Prescriptive Condensing Boiler Impact Evaluation

Project 5 Prescriptive Gas

Massachusetts Energy Efficiency Programs' Large Commercial & Industrial Evaluation

Prepared for: Massachusetts Energy Efficiency Program Administrators
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List of Tables:

1. Executive Summary

Massachusetts is moving toward a consistent, statewide energy efficiency offering. Energy efficiency program administrators (PAs) are working to create consistency in program delivery and savings estimates throughout the state. As part of this transition, impact evaluations are being performed on most programs. The evaluations are designed to inform program design and implementation going forward.

The PAs offer a wide range of gas measure rebates through “prescriptive” measure installations. Prescriptive measures share enough characteristics that the energy savings, incremental costs and rebates can be deemed or “prescribed” for a particular measure. Results for 2008 – 2009 showed that prescriptive measures receiving rebates for reduction in natural gas consumption accounted for approximately 40% of all Commercial and Industrial natural gas savings in the state. The prescriptive programs exclude measures which require site-specific or custom energy savings calculations, or calculations on a per square or linear foot basis. Those measures fall under the Custom Gas program.

To date, no formal impact evaluation has been completed for C&I prescriptive gas measures due to the relatively small program budgets and lesser emphasis on evaluation by the gas PAs. Savings have been estimated using various methods but no formal evaluations have been done in the state. This evaluation of the prescriptive gas program will provide a foundation on which the PAs can create consistency in program delivery and savings estimates throughout the state.

1.1 Objective of the Study

The overall stated objective of the impact evaluation was to develop annual gas savings impacts based on measures installed by participants in the Commercial Efficiency Programs. The particular focus of the evaluation was to develop annual savings estimates for installations going forward.

The original objective of the study was to provide impact estimates for:

- A subset of four heating equipment categories where quantitative evaluation was possible and desirable
- Programmable Thermostats.

After discussion with the EEAC and Program Administrators, (PAs) a joint decision was made to focus the evaluation on all five size categories of condensing boilers, a heating equipment category that represents about half of all prescriptive gas savings.

1.2 Study Design

KEMA gathered tracking data for all prescriptive gas measures installed by participating Massachusetts PAs. This process was challenging, in itself, because each PA ran a unique program. The definitions of measures, the scope of program offerings, rebates levels, tracking data available and estimated savings varied from PA to PA.

To complicate the matter, the requirements for inclusion in the prescriptive impact evaluation were based on the draft Massachusetts Technical Resource Manual (TRM) definitions being finalized at the time of the evaluation. The definition of a prescriptive measure for this evaluation was based on the definition of prescriptive going forward as codified by the TRM. As a result, a number of projects, initially classified as custom projects, were re-classified as prescriptive projects.

After defining a population of prescriptive projects from mid-2008 through early 2010, KEMA designed a sample for telephone and on-site surveys to be performed by KEMA engineers. The sample was stratified by size category and whether a site had billing data available or not. Billing data was important for informing the equivalent full load hours (EFLH) of the boilers.

Regardless of any savings originally assigned by the PA to a unit or project, KEMA established the annual TRM savings for each project as the “going forward” tracking data savings estimate. Working within the TRM savings calculation framework, KEMA developed estimates of unit savings at three subsequent levels: Nameplate, Telephone Survey, and On-site Survey. Table 1-1 provides basis on which the three key unit characteristics were developed for the savings estimate at each level.

Table 1-1
Overview of Four Levels of Savings Estimates

Unit Characteristics	Source of Data for Saving Calculations			
	TRM	Nameplate	Telephone Survey	On-site Survey
Efficiency	0.92	Nameplate	Confirmed Nameplate	Confirmed Nameplate
Capacity	Midpoint	Nameplate	Confirmed Nameplate	Confirmed Nameplate
EFLH	1500	1500	Confirmed billing analysis	Confirmed billing analysis or load calc
n=	394	394	147	36

The four levels of annual savings were combined in a ratio estimator framework. This is the typical framework used for sample based, engineering impact analysis. In the typical framework, a ratio is developed between estimated savings and tracking savings for a sample of projects and that ratio is applied to the overall savings from the tracking population. In this case there are four estimates of savings that are being combined to reach the final realization rate. TRM savings and Nameplate savings are both available at the population level, making them, essentially, different versions of the tracking data. This ratio is a simple calculation rather than a sample-based estimate. This ratio is referred to the Nameplate/TRM ratio.

For this evaluation, the well established ratio estimator approach was extended to include two additional ratios. Separate sample-based ratio estimates were developed for telephone savings relative to nameplate savings and on-site savings relative to telephone savings. The second ratio was based on a subsample of on-site interviews within the initial telephone sample. These latter two ratio estimates are "chained" to get a single realization rate that is referred to as the nameplate/telephone/on-site ratio throughout the report[1].

1.3 Results

The objective of this evaluation was to develop annual savings estimates for prescriptive gas condensing boilers. The results of this study would then be used to create realization rates to be

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[1] This nomenclature should not be understood to represent the mathematical relationship between these savings estimates. In simplified form, that would be (telephone/nameplate)*(on-site/telephone).

applied to the program prescribed savings going forward. The analysis, in fact, works in the opposite order. The analysis approach for this evaluation used a combined ratio estimator approach that effectively estimated the realization rates directly. These ratios were then applied to the TRM prescribed savings, the "tracking" savings, to get estimates of savings based on the observed program population.

Table 1-2 presents the realization rates to be applied to the TRM prescribed savings levels. These realization rates combine two steps:

- A size category specific, Nameplate/TRM ratio, based on the full program population, adjusting the TRM prescribed annual savings to nameplate annual savings; and
- An overall, On-site/Telephone/Nameplate Ratio savings ratio estimated across all size categories, that adjusts nameplate savings based on the sample-based analysis performed for this evaluation.

Table 1-2
Condensing Boiler, Unit Level TRM Realization Rates

TRM Size Category	Nameplate/TRM Ratio	Overall On-site/ Telephone/ Nameplate Ratio	TRM Realization Rate
Capacity ≤ 300	1.27	0.54	0.68
300 < Capacity < 500	1.00		0.54
500 ≤ Capacity < 1000	0.98		0.53
1000 ≤ Capacity ≤ 1700	1.00		0.54
1700 < Capacity	1.39		0.75
Overall	1.14		0.61

The nameplate/TRM ratio captures the difference between the prescribed savings levels for condensing boilers in the TRM and the updated nameplate savings based on observed population nameplate efficiency and capacity (but using the same EFLH of 1500). The difference between TRM and nameplate savings as captured in the size category level ratios is caused by the TRM assumptions regarding thermal efficiency and capacity. The assumed TRM assumption of .92 for efficiency is low compared to observed nameplate efficiencies at every size category. For capacity, the TRM size category "mid-points" for the smallest and largest size categories are substantially lower than the observed average capacity across the population in those size categories. As a result, the prescribed savings levels for condensing boilers in the

TRM are well below the average observed nameplate savings for those categories. This is what drives the relatively high nameplate/TRM ratio for the smallest and largest size categories. The on-site/telephone/ nameplate ratio developed for this evaluation is at the overall level. KEMA calculated size-category-specific ratios but the precisions were not good enough to use for application at that resolution in the final results. As a result, all size categories of nameplate annual savings are adjusted with the same 0.54 on-site/telephone/ nameplate ratio.

The 0.54 ratio is driven in equal parts by reduction in effective full load hours (EFLH) and efficiency. In both cases the reductions conform to expectation. The assumption of 1500 EFLH, which carried over to the nameplate estimate of savings from the TRM, seems unrealistically high and does not appear to be based on Massachusetts-specific, commercial building research. For a point of comparison, the highest EFLH reported in the ASHRAE manual[2], for a typical Boston office building, is 1000 hours. The reduction of average EFLH to between 1100 and 1200 as found in this study appears to be a reasonable, perhaps even conservative, correction.

Similarly, the nameplate thermal efficient represents optimal boiler performance under ideal conditions. While replacing the TRM assumption of 0.92 with the higher nameplate efficiency was important to make the savings calculation more unit specific, previous research combined with data gather for this analysis made it clear that a relatively low percentage of condensing boilers operate at optimal efficiency levels.[3]

With the combination of the two ratios, the TRM realization rate is substantially higher for the largest and smallest size categories. It is essential to understand the differences are solely an artifact of the TRM savings calculation method. The higher rates for those two size categories do not indicate that the installations in these size categories necessarily performed better as installed boilers.

In fact, the size category on-site/telephone/nameplate ratios, which are not sufficiently precise to use for application at that resolution in the final results, reveal a different story. The ratio for the largest boiler size category single-handedly lowers the overall realization rate. The four smaller size categories are close to or above the overall ratio while the large size category is well below

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[2] ASHRAE RP-1120, Stephen Carlon, Cdh Energy Corp. December, 2000. pgs 60-64.
[3] NYSERDA Natural Gas Program Evaluation, Measurement and Verification of Condensing Boilers. ERS. Betsy Ricker and Jonathan B. Maxwell, PE. June 2010

the overall ratio. Two related conclusions should be drawn from this observation: Performance does appear to vary across size categories and true size category realization would better reflect that variation.

Table 1-3 presents the final estimates of savings at the size category level. The table presents:

- TRM savings -- the deemed value that would be applied automatically to a condensing boiler within that size range. This is the “Tracking” estimates for this evaluation.
- Annual Nameplate savings – Savings calculated using nameplate values for capacity and thermal efficiency. This intermediate savings value is a potential alternative to the fully deemed estimate.
- Annual gross adjusted savings estimates – Average savings based on this analysis.
- The 80 percent confidence intervals for the gross adjusted savings estimates

Table 1-3
Condensing Boiler, Unit Level Savings Estimates, Therms

TRM Size Category	TRM Savings (Therms)	Nameplate Savings (Therms)	Gross Adjusted Savings (Therms)	+/- (Therms)
Capacity ≤ 300	323	410	221	33
300 < Capacity < 500	783	787	423	63
500 ≤ Capacity < 1000	1,467	1,433	771	114
1000 ≤ Capacity ≤ 1700	2,641	2,651	1,426	211
1700 < Capacity	3,326	4,629	2,490	369

1.4 Conclusions

The adjusted gross annual savings estimates presented with this evaluation represent a more accurate picture of expected prescriptive gas condensing boiler savings than the present TRM values. The new annual savings estimates were developed using the same savings framework as the TRM but with updated values for the three key components of the savings equation: capacity, thermal efficiency and equivalent full load hours (EFLH).

The varying realization rates across the size categories are not reflective of varying performance across the size categories with respect to program savings. Those differences are due primarily to the choice of size category capacity "midpoints" chosen for calculating the TRM savings values. This analysis establishes that after putting unit savings on a nameplate basis, programs adjusted gross savings represent 54 percent of the expected savings. The 54 percent realization rate was driven by a combination of lower EFLH and lower efficiencies as confirmed from the telephone and on-site surveys.

