligned} &Annual\ MMBtu\ Savings_{blended} \\ &\quad = 0.74\ x\ 0\ MMBtuSavings\ _{electric} + 0.13\ x\ MMBtuSavings_{propane} \\ &\quad + 0.13\ x\ MMBtuSavings_{oil} \end{aligned}$$

Please note that there are no MMBtu savings for the electric baseline.

[49] Assuming that the prior water heater is the baseline may not be an accurate assessment of the baseline. For example, a homeowner with an oil integrated water tank that failed may well decide to replace it with an electric resistance heater. The survey investigated the different water heaters considered by the homeowners and incorporated these findings into the baseline.

4.5 ECM Furnace Fans

The overall realization rate for the ECM furnace fans is 125%, comparing the evaluated results to the program reported savings. Figure 4-7 provides per unit kWh claimed and evaluated savings for furnance fans. The analysis was done using AMI data and showed an increase in the winter savings and summer savings in comparison to the PSD. One of the primary reasons is that UI and Eversource are only claiming the winter savings, which overlooks summer savings from central air conditioning.

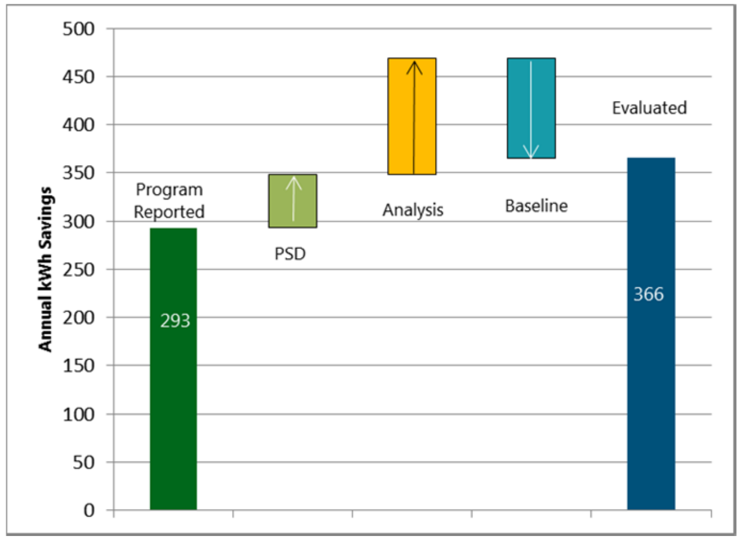

FIGURE 4-7: FURNACE FAN KWH SAVINGS PER UNIT

The adjustments are listed in Table 4-31.

TABLE 4-31: OVERVIEW OF ADJUSTMENTS TO ECM FURNACE FAN SAVINGS

Reason for Adjustment	Annual kWh			Adjustment (kWh)	Discussion
	Winter kWh	Summer kWh	Total kWh		
Average Program Reported Savings	293	0	293		Deemed savings, no summer savings claimed
2015/2017 PSD Savings	293	55	348	55	PSD deemed savings, assuming central A/C in 60% of homes
Billing Analysis	411	57	469	121	Adjusted savings based on fan kW and run hours
Evaluated savings after Baseline Adjustment	321	45	366	-103	Baseline as determined from contractor and distributor surveys

The program reported savings, PSD savings and realization rates are presented in Table 4-32.

TABLE 4-32: COMPARISON OF SAVINGS FOR FURNACE FANS

	Winter kWh	Summer kWh	Total Annual kWh	Seasonal Winter Peak kW	Seasonal Summer kW
Program Reported	293	0	293	0.090	0.000
PSD[1]	293	55	348	0.090	0.720
Evaluated	321	45	366	0.118	0.065
Realization Rate	100%	N/A	125%	131%	N/A

[1]*Connecticut Program Savings Document*, 10th Edition for 2015 Program Year, the United Illuminating Company, page 134

The verification of the seasonal winter and summer peak kW reduction meets the ISO-NE Forward Capacity Market standards. Additional detail on the calculation of the seasonal peak kW reduction is provided in Appendix M.

4.5.1 Program Reported Savings

Program reported savings match the PSD deemed winter kWh savings for both utilities as shown in Table 4-33. It appears that both utilities are claiming savings based only on winter usage. As a substantial proportion of homes with furnaces use the same fans for central air conditioning, this is a conservative estimate.

4.5.2 PSD Savings

The PSD savings for ECM furnaces fans are deemed values, with separate kWh values for the summer (cooling) and winter (heating). These values are based on a 2003 study in Wisconsin,[50] adjusted for heating and cooling degree day differences between the two states.

4.5.3 AMI Analysis Results

ECM furnace fan motors are required on all eligible furnaces. UI provided 15-minute AMI data for many of the households who installed furnaces. The savings for the winter and summer portion of furnace fan usage was calculated using house-by-house regression models. Key components of the analysis are described briefly below:

- Pre/post analysis, based on assumption the existing furnace had a PSC motor
- 15-minute, whole house electric data
- Regression of electric use (kW) on 5°F temperature bins
- Late night hours only to limit the impact of other household end uses

[50] "Electricity Use by New Furnaces – A Wisconsin Field Study, Energy Center of Wisconsin," referenced on page 144 of the 2017 PSD.

- Furnace fan portion of the usage was calculated as the temperature-dependent part of the total usage
- Separate models were run using pre-install (baseline) and post-install (efficient case) records

There are two key assumptions behind this approach: 1) the furnace fan use is weather-dependent, and the temperature dependency determined through the regression can be applied to the population through weather normalization, and 2) the pre-install furnace had a PSC motor. Homes were removed if the temperature dependent usage was higher than expected, indicating the homes had a source of electric heat such as heat pumps or electric resistance heat.

Only homes with a temperature-dependent regression in both the pre- and post-install periods were used in the analysis. This approach was adopted for the following reasons:

1. It allows for a pre/post comparison by home, providing a clear link between the existing (PSC) and new (ECM) furnace fans
2. It is also likely to remove homes with a substantial difference in the pattern of operation between the pre- and post-install periods[51]

The inputs into the analysis are summarized in Table 4-33.

TABLE 4-33: ECM FAN ANALYSIS INPUTS

Input	Source	Notes
Annual Hours	AMI (UI only)/ monthly billing records	Estimated from AMI data Normalized to typical year temperatures
Historic Seasonal Peak Data	ISO-NE[52]	Used with NOAA temperatures for to predict the seasonal peak kW
Baseline	Contractor Survey	Percent of PSC/ECM motors (market baseline)
Weather Data	NOAA	Data from four weather stations Used nearest weather station with complete data
Normalized Weather Data	NOAA	Normalized NOAA weather data averaged over the previous six years for the four weather stations

The kWh and kW savings were calculated as the average difference in kWh between the pre and post installation regressions, normalized to typical temperatures using NOAA hourly

[51] Changes in the pattern of use are likely to affect the temperature dependency, leading to homes failing to meet the criteria of strong temperature dependency in both the pre- and post-installation periods.

[52] https://www.iso-ne.com/isoexpress/web/reports/load-and-demand/-/tree/season-peak-hour-data

temperature data from the last six years. The winter and summer kW savings were adjusted to account for the distribution of temperature bins in the historic seasonal peak period hours. Refer to Appendix M for additional detail on the seasonal peak period calculation. The results of the analysis are summarized in Table 4-34 below.

Table 4-34: Furnace Fan AMI Analysis Results

	Pre-Install Period		Post-Install Period	Savings
	All Homes w/Pre-Install Data	Both Pre and Post Data	Both Pre and Post Data	
Number of Homes	195	111	111	111
Average Furnace Fan Winter kWh	771	824	412	411
80% Confidence Interval	37	48	33	19
Relative Precision at 80%	5%	6%	8%	5%
Mean Winter Seasonal Peak kW	0.284	0.303	0.152	0.151
Mean Annual Hours	1275	1351	N/A	

The AMI analysis was limited by the relatively small data signal from the furnace fan and there are possible sources of uncertainty which could have either an upward or downward impact on the savings, as shown in Table 4-35. A reality check was conducted, as discussed below.

Table 4-35: Sources of Uncertainty in the Furnace Fan AMI Analysis

Source of Uncertainty	Description	Direction of Uncertainty
Raise thermostat setting during post-period	Increase furnace fan use during post-period; 5% of survey respondents reported increasing the thermostat setting[1]	Increase savings
Lower thermostat setting during post-period	Decrease furnace fan use during post-period; 28% of survey respondents reported decreasing the thermostat setting	Decrease savings
Lower nighttime temperature (setback)	May be removed from analysis due to lack of temperature dependency (24% of respondents decrease the thermostat by 5°F or more)	Increase savings
Higher nighttime temperature	May be removed from analysis due to lack of temperature dependency (14% of respondents increase the thermostat by 2°F or more)	Decrease savings
Continuous fan operation[2]	Likely to be removed from analysis due to lack of temperature dependency	Decrease savings

[1] The amount of the change in the setting was not specified; a small change in thermostat setting would have a correspondingly small impact on the operation of the furnace.
[2] Furnace fans may be used continuously in combination with air cleaning and dehumidification systems. This issue was not covered in the customer survey

As a final reality check, the annual operating hours of the furnace fan (about 1,300, Table 4-34) were compared to the FLH of the furnaces from the natural gas billing analysis (about 1,000, Table 4-2). Similar to boilers, the annual operating hours of the fans are expected to be higher than the FLH of the furnaces, as furnaces cycle off at the high temperature setting and back on when a low temperature setting is reached while the fans continue to run until the call for heat is satisfied. This comparison suggests that the annual operating hours of the furnace fan are within a reasonable range.

4.5.4 Baseline Adjustment

The AMI data analysis portion used the pre-installed furnace fans as the baseline. It is very likely that the pre-existing furnaces had inefficient, permanent split capacitor (PSC) motors. The results from contractor and distributor surveys were used to inform the market baseline percent of ECM and PSC fans. Contractors reported that 38% of furnace fans installed without rebates were ECM fans. (See Table 4-36.) The method for determining the baseline is described in Section 4.6.

Table 4-36: Baseline Survey Results for ECM Furnace Fans

	Number of Respondents	Percent ECM Without Rebate	Percent PSC
Contractors[1]	28	38%	62%
Distributors[1]	17	36%	64%
Unadjusted Average		37%	63%
Adjustment for Program-Eligible Furnaces[2]		-15%	+15%
Adjusted Average		22%	78%

[1] Weighted by percent of program sales.
[2] The percent of PSC motors was adjusted by the estimate of sales of high efficiency furnaces meeting the program eligibility requirements, as these sales could possibly reflect spillover and incorporating these sales into the baseline could unfairly penalize the program. This topic is discussed further in Section 4.6.

4.5.5 Recommended Changes to the PSD

The PSD provides deemed savings for this measure. We recommend the deemed savings be updated to match the results of this evaluation. The summer savings were estimated based on the assumption that 60% of homes with furnaces have central air conditioning.[53] Recommended changes to the PSD are summarized in Table 4-37.

[53] This assumption is based on Census data of central A/C and furnace usage in CT. About 40% of CT homes have central A/C, and about 40% have furnaces. However, the Census data does not explicitly delineate the percent of homes with both a furnace and

TABLE 4-37: RECOMMENDED CHANGES TO THE PSD FOR ECM FURNACE FANS

Deemed Value	2015/2017 PSD	Recommended	Comments
Winter kWh	293	321	AMI data analysis
Summer kWh	55	45	AMI data analysis; both values adjusted to account for 60% of homes with central A/C
Total Annual kWh	348	366	UI and Eversource only claimed winter savings
Winter Seasonal Peak kW	0.090	0.118	AMI data analysis allowed estimation of peak period reduction
Summer Seasonal Peak kW	0.072	0.065	AMI data analysis, adjusted to account for 60% of homes with central AC

Higher savings in comparison to the PSD were also found in the 2009 evaluation of ECM furnace fans in Wisconsin.[54] That study estimated annual savings of 733 kWh, an increase from the 440 kWh used in the PSD derived from an earlier (2003) Wisconsin study.

4.6 Baseline Method

In the PSD, the efficiency of the baseline heating equipment was assumed to be the federal minimum standard. However, this assumption does not account for actual purchasing patterns. To address this issue, the evaluated baseline was determined from the contractor and distributor surveys. This section covers efficient furnaces, furnace fans, boilers and boiler circulating pumps.[55]

The baseline questions asked contractors to estimate the percent of units installed without the rebate by efficiency category. For example, the four efficiency categories for furnaces were 80 to 84% AFUE, 85 to 89%, 90 to 94% and 95% and above.

Validation of the survey responses was conducted to address two issues:

- Review of the survey responses suggested some contractors did not interpret the baseline questions correctly
- Installations of program-eligible units without a rebate could reflect spillover, and adjusting the baseline downward for potential spillover would unfairly penalize the program

The validation was conducted by comparing the baseline responses to other survey questions for consistency and potential misinterpretation. For example, if the respondent indicated that the percent of units installed with the rebate was identical to the percent in the program-eligible

central A/C. As homes with a furnace already have the ductwork and are more likely to have central A/C, we increased the percent of homes with furnaces and central A/C to 60%.

[54] Focus on Energy Evaluation - ECM Furnace Impact Assessment Report, Public Service Commission of Wisconsin, January 2009.

[55] The method of calculating the baseline for heat pump water heaters is described in Section 5.4.5 and the furnace fan baseline was determined from the furnace baseline, as all program-eligible furnaces are required to have an efficient furnace fan.

baseline efficiency category (sold without the rebate), we concluded that the question was misinterpreted and we adjusted the responses accordingly. In some cases, only the baseline questions were answered and we had no additional information for validating the responses.[56]

The validation was conducted for both the contractor and distributor surveys. The specifics of the contractor validation are explained below. A similar process was used for the distributors.

For the baseline/spillover validation, we relied on questions indicating the following:

1. the contractor changed his or her behavior due to the rebate by increasing recommendations of high efficiency equipment
2. the contractor attributed an increase in sales of high efficiency equipment to the rebate

If the contractor's responses fell into at least one of these two categories, we assumed the percent of high efficiency baseline units could be spillover and the percent of program-eligible units was proportionally distributed into the other baseline efficiency categories.

Spillover was estimated separately, as described in Section 5.3. Table 4-38 and Table 4-39 summarize the baseline survey responses.

Table 4-38: Contractor Baseline Survey Response Summary

	Furnaces	Boilers	Boiler Circulating Pumps	Furnace Fans	Comments
Total surveys with baseline response	52	50	40	46	Extra solicitation efforts to improve the response rate were employed
Install type of equipment	48	45	40	41	Some contractors do not install one more of the three types of equipment
Removed	11	7	10	13	Incomplete survey, misinterpretation of questions, inconsistency of responses
Total included in analysis	37	38	30	28	Responses were checked for consistency and correct interpretation
Included and validated	31	29	22	21	Baseline questions were compared to other questions about recommendations and program-induced changes in sales
Included and not validated	7	8	8	7	Only the baseline questions were answered

[56] Non-validated baseline responses with a high percentage (70% or higher) of installations in the program-eligible baseline category were dropped due to concerns that the respondent reported the percent with the rebate rather than the percent without the rebate, as appeared to occur with a large majority of the validated responses with a high percent in the highest efficiency category.

