Project 15 Prescriptive Gas – Final Program Evaluation Report

Massachusetts Energy Efficiency Programs
Large Commercial & Industrial Evaluation

Prepared for: Massachusetts Energy Efficiency Program Administrators
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1. Executive Summary

This report presents the results of the impact evaluation of the Program Year 2010 (PY10) Massachusetts Prescriptive Gas Measures Program. The evaluation consists of on-site monitoring and verification of the savings for a sample of participants for four of the top five measures installed, in terms of savings. The sample sites were monitored for about eight weeks in an attempt to capture seasonally sensitive variations in energy consumption between the winter and swing seasons. The first monitoring equipment was installed in early February and recovery was completed during the second week of April. The on-site sample design was designed to achieve a relative precision of ± 20% at the 80% confidence interval using a two-tail test for the overall program savings.

1.1 Program Savings Results

Table ES 1 provides the on-site savings results, realization rate and relative precision for each of the four prescriptive gas measures that were evaluated as well as the total for all four. The overall realization rate for the four measures was about 104% and the relative precision was about ±15%. The Condensing Boiler measures had the highest realization rate of 137%. Since they represent about 64% of total program savings this increase offset the decreases observed for the other measures. The indirect water heater measure had the second best realization rate of almost 59%. Furnace and Infrared Heating measures had low realization rates of 33% and almost 21% respectively. All of the measures met or exceeded their target relative precision and the total precision was also better than planned.

Table ES 1: Program Savings Results

Description	Revised Total Therms Saved	On-site Total Therms	Realization Rate	Relative Precision
Boiler	386,630	530,357	137.2%	±17.6%
Furnace	49,951	16,532	33.1%	±6.1%
Infrared Heating	72,912	15,058	20.7%	±8.5%
Indirect Water Heater	69,616	40,791	58.6%	±30.5%
Total	579,109	602,738	104.1%	±14.9%

1.2 Measure Savings Recommendations

This section provides the recommended new TRM measure savings values that should be used for tracking and planning purposes. All of the measures experienced significant variation

between the on-site and TRM savings values and for this reason we would recommend an additional round of evaluation for each of these measures.

1.2.1 Condensing Boiler Recommendations

The savings for the condensing boiler measures is derived from three primary variables, the input capacity of the boiler, the measured efficiency of the boiler (expressed as AFUE)[1], and the operating hours (expressed as EFLH). The capacity values were addressed as part of the 2011 KEMA evaluation of condensing boilers and the current savings recommendation includes those values. The mean measured efficiency observed in the sample was 88.9%, which is consistent with the value determined in the prior evaluation.

The mean EFLH observed in the sample was 1,421 hours per year, which is not significantly lower than 1,500 hours that was used in the original TRM savings calculation however it did represent a second year of decrease for this variable.[2] There was some variation observed within the size categories, but most category level samples were small and there is no compelling reason to develop different EFLH values for the different categories. As a result it is recommended that the EFLH value for the recommended prospective savings calculation be reduced to 1,400 hours for all size categories. Table ES 2 provides the savings variables and original savings values for each of the five size categories along with the evaluated (retrospective) savings values and the recommended prospective savings values.

Table ES 2: Recommended Condensing Boiler Savings

Size Category	Revised Capacity (MBtu)	AFUE	EFLH	Original Savings (ΔMMBtu/Unit/yr)	Evaluated (Retrospective) Savings (ΔMMBtu/Unit/yr)	Recommended Prospective Savings (ΔMMBtu/Unit/yr)
Capacity ≤ 300	209.6	88.9%	1400	22.1	29.8	29.4
300 < Capacity < 500	400	88.9%	1400	42.3	56.9	56.1
500 ≤ Capacity < 1000	735	88.9%	1400	77.1	104.6	103.0
1000 ≤ Capacity ≤ 1700	1350	88.9%	1400	142.6	192.1	189.2
1700 < Capacity	2363	88.9%	1400	249.0	336.2	331.2

[1] The term AFUE is used here and throughout the report to represent the measured efficiency based upon monitoring data.
[2] The MA Prescriptive Condensing Boiler Impact Evaluation of the 2008-2009 Prescriptive Gas study also concluded that EFLH for condensing boilers was less than 1,500 hours.

1.2.2 Condensing Furnace Recommendations

The condensing furnace savings calculations utilize the same three primary savings variables as the condensing boilers, the input capacity of the furnace, the efficiency of the furnace (expressed as AFUE), and the operating hours (expressed as EFLH).

The mean EFLH observed in the sample was 452 hours per year based upon a sample of 12 furnaces monitored at nine different sites and a few of these sites had really low usage. Secondary research indicated that the mean hours are lower than would typically be expected for commercial use.

The mean input capacity observed in the on-site sample of furnaces was 90 MBTUs and this value will be used to calculate the revised savings value. The sample furnaces were primarily identified as 92% efficient furnaces and the mean measured efficiency observed in the sample was 93.6%, we would recommend that an AFUE of 95.6% be used for the 94% efficient furnaces. The TRM savings values also include a 7.1% decrease in savings due to a reduction in motor heat from the installation of ECM fan motors.

Given the low EFLH observed in the sample sites (due primarily to non-standard operating hours) and the relatively small sample, the recommended prospective savings will be adjusted to the mean between the original TRM savings and the evaluated (retrospective) savings. Table ES 3 provides the original savings values along with the evaluated (retrospective) savings and the recommended prospective savings for each furnace efficiency category.

Table ES 3: Recommended Condensing Furnace Savings

Furnace Efficiency	Original Savings (ΔMMBtu/Unit/yr)	Evaluated (Retrospective) Savings (ΔMMBtu/Unit/yr)	Recommended Prospective Savings (ΔMMBtu/Unit/yr)
Furnace AFUE =>92%	21.1	5.9	13.5
Furnace AFUE =>92% w/ECM	19.6	5.5	12.5
Furnace AFUE =>94% w/ECM	23.6	6.2	14.9

1.2.3 Infrared Heater Recommendations

The Infrared Heater (IR Heater) savings calculation is somewhat similar to the previous heating measures except that the radiant nature of an IR Heater allows the unit to be sized smaller than a conventional warm air heater. The three primary variables used in the IR Heater savings calculation are the IR compensation factor, the capacity of the IR Heater and the EFLH.

The IR Heater compensation factors is the percentage of capacity reduction that IR Heater can be sized and still provide the same level of comfort to the building occupants. The mean compensation factor observed in the sample was 0.82, which represents a mean unit height of 20 feet above the floor. The mean unit capacity observed in the sample data was 108 MBTU/hr. The mean EFLH observed in the sample was 677 hours.

Given the small sample size KEMA recommends that the mean value between the original TRM savings and the evaluated (retrospective) savings value be used for recommended prospective savings until additional evaluation work can be completed for this measure. Table ES 4 provides the original savings estimate for the IR Heater measure along with the evaluated (retrospective) savings and the recommended prospective savings.

Table ES 4: Recommended Infrared Heater Savings

Measure Type	Original Savings (ΔMMBtu/Unit/yr)	Evaluated (Retrospective) Savings (ΔMMBtu/Unit/yr)	Recommended Prospective Savings (ΔMMBtu/Unit/yr)
Infrared Heater	74.4	22.3	48.3

1.2.4 Indirect Water Heater Recommendations

The Indirect water heater savings is primarily a function of the amount of domestic hot water usage and as such, it is difficult to develop a prescriptive variable that would be predictive with respect to the amount of savings. The original savings value was 30.4 MMBtu/unit/yr and the mean savings value observed in the on-site sample was 20.7 MMBtu/unit/yr.

Table ES 5 provides the original savings value along with the evaluated (retrospective) savings and recommended prospective savings, which are both 20.7 MMBtu/unit/yr.

Table ES 5: Recommended Indirect Water Heater Savings

Measure Type	Original Savings (ΔMMBtu/Unit/yr)	Evaluated (Retrospective) Savings (ΔMMBtu/Unit/yr)	Recommended Prospective Savings (ΔMMBtu/Unit/yr)
Indirect Water Heater	30.4	20.7	20.7

2. Introduction

This report presents the results of the impact evaluation of the Program Year 2010 (PY10) Massachusetts Prescriptive Gas Measures Program. This evaluation consists of on-site monitoring and verification of the savings for a sample of participants in the 2010 program year for four of the top five measures installed, in terms of savings. The sample sites were monitored for about eight weeks in an attempt to capture seasonally sensitive variations in energy consumption between the winter and swing seasons. The first monitoring equipment was installed in early February and recovery was completed during the second week of April.

2.1 Purpose of Study

The primary objective of the PY10 Prescriptive Gas Evaluation was to complete a retrospective impact evaluation for the selected measures through site inspection, monitoring and analysis. The evaluation was based on the population of measures rebated during the 2010 program year and selected measures were sampled at the site-level. The goal of this gas evaluation was to develop realization rates for program planning and for reporting 2011 and possibly later program results. The evaluation was targeted to produce findings at the 80% confidence level with precision of plus or minus 20% for the full prescriptive gas program. Confidence and precision at the individual measure level were also calculated and presented.

2.2 Scope

The scope of work for this evaluation project was to develop statewide realization rates and statewide recommendations for future prescriptive measure savings values for condensing boilers, condensing furnaces, infrared heaters and indirect water heaters. There was no attempt to develop PA-level realization rates or recommendations regarding the reporting of overall Prescriptive Gas Program results statewide. On-site monitoring was conducted for a sample of the following measures;

- Condensing Boilers,
- Condensing Furnaces,
- Infrared Heaters, and
- Indirect Water Heaters.

The data collected through the monitoring effort was processed, analyzed, and expanded to the population level for each measure.

3. Description of Sampling Strategy

DNV KEMA reviewed the participant populations provided by the Program Administrators (PA), analyzed the distributions of savings by PA, measure type, and project numbers and developed the sample plan for PA review. Table 1 below summarizes the prescriptive measures tracked for 2010 and the relative contribution to number of project and savings by measure. The measures selected for study are highlighted.

Table 1: All Prescriptive Measures

Prescriptive Gas Projects and Savings by Measure Category				
Measure Category	Number of Projects	% of Projects	Annual Therms Savings	% of Savings
BOILER RESET CONTROLS	15	1.50%	11,715	1.17%
BROILER	4	0.40%	4,644	0.46%
COMBINED HIGH EFFICIENCY BOILER AND WATER HEATER	1	0.10%	246	0.02%
COMMERCIAL FRYER	21	2.10%	30,472	3.05%
COMMERCIAL GAS-FIRED OVEN	19	1.90%	6,448	0.65%
COMMERCIAL GAS-FIRED STEAMER	2	0.20%	2,122	0.21%
CONDENSING STAND-ALONE WATER HEATER	7	0.70%	2,250	0.23%
CONDENSING UNIT HEATER	1	0.10%	818	0.08%
GAS-FIRED LOW INTENSITY INFRARED HEATING	37	3.69%	72,912	7.30%
HIGH EFFICIENCY FREE STANDING WATER HEATER	9	0.90%	68	0.01%
HIGH EFFICIENCY INDIRECT WATER HEATER	124	12.38%	69,616	6.97%
HIGH EFFICIENCY NATURAL GAS BOILER	319	31.84%	638,134	63.86%
HIGH EFFICIENCY NATURAL GAS WARM AIR FURNACE	155	15.47%	49,951	5.00%
HIGH EFFICIENCY TANKLESS WATER HEATER	59	5.89%	7,384	0.74%
OTHER	1	0.10%	2,000	0.20%
PRE-RINSE SPRAY VALVE	28	2.79%	13,439	1.34%
PROGRAMMABLE THERMOSTAT	196	19.56%	35,226	3.53%
STEAM TRAPS	4	0.40%	51,865	5.19%
Total	1,002	100.00%	999,310	100.00%

The initial population frame for this evaluation was the 1,002 records defined as unique project and measure categories. This approach was different than that taken in the Custom Gas impact evaluation where measure categories were aggregated within sites to define the population and select the sample. KEMA recommended sampling by measure category for this evaluation since it is more straight-forward and likely to be more accurate than site-level sampling for the Prescriptive Gas Program. Within the population of 1,002 unique project and measure categories, the four measure categories chosen for this study include 635 projects. Table 2 below summarizes the population from which the sample for this study was drawn.

Table 2: Study Measure Population

Measure Category	Projects	Total Therms	Average Therms	Minimum	Maximum	StdDev	CV
Boiler	319	638,134	2,000	72	29,393	3,225	1.61
Furnace	155	49,951	322	196	4,312	382	1.19
Infrared Heating	37	72,912	1,971	744	7,440	1,625	0.82
Indirect Water Heater	124	69,616	561	304	9,728	1,020	1.82
Total	635	830,613					

DNV KEMA worked with the PA representatives to develop a stratified sample efficiently allocated 43 sample points across the measure categories as shown in Table 3.

Table 3: Sample Design

Measure Category	Stratum	Maximum Therms Saved	Number of Sites	Total Therms Saved	Sample Size	Inclusion Probability
Boiler	1	1,467	201	112,080	5	0.0249
Boiler	2	2,934	65	145,079	4	0.0615
Boiler	3	6,000	36	165,425	4	0.1111
Boiler	4	29,393	17	215,550	4	0.2353
Furnace	1	211	71	14,516	4	0.0563
Furnace	2	422	58	15,079	3	0.0517
Furnace	3	4,312	26	20,356	3	0.1154
Infrared Heating	1	1,488	21	19,344	3	0.1429
Infrared Heating	2	2,976	10	23,064	2	0.2000
Infrared Heating	3	7,440	6	30,504	2	0.3333
Indirect Water Heater	1	304	62	18,848	3	0.0484
Indirect Water Heater	2	608	48	19,760	3	0.0625
Indirect Water Heater	3	9,728	14	31,008	3	0.2143

Table 4 below shows the precision at the 80% confidence level anticipated for this design. This design offers decent precision (±21.74%) for boilers, the largest measure category and an overall precision of ±17.20% for the four measures studied.

Table 4: Anticipated Precisions

Measure Category	Projects	Total Therms Saved	Error Ratio	Confidence Level	Planned Sample Size	Anticipated Relative Precision
Boiler	319	638,134	0.7	80%	17	±21.74%
Furnace	155	49,951	0.7	80%	10	±30.12%
Infrared Heating	37	72,912	0.7	80%	7	±30.88%
Indirect Water Heater	124	69,616	0.7	80%	9	±31.59%
Total	635	830,613	0.7	80%	43	±17.22%

3.1 Revision of Tracking Data

Tracking data provided by the PAs on July 3, 2011 was the basis for the sample design and subsequent field work. Concurrent with this effort KEMA was completing an impact evaluation of the condensing boiler program measure. The report, titled; *Prescriptive Condensing Boiler Impact Evaluation - Project 5 Prescriptive Gas* and dated June 2, 2011 was not finalized until August of 2011 and therefore the condensing boiler savings values in the tracking data used for the sample design had not been updated. Table 5 provides a summary of the tracking system revisions at the measure level and in aggregate that served as the reference point for this evaluation. The boiler savings were reduced 39%, from 638,134 therms to 386,630 therms and the total savings for the four measures was reduced by 30%.

Table 5: Summary of Tracking System Revisions

Description	Projects	Original Total Therms Saved	Revised Total Therms Saved	Percent Change
Boiler	319	638,134	386,630	-39%
Furnace	155	49,951	49,951	0%
Infrared Heating	37	72,912	72,912	0%
Indirect Water Heater	124	69,616	69,616	0%
Total	635	830,613	579,109	-30%

4. Description of Methodology

4.1 Measurement and Verification Plans

KEMA developed measurement and verification (M&V) templates for the four study measures that were approved by the PAs prior to implementation. The use of templates ensures data quality and consistency. The M&V templates contained the following:

- An overview of the measure and its relative contribution to energy savings;
- A description of the analysis methods;
- Identification of the key savings calculation inputs required for analysis;
- The proposed monitoring approach; and,
- Verification methodology.

Specific details of the M&V plans for each measure are reported in the measure level Appendices A - D.

5. Results

KEMA installed 118 data recording devices to measure the performance of 72 incentivized units. For some sites that had multiple types of measures installed, e.g. a site where both a condensing boiler and an indirect water heater were present, if only one measure was drawn for the sample, both may have been monitored. These monitored data were used in conjunction with billing data to create calibrated regression models that were utilized to develop on-site savings estimates for the four evaluated measures. The verified estimate of savings and the tracking system estimate of savings were used to develop a stratified ratio estimate of program savings.

Equation 1 shows the ratio estimator. In this equation "*y*" denotes the onsite verified estimate of savings, "*x*" denotes the tracking system estimate of savings, and *"w"* denotes the case weights.