1.5 Findings

1.5.1 Program Findings

On-site visits identified a number of oversized systems among the evaluated projects. Oversized systems will produce lower savings per MBH of installed capacity. The PAs should devise some way to limit over sizing of installations. This would produce more savings for program expenditure by increasing the full load hours. This would also save customers money by allowing them to install more appropriately sized units.

Approximately half of the reductions in savings came as a result of reductions in the “confirmed” unit efficiency. Evidence points toward the presence of a dedicated maintenance person and/or maintenance plan having a positive impact on observed efficiency. The PAs should consider evidence of a dedicated maintenance person and/or maintenance plan as a requirement for the incentive.

1.5.2 TRM Findings

There are at least two different ways that the TRM approach to prescribing savings can incorporate the results of this evaluation. Listed in the order of decreasing simplicity:

- Replace the present TRM values with the gross adjusted savings estimate produced for this evaluation.
- Use the TRM framework equation to calculate nameplate savings individually for each unit, and then apply the overall on-site/telephone/ nameplate ratio of 0.54.

The first option, replaces the present TRM savings with the best results from this evaluation. Those results are completely based on the specific population distribution of the units in the analysis population. The second option would take advantage of the nameplate data available from program tracking data going forward to make sure the nameplate savings, which is adjusted, was fully representative of the program population going forward.

The largest boiler size category includes boilers of capacity 1701 MBH up to almost 3400 MBH. Incentive forms list the size category as 1701 – 2000 MBH, but prescriptive incentives for this size category have been paid for boilers exceeding 2,000 MBH. The resulting size range is greater than the capacity range of all the remaining categories. The apparent difference between these two groups in the analysis raises the issue of whether the present large size category should be adjusted. The category could either be split into two size groups or, alternatively, the 2,000 MBH cap be strictly enforced.

1.5.3 Evaluation Findings

Despite the apparent successful gathering of substantial amounts of data through engineer telephone interviews, the telephone step of the chained ratio approach does not appear to have added substantial value to the analysis. The on-site/nameplate ratio (an alternative to the nameplate/telephone/on-site ratio, which was calculated but is not reported here) only differed by two percentage points and had a similar standard error. Future evaluations should consider increasing the number of on-sites and forgoing the telephone interview step. This simplifies the analysis, returning it to the more widely used single ratio approach. If the size of the on-site sample could be increased by using the budget saved from the phone surveys, this should not compromise the quality of the final result.

More rigorous and costly levels of on-site evaluations are possible and might improve the accuracy of the evaluation. At a minimum, this would allow for site metering of flue gas temperature, multiple checks of evidence of condensing, etc. This would increase the cost per site substantially, but also provide more comprehensive data on which to base adjusted gross savings estimates.

2. Introduction

Massachusetts is moving toward a consistent statewide energy efficiency offering. Energy efficiency program administrators (PAs) are working to create consistency in program delivery and savings estimates throughout the state. As part of this transition impact evaluations are being performed on most programs. The evaluations are designed to inform program design and implementation going forward

The PAs offer a wide range of gas measure rebates through “prescriptive” measure installations. Prescriptive measures share enough characteristics that the energy savings, incremental costs and rebates can be deemed or “prescribed” for a particular measure. Results for 2008 – 2009 showed that prescriptive measures receiving rebates for reduction in natural gas consumption accounted for approximately 40% of all Commercial and Industrial natural gas savings in the state. The prescriptive programs exclude measures which require site-specific or custom energy savings calculations, or calculations on a per square or linear foot basis. Those measures fall under the Custom Gas program.

To date, no formal impact evaluation has been completed for prescriptive gas measures due to the relatively small program budgets and lesser emphasis on evaluation by the gas PAs. Savings have been estimated using various methods but no formal evaluations have been done in the state. This evaluation of the prescriptive gas program will provide a foundation on which the PAs can create consistency in program delivery and savings estimates throughout the state.

2.1 Objective of the Study

The overall stated objective of the impact evaluation was to develop gas savings impacts based on measures installed by participants in the Commercial Efficiency Programs. The particular focus of the evaluation was to develop savings estimates for installations going forward.

The original objective of the study was to provide impact estimates for :

- A subset of four heating equipment categories where quantitative evaluation was possible and desirable, and
- Programmable Thermostats.

After discussion with the EEAC and Program Administrators (PAs) a joint decision was made to focus the evaluation on all five size categories of condensing boilers, a heating equipment category that represents about half of all prescriptive gas savings..

3. Data

This evaluation required the compilation of prescriptive gas tracking and billing data from multiple sources. With those data as a starting point, additional data were developed through telephone and on-site surveys as well as billing analysis. This section discusses the source of the data gathered and developed for this evaluation. The tracking data section also provides a high level explanation of the decision to focus on condensing boilers for this phase of the evaluation.

3.1 Prescriptive Gas Tracking Data

3.1.1 Choice of Measure Categories

As a first step in defining the analysis plan for this evaluation, KEMA requested tracking data for all prescriptive program measures from the Massachusetts PAs. Table 3-1, shows an estimate of savings for major measure groups identified in tracking data. The savings estimates are based on deemed savings values calculated based on the TRM. Tracking data were included from mid 2008 through mid 2010.

Table 3-1
Major Measure Groups Tracking Savings and Savings Percentages

Measure Category	TRM Savings		Measure Type	TRM Savings	
	Therms	Percent		Therms	Percent
Boiler	1,284,779	79%	Boiler - Condensing	776,891	48%
			Boiler - Hydronic	282,218	17%
			Boiler - Steam	66,094	4%
			Boiler - Unknown	159,577	10%
Furnace	161,035	9.9%	Furnace - 92	27,852	1.7%
			Furnace - ECM	33,908	2.1%
			Furnace - Unknown	99,275	6.1%
Thermostat	166,089	10.2%	Thermostat	166,089	10.2%
Water Heater	16,552	1.0%	Water Heater	16,552	1.0%
Total	1,628,455	100%	Total	1,628,455	100%

Calculation of a consistent, TRM-based savings estimate required some assumptions. For the heating measures, for example, initially, size sub-categories were only available for the National Grid measures. To establish the TRM-based estimate of savings, the distribution of size categories rebated by National Grid was used to get an overall weighted average therms/measure saved. This average value was then applied to the other utilities for those heating measures. These sizes correspond with state-wide 2010 program categories.

The table shows that boilers, in total, represented almost 80 percent of savings for the major measures in the prescriptive gas programs during this time period. In combination, boilers and furnaces represented 90 percent of savings. The original plan for this evaluation called for the evaluation of 4 heating equipment size categories as well as programmable thermostats. Given the overwhelming amount of savings produced by the heating measures, the PAs, EEAC and KEMA made a joint decision to focus solely on heating measures.

Table 3-2 shows heating measures broken out to size categories. Condensing boiler size sub-categories represent five of the top six categories as a percentage of overall heating measure savings.

Table 3-2
Heating Measure Counts and Savings by Sub-category

Type	Size Category	TRM Savings	Percent savings
Boiler - Condensing	Unknown	27,000	2%
	Capacity < 300	111,004	9%
	300 ≤ Capacity < 500	153,000	13%
	500 ≤ Capacity < 1000	241,313	20%
	1000 ≤ Capacity < 1700	133,650	11%
	1700 ≤ Capacity	110,925	9%
Boiler - Hydronic	Capacity < 300	35,393	3%
	300 ≤ Capacity < 500	13,200	1%
	500 ≤ Capacity < 1000	12,375	1%
	1000 ≤ Capacity < 1700	81,000	7%
	1700 ≤ Capacity	140,250	11%
Furnace - 92		27,852	2%
Furnace - ECM		33,908	3%
Furnace - Unknown		99,275	8%

Given the magnitude and breadth of the savings in the condensing boiler measure, KEMA recommended a unified focus on all five size categories of this key measure. This approach had the advantage of generating consistent savings estimates for the whole range of condensing boiler sizes. The PAs, EEAC and KEMA agreed on this recommendation. The rest of the evaluation focused solely on condensing boilers installed under the prescriptive gas programs.

3.1.2 Identifying the analysis population

After focusing the evaluation on condensing boilers, additional prescriptive boiler data came to light from within the custom gas programs. These were boilers that were initially identified as custom projects within that PA's specific program structure but were installations that would be included within the prescriptive program going forward. These project data were integrated with the condensing boiler data reported in Table 3-1 and Table 3-2.

The overall population of condensing boiler projects was then screened for data issues that would undermine the analysis approach. Essential to this analysis was a complete tracking data record of the two key nameplate components of the savings calculation. KEMA required either capacity and efficiency be present in the tracking data or the presence of a model number with which both values could be looked up.

Table 3-3
Count of Rebates, Boilers and Sites by Utility in the Final Analysis Data

PA	Final Counts		
	Rebates	Boilers	Sites
Baystate	10	16	9
Berkshire	41	51	37
NE Gas	26	44	11
NGrid	279	441	259
NStar	109	155	73
Unitil	5	8	5
Total	470	715	394

3.2 Billing Data

The program administrators provided available billing data for the condensing boiler sites selected for the evaluation. Ultimately, 65 percent of the condensing boiler sites had billing data of sufficient quality to allow a billing data-informed estimate of EFLH. For those sites without billing data, some had insufficient billing data to use for this analysis. In other cases, the billing data was not a consistent record of monthly usage. The analysis structure was developed with the recognition that tractable billing data would not be available for all sites.

3.3 Telephone Survey Sample

The telephone sample design was produced using model-based sampling. This approach optimized the allocation of target completes to minimize the results overall ratio estimate standard errors and thus maximize the precision. Table 3-4 shows the ten strata, their definitions and the targets that were developed.

Engineer telephone interviews were completed in January and early February of 2011. Table 3-4 provides the targets and sample completes for the telephone interviews. KEMA completed telephone interviews from 147 of the targeted 150 sites. Where completes fell short of target, the stratum sites were exhausted. As a result of the shortfall in some of the strata, additional interviews were completed in strata with available sample.

Table 3-4.
Disposition of Telephone Interviews

Stratum	Size	Good Billing Data	Telephone Survey		On-site Survey	
			Target	Completes	Target	Completes
11	Capacity < 300		22	25	5	5
12		Yes	22	37	5	5
21	300 = Capacity 500		21	13	5	5
22		Yes	21	23	5	4
31	500 = Capacity < 1000		14	9	3	4
32		Yes	21	21	5	4
41	1000 = Capacity < 1700		7	4	2	2
42		Yes	9	9	2	3
51	1700< Capacity		6	3	1	2
52		Yes	7	3	2	2
_1	All		70	54	16	18
_2		Yes	80	93	19	18
Total			150	147	35	36

3.4 On-site Survey Sample

The on-site sample was developed from the completed telephone sample. The targets were proportional to the original telephone level targets. KEMA completed on-site interviews from 36. Once again, where completes fell short of target, the stratum sites were exhausted. As a result of the shortfall in some of the strata, additional interviews were completed in strata with available sample. Table 3-4, above, provides the targets and completes for the on-site portion of the fieldwork.

