HPwES On Bill Recovery Impact Evaluation

Final Report

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1 Introduction

On-Bill Recovery (OBR) was started in 2012 to offer Home Performance with ENERGY STAR® (HPwES) program participants the opportunity to obtain financing for qualified measures and make the payments on their utility bills. To be eligible for OBR financing, the estimated average monthly savings from the energy efficiency improvements must equal at least one-twelfth of the annual loan payment, using the program reported savings. OBR projects tend to be larger in scope than HPwES projects as a whole.

The evaluation period includes projects completed between January 2014 and September 2016 (inclusive). A summary of the evaluation objectives and methods is provided in Table 1 below.

Table 1: Summary of Objectives and Methods

Description	Purpose	Method
Estimate gross impacts	Establish reliable first year savings for OBR participants for both electricity and natural gas	Billing analysis
Investigate program savings	Research potential reasons that program reported savings are not achieved	Review of program modeling files
Cash flow analysis	Assess whether the OBR loans are cash flow positive	Comparison of loan amounts and achieved savings

1.1 Program Description

The Home Performance with ENERGY STAR® Program ("HPwES" or "Program") encourages owners and tenants of existing one- to four-family homes to implement comprehensive energy efficiency-related improvements working with contractors accredited by the Building Performance Institute and participating in the HPwES program.

Starting in 2010, participating in the HPwES program involved the following steps:

- An interested household requests a home energy audit.
- A participating HPwES contractor carries out the home energy audit

- Based on the audit, the participating contractor creates a building model in TREAT or Real Home Analyzer and uses the model to quantify the energy impacts of a package of recommended efficiency measures; this model is uploaded to the program portal as "audit". Beginning in 2013, the Program allowed additional software to be used for modeling. The additional software options used during the evaluation period include Auditor, Optimizer, Snug Pro, Cake Systems, and Homecheck.

- The participating contractor provides an audit report and recommendations to the participant household

- The participant household decides which efficiency measures, if any, they are interested in having installed and contracts with either the contractor who completed the audit or another HPwES participating contractor to complete the work

- The selected contractor uploads an updated model of the home that includes the selected package of efficiency measures as "contract."

- The selected contractor carries out the work and updates the home model a final time to reflect any changes from the contracted scope of work as well as any post-installation measurements of performance (e.g., CFM50 from a blower door test) as "complete."

The HPwES program was designed to offer enhanced assistance to moderate-income households. The "Assisted" component of the program is available to residents with up to 80% of area median income, or 80% of state median income, whichever is higher.

The option of OBR financing was added in 2012 to further expand the accessibility of the HPwES program. OBR financing has the following characteristics:

- Loan payments added directly on to the utility bills

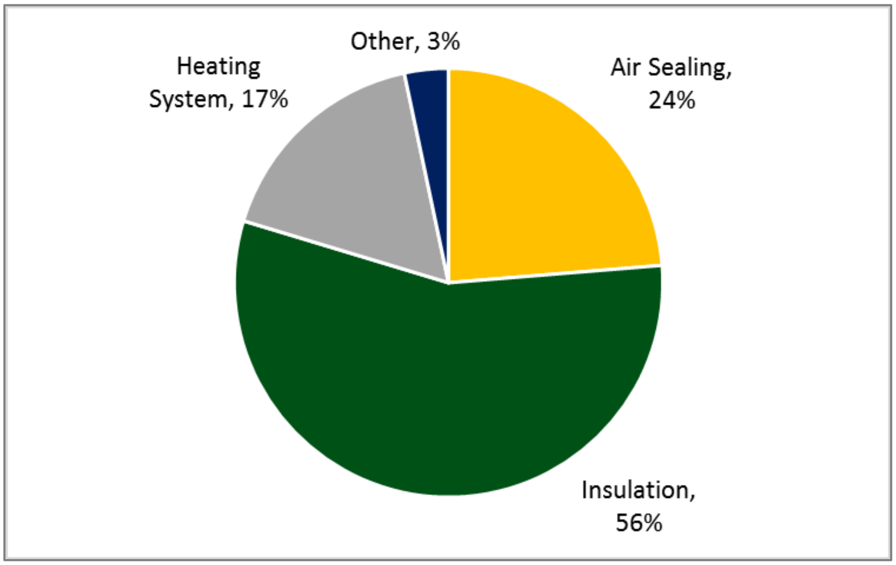
- Loan amounts range from $1,500 to $25,000 with term of 5, 10 or 15 years

- Any remaining balance may be transferred to the new owner if a home is sold

- Estimated monthly energy savings must be equal to or more than 1/12th of annual loan payment

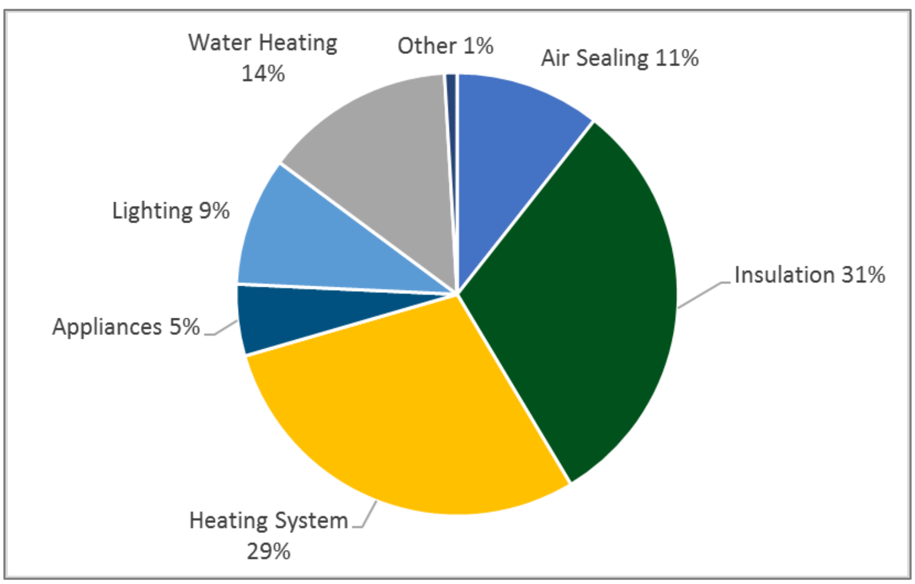
HPwES eligible measures include building shell measures, such as air sealing and insulation; appliances, such as ENERGY STAR refrigerators; heating measures, such as boilers and furnaces; cooling measures, such as ENERGY STAR room or central air conditioners, and certain renewable energy technologies. While most measures have net energy savings, specific measures sometimes result in savings from one fuel and additional use of another fuel. Examples are fuel switching and heat pumps. The program reported savings distribution by measure type are shown in Figure 1 and Figure 2 below.

Figure 1: Natural Gas Savings by Measure Type



The natural gas savings are almost entirely heating related, with the "other" category consisting primarily of hot water savings. The majority of the electric savings are also related to heating, with over 70% due to insulation, air sealing, and heating systems. This proportion of heating savings for the electric savings is higher than residential retrofit programs in other jurisdictions in the Northeast.

Figure 2: Electric Savings by Measure Type



2 Results

This section covers the results of the billing analysis, cash flow analysis, review of modeling files and comparison to other studies. Table 2 summarizes the evaluated performance of the OBR program during the 2014-2016 program years.

Table 2: Summary of Evaluation Results

	OBR 2014-2016[1]	
	Electric Savings	**Natural Gas Savings**
Realization Rate	26%	35%
90% Confidence Interval	+/-6%	+/-4%
Average Usage per Home	9,599 kWh	126 MMBtu
Program Reported Average Savings per Home	1,786 kWh	45.3 MMBtu
Evaluated Average Savings per Home	458 kWh	15.9 MMBtu
Evaluated Savings as Percent of Pre-Install Use	7%	13%
Program Reported Average Extra Use per Home[1]	-502 kWh	-40.3 MMBtu
Evaluated Average Extra Use per Home[1]	-163 kWh	-18.7 MMBtu
Number of Homes in Model	242	236
Number of Utilities in Model	3	2

[1] Not reported in the previous evaluation. The primary source of natural gas extra use occurs when the heating fuel is changed from oil or electricity to natural gas. For electricity, most of the extra use is associated with heat pumps, as adding a heat pump to a home with a fossil fuel heating system increases electric use.

These results are displayed graphically in Figures 3 and 4.