Ratio Estimate	Mean	Total
$\hat{B}_0 = \dfrac{\sum_{i=1}^{n_0} w_i\ y_i}{\sum_{i=1}^{n_0} w_i\ x_i}$	$\bar{y}_0 = \hat{B}_0\ \mu_{x0}$	$\hat{Y}_0 = \hat{B}_0\ X_0$
	where	$w_i = N_h / n_h$

Equation 1: Combined Ratio Estimation

In addition to the estimate of the mean savings and the population total of saving, the statistical precision associated with each variable estimate was also estimated. Equation 2 presents the three steps necessary to calculate the statistical precision associated with our combined stratified ratio estimator.

1. Calculate the residuals $e_i = y_i - \hat{B}_0\ x_i$

2. Calculate $se\left(\hat{B}_0\right) = \left(\dfrac{1}{\hat{X}_0}\right)\sqrt{\sum_{I=1}^{n_0} w_i\left(w_i - 1\right)e_i^2}$

   with $\hat{X}_0 = \sum_{i=1}^{n_0} w_i\ x_i$

3. Then $se\left(\bar{y}_0\right) = se\left(\hat{B}_0\right)\mu_{x0}$ and $se\left(\hat{Y}_0\right) = se\left(\hat{B}_0\right) X_0$

Equation 2: Calculating the Statistical Precision

5.1 Program Savings Results

Table 6 presents the savings estimates by measure type. The estimated savings for boilers was 530,357 therms, for an overall realization rate of 137% (based on the adjusted tracking savings). The estimated savings for furnaces was 16,532 therms, for an overall realization rate of 33%. The estimated savings for infrared heating was 15,058 therms, for an overall realization rate of 21%. The estimated savings for indirect water heaters was 40,791 therms, for an overall realization rate of 59%. Overall, the realization rate for the four measures was 104%. The results show that the analysis achieved the targeted statistical precision for all measures, and in aggregate the total precision was ±14.9%.

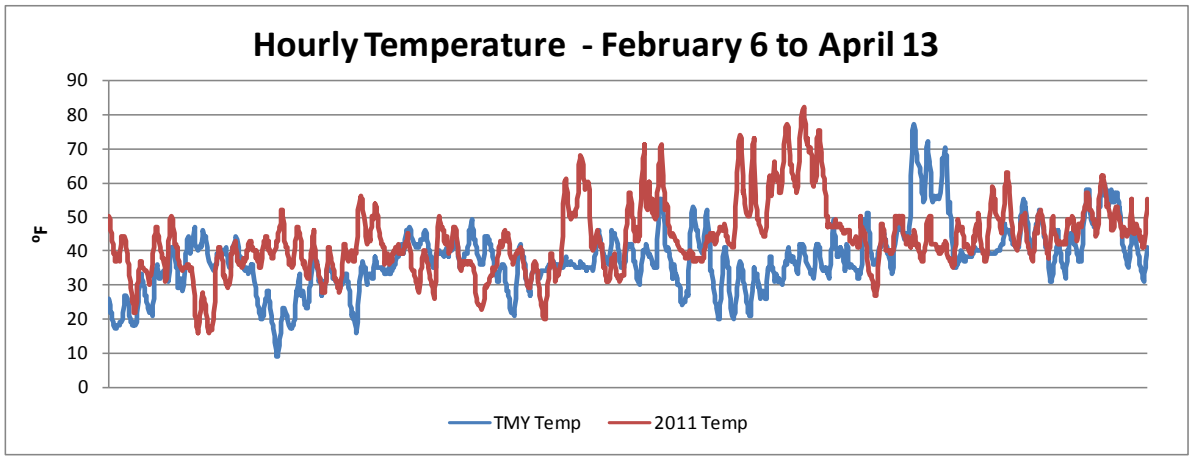
Table 6: Program Savings Analysis Results

Description	Revised Total Therms Saved	On-site Total Therms	Realization Rate	Relative Precision
Boiler	386,630	530,357	137.2%	±17.6%
Furnace	49,951	16,532	33.1%	±6.1%
Infrared Heating	72,912	15,058	20.7%	±8.5%
Indirect Water Heater	69,616	40,791	58.6%	±30.5%
Total	579,109	602,738	104.1%	±14.9%

The results above show that the condensing boiler measure had a significant (37%) increase in the on-site savings values relative to the revised tracking numbers. Since boilers accounted for roughly two thirds of the total savings, the increase in boiler savings more than offset the decreases in savings calculated for the other three measures. The following sections of this report describe the process used to develop measure-level savings estimates and the findings of this evaluation.

The program savings result was calculated by expanding the sample data to both the full population and the full year using regression models. With regard to the latter, there was a substantial difference between the observed temperatures during monitoring period and the Typical Meteorological Year (TMY) temperatures for Worcester, MA as shown in Figure 1 below.

Figure 1: Outdoor Dry Bulb Temperature Differential



During the monitoring period 1,439 heating degree days (HDD 65 – the difference between the average temperature and the base 65ºF temperature) were recorded, compared to the TMY 3 value of 1,780 HDD. This is a difference in potential heating usage of over 19% for a portion of the heating season that typically includes about 34% of HDD recorded annually in Worcester.[3]

Table 7 below shows the differences in maximum, average, and minimum temperatures between the two datasets.

Table 7: Outdoor Dry Bulb (ODB) Temperature Comparison

Temperature Comparison - TMY to Monitoring Period			
ODB (ºF)	TMY	2012	Difference
Maximum	77	82	5
Average	37	43	6
Minimum	9	16	7

Heating load is driven primarily by the indoor and outdoor temperature differential and the heating equipment temperature schedule and varies from facility to facility. The current on-site analysis utilized the available equipment operating and temperature data and created

[3] Heating Degree days are a proxy variable used for estimating heating usage not a direct measurement of usage. Worcester MA was selected for analysis because it is representative of the statewide temperature data.

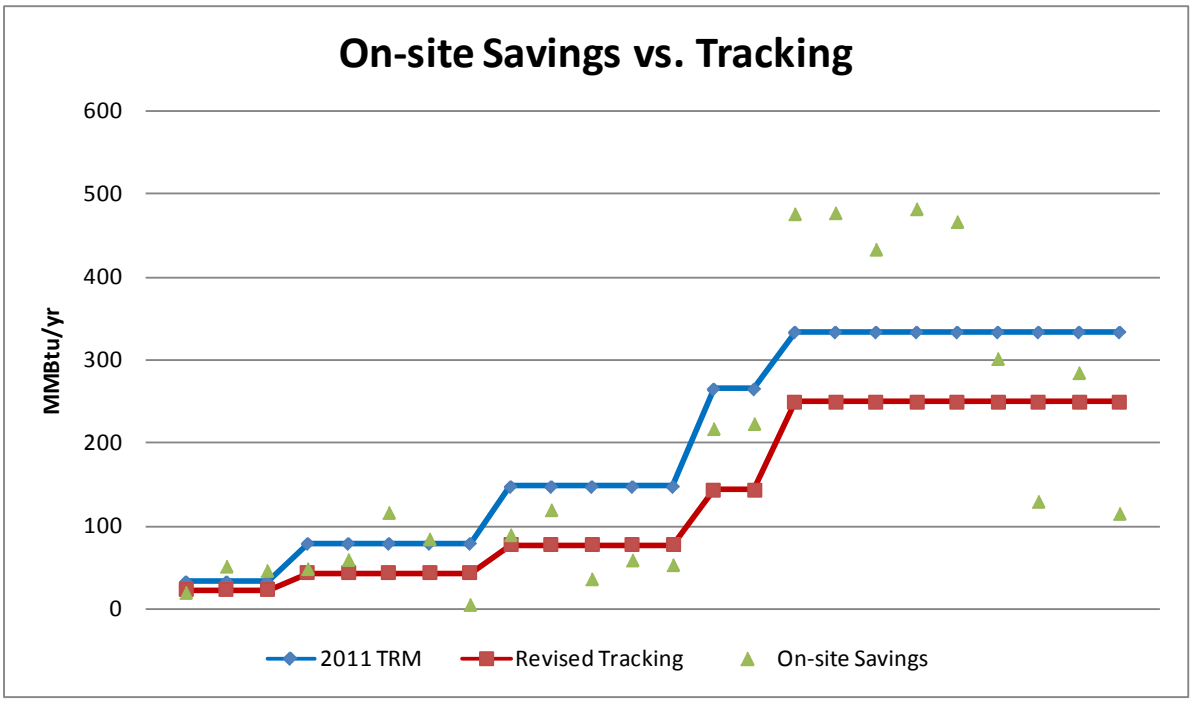
regression models that were then calibrated to normalized billing data. These models represent our best estimate of the expected typical savings impacts under the observed conditions. It has been suggested that the relatively mild temperatures observed during the metering period may have exerted downward pressure on the EFLH calculated for the equipment in the sample. However, the condensing boiler data did not appear to be impacted by the metering period. Absent of having another set of metered data for the sites during a more normal heating season, there is no straightforward way to calculate the potential impacts the temperature had on the heating equipment in the sample. Any attempt to adjust the heating EFLH without actual data to support the change would be highly speculative.

5.2 Condensing Boilers Findings

Figure 2 plots the on-site savings for the boilers compared to the 2011 TRM savings values and the revised tracking savings numbers from the 2011 KEMA evaluation report. The horizontal steps that are visible in the 2011 TRM and revised tracking numbers represent the five boiler size categories. Note that there about seven on-site savings values that are bracketed within the 2011TRM and revised tracking savings. The largest boiler size bin, with capacity greater than 1700 MBtu per hour, had the most variance with 6 of the 9 boilers having significantly greater savings than the 2011 TRM values. The on-site savings estimates for most of the smaller boiler size categories were generally smaller than 2011 TRM savings values with the exception of the smallest bin (less than 300 MBtu per hour). The simple unweighted average of the on-site savings was about 10% higher than the 2011 TRM savings and 64% higher than the revised tracking savings.

The next sections delve into the factors that drive the difference between the tracked savings and the evaluated savings.

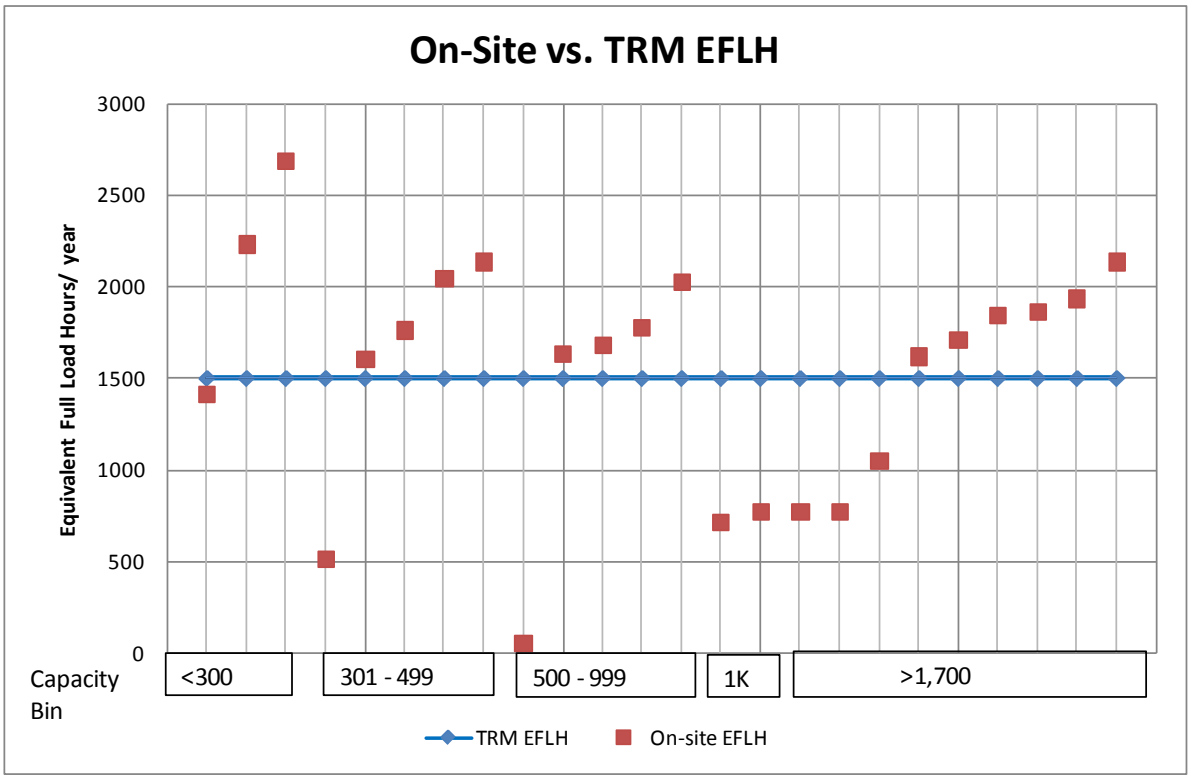
Figure 2: On-site Boiler Savings to 2011 TRM and Revised Tracking



5.2.1 Boiler Equivalent Full Load Hours (EFLH)

The difference between the hours of use , expressed in EFLH, incorporated in the TRM and calculated from the data collected on-site is the primary upwards driver on the calculated savings at the site level when compared to the TRM values. Figure below displays this difference. The blue line represents the TRM EFLH value of 1,500 hours and the graph shows that about twice as many on-site EFLH values are above the TRM value.

Figure 3: Comparison of On-site EFLH to TRM Value



The impact of this difference at the program level will be determined in the next round of analysis. As a starting point, and offered for PA consideration, Table 8 – Usage – On-Site vs. TRM Values below shows the average EFLH for the five capacity categories, (Size Bin) incorporated in the 2011 TRM. We would not recommend changing any of the EFLH values at the capacity bin level due to small sample sizes within the bins. The overall mean EFLH value of 1,421 hours annually is lower than the TRM value of 1,500 hours that was used in the original TRM savings calculation and it did represent a second year of decrease for this variable.[4]

[4] The MA Prescriptive Condensing Boiler Impact Evaluation of the 2008-2009 Prescriptive Gas study also concluded that EFLH for condensing boilers was less than 1,500 hours.

Table 8: Usage – On-Site vs. TRM Values

Condensing Boiler Size bin	Sample (n)	On-site Average EFLH	TRM EFLH	Delta	%
<300	3	2317	1500	817	154%
301-499	5	1613	1500	113	108%
500-999	5	1226	1500	-274	82%
1000-1700	2	1412	1500	-88	94%
1701+	9	1167	1500	-333	78%
Mean	**NA**	**1421**	**1500**	**-79**	**95%**

5.2.2 Annual Fuel Utilization Efficiency (AFUE)

The difference between the in-situ energy conversion efficiency of the heating equipment and the laboratory AFUE measurement, is a secondary contributing factor to the difference between the tracked and calculated savings. Figure 4 shows the calculated average AFUE of the installed equipment compared to the value presumed by the TRM. . Note that all but five of the boilers operate at efficiency below the TRM value and most of the boilers operate in an efficiency range between 86% and 89%.

Figure 4: Boiler AFUE – Calculated vs. TRM Values

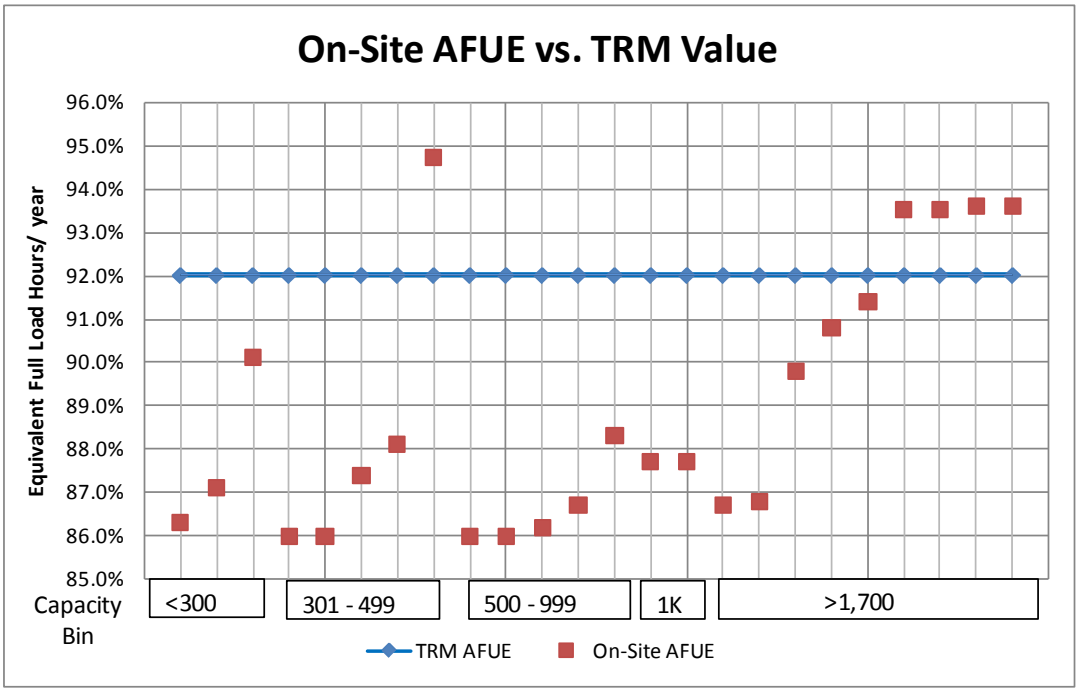


Table 9 provides an unweighted analysis of the differences in calculated and TRM efficiency values by size bin and overall mean value. Once again the small sample sizes within each bin and computational complexity necessary to develop revised values at this level preclude recommending bin-specific values. However we would recommend that the PAs' adopt the mean value of 88.9% efficiency across all bins to improve the accuracy of the deemed value calculation.