4. Methods

4.1 Technical Resource Manual Savings

The baseline estimate of savings against which realization rates will be calculated are the prescribe savings values from the TRM. Table 4-1 provides the savings values. In a typical evaluation, these would be the tracked, per unit prescriptive savings.

Table 4-1
Condensing Boiler Prescriptive Per Unit Savings by Size Category

TRM Size Category	TRM Savings (Therms)
Capacity ≤ 300	323
300 ≤ Capacity 500	783
500 ≤ Capacity < 1000	1,467
1000 ≤ Capacity < 1700	2,641
1700 ≤ Capacity	3,326

These savings values are calculated with the following equation incorporating assumptions discussed in the TRM.

Where $Savings = \left(\frac{TE_E - TE_B}{TE_E} \right) * Capacity * EFLH$

TE_E	=	.92	Thermal efficiency of the replacement unit
TE_E	=	.80	Assumed baseline thermal efficiency
Capacity	=	Size bin midpoint (165 MBH for smallest, 1,700 for largest, rest midpoint)	Boiler input capacity
EFLH	=	1500 hours	Equivalent Full Load Hours for the replacement unit

4.2 Nameplate Savings

KEMA calculated preliminary nameplate estimates as the first step of the evaluation process. The nameplate estimates employ the same equation as the TRM but replace the assumed efficiency and Capacity with nameplate values. KEMA obtained boiler capacity and efficiency from product documentation and from the tracking data. Boiler capacity was assumed to be maximum input MBH.

Table 4-2 compares the size category capacity assumptions from the TRM with the observed capacities within the TRM size categories at the unit level. In the biggest and smallest categories, where the TRM capacity had to be set at somewhat arbitrary levels, the average observed capacities were bigger than the TRM assumed capacities. For the three central categories, the observed capacities were, on average, lower than the category capacity midpoint used by the TRM.

Table 4-2

Comparison of TRM Boiler Size Assumptions and Observed Sizes at Unit Level

TRM Size Category	Sites	Capacity (MBH)	
		TRM "Midpoint"	Mean Tracked
Capacity ≤ 300	202	165	179
300 < Capacity < 500	105	400	347
500 ≤ Capacity < 1000	51	750	607
1000 ≤ Capacity ≤ 1700	20	1,350	1,112
1700 < Capacity	16	1,700	2,053

Table 4-3 provides the observed TE for boilers in the analysis population by size category. The TRM calculations all assume a TE of 0.92. The nameplate TE levels were higher than the TRM assumption for all size categories.

Table 4-3

Observed Thermal Efficiency by Size Category

TRM Size Category	Sites	Thermal Efficiency	
		TRM Size Category	Mean
Capacity ≤ 300	202	92	94.1
300 < Capacity < 500	105		93.5
500 ≤ Capacity < 1000	51		93.9
1000 ≤ Capacity ≤ 1700	20		94.8
1700 < Capacity	16		93.6
All	394		93.9

Table 4-4 provides the TRM savings and the mean savings for all units in the analysis population. The differences in the savings numbers are driven by the combined effect of the observed nameplate capacities and efficiencies compared to the size and efficiency assumptions adopted in the TRM.

Table 4-4: TRM and Nameplate Savings

TRM Size Category	Mean Savings (Therms)	
	TRM	Nameplate
Capacity ≤ 300	323	410
300 < Capacity < 500	783	787
500 ≤ Capacity < 1000	1,467	1,433
1000 ≤ Capacity ≤ 1700	2,641	2,651
1700 < Capacity	3,326	4,629

4.3 Billing Analysis estimates

KEMA completed site-level billing analysis for all sites with billing data available. The primary results model the post-installation bills only. These results were used to develop a billing analysis-based estimate of EFLH. Separate models were estimated for both pre- and post-installation periods where data were available. Estimates of savings based on pre-post difference were used as a comparison for the TRM structure estimates produced for the report.

The billing regression uses linear regression to model daily average usage as a function of heating degree days. The equation is:

$$E_{im} = \mu_i + \beta_H H_{im}(\tau_H) + \varepsilon_{im}$$

where

E_{im}	=	Therms used per day during month *m* for customer *i*;
$H_{im}(\tau_H)$	=	Average heating degree-days at the heating base temperature τ_H during month m, based on daily average temperatures, for customer i's meter reading period;
μ_i	=	baseload usage estimate for customer i;
β_H	=	Heating coefficient, determined by the regression;
τ_H	=	Heating degree-day base temperature, determined by choice of the optimal regression; and
ε_{im}	=	Regression residual.

In this equation, gas usage is a function of an intercept which represents baseload (μ_i) and average daily HDD, $H_{mi}(\tau_H)$, which correlates with heating usage. Monthly bill readings divided by the number of days in the billing period provide the daily therm usage, represented by E_{im}. Average daily degree days for the billing period are calculated by dividing the sum of daily HDD in the billing period by the number of days in the billing period. Monthly consumption data is defined by bill period, and not all customers are on the same bill cycle. As a result, heating degree-days for a given month vary among customers.

The intercept μ_i can be understood as base load consumption. This variable captures site-specific, non-degree day correlated gas usage that occurs across all time periods. Non-heating gas usage could include water heat, cooking or other process applications.

In order to identify the best fit for the weather adjustment components of the model, we tested the specification above using a range of potential degree day bases. This approach effectively estimates the average outdoor temperature at which the heating system turns on for each included site. We selected the degree day base that yielded the highest R^2 value. If the optimal model included a heating parameter estimate that was not statistically significant, site load is characterized by the average daily load across the available bills.

Using the site-level degree day regression parameters, we developed an estimate of normalized consumption using normalized annual degree days based on the chosen site-specific, optimal degree day base. The results include overall normalized annual consumption (NAC) as well as normalized annual heat (NAH) and baseload which represent a decomposition of the NAC estimate.

$$NAC_i = \mu_i * 365 + \hat{\beta}_H \tilde{H}_i(\tau_H) \qquad \text{Equation 1}$$

where

NAC_i = Normalized annual electric consumption for customer *i*;

$\tilde{H}_i(\tau_H)$ = Normal annual heating degree-days calculated at the heating base temperature τ_H of customer i;

$\hat{\beta}_H$ = Heating parameter estimate from the site level models.

The baseload and normalized heating load (NAH) are simply the two components on the right hand side of the equation above.

The primary purpose of the billing analysis estimates of normalized post-installation consumption are to adjust the EFLH values used in the engineering savings equation. Re-organizing the basic equation that underlies the savings estimates produces an equation that estimates EFLH as a function of efficiency, capacity and the billing-based estimate of usage. The heating-only EFLH would be estimated as

$$EFLH_H = \left(\frac{TE_E}{Capacity} \right) * NAH$$

The full consumption EFLH would use the same equation but would include NAC rather than NAH.

The results of these calculations will be substituted into the savings equation in place of the 1500 hours EFLH from the TRM where the results of the telephone and on-site surveys indicate the that billing analysis will be applicable given nature of the gas load at the site.

4.4 Telephone Survey-Based Savings Methodology

The proposed objective of the phone survey was to improve savings estimates by confirming nameplate data on capacity and efficiency and determining the suitability of a site’s billing analysis-based estimate of EFLH. The nameplate savings estimates relied on partial tracking data, manufacturer data look-ups and standardized usage assumptions rather than taking the actual behavior of the end-user into account. Besides verifying the tracking data, KEMA used the phone surveys to get a clearer picture of the operating conditions of the incentivized boilers. This information was used by KEMA engineers to make documentable adjustments to the listed thermal efficiency, EFLH and capacity.

4.4.1 Key Parameters

4.4.1.1 Thermal Efficiency

Nameplate data reflect boiler operations under optimal conditions. The listed thermal efficiencies will only be applicable at a specific return water temperature, change of water temperature across the boiler, and firing rate as a percentage of total capacity. The boiler must also be in perfect working order and optimally tuned to meet its load. Typical work loads are not constant and the boiler operating efficiency will fluctuate with operating conditions. These considerations make it reasonable to lower the expected thermal efficiency based on a range of data reflecting boiler operations.

Importantly, for this evaluation, thermal efficiency will never be lowered below 88%, the optimal efficiency of a non-condensing boiler. While efficiency reductions below 88% might be realistic, reductions of that magnitude would raise questions about the appropriate efficiency level of the baseline unit. If efficiency is low due to configuration issues, for instance, it is likely that the standard efficiency baseline boiler would also work at a similarly decreased level of efficiency. Given the requirement of remaining within the simple savings framework of the TRM, for which baseline efficiency is assumed to be 80%, KEMA only considered adjustments to boiler efficiency associated with the condensing function of the boiler.

4.4.1.2 Equivalent Full Load Hours (EFLH)

A key objective of the phone survey was to ascertain the suitability of billing analysis-based estimates of EFLH for the site at hand. The questions are designed to determine whether a billing data-based approach is even feasible, and if so, where the EFLH should based on total consumption or heating only.

For sites with lead lag configurations, the effective reduction in capacity could either be captured in the capacity term or in EFLH. In the EFLH equation, EFLH and capacity are balanced. Rather than try to adjust capacity based on configuration, these kinds of situations were captured in the EFLH. If a site is over built with respect to capacity, the EFLH will reflect that by being proportionally lower.

4.4.1.3 Capacity

Changes to nameplate capacity were limited to corrections to tracking data values.

4.4.2 Survey Logic

Every phone survey verified essential tracking data fields in order to be considered ‘complete’. These fields include:

- contact name,
- business contact information,
- number of incentivized boilers,
- boilerplate make and model,
- listed input capacity and
- listed thermal efficiency.

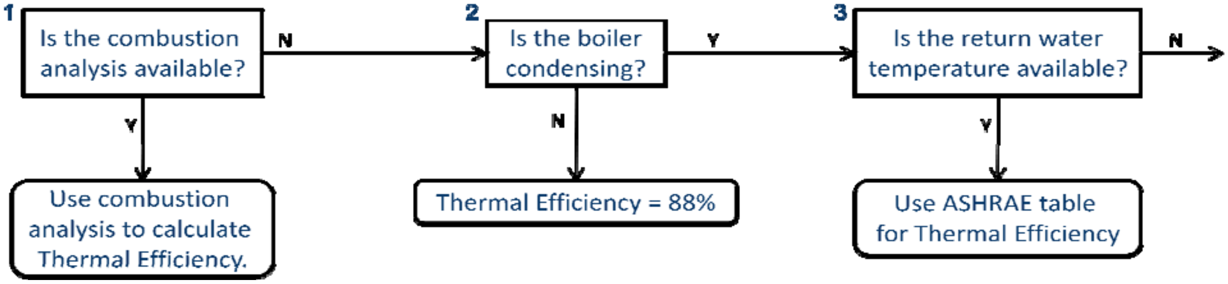
Once the minimum data was collected the engineer used the approved phone survey instrument as a guide to best inform the thermal efficiency and EFLH flow charts.

