Dynamic Duo: How Combining Billing Analysis and Engineering Simulation Methods Improves Evaluation Quality and Understanding

Kimberly Crossman, National Grid, Waltham, MA; Laura Tabor, Navigant, Boulder CO; Matei Perussi, The Cadmus Group, Portland, OR; David Basak, Navigant, Boulder CO

ABSTRACT

Billing analysis and engineering analysis are generally seen as competing impact evaluation methodologies, but when leveraged together they offer powerful insights. This paper describes how these methods were combined to determine savings for a range of weatherization and direct install measures installed through the Massachusetts Home Energy Savings (HES) and Low Income Weatherization (LI) programs. The purpose of the evaluation was to quantify electric, gas and oil energy savings associated with both programs. The HES program is a residential retrofit program which offers a range of weatherization measures as well as direct-install measures such as CFLs. The LI program offers similar measures as well as heating system replacements to low-income participants.

In both evaluations, key assumptions and input within each methodology were influenced by that of the alternative methodology, which led to results that were largely in agreement. This enabled the team to provide greater insight into the data trends behind the results, and confidently address regulatory requirements to extrapolate evaluation findings to program participants with oil heating systems.

Another benefit to this approach was the ability to use the engineering analysis to delve into the reasons for discrepancies between claimed and verified savings across the programs' measures. A few examples are:

- Using engineering results to split out individual insulation measures from bundled household savings
- Relating quantity of insulation installed and number of insulation measures installed to observed savings
- Comparing program administrator assumptions about heating system efficiency and heating load to audit data and billing analysis actual consumption
- Comparing CFL unit savings from billing analysis to engineering calculations

Introduction

The purpose of the evaluation was to quantify electric, gas and oil energy savings associated with the HES and LI programs across the state of Massachusetts for the 2010 program year. The HES program is a residential retrofit program which offers a range of weatherization measures as well as direct-install measures such as CFLs. The LI program offers similar measures as well as heating system replacements to low-income participants.

Program History

The HES program has been in place since the early 1980s and targets all non-low income residential customers living in single-family houses or multifamily buildings with one to four units. The program offers home energy audits to customers, regardless of heating fuel. Through these audits, technicians identify opportunities for saving energy and offer incentives through a variety of home improvements. The program's primary goal is to achieve significant energy savings by promoting a whole-house approach, offering education, incentives, and financing options for gas and electric measures. All cost-effective, energy-saving improvements are targeted, including: building envelope measures, heating and cooling systems, water heating, and lighting and appliances. Using a single statewide 800 number, customers are screened for qualification and are directed to the correct program and services.

The LI program implements cost-effective, energy efficiency products and services for residential customers living in one to four unit dwellings in which the household income is at or below 60 percent of the state median income level. The program piggybacks on the current Department of Housing and Community Development's Weatherization Assistance Program. All applicable revenue streams available are leveraged to enhance services consistent with a whole-house approach. Once customers are deemed eligible, they receive an in-home energy assessment from their local CAP (Community Action Program) agency. The CAP agency will then arrange for all applicable measures and services to be installed by a qualified contractor.

This is the first statewide impact evaluation for both programs, but National Grid's HES and LI programs had been evaluated in prior years primarily through billing analyses for both gas and electric measures.

2011 Evaluation Approach

Billing analysis has historically been the standard evaluation approach for Massachusetts' weatherization programs, and while previous evaluations were generally successful, variances around smaller impact measures were fairly large. The evaluation team therefore took a two-pronged approach to the impact evaluation:

1. Given the historical use of billing analyses and related program administrator, regulatory, and other stakeholders' preference for this approach, billing analysis results were used when specific, predetermined statistical confidence and relative precision criteria were satisfied.
2. The team conducted engineering simulation modeling and analysis based on extensive audit data in parallel with the billing analysis, and used these results when the billing analyses did not meet the agreed-upon statistical requirements. For weatherization measures, the engineering team built an energy model using pre- and post-retrofit home characteristics from the audit data. The team calibrated this model to the annual consumption observed in the billing data. For other measures, the engineering team relied on engineering calculations based on the audit data.