Figure 3: Summary of Electric Evaluation Results

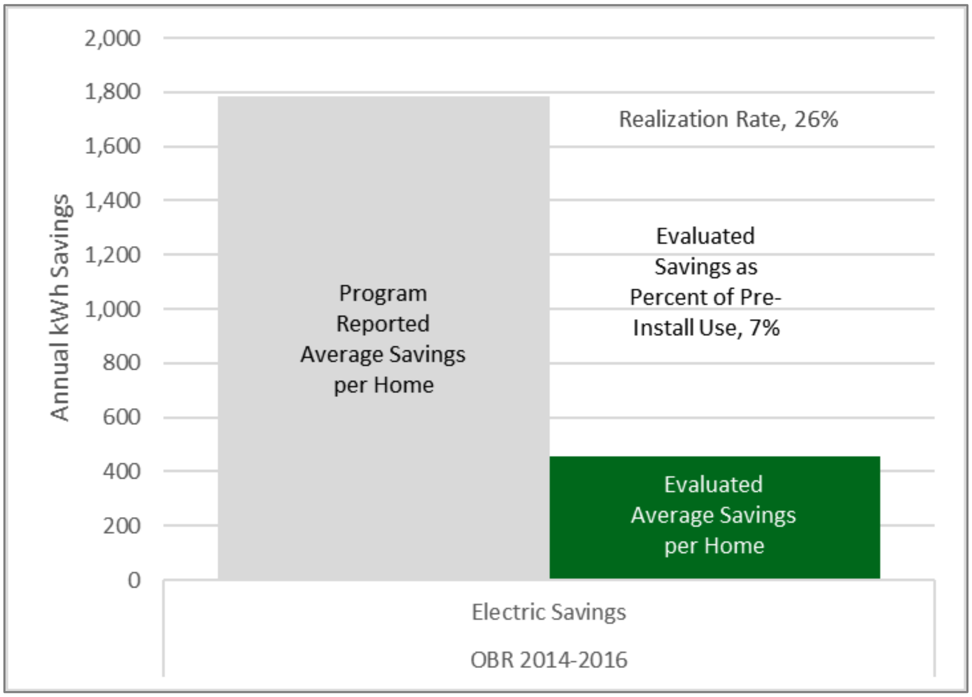
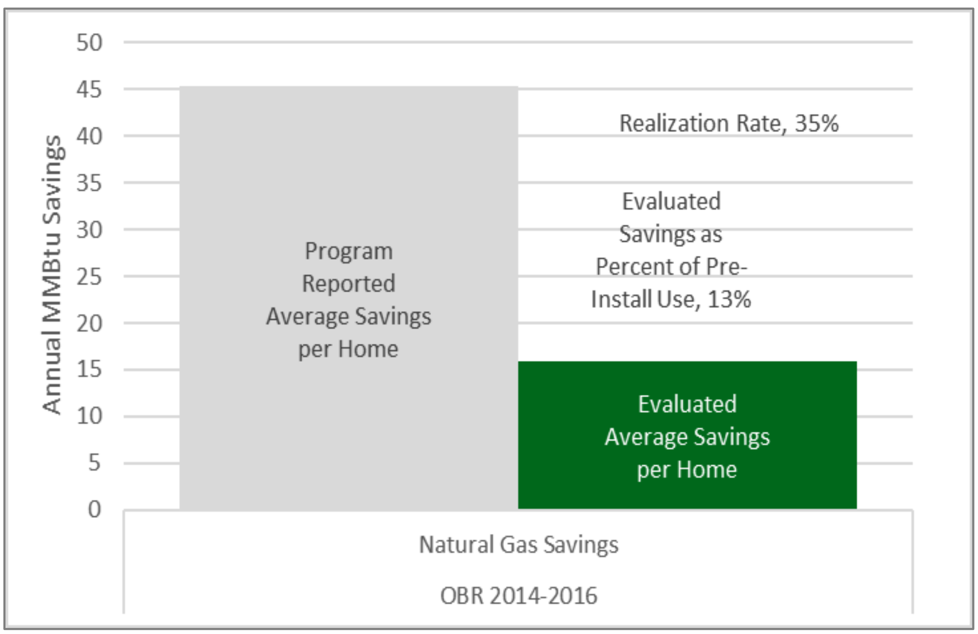


Figure 4: Summary of Natural Gas Evaluation Results



The key findings are described briefly below with more detail in the following subsections:

1. The evaluated savings as a percent of pre-install use are high in comparison to evaluated savings from other, similar programs, particularly for natural gas, indicating that the program is achieving substantial savings.

2. The program reported thermal savings represented a substantially higher percent of pre-install consumption (47% for thermal, non-electric fuels) than the highest evaluated savings of other, similar programs in the Northeast (about 22%).

3. The realization rates are low for both thermal (50%) and electric (26%) savings, suggesting that program reported savings are substantially overstated.

4. For electric measures, the main contributors to the low realization rates were envelope and heating system measures. An unusually high proportion of the program reported electric savings are associated with heating-related measures, although the incidence of electric space heat is low in New York State.

5. Almost a third of homes with heating-related electric savings did not appear to have any temperature dependent electric use during the pre-install period.

6. Heating-related measures were also the driving factor in the realization rate for thermal measures. The review of modeling files suggests that the energy use calculations are not consistently calibrated to bills and that the efficiency of the pre-existing home may be understated, possibly resulting in an overstatement of savings.

7. The cash flow analysis indicates a large percentage (over 75%) of homes are unlikely to meet the OBR 1/12th rule using the evaluated savings.

The next section provides the results of the billing analysis, followed by the cash flow analysis. While a billing analysis cannot explain why savings were overstated, the review of engineering modeling files provides some insights, as discussed in the following section, which is followed by a comparison of the OBR program to other, similar programs in the Northeast.

2.1 Billing Analysis Results

As with many residential retrofit programs, NYSERDA's HPwES Program covers a variety of measures, including insulation, air sealing and water and space heating system replacement. It is somewhat different from other programs in that fuel switching is common, i.e., many homeowners change the space or water heating system from one fuel to another. For homes that recently obtained access to natural gas, fuel switching generally entails moving from an unregulated fuel, such as oil or propane, to natural gas, which increases the natural gas use. As with the natural gas measures, electric measures also produce both savings and extra use. For electricity, ductless heat pumps are a commonly installed measure; heat pumps increase the electric load during the winter periods in homes that were previously using fossil fuels for heating.

Consequently, the billing models were configured to include coefficients for both savings and extra use and the results are reported separately for both fuel types. The following subsections cover the results of the natural gas and electric billing analyses. Details of the regression output are provided in Appendix B.

2.1.1 Natural Gas Results

Due to the prevalence of fuel switching measures, the results are presented separately by savings and by extra use and the savings from other, unregulated fuels are also included. This approach provides a comprehensive view of the program as a whole. Average annual fossil fuel savings were 29 MMBtu per household, accounting for about 23% of pre-install annual use.

The savings in Table 3 are averaged over all homes with natural gas savings or extra use. As many programs in other jurisdictions do not include fuel switching options, there may be few, if any, measures with extra use. For comparing to other programs, OBR homes saved 20% of pre-install use when only homes with natural gas savings are included.[1]

[1] This includes the 766 homes with natural gas net savings rather than the 1231 homes with either natural gas savings or extra use (as shown in Table 3).

Table 3: Overview of Thermal Savings and Extra Use

	Natural Gas		Other Non-Electric Fuels	All Non-Electric Fuels
	Average Savings per Home	Average Extra Use per Home	Average Savings per Home	Average Net Savings per Home
Mean Pre-Install Heating Use[1]	126 MMBtu			
Mean Program Reported Savings[2]	45.3 MMBtu	-40.3 MMBtu	53.6 MMBtu	58.6 MMBtu
Program Reported as Percent of Pre-Use	36%	-32%	43%[3]	47%
Mean Evaluated Savings	15.9 MMBtu	-18.7 MMBtu	32.2 MMBtu	29.4 MMBtu
Evaluated as Percent of Pre-Use	13%	-15%	26%[3]	23%
Realization Rate	35%	46%	60%[4]	50%

[1] Average annual consumption per home for all homes included in final model (n=236)
[2] Average for all program participants with natural gas savings or extra use (n=1,231)
[3] These percentages are based on the annual natural gas pre-installation consumption from this evaluation, which is similar in magnitude to the pre-install consumption found in the 2012 impact evaluation of HPwES unregulated fuels.
[4] Using the realization rate (60%) from the 2012 HPwES evaluation of unregulated fuels.