Table 9: AFUE values – Calculated vs. TRM

Condensing Boiler Size bin	Sample (n)	Average AFUE	TRM AFUE	Delta	%
<300	3	87.8%	92.0%	-4.2%	5%
301-499	5	88.4%	92.0%	-3.6%	4%
500-999	5	86.6%	92.0%	-5.4%	6%
1000-1700	2	87.7%	92.0%	-4.3%	5%
1701+	9	91.1%	92.0%	-0.9%	1%
Mean	24	**88.9%**	**92.0%**	**-3.1%**	**3%**

High return water temperatures, which make it impossible for the boilers to operate in condensing mode, were consistently recorded at most sites. As shown in Figure 5, the condensing boiler does not operate in condensing mode until the return water temperature drops below about 130ºF and just prior to reaching the condensing temperature the boiler is operating at about 87% combustion efficiency. As the return water temperature decreases below the condensing temperature of the flue gas, the theoretical efficiency of the boiler increases to a value which can reach as high as 99% at 40ºF.

Figure 5: Boiler Efficiency by return Water Temperature[5]

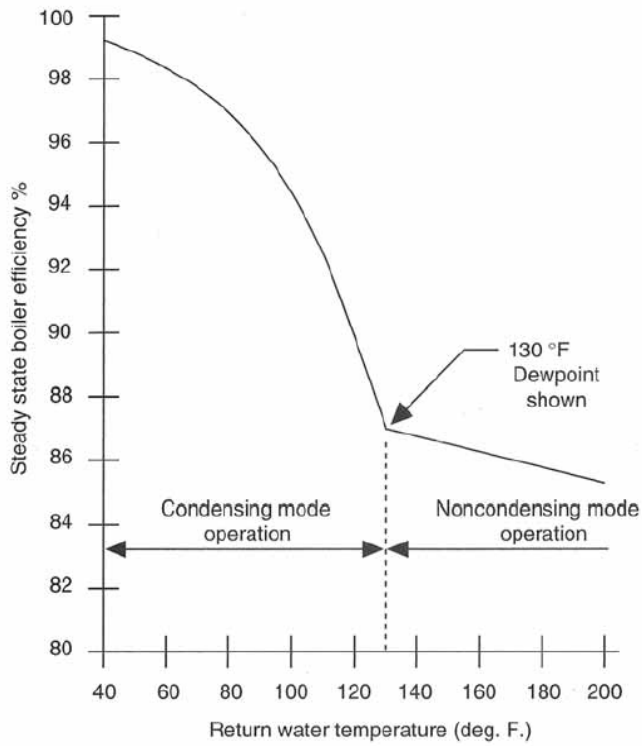
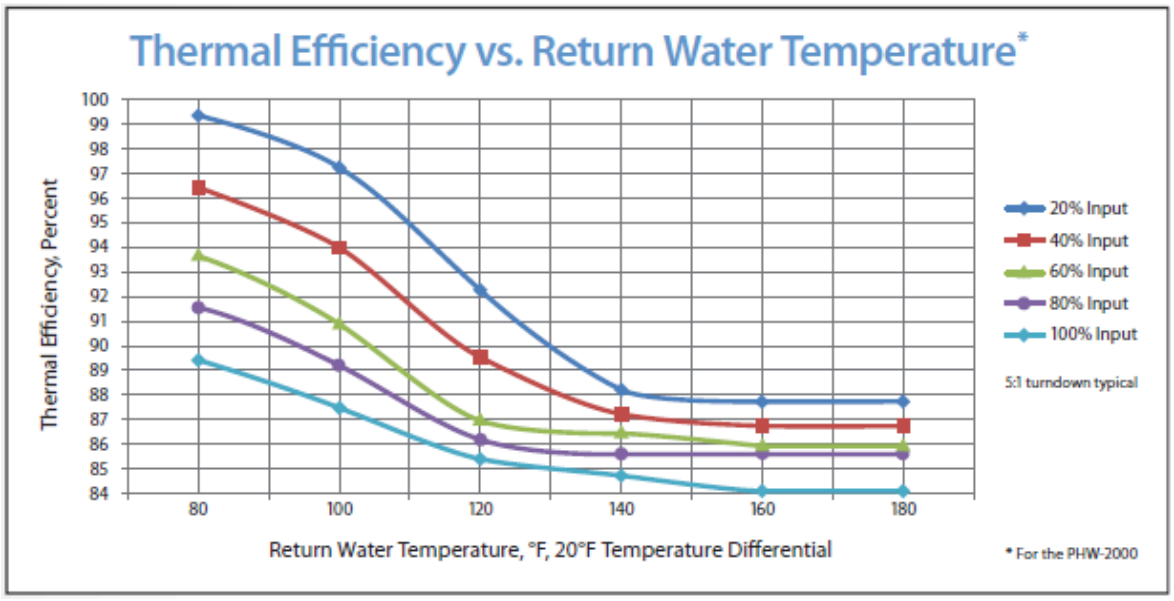


Figure 6 shows the part-load effect on the thermal efficiency of an example modulating condensing boiler. The combined effects of reducing entering water temperature and operating at reduced firing rate can greatly increase the overall efficiency (thermal efficiency) of condensing boilers. Operating in this mode would mean that the actual overall efficiency could be higher than the published combustion efficiency (boiler efficiency). In a conventional boiler system, the overall efficiency will never be above the published combustion efficiency. The graphic clearly indicates that highest boiler efficiencies are achieved when the condensing boilers are modulated to operate at low input and at a low return water temperature.

[5] ASHRAE Handbook Fundamentals, 2008 p.31.4

Figure 6: Thermal Efficiency at Part Load[6]



In order to achieve the boiler's design efficiency values the heat distribution system needs to be properly sized and the supply and return temperatures need to be maintained within specified ranges. Most of the boilers were not consistently operating within these ranges and thus the observed efficiency of the boilers averaged 88.9% annually. The nine larger boilers monitored , with capacities over 1,701 MBtu/hour, were operated significantly better than the smaller boilers and achieved a mean efficiency of 91.1%, but even these did not achieve the TRM value of 92%.

5.2.3 Summary of Boiler Findings

Table 10 provides the on-site savings estimates for each of the boilers evaluated, along with the capacity and calculated AFUE and EFLH.

[6] ASHRAE Journal, July 2006, "Boiler System Efficiency" by Thomas Durkin P.E.Sample part-load condensing boiler efficiency curve from Fulton Pulse HW appliance

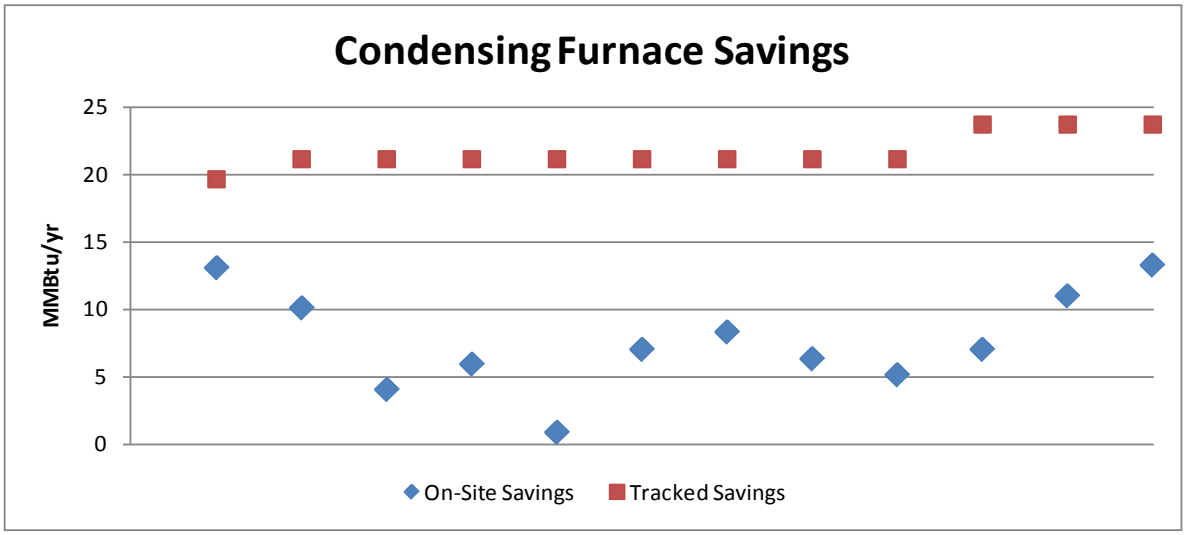
Table 10: On-site Savings Variables by Boiler

Report ID	Size Bin	TRM Savings	On-site Savings	On-site Capacity	On-site AFUE	On-site EFLH
41	<300	32.3	18.5	83.3	87.1%	2234
247	<300	32.3	50.1	183	90.1%	2028
250	<300	32.3	45.0	183	86.3%	2688
170	301-499	78.3	58.1	379	86.0%	1765
170	301-499	78.3	47.2	379	86.0%	1416
216	301-499	78.3	83.0	467	87.4%	1685
216	301-499	78.3	114.8	467	88.1%	2139
234	301-499	78.3	4.0	369	94.7%	55
27	500-999	146.7	57.6	702	88.3%	718
27	500-999	146.7	34.9	702	86.0%	512
158	500-999	146.7	88	556	86.0%	1782
197	500-999	146.7	118.1	660	86.2%	2050
309	500-999	146.7	51.9	720	86.7%	774
228	1000-1700	264.1	221.9	1237	87.7%	1622
228	1000-1700	264.1	215.8	1237	87.7%	1604
237	1701+	332.6	474.6	1853	93.6%	1426
237	1701+	332.6	475.8	1853	93.5%	1425
237	1701+	332.6	431.9	1853	93.6%	1303
237	1701+	332.6	480.6	1853	93.5%	1450
307	1701+	332.6	465.2	1860	90.8%	1710
307	1701+	332.6	300.2	1860	89.8%	1173
309	1701+	332.6	283.2	1728	91.4%	1053
309	1701+	332.6	113.7	1728	86.7%	722
309	1701+	332.6	128.2	1728	86.8%	774

5.3 Condensing Furnaces Findings

Figure 7 provides a graphical comparison of the on-site calculated savings compared to the 2011 TRM prescriptive savings values.

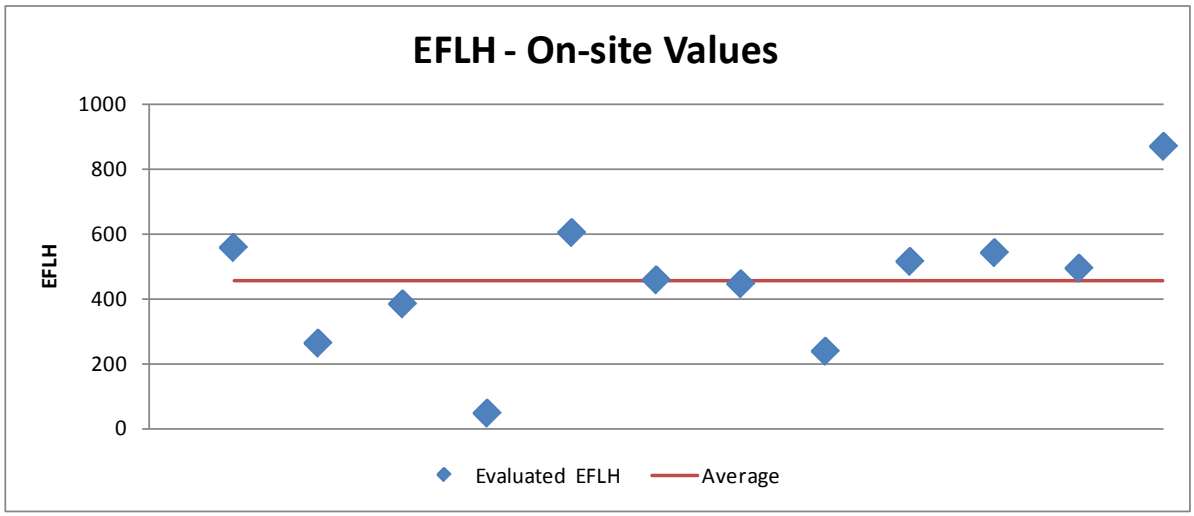
Figure 7: Condensing Furnace Savings – On-site to 2011 TRM Values



5.3.1 Furnace EFLH

As with condensing boilers, the variance in hours of use between the monitored equipment and the values implied in the TRM's prescriptive savings values is the driver for the difference in savings. Lower usage translates into lower savings. The calculated usage of the monitored furnaces, ranged between 47 and 870 EFLH for the monitored equipment, with an average of 452 hours per year. Figure 8 below displays the calculated usage of the monitored equipment.

Figure 8: Evaluated Usage



Equivalent full load hours are largely site-specific. However, over time efforts have been made to generalize usage. Table 11 below summarizes the usage developed for Providence RI.[7]

Table 11: Heating Equipment EFLH by Building Type

	Building Type						
Location: Providence RI	Assembly	Education	Food Service	Lodging	Office	Retail	Warehouse
With Temperature Setback	1894	795	1388	1523	504	454	740
Without Temperature Setback	1927	1272	1269	1523	972	1207	1074

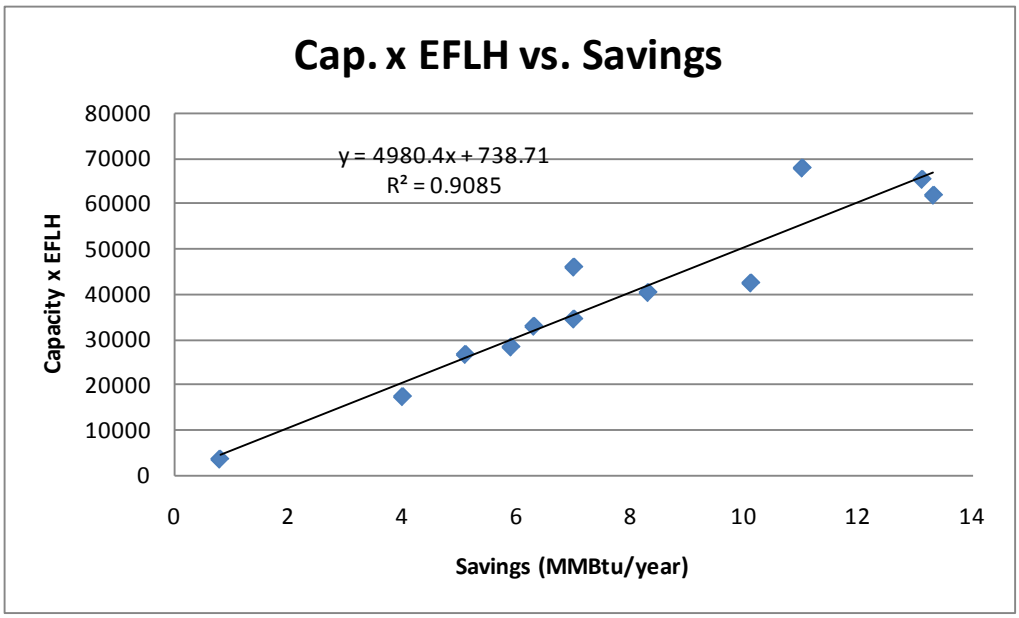
The sites with setback regimes appeared to have usage in line with the regional average. The lower usage measured at facilities without setback, overall close to the same average as those with, is a major contributing factor to the lower calculated savings. This could be due to furnace over-sizing at the sample sites; however data to perform sizing calculations were not collected.

Analysis of usage in relation to a variety of factors discovered a very high correlation between the product of furnace capacity and usage and the calculated on-site savings. Figure 9 provides a plot of these factors. Therefore any modification to the prescriptive savings values should account for these variables. The present TRM values for prescriptive savings only account for

[7] U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy (DOE-EERE). 2000. *Energy Conservation Program for Consumer Products: Screening Analysis for EPACT-Covered Commercial HVAC and Water-Heating Equipment Screening Analysis*. DOE-EERE, Washington, D.C.

differences in efficiency (AFUE) and the presence or absence of electronically commutated motors (ECM) powering distribution fans.