4.4.2.1 Thermal Efficiency

The thermal efficiency of a boiler is a variable and complicated number to precisely represent in a single annualized value. To determine an annualized thermal efficiency with a high degree of certainty requires a significant duration of logging with expensive equipment and then further site specific modeling. For the scope of this evaluation such measures were not possible. KEMA's method was developed to move the nameplate thermal efficiency to a more reasonable level over a much broader population by employing rational adjustments based on reported conditions from the phone survey.

Figure 4-1, below, shows part A of the logical flow chart used by the engineer survey administrator to determine a revised thermal efficiency for the incentivized boiler. The questions asked in each box represent generalized questions for which multiple more specific survey questions might be asked.

Figure 4-1
Thermal Efficiency logic, Part A



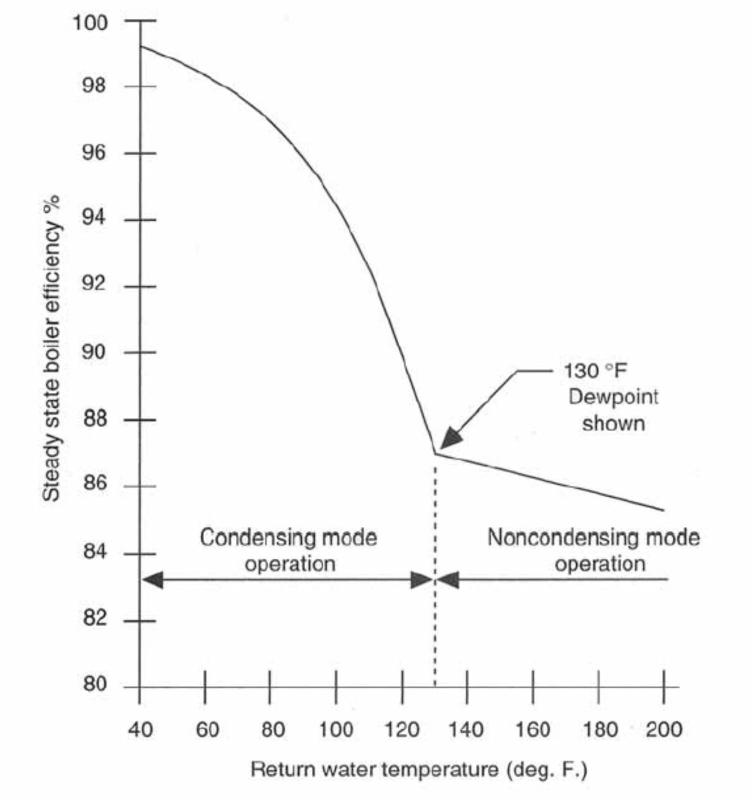
In step one, the question reads "Is the combustion analysis available?" This question assumes that there has been a tune up in the time period since installation. If that the answer is "yes", the engineer would use it to calculate thermal efficiency at the time of testing.

If the answer to question one is "no" then the logic moves to question 2, "Is the boiler condensing?" This is often tricky to answer because many participant contacts will not know one way or another. If the contact is unsure, or the boiler condensate is captured in a way that makes visual inspection impossible, then the engineer would record "don't know" and move on to question three. However, if the participant was sure that condensate never flowed out the drain of the boiler then this would be a clear sign that the boiler never operates in condensing mode. Condensing is required to achieve a thermal efficiency of greater than 88%. Thus, where condensing was known to not be occurring, an efficiency of 88% was recorded.

If question three, “Is the return water temperature available?” Figure 4-2, is answered in the positive, the engineer must determine the design return water temperature. If return water temperature is dependent on a schedule or outdoor temperature then the engineer will find the average, and select the new ‘ideal’ thermal efficiency from, below. This revised efficiency should not be greater than the manufacturer’s nameplate value.

Figure 4-2

Thermal Efficiency by Return Water Temperature[4]



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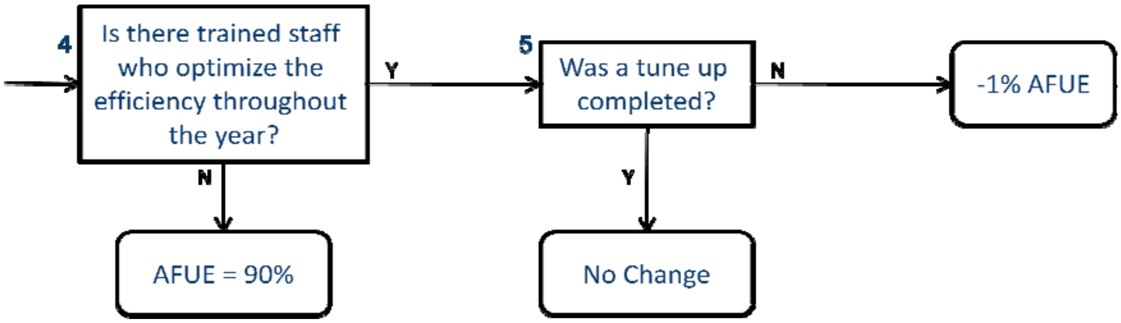
[4] (ASHRAE Handbook - Fundamentals, 2008 p. 31.4)

If the answer to step 3 is “no” then the logic moves to the flow chart in Figure 4-3**Error! Reference source not found.**. Question 4 reads “Is there trained staff who optimize the efficiency throughout the year?”

Figure 4-3
Thermal Efficiency logic, Part B



ERS conducted a study of condensing boilers in 2010 for NYSERDA which found that without a fully trained staff member who could optimize the efficiency of the boiler throughout the year it was unlikely the boiler would achieve efficiencies greater than 89%.[5]

Figure 4-4, below, summarizes the relationship between the measured thermal efficiencies and rated thermal efficiencies completed by ERS in the referenced study. The diagonal line represents a measured efficiency equal to the nameplate efficiency.

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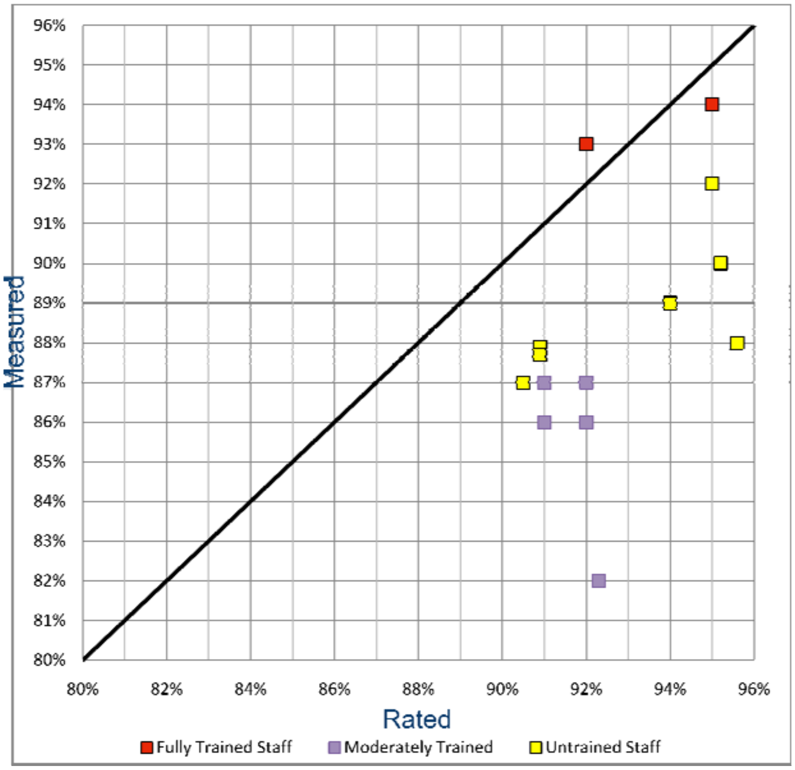
[5] NYSERDA Natural Gas Program Evaluation, Measurement and Verification of Condensing Boilers. ERS. Betsy Ricker and Jonathan B. Maxwell, PE. June 2010

Figure 4-4
Measured vs Rated Thermal Efficiency



KEMA considered the answer to question 4 in Figure 4-4 to be “yes” if the participating company either had a dedicated building technician responsible for the boiler(s) and/or had a service agreement to keep the boilers operating at high performance. If the program participant was unable to answer any questions about tune-up’s, condensation, water temperature, staff or maintenance then a separate efficiency reduction was made based on end-use. In the previously referenced study by ERS, it was observed that on average boilers used only for domestic hot water operate at 3.00% less than rated efficiency, boilers used only for space heat operate at 5.08% less than rated efficiency, and boilers which provide both operate at 4.50% less than rated efficiency. This reduction was recorded only if the participant was unknowledgeable of the boiler and its operations, yet was the most appropriate person to talk to at the participating business. No correction was allowed to lower the efficiency below a minimum of 88%

4.4.2.2 EFLH

A key objective of the phone survey was to determine the suitability of the billing analysis based estimates for EFLH. The billing analysis generated two values for each participant. The first, EFLH_NAC includes all the usage seen at the gas meter and normalizes the weather dependant part for a typical year. Because this value takes into consideration all gas usage it is only applicable when the incentivized boilers are the only gas end-use represented on the meter. The second value generated by the billing analysis, EFLH_NAH, considers only the portion of the gas usage which correlates to weather. This value is applied in situations where the incentivized equipment only supplies space heating and is the only space heat end-use.

Figure 4-5 shows the logic chain followed by the engineer after the survey was administered. In the first question, “Is the billing analysis flawed?” KEMA used data gathered from the phone survey to decide if the billing analysis could be applied. If the billing analysis was not completed due to unavailable data, or because the data was too erratic for acceptable computation then the answer would be ‘Yes’. If the billing analysis was completed but the engineer determined the site configuration was too complicated to apply to the incentivized boilers then the answer would also be ‘Yes’. As an example, one of three boilers in a restaurant was replaced through the program, and provided both space heat and hot water. The restaurant also has gas end-uses in the kitchen for cooking. In this case the billing analysis did not represent only the incentivized boiler. As a result, the billing analysis was considered flawed.

Figure 4-5
EFLH Logic

Step two of the EFLH logic states “Does the boiler have a dedicated meter?” The answer is “yes” if the incentivized boiler is the only gas end-use represented on the meter. In this case, EFLH_NAC is the best value because it includes all gas consumption from the meter in the calculation.

In step three, the engineer answers the question “is the boiler only used for space heat, and the only space heat end-use?” EFLH calculated from NAH refers to the part of the billing data which correlates to heating degree days and was normalized to a Typical Meteorological Year. This value only includes the usage which correlates to temperature. This allows most process heating and domestic hot water end-uses to be ignored. The answer to step three is “yes” only if the incentivized boilers provide all the space heating represented on the meter and do not provide domestic hot water.