TABLE 4-39: DISTRIBUTOR BASELINE SURVEY RESPONSE SUMMARY

	Furnaces	Boilers	Boiler Circulating Pumps	Furnace Fans	Comments
Total surveys with baseline response	29	27	24	29	
Install type of equipment	19	24	20	20	Some distributors do not sell one more of the three types of equipment
Removed	3	5	0	3	Incomplete survey, misinterpretation of questions, inconsistency of responses
Total included in analysis	16	19	20	17	Responses were checked for consistency and correct interpretation
Included and validated	12	12	14	12	Baseline questions were compared to other questions about stocking and program influence
Included and not validated	4	7	6	5	Only the baseline questions were answered

The results of the survey were weighted based on the number of units sold through the program by the contractors and distributors who responded to the survey and the contractor and distributor baselines were averaged, as reported in the measure results sections above (Tables 4-3, 4-12, 4-16 and 4-35). The baseline estimates from the two sources (contractors and distributors) were averaged to take into account the two perspectives:

- Distributors' responses were more likely to reflect the overall sales
- Contractors' responses were more likely to reflect what they were installing.

Both perspectives provide key information about the baseline market practices.

5 Net-to-Gross Methods and Results

Program attribution was estimated for boilers, furnaces, heat pump water heaters and boiler circulating pumps. The self-report approach may tend to understate program attribution due to hindsight bias, i.e., as time passes, people tend to conclude that a previous decision was predictable and may be more likely to say that they would have made the same choice in the absence of the program.[57] However, program influence questions may tend to overstate program attribution as respondents are more likely to give the socially desirable response.[58]

Consequently, the approach to estimating net savings utilized the self-report method and incorporated program influence. Both the self-report and program influence questions were tied to the program's causal mechanisms on the market actors. The NTGR estimates were developed for the three markets actors, i.e., customers, contractors and distributors, and the results were combined to reflect the relative contribution of the market actors to the decision.

An experimental method to estimate program influence, the Barriers Approach, was also tested. As this method reflects a departure from the commonly-use self-report method and has not yet been widely tested, the Barriers Approach results were not directly incorporated into the NTGR estimates. Some questions used to estimate program influence were common both the Barriers Approach and the program influence component used in the final estimate of the NTGR. A description of the approach and the results are provided in Appendix K.

The self-report method has been used extensively in many jurisdictions. It is based on asking market actors what they would have done in the absence of the program. In this evaluation, we applied an innovative approach by defining the causal mechanisms, *i.e.*, how the program intervention affects the market actors, and conducting primary research to understand how these specific mechanisms worked.

For free ridership, both the self-report approach and the program influence questions accounted for the decision-making at three levels, *i.e.*, customer, contractor and distributor. Due to the upstream program design, spillover was assumed to occur at the distributor level. The two methods have some key similarities:

- Data collection through surveys
- Assessment of impacts through specific causal mechanisms
- Measure-level analyses
- Combination of the NTGR from the three market actors by estimating the relative impacts of each market player on the decision to install the efficient equipment

The **self-report approach** relies on direct questions to customers about what they would have done in the absence of a rebate and estimates from contractors and distributors about the percent of sales or stocking of efficient equipment with and without the rebates. The **program**

[57] Kahnman, Daniel. 2001. *Thinking Fast and Slow*. Farrar, Strauss and Girard, New York City, NY, pp. 202 to 204.
[58] McRae, M. "'Sure you do. Uh-huh': Improving the Accuracy of Self-Reported Efficiency Actions." In Proceedings of the 2002 ACEEE Summer Study on Energy Efficiency in Buildings. Pacific Grove, CA: American Council for an Energy-Efficient Economy

influence component was based on direct questions about program influence or pairwise questions comparing program activities to outside influences.

Cognitive interviews were conducted to understand how the players talk about the program and to understand the causal mechanisms. These interviews influenced the survey instrument design for customers, contractors and distributors.

The following sections describe the NTG methods and results in the following order:

1. Estimating the **self-report NTGR's** by market actor
2. Estimating **program influence** by market actor
3. Combining the **self-report and program influence** estimates of the NTGR's
4. Combining the NTGR's **by market actor**
5. **Spillover** method and results
6. **Summary** of the NTGR's results

The final section provides tables with all the interim and final values by measure and market actor. Survey instruments are provided in Appendix A and details about the sampling approach are in Appendix J.

5.1 Self-Report Approach

The self-report approach combines traditional self-report NTG questions with the causal mechanisms associated with the upstream rebate. The steps in the self-report are as follows:

1. Identify the causal mechanisms for each market actor
2. Define the self-report indicator for each market actor
3. Estimate the net-to-gross ratio (NTGR) for each market actor

Each of these steps is described in more detail below. Combining the NTGR from the three market actors to develop a measure-level estimate is discussed in Section 5.4.

5.1.1 Causal Mechanisms

The causal mechanisms are based on recent research conducted for an upstream, commercial HVAC program in California, and adapted for the Upstream HVAC Program.[59] The three main causal mechanisms are as follows:

1. **Rebate -** affects the customer by reducing the price and the incremental cost of the efficient equipment

[59] "Net-to-gross Evaluation of 2013-2014 Upstream HVAC Programs", prepared for the California Public Utilities Commission by DNV-GL. September, 2016.

2. **Upselling -** contractors may use the rebate as a hook to engage the customer and to encourage the purchase of HE equipment
3. **Stocking -** distributors may increase the stocking of HE equipment, making it more readily available for emergency installations

The process for the upstream program and how it affects the market actors is illustrated in Figure 5-1.

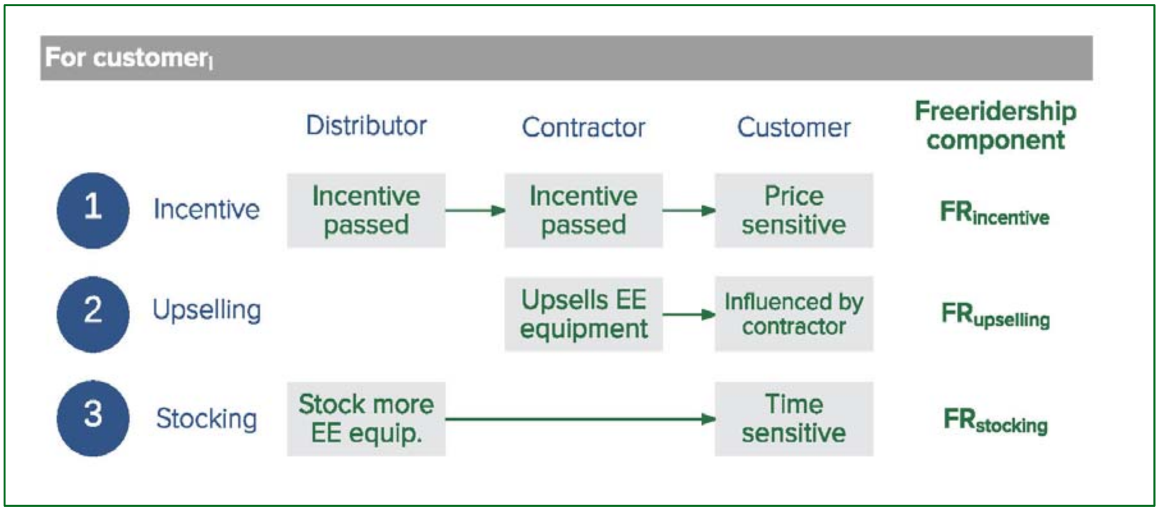

FIGURE 5-1: UPSTREAM HVAC CAUSAL MECHANISMS

The cognitive interviews were used to investigate the causal mechanisms for this market. The three pathways illustrated in Figure 5-1 were supported by the results of these surveys, as discussed in Table 5-1.

TABLE 5-1: FINDINGS ON CAUSAL MECHANISMS FROM THE COGNITIVE INTERVIEWS

Market Actor	Cognitive Interview Findings	Causal Mechanisms
Customer	Rebate seems to be the only causal mechanism directly affecting customers; many customers also rely heavily on contractor recommendations	Rebate is the primary program effect; pairwise question was modified based on responses; customers were also asked about the contractors' influence on their decision to install high efficiency
Contractor	Rebates seem to be primary causal mechanism; some contractors say it provides a hook to discuss energy efficiency	Also investigate increased recommendation of high efficiency equipment due to upstream rebate (upselling)
Distributor	Rebates are seen as driving customer demand. Some indication that stocking and promotion of HE has increased in response to rebates	Investigate increased promotions and stocking by distributors in addition to rebate mechanism

The cognitive interviews suggested that customers were not highly engaged in the decision, which was a marked contrast to our research with customers who had complete energy audits.

While customers identified other barriers, a main focus was the cost of the equipment. Contractors and distributors indicated that the rebates were seen as increasing purchases, which resulted in increased recommendations of the high efficiency equipment by contractors and higher stocking level of efficient equipment by distributors.

5.1.2 Defining the Indicators for the Causal Mechanisms

The foundation of the self-report method is to inquire about what the market actors would have done in the absence of the upstream rebates. For customers, standard self-report questions were used. Specific wording is provided in the next section.

Contractors and distributors were asked about the percent of installations or stock that would have been high efficiency without the rebate. The contractor questions were worded as follows:

> *Approximately what percentage of all <EQUIPMENTx> units you install in Connecticut is eligible for the upstream rebate?*
>
> *If the upstream rebates were not available, what percentage of all <EQUIPMENTx> units you install in Connecticut would meet the current eligibility requirements for the upstream rebates?*

The specific approach for each market actor is summarized in Table 5-2.

TABLE 5-2: SELF-REPORT APPROACH BY MARKET ACTOR

	Causal Mechanism	Free rider Questions	Comments
Customers	Pricing/Rebate	Would they have installed without rebate? If so, when?	Standard self-report questions
Contractors	Upsell	Percent of HE units installed if no rebate, percent HE units installed with rebate	Free riders = % HE no rebate/% HE with rebate
Distributors	Stocking	% of HE stock if no rebate % of HE stock with rebate	Free riders = % HE no rebate/% HE with rebate

5.1.3 Estimate the Self-Report Free Rider Rate

The wording of the questions and translation from the questions to the free rider rate for customers is shown in Table 5-3 below. This example is from the customer survey for furnaces. Rebate amounts were adjusted accordingly in the surveys for boilers and heat pump water heaters.

Table 5-3: Customer Self-Report Free Rider Questions and Scoring for Furnaces

Question	Response	Free Rider Rate
Would you have purchased any new furnace if no rebates had been available?	Yes	Continue
	No	FR = 0%
Would you have purchased the same furnace if the cost were $600 more than you paid?[1]	Definitely/probably would not/ not sure	Continue
	Definitely/probably would	FR = 100%
Would you have purchased the high efficiency furnace at a later time or a different type of furnace?	The high efficiency furnace at a later time	Continue
	Less efficient furnace	FR=0%
	Don't know	Removed from analysis
Would you say you would have made the purchase within six months, six months to one year or over a year from when you did?	Within 6 months	FR = 100%
	6 months to one year	FR=50%
	Over one year	FR=0%
	Don't know	Removed from analysis

1 This example is from the furnace survey. Wording and rebate amounts were adjusted in the surveys for other measures.

For contractors and distributors, the free rider factor for the contractor was calculated using Equation 5-1.

Equation 5-1

$$FR = \frac{\%\, eligible\ without\ rebate}{\%\, eligible}$$

The sample sizes for the contractor survey are quite small, as explained in more depth in Section 5.4. Due to the length of the survey, the NTG questions were asked for only one measure randomly selected for each respondent, which resulted in 18 responses for boiler circulating pumps, but only 4 responses for heat pump water heaters. In addition, some contractors did not respond to all questions or provided inconsistent or invalid responses. Validation of the contractor NTG results are discussed in Appendix L.

As the contractor NTGR's for the four measures were not statistically different, the average value for all measures was used, allowing for a somewhat larger sample size. Table 5-4 shows the self-report free rider rates for each level of market actors.

TABLE 5-4: ADJUSTED FREE RIDER RATES BY MARKET ACTOR

	Customers/ Price[1]		Contractors/ Upselling[1]		Distributors/ Stocking[1]	
	Number of Responses	FR	Number of Responses[2]	FR	Number of Responses	FR
Furnaces	94	57% +/-8%	48	46% +/-9%	9	56% +/-8%
Boilers	79	59% +/-7%	48	46% +/-9%	9	73% +/-7%
Boiler Circulating Pumps	N/A	N/A	48	46% +/-9%	6	55% +/-9%
Heat Pump Water Heaters	68	53% +/-6%	48	46% +/-9%	6	52% +/-10%

[1] Confidence intervals are calculated at the 80% confidence level and incorporate the sampling error for both the self-report FR and program influence components.
[2] The observations for the furnaces, boilers, boiler circulating pumps and heat pump water heaters were combined as the individual FR rates were not statistically different at the 90% confidence level.

5.2 Estimate Program Influence by Market Actor

An example of the two questions used to estimate program influence from the customer survey is presented below.

Thinking only about what tipped your decision to pay the premium for your efficient furnace, which statement is closest to how you made your decision?[60]

1. The rebate was the only important factor that tipped you toward the efficient furnace.
2. The rebate was more important than other influences.
3. The rebate and other influences were equally important.
4. Other influences were more important than the rebate.
5. Other influences were the only important factor.

[Assume option 2 was selected] Comparing the rebate to other influences, how would you rate the importance of the rebate? Was the rebate:

1. about the same as other influences
2. slightly more important than other influences
3. moderately more important than other influences
4. strongly more important than other influences
5. extremely more important than other influences

[60] "Rebate" was defined prior to this question as "discounts from your contractor, retailer or utility."

Table 5-5 below shows how the program influence estimates were calculated for customers and distributors.[61]

TABLE 5-5: PROGRAM INFLUENCE ESTIMATES FOR CUSTOMERS AND DISTRIBUTORS

	Program Influence Estimate (1-FR)	
	Rebate more important	Other influences more important
About the same importance	50%	50%
Slightly more important	60%	40%
Moderately more	70%	30%
Strongly more	80%	20%
Extremely more	90%	10%
Only one factor was important	100% (selected)	0% (not selected)

For contractors, program influence reflects the contribution of the rebate in contractors' decision to recommend the high efficiency equipment more frequently. The survey questions and estimates of program influence are presented in Table 5-6.

TABLE 5-6: CONTRACTOR QUESTION ON PROGRAM INFLUENCE

Question	Responses	Program Influence Estimate (1-FR)
Are you are more likely to recommend high efficiency units because the upstream rebates are available?	Much more likely	Continue to next question
	Somewhat more likely	Continue to next question
	Not more likely	0%
How much influence do the upstream rebates have on your decision to recommend high efficiency furnaces more frequently?	Not at all influential	0%
	Slightly influential	25%
	Moderately influential	50%
	Strongly influential	75%
	Extremely influential	100%

[61] A balanced scale was used to calculate the program influence for customers, contractors and distributors. An alternative scale was also tested with a non-linear scale giving less weight to "slightly" and "moderately" and more weight to "strongly" and "extremely." The change in scale had little effect on the NTGR's (less than 1%).