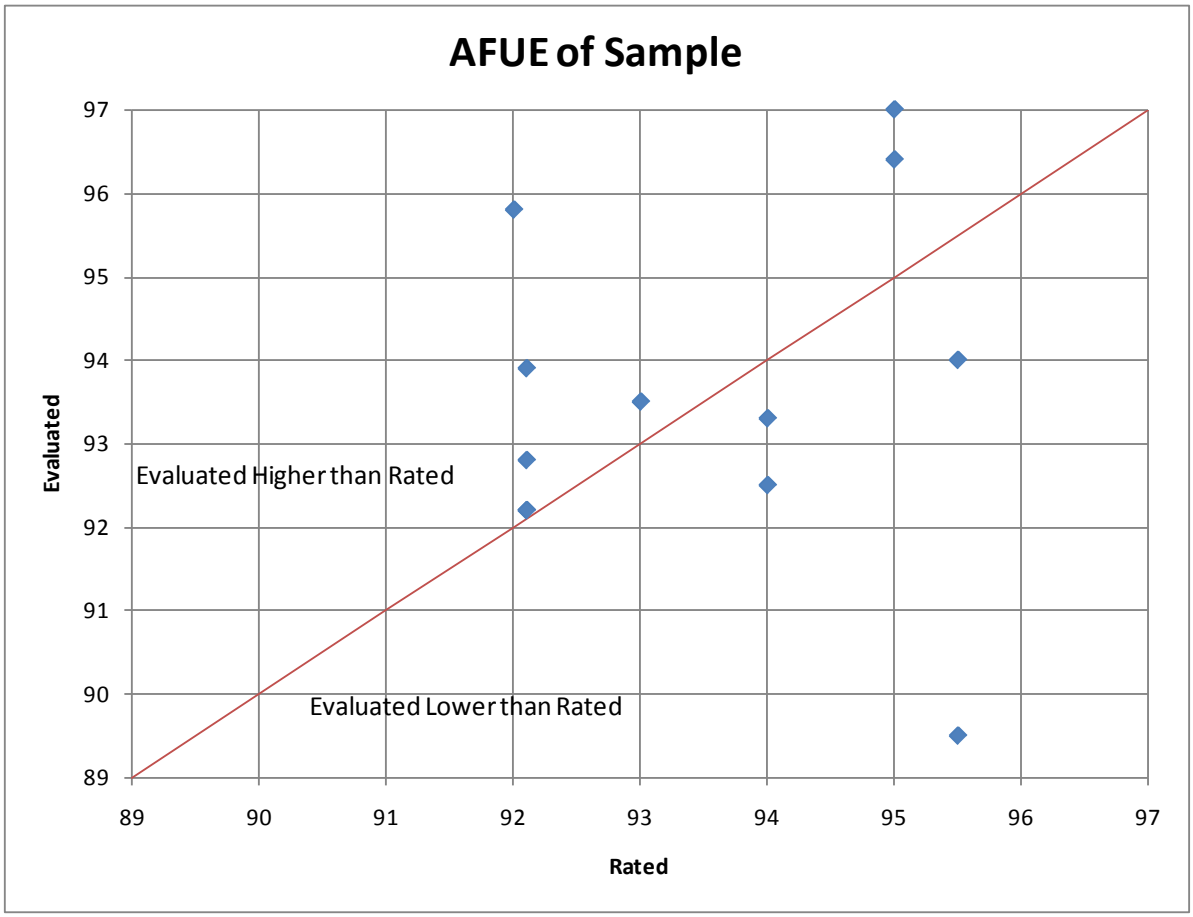
Figure 9: Capacity x EFLH to Savings



5.3.2 Furnace AFUE

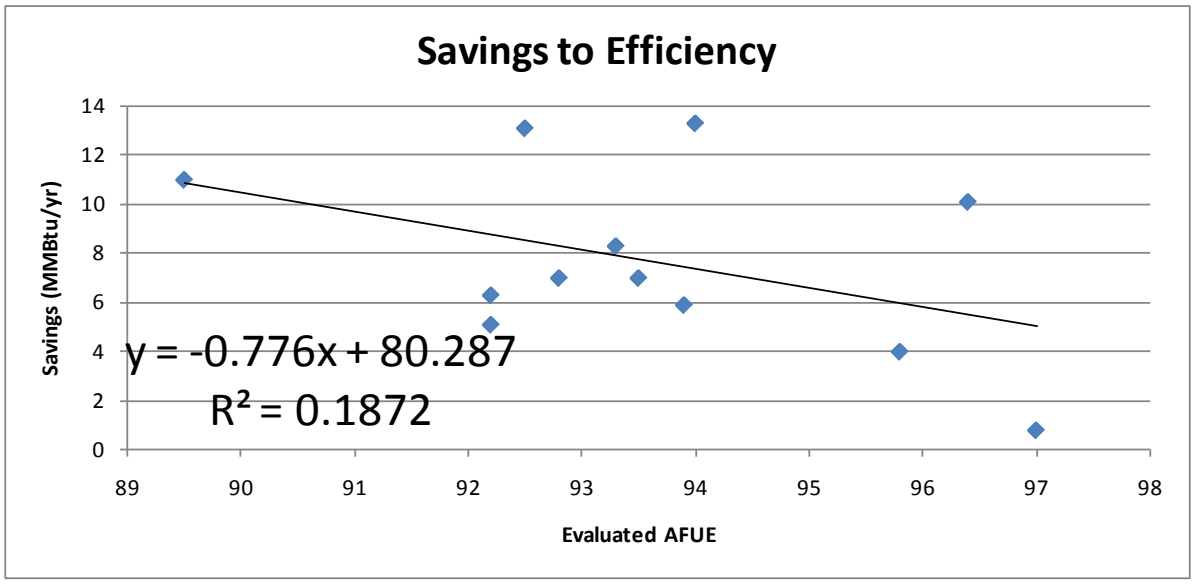
The evaluated average annual efficiencies of the monitored furnaces were slightly higher than the average nameplate rating, as shown in Figure 10 below.

Figure 10: AFUE – Comparison of Evaluated to Rated



While both the evaluated and nameplate efficiencies are slightly higher than the values incorporated in the TRM, the correlation between the AFUE and the savings generated, within the range of evaluated AFUE, is not statistically significant as shown in Figure 11 below.

Figure 11: Savings vs. Efficiency



5.3.3 Summary of Furnace Findings

Table 12 provides a listing of the furnace savings along with business type, capacity and EFLH.

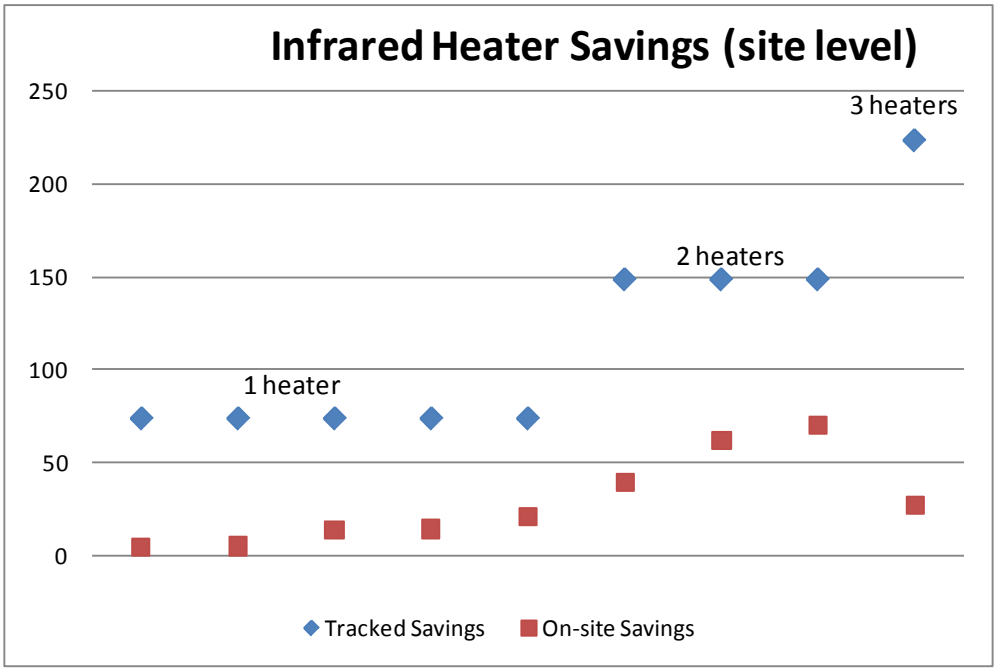
Table 12: List of Furnace Savings

Site ID	Unit ID	Business Type	Measure Description	TRM Savings	On-site Savings	On-site Capacity (MBTU)	On-site EFLH
321	35	Office	FURNACE => 92%	21.1	10.1	76	558
342	63	Manufacturing	FURNACE => 92%	21.1	4	66	263
355	51	Multifamily	FURNACE => 92%	21.1	5.9	74	384
365	25	Church -Office	FURNACE => 92%	21.1	0.8	76	47
365	27	Church -Office	FURNACE >= 92%	21.1	7	76	604
368	7	Warehouse	FURNACE => 92%	21.1	8.3	88	458
368	99	Warehouse	FURNACE >= 92%	21.1	6.3	74	446
376	6	Retail	FURNACE => 92%	21.1	5.1	112	238
463	48	Warehouse	FURNACE => 94% w ECM	23.6	7	67	515
467	2	Church -Office	FURNACE => 94% w ECM	23.6	11	125	542
467	67	Church -Office	FURNACE => 94% w ECM	23.6	13.3	125	494
474	66	Office	FURNACE => 92% w ECM	19.6	13.1	75	870

5.4 Infrared Heaters Findings

Figure 12 provides graphical comparison of the on-site savings estimate to the 2011 TRM savings values for infrared heaters, which shows significantly lower savings. The unweighted average savings for fourteen low intensity IR heaters was 18.8 MMBtu/yr, significantly less than the TRM value of 74.4 MMBtu/yr.

Figure 12: Infrared Heater Savings – On-site to 2011 TRM Values



We explored the three primary factors in the savings calculation, capacity reduction factor, capacity (Btu/hr) and usage (EFLH). There are numerous other factors that lead to savings for IR heaters such as reduction in temperature stratification and reduction in temperature setpoint due to increased comfort at work space level. However, the change in these variables cannot be measured by metering the building in the post installation case only and the ASHRAE compensation factor method was developed to address these variables. The mean capacity reduction factor observed in the sample was 0.82, which is equivalent to an IR heater mounting height of 20 feet. The mean input capacity of the IR heaters observed in the sample was approximately 108 MBtu/hr. Both of these variables had a relatively weak correlation to the difference in tracked and on-site savings.

5.4.1 Infrared Heater EFLH

As shown in Figure 13 the EFLH was highly variable within the sample ranging from a low of 170 hours to a high of 1,544 hours and the mean value was 677 hours.

Figure 13: Evaluated Usage

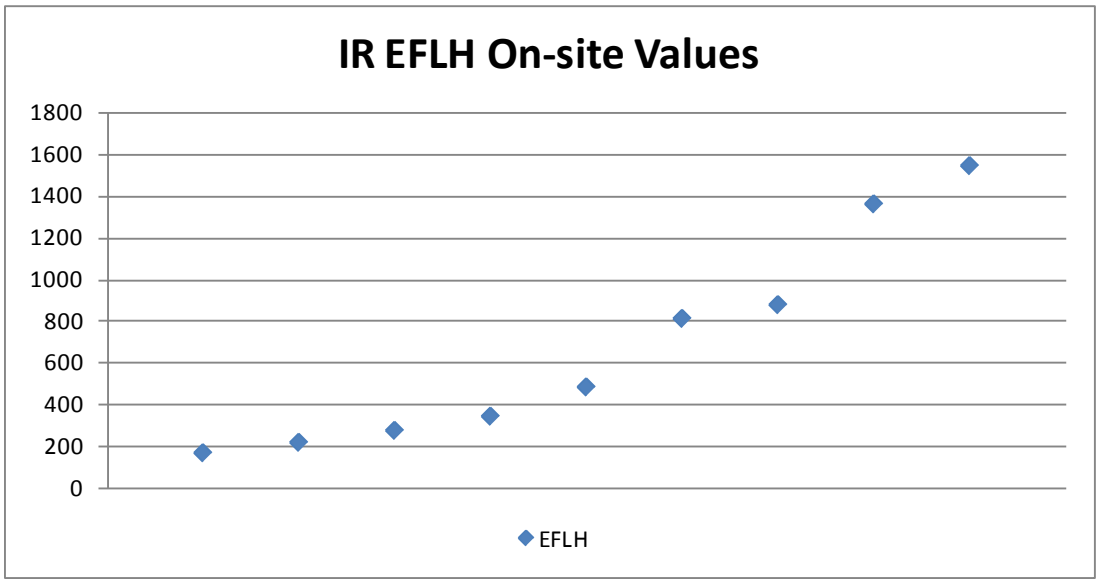
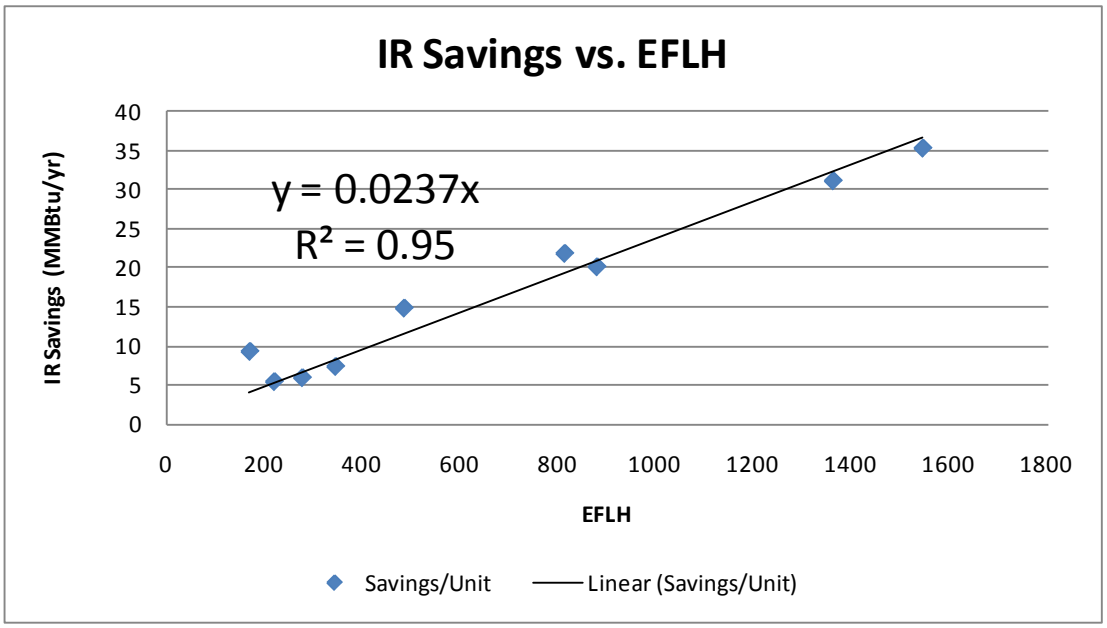


Figure 14 shows the IR per unit savings as a function of usage, which shows a very high correlation. Using the slope of this savings function to calculate the EFLH necessary to match the TRM savings value of 74.4 MMBtu/yr, the EFLH would have to be about 3,139 hours.

Figure 14: IR Savings per unit versus Usage



5.4.2 Summary of Infrared Heater Findings

Table 13 provides a summary of the tracking and on-site savings along with a listing of the variables that were utilized to develop the savings estimates.