Step four describes a recalculation of the billing analysis EFLH based on the judgment of the assigned engineer. EFLH_NAC is calculated as a function of capacity, efficiency, and NAC from billing analysis. For this step KEMA uses the fraction of NAC which was attributable to the incentivized boiler and applied it to the calculated EFLH_NAC. This was completed only when the usage was evenly divided between end-uses. For instance if an incentivized boiler, sized

200 MBH, shared space heat duty with an un-incentivized boiler of the same size, and there were no other gas end-uses, then the billing analysis-generated NAC would be reduced by one half.

In step five KEMA chose “yes” only when there was enough information to estimate building load. This estimate was typically dependant on building construction type and surface area, but could also be informed by usage provided by the participant.

Finally, in all cases where the engineer could not create a simple estimate for building load the average EFLH in the stratum was applied.

4.5 On-site Survey

KEMA completed a sub-sample of 36 on-site visits from the phone survey sample. These sites followed the same protocol as the phone survey but allowed KEMA to gather data more accurately with the advantage of being on site. For all on-sites surveys, the engineer was able to check and clarify all the logic questions from the phone survey with physical evidence as well as verify the tracking data (number of boilers, listed efficiency, and listed capacity). If it was necessary to develop an EFLH estimate the engineer used the advantage of being on-site to make an estimate based on the observed building characteristics.

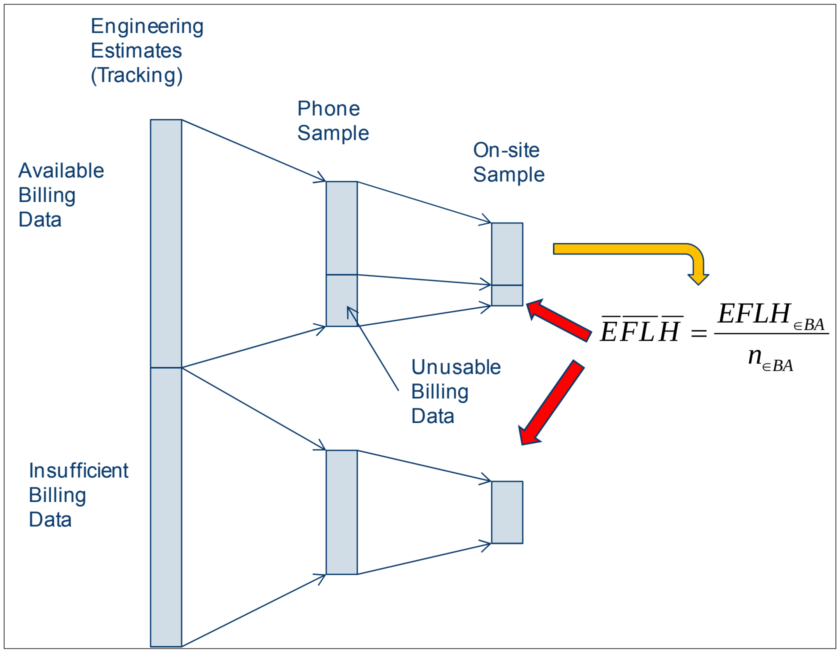
4.6 Calculation of Site level Savings

The results of the phone and on-site surveys provide the basis for a new estimate of savings for the sites included in the phone and on-site samples.

Telephone and on-site sample estimates use billing analysis-based estimates of EFLH where possible. As discussed in the previous section, at each level, the engineer confirmed that the billing analysis-based EFLH was possible to measure (dedicated meter, measurable other load) and the estimate was feasible. If this was the case the EFLH developed from the billing analysis NAC or NAH was used for savings calculations. Where the billing analysis-based estimate was not available, and particularly at the on-site level, estimates of EFLH based on load calculations were performed using building size and other inputs provided by the on-site contact. Where either the billing analysis-based EFLH or load calculation-based EFLH was not possible, EFLH was filled with the mean of EFLH for that size category..

Figure 4-6 provides a diagram of the process by which EFLH is informed by the available billing data. In the figure, the load calculation-based estimates of EFLH are not distinguished from the billing analysis-based estimates of EFLH.

Figure 4-6
Ratio Estimator Diagram, for Each Size Category



$$\overline{EFLH} = \frac{EFLH_{\in BA}}{n_{\in BA}}$$

Within each size category, some subset of site will have unique estimates of either billing analysis-based or load calculation-based EFLH. Those sites with unique EFLH are used to inform the EFLH of the sites in the size category for which the engineers were otherwise unable to produce an improved estimate of site-specific EFLH. The EFLH filling process was independent at the phone and on-site levels.

Table 4-5 summarizes how EFLH was calculated for sites in the phone and on-site samples. The sample design assured that sites requiring filling for EFLH were distributed evenly across the five size categories.

Table 4-5
Summary of EFLH Basis for Phone and On-site Samples

	Counts	
EFLH Estimate Basis	Phone Sample	On-site Sample
NAC-based	55	8
NAH-based	23	2
Load-based Calculations	29	17
Filled	40	9
Total	147	36

For the on-site sample, each site has four independent estimates of saving. Each step is designed to improve the analytical basis for that savings estimate and thus increase the accuracy that estimate. The next step, the combined ratio estimation process, captures the stepped process in a series of ratios that can be used to adjust the initial estimates of savings, the TRM estimates, to the best estimate of adjusted gross annual therm savings.

4.7 Ratio Estimator Impact Estimation

For this analysis, KEMA proposed to use a chained, ratio estimation approach. The approach was designed to combine the large number of relatively inexpensive engineer phone interviews with the smaller number of engineer on-site visits. The phone interviews allowed for wider coverage of the population, while the site visits provided more accurate data than could be gathered on the telephone.

The equation for the ratio estimator produces a realization ratio to be applied to the nameplate savings. The equation for the on-site/telephone/ nameplate ratio is

$$R_E = \frac{\sum_{\in Pk} \frac{n_{Ek}}{n_{Pk}} Y_{Pk}}{\sum_{\in Pk} \frac{n_{Ek}}{n_{Pk}} Y_{Ek}} \times \frac{\sum_{\in Ok} \frac{n_{Pk}}{n_{Ok}} Y_{Ok}}{\sum_{\in Ok} \frac{n_{Pk}}{n_{Ok}} Y_{Pk}}$$

where

R_E = On-site/telephone/ nameplate ratio to adjust nameplate savings for analysis findings regarding savings;
Y_{Ek} = Site-level nameplate therm savings in size category k;
Y_{Pk} = Site-level phone therm savings in size category k;
Y_{Ok} = Site-level on-site therm savings in size category k;
n_{Ek} = Count of sites in the population for size category k;
n_{Pk} = Count of sites in the phone sample for size category k;
n_{Ok} = Count of sites in the onsite sample for size category k;
$\in Pk$ = Summation is over all sites in the phone sample in size category k;
$\in Ok$ = Summation is over all sites in the phone sample in size category k;
n_{Ek}/n_{Pk} = Sample weight for nameplate/phone ratio for size category k.

The equation, as written, produces a single overall ratio with the strata appropriately weighted. If the equation is calculated at the size category level, it produces realization ratios at the size category level. The size category level is a combination of two strata, one with savings based on unique site-level, billing analysis-based EFLH, the other with savings based on the mean EFLH of those sites with billing analysis-based EFLH.

The equation is actually quite simple. The right hand ratio sums on-site and phone estimates of savings, appropriately weighted, over the 35 participant where on-sites were performed. The left hand ratio sums phone and engineering estimates of savings, appropriately weighted, over the 147 participant where telephone interviews were completed. The two ratios are multiplied to produce a single ratio that adjusts the nameplate value with the combined findings of the on-site and telephone surveys.

The nameplate/TRM ratio captures the relationship between nameplate and TRM savings. This calculation is simply a ratio because both nameplate and TRM savings are available at the overall population level.

$$R_{Tk} = \frac{\sum_{\in Ek} Y_{Ek}}{\sum_{\in Ek} Y_{Tk}}$$

where

R_{Tk}	=	nameplate/TRM ratio to transform TRM to nameplate savings for size category k.
Y_{Ek}	=	Site-level nameplate therm savings in size category k;
Y_{Tk}	=	Site-level TRM therm savings in size category k;
T	=	TRM.

The nameplate/TRM equation uses the same structure as the ratio estimator (sum of one over the sum of the other) and is calculated at the size category level. This equation could be calculated at the overall level but that would lose information unnecessarily.

Finally, the two ratios are applied to the size category TRM per unit savings to estimate the adjusted gross annual therms savings for each size category.

$$Y_{Ak} = Y_{Tk} \times R_{Tk} \times R_E$$

where

Y_{Ak}	=	Adjusted gross therm savings for size category k;
Y_{Tk}	=	TRM therm savings for size category k;

4.7.1 Post-Stratification

KEMA made a minor adjustment to the stratification for the final results. The large boiler category had a range of boiler sizes that was greater than the range of the other size categories. In particular, there were two boiler installations with multiple boilers greater than 3,300 in capacity. Almost all of the remaining boilers in the large size category were between 1700 and 2000 MBH. Boilers with nameplate MBH greater than should have, and could have, been assigned a strata of their own at the onset, but the intent at that time was to stay true to the TRM size categories.

Post-stratification, for these two sites is a reasonable and simple option to isolate the effects of these two groups of boilers on each other. The results is a single extra stratum with only two sites in it. Because effectively all of the sites large boiler size categories were contacted for participation in the telephone sample, both site had telephone interviews. One of the two was then selected for the on-site.

The final results are reported at the TRM size category, because those are the relevant categories, at present, for the TRM. The apparent difference between these two groups in the analysis raises the issue of whether the present large size category should be adjusted. The category could either be split into two size groups or, alternatively, a cap could be enforced on the size of a boiler that could be considered a prescriptive.

5. Results

The objective of this evaluation was to develop savings estimates for prescriptive gas condensing boilers. The results of this study would then be used to create realization rates to be applied to program prescribed savings going forward. The analysis, in fact, works in the opposite order. The analysis approach used for this evaluation uses a combined ratio estimator approach that effectively estimates the realization rates directly. To get estimates of savings from the analysis data, these ratios are then applied to the population measures of savings from the tracking data.

Table 5-1 presents the overall gross realization rates and the average per unit gross savings estimates for prescriptive boilers. These results are not, themselves, useful but are informative as a first step in the development of the size category specific realization rates. The overall realization rate is expressed with two different numbers depending on whether the rate is to be applied to the TRM savings or the nameplate savings. At the overall level, however, the gross adjusted impacts are the same. The only difference between the two realization rates is the incorporation of the ratio between TRM and nameplate savings, both of which are available at the population level.