5.3 Combining Self-Report Free Ridership and Program Influence

For contractors and customers, the self-report NTGR (1-FR, excluding spillover) and program influence estimate (reflecting the contribution of the program to the decision) were combined for each survey respondent using the following rules:

1. If both the self-report and program influence questions were answered by the respondent, the responses were averaged
2. If only the self-report questions were answered, the self-report NTG was used
3. If only the program influence questions were answered, the program influence equivalent of the NTG was used

For the distributors, the self-report NTGR and program influence were estimated separately and then the two values were averaged. This simpler approach was used as the distributor contribution to the overall NTGR is related only the emergency installations and is quite small in comparison to the customer and contractor contribution. (See Section 5.4 and Table 5-9.)

TABLE 5-7: NTGR BY MARKET ACTOR AND ADJUSTED FOR PROGRAM INFLUENCE

	Customers/ Price[1]		Contractors/ Upselling[1]		Distributors/ Stocking[1]	
	Number of Responses	NTGR	Number of Responses[2]	NTGR	Number of Responses	NTGR
Furnaces	130	43% +/-5%	48	54% +/-9%	14	45% +/-8%
Boilers	95	41% +/-8%	48	54% +/-9%	16	27% +/-7%
Boiler Circulating Pumps	N/A	N/A	48	54% +/-9%	17	45% +/-9%
Heat Pump Water Heaters	93	47% +/-7%	48	54% +/-9%	14	48% +/-10%

[1] Confidence intervals are at the 80% confidence level.
[2] In the contractor survey, respondents were asked about only one measure due to the complexity and length of the survey, and the number of responses for each measure were small (4 to 18). Thus, the responses for all four measures were combined as the individual NTGR's were not statistically different at the 90% confidence level.

5.4 Combining NTGR's Across Market Actors

Estimating NTGR's for upstream programs required a method to combine the results across multiple market actors. Our approach was to weight the NTGR's according to the contribution of the market actor to the decision-making process. Ultimately, the decision to install the high efficiency equipment is the customer's. However, the contractor's input into the decision can vary greatly from one homeowner to the next. Some homeowners conduct their own research and select the equipment themselves; others will accept the contractor's recommendation without any discussion. The Decision Maker Index (DMI) was used to combine estimates of program influence by including all three levels of the market actors (customer, contractor and distributor) in relation to their contribution to the decision.

The DMI reflects the proportion of the decision that is associated with the specific market actor. The approach is based on the following construct:

1. **Customers** are in the best position to describe how much influence the contractor had on the decision-making process (customer DMI)
2. **Distributors** affect the contractor's decision rather than the customers (so the contractor's DMI is used to adjust the distributor's contribution to the overall NTGR)

Customers were asked the extent to which the contractor influenced their decision to install the efficient equipment rather than a standard unit by comparing the importance of their own, personal research to the contractor's influence. Pairwise questions were used to quantify this aspect of the decision-making process. The contractor DMI is the reverse of the customer DMI ($1 - DMI_{customer}$).

The FR and NTGR (excluding spillover) for each market actor was adjusted by the DMI and the weighted factors were added together to obtain the combined NTGR for the measure. This strategy ensures that the final FR is reasonable in the context of the FR's from the individual market actors.

The California study developed a different approach. In both studies (California and Connecticut), weights were constructed to reflect the change in the market (*e.g.*, increased stocking of high efficiency equipment) due to the upstream rebates. However, the studies differ in the approach used to combine these factors. In the California study, evaluators used multiplicative approach and we used an additive approach, as explained in Table 5-8.

TABLE 5-8: APPROACHES TO COMBINING NTGR'S ACROSS MARKET ACTORS

Approach	Additive Approach (CT)	Multiplicative (CA)
Description	$\sum NTGR_i$	$1 - \prod FR_i$
Advantages	Accounts for all causal mechanisms Weighted by contribution of market actor to the decision to install EE Scales to 1.0 for Barriers Approach	Accounts for all causal mechanisms Scales results to 1.0
Disadvantages	For self-report, FR could theoretically exceed 1.0	With CT data, appears to underestimate impacts, likely due to differences in evaluation design
Comments	FR was capped at 1.0; actual results did not approach the cap	Replication with FR=0% for all market actors gave NTGR in range of 78%-88% with three market actors[1]

[1] Replication was done as closely as possible given the differences in evaluation design, e.g., the California study had two market actors (buyer and distributor) but our study has three and the methods for estimating the net effects were not identical.

The DMI was used to reflect the relative importance of the customers' research and the contractor's influence on the decision to install the high efficiency model.

At the distributor level, the stocking pathway is predicated on the assumption that energy efficient products are more available for emergency installations. In the customer survey, respondents were asked about the condition of their previous equipment. Respondents who indicated it had failed and needed to be replaced immediately (within a week or two) were considered to be emergency installations. Table 5-9 shows the responses to the emergency installation question.

TABLE 5-9: EMERGENCY INSTALLATION TIMING ADJUSTMENT

	Total Number of Respondents	Emergency Installations
Furnace	130	20%
Boilers	95	13%
Boiler Circulating Pumps[1]	N/A	13%
Heat Pump Water Heaters	100	20%

[1] Customer surveys were not conducted, as explained in the footnote to Table 4. The percent of emergency installations for boiler circulating pumps was assumed to be the same as for boilers.

The self-report method is summarized in Figure 5-2.

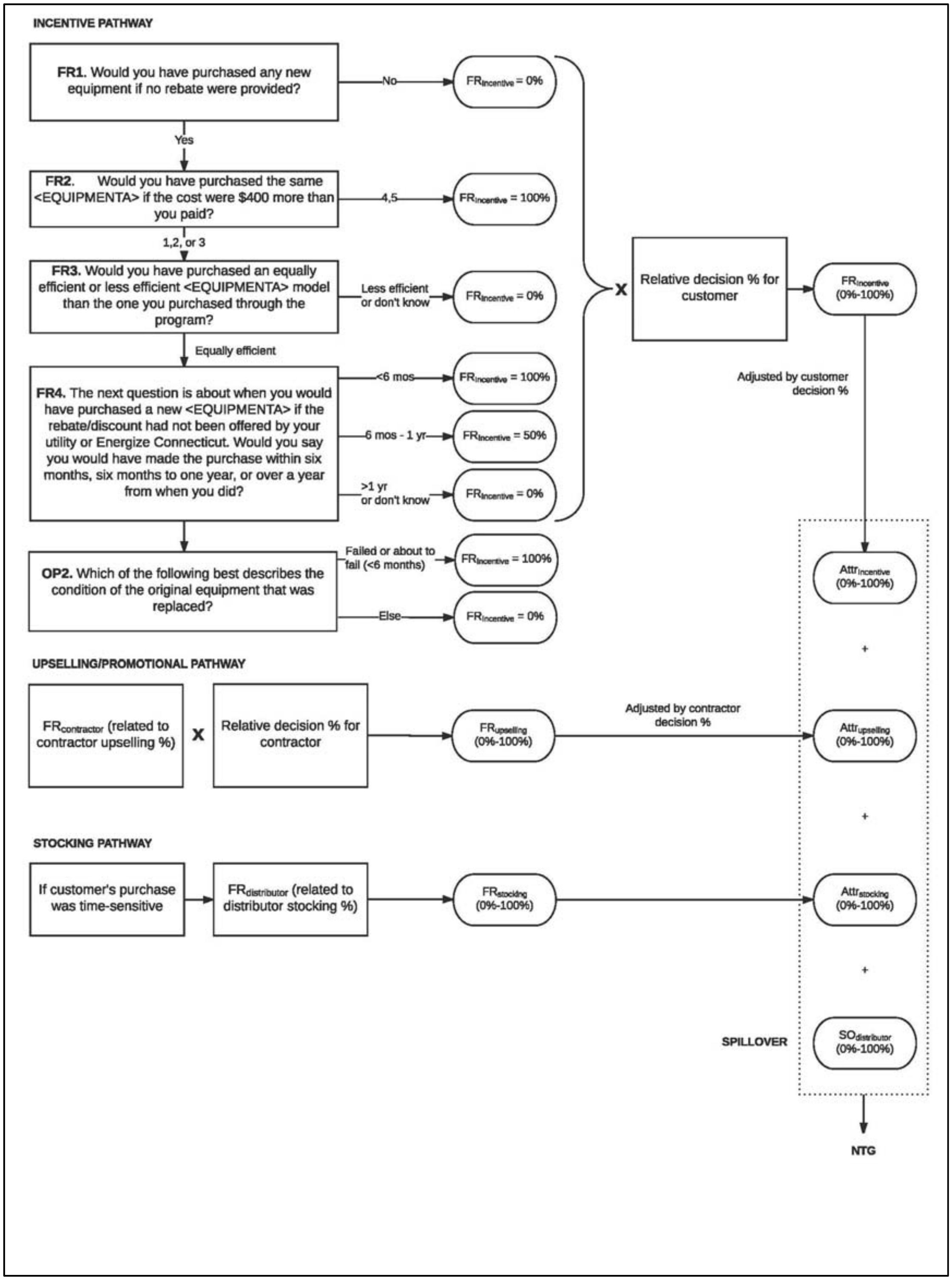

FIGURE 5-2: SUMMARY OF THE SELF-REPORT METHOD

5.5 Spillover

For an upstream program, spillover occurs when contractors and distributors increase their promotion of high efficiency equipment in response to the upstream incentive, resulting in an uptake in the efficiency levels of **non-rebated** units. Our initial assumption was that there would be no spillover due to the program design, *i.e.*, every eligible unit receives a rebate. However, the distributor surveys indicated spillover could occur in at least three ways:

1. One utility stopped paying the rebate when they reached their budget cap
2. Rebates are not available for customers who have a pattern of late payment on utility bills
3. Some distributors do not pay the rebate under limited circumstances, such as lacking assurance that the installation is in a eligible, residential location

Spillover was determined from distributor surveys, using the estimated percent of eligible, efficient products sold without a rebate. To result in spillover, three conditions need to be met:

- The distributor recognizes that there has been an increase in their sales of high efficiency equipment since the upstream rebates have been available
- The distributor attributes at least a portion of the increased sales to the rebates
- The distributor can estimate the magnitude of the increase in sales

In addition, the responses to the survey questions should be consistent and indicate that the respondent understood the questions.

The wording of the spillover questions for furnaces is provided below.

> *1. Of all the eligible furnace units you sell to CT customers, what percentage of these does not receive a rebate through the upstream HVAC and Water Heating program?*
>
> *2. Approximately what percent of all furnace units you stock meets the eligibility requirement for the upstream rebate? Your best estimate is fine.*
>
> *3. Under what circumstances does your site not pay the rebate for qualifying equipment? [open ended]*
>
> *4. Without the upstream rebates, would your current stock of high efficiency furnaces be higher, lower, or the same?*
>
> *5. Has the program had any influence on your decision to stock more program eligible equipment? [0 to 10 scale]*

The spillover percent was calculated using the percent of eligible equipment sold without a rebate (Question 1). The remaining four questions were consistency checks and verification of program influence. The distributor responses were reviewed as follows:

1. If the percent of non-rebated, eligible sales (Question 1) plus the percent of all units that met the eligibility requirements (Question 2) was equal to 100%, we concluded the respondent did not correctly interpret the questions, as these two percentages should be independent of each other

2. The response to the open-ended question (when available) had to indicate that spillover was a possibility
3. The distributor indicated the current stock of efficient equipment (with the rebate) would be lower without the rebate
4. The distributor indicated the program influenced their decision to stock more energy efficient equipment

Each of the responses was checked for internal consistency and removed if inconsistent, *e.g.*, three responses were adjusted to zero as they reported a percent of units that did not receive a rebate but then clearly stated in the open ended question that no units were sold without a rebate. The results are presented in Table 5-10.

TABLE 5-10: SPILLOVER FROM DISTRIBUTOR SURVEYS

Measure	Total Number of Responses[1]	Number of SO Responses[1]	Spillover[2]
Furnaces	27	7	4% +/- 3%
Boilers	22	11	4% +/- 3%
Boiler Circulating Pumps	22	7	9% +/- 5%
Heat Pump Water Heaters	27	7	1% +/- 1%

[1] The total number of responses is the number of distributors who answered questions about the specific measure. (Some distributors did not sell all four types of equipment.) Some respondents did not provide valid answers to the key spillover question.
[1] The number of SO responses reflects the respondents with valid answers for this component of the analysis.
[2] Confidence intervals are at the 80% confidence level.

5.6 Summary of NTG Results

The NTG results are summarized in Table 5-11.

TABLE 5-11: SUMMARY OF NTGR BY MEASURE

Measure	Adjusted NTGR[1]	Spillover	Recommended NTGR[2]
Furnaces	58%	4%	62% +/- 8%
Boilers	52%	4%	56% +/- 8%
Boiler Circulating Pumps[1]	60%	9%	69% +/- 11%
Heat Pump Water Heaters	58%	1%	59% +/- 6%

[1] This is the combination of the self-report NTGR and the program influence responses.
[2] The confidence intervals were calculated at the 80%confidence interval and incorporate the sampling error for each component in the calculation.

Table 5-12 shows the NTGR results by measure and market actor.

TABLE 5-12: ADJUSTED NTGR RESULTS BY MEASURE AND COMPONENT

Measure	Component	Customers/ Price	Contractors/ Upsell	Distributors/ Stocking	Overall
Furnace	Attribution (1-FR)	43%	54%	45%	
	Decision Maker/ Timing Adjustment	42%	58%	20%	
	Adjusted Attribution	18%	31%	9%	58%
	Spillover	0%	0%	4%	4%
	NTGR	18%	31%	13%	62%
Boilers	Attribution (1-FR)	41%	54%	29%	
	Decision Maker/ Timing Adjustment	48%	52%	13%	
	Adjusted Attribution	20%	28%	4%	52%
	Spillover	0%	0%	4%	4%
	NTGR	20%	28%	8%	56%
Boiler Circulator Pumps	Attribution (1-FR)		54%	45%	
	Decision Maker/ Timing Adjustment		100%	13%	
	Adjusted Attribution		54%	6%	60%
	Spillover		0%	9%	9%
	NTGR		54%	15%	69%
Heat Pump Water Heaters	Attribution (1-FR)	47%	54%	48%	
	Decision Maker/ Timing Adjustment	74%	26%	20%	
	Adjusted Attribution	35%	14%	10%	59%
	Spillover	0%	0%	1%	1%
	NTGR	35%	14%	11%	60%

In 2017, the utilities made a change to the incentive structure for efficient boilers from a single incentive of $750 for all boilers with an efficiency greater than 90% to a two-tiered system with an incentive of $450 for boilers with rated efficiencies from 90% to 93.9% and $750 for efficiencies of 94% or greater.