Design and Methodology

The Evaluation team assessed the gross per-unit savings generated by each measure using two approaches: a billing analysis and an engineering analysis. A brief description of each is provided below:

Billing Analysis. The Evaluation team specified a fixed-effects conditional savings regression model with paired pre- and post-participation months to estimate measure-level savings for measures installed by program administrators (PAs) that provide electricity and/or natural gas. We leveraged these weather-normalized models with detailed measure data and home characteristics provided by each PA's implementer. For the billing analysis, The team also utilized a control group composed of 2011 program participants to account for macroeconomic factors that might have impacted energy consumption between the pre- and post-periods. The billing analysis also accounted for participation in other programs such as High Efficiency Heating and Water Heating (HEHE), Cool Smart (residential air conditioning), and OPOWER (behavior).

Engineering Analysis. The team utilized two engineering analysis approaches to estimate measure-specific savings for all three fuel types (electric, natural gas, and heating oil). For program measures known to generate interactive effects (i.e., those that increase or decrease the energy consumption of another end use), we estimated savings using a DOE-2-based simulation model, which we calibrated using the average pre-program energy consumption of HES participants. For measures not typically subject to interactive effects, we estimated savings using standard industry engineering algorithms. Both engineering approaches were primarily informed by the same detailed measure data and home characteristics we utilized in the billing analysis.

Table 1 shows some of the advantages and disadvantages of each approach. While billing analysis was the preferred approach of many stakeholders, it cannot always provide sufficient precision for smaller measures and is not an option for oil customers. By adding engineering analysis and using assumptions and inputs that were common to the billing analysis, the team was able to characterize a broader selection of measures.

Table 1: Advantages and Disadvantages of Approaches

	Billing Analysis	Engineering Analysis
Advantages	Captures actual changes in usage due to efficiency upgrades and behavioral change Accounts for interactive savings effects between the measures. Preferred approach used in previous Massachusetts evaluations	Directly tied to data on type and quantity of measures installed Can be used for measures of any size, participation level and fuel type
Disadvantages	Requires relatively large impacts and/or sample sizes May not provide sufficient relative precision for smaller measures Requires monthly billing data: not applicable for oil heating customers	Limited by quality and quantity of audit data available Does not capture behavioral effects

The danger of using two parallel and defensible approaches is that it can be easy to "cherry pick" results based on which approach yields more favorable savings estimates. To eliminate this danger, the team created firm rules for when to use billing analysis and when to use engineering analysis. The HES and LI programs have historically been evaluated using billing analyses: this method is often preferred for home weatherization programs because it captures actual changes in energy consumption within participating homes from energy-efficiency improvements as well as behavior modifications. Hence, the team elected to report the measure- and fuel-specific results of the billing analysis whenever they met a predetermined threshold of precision. We set this acceptable threshold to a relative precision of 20% or less at the 90% confidence level. However, several measures did not meet this criterion, and for these the team reported engineering-based values.

Table 2 and Table 3 detail which approach we used for each HES and LI measure, respectively, by fuel type. The precision associated with each billing analysis-based savings estimate is also provided. While in the HES evaluation the sample sizes were large enough to use billing analysis for all major weatherization measures (except basement insulation) in homes with natural gas heating, the LI sample sizes were much smaller and we used simulation and engineering algorithms for most measures.[1] Since natural gas and oil are the predominant heating sources in Massachusetts, there was little participation from electrically heated homes. The small electric weatherization sample sizes meant that we could not use billing analysis for these measures.

[1] Due to the lack of digital audit data for the LI program, the sample size was limited by the time required for manual data collection from paper records.