Measure-level savings are more difficult to estimate with precision from billing models, particularly when the number of homes in the model is relatively small. However, measure-level results are provided for informational purposes. The final model estimated savings for three measure groups:

1. Envelope (insulation, air sealing, windows and doors)
2. Heating equipment repairs and replacements
3. Water heater repairs and replacements

The model also included variables accounting for extra use of heating equipment and water heater repair and replacement. However, these results were not used due to the small number of homes in the model; instead the realization rate from the savings was applied to the extra use measures in the same measure group. Table 4 presents the savings estimates from the final model for these measure groups.

Table 4: Estimated Natural Gas Savings by Measure Group from the Final Model

Measure Group	Homes in Model (n=236)	Mean MMBtu Savings		Realization Rate
		Program Reported[1]	Model Estimate	
Envelope	229	51.6	15.6	30%
Heating System Repair and Replace	73	24.0	8.3	35%
Water Heater Repair and Replace	40	5.8	7.6	132%

[1] Calculated for participants in final model for comparison purposes. Table 3 gives the total program reported participant counts and savings amounts.

The results from the household regression were slightly higher than the measure-specific model, indicating that some savings could not be associated with a specific measure. The realization rate for the program was calculated by applying the measure-specific realization rates to all OBR participants in the evaluation period. To adjust for the higher household savings, the realization rates for the measures included in the model were increased by 6.7% to reflect the difference in savings between the measure-specific and household models.

Table 5 shows how the measure group realization rates were calculated from the final natural gas model to produce an overall natural gas realization rate of 35% for the savings and 46% for the extra use. This result was driven largely by the performance of envelope measures, the most widely installed and highest impact natural gas measure. Measures not estimated from the billing analysis were given the weighted average realization rate of the other measures.

Table 5: Total Evaluated Natural Gas Savings by Measure Group

Measure Group	Homes with Measure		Total Program Reported (MMBtu x 1000)		Total Evaluated MMBtu (MMBtu x 1000)		Realization Rate	
	Savings	Extra Use	Savings	Extra Use	Savings	Extra Use	Savings	Extra Use
Envelope	956	1	45.1	~0a	14.6	0	32%	32%b
Heating System Repair and Replace[1]	500	464	9.2	-44.6	3.4	-16.5	33%	33%b
Water Heater Repair and Replace	169	296	1.0	-4.5	1.4	-6.3	135%	135%b
DHW Conservation	220	6	0.4	~0a	0.1	0	35%c	46%c
Other	5	10	0.1	-0.3	~0	-0.1	35%c	46%c
Total	1043d	572d	55.8	-49.7	19.5	-23.0	35%c	46%c

[1] Extra use is primarily fuel switches to natural gas. This category also includes thermostats.
a The extra use from these measures are included in "Other."
b The RR for the extra use could not be estimated from the model due to too few homes in the model. The RR estimated for the savings was applied.
c The RR could not be estimated from the model. The weighted RR for the evaluated measures was applied.
d As many homes had measures installed with both natural gas savings and extra use, the column adds up to more than the total number of OBR homes.

2.1.2 Electric Results

Average evaluated net savings were 295 kWh per household per year, amounting to around 3% of average household electricity consumption. An overview of the savings and extra use are provided in Table 6.

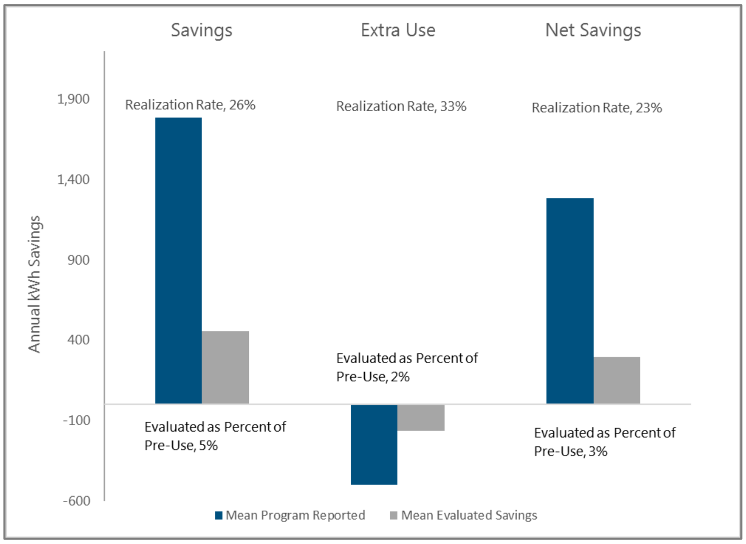
Table 6: Overview of Electric Savings and Extra Use

	Savings	Extra Use[1]	Net Savings
Mean Pre-Install Usage[2]	9,599 kWh		
Mean Program Reported[3]	1,786 kWh	-502 kWh	1,284 kWh
Program Reported as Percent of Pre-Use	19%	-5%	13%a
Mean Evaluated Savings	458 kWh	-163 kWh	295 kWh
Evaluated as Percent of Pre-Use	5%	-2%	3%
Realization Rate	26%	33%	23%

[1] Most of the extra use is associated with heat pumps, as adding a heat pump to a home with a fossil fuel heating system increases electric use.
[2] For all homes included in final model (n=242).
[3] For all 2014-16 program participants with electric savings or extra use (n=910).
a Savings and extra use do not add exactly due to rounding.
.

These results are displayed graphically in Figure 5.

Figure 5: Overview of Electric Savings and Extra Use



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

1. Envelope (included insulation and air sealing) heating savings in homes with cold weather temperature-dependent electric use during the pre-install period
2. Envelope (included insulation and air sealing) cooling savings in homes with hot weather temperature-dependent use during the pre-install period
3. Heating system repair and replace, and thermostats
4. Heating system fuel switch (heating only)
5. Heat pump savings in homes with cold weather temperature-dependent electric use during the pre-install period
6. Heat pump extra use in homes without cold weather temperature-dependent electric use during the pre-install period (no sign of electric heat)
7. Water heater repair and replace
8. Water heater fuel switch

Table 7 presents the savings estimates produced by the final model for these measure groups. Savings from other measures, including lighting and refrigerators, could not be estimated from the model, possibly due to the small number of homes with the measure.

Table 7: Estimated Electric Savings by Measure Group

Measure Group	Homes in Model (n=242)	Mean kWh Savings		Realization Rate
		Program Reported	Model Estimate	
Envelope Heating and Cooling Savings[1]	138	1,067	315	30%
Heat Pump Savings[2]	1	1,728	820	47%
Heat Pump Extra Use	17	-8,135	-2,276	28%
Heating System Fuel Switch Savings	7	8,406	976	12%
Heating System Repair and Replace Savings	54	1,162	226	19%
Water Heater Repair and Replace and Fuel Switch Savings	19	2,562	847	33%
Water Heater Repair and Replace Extra Use	6	-1,027	-1,077	105%

[1]The cooling and heating savings were modeled separately and combined to get the total savings from envelop measures.
[2]As only one home was included in the model, the results were not applied to estimate savings.

Estimating savings at the measure-level with regression models often yields variable results. The final electric model did not produce stable results within the 90/10 standard of confidence/precision for any of the individual measure groups, mostly likely due to the relatively small number of homes included in the final model. For measures excluded from the model, the weighted average realization rate of the evaluated measures was used (26% for savings, 33% for extra use).

For heat pumps, the program reported average extra use at 8,135 kWh is substantially higher than found in other recent impact evaluations in the Northeast. These metering studies suggest that average kWh use of 2,200-2,400 kWh per heat pump in heating mode is typical of residential cold climate heat pumps in VT and ME.[2,3] The results of the billing analysis are consistent with these studies.

Table 8 shows how the measure group realization rates from the final electric model were applied to the program reported savings to calculate an overall realization rate of 26% for the savings and 33% for the extra use. The savings were driven largely by the heating measures (envelope and heating system repair and replace), as they represent the majority of the savings. The realization rate for extra use was driven by heat pumps.