Eversource provided additional data showing a substantial increase in the percent of rebates for the higher efficiency boilers in 2017 as compared to 2016 and prior years (from about 40% to about 80%), suggesting that an adjustment to the NTGR was required.

Accordingly, the evaluators recommend adjusting the boiler NTG by doubling the contractor contribution to the NTGR, as the contractors are likely to be the market actor having the most impact on the increase in uptake of the high efficiency boilers. This adjustment increases the NTGR from 56% to 84% for boilers purchased in 2017 with efficiencies of 94% or higher.

6 Process Evaluation Findings

This section presents findings from the process evaluation. The objectives of the process evaluation are as follows:

- Document program activities[62]
- Assess program management and administrative experiences
- Assess program experiences from market actors (customers, contractors, and distributors).

To meet these objectives, the Evaluation Team reviewed program documentation, interviewed program managers, and surveyed participating distributors, participating contractors, and participating customers.

Based on results from of our research, the Evaluation Team found the overall program design to be successful. The mid-stream program design aligned with traditional supply chain systems and the rebates address cost barriers associated with the equipment.

While the program is running successfully, the Evaluation Team also found several opportunities for program improvements:

- Increase training and engagement with contractors regarding the program and/or high efficiency equipment
- Increase customer interest for the products through enhanced marketing and customer outreach
- Provide additional support to market actors with on-line information, including easy-to-find incentive information and AHRI ratings)

The remainder of this section first presents findings related to program management and administration. It then presents synthesized findings from surveys with market actors. Specific findings from each data collection activity can be found in Appendices G, H and I. Detailed recommendations based on these findings are presented in Section 8.

6.1 Program and Administrative Findings

The Evaluation Team interviewed the three utility staff who manage the Upstream HVAC Program, one from UI and two from Eversource (one of who manages the upstream rebates and one who manages the downstream rebates). This section presents the key findings from the staff interviews. Appendix F presents detailed findings relating to management distributor enrollment, marketing and outreach, rebate processing, and staff views on program successes and program challenge.

[62] Program activities are documented in Section 2. The evaluation team had a fourth objective, which was to test linkages between program activities and desired outcomes. The evaluation team could not specifically assess this objective because the program lacks a logic model.

Program managers reported that the program was running smoothly. From a management perspective, they did not express any concerns in regard to meeting short-term program goals, program processes, or schedule. The program managers reported that they had met expectations relating to the number of units rebated through the program. They also noted that the upstream program model has substantially increased the number of rebates issued and that distributors reported equipment was moving fast.

Program managers also identified three areas where they either faced challenges or they would like to improve the overall program design: limited budgets, measuring program outcomes and moving more measures upstream, as explained in Table 6-1 below.

TABLE 6-1: PROGRAM MANAGERS' CHALLENGES

Area of Improvement	Details
Limited Budget	Strong program enrollment resulted in the program being fully subscribed earlier than expected. Rebate levels do not address incremental cost barriers. This is compounded by lower heating costs due to mild weather and low natural gas prices.
Difficult to measure outcomes	Staff reported having little to no data to measure market transformation. Better documentation at outreach events, currently there is little feedback on effectiveness. Unclear whether customers in the program know that they are receiving a discount on their equipment from the utility. Mangers have limited means to measure how the discount is impacting customer experiences and purchasing decisions.
Challenges to moving more measures upstream	Bulk purchases are difficult to track using current program processes. The configuration of the equipment influences savings so much that offering an upstream rebate for the equipment would be very difficult.

In summary, program managers reported that the program was running smoothly and felt confident in meeting goals. Following the staff interviews, the Evaluation Team spoke to the following market actors to understand how they experienced the program: distributors, contractors, and participants. The next section explores these results.

6.2 Synthesized Market Actor Findings

The Evaluation Team asked distributors, contractors, and participating customers a series of questions relating to their experiences with the program and the HVAC market in general. The Evaluation Team analyzed results from each market actor and then synthesized results to develop an overall understanding of how the Upstream HVAC Program operates. To view market actor specific findings, see Appendices G, H and I. The remainder of this chapter presents synthesized findings from all market actors by the following themes:

- Participant characteristics
- Program awareness
- Motivations to sell and/or purchase energy efficiency equipment
- Barriers to sell and/or purchase energy efficiency equipment

- Program experiences, organized by market actor including findings from program staff, distributors, contractors, customers.

6.2.1 Participant Characteristics

To understand the types of market actors participating in the program, the Evaluation Team analyzed distributor and contractor participation in the program by looking at program data. The Evaluation Team analyzed customer characteristics by comparing demographic data of customer respondents to Connecticut census data.

Distributor Participation

To understand distributor participation, the Evaluation Team combined information from both Eversource and United Illuminating and then tallied up the number of rebates by distributor, combining multiple locations into a single parent organization. The Evaluation Team found a total of 48 distributors participating in the program. Like many energy efficiency programs, some distributors (in terms of number of rebates) were more active than others.

The top ten distributors accounted for the following:

- At least 34% of the rebates
- At least 850 rebates per distributor for furnaces and boilers

The top two distributors outperformed the other distributors in the top ten group by 30%.

Contractor Participation

The Evaluation Team performed a similar analysis for contractors. Over 4000 contractors installed equipment through this program, and about 270 made more than 20 installations during the study period. Similar to the distributors, some contractors were more active than others, though overall the skew was less pronounced for contractors. The top ten contractors performed at least 12% of the projects.[63]

The top ten most active contractors performed between 428 and 883 installations of boilers and furnaces. Most of these contractors received the bulk of their rebates through Eversource.

Customer Participation

Comparing survey results to the US Census data for Connecticut, the Evaluation Team found that customers participating in the HVAC Upstream Program overall were generally older, had higher incomes, and were more educated. When the comparison was limited to Connecticut homeowners, who are likely to reflect the population who replaces space and water heating equipment, program participants are closely matched to the population of homeowners in terms of age and income.

[63] The "contractor" field was blank for roughly 22% of rebates, limiting our ability to assess the distribution of work by each contractor.

6.2.2 Program Awareness

As shown in Figure 6-1, market actors most commonly learn about the program through typical supply chain mechanisms: once the utility engages distributors about the program, the distributors inform contractors, who in turn, inform customers. While this is the most common flow of information, some contractors and customers reported learning about the program directly from Energize CT or their utility. This finding suggests that direct and indirect marketing efforts have been effective tools of engagement.

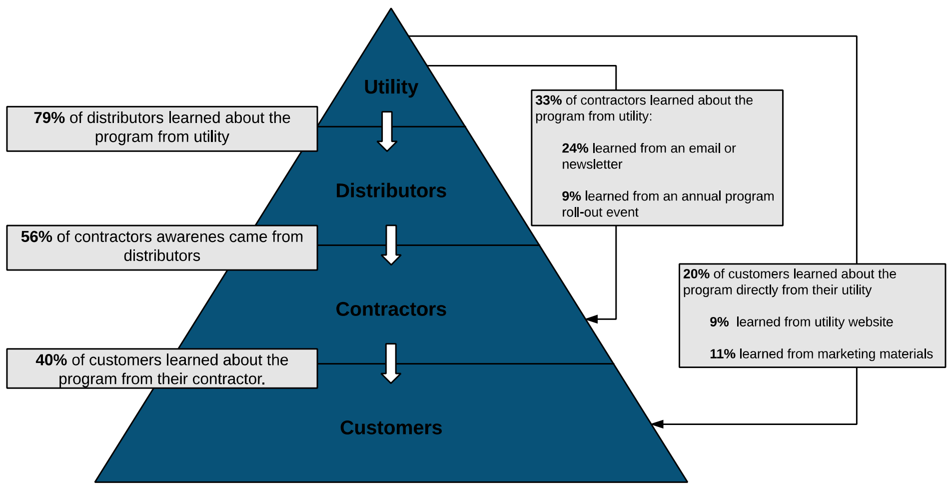

FIGURE 6-1: MARKET ACTOR AWARENESS CHANNELS

Additional details on how market actors communicate and/or learn about the program are as follows:

- Most distributor respondents promote the program through one-on-one conversations. Distributors also reported using Energize CT literature and other literature to promote the program. In-store demonstrations and counter days are employed less frequently, aligning with the lower frequency of these events.
- Contractor respondents reported that they typically discuss the program offering during the project scoping phase, with a smaller proportion of contractors discussing the offering when presenting a bid to their customers.
- Most contractors refer to the program as an "instant rebate from Energize CT," particularly among contractors who install boilers or heat pump water heaters. A smaller proportion of contractors refer to the program as an "instant *discount* from Energize CT," and/or as the rebate being from the customer's utility.
- Customer respondents reported learning about the program directly from who was selling the equipment. For most measures, they learned about the program from their

contractor. For HPWH, however, customers tended to learn about the program either from their retailer or their contractor, as many projects were installed by the customer.

The following table provides some additional detail about awareness of the rebate. Customers who installed heat pump water heaters were most likely to be aware of the rebate. About 30% of these installations were self-installed, so the customer would have received the rebate directly. The responses regarding awareness of the rebated are summarized in Table 6-2.

TABLE 6-2: AWARENESS OF REBATE

Measure	% of Participants Aware of Rebate
All	71%
Furnaces	68%
Boilers	66%
Heat Pump Water Heaters	Self-installed: 90 % Contractor installed: 75%

6.2.3 Motivations to Sell and Purchase Energy Efficiency Equipment

The Evaluation Team asked respondents about their motivations to sell program-eligible equipment. Understanding motivations can help program implementers with messaging techniques that can best engage market actors. As shown in Figure 6-2 and Figure 6-3, all respondents reported financial reasons as being very important motivators to selling and/or purchasing the equipment.

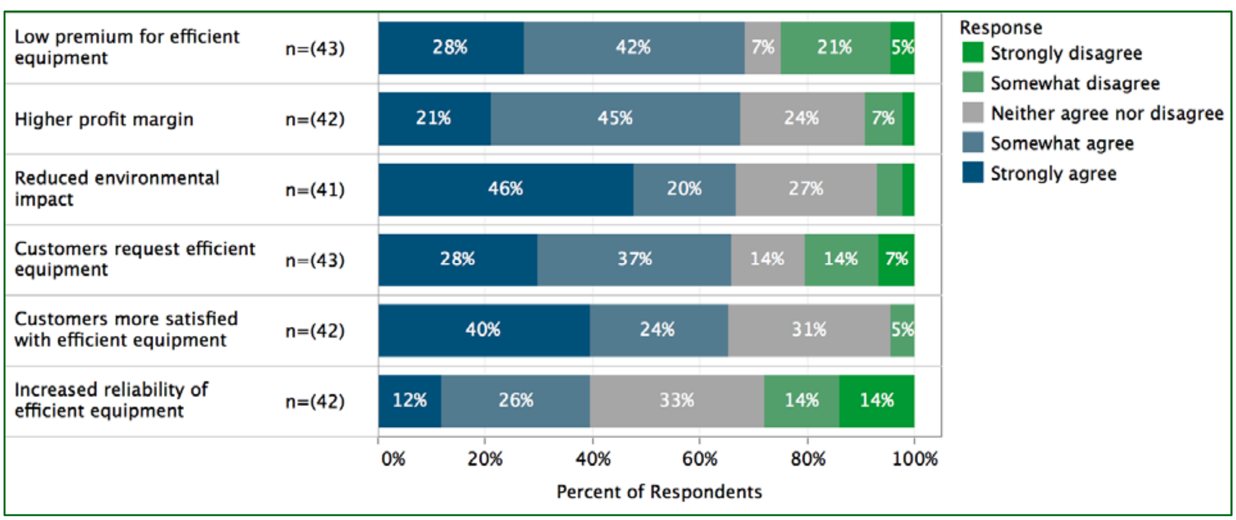

FIGURE 6-2: CONTRACTOR MOTIVATIONS FOR BUYING HIGH-EFFICIENCY HVAC

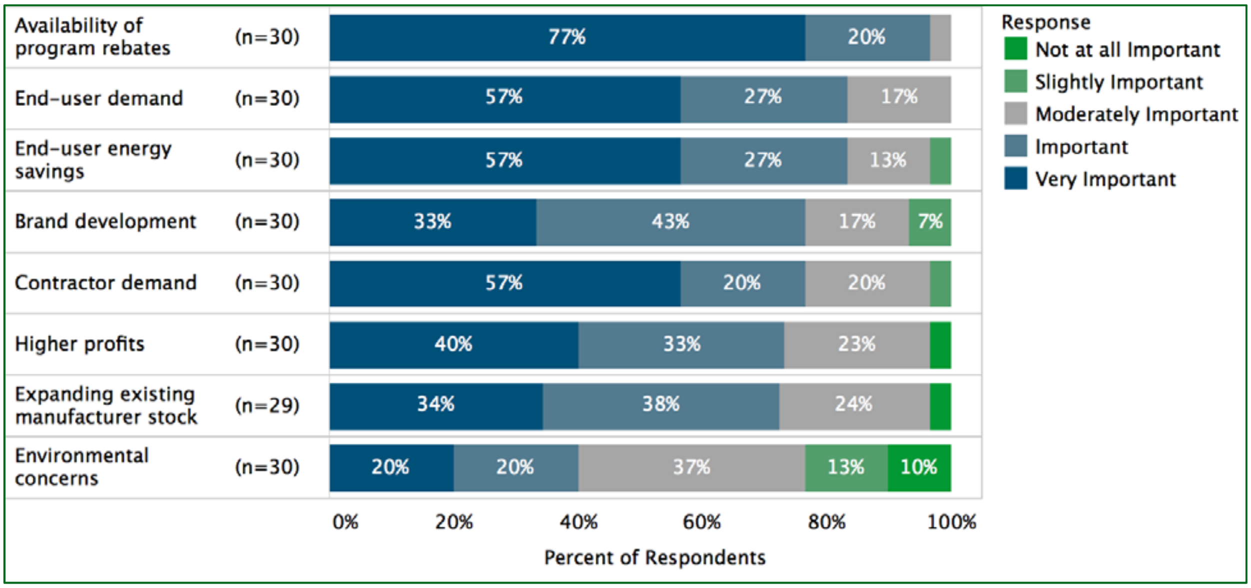

FIGURE 6-3: DISTRIBUTOR MOTIVATIONS FOR SELLING HIGH-EFFICIENCY HVAC

The types of financial motivators, however, varied between sellers and buyers. Distributor and contractor respondents most commonly reported being very motivated to sell the equipment because of the rebate and/or lowered incremental costs for the equipment. Customers, on the other hand, reported being motivated to purchase the equipment because of lowered operating costs and upfront costs (efficiency, lowered operating costs, and lowered installation costs). These motivator factors align with the overall design of the program, leveraging financial incentives.

Over half (65%) of the contractor respondents also reported they were motivated to sell high efficiency equipment because their customers requested the equipment. In contrast, the customer survey indicated that contractors played an important role in informing and encouraging customers to purchase the high efficiency equipment.

In summary, these results indicate that the program is functioning as designed. The rebates motivate distributors and contractors to sell high efficiency equipment. Faced with reduced first costs, customers are then motivated to purchase the equipment due to reduced operating costs. To build off of these findings, program staff could help to train more contractors on communicating the reduced operating costs to their customers.