Table 2. Methodological Approach to Calculating Savings by Measure and Primary Fuel Type: HES

Category	Measure	Natural Gas (therms/year)	Electric (kWh/year)	Oil (MMBtu/year)
Insulation & Air Sealing	Insulation (overall)*	Billing Analysis (±9%)	Simulation Modeling	Simulation Modeling
	- Attic Insulation	Billing Analysis (±19%)	Simulation Modeling	Simulation Modeling
	- Wall Insulation	Billing Analysis (±16%)	Simulation Modeling	Simulation Modeling
	- Basement Insulation	Simulation Modeling	Simulation Modeling	Simulation Modeling
	Air Sealing	Billing Analysis (±18%)	Simulation Modeling	Simulation Modeling
	Furnace Fan (due to insulation)	Simulation Modeling	--	Simulation Modeling
	Cooling Savings (due to insulation)	Simulation Modeling	--	Simulation Modeling
Heating System	Oil Furnace Replacement	--	--	Engineering Algorithm
	Furnace Fan (due to oil furnace replacement)	--	--	Engineering Algorithm
	Oil Boiler Replacement	--	--	Engineering Algorithm
	Boiler Reset Controls	Engineering Algorithm	--	Engineering Algorithm
	Boiler Pipe Wrap	Engineering Algorithm	--	Engineering Algorithm
	Programmable Thermostat	Engineering Algorithm	Engineering Algorithm	Engineering Algorithm
Lighting & Appliances	Refrigerator Replacement	--	Billing Analysis (±12%)	--
	CFLs	--	Billing Analysis (±4%)	--
Domestic Hot Water	Showerhead	Engineering Algorithm	Engineering Algorithm	Engineering Algorithm
	Faucet Aerator	Engineering Algorithm	Engineering Algorithm	Engineering Algorithm
	Pipe Wrap	Engineering Algorithm	Engineering Algorithm	Engineering Algorithm
	Indirect Water Heater	Engineering Algorithm	--	Engineering Algorithm
Distribution	Duct Insulation	Engineering Algorithm	Engineering Algorithm	Engineering Algorithm
	Duct Sealing	Engineering Algorithm	Engineering Algorithm	Engineering Algorithm

* This row refers to any participant that received attic, and/or wall, and/or basement insulation.

Table 3: Methodological Approach to Calculating Savings by Measure and Primary Fuel Type: LI

Category	Measure	Natural Gas (therms/year)	Electric (kWh/year)	Oil (MMBtu/year)
Insulation and Air Sealing	Insulation and Air Sealing*	Billing Analysis (±8%)	Simulation Modeling	Simulation Modeling
	Air Sealing	Simulation Modeling	Simulation Modeling	Simulation Modeling
	Attic Insulation	Simulation Modeling	Simulation Modeling	Simulation Modeling
	Wall Insulation	Simulation Modeling	Simulation Modeling	Simulation Modeling
	Basement Ceiling Insulation	Simulation Modeling	Simulation Modeling	Simulation Modeling
	Basement Wall Insulation	Simulation Modeling	Simulation Modeling	Simulation Modeling
	Furnace Fan (due to weatherization)	Simulation Modeling	Simulation Modeling	Simulation Modeling
Heating System	Heating System Replacement	Billing Analysis (±16%)	--	Engineering Algorithm
	Oil Boiler Replacement	--	--	Engineering Algorithm
	Boiler Reset Controls	--	--	Engineering Algorithm
	Programmable Thermostat	--	--	Engineering Algorithm
	Furnace Fan (due to heating system/boiler replacement)	Engineering Algorithm	--	Engineering Algorithm
Appliances	Refrigerator Replacement	--	Engineering Algorithm	--
	Second Refrigerator Removal	--	Engineering Algorithm	--
	Freezer Replacement	--	Engineering Algorithm	--
	Window AC Replacement	--	Engineering Algorithm	--
Lighting	CFLs	--	Engineering Algorithm	--
	Torchieres	--	Engineering Algorithm	--
	Fixtures	--	Engineering Algorithm	--
Domestic Hot Water	Domestic Hot Water (Overall)	Engineering Algorithm	Engineering Algorithm	Engineering Algorithm
	Low Flow Showerhead	Engineering Algorithm	Engineering Algorithm	Engineering Algorithm
	Faucet Aerator	Engineering Algorithm	Engineering Algorithm	Engineering Algorithm
	Pipe Wrap	Engineering Algorithm	Engineering Algorithm	Engineering Algorithm
Distribution	Duct Insulation	Engineering Algorithm	--	Engineering Algorithm
	Duct Sealing	Engineering Algorithm	--	Engineering Algorithm
Other	Baseload (TLC Kits)	--	Engineering Algorithm	--

* This row refers to any participant that received attic, and/or wall, and/or basement insulation or air sealing.

