High Efficiency Heating Equipment Impact Evaluation

Final Report
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Prepared for:
The Electric and Gas Program Administrators of Massachusetts
Part of the Residential Evaluation Program Area

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Executive Summary

Program Background and Objectives

The Massachusetts High-Efficiency Heating Equipment Rebate Program (HEHE) offers prescriptive rebates of up to $1,600 for the installation of new high-efficiency natural gas heating and water heating equipment. The objective of this evaluation was to determine gross energy savings for gas furnaces and boilers installed through the HEHE program, and refine the estimates of baseline efficiency and heating consumption. The evaluation sought to answer the following researchable questions:

- How much energy is being saved for the average installation of efficient space heating equipment through the Massachusetts HEHE program?
- How does the *in situ* efficiency of standard efficiency furnaces and boilers that are installed outside of the program compare to their rated efficiency?
- How does the *in situ* efficiency of existing equipment that is retired early compare to its rated efficiency?
- How are condensing boilers being installed and controlled, as it relates to their potential savings?[1]

Methodology

The team sought to assess home heating (and boiler hot water) consumption and annual heating loads for all types of installations, the efficiency of baseline space heating equipment, and the efficiency of new space heating equipment promoted through the program. With this in mind, the evaluation team designed the field portion of the study with two main components:

1. **Spot measurement of baseline and new equipment *in situ* efficiency**. This task provided efficiency estimates to reduce the uncertainty around new, early retirement and standard baseline furnace and boiler performance, including oil units. Additionally, spot measurements of baseline equipment provided an opportunity to better estimate fuel switching savings.[2]
2. **Long-term metering of post-retrofit high efficiency equipment** (majority of 2013-2014 heating season). This task refined estimates of annual heating load for furnaces and boilers. Logging of operating parameters was particularly important for condensing boilers where efficiency is dependent on return water temperature. The team minimized costs and uncertainty by conducting a preliminary billing data disaggregation. The metering sites were selected from within the billing data disaggregation population in a nested sampling design.

[1] The high efficiency of condensing boilers relies on a low boiler return water temperature, which means that differences in installation practices that impact return water temperature have a large impact on savings.

[2] For new high-efficiency boilers, long term metering data also informed efficiency estimates as efficiency varies with return water temperature on all condensing boilers. Oil measurements are relevant only for fuel conversion baselines; the evaluation did not calculate any oil savings.

Results

The following sections present savings for furnaces and boilers. All savings in this report are first-year savings.

Furnace Results: Replace on Failure

Table 1 summarizes the verified savings estimates for furnaces. The results were calculated using the new baseline of 85 percent AFUE that the PAs will use for replace-on-failure units from 2014 forward; this calculation does not include an evaluation adjustment since the baseline is a negotiated value. Results based on a rated baseline of 80 percent AFUE with the evaluation adjustment for actual unit performance can be found in Appendix E. The team found that on average, standard efficiency furnaces performed slightly better than their rated efficiencies.

Table 1. Furnace Savings Findings

Measure	AFUE Type	Efficient AFUE	Baseline AFUE	Verified ROF Therm Savings	2013 Report TRM ROF Therm Savings	Relative Precision at 90% Confidence
95% AFUE Furnace ROF Baseline	Rated	95.2%	Negotiated Baseline: 85%	75	147	8.7%
	Verified	95.4%				
97% AFUE Furnace ROF Baseline	Rated	97.0%		86	162	
	Verified	97.2%				

The primary driver for reduced furnace savings was the fact that typical furnace participant heating consumption was lower than assumed in the current savings methodology. This is likely because the current methodology uses an annual heat load estimate for all gas system types, and this evaluation found that the average participant high efficiency furnace home uses less gas than the average participant home in Massachusetts.[3] Furnace savings were also reduced because of changes to the deemed baseline efficiency.

Boiler Results: Replace on Failure

Table 2 and Table 3 summarize the verified savings for standard boilers and combination boilers.[4]

[3] The evaluation team conducted additional research to understand factors driving lower heating consumption in furnace homes; these findings can be found in Appendix D.

[4] Combination boilers are boilers that provide a combination of heating and hot water in one contained unit. By including a small insulated hot water tank inside the same box as the boiler, these units preclude the need to install a separate indirect hot water heater.