6.2.4 Barriers to Energy Efficiency

The Evaluation Team asked distributors and contractors about their barriers to selling high efficiency equipment *before* the upstream program started. Customers were asked about the barriers to purchasing the high efficiency equipment they installed. All market actors reported cost to be the primary barrier; however other barriers were also identified, including customer interest, equipment availability, equipment concerns, and finding contractors.

As shown in Figure 6-4 and 6-5 below, distributors and contractors reported facing similar barriers to selling high efficiency equipment before the upstream program. They both reported the strongest barrier to be first costs (equipment premium). Since this group also reported that the rebate was a major motivator to selling high efficiency equipment, the rebates appear to be successful at overcoming this barrier.

Other barriers to selling high efficiency equipment prior to the upstream program include the following:

- **Customer interest** – To overcome customer interest barriers, distributors and contractors must know how to upsell the equipment to their customers. Program staff can collaborate with sales experts to help train distributors and contractors on the benefits of high efficiency equipment, focusing on the reduced first costs and long-term reduced operating costs.
- **Equipment availability** – Most contractors (67%) reported that equipment availability increased since the inception of the upstream program. Although contractors attributed many reasons for this increase, 84% of contractors agreed that the rebates were a factor in equipment availability increasing.
- **Equipment concerns** – The most commonly reported equipment concern among contractors was the lack of available replacement parts for the high-efficiency equipment, followed by more frequent customer call backs and increased maintenance needs. To address these barriers, program staff can discuss concerns regarding replacement parts with distributors and increase training to contractors on installation and maintenance concerns.

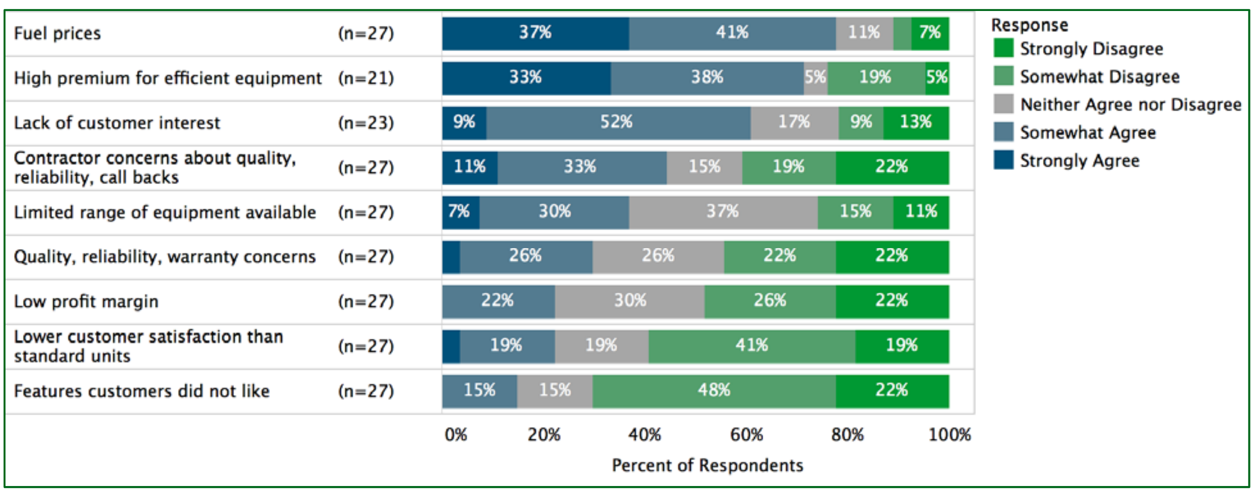

FIGURE 6-4: DISTRIBUTOR BARRIERS TO SELLING EE EQUIPMENT BEFORE THE UPSTREAM PROGRAM

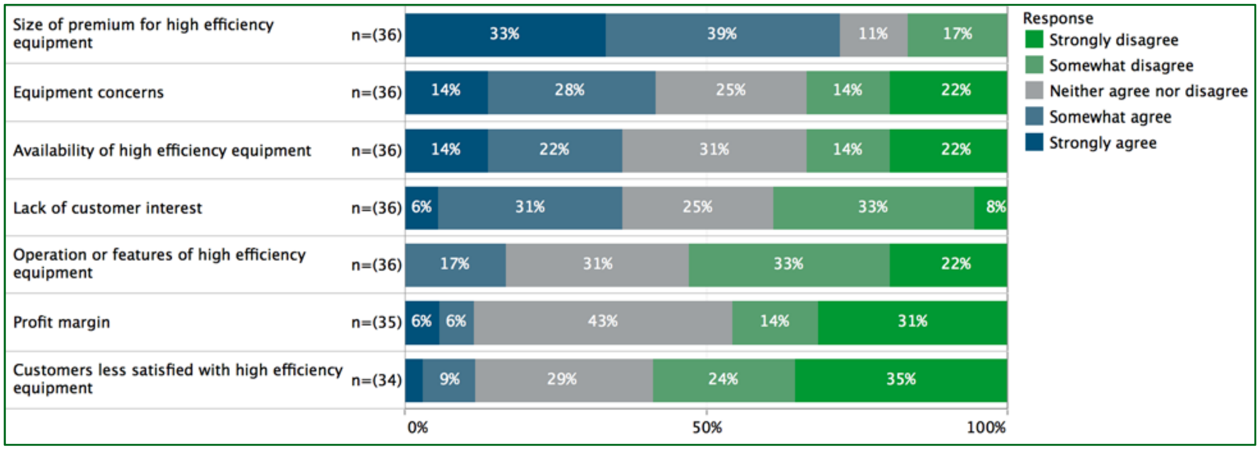

FIGURE 6-5: CONTRACTOR BARRIERS TO SELLING EE EQUIPMENT BEFORE THE UPSTREAM PROGRAM

As shown in Figure 6-6 below, the highest ranked customer barrier was the premium cost to purchase the high efficiency equipment. This finding suggests that while the rebate reduced first costs, first costs remained a barrier for many customers. As discussed previously, participants who considered long term costs and had the available capital were able to overcome this barrier. However, it is possible that first cost remains significant barrier for nonparticipating customers considering the purchase of high efficiency equipment, particularly moderate and lower-income customers.

Other nonfinancial barriers were also identified, as follows:

- **Finding a trustworthy contractor** – many customers were concerned about finding a contractor they can trust.
- **Equipment concerns** – Customers often reported that they were uncertain about the performance of quality of the high efficiency equipment and this was a barrier to participation. However, it was not commonly rated as highly as other barriers. These concerns may mirror those reported by contractors.

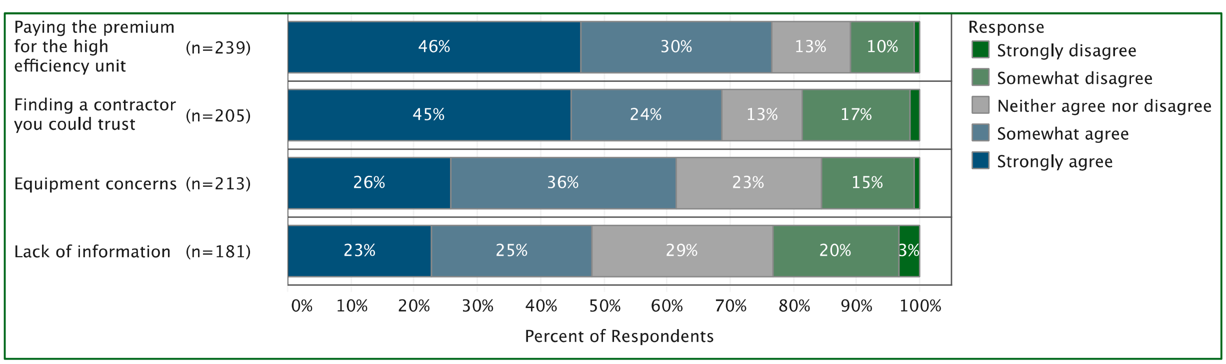

FIGURE 6-6: CUSTOMER BARRIERS TO PURCHASING EE EQUIPMENT

6.2.5 Distributor Program Experiences

Overall distributors spoke favorably of the program. However, their satisfaction was lowest among the three market actors due to the administrative burden placed on them and the time it took for them to receive the rebates. To increase distributor satisfaction, program staff can work more closely with distributors to best set expectations around program requirements – including administrative processes and rebate administration. The Evaluation Team did not originally prioritize investigating the rebate processing because this was not a concern expressed by program staff. However, distributors' dissatisfaction with this aspect of the program indicates that future research could focus on optimizing the rebate process.

Distributor Program Satisfaction

As shown in Figure 6-7, the greatest proportion of distributor respondents reported feeling very satisfied or somewhat satisfied with the program training (77%), the quality of information about the program (63%), and the enrollment process (62%). Respondents were less satisfied with the communication from the utilities (53%), the administrative process for dealing with rebates (44%) and the time taken to receive the rebates (24%). It appears that these factors had a negative impact on overall program satisfaction (53%).

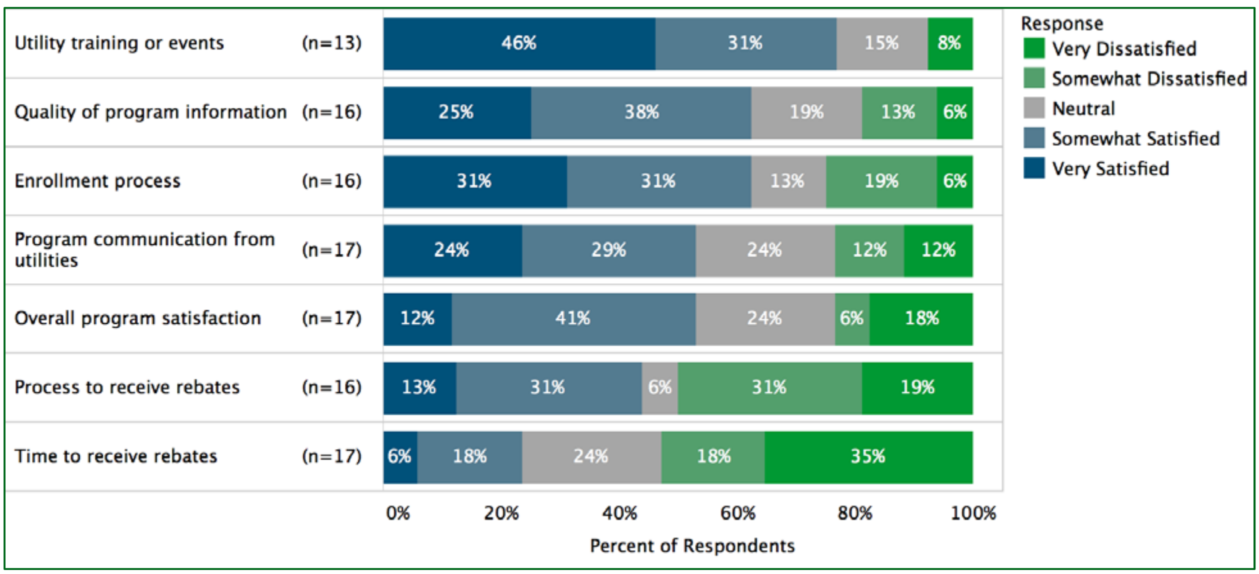

FIGURE 6-7: DISTRIBUTOR SATISFACTION WITH PROGRAM COMPONENTS

Distributors were most satisfied with the rebates associated with high-efficiency furnaces, followed by heat pump water heaters and high-efficiency boilers as shown in Figure 6-8. The lowest satisfaction rating with the rebate amount was for boiler circulating pumps, although 65% of respondents were still either very satisfied or somewhat satisfied.

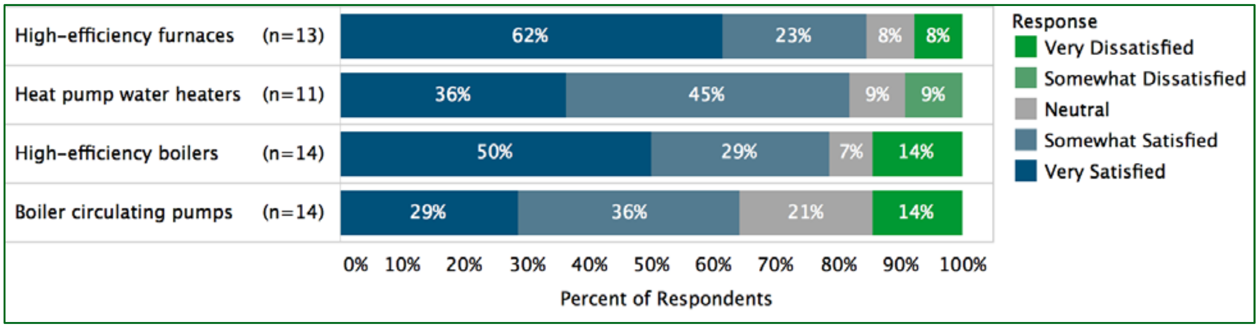

FIGURE 6-8: DISTRIBUTOR SATISFACTION WITH REBATE LEVELS

Distributor Program Administration Experiences

When asked about their experiences in administering program rebates, all the distributor respondents reported seeking rebates for all eligible projects.[64] Most respondents (59%) reported that they apply the rebate before receiving confirmation of a customer's eligibility. To process the rebates, distributors reported collecting a variety of customer and project data from their customers:

- All distributor respondents collected data on the name of the end-use customer.
- Most distributor respondents collect basic demographic data on customers and contractors.
- A smaller proportion of distributors respondents collect information on customers' service territory.
- One distributor collected information about customers' utility account number.

Because most distributors apply the rebates before the customer's eligibility is verified, it is possible that distributors are providing the rebates to ineligible customers; however, as the program covers most of the state, most of their Connecticut customers are likely to be eligible.

Distributor Program Outreach Experiences

The Evaluation Team spoke to distributors about their experiences with outreach and training events. The majority of distributors surveyed (13 of 17) reported participating in an Energize CT event in 2016 or 2017. Among the distributors who attended an event, most reported the topic to be about logistical considerations for program participation. Few distributors reported learning technical details about eligible equipment, which is not important as these are more typically geared towards contractors. Respondents who did not attend an event reported a wide variety of reasons for not attending, indicating no clear trends.

[64] One respondent did not know whether they sought rebates for all eligible projects.

6.2.6 Contractor Program Experiences

Contractor respondents reported greater program satisfaction, compared to distributor respondents, likely due to limited rebate administration burden compared to distributors.

Contractor Program Satisfaction

As shown in Figure 6-9, contractor respondents were generally satisfied with the program and mostly satisfied by the rebate amounts, which they also viewed as being the most valuable aspect of the program. They were least satisfied with the training received through the program. Contractor experiences with training are discussed in more detail later in this section.