Table 13: Infrared Heaters Summary of Savings

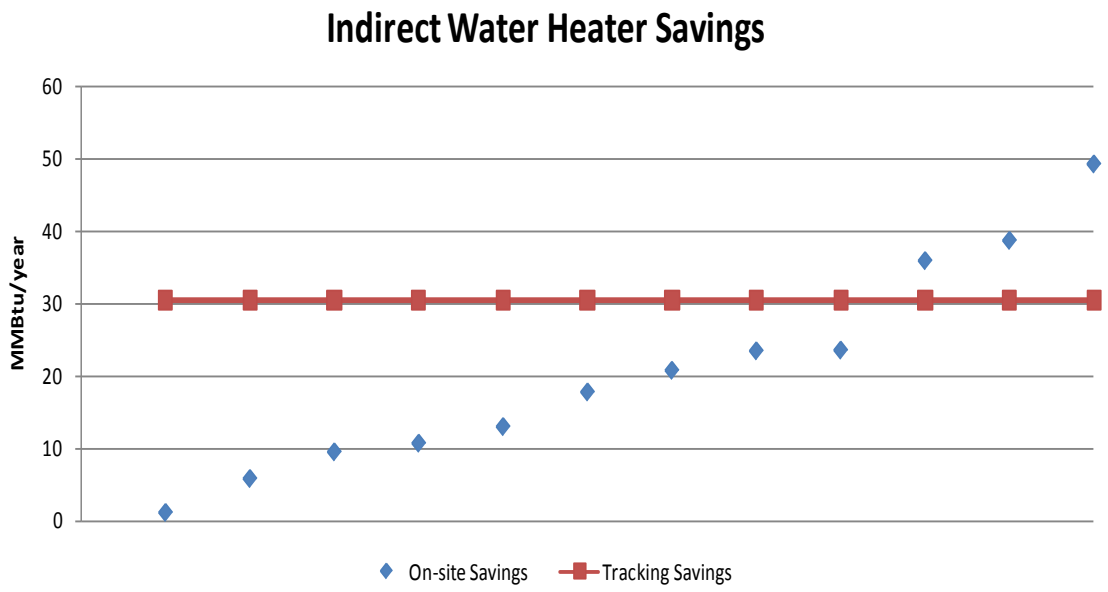
Site ID	Unit ID	QTY	TRM Savings	On-site Savings	Unit Height	Compensation Factor	On-site Capacity (MBTU)	On-site EFLH
490	30	1	74.4	5.4	20	0.82	80	220
505	50	1	74.4	21.8	10	0.75	60	813
496	55	2	74.4	14.6	15	0.795	120	345
496	6	1	74.4	5.9	15	0.795	60	277
497	1	3	223.2	27.7	30	0.87	750	170
502	92	1	74.4	14.8	20	0.82	100	485
502	29	2	148.8	70.6	20	0.82	150	1,544
502	96	2	148.8	40.2	20	0.82	150	879
502	98	2	148.8	62.3	20	0.82	150	1,361

5.5 Indirect Water Heaters Findings

The unweighted average savings for the twelve evaluated units is 20.7 MMBtu per year, significantly less than TRM value of 30.4 MMBtu/year, as shown in dispersion of values from the mean, is 14.5 MMBtu/yr, over half the average value. Thus there is a high degree of variance in the savings estimate and the TRM savings value is within the error bounds of the on-site sample savings estimate. Given the uncertainty around the variables utilized to generate the original savings estimate additional investigation may be warranted.

Figure 15 below comparing the calculated savings to the TRM prescriptive values. The unweighted average is not a reasonable representation of the actual values. In fact, the standard deviation, or the dispersion of values from the mean, is 14.5 MMBtu/yr, over half the average value. Thus there is a high degree of variance in the savings estimate and the TRM savings value is within the error bounds of the on-site sample savings estimate. Given the uncertainty around the variables utilized to generate the original savings estimate additional investigation may be warranted.

Figure 15: Indirect Water Heater Savings – On-site to 2011 TRM Values



5.5.1 Usage - Gallons per Day

Through examination of the sample data, we found that the primary explanatory metric for the difference range of savings calculated was the calculated daily demand for hot water, in gallons per day (GPD).

Figure 16 below shows the comparison to the observed daily demand for hot water to the value referenced in the underlying TRM source material, 250 gallons per day.

Figure 16: Tracking to On-Site Flow

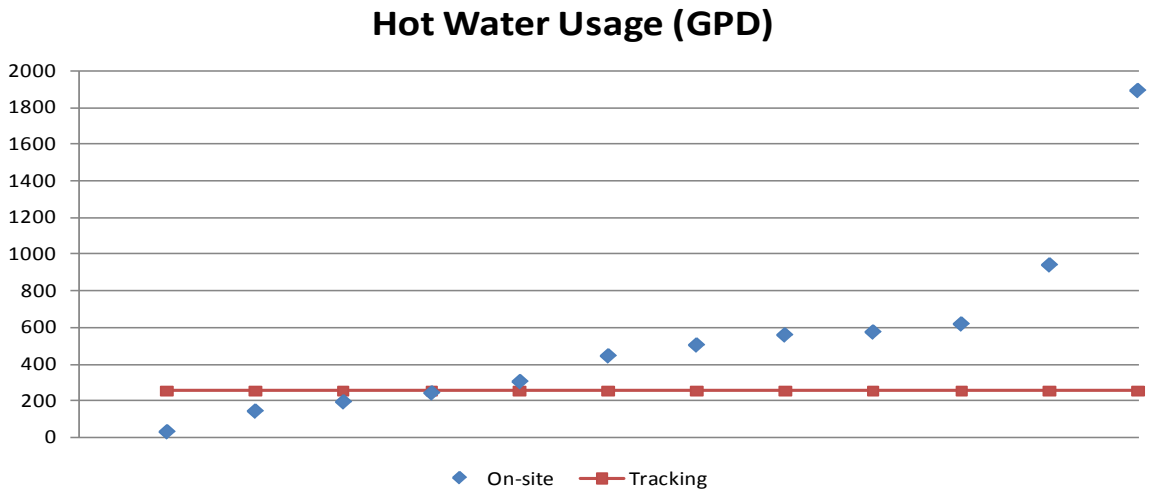
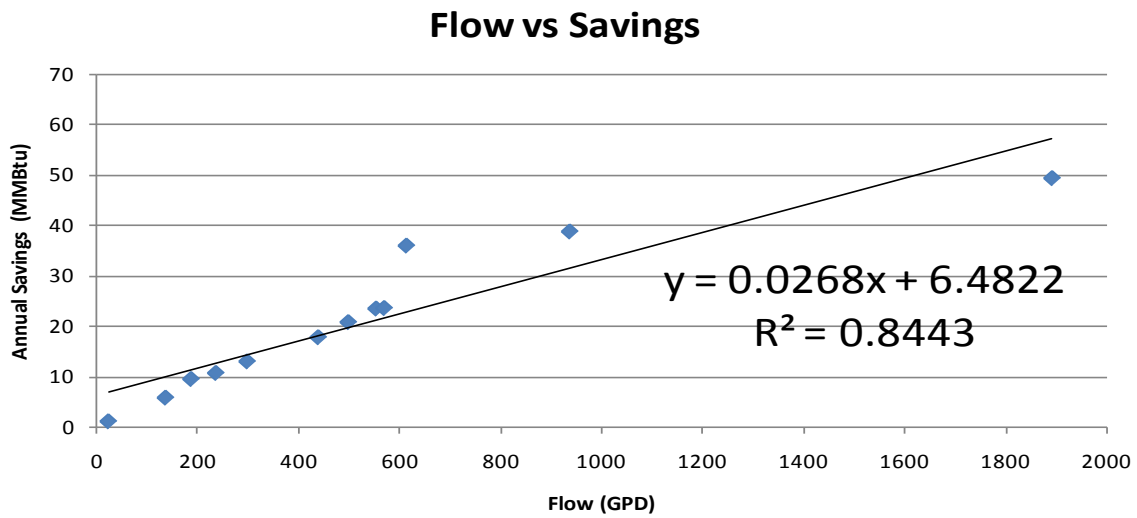


Figure 17 shows that the savings is highly correlated to domestic hot water usage, as expected.

Figure 17: Flow to Savings

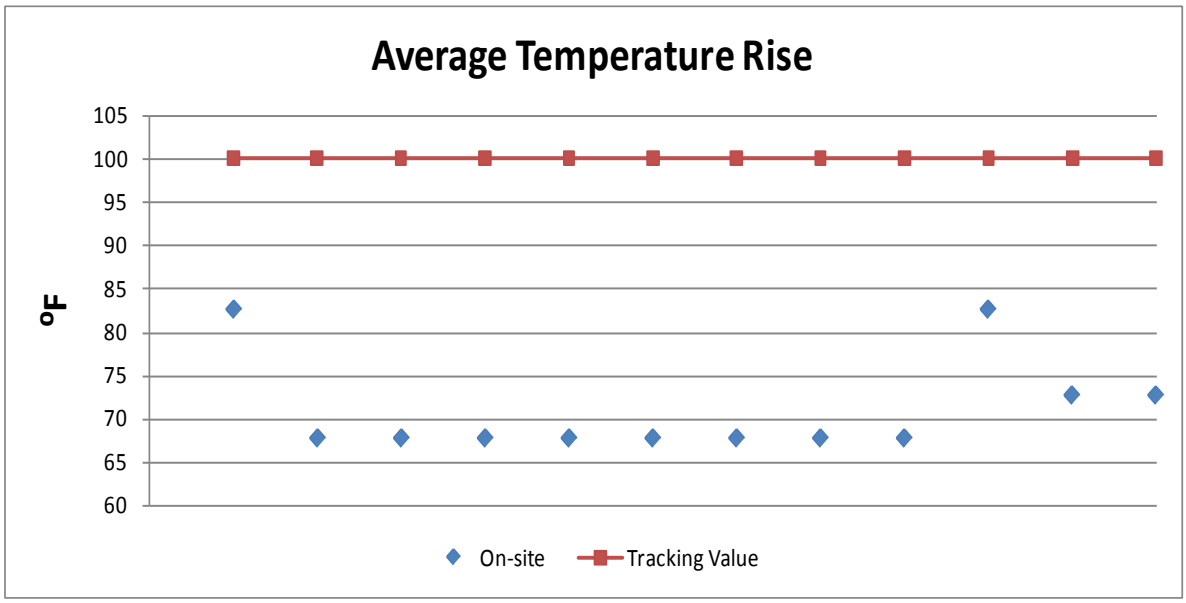


Despite the fact that the on-site data analysis generally found greater flows than the 250 GPD incorporated in the TRM, savings were generally lower.

5.5.2 Temperature Rise

The differential between the TRM values and the on-site calculated savings is largely due to the difference in temperature rise. The ESource tool referenced in the TRM notes that the assumed temperature rise is 100º F. The temperature rise calculated for the monitored site was uniformly lower than this value, as show in Figure 18 below.

Figure 18: On-Site vs. Tracking System Temperature Rise



The assumption of a 100º F rise in temperature would require that the average entering water temperature would have to be 40º F if the tank holding temperature were set to 140º F, which was the highest observed in the sample. The mean tank holding temperature was 128º F, which would require a mean entering temperature of 28º F. The lowest ground temperature observed in the Worcester, MA TMY3 weather file was 35.4º F and the mean annual temperature was 47.3º F. This is one of the main reasons for the difference in the on-site savings estimate relative to the TRM savings given that most sites have higher hot water usage, but lower savings.

5.5.3 Summary of Indirect Water Heater Findings

The site-level findings are summarized in Table 14 below.

Table 14: Findings Summary – Indirect Water Heaters

Site ID	Category	On-site GPD	Average Temperature Rise (^{0}F)	On-site Savings (MMBtu/yr)	Boiler Efficiency
566-04	MF	613	82.7	35.9	91.7
570-11	Retail	23.4	67.7	1	89.6
581-34	MF	553	67.7	23.4	91.7
592-18	MF	1890	67.7	49.3	89.6
592-51	MF	569	67.7	23.5	89.6
592-64	MF	936	67.7	38.7	89.6
599-60	MF	187	67.7	9.4	89.6
602-56	MF	438.5	67.7	17.7	89.6
604-83	MF	498	67.7	20.7	89.6
616-54	School	136.5	82.7	5.7	89.6
623-39	MF	298	72.7	12.9	89.6
624-40	MF	236	72.7	10.6	89.6

6. Next Steps

The on-site evaluation numbers for each of the measures showed a significant variance from the current deemed values. These differences warrant the consideration of adjustments to the deemed savings values used for future measure installations. Additionally retro-active adjustments to unfiled savings may also be considered.

Although we observed significant variations between estimated and tracked savings for several of the measures, caution should be exercised in interpreting and applying these results. While we provide point estimates of savings and recommendations based upon our work below, some of the limitations in our work include the following:

- Some of these measures have savings estimates based upon small sample sizes – in particular, furnaces and infrared heaters with had nine and five sample points, respectively.[8]

- The M&V for all of this site work was performed during a winter and spring of unusually warm weather. While this might not affect a measure such as an indirect water heater, the weather under which the monitoring was performed can be expected to put downward pressure on hours of use for the other measures examined.[9] This would manifest as less savings than might be expected during a more normal winter weather pattern.

- Some measures, such as infrared heaters, are particularly sensitive to baseline assumptions. While this study has examined this issue carefully and applied what we believe are reasonable baseline assumptions, this issue nonetheless presents additional uncertainly in results when it is not fully known. Given the complexity of assumptions around IR Heaters this measure in would benefit from the use of pre-post billing analysis of retrofit installations at sites where the gas usage is primarily related to the measure.

[8] Typically sample size is a function of the variability of the measure and the desired level of uncertainty. Since the population of these measures was small a relatively small sample may be adequate to describe the population however since these points are being used to predict savings for a future larger population of measures a sample on the order of 20 to 30 installations would be better.
[9] We expect this influence to be small, however it might make sense to hold off changing TRM savings values until another evaluation of the furnace and IR Heaters is conducted.

- The economy can also be considered an exogenous factor that can influence measure savings. Shorter or fewer working shifts, the loss of employees and decreases in production are all factors that have likely had a negative influence on the acquisition of anticipated savings.[10]

Despite these caveats, taken as a whole, we believe the analysis of the various measures in this report suggests the savings estimates as calculated by the PAs are reasonable overall (104.1% realization rate). However, our work does indicate that savings are under-estimated for boilers and that the other measures examined are experiencing significantly less savings than their reported savings levels. The boiler savings have actually increased from the savings impacts provided in last year's evaluation and a similar pattern could occur with the other measures. One of the problems with the prescriptive gas program is that the population of measures is relatively small and therefore the samples are small, which is leading to volatility in the savings estimates.

Below we provide recommendations for sponsor consideration based upon the observations from this study. However, for the reasons outlined above, a high level recommendation we would like to provide is that of considering further examination of these measure types. Such an effort could piggyback upon the work that has been performed, thereby leveraging the information that has already been gathered. The design of this effort could also target information such as baseline and pre-existing conditions for those measures that are particularly sensitive to those assumptions. The outcome of this effort would be to gather a greater mass of information on the measures of interest from which more confident savings assumptions can be derived.

Despite this overarching recommendation, we provide measure specific recommendations below that rest upon the findings from the M&V work done for this study below.

[10] There was no direct collection of this type of data as part of the study and these comments are included based upon generally observed economic conditions.

6.1 Condensing Boiler Recommendations

The savings for the condensing boiler measures is derived from three primary variables, the input capacity of the boiler, the measured efficiency of the boiler (expressed as AFUE)[11], and the operating hours (expressed as EFLH). In the 2011 KEMA evaluation of Prescriptive condensing boilers the mean observed capacity was evaluated for each of the five boiler size categories. Table 15 provides original TRM capacity size assumptions by size category along with the recommended revised capacities. We would recommend that these capacity changes be incorporated into the revised savings calculations. Note that the largest and smallest size categories have increases of 39% and 27% respectively and the middle size category has a 2% decrease in capacity.

Table 15: Revision to Boiler Capacity Assumption

Size Category	Ratio	Original Capacity (Mbtu)	Revised Capacity (Mbtu)
Capacity ≤ 300	1.27	165	209.6
300 < Capacity < 500	1	400	400
500 ≤ Capacity < 1000	0.98	750	735
1000 ≤ Capacity ≤ 1700	1	1350	1350
1700 < Capacity	1.39	1700	2363

The overall mean measured efficiency observed in the sample was 88.9%, which is significantly lower than the 92% AFUE used in the TRM savings calculation. The on-site data also showed that the four smallest size categories had a mean measured efficiency of 87.6% (sample of 15) and the largest boilers had a mean measured efficiency of 91.1% (sample of 9). However, four of the largest boilers with the highest measured efficiency were installed at a greenhouse and when those four boilers are removed from the calculation the mean measured efficiency is 89.1%, only slightly higher than the overall mean. At this point we would recommend using the overall mean for all of the size categories.

The mean EFLH observed in the sample was 1,421 hours per year, which is not significantly lower than 1,500 hours that was used in the original TRM savings calculation however it did

[11] The term AFUE is used here and throughout the report to represent the measured efficiency based upon monitoring data.

represent a second year of decrease for this variable.[12] There was some variation observed within the size categories, but most category level samples were small and there is no compelling reason to develop different EFLH values for the different categories. As a result we are recommending that the EFLH value for the TRM savings calculation be reduced to 1,400 hours for all size categories.

Table 16 provides the savings variables and original savings values for each of the five size categories along with the evaluated (retrospective) savings values and the recommended prospective savings values.

Table 16: Recommended Condensing Boiler Savings

Size Category	Revised Capacity (MBtu)	AFUE	EFLH	Original Savings (ΔMMBtu/Unit/yr)	Evaluated (Retrospective) Savings (ΔMMBtu/Unit/yr)	Recommended Prospective Savings (ΔMMBtu/Unit/yr)
Capacity ≤ 300	209.6	88.9%	1400	22.1	29.8	29.4
300 < Capacity < 500	400	88.9%	1400	42.3	56.9	56.1
500 ≤ Capacity < 1000	735	88.9%	1400	77.1	104.6	103.0
1000 ≤ Capacity ≤ 1700	1350	88.9%	1400	142.6	192.1	189.2
1700 < Capacity	2363	88.9%	1400	249.0	336.2	331.2

6.2 Condensing Furnace Recommendations

The condensing furnace savings calculations utilize the same three primary savings variables as the condensing boilers, the input capacity of the furnace, the efficiency of the furnace (expressed as AFUE), and the operating hours (expressed as EFLH). The TRM savings values for these measures were distinguished only by rated efficiency level and the presence of an Electrically Commutated Motor (ECM) as shown Table 17.