Table 2. Standard Boiler Verified Savings

Measure	AFUE Type	Efficient AFUE	Baseline AFUE	Verified ROF Therm Savings	2013 Report TRM ROF Therm Savings	Relative Precision at 90% Confidence
90% AFUE Boiler ROF Baseline	Rated	92.7%	Rated: 82.0% Verified: 79.3%	110	104	9.9%
	Verified	87.2%				
95% AFUE Boiler ROF Baseline	Rated	95.0%		137	123	
	Verified	89.4%				
96% AFUE Boiler ROF Baseline	Rated	96.0%		148	131	
	Verified	90.3%				

The team found that although boilers serve larger loads than the deemed savings assumed,[5] verified savings estimates are similar to current deemed values because high-efficiency boilers are operating well below their rated efficiency. The average operating efficiency of the metering sample (standard and combination systems) was 88.4 percent, almost six percentage points below the average rated new efficiency of 94 percent. The team also found that baseline units operate below their rated AFUE, but not as significantly as high-efficiency equipment and for different reasons. The primary cause for lower efficiency in this group is that boilers are not fully utilizing available controls such as outdoor reset to keep supply and return water temperatures low enough to achieve condensing operation in most cases. The Boiler Results section includes additional detail on these findings.

[5] On average, boilers had both higher heating and higher hot water loads than were used in the deemed assumptions.

Table 3. Combination Boiler Verified Savings

Measure	AFUE Type	Assumed Efficient Case	Assumed Baseline Case	Verified ROF Therm Savings	Weighted Average Verified ROF Therm Savings	2013 Report TRM ROF Therm Savings	Relative Precision at 90% Confidence
≥90% AFUE Combination Boiler Indirect ROF Baseline	Rated	92.2% Combination	82% Boiler with Indirect	88	96	178	10.6%
	Verified	86.8% Combination	79.3% Boiler with Indirect				
≥90% AFUE Combination Boiler Standalone DHW ROF Baseline	Rated	92.2% Combination	82% Boiler 0.575 EF DHW	130			
	Verified	86.8% Combination	79.3% Boiler 0.575 EF DHW				
≥95% AFUE* Combination Boiler Indirect ROF Baseline	Rated	95% Combination	82% Boiler with Indirect	113	121	-	
	Verified	89.4% Combination	79.3% Boiler with Indirect				
≥95% AFUE* Combination Boiler Standalone DHW ROF Baseline	Rated	95% Combination	82% Boiler 0.575 EF DHW	155			
	Verified	89.4% Combination	79.3% Boiler 0.575 EF DHW				

*This is a new measure and thus there is no TRM savings estimate for comparison.

As with standard boilers, combination boilers operated well below their rated efficiency. Homes with combination systems also tended to serve smaller annual loads than homes with standard boilers, further reducing savings estimates. This could be due to a number of factors such as combination systems being installed in smaller, newer or better insulated homes. The team calculated savings for two baseline options: a boiler and a standalone domestic water heater, or a boiler with an indirect domestic water heater. Based on 2013 tracking data and on-site observations of the presence of indirect versus standalone water heaters, the team estimates that approximately 80 percent of standard (i.e. not combination) boilers have indirect water heaters. The weighted average savings values in Table 3 reflect this baseline share.

Early Retirement Results

The goal of this research was to understand the relationship between rated and actual performance of these units. Due to difficulty recruiting, the team only visited 38 sites across four equipment types and was not able to collect enough data to provide a statistically valid quantitative adjustment to early retirement baseline efficiency.

Although the team did not adjust the baseline with data from this portion of the study, the early retirement research did point to the following qualitative findings:

- There is not much difference in the ratios of actual to rated performance of old and new gas units. For the group of early retirement gas units less than 30 years old, the evaluation did not find evidence of significant degradation of efficiency.
- The results showed that the "early retirement" baseline of 72.5 percent AFUE may not be appropriate for units less than thirty years old and should be reviewed in future planning work. All but one sampled gas unit had rated and/or measured efficiencies above 75 percent AFUE.
- Oil units generally performed worse relative to their rated efficiencies than gas units.

Given these findings, the team estimated the early retirement baseline rated efficiency as the federal minimum efficiencies in place before the most recent standards came into effect. These efficiency standards have been in place since 1992, earlier than the installation of most early retirement units under 30 years old. Given the similarity in actual performance relative to efficiency ratings between the early retirement and standard new group and the small early retirement sample sizes, the team applied the standard new adjustment factors to the early retirement rated baselines as shown in Table 4.