[2] The Cadmus Group, 2017. Evaluation of Cold Climate Heat Pumps in Vermont, Prepared for the VT Public Service Department

[3] West Hill Energy and Computing, 2019. Efficiency Main Trust Home Energy Savings Program Impact Evaluation Program Years 2014-2016, Prepared for Efficiency Maine Trust

Table 8: Total Evaluated Electric Savings by Measure Group

Measure Group	Homes with Measure		Total Program Reported MWh		Total Evaluated MWh		Realization Rate	
	Savings	Extra Use	Savings	Extra Use	Savings	Extra Use	Savings	Extra Use
Envelope[1]	642	51	683.7	-15.8	201.9	-4.7	30%	30%
Heating System Fuel Switch	14	0	201.4	N/A	23.4	N/A	12%	N/A
Heating System Repair and Replace[2]	270	27	195.8	-45.2	38.1	-8.8	19%	19%
Hot Water Repair and Replace	129	38	160.6	-31.2	53.1	-32.7	33%	105%
Heat Pumps[3]	11	43	79.4	-358.0	22.2	-100.1	28%	28%
Lighting[4]	216	0	155.1	N/A	39.8	N/A	26%	N/A
DHW Conservation[4]	51	9	50.0	-5.7	12.8	-1.9	26%a	33%
Air Conditioning[4]	59	1	44.4	-0.7	11.4	-0.2	26%	33%
Refrigeration[4]	36	0	31.0	N/A	8.0	N/A	26%	N/A
Other[4]	26	4	23.9	< 0.1	6.1	< 0.1	26%	33%
Total[5]	847a	160a	1,625.4	-456.6	416.9	-148.4	26%	33%

[1] The regression coefficients for the heating and cooling savings were prorated to calculate the average kWh savings per home, accounting for the percent of homes with consumptions patterns consistent with electric space heat and/or air conditioning.
[2] Thermostats are included in this category. The final regression model only included measures with savings, not with extra use. The same realization rate was applied to both.
[3]The final regression model only included one home with heat pump savings. The realization rate for the heat pumps with extra use was applied to both.
[4] For measures excluded from the model, the weighted average realization rates of the evaluated measures were applied, *i.e.*, 26% for savings and 33% for extra use.
[5] Columns may not add to the total exactly due to rounding.
a As many homes had multiple measures with both natural gas savings and extra use, the columns adds up to more than the total number of OBR homes.

The performance of heating measures (envelope and heating system repair and replace) are the primary factors contributing to the overall realization rate. As was found in the previous HPwES impact evaluations, a high proportion of the electric savings were associated with heating measures. As electric space heat is relatively uncommon in New York State, the exact source of these savings is unclear. While some amount electric savings may occur in homes not heated with electricity, for example from reduced fan motor and circulating pump run times, the magnitude of savings reported for many homes was higher than would be expected from these sources.

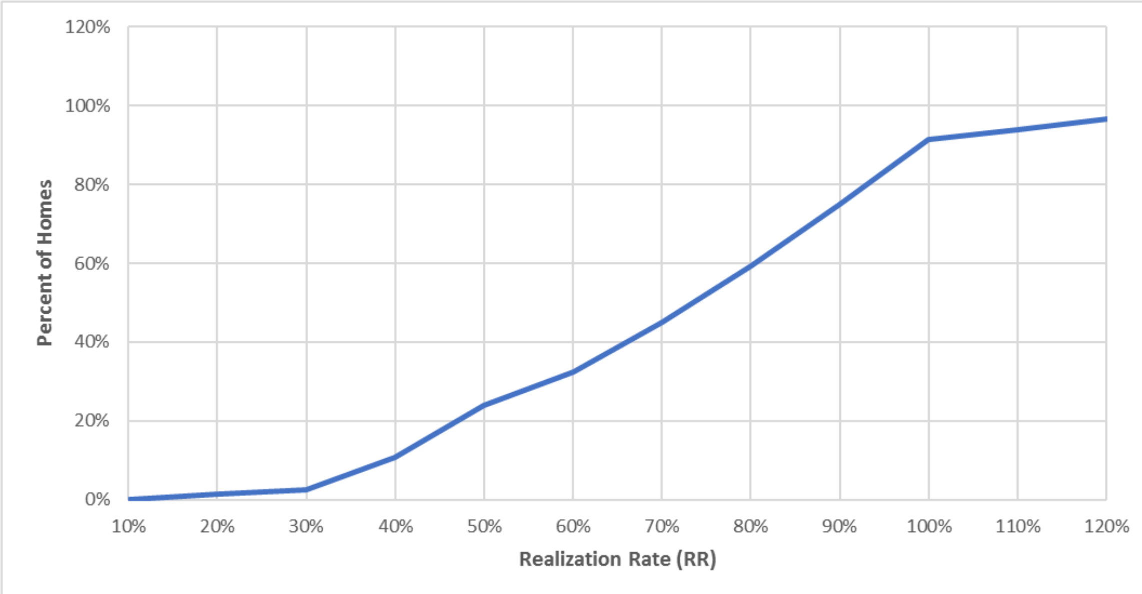
The overall savings from the measure-level model shown in Table 8 were higher than the results from a simpler, pooled, household model. This outcome was due to additional variables that more accurately model the savings and extra use in homes with heating system repair and replace measures but no weather dependent electric usage.[4] Consequently, the higher savings from the measure level model are likely to be a more accurate estimate of overall household savings.

2.2 Cash Flow Results

The realization rate from this billing analysis was applied to the program savings and when the 1/12th rule was compared to the resulting evaluated savings only 23% (62) of the homes met the threshold. To understand the impact of the realization rate on these results, a sensitivity analysis was conducted using a range of realization rates. The results are shown in Figure 6 below.

[4] Homes with a pattern of consumption showing heating use were identified as potentially having electric space heat. The threshold was low and could have captured homes with secondary electric space heat, heat pumps or other weather-dependent use. In the measure-specific model, additional variables were added to isolate savings and extra use in these homes.

Figure 6: Impact of Realization Rate on the Percent of Homes Passing Screening Rule



2.3 File Review Results

Potential reasons for the low savings were analyzed and the results are included below. For electric savings, the main reason for the low realization rate appears to be the overstatement of heating savings in homes where there is no sign of cold-weather-dependent electric use. As the reasons for the natural gas realization rate are not clear, the file review focused on homes with natural gas savings. The results of the analyses and brief discussion of methods to improve the RR are provided in Table 9.

Table 9: Summary of Review Topics and Conclusions

Review Topic	Discussion	Potential Impact on RR
TREAT Warnings	As a large majority of the TREAT warnings identify issues that tend to overstate savings. Correcting inputs based on TREAT warnings could improve the realization rate.	Low to moderate
R-Values	Understatement of pre-install R-values may overstate savings for insulation; having contractors add R-2 to estimated R-values is one approach to addressing this issue.	Moderate to high
Heating System Efficiencies	Understatement of heating efficiency leads to overstatement of savings; it appears that the system efficiencies are not consistently tested and entered.	Low for insulation, moderate for heating system replacement
Reconciliation to Bills	TREAT overstates savings when there is no reconciliation to bills; although TREAT has a reconciliation function, it appears that contractors do not use it.	Moderate to high
TMY3 Temperature Data	TMY3 weather data on average overstates savings by 7 to 10% in the most populated areas in comparison to the 4-year average HDD.	Low to moderate, depending on the weather station

It seems likely that a primary contributor for insulation is understatement of the pre-install R-value. With low R-values (under R-8), even a small error may result in a large overstatement of savings. The modeling file review indicates that the TREAT function that allows reconciliation to billing history is not used by the contractors and, consequently, the pre-install consumption, on average, is overstated. The reconciliation process allows an overall comparison of the modeling to actual use and is one way to improve the accuracy of the modeling. Additional detail on each of the topics is provided below.

2.3.1 TREAT Warnings

A high-level check of model inputs was conducted by looking at the model validation incorporated into the TREAT software. Each TREAT warning was initially categorized by type (e.g., insulation R-value, window area, heating system capacity, household heating slope, etc.), and then by the potential direction of the bias, i.e., whether it signaled an overstatement or understatement of savings.[5] Of the 178 projects, 83% had at least one warning associated with a potential overstatement of savings while 26% had warnings associated with a possible understatement of savings. If these warnings are errors, not unusual features of the building, they will result in a net overstatement of savings, although the impact is uncertain due to the range of errors. It is not clear whether these warning are being considered by the contractors.