For the impact analysis (billing analysis, engineering algorithm, and simulation modeling), The team utilized treatment groups composed of 2010 HES and LI participants that installed measures between January 1, 2010 and September 30, 2010. The billing analysis specifically required that participants included in the treatment group had not moved since participating, have at least 11 months of pre-period billing data—including a minimum of three winter months (to sufficiently capture the heating season)—and were not flagged as outliers. (Outliers exhibited annual kWh or therm consumption that was outside three standard deviations of the population mean).[2] For LI, the team did not have sufficient digital audit data available for all participants, and manually collected data from CAP agencies for a subset of participants with

[2] With the exception of billing data used for model calibration (which aligned with the billing analysis sample), the engineering analysis relied only on audit data, and therefore did not impose similar requirements.

sufficient billing data. The combination of these filters resulted in the billing analysis treatment group sizes shown in Table 4. For HES, the engineering analysis also used audit data from participants that lacked sufficient billing data.

Table 4. Treatment Group – Analysis Datasets

Analysis Approach	Electric		Natural Gas	
	HES	LI	HES	LI
Billing Analysis[3]	11,788	489	2,635	402

The engineering analyses utilized audit data provided by program implementers, as well as pre-installation billing data for the measures evaluated using calibrated simulation. The team collected and standardized key data from each implementer for the HES program, yielding a large and rich database. For LI, the team was limited to the same dataset as the billing analysis due to the lack of digital audit data. Table 5 shows the total audit records provided for each program by PA.

Table 5: HES and LI Audit Data Summary

PA	HES Audit Records	LI Audit Records
National Grid	29,404	374
NSTAR	24,051	224
Berkshire	1,024	128
CLC	6,927	234
Columbia	5,495	305
NE Gas	309	-
Unitil	N/A	9
WMECO	560	47

Findings

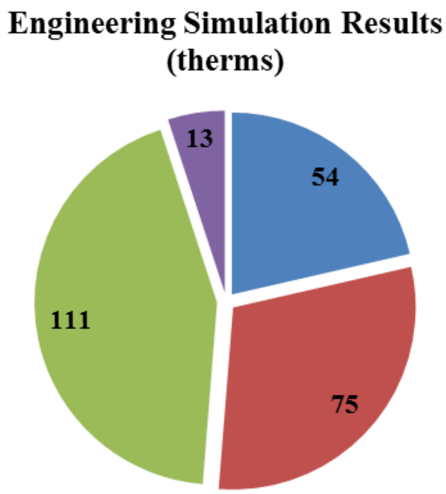
The strong agreement between the billing analysis and engineering analysis for measures with statistically valid billing analysis results both gave the team confidence in the engineering approach for the remaining measures and allowed us to shed light on some of the factors behind the billing analysis results.

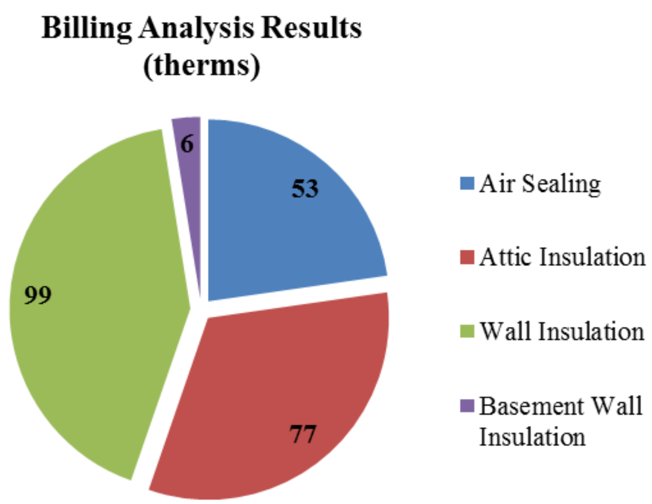
Using engineering results to add granularity to and extrapolate from billing analysis

The billing analysis and engineering analysis results showed strong agreement for all measures with valid billing analysis results. The clearest examples are the HES weatherization results. While the team only reported billing analysis results for these measures,[4] the consistency of results gave us great confidence in the engineering results that we did report.