Table 17: TRM Furnace Deemed Savings Values

Furnace Efficiency	Savings ΔMMBTU/Unit/yr
Furnace AFUE =>92%	21.1
Furnace AFUE =>92% w/ECM	19.6
Furnace AFUE =>94% w/ECM	23.6

[12] The MA Prescriptive Condensing Boiler Impact Evaluation of the 2008-2009 Prescriptive Gas study also concluded that EFLH for condensing boilers was less than 1,500 hours.

Unfortunately the exact inputs utilized to calculate the TRM deemed savings values were not clearly documented and we cannot recreate the savings.

The mean EFLH observed in the sample was 452 hours per year based upon a sample of 12 furnaces monitored at nine different sites and a few of these sites had really low usage. Secondary research indicated that the mean hours are lower than would typically be expected for commercial use.

The mean input capacity observed in the on-site sample of furnaces was 90 MBTUs and this value will be used to calculate the revised savings value. The sample furnaces were primarily identified as 92% efficient furnaces and the mean measured efficiency observed in the sample was 93.6%, we would recommend that an AFUE of 95.6% be used for the 94% efficient furnaces. The TRM savings values also include a 7.1% decrease in savings due to a reduction in motor heat from the installation of ECM fan motors.

Given the low EFLH observed in the sample sites (due primarily to non-standard operating hours) and the relatively small sample, it is recommended that the new TRM savings be adjusted to the mean between the original TRM savings and the on-site savings. Table 18 provides the original savings values along with the evaluated (retrospective) savings and the recommended prospective savings for each furnace efficiency category.

Table 18: Recommended Condensing Furnace TRM Savings Values

Furnace Efficiency	Original Savings (ΔMMBtu/Unit/yr)	Evaluated (Retrospective) Savings (ΔMMBtu/Unit/yr)	Recommended Prospective Savings (ΔMMBtu/Unit/yr)
Furnace AFUE =>92%	21.1	5.9	13.5
Furnace AFUE =>92% w/ECM	19.6	5.5	12.5
Furnace AFUE =>94% w/ECM	23.6	6.2	14.9

6.3 Infrared Heater Recommendations

The Infrared Heater (IR Heater) savings calculation is somewhat similar to the previous heating measures except that the radiant nature of an IR Heater allows the unit to be sized smaller than a conventional warm air heater. The three primary variables used in the IR Heater savings calculation are the IR compensation factor, the capacity of the IR Heater and the EFLH.

The IR Heater compensation factors is the percentage of capacity reduction that IR Heater can be sized and still provide the same level of comfort to the building occupants. The

compensation factor is a function of mounting height and the values are provided in Table 19. The mean compensation factor observed in the sample was 0.82, which represents a mean unit height of 20 feet above the floor.

Table 19: IR Heater Compensation Factors

Mounting Height	Compensation Factor
12	0.78
16	0.80
20	0.82
24	0.84
28	0.86
32	0.88
36	0.90
40	0.92

The mean unit capacity observed in the sample data was 108 MBTU/hr. The mean EFLH observed in the sample was 677 hours. Using the mean assumption identified in the sample the on-site IR Heater savings would be 22.3 MMBtu/unit. Given the small sample size KEMA recommends that the mean value between the original TRM savings and the on-site savings value be used for future measure estimates. Table 20 provides the original savings estimate for the IR Heater measure along with the evaluated (retrospective) savings and the recommended prospective savings.

Table 20: Recommended Infrared Heater Savings

Measure Type	Original Savings (ΔMMBtu/Unit/yr)	Evaluated (Retrospective) Savings (ΔMMBtu/Unit/yr)	Recommended Prospective Savings (ΔMMBtu/Unit/yr)
Infrared Heater	74.4	22.3	48.3

The size range of the output capacity for this measure varied from smaller units with capacities of 60 to 80 MBtu's to large units with a capacity of 250 MBtu, which is more than four times larger than the smallest unit in the sample. The PA's should probably consider establishing at least two size bins for savings values in the TRM for this measure

6.4 Indirect Water Heater Recommendations

The Indirect water heater savings is primarily a function of the amount of domestic hot water usage and as such, it is difficult to develop a prescriptive variable that would be predictive with

respect to the amount of savings. The original savings value was 30.4 MMBtu/unit/yr and the mean savings value observed in the on-site sample was 20.7 MMBtu/unit/yr.

Table 21 provides the original savings value along with the evaluated (retrospective) savings and recommended prospective savings, which are both 20.7 MMBtu/unit/yr.

Table 21: Recommended Indirect Water Heater Savings

Measure Type	Original Savings (ΔMMBtu/Unit/yr)	Evaluated (Retrospective) Savings (ΔMMBtu/Unit/yr)	Recommended Prospective Savings (ΔMMBtu/Unit/yr)
Indirect Water Heater	30.4	20.7	20.7

7. Appendix A - Condensing Boilers

7.1 Measure Description

Condensing boilers take advantage of improved design, sealed combustion, and condensing flue gasses in a second heat exchanger to increase efficiency. The flue gasses are then vented outdoors. The stack piping configuration also contains a separate inlet that draws combustion air from outdoors. This eliminates the use of interior space air for combustion and reduces infiltration into the building.

High efficiency boilers account for 319 projects with a total of 386,630 therms of savings in the Prescriptive Gas Tracking Data. Measurements were recorded and verification analyses were performed for 15 of these projects on 24 boilers.[13] These projects have total annual savings of 4,743.5 MMBTUs.[14] This is 7.4% of the total tracking savings for this measure.

Both the 2010 TRM and KEMA's analytic approach calculate the energy savings as a product of the hourly energy input times the annual hours of use times a factor representing the change in efficiency.

The 2010 TRM contains the following algorithm for calculating natural gas savings from these measures:

Equation 3 – 2010 TRM Boiler Savings Calculation

$$\Delta\text{MMBtu} = (CAP)(EFLH_{heat})\left(\frac{\eta_{ee} - \eta_{base}}{\eta_{ee}}\right)$$

Where:

ΔMMBtu	=	gross annual MMBtu savings from the measure.
CAP	=	equipment heating capacity (MMBtu/h).
$EFLH_{heat}$	=	equivalent full load heating hours.
η_{ee}	=	installed equipment efficiency (expressed as AFUE, E_c, or E_t).
η_{base}	=	baseline equipment efficiency (expressed as AFUE, E_c, or E_t).

[13] There were two additional sites that were metered but the customer at one site removed the meters after three days and the other customer refused to allow the meter retrieval.
[14] This figure represented the boilers that were metered.

As shown in the savings equations, above there are three key variables that impact the savings for the condensing boiler, the capacity of the unit, the Equivalent Full Load Hours (EFLH) and the Average Fuel Utilization Efficiency (AFUE). Table 22 provides the assumed values for these variables that KEMA used to calculate the revised TRM savings values.

Table 22: Condensing Boiler TRM Savings Variable Values

Boiler Size Bin	Capacity	EFLH	$AFUE_{ee}$	$AFUE_{base}$
<= 300 MBH	165	1500	92%	80%
301-499 MBH	400	1500	92%	80%
500-999 MBH	750	1500	92%	80%
1000-1700 MBH	1350	1500	92%	80%
1701+ MBH	1700	1500	92%	80%

The 2011 TRM defines prescriptive savings based on five size strata. The values in the 2011 TRM are shown in Table 23 below.

Table 23: 2011 TRM Prescriptive Boiler Savings

Boiler Size/Efficiency	Savings (MMBtu/yr)
<=300 MBH - 90% AFUE or greater	32.3
301-499 MBH - 90% thermal efficiency or greater	78.3
500-999 MBH - 90% thermal efficiency or greater	146.7
1000-1700 MBH - 90% thermal efficiency or greater	264.1
1701+ MBH - 90% thermal efficiency or greater	332.6

These strata, and the associated savings, are consistent with the one of the approaches discussed in KEMA's *Prescriptive Condensing Boiler Impact Evaluation - Project 5 Prescriptive Gas* report dated June 2, 2011. This study used billing data analysis, on-site investigation, and telephone surveys to evaluate condensing boiler measures installed from mid-2008 through early 2010. Based on this information, KEMA developed the revised gross adjusted savings numbers shown in Table 24 below.

Table 24: Recommended Condensing Boiler Savings

TRM Size Category	TRM Savings (MMBtu/yr)	Gross Adjusted Savings (MMBtu/yr)
Capacity ≤ 300	32.3	22.1
300 < Capacity < 500	78.3	42.3
500 ≤ Capacity < 1000	146.7	77.1
1000 ≤ Capacity ≤ 1700	264.1	142.6
1700 < Capacity	332.6	249.0

Although the PA's have adopted the revised savings estimates above, the tracking data used to develop the sample design was provided prior to adoption on July 3, 2011 and did not incorporate these values. For the purposes of this analysis, KEMA compared the gross adjusted savings for each stratum, and not the TRM value, to the savings based on measured data.

7.2 Methodology

Onset Hobo Microstation time-of-use loggers were installed that measured the current of the combustion blower and the temperature of the supply and return water at the boiler at five minute intervals. At one site separate data loggers were used for the supply and return temperature. The loggers were in place for between 26 and 63 days, with an average monitoring period of 52 days.

After logger retrieval the data was checked for consistency and completeness. The following steps were applied to the data for each measure:

1. The Logger data were trimmed to remove any pre- and post-installation data that does not represent actual operating conditions.

2. The remaining data set was examined for anomalies, such as readings outside the expected range. For example, the current draw by the combustion blower was recorded in a small number of 5-minute intervals during the start-up phase. In these cases, which occurred for less than a fraction of one percent of the readings, the recorded data point exceeded the average by a factor of approximately five. Since this was an instantaneous reading, and not representative of the 5-minute interval, using this data point in subsequent analyses would skew the results. Consequently, these data points were replaced with the average of the data set absent the outliers.

Two other data sets were required for the analysis, and both weather related. These were the average hourly temperature for the study period and the TMY data for four weather stations in Massachusetts, at Boston, Worchester, Chicopee Falls, and Pittsfield both expressed as outdoor dry bulb (ODB). This process resulted in clean and consistent sets of measured data incorporating the variables shown in Table 25 below.

Table 25: Measured Variables

Measured Variables (Study Period)		
Name	**Measurement Interval**	**Source**
Combustion Blower Current (amperage)	5-minute	Data logger
Supply Water Temperature (^{o} F)	5-minute	Data logger
Return Water Temperature(^{o} F)	5-minute	Data logger
Study Period Outdoor Dry Bulb Air Temperature(^{o} F)	Hourly	NOAA
Typical Meteorological Year Outdoor Dry Bulb Temperature(^{o} F)	Hourly	TMY

The final piece of data utilized in the savings analysis was the monthly gas usage data for the site. In most cases, it was relatively easy to determine the amount of total gas usage that was attributable to the boilers and the engineering models were susceptible to calibration.

The analysis process began with the cleaned data sets.

Analysis Process Steps

In this section we provide a high-level overview of the steps in the analysis. While this accurately represents the logic of the analysis, in practice this is an iterative process that does not require a strict sequential order.

Step 1. The cleaned 5-minute interval data set is processed to develop average hourly combustion blower current draw and the average hourly supply and return water temperatures.

Step 2. The hourly data set is differentiated into two periods, weekdays (WD) and weekend/holiday (WEH) to accommodate typical control strategies.

Step 3. A boiler run time fraction is calculated for each hour in the sample. This factor is based on the current draw of each hour as compared to the average current draw of all time periods when the burner is operating.

The next series of steps expands the sample time frame measurements to the full year (8760 hours) and develops the factors necessary to calculate the usage difference between the installed and baseline equipment.

Step 4. Through an iterative series of regression analysis, coefficients are developed to calculate the boiler run time fraction, the supply temperature, and the return temperature for each hour based on the ODB temperature from typical meteorological year weather data. The objective of this analysis is to develop an equation that produces values for these three factors as close as possible to the observed measurements. These factors varied by site.

Step 5. Using the equations developed in Step 4, the following are calculated for each hour of the year:

a. Boiler Run Time Fraction

b. Supply Water Temperature

c. Return Water Temperature

Step 6. Boiler performance coefficients are calculated based on secondary data. In the absence of specific data for the boiler installed at the monitored site, we used coefficients developed from representative boiler performance curves.

Step 7. The following hourly boiler operating variables are calculated based on the above:

a. Water Temperature Rise – The difference between the return water temperature and the supply water temperature, a function of heat input.

b. Pumping Heat Input – Calculated from estimated pump horsepower. Pumping contributes a small heat gain to the system which is captured in our analysis.

c. Boiler Power Output Fraction – Calculated as a function of the boiler run time and boiler return temperature, this factor captures the effects of modulating boilers.

d. Boiler Output – This is the calculated Btu output for the hour as a product of the steady-state output and the boiler power output fraction.

e. Boiler Efficiency - Hourly boiler operating efficiency is calculated as a factor of return water temperature and boiler run time fraction using the coefficients developed in Step 6 above.

f. Boiler Gas Input – A function of the installed gas input and the baseline boiler efficiency incorporating an adjustment for Btu added by pumping.

g. Baseline Gas Input – A function of the baseline efficiency for the equipment under consideration per the TRM, the weighted average annual efficiency calculated for the sample point, and the calculated boiler gas input.

At this phase in the analysis hourly factors for the full year have been developed. The next steps calculate the annual factors necessary to compare the measured savings to the tracked savings and to check the methodology and results.

Step 8. EFLH for the baseline and installed equipment are calculated based on the hourly boiler gas input and average efficiency.

Step 9. The average hourly inputs for the both the baseline and installed measure are calculated for the heating season based on the average efficiency and EFLH.

Step 10. Billing analysis is used to calibrate the analysis outputs.

Step 11. The installed boiler gas input and baseline boiler gas input each are summed to develop the respective annual inputs. The difference between the two is ΔMMBtu, or the evaluated savings.

The on-site data analysis method utilized five-minute boiler combustion fan data that allowed for the measurement of boiler modulation effects. There was no need to add computational complexity to accommodate domestic water heating loads since they would be the same whether the boiler was efficient or baseline. Similarly there was no need to accommodate heat loss form distribution system, or standby losses since they would be essentially equivalent regardless of boiler efficiency. There was no need to utilize different performance curves related to modulating firing rates, because the dew point of the flue gas is the same regardless of firing rate.

The use of TMY data to expand the on-site data was included to normalize the usage so that the results would represent more “typical” expected usage and savings.

7.3 Boiler Site Description Summary

This section contains a brief overview of the sites included in the sample that had sufficient data to be carried forward into analysis.

Site ID #27 – Church and community building

Two retrofit boilers rated at a maximum output capacity of 702,000 Btu/hr were installed in this facility. The facility houses a place of worship, a soup kitchen, and administrative offices. The distribution system is zoned controlled by individual thermostats. According to the PA tracking system, indirect water heaters are on site. Temperature settings and set-back schedules could not be determined. Boiler operation was monitored for 26 days. Due to the warm weather during the sampling period, the facility operators had shut down both boilers for considerable periods of time.

Site ID #41 – Small office building

A retrofit boiler with a maximum output capacity of 83,300 Btu/hr was installed in this small, free-standing 2 story office building with fewer than five tenant business. The boiler provides all of the space heat. The distribution system is broken into zones with individual thermostats for each. There is no system-wide temperature setting or set back schedule. The boiler operation was monitored for a total of 63 days.

Site ID #158 – Multifamily complex

Four boilers with rated input capacity of 600,000 Btu/hr serve this multifamily complex comprised of two six-story residential units and a two story recreation building. Two of the boilers are retrofit condensing boilers and two are standard boilers at 80% efficiency. Two indirect water heaters are connected to the retrofit boilers. Thermostats are located throughout the residential units and set-points and setback scheduled could not be determined. Boiler operation was monitored for 35 days.

Site ID #170 – Church and community building

Two retrofit 379,000 Btu/hr output boilers supply the heat for this standalone three-story church which contains administrative offices and serves as a community recreation center. The boilers provide all of the space heat. Thermostats are located in multiple zones. During the monitoring

period one of the boilers was reported to have mechanical difficulties and was out of service. Boiler operation was monitored for 54 days.

Site ID #197 – Multifamily building

Two 660,000 Btu/hr output capacity retrofit boilers and two 119 gallon indirect water heaters provide the space heat and domestic hot water for a free-standing five-story residential unit. Thermostats are located in the residential spaces and set points and set back schedules are unknown. Boiler operation was monitored for 56 days.

Site ID #216 – Recreational building

Three 467,000 Btu/hr output capacity retrofit boilers provide the space heat for this large, single-story recreation building that contains offices, game rooms, classrooms and a full-size swimming pool. The pool area and others are independently zoned. The temperature and set-back schedules are unknown. Boiler operation was monitored for 54 days.