2.3.2 R-Values

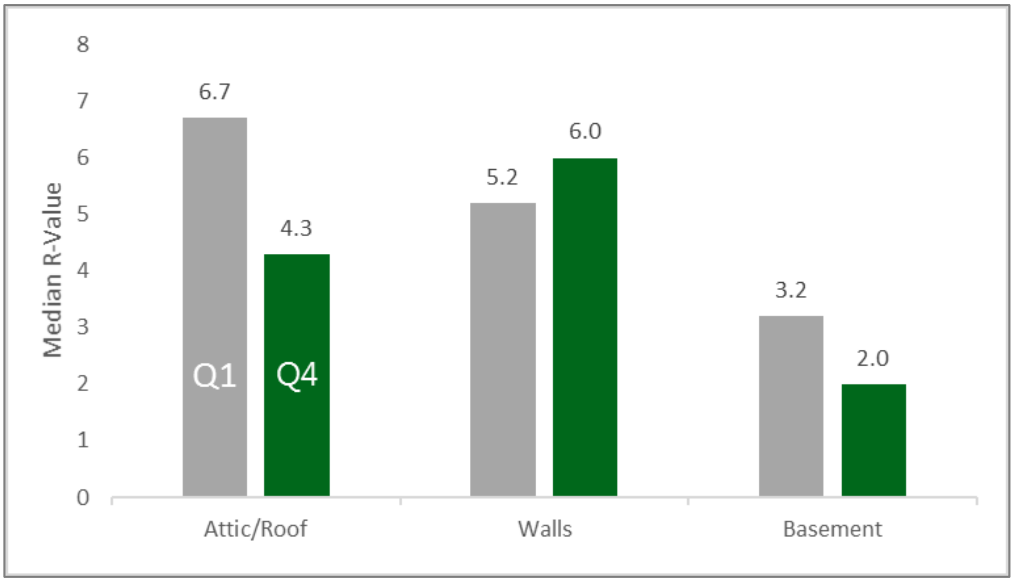
In the modeling files, the R-values of the pre-existing conditions are recorded regardless of whether insulation is recommended or installed. These initial attic, wall, and basement R-values were closely reviewed, as underestimating the efficiency of the home prior to an efficiency upgrade leads to high estimates of baseline energy use and overstatement of savings.

The 55 homes with billing data and modeling files were divided into four equal parts (quartiles) based on the program reported savings as a percent of pre-install use, i.e., quartile 1 (Q1) contains the 14 projects with the lowest percent of program reported savings as compared to pre-install use.

The results are shown in Figure 7. Q4 (in green) represents the low-performing homes, i.e., the 25% of homes with the highest program reported savings in comparison to pre-install use; the TREAT average estimate of pre-install annual consumption was about 50% higher than found in the bills. In contrast, Q1 homes (in grey) are high performing, with the lowest 25% of program reported savings; for these homes, the TREAT annual consumption was equal to the bills. Differences between these two groups provide some possible insights into the reasons for the low realization rates.

[5] See Appendix B for details on the warnings and the assignment to the overstatement or understatement group.

Figure 7: Median R-Value by Program Savings Quartile and Insulation Type

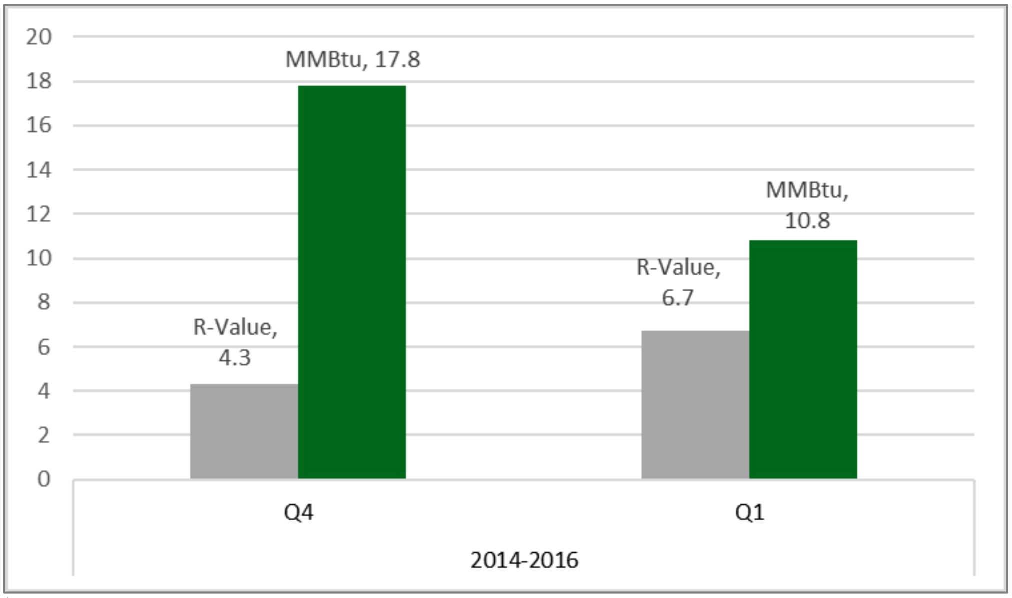


[1] The R-values were weighted by area

For attic and basement, the Q4 homes have a substantially lower median R-value than the Q1 homes. While the difference between 4.3 and 6.7 seems small, even small changes in pre-install R-values can make a large difference in insulation savings, which account for a substantial portion of the program savings. In addition, overstating the existing R-value of the home would result in overstating the pre-install annual consumption, as was demonstrated to be the case on average for the Q4 homes.

A heat load calculation comparing the estimated savings from adding R-50 attic insulation illustrates this fact: estimated savings for adding insulation to an existing building with insulation of R-4.3 are 60% greater than for a building with R-6.7 insulation. The results of this sensitivity analysis are shown in Figure 8. The grey bars represent the existing R-value and the green bars show the MMBtu savings for insulating a 1,000 square foot attic from the existing R-value to R-50.

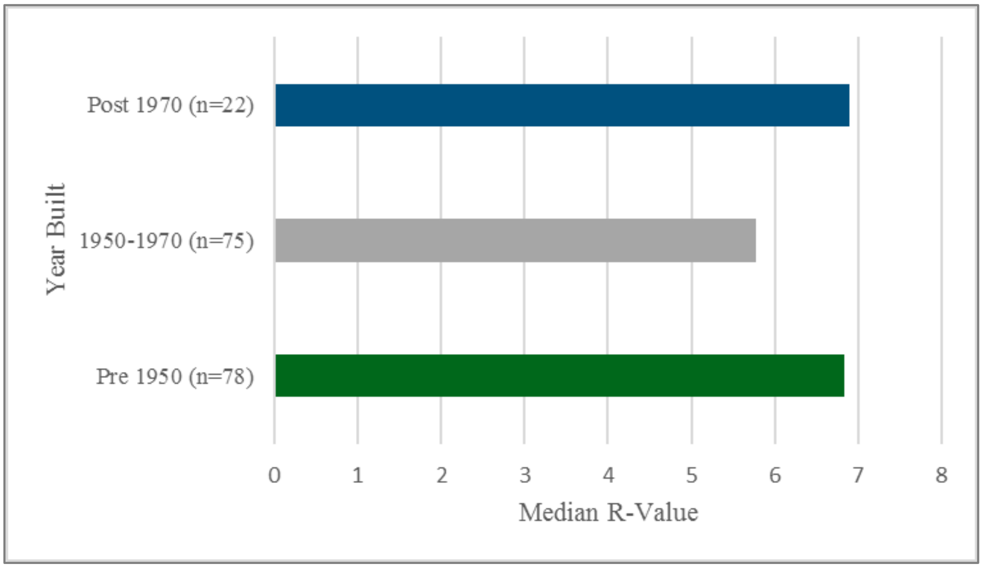
Figure 8: Comparison of MMBtu Savings at Pre-Install R-Values



[1] Based on 1000 sqft area and the normalized HDD60 of JFK Airport (the most common weather station); savings are from increasing the insulation from the pre-install level to R-50.
[2] The savings from the highest quartile are 64% and 34% higher than the savings from the lowest quartile, respectively.

While this analysis does not definitively demonstrate that the modeling inputs are incorrect, these low median R-values suggest that the majority of homes are being modeled as if they have very little attic insulation, which seems unlikely. As shown in Figure 9 below, low existing insulation values are not limited to older housing stock. Since the 1950's, attic insulation has been a standard feature in new homes, and it seems unlikely that so many homes built since 1950's would have R-values under R-7 on average for all attic building components.