[3] The engineering analysis did not exclude Q4 2010 participants or those removed due to insufficient billing data.
[4] With the exception of Basement Ceiling Insulation, not shown, where only engineering results were reported.

Figure 1: Comparison of HES Weatherization Measures with Valid Billing Analyses



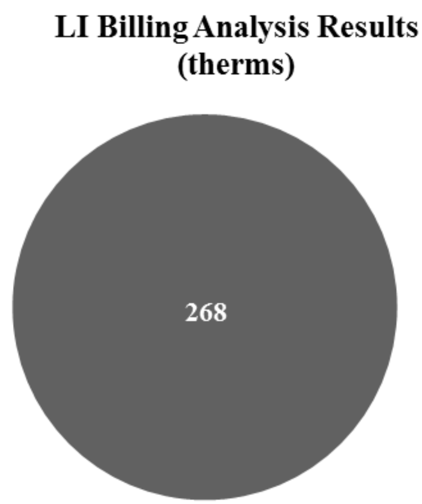


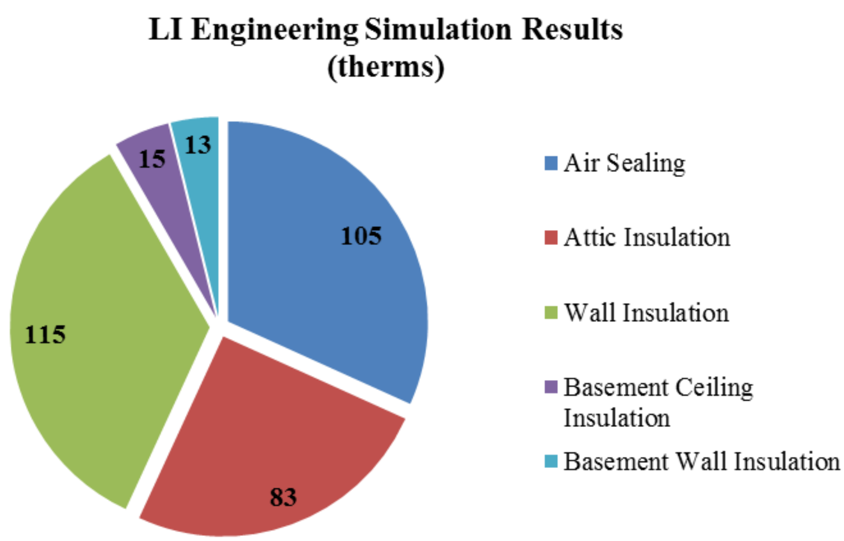
Overall Engineering Simulation = 102 therms ***Overall Billing Analysis = 96 therms***[5]

In the HES evaluation, we had sufficient data to use billing analysis results for almost all individual insulation locations for homes heated with natural gas. This was not the case for LI, but using the same approach for LI, we could use the engineering results to fill in the picture of weatherization measure breakdown given the agreement in overall weatherization measure savings. This breakdown showed that low income homes generally saved considerably more than their HES counterparts in air sealing, and also achieved slightly higher insulation savings.

[5] Overall numbers are weighted averages based on the number of installations of each insulation type and reflect the average participant: individual measure estimates do not sum to the "overall" estimate.