Site ID #228 – Church, community building, and convent

Two 1,237,000 Btu/hr output capacity retrofit boilers serve a sprawling building housing chapel, convent, elementary and high school spaces. Thermostats are located in multiple zones in each building. The temperature and set-back schedules are unknown. Boiler operation was monitored for 36 days for one of the boilers. The other logger was inoperable on recovery.

Site ID #234 – Department of Public Works

One 369,000 Btu/hr output capacity boiler was installed at this facility, which is large building that contains administrative offices, garages, service bays and warehouse space. The tracking system indicated that there were eleven boilers installed, but the site contact confirmed that only one boiler was installed. The incentivized boiler is used to heat water for some cleaning processes run within the facility. The boiler operation was monitored for a period of 53 days, but the observed usage was low.

Site ID #237 – Greenhouse

Four 1,853,000 Btu/hr output capacity boilers heat provide the heat for a five-acre greenhouse. In addition to maintaining ambient temperatures for horticulture, a substantial amount of boiler operating energy is used to melt snow that accumulates on top of the greenhouses. For this reason, fuel usage is a function of both temperature and snowfall. There was relatively little

snowfall during the monitoring period. Thermostats are located throughout the greenhouse. The temperature and setback schedules are unknown. Boiler operation was monitored for 62 days.

Site ID #250 – Multifamily building

One 183,000 Btu/hr output capacity retrofit boiler connected to a 80 gallon indirect water heater provides the space heat and domestic hot water for a two-story multifamily residential building operated by a housing authority. Space heating thermostats are located in the residential spaces. The temperature and setback schedules are unknown. The water heater is thermostat is set at 125 degrees Fahrenheit. Boiler operation was monitored for 55 days.

Site ID #307 – Medical office building

Two 1,860,000 output capacity retrofit boilers provide the space heat for a large re-purposed mill building being used as a medical facility and office space for other businesses. Thermostats are located in several spaces. The temperature and setback schedules are unknown. Boiler operation was monitored for 54 days.

Site ID #309 – Convent

Three 1,728,000 Btu/hr and one 720,000 Btu/hr output capacity retrofit boilers provide the space heat for a building that includes spaces used for worship, sleeping, leisure, and a cafeteria/kitchen. Thermostats are located throughout the spaces. The temperature and setback schedules are unknown. Boiler operation was monitored for 60 days.

8. Appendix B - Condensing Furnace

8.1 Condensing Furnace Measure Description

This projected evaluated the performance of high efficiency natural gas warm air furnace both with and without an electronically commutated motor (ECM) for the fan. High efficiency furnaces are better at converting fuel into direct heat and better insulated to reduce heat loss. These furnaces achieve higher efficiency by sending flue gasses through a secondary heat exchanger that extracts heat from the exhaust gasses. The flue gasses are then vented outdoors. The stack piping configuration also contains a separate inlet that draws combustion air from outdoors. This eliminates the use of interior space air for combustion and reduces infiltration into the building.

High efficiency warm air furnaces account for 155 projects with a total of 49,951 therms of savings in the Prescriptive Gas Tracking Data. Measurements were recorded and verification analyses were performed for 9 of these projects.[15] These 9 projects have total annual savings of 2,788 therms. This is 5.6% of the total tracking savings for this measure.

Both the 2010 TRM and KEMA's analytic approach calculate the energy savings as a product of the hourly energy input times the annual hours of use times a factor representing the change in efficiency.

The 2010 TRM contains the following algorithm for calculating natural gas savings from these measures:

$$\Delta\text{MMBtu} = (CAP)(EFLH_{heat})\left(\frac{\eta_{ee} - \eta_{base}}{\eta_{ee}}\right) - MMBtu_{ECM}$$

ΔMMBtu	=	gross annual MMBtu savings from the measure.
CAP	=	equipment heating capacity (MMBtu/h).
$EFLH_{heat}$	=	equivalent full load heating hours.
η_{ee}	=	efficient equipment efficiency (expressed as AFUE, E_c, or E_t).
η_{base}	=	baseline equipment efficiency (expressed as AFUE, E_c, or E_t).

[15] The tenth site included in the sample actually had a condensing boiler installed, but it was scheduled too late to substitute an additional furnace site.

$MMBTU_{ECM}$ = increased heating fuel consumption in MMBtu to compensate for reduced fan motor waste heat (**applies to furnaces with ECM fan motors only**)[16].

$$= (0.019)(CAP)(EFLH_{heat})\left(\frac{\eta_{base}}{\eta_{ee}}\right)$$

The 2011 TRM defines prescriptive savings based on three efficiency strata. The values in the 2011 are shown in Table 26 below.

Table 26: 2011 TRM Prescriptive Furnace Savings

Furnace Efficiency	ΔMMBTU/Unit/yr
Furnace AFUE =>92%	21.1
Furnace AFUE =>92% w/ECM	19.6
Furnace AFUE =>94% w/ECM	23.6

KEMA followed the documentation trail for these prescriptive savings to the sources referenced in the TRM, a potential study report[17] and a deemed savings database.[18] Table 27 provides the sources and values in the documentation referenced by the TRM.

Table 27: Condensing Furnace TRM Sources

Market Category	Baseline Efficiency (value)	Savings Factor (value)	Annual Savings (MMBtu)
Market Driven	Energy Star Furnace Savings Calculator (78% AFUE)	GDS Calculation based on 92% AFUE (15.2%)	NYSERDA Deemed Savings Database, Rev 09-082006 adjusted to Boston, measure efficiency difference,92% vs. 90% and size 120,00 Btu vs. 80,000 Btu with base usage = 266.2 MMBtu (40.46 MMBtu)
Retrofit	Summit Blue Estimate (78% AFUE)	GDS Calculation based on 92% AFUE (18.5%)	NYSERDA Deemed Savings Database, Rev 09-082006 adjusted to Boston, measure efficiency difference,92% vs. 90% and size 120,00 Btu vs. 80,000 Btu with base usage = 276.9 MMBtu (51.17 MMBtu)

The GDS does not provide sufficient information to allow the methodology to be replicated. KEMA acquired and reviewed the deemed savings database, which did not include the

[16] Adapted from "Electricity Use by New Furnaces: A Wisconsin Field Study," Energy Center of Wisconsin, 10/2003.
[17] GDS Associates, Inc. (2009). *Natural Gas Energy Efficiency Potential in Massachusetts*. Prepared for Gas Networks.
[18] "NYSERDA Deemed Savings Database, Rev 09-082006"

underlying calculation methodology. Thus our analysis could only compare our calculated savings to the values listed in the TRM.

The baseline efficiency is defined as shown in Table 28 below, in both the 2010 and 2011 TRM.

Table 28: TRM Furnace Baseline

Equipment Type	Size Category (Input)	Subcategory or Rating Condition	Minimum Efficiency
Warm air furnace, gas fired	<225,000 Btu/h	-	78% AFUE or 80% E_t
	>=225,000 Btu/h	Maximum capacity	80% E_t
Warm air duct furnace	All capacities	Maximum capacity	80% E_t

KEMA used these baseline efficiencies for the analysis.

8.2 Condensing Furnace Methodology

Onset Hobo Microstation time-of-use loggers were installed that measured the current of the combustion blower and the temperature of the supply and return air at the furnace at five minute intervals, and where the conditioned space was accessible, the temperature at the controlling thermostat. The loggers were in place for between 26 and 67 days, with an average monitoring period of 54 days.

After logger retrieval the data was checked for consistency and completeness, the following steps were applied to the data for each measure:

1. The Logger data were trimmed to remove any pre- and post-installation data that does not represent actual operating conditions.

2. The remaining data set was examined for anomalies, such as readings outside the expected range. For example, the current draw by the combustion blower was recorded in a small number of 5-minute intervals during the start-up phase. In these cases, which occurred for less than a fraction of one percent of the readings, the recorded data point exceeds the average by a factor of approximately five. Since this was an instantaneous reading, and not representative of the 5-minute interval, using this data point in subsequent analyses would skew the results. Consequently, these data points were replaced with the average of the data set absent the outliers.

Two other data sets were required for the analysis, and both weather related. These were the average hourly temperature for the study period and the TMY data was for four weather stations

in Massachusetts, at Boston, Worchester, Chicopee Falls, and Pittsfield. This process resulted in clean and consistent sets of measured data incorporating the variables shown in Table 29 below.

Table 29: Measured Furnace Variables

Measured Variables (Study Period)		
Name	Measurement Interval	Source
Combustion Blower Current (amperage)	5-minute	Data logger
Supply Air Temperature (° F)	5-minute	Data logger
Return Air Temperature(° F)	5-minute	Data logger
Temperature at Thermostat (° F)	5-minute	Data logger
Study Period Outdoor Dry Bulb Air Temperature(° F)	Hourly	NOAA
Typical Meteorological Year Outdoor Dry Bulb Temperature(° F)	Hourly	TMY2

The analysis process began with the cleaned data sets.

Analysis Process Steps

In this section we provide a high-level overview of the steps in the analysis. While this accurately represents the logic of the analysis, in practice this is an iterative process that is not conducive to strict sequential presentation.

Step 1. The cleaned 5-minute interval data set is processed to develop average hourly combustion blower current draw and the average hourly supply and return air temperatures.

Step 2. The hourly data set is differentiated into two periods, weekdays (WD) and weekend/holiday (WEH) to accommodate typical control strategies.

Step 3. A furnace power output fraction is calculated for each hour in the sample. This factor is based on the current draw of each hour as compared to the average current draw of all time periods when the burner is operating.

The next series of steps expands the sample time frame measurements to the full year (8760 hours) and develops the factors necessary to calculate the usage difference between the installed and baseline equipment.

Step 4. Through an iterative series of regression analysis, coefficients are developed to calculate the burner run time fraction, the furnace output fraction, the supply

temperature, and the return temperature for each hour based on the outdoor dry bulb (ODB) temperature from typical meteorological year weather data. The objective of this analysis is to develop an equation that produces values for these factors as close as possible to the observed measurements. These factors will vary for each site.

Step 5. A factor for heat added from air circulation, including the blower motor waste heat is calculated for each system.

Step 6. Using the equations developed in Step 4, the following are calculated for each hour of the year:

a. Furnace Run Time Fraction

b. Furnace Output Fraction

c. Supply Air Temperature

d. Return Air Temperature

Step 7. Furnace performance coefficients are calculated based on secondary data. In the absence of specific data for the furnace installed at the monitored site, we used coefficients developed from representative furnace performance curves.

Step 8. The following hourly boiler operating variables are calculated based on the above:

a. Furnace Output – This is the calculated Btu output for the hour as a product of the steady-state output and the furnace power output fraction.

b. Furnace Efficiency - Hourly furnace operating efficiency is calculated as a factor of supply air temperature, furnace run time fraction, and furnace output fraction using the coefficients developed in Step 4 above.

c. Furnace Gas Input – A function of the installed gas input and the baseline boiler efficiency incorporating an adjustment for Btu added by circulation.

d. Baseline Supply Air Temperature – A function of the calculated hourly return air temperature of the operating unit.

e. Baseline Furnace Efficiency – A function of the calculated run time and output fractions of the measured unit, the baseline efficiency contained in the TRM, and the baseline supply air temperature.

f. Baseline Gas Input – A function of the baseline efficiency for the equipment under consideration per the TRM, the weighted average annual efficiency calculated for the sample point, and the calculated boiler gas input.

At this phase in the analysis hourly factors for the full 8760 hours of the year have been developed. Our analysis also develop equivalent full load hours and average efficiency (in AFUE) for each unit, but, in the absence of a documented methodology and set of assumptions underlying the development of the TRM values, we did not compare our findings to a deemed calculation.

Step 9. The installed furnace gas input and baseline furnace gas input each are summed to develop the respective annual inputs. The difference between the two is ΔMMBtu, or the evaluated savings.

8.3 Furnace Site Descriptions

Site #321-35 – Store front: 80,000 Btu/hr input

Furnace provides all of the space heat for a store front in a brick commercial building with interior walls on both sides and other tenants above. The furnace supplies heat for this unit only. The temperature schedule was 72ºF when open and 60ºF when closed. Furnace operation was monitored for 49 days.

Site #342-63 – Light industrial: 72,000 Btu/hr input

The retrofit furnace provides space heat for half of a basement factory space in a brick industrial building. Three other furnaces heat the other half of the basement and part of the first floor. There are pieces of machinery in the conditioned space which lower the heating load on the furnaces. The space is maintained at a constant 70ºF. Operation was monitored for 26 days.

Site #355-51 – Multifamily: 80,000 Btu/hr input

The retrofit furnace provides all of the space heat for one detached unit in a multifamily complex. Temperature is maintained at a constant 70ºF with a thermostat located in an interior hallway. Operation was monitored for 50 days.

Site #365 – Church office and support

#365 -25: 60,000 Btu/hr input

#365 -27: 75,000 Btu/hr input

The furnaces provide space heat to a church facility with intermittent use and reported low usage during the monitoring period. The heated space is attached to building on both sides. The smaller furnace temperature schedule is 71ºF when open, 66ºF when closed. The larger furnace is set to 66ºF when open and turned off when the building is closed. The operation of both units was monitored for 62 days.

Site #368-7 & -99 – Warehouse, 2 Story: Two 90,000 Btu/hr input

This facility is a freestanding two-story building used as a garage, warehouse, and offices. One furnace provides space heat for the first floor. The temperature schedule is 70ºF when operating, 60ºF when closed. The second furnace was installed on the second floor and is not connected to a thermostat. The operator reports that it has never run. Both units were retrofit. Operation was monitored on both units for 67 days and some usage was detected on the second unit.

Site #376-6 – Retail: 120,000 Btu/hr input

This retrofit furnace provides all of the space heat for a single-story freestanding building housing a retail sales floor, storage and offices. This is a small building approximately 1,500 square feet. The temperature is set at a constant 70ºF. Operation was monitored for 55 days.

Site #463-48 – Warehouse: 69,000 Btu/hr input

This freestanding commercial building houses a supply company that operates roughly 25 hours per week. The temperate schedule was not determined. The furnace provides all of the space heat for the building. Operation was monitored for 57 days.

Site #467-2 &-67 – Church offices: Two 130,000 Btu/hr input

This facility is a freestanding, single-story, converted barn that houses church offices. The full space heat load is served by the two retrofit furnaces. The temperature schedule is 72ºF when open, about 50 hours per week, 58ºF when closed. Operation of both was monitored for 54 days.

Site #474-66 – Professional offices: Two 80,000 Btu/hr and one 40,000 Btu/hr input

This new construction two-story building houses a medical practice. Three furnaces provide all of the space heat requirements. The temperature schedule is 74ºF when open (approximately 50 hours per week) and 65ºF when closed. Loggers were in place for 50 days, but due to logger failure data was collect only for one of the larger furnaces.

9. Appendix C - Infrared Heaters

9.1 Infrared Heaters Measure Description

This project evaluated the performance of gas-fired low intensity infrared heating systems in place of unit heater, furnace, or other standard efficiency equipment. Low-intensity heaters have an enclosed flame. When heat is required, the burner control box ignites a gas/air mixture and hot gases are pushed through steel radiant tubing by an internal fan. As these gases pass through the assembly, the tubing is heated and emits infrared energy, which is then directed toward the floor by highly polished reflectors. This energy is absorbed by objects in its path, such as the floor, machinery, and people. Objects in the path of the infrared energy in turn re-radiate this heat to create a comfort zone at the floor level.

Infrared-heating accounts for 37 projects with a total of 72,912 therms of savings in the Prescriptive Gas Tracking Data. Measurement and verification analyses will be performed on 6 of these projects. These 6 projects have total annual savings of 13,392 therms. This is 18.4% of the total tracking savings for this measure.

Both the 2010 and 2011 versions of the Massachusetts TRMs have a fixed savings per installed unit. The value shown for the 2010 TRM is 77.4 MMBtu/year while the value shown in the 2011 TRM is 74.4 MMBtu/year. Both TRMs reference modeled data from 62 low-intensity infrared heaters installed by the predecessor of Columbia Gas of MA. The data is contained in a spreadsheet with the name “Infrared Samples - Bay State Gas.xls.” This file contains nine records with savings that average to 74.4 MMBtu/year. These savings are listed as “Estimated” but the estimation methodology is not documented. It appears that the intended value for savings from this source is consequently 74.4 MMBtu/year.

KEMA reviewed the material provided by the program sponsors and was not able to document the equations used to determine the savings beyond a simple average of the projects listed in the spreadsheet referenced above. We reviewed the literature on IR savings[19] and developed the equation below to calculate savings for each project.