Figure 9: Median Attic R-Values by House Age[6]



2.3.3 Heating System Efficiency

The heating system efficiencies were also reviewed and assessed for potential inaccuracies. From 1992 to 2012, the minimum efficiency of a new natural gas hydronic boiler has been 80%, increasing to 82% in 2012. Similarly, natural gas furnaces have had a minimum efficiency of 78% since 1992, increasing to 80% in 2015.[7,8]

[6] This figure included all homes with natural gas savings in the file review sample. The total is 175 homes, as three homes did not have a house age entered in the TREAT file.
[7] Electronic Code of Federal Regulations, Title 10, Chapter 2, Subchapter D, Part 430, Subpart C, https://www.ecfr.gov/cgi-bin/retrieveECFR?gp=&SID=4e859f96449c143e052cb4b499b65c0d&mc=true&n=sp10.3.430.c&r=SUBPART&ty=HTML
[8] Oil boilers have an 84% minimum efficiency as of 2012, while oil furnaces have a minimum efficiency of 83% as of 2013.

Table 10: Heating System Efficiency Summary

Heating System	Minimum 1992 Efficiency	Total Homes[1]	Percent Below 1992 Efficiency	Percent at Exactly 80% Efficiency
Hydronic Boiler	80%	66	39%	18%
Furnace	78%	99	23%	19%

[1]There were 165 homes with boilers and furnaces. Of the remaining 13 homes, nine had steam boilers, one had a heat pump and three had other systems.

As Table 10 shows, 23% to 39% of the homes had pre-install efficiencies below the 1992 standard. For context, the NY Residential Baseline Study found that about 20% of heating systems in existing buildings were 20 years old or older.[9] Some of the slightly lower efficiencies (such as four homes with a heating system efficiency of 79%) could be due to the tested efficiency being lower than the rated efficiency, but the relatively large number of homes with heating system efficiency of exactly 80% suggests that many may be assumed values rather than tested by the contractor.

Overall, these values seem to be lower than expected, which could contribute to the overstatement of savings for insulation, air sealing measures and heating system replacements.

2.3.4 Reconciliation to Bills

The pre-installation consumption was compared between the TREAT files and the results of the natural gas billing analysis for the 55 homes in both data sets. On average, the TREAT natural gas consumption per household was 30% higher than the billing model, at 152 MMBtu as compared to 117 MMBtu.[10]

TREAT allows the user to add utility bills to compare to model and adjust the model to more closely match the billing consumption. Only six of the 178 homes with TREAT output files had a

[9] NYSERDA Residential Statewide Baseline Study Volume 1: Single-Family Report Final Report. Prepared by Tetra Tech, GDS Associates and PSD for NYSERDA. July 2015. NYSERDA Report 15-07. Page 28.

[10] The 117 MMBtu reflects the consumption per household for the 55 homes from the billing data. This value is higher than average consumption from NY Patterns and Trends of 73 MMBtu for natural gas, which includes all NY housing stock, which the homes in this program are primarily single-family homes.

record of bills in the modeling file, and one of those was included in the billing model. For the home in the billing model, the pre-install consumption was 97% of the TREAT value.

This analysis suggests the following:

1. TREAT overestimates savings on average when there is no reconciliation to pre-install billing history
2. Reconciliation to billing history does not occur on a regular basis

Overstatement of the pre-install use is likely to be related to the overstatement of savings.

2.3.5 TMY3 Temperature Data

Both TMY3 and TMY2 weather data have lower temperatures than more recent years, which results in the models overestimating the heating use of homes. Due to the limited data available for this evaluation, it is unknown if TMY2 or TMY3 data was used for the TREAT models. However, even the use of TMY3 data results in higher average HDD60 values across the weather stations, as shown in Table 13. The impacts vary by weather station, with three stations showing almost no change (1% or 2%), to three showing a 10% or higher difference.

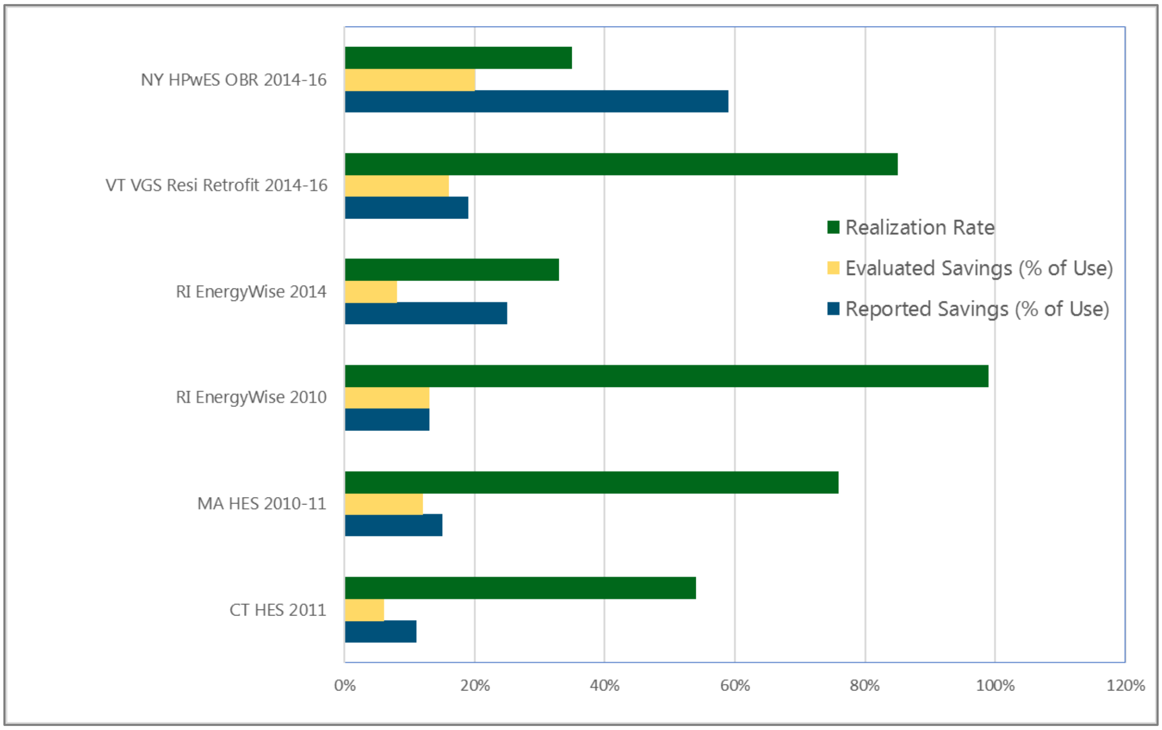
Table 11: Percent Change in HDD60 between TMY3 and Normalized 4-Year Average

Weather Station Name	Percent Increase in HDD60	Sites in Program
JFK Airport, NY	8%	1236
Bridgeport, CT	7%	882
Albany, NY	10%	353
Buffalo, NY	4%	141
Binghamton, NY	1%	134
Syracuse, NY	2%	116
Other Weather Stations	1-14%	163

2.4 Comparison to Other Studies

Evaluated savings for programs in the Northeast similar to the OBR HPwES program are shown in Figures 10 and 11. Comparison across programs is complex due to the differences amongst the programs. NYSERDA's HPwES encourages fuel switching, which is not permitted in some jurisdictions. The New England programs are primarily installing envelope and air sealing measures. The OBR program compares favorably to other, similar programs with 20% savings as compared to pre-install use, the second highest of the 10 similar programs included in the review.[11] The current natural gas analysis shows higher savings as compared to the previous impact evaluation of the NYSERDA HPwES programs.

Figure 10: Comparison of Natural Gas Impacts for Similar Programs



While the savings as a percent of pre-install use fall within a fairly narrow band, Figure 10 shows a wide spread of realization rates, ranging from 31% to 99%. This program is at the bottom end of the realization rate range due to the high reported savings, even though the evaluated savings as a percentage of pre-install usage are high.[12]

Some of the programs estimate savings through individual house-by-house modeling and other use some variation of deemed savings. The RR does not seem to be related to the method of