Table 5-1
Overall Adjusted Gross Realization Rates for Prescriptive Condensing Boilers

Applied to	Realization Rate	80/x Precision	Gross Adjusted Savings (Therms)	+/- (Therms)
Nameplate savings	0.54	15%	1,081	160
TRM savings	0.61			

Table 5-2 illustrates the process by which the ratios are generated. Savings are compared between identical samples or populations. On-site savings were compared to phone savings for the sub-sample that received on-sites (orange). Phone survey savings were compared to nameplate savings for the telephone survey sample (blue). Nameplate savings were compared to TRM savings at the population level (green). Each of these comparisons generates a ratio. These ratios were then combined to produce the two overall realization rates presented in Table 5-2.

Table 5-1Table 5-2
Ratio Estimator Heuristic

Estimate Type	Average Savings at Each Level of Analysis			
	Population	Population	Telephone Sample	On-site Sample
TRM Savings (T)	1,768	1,768	1,794	1,648
Nameplate Savings (E)		2,010	2,077	1,997
Telephone Savings (T)			1,136	1,057
On-site Savings (O)				1,038
n=	394	394	147	36
Ratio		Nameplate /TRM	Telephone/ Nameplate	On-site/ Telephone
Ratio		1.14	0.55	0.98
(P/E)*(O/P) Apply to Nameplate			0.54	
(T/E)*(P/E)*(O/P) Apply to TRM		0.61		

The outcome, at the overall level, is an average per unit estimate of adjusted gross savings across all boiler sizes. This is not a particularly useful result given that the PAs need adjusted gross savings at the size category level.

Table 5-3 presents the realization rates to be applied to the TRM prescribed savings levels at the size category level. These realization rates combine two steps:

- A size category specific ratio, based on the full program population, adjusting the TRM prescribed savings to nameplate savings
- An overall savings ratio estimated across all size categories that adjusts nameplate savings based on the sample-based analysis performed for this evaluation

Table 5-3
Condensing Boiler, Unit Level TRM Realization Rates

TRM Size Category	Nameplate/TRM Ratio	Overall On-site/ Telephone/ Nameplate Ratio	TRM Realization Rate
Capacity ≤ 300	1.27	0.54	0.68
300 < Capacity < 500	1.00		0.54
500 ≤ Capacity < 1000	0.98		0.53
1000 ≤ Capacity ≤ 1700	1.00		0.54
1700 < Capacity	1.39		0.75
Overall	1.14		0.61

The nameplate/TRM ratio captures the difference between the prescribed savings levels for condensing boilers in the TRM and the updated nameplate savings based on observed population nameplate efficiency and capacity (but using the same EFLH of 1500). This difference is caused by the TRM assumptions regarding thermal efficiency and capacity. The assumed TRM assumption of .92 for efficiency is low compared to observed nameplate efficiencies at every size category. For capacity, the TRM size category "mid-points" for the smallest and largest size categories are substantially lower than the observed average capacity across the population in those size categories. As a result, the prescribed savings levels for condensing boilers in the TRM are well below the average observed nameplate savings for those categories. This is what drives the relatively high nameplate/TRM ratio for the smallest and largest size categories.

The overall nameplate/TRM ratio is included in addition to the size category level ratios to illustrate the importance of using the size category ratios where possible. While the overall ratio characterizes the population as a whole, it does a poor job of characterizing any of the individual size categories.

The on-site/telephone/ nameplate ratio developed for this evaluation is at the overall level. KEMA calculated size-category-specific ratios but the precisions were not good enough to use for application at that resolution in the final results. As a result, all size categories are adjusted with the same 0.54 ratio.

The 0.54 ratio is driven in equal parts by reduction in effective full load hours (EFLH) and reduction in efficiency. In both cases the reductions conform to expectation. The assumption of 1500 EFLH, which carried over to the nameplate estimate of savings from the TRM, seems unrealistically high and does not appear to be based on Massachusetts-specific, commercial building research. For a point of comparison, the highest EFLH reported in the ASHRAE manual[6], for a typical Boston office building, is 1000 hours. The reduction of average EFLH to approximately 1100 appears to be a reasonable, perhaps even conservative, correction.

Similarly, the nameplate thermal efficient represents optimal boiler performance under ideal conditions. While replacing the TRM assumption of 0.92 with the higher nameplate efficiency was important to make the savings calculation more unit specific, previous research made it clear that a relatively low percentage of condensing boilers operate at optimal efficiency levels.

With the combination of the two ratios, the TRM realization rate is substantially higher for the largest and smallest size categories. It is essential to understand the differences are solely an artifact of the TRM savings calculation method. The higher rates for those two size categories do not indicate that the installations in these size categories necessarily performed better as installed boilers. In fact, the size category, on-site/telephone/ nameplate ratios, which are statistically significant, but not sufficiently precise to use for application at that resolution in the final results, reveal a different story. The ratio for the largest boiler size category single-handedly lowers the overall realization rate. The four smaller size categories are close to or above the overall ratio while the large size category is well below the overall ratio. Two related conclusions should be drawn from this observation: Performance does appear to vary across size categories and true size category realization would better reflect that variation.

Table 5-4 presents the final estimates of savings at the size category level. The table presents:

- TRM savings -- the deemed value that would be applied automatically to a condensing boiler within that size range. This is the “Tracking” estimates for this evaluation.
- Nameplate savings – Savings calculated using nameplate values for capacity and thermal efficiency. This intermediate savings value is a potential alternative to the fully deemed estimate.
- Gross adjusted savings estimates – Average savings based on this analysis.
- The 80 percent confidence intervals for the gross adjusted savings estimates.

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[6] ASHRAE RP-1120, Stephen Carlon, Cdh Energy Corp. December, 2000. pgs 60-64.

Table 5-4
Condensing Boiler, Unit Level Savings Estimates, Therms

TRM Size Category	TRM Savings (Therms)	Nameplate Savings (Therms)	Gross Adjusted Savings (Therms)	+/- (Therms)
Capacity ≤ 300	323	410	221	33
300 < Capacity < 500	783	787	423	63
500 ≤ Capacity < 1000	1,467	1,433	771	114
1000 ≤ Capacity ≤ 1700	2,641	2,651	1,426	211
1700 < Capacity	3,326	4,629	2,490	369

5.1 Size Category Ratios

Though KEMA does not recommend using the size category level realization rates,

Table 5-5 provides them to illustrate what would happen if they were used. The relevant point of comparison is the overall nameplate realization rate of 0.54. The table makes clear that the performance of the largest size category is driving down the realization rates for all of the remain categories. If the size category realization rates were applied, the largest size category savings would be reduced by 15 percent while the others would stay about the same or increase by up to 19 percent.

Table 5-5
Size Category Realization Rates

Applied to	Size Category	Realization Rate	Precision at 80 % Confidence
Engineering savings	Capacity ≤ 300	0.58	18%
	300 < Capacity < 500	0.54	46%
	500 ≤ Capacity < 1000	0.52	20%
	1000 ≤ Capacity ≤ 1700	0.63	24%
	1700 < Capacity	0.50	34%

5.2 Pre-Post Billing Analysis Savings Check

In this analysis, billing analysis is used to improve the estimate of EFLH that is used to estimate savings. To improve the EFLH, only the post-installation billing data is required. This is the only way to integrate information from the billing data into the savings framework established by the TRM and used for this evaluation.

Another way billing analysis can be used in an evaluation framework is measuring the change in usage between the normalized usage from the pre- and post-installation periods. The pre-post difference represents an alternative estimate of savings based solely on the billing data and billing analysis models. Pre-post estimates of savings implicitly assume that the existing unit gas consumption in the pre-installation period represents baseline usage. Because the existing unit baseline should always be the same or lower than a standard installation baseline, the pre-post savings from the billing analysis should always represent an upper bound on the savings at that site.

In the interest of performing this test, KEMA compared site level calculated savings estimates for all phone survey participants (at the phone survey level) the pre-post billing analysis savings where they were available. Table 5-6 presents to results of the comparison. Of the 78 sites with EFLH values based on billing analysis results, 50 sites also had a suitable pre-installation billing analysis model. Of those 50 sites, the pre-post savings was greater than the calculated phone survey savings for 30 sites. For the other 20 sites, the pre-post savings indicated less savings, including 11 sites where no savings were observed at all.

Table 5-6

Pre-Post Billing Analysis Savings Compared to Telephone Savings

Pre-Post Result	Count of Sites
Negative Savings	11
Phone calculated savings greater than Pre-post savings	9
Pre-post savings Greater than phone calculated	30

The presence of 11 sites with no observed savings provides clear evidence that the pre-post billing analysis savings estimate was likely confounded with other consumption dynamics at the site. In fact, it is not all unusual to see this in pre-post savings estimates and that is why estimates of savings generate through this approach are generally limited to large populations. If the pre-post savings estimates were to be believed, the implication would be that, for 40 percent of the sites, the savings calculated at the phone survey level were over-estimates of savings. The remaining 60 percent of sites' saving estimates were consistent with the pre-post estimate of savings as an upper bound on savings, and under that bound could be either greater or less than actual savings.

5.3 Boiler Sizing

KEMA assessed the presence of boiler oversizing among the 36 sites for which on-site visits were completed. The assessment was conducted after the fact using notes from the on-site visits. It is difficult to determine whether or not a boiler system is oversized for a particular building or load during a short on-site visit. Furthermore, an investigation of oversizing was not a goal of the original on-site instrument.

In the interest of providing an indication of the prevalence of oversizing based on consistent evidence across the on-site visits, KEMA focused on self-reported evidence of oversizing in the on-site interviews. During the on-site inspections, there was a common theme among five sites that indicated boiler systems that were oversized for the building. All of the sites had multiple boilers, and on-site contacts volunteered that the system was designed so that all of the boilers would not run simultaneously. The specific reasons for each site vary, and are explained below:

- Two systems ran in tandem. One system would be the condensing boilers which would activate only if the outside temperature was above 32F, and the other non-condensing boilers would activate when outdoor temperatures dropped below 32F, with the condensing system automatically turning off
- Having more boilers allowed the facility to conduct maintenance on a portion of the heating system without having to completely shut down the heating system
- Sharing the load across multiple, smaller, boilers allowed the strain of the heating load to be shared across multiple boilers, theoretically decreasing the wear on the boilers
- A Lead/Lag or Staged control system was in place to ensure that each boiler in the system would never run at full capacity, and would share the heating load appropriately

This information gathered from the site contacts helps explain why some sites had seemingly too much capacity installed at the facility. Because, in all five cases, this information was volunteered, this 14 percent present of likely oversizing should be considered a lower bound on the condition.