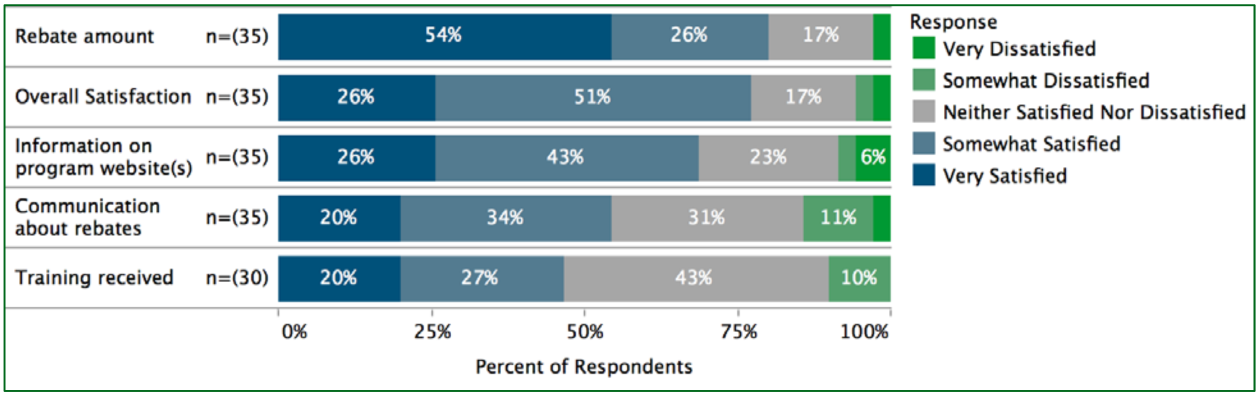

Figure 6-9: Contractor Respondent Satisfaction with Program Components

The Evaluation Team asked contractors reasons for their dissatisfaction. The Evaluation Team identified two themes:

- **Greater online support** - Four contractors reported challenges related to information available on the internet. It is unclear whether these challenges related specifically to the Energize CT or utilities websites, or to accessing general information about high efficiency equipment specifications. One contractor specifically reported that the Air Conditioning Heating and Refrigeration Institute (AHRI) directory was difficult to access and use.
- **Communication about program changes** - One contractor reported a need for better communication from the utility on program changes. Another contractor reported receiving conflicting program information between their distributor and the program's website.

Contractors were asked a variety of questions relating to how they sell high efficiency equipment to their customers. Nearly all of the contractors (95%) reported offering their customers a variety of efficiency levels; however, the efficiency levels presented to customers often depend on the customers' specific situation.

The clear majority of contractors felt that the rebate made them much more likely to recommend high-efficiency units, and only 2% of contractors felt that the availability of the rebate had no impact on their likelihood to recommend high-efficiency units. Most contractors who offered standard efficiency equipment along with rebate-eligible equipment said that they did so when customers were particularly price sensitive. Of the 40 contractors who responded to the question, only 15 (38%) said that they offer standard options as a regular practice.

Contractors were also asked how the upstream rebate supported them in selling more high efficiency equipment. The most commonly selected response was the price reduction, followed by customer interest in rebates and having a hook to start the conversation about high efficiency. Almost half of the respondents (46%) selected more than one of these three options. Only one of the 35 contractors who responded indicated that the program did not support them in any of these ways. These responses are presented in Figure 6-10.

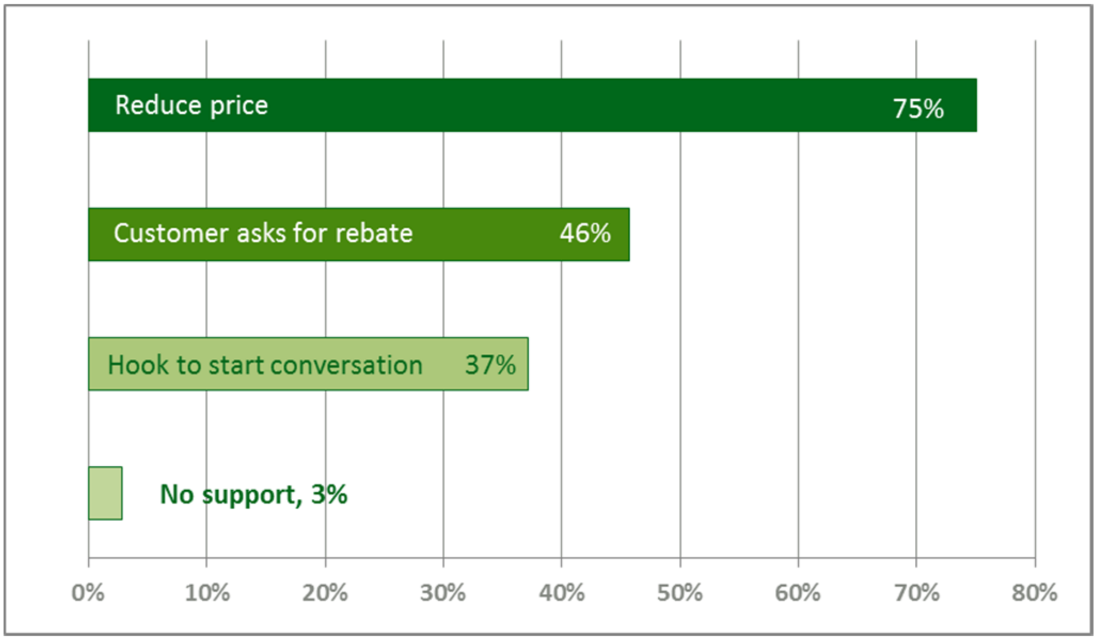

FIGURE 6-10: HOW THE UPSTREAM REBATE SUPPORTS CONTRACTORS

Contractor Program Administration Experiences

Consistent with the distributor findings, contractors reported that distributors provided most rebates at the time of purchase, while a small minority of distributors paid rebates after the time of sale. Of the 17 distributors who responded to a question about when they paid rebates, 7 (41%) reported that they typically paid rebates *after* confirming a customer's eligibility. The other 10 distributors who answered the question reported that they pay the rebates before receiving confirmation of a customer's eligibility. Figure 6-11 shows the contractor-reported percent of rebated paid at the time of purchase.

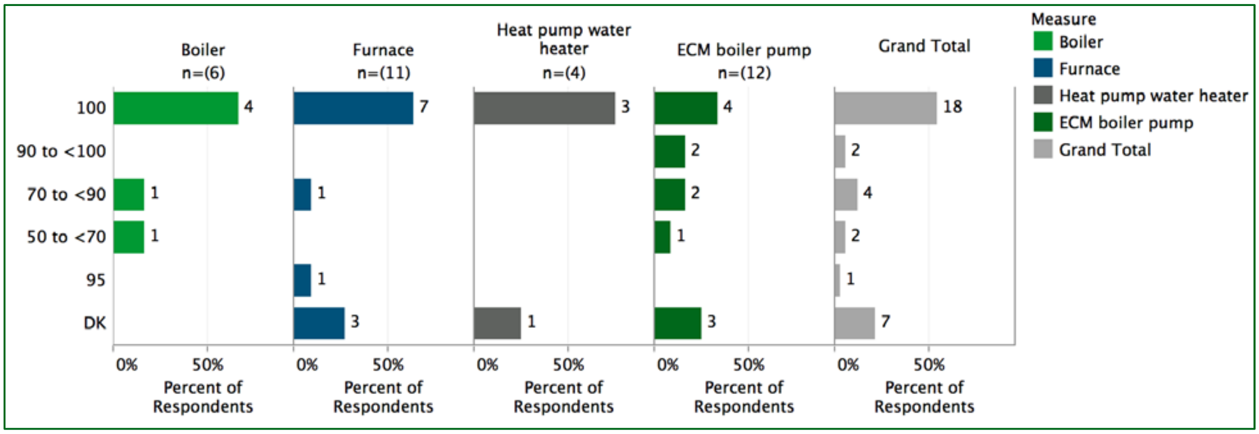

FIGURE 6-11: PERCENT OF PROJECTS PAID BY THE DISTRIBUTOR AT TIME OF PURCHASE

Contractor Program Outreach Experiences

A majority of contractor respondents reported to have attended an EnergizeCT training or outreach event within the last year. Most of these respondents reported the training covered topics related to program logistics: the rebate amounts, the eligibility requirements, and other data requirements associated with the program. Slightly over one-third of the contractors who attended a training event reported they learned technical details about equipment installation. When contractors did receive training on equipment, it was most often training on condensing boilers, followed by heat pump water heaters.

Contractors who had not attended a training event reported the following reasons:

- Not aware of the training event (63%)
- Information was easier to obtain elsewhere (38%)

Of the 28 contractors who provided recommendations for future training, 4 reported that they would like additional training in program logistics, with slightly fewer reporting that they would like technical training on eligible equipment installation and maintenance.

6.2.7 Customer Program Experiences

Customers were highly satisfied with a number of different program components. Questions focused on their experiences with their contractor, the equipment, savings on their energy bills, and the rebate values. Boiler and furnace respondents were asked about their satisfaction with both the energy cost savings and the rebate values.[65] A majority of the respondents were either very satisfied or satisfied with the rebate values. However, a larger share of furnace rebate recipients was very dissatisfied (9%) or neutral (18%). Below, Figure 6-12 shows customer satisfaction with contractors and the rebate amount.

[65] The evaluation team did not ask customers who purchased heat pump water heaters this question to prioritize other evaluation needs.

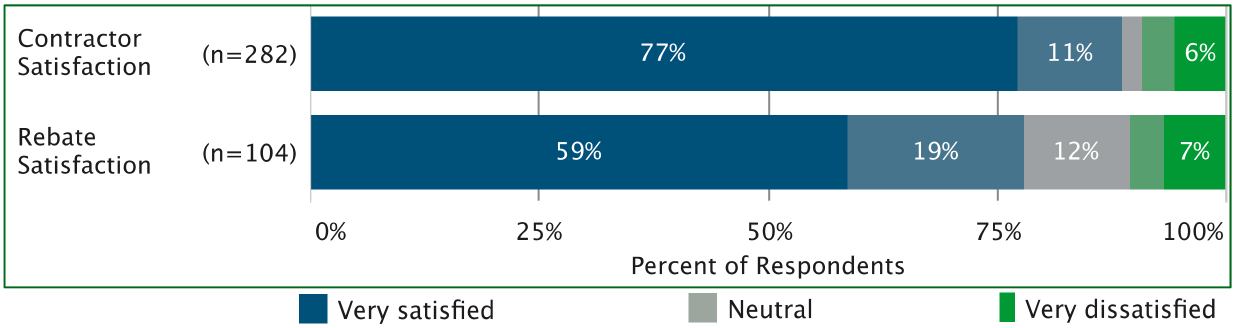

FIGURE 6-12: CUSTOMER SATISFACTION WITH CONTRAC

Participants also reported their perceptions of their e... compared to the system they had before. The overwhelming majority (90%) furnace customers reported their energy bills were lower after installing the ... equipment, as shown in Figure 6-13.

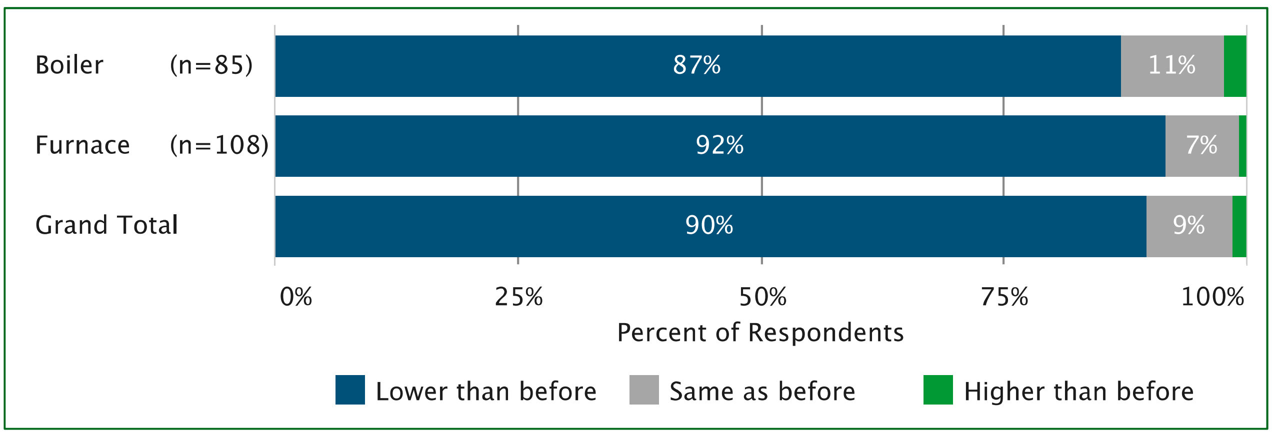

FIGURE 6-13: UTILITY BILL COSTS COMPARED TO PREVIOUS SYSTEM

When asked about specific details about their experiences with their contractors, most customers were satisfied. The single category with low satisfaction rates was the contractor's explanations of the Energize CT offerings.[66]

Overall, the overwhelming majority of all customers were at least somewhat satisfied with their equipment (95%), and over four-fifths were very satisfied (83%). Figure 6-14 shows customer satisfaction with the equipment purchased through the program.

[66] While this was the lowest rated score, 68% of customer respondents remained satisfied with the contractor's ability to provide program-related information.

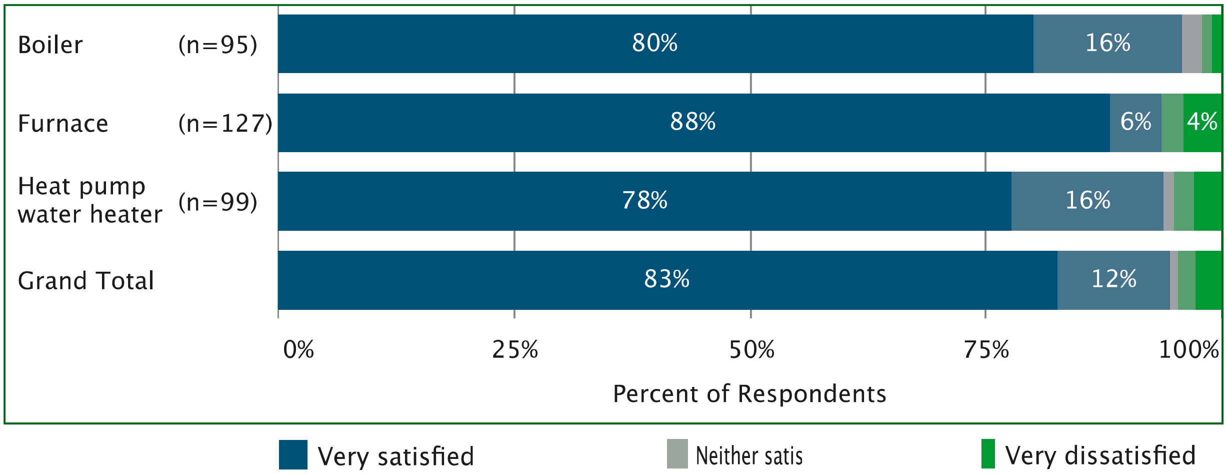

FIGURE 6-14: CUSTOMER SATISFACTION WITH EQUIPMENT

7 Program Comparisons

The CT Residential HVAC and Water Heating Program is one of a small number of energy efficiency programs focused on incentivizing HVAC equipment through an upstream/midstream channel. The Evaluation Team identified several programs with similar focus and delivery mechanism.