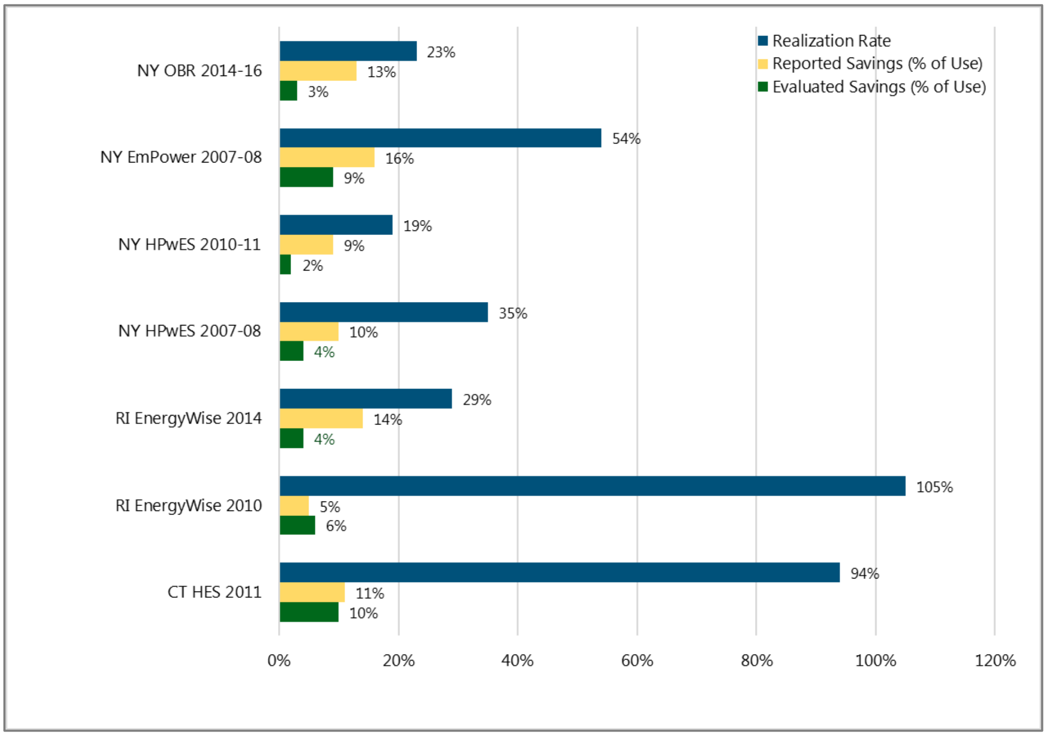
[11] The 20% savings is for homes with natural gas savings rather than an average over all homes with either natural gas savings or extra use. Please refer to Section 4.1 for further discussion. Appendix E includes the comparison to all 10 programs.

[12] The program reported net thermal savings were 46% of average pre-install use. This level of savings is substantially higher than found in the impact evaluations of the most effective program reviewed (22%).

estimating savings for reporting purposes, as programs using modeling are found near both the top and the bottom of the range of RR's. For many programs, reconciliation to pre/post billing may not be an option; calibrating the savings to pre-install use may be more feasible.

For electric savings (see Figure 11), the range of evaluated savings as a percent of pre-install use is 2% to 10%. Five of the eight studies are between 4% to 6%; OBR is at the low end with 3% for program years 2014 to 2016. This is similar to the 2% and 4% of use found in the two previous evaluations of NYSERDA's HPwES program.

Figure 11: Comparison of Electric Impacts for Similar Programs



3 Methods

This section describes the methods used to develop the realization rates, investigate program savings and conduct the cash flow analysis. The methods used for each component are explained in more detail below.

3.1 Overview of Billing Analysis Data Sources

Three major data sources were used for the billing analysis:

1. Program data on location of each home, measures installed, installation date, and characteristics of the homes
2. Consumption history pre- and post-retrofit (billing records) from electric and natural gas utilities
3. Weather data from the National Oceanic and Atmospheric Administration (NOAA)[13]

The program data was used to identify the major measure groups installed in each home and the project completion date. Billing data was provided by the utilities.

3.2 Weather Data Processing

The NOAA data used was hourly temperature data for weather stations throughout New York. For the billing analysis the heating degree days (HDD) and cooling degree days (CDD) for each billing cycle were calculated from the NOAA temperature data and linked to the billing data using the weather station. For this analysis, a base temperature of 60°F was used for heating (HDD60) and 70°F for cooling (CDD70).

Four years of historic weather data were used to calculate annual, normalized HDD60 and CDD70 and to normalize the billing analysis results to a typical year. A list of the weather stations used and additional details on the NOAA data are included in Appendix A.

[13] https://www.ncei.noaa.gov/data/global-hourly/access/

3.3 Data Cleaning

Data cleaning is a critical component of any billing analysis. Data from the three sources shown in Section 3.1 above were combined and carefully reviewed to remove homes with insufficient billing data and other data issues. This was a two-stage process, comprised of the following:

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

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

3.3.1 Initial Review

The program data (including installed measures) was grouped by site, which allowed matching the specific household to the related electric and/or natural gas accounts. There may be multiple projects for one site if work occurred at different times.

In the billing data, individual monthly meter reads were dropped if consumption or billing cycles overlapped or showed a pattern consistent with multiple estimated reads.[14] Homes with gaps of more than 30 days between reads were dropped. Participants were required to have a substantial amount of billing history during heating seasons to be included in the analysis. Table 12 summarizes the criteria for the natural gas and electric models.

[14] Such idiosyncrasies are commonly associated with estimated reads. One utility provided data for a number of homes with alternating estimated and actual reads that could not be included in the analysis.

Table 12: Criteria for Inclusion in the Billing Models

Fuel	Criteria
Natural Gas	Minimum of 180 days in both pre- and post-installation periods Include at least 2 winter months or sixty-five percent of normalized annual HDD60
Electric	Minimum of 180 days in both pre- and post-installation periods Include at least 2 winter months or sixty-five percent of normalized annual HDD60 if heating measures with electric savings Include at least 2 summer months if cooling measures Minimum of 300 days in both pre- and post-installation periods if home has both cooling and heating measures

3.3.2 Secondary Review

The secondary review started with conducting house-by-house regressions of weather on consumption for all homes that met the initial review criteria laid out above. These house-by-house regressions served different purposes in the construction of pooled models for each fuel. The following subsections describe the secondary review for the natural gas model and the electric model.

Natural Gas Model

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

1. An intercept model that assumes the home uses natural gas for both water heating and space heating[15]
2. A no-intercept model that assumes the home uses natural gas for space heating only

[15] The intercept term reflects base (non-heating) consumption. Water heating is generally the only base end-use large enough to be captured in an intercept term. Because the program data did not adequately identify homes' water heating fuel, it was necessary to analyze each home's data with an individualized regression model in order to flag homes that showed natural gas base use.

Based on the results from the model with the better fit, participants were excluded from the final model for any of the following reasons:[16]

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

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

Electric Model

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

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

These reasons are explained further in the subsections below.

Weather-Dependent Use

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

1. To identify the homes where weather-dependent savings are likely to be found
2. To ensure that heating and cooling use was captured by the model for all homes with these end uses[17]

[16] As most homes with access to natural gas use the fuel for both space and water heating, the default assumption was that the intercept model was the best choice. The no-intercept model was used only in cases where the R^2 was substantially higher than the intercept model or if the intercept was negative.
[17] This approach reduces the error in the model and avoids the possibility of biasing the savings estimates due to changes in space heating and/or cooling use.

For each home, a regression model was run for the pre-period that included an intercept term representing non-weather dependent (base) use and separate terms for heating and cooling use. Homes were defined as having some type of electric space heating by the strength and magnitude of the relationship between their electric energy consumption and heating degree days. Similarly, homes were identified as having air-conditioning by the strength and magnitude of the relationship between their consumption and warm weather temperatures (cooling degree days).[18]

Exclusion from the Model

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

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

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

3.3.3 Attrition Summary

From previous experience with billing analyses, the Impact Evaluation Team has typically found that between 40% and 60% of total eligible participants with billing data are included in the final models. The largest factor affecting the attrition for this evaluation is that bills were not provided for a large majority of program participants, as shown in Table 13.

[18] Equipment other than air conditioning may also exhibit weather-dependent usage, such as whole house fans or dehumidifiers. However, the threshold for defining air conditioning users was set high enough to preclude mistaking these less intensive end uses for direct cooling.

Table 13: Overview of Billing Data

	Natural Gas	Electricity
Total number of utilities	7	7
Number of utilities providing billing data	4	5
Total number of OBR participants with measures	1,231	910
Total number of OBR participants with billing data	400	484
Percent of OBR participants with billing data	32%	53%

Billing data from two utilities could not be used due to the pattern of estimating reads every other month, which was not sufficient granularity for the billing analysis. Tables 14 and 15 present a summary of the attrition resulting from the data preparation described above. For homes with billing data, the attrition falls within a typical range, i.e., 59% for natural gas and 50% for electricity.

Table 14: Natural Gas Model Summary of Attrition

Reason for Removal	Number Removed	Participants Remaining	Percent of OBR Participants Remaining	Percent of OBR Participants with Bills Remaining
Total Participants		1,231	100%	
No Bills	831	400	32%	100%
Insufficient Pre/Post	54	346	28%	87%
Estimated Reads/Gaps[1]	105	241	19%	60%
Irregular or High/Low Usage	5	236	19%	59%
Final Model Count		236	18%	59%

[1] Includes homes with alternating estimated and actual reads.