Figure 2: LI Billing Analysis and Engineering Simulation Results





Overall per participant weatherization engineering simulation savings = 253 therms

In both evaluations, electric sample sizes were much smaller than natural gas sample sizes and, due to the long billing periods for customers with oil heat, oil billing analysis was not feasible. The team used the engineering models to characterize savings for these fuel types:

- We used electric billing data to calibrate electrically heated home models
- We adjusted the calibrated natural gas home models to use typical oil heating system efficiencies and oil customer home characteristics

Using engineering and audit data to provide context for billing analysis results

In addition to providing results for measures where the billing analysis was not sufficiently precise, the wealth of audit data cleaned and aggregated as part of the engineering analysis also provided useful insights into some of the discrepancies between program planning and implementation estimates and evaluated results.

Heating Systems

In the LI program, a major measure is the early replacement of heating systems, namely furnaces and boilers. The evaluation team compared the statistically valid billing analysis results to the similar engineering analysis results which were based on actual participant consumption (from the billing analysis) and estimated pre- and post-retrofit heating system efficiencies. This comparison showed that baseline efficiencies were higher than some PAs had estimated (as low as 65%), though still well below the average system in HES homes (78%).

Table 6: Comparison of Engineering and Billing Analysis Gas Heating System Replacement Results

Heating System Measure	n	Existing Efficiency	Installed Efficiency	Engineering Savings Estimate (therms)	Billing Analysis Savings Estimate (therms)
Boiler	87	71%	86.4%	180*	194*+
Furnace	53	72%	93.1%	186	207
Overall				**182**	**199**

*Includes some units with integrated hot water

+Relative precision over 20%

CFLs

In the HES program, the large volume of participants receiving CFLs enabled the team to use billing analysis results for this measure. Many audits showed homes receiving large numbers of lamps—the average participant reported nearly 19 CFLs installed. As shown in

Figure 3 and Table 7, average savings per CFL drop off quickly with the number of CFLs installed. Using the pre- and post-retrofit wattages from the audit data, the team was also able to characterize changes in average estimated hours of use for homes with a range of installed CFL quantities.