This section also provides a comparison of the results from this current evaluation to evaluations conducted for two previous peer programs. Due to the limited number of upstream residential programs currently in existence, most of these programs have a commercial/industrial focus.

The final section provides a comparison of Connecticut PSD measure-level savings to the technical reference manuals from three other New England states.

7.1 Program Summaries

The Evaluation Team identified six programs that were comparable to the Residential HVAC and Water Heating Program in Connecticut, as summarized in Table 7-1. Many of these programs operated similarly to the CT program. The main difference appears to be whether the programs require distributors to pass on the incentive to customers.

TABLE 7-1: PEER PROGRAM COMPARISONS

Utility (State)	Sector Focus[a]	Pass-through requirements	Market actor focus	Measures	Training offered
CT EEB (CT)	R	Yes, at time of sale	Distributors	Space Heating, Water Heaters, Heat Pump Water Heaters	Yes, to distributors and contractors
PG&E (CA)	C	No	Distributors	HVAC	Yes, to distributors
PSC of NM (NM)	C	Yes, at time of sale	Distributors	Packaged terminal AC (PTAC) Packaged terminal heat pumps (PTHP) Unitary and split AC Air source heat pumps	Yes, to participating distributors and contractors
CenterPoint Energy (TX)	R	No[b]	Distributors	AC Heat pumps	NA[c]
MassSave (MA)	C	No	Distributors and Manufacturers	AC, heat pumps, VRF systems, ECM pumps, dual enthalpy economizers	Yes[d]
Xcel Energy (CO)	C	No	Distributors	HVAC	No

a "R" represents residential sector, "C" represents commercial sector.

b Online research indicated no requirement to pass on incentive; however the Evaluation Team did not conduct peer program interviews to confirm this.

c Online research did not determine whether the utility provides training.

d The program website described trainings broadly, the evaluators did not confirm the audience.

PG&E Commercial/Industrial Upstream HVAC Programs

PG&E has utilized an upstream market strategy to encourage the adoption of efficient HVAC equipment by C/I customers since 1998. The program grew out of a need to address stocking limitations in the HVAC market, which supported the sales of less expensive, standard efficiency equipment for replace-on-failure scenarios, since these units were typically stocked by distributors and required less lead time for installation. The combination of higher price and long delivery times for high efficiency units created serious market barriers to greater adoption of efficient equipment.

Early iterations of the PG&E program had rebates paid directly to distributors with the assumption that the price reductions would pass through from the distributor to the customer. This approach allowed participating distributors to sell premium efficient HVAC equipment for close to the same price as standard equipment, or at a small price premium. PG&E expended effort to recruit and train distributors, and focused on ongoing communication to distributors participating in the program. Though detailed data are not available, it is estimated that energy efficient packaged HVAC systems achieved a much higher market share through the upstream program compared to years when a downstream rebate was used instead.

Public Service Company of New Mexico Midstream Commercial HVAC Program

In 2015, Public Service Company of New Mexico (PNM) implemented a midstream commercial HVAC program for the installation of packaged terminal AC (PTAC), packaged terminal heat pumps (PTHP), unitary and split AC, and air source heat pumps. The customer receives a rebate instantly "at the time of purchase - and doesn't have to complete any paperwork," and distributors receive program incentives within two weeks of reporting the transaction. The rebate amount is determined by heating/cooling capacity and a two-tiered efficiency rating. Rebate amounts vary from $30 for small units to $2,400 for larger units. As of August 2015, the program had six participating HVAC distributors. The estimated net-to-gross ratio in the program's first year was 90%, while in 2016 it was 80%. In addition to paying incentives, PNM conducts several training sessions each year for participating trade allies in which the program processes are reviewed and technical training is provided on new efficiency approaches. Although PNM does not currently offer a residential version of this program, they may consider transitioning residential HVAC incentives to the midstream channel in the future.

CenterPoint Energy (TX) A/C Distributor Program

The CenterPoint Energy A/C Distributor Program provides incentives to HVAC distributors who promote the installation of high efficiency AC units and heat pumps in single-family homes, multi-family homes, and small businesses within CenterPoint Energy's electric service territory.[67] Incentives of up to $1,420 are available per qualified system, which may include AC systems between 1.5 tons and 5 tons that are installed in retrofit jobs (equipment for new construction does not qualify). The program requires AHRI-matched residential and small

[67] Source: http://www.centerpointenergy.com/en-us/residential/save-energy-money/electric-efficiency-programs/a-c-distributor-program?sa=ho

commercial systems that meet or exceed guidelines of A/C systems: minimum 16 SEER/12 EER, 1.5 to 5 tons; Heat pump systems: minimum 16 SEER/12 EER/8.6 HSPF, 1.5 to 5 tons. The program does not pay incentives directly to customers, and there is no indication of whether the distributor is required to "pass-through" the incentive they receive.

MassSave (MA) Commercial Upstream HVAC/HP Initiative

MassSave's statewide Commercial Upstream HVAC/HP Initiative began in 2013, after the successful implementation of a statewide upstream lighting program. The program covers several types of commercial air conditioning and heat pump units, including VRF systems, ECM Pumps and dual enthalpy economizers. The program design is very similar to the CT Residential HVAC and Hot Water Heater program in that incentives are paid directly to distributors/manufacturers for the sale of eligible units. However, the program design differs in that there is no "pass-through" requirement for distributors/manufacturers to pass this incentive along to contractors or customers.

By comparison, the MassSave program is larger than the CT program. In 2013, the utilities paid out $400,000 in incentives for just over 1 million kWh of gross annual savings (40 cents per gross annual kWh). The program moved a combined total of 960 pieces of HVAC equipment in 2013. As of February 2014, program participation represented nearly all manufacturers and distributors selling in the Massachusetts market (approximately 47 participating distributors and manufacturers). In addition to paying incentives directly to distributors/manufacturers, the program provides a wide range of services; incentives, trainings, and information promoting energy efficiency to help residents and businesses manage energy use.

Xcel Energy - Colorado Commercial Cooling Efficiency Program

The Xcel Energy Commercial Cooling Efficiency program in Colorado consists of two main offerings: (1) a traditional downstream rebate offering, including both prescriptive and custom rebates paid to participating customers and (2) a newer midstream offering where incentives are paid directly to participating distributors. The downstream offering has been in operation since 2008, while the midstream offering was launched in Q4 2015. The two offerings (midstream and downstream) are designed to impact the market in different ways. The downstream rebate offering is primarily targets first-cost barriers associated with the purchase of high efficiency equipment by end users. In contrast, the midstream offering is primarily targeted at changing stocking and upselling practices by distributors and contractors in the middle of the supply chain. In this program, incentives are paid directly to the distributor for sales of qualifying HVAC units to customers within the Xcel Energy service territory in CO. There is no pass-through requirement for the incentives.

7.2 Comparison to Peer Program Evaluations

The Evaluation Team was unable to obtain evaluation results on many of the programs presented above. However, we do provide a brief comparison of the current evaluation to the evaluation conducted for the California program below.

Comparison to the California IOUs' 2013-2014 Upstream HVAC Programs

The evaluation of the California 2013-2014 Upstream HVAC Programs took a very similar approach as the current evaluation, utilizing the concept of "causal pathways" in measuring program influence. These causal pathways were dependent on the actions and attitudes of both the seller (i.e., the distributor) and the buyer (i.e., the contractor or customer). To assess the influence of each of these pathways, the Evaluation Team conducted interviews with distributors and surveys with customers (buyers). After these data collection activities were completed, the distributors and their associated buyer were linked together at the transaction level to compute a joint attribution score. These scores were then extrapolated up to the population. This resulted in an overall NTGR of 64% for the upstream program.

In that evaluation, the Evaluation Team computed an overall NTGR instead of a measure-specific NTGR (because the sample for some measure types was too small to compute a measure-specific NTGR and because little variability was found between measure categories). Table 7-2 shows how each of the causal pathways contributed to this overall value.

TABLE 7-2: ATTRIBUTION SCORES BY CAUSAL PATHWAY (CA 2014 UPSTREAM PROGRAM)

Causal Pathway	Distributor Attribution	Buyer Attribution
Stocking	35%	21%
Upsell	26%	81%
Price	54%	98%
Efficiency (consistency check)	-	4%
Sales (consistency check)	41%	-

These results show a fairly significant contribution from the price reduction (98% buyer attribution) and upselling (81% buyer attribution), but also indicate that 35% of distributors' high efficiency stock was due to the program, and that 21% of buyers were impacted by a distributor's stocking decisions during their purchase.

7.3 Comparison of Savings Estimates to Other States

The Connecticut PSD savings were compared to the Technical Reference Manual's used in other New England states, as shown in Table 7-3. This comparison covered the following documents:

- Connecticut Program Savings Document, 2017 version, October 31, 2016
- Vermont Technical Reference Manual, version 2016-92, August 10, 2016
- Maine Technical Reference Manual, version 2016.3, effective July 1, 2015
- Massachusetts Technical Reference Manual, 2016-2018 version, October 30, 2015

This comparison shows that most of the other states were using higher baseline efficiencies for boilers and efficiencies and lower energy factors for the heat pump water heaters.

Table 7-3: Comparison to PSD Savings to Other New England States

Measure	State/TRM	CT	VT	ME	MA
Furnace	MMBtu	14.1	6.3	17.5	8.1
	Annual Consumption/ Efficiencies	66.6 MMBtu/yr 82% Baseline N/A Efficient	75 MMBtu/yr 88% Baseline, 95% Efficient	121 MMBtu/yr[1] 80% Baseline, 95.5% Efficient	N/A 85%/78% Baseline 95% Efficient
Boiler	MMBtu	11.5	10.2	13	12.8
	Annual Consumption/ Efficiencies/ DHW savings	66.6 MMBtu/yr 82% Baseline Incl. partial DHW	101 MMBtu/yr 85% Baseline 95% Efficient DHW unknown	121 MMBtu/yr[1] 84% Baseline 93% Efficient No DHW	Study results 95% Efficient Incl. DHW
ECM Pump	Annual kWh	285	87	N/A	142
	Winter kW	0.056	0.03	N/A	0.013
ECM Fan	Annual kWh	385	675	N/A	168
	Winter kW	0.09	0.123	N/A	0.019
	Summer kW	0.12	0.224	N/A	-
	MMBtu	0	0	N/A	-0.72
	Notes	Central AC	Central AC		No AC
HPWH	Annual kWh	1,675	1,443	1,687	1,654
	Winter kW	0.201	0.229	0.374	0.34
	Summer kW	0.171	0.116	0.175	0.16
	MMBtu	0	-3.3	0	0-
	Average Energy Factor	2.68	2.43	2.35	N/A

1 These calculation were based on heating system capacity and FLH, converted to MMBtu/yr for comparison

8 Conclusions and Recommendations

The fundamental question for implementers is how to improve the savings from this program. The integration of process and impact evaluation involves matching the reasons that savings are not being achieved with possible actions that could be taken by the program staff to improve the savings.

The options for improving savings are dictated by the program design, as some of reasons for reductions in savings identified through the impact evaluation are outside of the control of program staff. For example, the baseline for furnaces and boilers was found to be substantially higher than assumed in the PSD. This evaluation result requires a change to the PSD assumptions, but there is no way to change the baseline through modifying the program design or implementation. On the other hand, some installation issues, such as educating customers about using the modes on the heat pump water heaters, may be addressed through enhanced contractor training.

As shown in Table 8-1, one of the findings from the process evaluation dovetails nicely with the impact and NTG analysis to suggest some ways that savings could be improved.

TABLE 8-1: INTEGRATION OF PROCESS AND IMPACT FINDINGS

Process Finding	Program Action to Improve Savings	Impact Finding	Type of Savings
Contractors would like more engagement with the program	Provide additional, targeted technical training for contractors	Metering and site visit inspection helped to identify specific technical issues to be addressed	Gross
Contractors expressed concerns about finding replacement parts	Ensure distributors are stocking replacement parts	Contractors and homeowners mentioned specific equipment failures	Gross

A key strategy for improving program savings given the upstream rebate design is to expand contractor training to cover technical issues that are depressing the savings and strengthen upselling strategies to improve gross savings. In addition, distributors can be encouraged to stock replacement parts. The sections below explore the approach to improving gross savings.

8.1 Improving Gross Savings

Metering heat pump water heaters, boilers and boiler circulating pumps provides the Evaluation Team with direct information about the operation of the equipment and allows us to identify some possible areas for contractor training. Table 8-2 below summarizes the evaluation results for the gross savings by measure. The key below the table indicates the color associated with the magnitude of the adjustment and the arrow indicated the direction of the adjustment to the measured savings. The rightmost column indicates whether there may be potential for improving savings through contractor training or other mechanisms.

TABLE 8-2: REASONS FOR GROSS SAVINGS ADJUSTMENT BY MEASURE

Measure	Change in Gross Energy Savings	Baseline	Metering	Billing Analysis	Potential for Increased Savings
Furnace	-19%	↓ (High Impact)		↑ (High Impact)	Unknown - billing analysis/baseline only
Boiler	-31%	↓ (High Impact)	↓ (Moderate Impact)	↑ (High Impact)	**Yes - improve condensing in some homes**
Boiler Circulating Pump	-76%	(No Change)	↓ (High Impact)		**Yes – many installed in low use locations, also could reduce number of pumps**
Heat Pump Water Heater	+8%	Elec. ↓ Foss.Fuels ↑ (High Impact)	↑ (Moderate Impact)		**Yes - improve info on modes, and installation location**
Furnace Fan	+25%	↓ (High Impact)		↑ (High Impact)	Unknown – AMI analysis/baseline only

High Impact ↑ Savings went up
Moderate Impact ↓ Savings went down
No Change

Each of the measures with potential for additional savings is discussed below, with suggestions for improving savings per unit. The following discussion covers the potential increase in net savings.

8.1.1 Boilers

The program savings is based on the manufacturer-specified AFUE as the installed efficiency reported to the program. High efficiency boilers achieve their rated efficiencies when the flue gas temperature is lowered in the heat exchanger to the point where condensate forms. Depending on the setup or location, condensing may occur less often than expected or not at all if the flue gas temperature is too high. A minority of the boilers were not condensing properly, resulting in a net average downward adjustment in efficiency of about 2%.

Contractor training could be designed to try to address the issues with installing condensing boilers. Some possibilities to include in the contractor training are as follows:

- Site inspection conducted with the metering suggests that outside boiler reset controls are not consistently installed; while these controls are not effective in all situations, educating contractors about when it is appropriate to install these controls could increase savings.
- Other strategies may include downsizing the boiler, review programming strategies for modulating boilers or lowering the supply temperature (if feasible)

Bringing in a knowledgeable contractor with direct experience to assist with the training materials may be productive.