Table 15: Electric Model Summary of Attrition

Reason for Removal	Number Removed	Participants Remaining	Percent of OBR Participants Remaining	Percent of OBR Participants with Bills Remaining
Total Participants		910	100%	
No Bills	426	484	53%	100%
Insufficient Pre/Post	59	425	47%	88%
Estimated Reads/Gaps[1]	182	243	27%	50%
Irregular or High/Low Usage	1	242	27%	50%
Final Model Count		**242**	**27%**	**50%**

[1] Includes homes where data included alternating estimated and actual reads.

Comparing the homes in the model to all OBR homes, the average electric savings for homes in the model were about 20% lower, and natural gas savings were about 10% higher. This result suggest that the modeled homes are within a reasonable range as compared to the OBR population. Additional analysis was also conducted to assess whether the models included the larger contractors. The four largest contractors representing about 30% of the projects were represented in the models. Of the next 14 largest contractors accounting for another 30% of the projects, ten were represented in the models. This analysis indicates that larger contractors were well represented in the model.

3.4 Billing Models

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

The final models incorporated weather and measure groups as predictor (independent) variables. Timing variables were also included to capture any widespread changes in energy use over time. Appendix B provides the model equations and additional details about the different model specifications tested, selection criteria used to settle on the final parameters and diagnostic metrics. Appendix C includes a memo prepared for NYSERDA that provides supporting information about the modeling process. Appendix D includes a second memo discussing the metrics used for regression diagnostics.

3.5 Model Selection

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

One of the key issues with modeling program savings is the combination of measures installed in each home. Attempting to estimate the savings from each measure individually, without accounting for the range of measures installed in the home, introduces multicollinearity into the model, which can result in estimators that are of a substantially different magnitude or of the wrong sign. To address this issue, the alternative models included various configurations of measures commonly installed together.

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

3.6 Exogenous Effects

A billing analysis is based on the assumption that overall changes in household consumption can be used to calculate the savings from participation in efficiency programs. Energy use may be affected by widespread economic changes, or other factors outside the influence of the program. In a two-stage model where the regression is conducted only at the household level,[19] a comparison group is sometimes used to account for exogenous effects. However, a comparison

[19] While household regressions were conducted in this evaluation as part of the data cleaning process, the final results were estimated from pooled models including all eligible homes.

group may introduce additional uncertainty in the model, as it includes naturally occurring efficiency and the end result cannot be clearly interpreted as either gross or net savings.[20] In addition, defining an equivalent comparison group can be a complicated process.

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

1. The fixed effects model accounts for the factors in each home that remain stable over time
2. The timing variables account for widespread changes in energy use across all homes in the model
3. The model includes all homes meeting the criteria for inclusion, indicating random changes internal to the household should not bias the results[21]

In addition, previous research indicates the large, pooled models do not produce biased estimators when compared to a model incorporating detailed survey data regarding changes in household composition and energy use.[22]

3.7 Model File Review

This component of the evaluation was designed to identify potential reasons for the low realization rates and the overstatement of savings. The Impact Evaluation Team identified four potential sources for the discrepancy between evaluated and program reported savings:

1. Incorrect inputs entered into the modeling software
2. Lack of reconciliation to pre-install billing
3. Modeling algorithms
4. Poor quality installations

[20] Randazzo, K.; Ridge, R.; and Wayland, S. (2017, in revision). Observations on Chapter 8 of the Uniform Methods Project: A Discussion of Comparison Groups for Net and Gross Impacts. Opinion Dynamics, submitted to PG&E
[21] For example, some houses will experience an increase in occupancy and others a decrease. As these changes are random, they will cancel each other out.
[22] Megdal & Associates, LLC, West Hill Energy & Computing, Inc. NYSERDA 2007-2008 Empower New York Program Impact Evaluation Report

The first two items were investigated. Site visits to assess the installation quality were out of the scope of this evaluation. In addition, only the inputs and results of the modeling were available, and the underlying modeling algorithms could not be examined.

The modeling output files for the OBR projects were reviewed and, where possible, compared to the consumption found in the billing model. This process included reviewing the available inputs such as R-values and heating system efficiencies as well as the outputs, including the TREAT estimated consumption, and any warnings included regarding the model.

In the absence of on-site inspections prior to the retrofits, it was not possible to verify the accuracy of the inputs for individual homes. Consequently, the analysis was restricted to calculating average inputs and using professional judgment to assess whether these inputs seem to be within a reasonable range.

A total of 178 homes with TREAT or HPXML[23] output files were incorporated into the analysis, including 55 homes with both TREAT output files and annual usage from the billing model available. Appendix A provides additional detail on the downloading process.

The actual pre-install consumption is a strong indicator of the savings that can be achieved at any specific home. Savings that are a high percent of the pre-install use are more likely to be overstated. Thus, the 55 projects with billing records were analyzed by program reported savings as a percent of annual pre-install natural gas consumption.[24] Quartiles were established and homes in the bottom and top quartiles were compared. Other analyzes were conducted for the 178 homes with natural gas savings and modeling files.

Table 18 provides a description of the file review process. The analyses were conducted using different groups depending on the available information, as follows:

1. All participating OBR projects

2. Projects with modeling files (178 homes)

3. Projects with modeling files and billing data (55 homes)

The analysis group is identified for each topic in Table 16.

[23] In the remainder of this document, "TREAT" files or software refers to both TREAT and HPXML.
[24] The pre-install consumption was normalized using 4 years of weather data.

Table 16: Summary of File Review

Review Topic	Description	Analysis Group
TREAT Warnings	The TREAT software has model validation warnings on potential issues that could overstate or understate the savings	Modeling files
R-Values	Reviewed the average pre-installation R-values for walls, attics, and basements and compared to typical values.	Modeling files and billing data
Heating System Efficiencies	Reviewed the pre-installation heating system efficiencies and compared to 1992 standards	Modeling files
Reconciliation to Bills	Compared pre-installation usage from billing model to usage from TREAT models	Modeling files and billing data
TMY3 Temperature Data	Comparison of TMY3 data used in TREAT weather normalization to average weather from the last 4 years	All projects

3.8 Cash Flow Analysis

A cash flow analysis was conducted to assess whether the OBR projects met the "1/12 rule", i.e., the estimated average monthly savings from energy efficiency improvements must equal at least 1/12th of the annual loan payment. To assess program success at meeting this criterion, monthly payments for the loan used to finance the efficiency project were compared to the money saved through the reduction in energy use found in the billing models.

In addition to the data used in developing the HPwES OBR billing models, several other sources of information were used in the analyses, as shown in Table 17.

Table 17: Cash Flow Data Sources

Description	Source	Purpose
Details of the loan amounts, terms, and interest rates for each OBR project	NYSERDA	Calculate expected monthly payment
Average energy prices used by NYSERDA program staff in screening 2015 projects	NYSERDA	Calculate energy cost savings
Average wood and pellet prices	Previous Evaluation	Calculate energy cost savings

Analysis was limited to the homes included in the OBR billing models. The analysis consisted of three steps:

1. The original program calculations were verified with the program reported savings to ensure that the projects met the 1/12th rule under the program guidelines.

2. A sensitivity analysis was performed to determine the impact of the RR on the percent of projects meeting the 1/12th rule using the evaluated savings.

3. The analysis was conducted applying the RR to the program reported savings to assess the percent that met the 1/12th rule using evaluated savings.

The realization rate for the unevaluated, unregulated fuel savings was assumed to equal that found by the previous unregulated fuels evaluation of HPwES.[25]

The Impact Evaluation Team calculated cash flow using the same methodology as used by the Program. Monthly payments for the loan were compared to average monthly avoided costs due to savings. The avoided costs were calculated as the future value of the verified energy savings over the life of the loan, considering inflation and expected increases in fuel prices.

[25] Energy & Resource Solutions, West Hill Energy, 2012. Home Performance with Energy Star: Unregulated Fuels Impact Evaluation, prepared for the New York State Energy Research and Development Authority.

4 Glossary

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

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

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

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

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

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

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

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

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

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

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

Extra Use – Additional use of electricity or natural gas related to a specific measure, such as additional electric use from installing a heat pump in a home with a fossil fuel heating system or switching the heating fuel from oil to natural gas

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

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

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

Program Year, PY – The calendar year when a project was completed.

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

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

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

5 References

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