[19] http://www.spaceray.com/pdf/infrared-heating_engineering-manual_0305.pdf

$$\Delta MMBtu = (CAP)(EFLH)\left(\frac{CF_{base}}{\eta_{base}} - \frac{CF_{ee}}{\eta_{ee}}\right)$$

Where:

ΔMMBtu	= gross annual MMBtu savings
CAP	= Heating load requirement (MBtu/hr)
EFLH	= equivalent full load hours
CF_{base}	= Compensating factor for baseline equipment
η_{base}	= Thermal efficiency of baseline equipment
CF_{ee}	= Compensating factor for efficient equipment
η_{ee}	= Thermal efficiency of efficient equipment

The compensating factors and thermal efficiency values are discussed in the following section.

9.2 Methodology

Time-of-use loggers were installed to measure the flow of current to the infrared heaters installed through the program. Data loggers to measure space temperature were installed if not precluded by the nature of operations and/or the facility. The loggers were in place for between 52 and 64 days, with an average monitoring period of 57 days.

After logger retrieval the data was checked for consistency and completeness. The data set then was examined for anomalies, such as readings outside the expected range, and corrected. For example if the space temperature reading exceeded the reasonable range or the current inrush was captured by the logger, these data points are corrected to fall within a reasonable range.

In addition to the site-collected data, the analysis required the measured hourly temperatures and typical meteorological year data for weather stations in Massachusetts, at Boston, Worchester, Chicopee Falls, and Pittsfield. The variables for the analysis are shown in Table 30.

Table 30: Infrared Heater Variables

Variables (Study Period)		
Name	Measurement / Input Interval	Source
Combustion Blower Current (amperage)	5-minute	Data logger
Indoor Temperature (° F)	5-minute	Data logger
Study Period Outdoor Dry Bulb Air Temperature(° F)	Hourly	NOAA
Typical Meteorological Year Outdoor Dry Bulb Temperature(° F)	Hourly	TMY

Analysis Process Steps

In this section we provide a high-level overview of the steps in the analysis. While this accurately represents the logic of the analysis, in practice this is an iterative process that does not require a strict sequential order.

Step 1. Additional variables were required to calculate energy usage and saving relative to the baseline in the absence of a defined equation-based methodology for calculating savings. These include:

a. IR Compensating Factor – Manufacturers' sizing recommendations incorporate a compensating factor for IR heating equipment based on the difference in heat output required to heat objects by radiation as compared heating the ambient air and the objects within the envelope by convection.[20] This factor is directly related to the mounting height of heater.

Table 31: IR Compensating Factors

Mounting Height	IR Compensating Factor
12	0.78
16	0.80
20	0.82
24	0.84
28	0.86
32	0.88
36	0.90
40	0.92

[20] Ibid.

b. Thermal efficiency of the IR heater – The thermal efficiency of the IR heater was calculated by an engineering analysis of the physical properties of atmospheric natural gas combustion, the theoretical minimum and maximum temperatures at which a low intensity heater fire tube would radiate heat, and other factors. Based on this analysis we determined to use 82% thermal efficiency in our calculations.

c. The baseline equipment for all analyses was modeled as a suspended unit heater with thermal efficiency of 80% serving the equivalent area as the site IR heaters. The output of the unit heater is sufficient to meet the same building heat requirement as the IR heater(s) monitored.

Table 32 below illustrates the comparison of these factors, and how they relate to building heat requirements.

Table 32: Sample Calculation of IR vs. Unit Heater Sizing

Sample Calculation		
	IR Htr	Unit Htr
ASHRAE building heat load	100,000	100,000
Compensation factor	0.850	1.000
Output heat Required	85,000	100,000
Thermal Efficiency	82.0%	80.0%
Input heat Required	103,659	125,000

Step 2. The following factors are developed for the cleaned 5-minute interval data set:

a. Maximum Current Draw

b. Heat Output Fraction – The 5-minute interval current divided by the maximum current draw.

c. IR Btu/hr Input – The total input capacity of the unit(s) monitored multiplied by the heat output fraction.

d. IR Btu/hr Output – The IR Btu/hr input times the IR thermal efficiency.

e. Unit Heater Btu/hr Output – The IR Btu/hr output divided by the IR compensating factor.

f. Unit Heater Btu/hr Input – The unit heater output divided by the unit heater efficiency.

g. Savings – The difference between IR heater and unit heater inputs

Step 3. The five-minute interval data for the factors above are processed to develop hourly averages across the monitoring period.

The next series of steps expands the sample time frame measurements to the full year (8760 hours) and develops the factors necessary to calculate the usage difference between the installed and baseline equipment.

Step 4. The hourly data set is differentiated into two periods, weekdays (WD) and weekend/holiday (WEH) to accommodate typical control strategies.

Step 5. Coefficients for the independent variables of hour of the day and outdoor temperature, differentiated by weekday and weekend/holiday, are developed to provide the best fit between the heat output fraction, IR Btu/hr input, and the unit heater Btu/hr input calculated using these coefficients and the values derived from the monitoring data.

Step 6. These coefficients are used to generate the Btu/hr inputs required for both IR heater and the baseline across the full year. For this set of calculations, the space heating equipment was forced off when the outdoor temperature exceeded a calibrated, site-specific threshold temperature.

Step 7. The hourly Btu inputs for the IR heater(s) and baseline are summed across the year and the difference between the two is the annual savings, expressed in MMBtu.

9.3 Infrared Heaters Site Descriptions

Site ID #490 – Commercial Rental Space: 80,000 Btu/hr

This heater serves a space approximately 20 feet by 30 feet with a large bay door and small, partially-enclosed office space. It has shared walls with conditioned spaces on either side. The heater is mounted 20 feet above the floor. The temperature schedule is unknown. Heater operation was monitored for 64 days.

Site ID #505 – Light Industrial: 60,000 Btu/hr

The heater serves a metal building approximately with a footprint of approximately 20 feet by 40 feet with a ceiling height of 12 feet. The building has two bay doors and is connected to conditioned workshops on both sides. The heater is controlled by an on/off switch instead of a thermostat as needed by the occupants, so it was not possible to determine a set schedule in advance. Operation was monitored for 56 days

Site ID #496 – Auto shop: Two 60,000 Btu/hr

Three automobile repair bays with common sidewalls are each heated by a single IR heater. Each bay has its one overhead door which is normally closed during the heating season. Each space is approximately 20 feet by 20 feet with heater mounting heights of approximately 15 feet. The heaters are thermostatically controlled with set points of 65ºF. There was no setback schedule reported by the occupants. Heater operation in two of the units was monitored for a total of 61 days.

Site ID #497– Light Industrial: Three 60,000 Btu/hr

These units provide space heat to carpentry workshop spaces. Each unit heats an area approximately 100 feet by 50 feet. The units are mounted 30 feet in the air. The spaces are accessed by large bay doors which occasionally remain open for long periods of time. The thermostat setting is fixed at 60ºF. The equipment was monitored for 63 days.

Site ID #502 - Light Industrial: Six 75,000 Btu/hr and one 100,000 Btu/hr

Four workshops of one light industrial operation are fully heated this equipment. Three of the workshops are approximately 30 feet by 60 feet. These are each heated by two 75,000 Btu/hr heaters. The other workshop is approximately 30 feet by 30 feet and is served by one 100,000 Btu/hr heater. All heating units are 20 feet above the workshop floors and provide 100% of the heating to the affected spaces. The thermostats are set to 70ºF during production hours and the heaters are turned off otherwise. Operation was monitored for 52 days.

10. Appendix D - Indirect Water Heaters

10.1 Indirect Water Heaters Measure Description

Indirect water heaters use an insulated storage tank containing a heat exchanger energized by a closed recirculation loop off the space heating boiler. This system design can contribute to reduced standby heat loss, increased efficiency from burner operation at or near steady-state efficiency and reduce cycling losses during the heating season.

Indirect water heating accounts for 24 projects with a total of 69,616 therms of savings in the Prescriptive Gas Tracking Data. Measurement and verification analyses were performed on 10 of these projects. These 10 projects have total annual savings of 7,296 therms. This is 10.5% of the total tracking savings for this measure.

Both the 2010 and 2011 versions of the TRM assign a fixed quantity of prescriptive savings, 30.4 annual MMBtu[21], to each unit installed.

In order to adequately analyze the TRM values it was necessary to determine, to the extent possible, the calculations underlying the prescriptive savings value. The source referenced in both TRMs was a GDS report. The sources listed in this report are shown in Table 33 below:

Table 33: Indirect Water Heater Sources for TRM Values

Market Category	Baseline Efficiency (value)	Savings Factor (value)	Annual Savings (MMBtu)
Market Driven	US DOE Federal Energy Management Program (Storage tank water heater at 0.59 EF)	GDS Calculation (28.1%)	ESource – Gas Fired Water Heater Screening Tool - Assumptions of .85 thermal efficiency and 250 gallons per day. Base use = 108.3 MMBtu (30.38 savings)
Retrofit	Federal Code FR66/11/Jan. 17,2001, p 4497 ((Storage tank water heater at 0.55 EF)	GDS Calculation (32.9%)	ESource – Gas Fired Water Heater Screening Tool - Assumptions of .85 thermal efficiency and 250 gallons per day. Base use = 111.5 MMBtu (36.72 savings)

KEMA used the current version of the screening tool[22] populated with the values in listed in the GDS report and was not able to replicate the values listed in the report. The values calculated

[21] Natural Gas Energy Efficiency Potential in Massachusetts, Appendix B-2, p.2, GDS, 2009.

[22] http://www.esource.com/BEA/demo/Shared/PA_41_calc.html, accessed 5/10/12

by this tool for each of a variety of efficiency ratings, and resulting savings, all based on a 250 gallon daily draw and 100ºF temperature rise as specified in the report and tool documentation, are shown in Table 34 below.

Table 34: Indirect Water Heater Usage and Savings Calculated from TRM Source

Energy Factor	Thermal Efficiency	Calculated Annual Usage (MMBtu)	Savings at 108.3 MMBtu base usage	Savings at 111.5 MMBtu base Usage	Savings assuming base usage at .55 EF	Saving assuming base usage at .59 EF
0.55	X	137.8	-29.5	-26.3	X	X
0.59	X	128.5	-20.2	-17	9.3	X
0.82	X	92.4	15.9	19.1	45.4	36.1
0.85	X	89.2	19.1	22.3	48.6	39.3
X	82%	105.3	3	6.2	32.5	23.2
X	85%	101.1	7.2	10.4	36.7	27.4

The level of documentation provided in the 2010 & 2011 technical reference manuals was not sufficient to enable us to independently arrive at the prescriptive savings value of 30.4 MMBtu annual savings per unit.

10.2 Indirect Water Heater Methodology

Onset Hobo Microstation time-of-use loggers were installed that measured the current to the circulating pump. In some cases, loggers were also installed on the boiler combustion blower. The loggers were in place for between 35 and 62 days, with an average monitoring period of 53 days. The temperature at the hot water tap and/or the set point of the indirect water heater was recorded.

After logger retrieval the data was checked for consistency and completeness. The following steps were applied to the data for each measure:

1. Loggers record pre- and post-installation data that does not represent actual operating conditions. This data was removed from the set.

2. The data set was examined for anomalies, such as readings outside the expected range. For example, the current draw by the circulating pump was recorded in a small number of 5-minute intervals during the start-up phase. In these cases, which occurred for less than a fraction of one percent of the readings, the recorded data point exceeds the average by a factor of approximately five. Since this was an instantaneous reading, and not representative of the 5-minute interval, using this data point in subsequent analyses

would skew the results. Consequently, these data points were replaced with the average of the data set absent the outliers.

The other data set required for the analysis was the typical meteorological year data for weather stations in Massachusetts, at Boston, Worchester, Chicopee Falls, and Pittsfield. This process resulted in clean and consistent sets of measured data incorporating the variables shown in Table 35 below.

Table 35: Indirect Water Heater Variables

Variables (Study Period)		
Name	Measurement / Input Interval	Source
Circulating Pump Current (amperage)	5-minute	Data logger
Makeup Water Temperature (° F)	Hourly	TMY ground water temperature plus 10° F
Boiler Water Temperature(° F)	5-minute	Calculated from site data or proxy
Water Heater Output Temperature(° F)	Once	Measured at tap
Study Period Outdoor Dry Bulb Air Temperature(° F)	Hourly	NOAA
Typical Meteorological Year Outdoor Dry Bulb Temperature(° F)	Hourly	TMY

Analysis Process Steps

In this section we provide a high-level overview of the steps in the analysis. While this accurately represents the logic of the analysis, in practice this is an iterative process that does not require a strict sequential order.

Step 1. The cleaned 5-minute interval data set is processed to develop hourly averages for the circulating pump current draw, the tank temperature rise, the average Btu input to the tank.

Step 2. The hourly data set is differentiated into two periods, weekdays (WD) and weekend/holiday (WEH) to accommodate typical control strategies. Since the monitoring period included February 29, which is excluded from the TMY data, differentiation into WD or WEH permits the sample data to be applied to the typical year data.

Step 3. Monthly average make-up water temperatures are assigned to the hourly values based upon the monthly ground temperatures contained in the TMY weather data.

The next series of steps expands the sample time frame measurements to the full year (8760 hours) and develops the factors necessary to calculate the usage difference between the installed and baseline equipment.

Step 4. Through an iterative process coefficients for the independent variables of the pump run time fraction, the Btu input to the indirect water heater, and the water temperature rise for each hour of the day, differentiated by weekday and weekend/holiday, are developed to provide the best fit to observed measurements across the sampling period.

Step 5. Using the coefficients developed in the step above, linear regression factors are calculated for these variables

Step 6. The following variables are calculated for each hour of the year using the regression factors and the independent variables:

a. Pump Run Time Fraction

b. Btu to DWH Tank

c. Water Temperature Rise

Step 7. Boiler efficiency, necessary to determine the boiler gas input that produces the required Btu output, is acquired from either analysis of boiler performance where monitoring devices were installed on this equipment, or from average performance data for condensing or non-condensing boilers.

Step 8. Based on the values calculated above, adjusted by factors for water heater tank standby loss and pumping energy input, the boiler gas input necessary to meet the demand for hot water is calculated.

Step 9. The baseline gas input necessary to meet the calculated demand for hot water is calculated based on the pump run time fraction, a factor for pumping energy gain, and the baseline energy factor of a gas-fired water heater as set at 0.59 by the TRM.

Step 10. The boiler gas input calculated and baseline boiler gas input each are summed to develop the respective annual inputs. The difference between the two is ΔMMBtu, or the evaluated savings.

10.2.1 Indirect Water Heater Site Description Summary

This section contains a brief overview of the sites included in the sample that had sufficient data to be carried forward into analysis.

Site ID #566 – Multifamily: 119 gallon capacity

This building is a three-story detached brick condominium. The facility contains one indirect water heater and three 1,237,000 Btu/hr boilers which serve the entire space heat and domestic hot water load. All of the equipment was installed through the program. In addition to monitoring the circulating pump, the operation of all three boilers was monitored for a total of 62 days.

Site ID #570 – Retail: 35 gallon capacity

This building is a residential home converted to a retail store which is only open three days a week for limited hours. Hot water is primarily used in the bathroom. The indirect water heater is energized by a loop connected to an 80.1% efficient boiler. The circulating pump operation was monitored for 56 days.

Site ID #581 – Multifamily: Two 119 gallon capacity

Two indirect water heaters and two incentivized 660,000 Btu/hr condensing boilers serve this five story residential unit. The operation of both boilers and the circulating pump that serves both water heaters was monitored for 56 days.

Site ID #592 – Multifamily:

#592-18: 119 gallon capacity

#592-51: 80 gallon capacity

#592-64: 119 gallon capacity

This multifamily residential complex is in the process of retrofitting all of its buildings with efficient space and water heating equipment. Indirect water heaters were monitored in three buildings, with capacities as shown above. Each building is served by its own boiler and water heater. The equipment was monitored for 51 days.

Site ID #599 -– Multifamily: 80 gallon capacity

This two-story residential unit is served by a condensing boiler rated at 183,000 Btu/hr and one indirect water heater. Both are retrofitted equipment and both were monitored during for a total 55 days.

Site ID #602 – Multifamily: 80 gallon capacity

This two-story residential unit is served by a condensing boiler rated at 183,000 Btu/hr and one indirect water heater. Both are retrofitted equipment and both were monitored during for a total 55 days.

Site ID #604 – Multifamily: 80 gallon capacity

This two-story residential unit is served by a condensing boiler and one indirect water heater. Both are retrofitted equipment and both were monitored for 55 days.

Site ID #616 – School: 119 gallon capacity

This two-story detached building is used an elementary school. Hot water usage is linked to the academic year, and near zero from June until September. The circulating pump and the boiler combustion blower were monitored for 35 days.

Site ID #623 – Multifamily: Two 75 gallon capacity

This large detached multifamily building is served by two retrofit condensing boilers rated at 223,000 Btu/hr and two indirect water heaters. The circulation pump that serves both water heaters was monitored for 55 days.

Site ID #624 – Multifamily: Two 75 gallon capacity

This large detached multifamily building is served by two retrofit condensing boilers rated at 154,000 Btu/hr and two indirect water heaters. The circulation pump that serves both water heaters was monitored for 55 days.