Table 4. Early Retirement Baselines

Measure	Rated Baseline	Baseline Adjustment	Verified Baseline
Furnaces	78%	1.01	78.9%
Boilers	80%	0.97	77.4%

Overall Savings Results

The following tables present the evaluation team's recommended revised deemed savings values for each furnace and boiler measure. The team used the percentages of early retirement and replace on failure installations found in the 2012 HEHE and Cool Smart net-to-gross evaluation[6] to weight savings from each group into a single value for each measure. Furnace savings are calculated assuming 11.7 percent early retirement, boiler savings are calculated assuming 13.2 percent early retirement, and combination boiler savings assume 32.2 percent early retirement.

[6] "2012 Residential Heating, Water Heating and Cooling Equipment Evaluation: Net-to-Gross, Market Effects, and Equipment Replacement Timing." Cadmus Group, June 2013.

Table 5. Furnace Results, 85 Percent AFUE Baseline

Measure	Verified ROF Therm Savings	Verified ER Therm Savings	Verified Average Savings	2013 Report TRM Therm Savings
95% AFUE Furnace	75	127	81	159
97% AFUE Furnace	86	139	92	173

Table 6. Boiler Results

Measure	Verified ROF Therm Savings	Verified ER Therm Savings	Verified Average Savings	2013 Report TRM Therm Savings
90% AFUE Boiler	110	140	114	120
95% AFUE Boiler	137	167	141	139
96% AFUE Boiler	148	178	152	147

Note: Boiler savings include hot water loads from indirect water heaters.

Table 7. Combination Boiler Results

Measure	Baseline	Verified ROF Therm Savings	Verified ER Therm Savings	Verified Average Therm Savings	Weighted Average Verified Therm Savings	2013 Report TRM Therm Savings
90% AFUE Combination Boiler	Standalone Water Heater	130	159	139	104	238
	Indirect Water Heater	88	111	95		
95% AFUE Combination Boiler	Standalone Water Heater	155	184	164	129	-
	Indirect Water Heater	113	136	120		

Program Implications and Conclusions

This evaluation provided revised savings estimates for high-efficiency furnace and boiler replacements. In addition, the team noted several key findings:

- There are differences in annual heating load between equipment types: Average annual heating loads[7] for HEHE-installed furnaces and combination boilers were 26 percent and 19 percent

[7] The term "load" is used throughout this report to characterize heat delivered to the home by the furnace or boiler over the course of the year—i.e., the thermal "load" on the heating system. This is calculated as the actual consumption divided by the actual efficiency.

lower than the standard boilers, respectively. The team analyzed furnace and boiler home characteristics for over 180,000 homes in the Massachusetts Home Energy Services (HES) program and determined that these differences are largely due to the fact that boiler homes tend to be older, larger and less efficient than furnace homes.[8] Previous deemed savings used the same annual heating load for both furnaces and boilers.

- It is important to consider standby and cycling losses in addition to combustion efficiency when evaluating gravity-drafted equipment such as standard and early retirement boilers and furnaces. Older boilers in particular can have higher standby losses due to their large mass, especially when serving hot water loads year-round.
- High-efficiency boilers are not being installed to maximize potential savings. The PAs should consider ways to improve boiler operating efficiency through quality installation, and contractor and homeowner education. The Program Considerations and Conclusions section of this report discusses specific recommendations for further research in this area.
- Many older gas furnaces and boilers considered "early retirement" equipment have AFUEs of at least 75 percent, even when considering actual instead of rated performance. The PAs should use the revised early retirement baselines shown in Table 4 and broader research on early retirement units less than thirty years old may be needed if early retirement participation increases.
- Evaluation research suggests that as many as 80 percent of new combination systems are replacing boilers with indirect water heaters, but the TRM currently assumes a boiler and a standalone water heater as the baseline. Since the baseline system has a significant impact on savings, the PAs should consider conducting additional baseline research and/or requiring application information on what combination systems are replacing.

[8] There was not sufficient data to also make this comparison for combination systems, but the team believes these homes are also likely smaller and newer than standard boiler homes. Additional detail on the analysis of HES participants can be found in Appendix D.