Figure 3: Savings per CFL as a function of number of CFLs installed

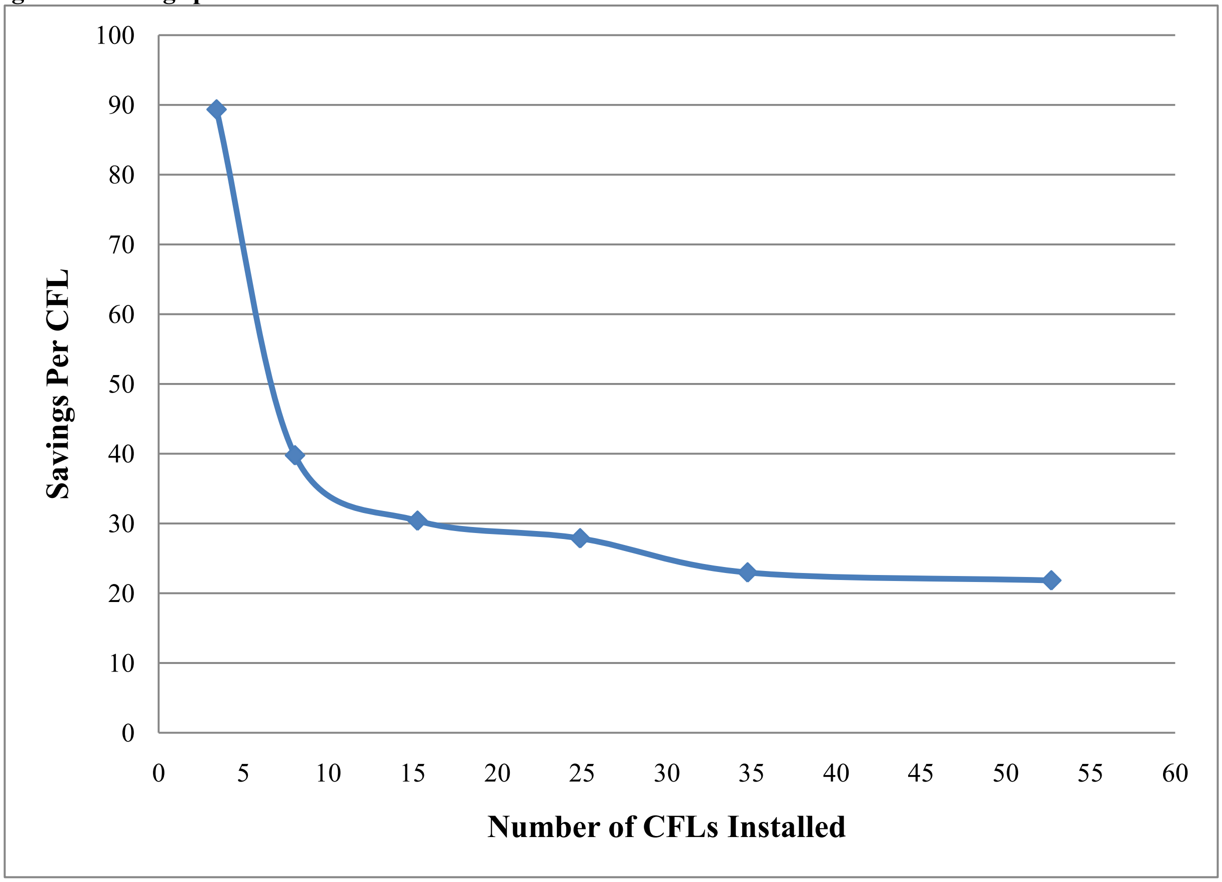


Table 7: Savings and Derived HOU for CFLs in HES Program

CFLs Received	Percent of Analysis Dataset	Average # of Installed CFLs	Billing Analysis kWh Saved/CFL	Billing Analysis Derived HOU*
1-5	10%	3.4	89	5.5
6-10	18%	8.0	40	2.5
11-20	36%	15.3	30	1.9
21-30	21%	24.9	28	1.7
31-40	9%	34.8	23	1.4
>40	6%	52.7	22	1.4
Overall	**100%**	**18.9**	**29**	**1.8**

* Based on a change in wattage of 44 kW (the average based on HES tracking data).

Insulation Quantity

For insulation measures, the engineering analysis utilized the quantity and thickness of insulation installed in each location. In addition to providing these details to the PAs, the team also compared the average number of insulation installations across programs and fuel types (for example, a home receiving both attic and wall insulation has two installations). Table 8 shows that the percent of heating energy use saved generally increased with the number of measures installed across programs and heating fuel types.

Table 8: Summary of Weatherization Measures Installed and Percent Savings by Program and Fuel

Heating Fuel	HES		LI	
	Measures per Home	Percent Heating Savings	Measures per Home	Percent Heating Savings
Gas	1.37	11%	2.69	30%
Electric	1.28	9%	2.34	30%
Oil	1.42	15%	2.67	34%

Conclusions

The combined approach of these two evaluations provided two major benefits for National Grid and the other Massachusetts PAs. The first was providing evaluated oil savings and the second was the ability to disaggregate the household savings to the measure level. The combined approach also enabled the PAs to finally have a more accurate estimate of the programs oil savings by measure. In the past the PAs relied on various less sophisticated methods to estimate the oil savings, and this approach provided clear and defensible estimates for future years.

Moreover, PAs have previously only been able to get evaluated saving estimates at the household level or for measures in which the billing analysis was able to provide them. Adding engineering simulations for a combined approach not only provided savings at the measure level—say, insulation—but also for specific insulation locations (attic, wall, basement). This level of detail has provided for better savings estimates that are more useful for program planning.

In addition to these benefits, the dual-pronged approach allowed PAs to examine billing analysis results in greater detail and see what program factors—such as the actual efficiency of old heating systems or the number of CFLs distributed to participating homes—might be driving results. The ability to see how these factors play into results can also help evaluators, PAs and implementers alike better understand the underlying reasons for program realization rates.

The successful combination of billing and engineering analyses in these evaluations shows that leveraging multiple approaches can greatly enhance the value of program evaluations with many measures and fuel types. For weatherization programs with sufficient audit data across weatherization and direct install measures, engineering analysis can smoothly supplement billing analyses to provide programs with greater granularity and more accurate insights for billing analysis results.