Proper sizing is an important consideration in HVAC installations. An oversized unit generally generates similar savings to a proper sized unit at a greater cost to the program. This can depress expected savings for a given size boiler which runs lower hours than a properly sized unit thus lowering the benefit cost ratio. This issue is widely recognized with air conditioners where oversizing is motivated by generous calculation of sufficient cooling capacity. With condensing boilers there is the additional factor that increasing capacity can increase system efficiency. Condensing boiler manufacturers recommend running their boilers at lower loads for highest efficiency. This makes optimal sizing calculations more complicated and could lead to different conclusions regarding optimal system size from the customer and the program perspective.

6. Conclusions

The adjusted gross annual savings estimates presented with this evaluation represent a more accurate picture of expected prescriptive gas condensing boiler savings than the present TRM values. The new annual savings estimates were developed using the same savings framework as the TRM but with updated values for the three key components of the savings equation: capacity, thermal efficiency and equivalent full load hours (EFLH).

The varying realization rates across the size categories are not reflective of varying performance across the size categories with respect to program savings. Those differences are due primarily to the choice of size category capacity "midpoints" chosen for calculating the TRM savings values. This analysis establishes that after putting unit savings on a nameplate basis, programs adjusted gross savings represent 54 percent of the expected savings.

7. Findings

7.1 Program Findings

On-site visits identified a number of overbuilt systems among the evaluated projects. Oversized systems will produce lower savings per MBH of installed capacity. The PAs should devise some way to limit over sizing of installations. This would produce more savings for program expenditure.

Approximately half of the reductions in savings came as a result of reductions in the “confirmed” unit efficiency. Evidence points toward the presence of a dedicated maintenance person and/or maintenance plan having a positive impact on observed efficiency. The PAs should consider evidence of a dedicated maintenance person and/or maintenance plan as a requirement for the incentive.

7.2 TRM Findings

There are at least two different ways that the TRM approach to prescribing savings can incorporate the results of this evaluation. Listed in the order of decreasing simplicity:

- Replace the present TRM values with the gross adjusted savings estimate produced for this evaluation.
- Use the TRM framework equation to calculate nameplate savings individually for each unit, then apply the overall on-site/telephone/ nameplate ratio of 0.54.

The first option, replaces the present TRM savings with the best results from this evaluation. Those results are completely based on the specific population distribution of the units in the analysis population. The second option would take advantage of the nameplate data available from program tracking data going forward to make sure the nameplate savings, which is adjusted, was fully representative of the program population going forward.

The largest boiler size category includes boilers of capacity 1701 MBH up to almost 3400 MBH. Incentive forms list the size category as 1701 – 2000 MBH, but prescriptive incentives for this size category have been paid for boilers exceeding 2,000 MBH. The resulting size range is greater than the capacity range of all the remaining categories. The apparent difference between these two groups in the analysis raises the issue of whether the present large size category should be adjusted. The category could either be split into two size groups or, alternatively, the 2,000 MBH cap should be strictly enforced.

7.3 Evaluation Findings

Despite the apparent successful gathering of substantial amounts of data through engineer telephone interviews, the telephone step of the chained ratio approach does not appear to have added substantial value to the analysis. The on-site/nameplate ratio (an alternative to the nameplate/telephone/on-site ratio that was calculated but is not reported here) only differed by two percentage points and had a similar standard error. Future evaluations should consider increasing the number of on-sites and forgoing the telephone interview step. This simplifies the analysis, returning it to the more widely used single ratio approach. If the size of the on-site sample could be increase using the budget saved from the phone surveys, this should be able to be done without compromising the quality of the final result.

More rigorous and costly levels of on-site evaluations are possible and might improve the accuracy of the evaluation. At a minimum, this would allow for site metering of flue gas, multiple checks of evidence of condensing, etc. This would increase the cost per site substantially, but also provide more comprehensive data on which to base adjusted gross savings estimates.

Appendix A Premise ID Survey

CUSTOMER INFORMATION

Customer Name:
Street Address:
City/State:
Phone Number:
Install Date:
Equipment type:
Quantity:
Manufacturer:
Model Number:

Site Contact:

Look at aerial photos of the site.

Hello,
My name is _______. I am calling from KEMA on behalf of (NStar/Gas Networks). I understand you have received an incentive for the installation of heating equipment through the Condensing Boiler program. I am helping to calculate the savings realized from this program. Do you have a few moments to speak with me?

Are you familiar with the heating equipment installed at this facility?

1) yes
2) no - get information for best contact.

-Confirm information cited above-

What is the primary activity at this location?

Just so I understand your perspective on the boiler installation. What are your job responsibilities at this facility?

Were heating or other operational changes made with the installation of the new boiler? Define if yes. [Including specification changes for new construction].

Space temperatures:
Discharge air temperatures [off heating coils]:
Occupied/unoccupied scheduling:
Ventilation levels:
Other:

Was a combustion efficiency test performed when the installation was completed or during a recent tune up?

Efficiency, if yes:

What prompted the installation of this boiler? Define.

New construction:
Replacement of failed existing equipment:
Replacement of operating unit [early replacement]:

Do you recall what type of boiler was in place before the replacement?

Baseline information

- Previous unit:
  - Quantity:
  - Age:
  - Make:
  - Model:
  - Efficiency:

BOILER CONTROLS AND OPERATION

Does the unit have a dedicated gas meter?

If no, what else uses natural gas from this meter? (Can that load be reasonably estimated and removed from the billing data?)

How is the boiler controlled?

Room thermostats:
Programmable thermostats:
Energy management system:

        Does this have detailed information?
    Other [explain]:

Are there any controls which modulate the return or feed water temperature?

What is the supply hot water temperature? Does it ever change or modulate?

Does the unit have a digital controller of any kind?
    Modulating blower?
    Display/ monitor CO2 or O2:
    Display/monitor stack temperature:

HEATING EQUIPMENT/BOILER DATA

What is the boiler used for?
    Space heating:
        Sq.ft. effected:
        Roof height:
        Overall insulation for the building (poor, fair, good, excellent) (R-values if known)
    Domestic hot water:
        Direct injection or secondary loop?
        Number of (beds, meals, residents.. in use -see DHW table):
    Process:
        Describe:
    Other [explain]:

What is the boiler type?
    Condensing:
        Do you know if the boiler is actively condensing?
    Near-condensing:
    Non-condensing:

Heating fuel?
    Natural Gas
    Propane - confirm you are talking about the correct rebated equipment
    Other: - confirm you are talking about the correct rebated equipment

Total quantity of boilers on premises: (do they serve the same area? - for heat or process)

- If single:
  - Single stage [one fixed out put]:
  - Multistage [multiple staged out put]:
  - About what % of capacity does it normally fire at?
- If multiple:
  - Are they on the same pipes?
  - What are the other unit’s capacities?
    - Are all the boilers on the same gas meter?

When does the system operate?

- All year [12 months operation]:
- Seasonally from ________ to ________:
- Daily from ________to________: (only for single unit single stage)

CLOSING

It is possible that we will need to visit your site to take some measurements. If this is the case we will contact you within the next few weeks. If you have any questions about our study, you can contact Dave Larson of National Grid at 781-907-1595. Thank you for taking the time to speak with me. We appreciate it. Good bye.

Appendix B On-Site Inspection Savings and Adjustments

KEMA completed on-site surveys for 36 condensing boiler program participants. The data gathered during on-site surveys improved the estimates of thermal efficiency, EFLH (equivalent full load hours), installed capacity and annual savings. This section is designed to provide transparency of the savings estimate process at the site level, and show how the savings estimates changed through the TRM savings assumptions, nameplate values, phone surveys and on-site inspection.

Table B-1: **Annualized Therms**

Site ID	# Units	TRM	Nameplate	Phone	Onsite
1	1	323	157	49	74
26	1	323	480	282	318
27	2	646	839	311	407
28	2	646	1,526	1,195	654
19	2	646	1,161	700	536
3	1	323	312	311	311
29	1	323	237	146	126
22	1	323	497	204	206
13	1	323	359	221	189
31	2	646	1,340	825	612
4	3	2,348	2,576	1,899	1,339
32	1	783	663	380	671
34	3	1,888	2,169	1,020	1,186
16	2	1,565	1,706	987	767
10	1	783	663	507	507
2	3	2,348	2,576	816	1,093
14	4	3,130	3,424	1,054	1,878
12	2	1,565	1,706	743	1,120
30	1	783	853	438	365
8	2	2,935	3,574	3,637	3,457
18	3	4,402	3,207	1,480	682
25	2	2,935	3,574	2,452	3,482
33	2	2,935	3,680	1,697	1,357
17	2	2,935	3,185	1,393	1,050
21	4	5,870	4,277	5,066	5,387
24	1	1,467	1,389	687	549
23	1	1,467	1,389	684	547
36	2	5,283	3,913	3,197	1,625
15	2	5,283	5,102	2,007	1,913
5	2	5,283	6,661	4,085	4,362
7	2	5,283	4,148	3,692	3,692
6	2	5,283	6,661	2,292	3,186
11	3	3,649	5,782	3,940	8,671
9	7	10,565	9,383	9,548	13,368
35	2	6,652	7,996	1,836	1,836
20	7	23,283	56,657	5,552	2,833

Table B-1 shows annualized therm savings for each participant in the on-site survey sample. The changes that took place to affect the savings seen above will be shown throughout this appendix. The TRM savings were developed by the Massachusetts Program Administrators to estimate savings for the incentivized condensing boilers. All units were assumed to have a thermal efficiency of 92%, capacity was assigned as a representative value for each of five size strata and the EFLH was set equal to 1500 hours. In the engineering, or nameplate savings, the nameplate thermal efficiency and capacity were used with 1500 hours EFLH to predict savings. For the phone survey KEMA followed a decision making logic described in the body of the report to adjust the engineering savings. The survey both verified the tracking data and gathered information about the operating characteristics of the boilers. The on-site savings were the product of an on-site inspection of the boilers and facilities. This information was used with the same decision making logic as the phone survey to generate adjustments to the savings realized by each boiler.

Thermal Efficiency

Table B-2 includes the estimated thermal efficiency assigned to each on-site survey participant by the TRM, engineering savings, phone survey, and on-site surveys. It also shows the decision chosen by KEMA engineers for both the phone and on-site surveys in the phone and onsite “choice” columns. Finally the table shows comments to further illustrate why the adjustments were made. A choice of “No Adjustment” indicates that the engineer saw sufficient evidence that the boiler was running near design conditions. ”Measured” means that documentation from recent maintenance indicating measured efficiency is available and was recorded. “Not condensing” indicates that the boiler does not run in condensing mode throughout the year and is recorded to have a thermal efficiency of 88%. “Return Temperature” indicates that the operating return water temperature of the boiler was available and used to determine the maximum thermal efficiency using the ASHRAE chart discussed in the body of the report. Sites which are “Not Optimized” do not have a dedicated building technician responsible for the boiler and/or have a service agreement to keep the boilers operating at high performance. Sites which are “Not Optimized” are recorded to have a thermal efficiency of no greater than 90%.“No Tune Up” means that the boiler has not been tuned up since installation and is recorded one percentage point lower than nameplate. Finally, if “No Info” is chosen, a reduction is made based on findings by ERS as detailed in the main report. This choice indicates that there was not enough data available to the engineer to make a thermal efficiency estimate.