8.1.2 Boiler Circulating Pumps

The main finding from the metering is that boiler circulating pumps are used substantially less than assumed. Many of the efficient models were installed on zones that are used very little. In addition, the efficiency of standard pumps has improved over time. Some possibilities for improving savings include the following:

- Recommend standard pumps for applications where the circulating pump is not expected to be in regular use
- Design the circulating loops with one circulating pump and zone valves; this approach will reduce the number of pumps and associated costs, and increase the per unit savings

Simply informing contractors of the low use for these pumps found in this evaluation could bring awareness to the issue.

8.1.3 Heat Pump Water Heaters

While the metered per unit savings were slightly higher than estimated in the PSD, customers expressed lower satisfaction with specific aspects of the water heaters. Enhanced contractor training may address some of these issues along with potentially increasing program savings. Some of the specific topics for heat pump water heaters are covered below.

- Modes: units are shipped in hybrid mode but savings are higher in heat pump mode in homes with more than two occupants; contractors should be discussing how and why to change modes with the customer
  - almost 40% of the surveyed customers who used a contractor reported that the contractor did not discuss the modes
  - almost 20% of these surveyed customers were not aware that there were different modes, whereas 10% of surveyed customers who installed the units themselves reported[68] that they were unaware of the different modes
  - Contractor training could emphasize the importance of discussing the modes and how to change them with the customers
- Size of room: manufacturers specify that the units should be installed in an area of not less than 200 square feet
  - About 12% of the units from metering and from the survey were installed in smaller spaces[69]

[68] This also includes respondents who had a friend or family member install the equipment.
[69] The sample of homes with on-site metering was too small to provide an estimate of the difference in COP due to the size of the room.

- Emphasizing options for working with space constraints where needed, such as adding louvered doors, could be helpful
- Providing clarity about when the heat pump water heater is not an appropriate installation could avoid some problematic installations

Addressing these issues with contractor training may improve the installation and increase savings.

8.2 Recommendations

8.2.1 Program Recommendations

Improve Program Tracking

Issues with the data quality had substantial effects on the evaluation. In addition, it is critical to maintain a connection between the rebate and the location of the installation to allow for verification. The evaluation team understands that this is not always possible in the upstream program design. Program designers and evaluation managers need to set expectations around requirements for end user contact information and its impacts on verification efforts. Specifically, the following changes should be made:

1. Improve QC to ensure that the information in the field is consistent with the definition of the field, e.g., check that the distributor's name is in the distributor field rather than the rebate processor or contractor
2. Designate unique keys to identify the end user, contractor and distributor, and ensure that the end user records can be directly tied to the utility billing system
3. Develop a standardized list of contractor and distributor names to be used consistently
4. Ensure that end user name and address are consistently collected for heat pump water heaters, to the extent possible within the upstream program design

Improve Rebate Processing

The overall satisfaction rating for distributors (53%) was substantially affected by low ratings for rebate processing, the time it took to receive the rebate and communication from the utilities. To sustain participation among distributors, program managers can improve communication to establish clear expectations with distributors around rebate requirements and timelines.[70]

Expand Contractor Training

Contractors expressed an interest in attending trainings offered by the utilities or third parties that increase their employee's technical knowledge of efficient products and familiarize them with program processes and requirements. Some possible areas for technical training to increase savings include the following:

[70] The utilities reported that since developing these findings, improvements have been made to the distributor rebate process.

- Installing condensing boilers to maximize the efficiency
- Avoiding high efficiency boiler circulating pumps in low use locations and reducing the number of circulating pumps where possible
- Providing more information to customers on how to use the modes on the heat pump water heater and ensure that the water heater is installed to meet manufacturer's specs

More frequent administrative trainings may also help to disseminate information about program changes in a timely way. Additionally, since customers can still face first cost barriers despite program incentives, the utilities could also provide trainings to contractors on non-monetary benefits to help them to upsell efficient equipment to their customers.

Encourage Distributors to Stock Replacement Parts

Contractors expressed concerns about equipment issues associated with the high efficiency equipment, including having trouble finding replacement parts. To address these equipment concerns barriers, program staff can work with distributors to stock replacement parts and increase training to contractors on installation and maintenance concerns.

8.2.2 Evaluation Recommendation

Conduct Further Research into the NTG for the Tiered Boiler Incentives

In 2017, the utilities made a change to the incentive structure for efficient boilers from a single incentive of $750 for all boilers with an efficiency greater than 90% to a two-tiered system with an incentive of $450 for boilers with rated efficiencies from 90% to 93.9% and $750 for efficiencies of 94% or greater. Eversource provided additional data showing a substantial increase in the percent of rebates for the higher efficiency boilers in 2017 as compared to 2016 and prior years (from about 40% to about 80%), suggesting that an adjustment to the NTGR was required. However, as this change to the incentive structure occurred outside the evaluation period, there was no primary research into the impact of this change.

In this evaluation, an adjustment to the NTGR for very high efficiency boilers was made based on the limited information available from the utilities. Future evaluation efforts are needed to develop a more defensible estimate of the NTGR.

8.2.3 Recommended Changes to the PSD

The recommended changes to the PSD are summarized in the tables below. The heating system measures are combined in Table 8-3 and the changes to the heat pump water heater are shown in Tables 8-4 and 8-5.

TABLE 8-3: SUMMARY OF RECOMMENDED CHANGES TO PSD FOR HEATING SYSTEM MEASURES

Measure	Input	2015/2017 PSD	2017 PSD Alternative	Recommended PSD
Furnace	Baseline AFUE	82%	85%	85%
	Heating factor (Btu/ft^2) x Average area heating by furnace (ft^2)	66.6 MMBtu/yr	55.1 MMBtu/yr	77.5 MMBtu/yr
Boiler	Baseline AFUE	82%	85%	85%
	Efficient AFUE	Rated efficiency from program tracking	Use regression to adjust installed efficiency	Adjust rated efficiency downward by 2%
	Heating factor (Btu/ft^2) x average area heated by boiler (ft^2)	66.6 MMBtu/yr	92.8 MMBtu/yr	85.2 MMBtu/yr
	Annual hot water load	11.2 MMBtu	11.2 MMBtu	No change
Circulating Pump	Annual kWh	285	N/A	68
	Winter Peak kW	0.056	N/A	0.024
	Summer Peak kW	0.000	N/A	0.000
Furnace Fan (ECM)	Winter kWh	293	N/A	321
	Summer kWh	55	N/A	45
	Total Annual kWh	348	N/A	366
	Winter Peak kW	0.090	N/A	0.118
	Summer Peak kW	0.072	N/A	0.0.065

The PSD provides the deemed savings for heat pump water heaters. We recommend that the deemed savings be updated to match the evaluation results. Tables 8-4 shows the recommended changes using either a baseline electric or fossil fuel water heater.

TABLE 8-4: RECOMMENDED CHANGES TO THE PSD FOR HPWH ENERGY SAVINGS

		Recommended Changes			
	2017 PSD[1]	Electric Baseline	Propane[2]	Oil[2]	Reason
Gallons per year(GPY)	19,839	15,415	15,415	15,415	Metering
$T_{dhw} - T_{aiw}$ (ΔT)	68	75	75	75	Metering/site visit measurement
Baseline Energy Factor (EF_b)	0.945	0.95	N/A	N/A	Manufacturer's specs
Efficient Energy Factor (EF_i)	2.68 or manufacturer specifications	2.46 or manufacturer specifications	2.46 or manufacturer specifications	2.46 or manufacturer specifications	Metering
P (heating penalty and recovery adjustment)	0.90	1.00	N/A	N/A	PSD assumption; no evidence to support
Annual kWh Savings	2,112	1,818	-1,418	-1,418	Calculated from above inputs[3]
Fossil Fuel Energy Factor (EF_{ff})	N/A	N/A	0.77a	0.65	Average of available units
Fossil Fuel Adjustment Factor (AF_{ff})	N/A	N/A	1.24	1.24	Adjustment for extra use
Annual MMBtu Savings	0	0	14.9	17.7	

[1]*Connecticut Program Savings Document*, 12th Edition for 2017 Program Year, the United Illuminating Company, page 300
[2] The calculations for the fossil fuel MMBtu savings and kWh extra use are given below.
[3] The kWh savings were estimated directly from the metering. The inputs into the PSD calculations were adjusted to match the metered energy savings as closely as possible.
a The EF for propane is a blended rate between on demand and stand-alone units.

Table 8-5 lists the recommended changes for the winter and summer kW peak reduction. [71]

[71] The ISO-NE Forward Capacity Market winter peak period is from 5:00 PM to 7:00 PM in December and January and the summer peak period is from 1:00 PM to 5:00 PM in June, July and August. The FCM also has the option of bidding in savings for the seasonal peak, which is based on kW that can be removed from the grid at specific hours when the grid is most constrained. This value was not calculated as there are currently no provisions in the program to control the heat pump water heater loads.

TABLE 8-5: RECOMMENDED CHANGES TO THE PSD FOR HPWH SEASONAL PEAK DEMAND REDUCTION

		Recommended Changes			
	2017 PSD[1]	Electric Baseline	Propane[2]	Oil[2]	Reason
Gallons per hour (GPH)	1.96	1.98 Winter/ 2.50 Summer	1.98 Winter/ 2.50 Summer	1.98 Winter/ 2.50 Summer	Metering/seasonal adjustment
$T_{dhw} - T_{aiw}$ (ΔT)	81 Winter/ 60 Summer	75	75	75	Metering/site visit measurement
Baseline Energy Factor (EF_b)	0.945	0.95	N/A	N/A	Manufacturer's specs
Efficient Energy Factor (EF_i)	2.68 or manufacturer specifications	2.46 or manufacturer specifications	2.46 or manufacturer specifications	2.46 or manufacturer specifications	Metering
P (heating penalty and recovery adjustment)	0.90	1.00	N/A	N/A	PSD assumption; no evidence to support
Seasonal Peak kW Reduction	.244 Winter/ .185 Summer	.234 Winter/ .296 Summer	-0.151 Winter/ -0.169 Summer	-0.151 Winter/ -0.169 Summer	Calculated from above inputs[3]
Fossil Fuel Adjustment Factor (AF_{ff})	N/A	N/A	-1.03 Winter/ -0.91 Summer	1.03 Winter/ 0.91 Summer	Adjusts for increased electric use

[1] *Connecticut Program Savings Document*, 12th Edition for 2017 Program Year, the United Illuminating Company, page 300
[2] The calculations for the fossil fuel MMBtu savings and kWh extra use are given below.
[3] The seasonal peak kW reduction was estimated directly from the metering. The inputs into the PSD calculations were adjusted to match the metered savings as closely as possible.
a The EF for propane is a blended rate between on demand and stand-alone units.

The calculations for the MMBtu savings and the extra electric use associated with installations in homes with a fossil fuel baseline are shown in Equations 8-1 through Equation 8-3 below.

EQUATION 8-1

$$MMBtu\ Savings = \frac{GPY\ x\ \Delta T\ x\ 8.3\frac{lbs}{gal}\ x\ 1.0\ \frac{Btu}{°F}\ /\ EF_{FF}}{3{,}412\ Btu/kWh}$$

EQUATION 8-2

$$kWh\ Extra\ Use_{FF} = \frac{GPY\ x\ \Delta T\ x\ 8.3\frac{lbs}{gal}\ x\ 1.0\ \frac{Btu}{°F}\ x\ AF_{ff}/\ EF_i}{3{,}412\ Btu/kWh}$$

EQUATION 8-3

$$Seasonal\ Peak\ kW\ Extra\ Use_{FF} = \frac{GPH\ x\ \Delta T\ x\ 8.3\frac{lbs}{gal}\ x\ 1.0\ \frac{Btu}{°F}\ x\ AF_{ff} / EF_i}{3{,}412\ Btu/kWh}$$

The blended baseline accounts for the incidence of baseline water heaters from the homeowner survey.[72] The blended baseline can be used when the fuel type of the baseline water heater is unknown. To calculate savings from the blended baseline, first calculate the savings from the electric and fossil fuel baselines using the inputs in Tables 8-4 and 8-5 and Equations 8-1 to 8-3, and then combine the results as shown in Equations 8-4 to 8-6.

EQUATION 8-4

$$Annual\ kWh\ Savings_{blended} = 0.74\ x\ kWhSavings\ _{electric} - 0.26\ x\ kWhExtraUse_{fossil\ fuels}$$

EQUATION 8-5

$$Annual\ Peak\ kW\ Savings_{blended} = 0.74\ x\ kWSavings\ _{electric} - 0.26\ x\ kWExtraUse_{fossil\ fuels}$$

EQUATION 8-6

$$Annual\ MMBtu\ Savings_{blended} = 0.74\ x\ 0\ MMBtuSavings\ _{electric} + 0.13\ x\ MMBtuSavings_{propane} + 0.13\ x\ MMBtuSavings_{oil}$$

Please note that there are no MMBtu savings for the electric baseline.

[72] Assuming that the prior water heater is the baseline may not be an accurate assessment of the baseline. For example, a homeowner with an oil integrated water tank that failed may well decide to replace it with an electric resistance heater. The survey investigated the different water heaters considered by the homeowners and incorporated these findings into the baseline.

9 Glossary

Annual runtime –Total hours the equipment runs in a year.

Annual Fuel Utilization Efficiency (AFUE) – A measure of thermal efficiency that attempts to represent the seasonal average efficiency of a heating system. Heating system ratings are presented as an AFUE value.

Billing Analysis – A statistical regression analysis using utility billing consumption data to quantify gross energy savings.

Coefficient of Performance (COP) – A measurement of efficiency used for heat pumps, refrigerators, or air conditioning. COP is a ratio of useful heating or cooling to the work required.

Coincidence Factor (CF) – The percent of time that equipment is running during a particular period; used in calculating demand savings during the winter and summer peak periods.

Electronically Commutated Motor (ECM) – Also known as brushless electric motors, use electronic rather than mechanical controls. Because of this they are more efficient, less noisy, and generally have a longer life than brushed motors.

Energy Factor (EF) – A rating of efficiency used for water heaters based on the hot water produced per unit of fuel in a day. Calculated based on a DOE testing methodology and includes standby and other losses. It is not dependent on temperature as the test is done at a set ambient temperature. Standard electric resistance water heaters typically have an EF of 0.9-0.95.

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.

Free riders - A free rider is a program participant who would have implemented the program measure or practice in the absence of the program. Free ridership refers to the percentage of savings attributed to customers who participate in an energy efficiency program but would have, at least to some degree, installed the same measure(s) on their own if the program had not been available.

Full Load Hours (FLH) – The equivalent number of hours the equipment operates at full load in a year. Actual runtime will be higher if the equipment operates at a variable load.

Net-to-gross/Net-to-gross ratio (NTG/NTGR) – The net to gross ratio is used to calculate the net program impacts after accounting for the program influence (spillover and free ridership).

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

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

Spillover (SO) _ - Refers to the energy savings associated with energy efficient equipment installed by consumers who were influenced by an energy efficiency program, but without direct financial or technical assistance from the program. SO includes additional actions taken by a program participant as well as actions undertaken by nonparticipants who have been influenced by the program.