Table B-2: Thermal Efficiency

Site ID	Phone Choice	Onsite Choice	TRM	Name-plate	Phone	Onsite	Comments
1	No Info	Measured	92.0	92.0	88.0	87.7	This unit had an efficiency test conducted recently, resulting in the low measured efficiency.
26	No Info	Return Temperature	92.0	94.0	89.5	93.0	Units were found not to be tuned up, and received -1% efficiency.
27	Not Optimized	No Info	92.0	93.0	90.0	88.5	Contact could not provide enough information to estimate efficiency, used ERS method here.
28	No Tune up	No Tune up	92.0	96.4	95.4	95.4	Reduction in thermal efficiency because there have been no tune ups since install.
19	Not Optimized	Return Temperature	92.0	95.0	90.0	88.0	Applied on-site measurements into ASHRAE chart to generate adjusted thermal efficiency.
3	No Adjustment	Return Temperature	92.0	96.0	96.0	96.0	Units running under ideal conditions.
29	Not Optimized	Not Optimized	92.0	94.0	90.0	90.0	There is no annual check or tuning of the incentivized equipment.
22	No Info	Return Temperature	92.0	95.0	89.9	90.0	There is no annual check or tuning of the incentivized equipment.
13	Not Optimized	Not Optimized	92.0	94.0	90.0	90.0	There is no annual check or tuning of the incentivized equipment.
31	Not Optimized	No Info	92.0	94.0	90.0	88.9	Contact could not provide enough information to estimate efficiency, used ERS method here.
4	No Adjustment	Return Temperature	92.0	93.4	93.4	89.0	Applied on-site measurements into ASHRAE chart to generate adjusted thermal efficiency.
32	No Tune up	Not Optimized	92.0	93.3	92.3	89.0	The units have not had a tune up since install and there is no annual check up on the unit.
34	Not Optimized	Not Optimized	92.0	93.6	90.0	90.0	There is no annual check or tuning of the incentivized equipment.
16	No Adjustment	Not Optimized	92.0	93.3	93.3	90.0	Units observe efficiency reduction due to lack of routine maintenance.
10	No Adjustment	No Adjustment	92.0	93.3	93.3	93.3	Units running under ideal conditions.
2	Not Optimized	No Adjustment	92.0	93.4	90.0	93.4	Units running under ideal conditions.
14	No Adjustment	No Adjustment	92.0	93.4	93.4	93.3	Units running under ideal conditions.
12	No Info	Not Optimized	92.0	93.3	89.0	90.0	There is no annual check or tuning of the incentivized equipment.
30	No Tune up	Not Optimized	92.0	93.3	92.3	90.0	There is no annual check or tuning of the incentivized equipment.
8	No Info	Return Temperature	92.0	94.0	90.0	89.0	Applied on-site measurements into ASHRAE chart to generate adjusted thermal efficiency.
18	No Adjustment	Return Temperature	92.0	93.3	93.3	88.0	Applied on-site measurements into ASHRAE chart to generate adjusted thermal efficiency.
25	No Adjustment	Return Temperature	92.0	94.0	94.0	94.0	Units running under ideal conditions.
33	Not Optimized	Return Temperature	92.0	97.0	90.0	88.0	Applied on-site measurements into ASHRAE chart to generate adjusted thermal efficiency.
17	No Adjustment	Return Temperature	92.0	94.3	94.3	88.0	Applied on-site measurements into ASHRAE chart to generate adjusted thermal efficiency.

Site ID	Phone Choice	Onsite Choice	TRM	Name-plate	Phone	Onsite	Comments
21	No Adjustment	Return Temperature	92.0	93.3	93.3	88.8	The participant was unable to provide enough information to generate an efficiency estimate.
24	Not Optimized	Return Temperature	92.0	94.6	90.0	88.0	Applied on-site measurements into ASHRAE chart to generate adjusted thermal efficiency.
23	Not Optimized	Return Temperature	92.0	94.6	90.0	88.0	Applied on-site measurements into ASHRAE chart to generate adjusted thermal efficiency.
36	No Adjustment	Return Temperature	92.0	92.0	92.0	88.0	Applied on-site measurements into ASHRAE chart to generate adjusted thermal efficiency.
15	Not Condensing	Not Condensing	92.0	95.1	88.0	88.0	This participant is not allowed to run in the units in condensing mode due to local restrictions.
5	No Info	No Adjustment	92.0	93.9	90.0	93.9	Units running under ideal conditions.
7	No Adjustment	No Adjustment	92.0	92.0	92.0	92.0	Units running under ideal conditions.
6	No Info	No Adjustment	92.0	93.9	90.0	93.9	Units running under ideal conditions.
11	No Adjustment	Measured	92.0	95.3	95.3	92.0	This unit had combustion efficiency test conducted recently. The test indicated a change from nameplate efficiency.
9	Not Optimized	No Adjustment	92.0	94.0	90.0	94.0	The incentivized equipment was found to be operating under ideal conditions.
35	No Adjustment	No Adjustment	92.0	92.3	92.3	92.3	Units running under ideal conditions.
20	No Adjustment	No Adjustment	92.0	95.3	95.3	95.3	Units running under ideal conditions.

EFLH

Table B-3 shows the changes made to the EFLH estimate through the four savings phases. Both the TRM and engineering nameplate savings used 1500 hours for all sites. KEMA’s phone and on-site estimates were based on an approved decision making logic similar to the thermal efficiency. This decision was based on the information gathered by KEMA’s engineering staff during the phone survey and on-site inspections. This decision is shown in the “choice” columns. A choice of “NAC” indicates that the NAC (normalized annual consumption) value from the billing analysis is the most appropriate given the information available at the time. A choice of “NAH” indicates that the billing analysis value of NAH (normalized annual heating) is most appropriate. For further description of these billing analysis generated values, please reference the main body of the report. A choice of “Calc” shows that the engineer used building data to calculate an estimated building load. This was only completed if the billing analysis was determined to inadequately account for the boiler usage. Finally, if the billing analysis was unavailable or inadequate for a site and the engineer was unable to estimate building load, than the average EFLH within the stratum is applied. This is indicated by a choice of “Average”.

Table B-3: EFLH

Site ID	Phone Choice	Onsite Choice	TRM/ NP	Phone	Onsite	Comments
1	NAC	Average	1,500	677	1,059	The on-site visit revealed that there was a domestic hot water unit on the same meter as the boiler.
26	Average	Average	1,500	1,238	1,059	Unit powers radiant floor, but the building is not yet in use because construction is not yet complete. Applied average EFLH due to lack of information.
27	NAC	Average	1,500	701	1,059	Too many end uses on site. The average EFLH within the stratum was applied.
28	average	Calc	1,500	1,238	678	Used information from on-site visit to generate EFLH estimate.
19	Calc	Calc	1,500	1,285	1,203	Used information from on-site visit to generate EFLH estimate.
3	NAC	NAC	1,500	1,507	1,499	No change, used EFLH NAC.
29	Average	Calc	1,500	1,238	1,072	Used information from on-site visit to calculate EFLH estimate.
22	NAH	NAH	1,500	883	883	No change, used EFLH NAH here.
13	Average	Average	1,500	1,238	1,059	No change, applied the average EFLH in the stratum due to lack of information from contact.
31	Average	Calc	1,500	1,238	1,017	Used information from on-site visit to calculate EFLH estimate.
4	Calc	Calc	1,500	1,106	1,106	on-site visit observed gas stoves in every unit in the building as well as 6 clothes dryers. Adjusted billing analysis EFLH NAC to reflect this.
32	NAH	Average	1,500	921	1,070	The site data indicated that only one boiler was installed here. Site visit observed three of the same units on the same meter, and the site contact stated that they were rebated for only 2 of the 3 units.
34	Average	Average	1,500	921	1,070	Site contact could not provide enough information to generate an accurate estimate of consumption. No billing analysis available
16	Calc	Calc	1,500	868	865	The Onsite visit revealed more specific data for the calculation.
10	NAC	NAC	1,500	1,147	1,147	Unit is the only device on the meter, this was verified during the on-site visit.
2	NAH	NAC	1,500	613	637	On-site visit determined that the boilers are the only devices on the meter. Used EFLH NAC instead of NAH.
14	average	Calc	1,500	921	1,651	Applied information gathered from on-site visit to generate revised estimate.

Site ID	Phone Choice	Onsite Choice	TRM/ NP	Phone	Onsite	Comments
12	Average	Calc	1,500	921	1,263	Used information from on-site visit to calculate EFLH estimate.
30	Calc	Calc	1,500	823	823	Used information from on-site visit to calculate EFLH estimate.
8	NAC	NAC	1,500	2,046	3,108	Capacity of units were incorrect on the application. This was discovered during the onsite inspection. EFLH NAC was used for both Phone and Onsite.
18	Calc	Calc	1,500	692	500	Used on-site information to calculate a more accurate EFLH value.
25	Average	Average	1,500	1,029	1,461	Site contact could not provide enough information to generate an accurate estimate of consumption. No billing analysis available
33	NAH	Calc	1,500	1,091	1,067	2 units were installed, but site visit observed an additional gas heating unit as well as 3 gas DHW tanked systems on the same meter, adjusted billing analysis EFLH to reflect increase in kbtuh capacity
17	Calc	Calc	1,500	656	825	The Onsite visit revealed more specific data for the calculation.
21	Calc	Calc	1,500	1,777	2,718	Applied information gathered from on-site visit to generate revised estimate.
24	NAC	NAC	1,500	1,030	1,007	No change, used EFLH NAC here.
23	NAC	NAC	1,500	1,025	1,003	No change, used EFLH NAC here.
36	Average	Calc	1,500	1,226	894	Used on-site information to calculate a more accurate EFLH value.
15	Calc	NAC	1,500	1,031	982	Billing analysis NAC was applied for the on-site EFLH because it was found that the boilers are the only devices on the meter.
5	Average	NAC	1,500	1,226	982	Units are the only device on the meter, applied EFLH NAC here.
7	NAH	NAC	1,500	1,335	1,335	On-site visit discovered that the boilers are the only devices on the meter, used EFLH NAC instead of NAH here.
6	NAH	NAC	1,500	688	717	On-site visit discovered that the boilers are the only devices on the meter, used EFLH NAC instead of NAH here.
11	average	Calc	1,500	1,020	2,764	Two boilers were incentivized. One large which only runs in the winter, and one small which only runs in the summer.
9	NAH	NAH	1,500	2,046	2,137	The incentivized boilers represent the only space heating on the meter.
35	NAH	NAC	1,500	344	344	On-site visit found that the boiler was the only device on the meter, used EFLH NAC instead of NAH.
20	Calc	Calc	1,500	147	75	This is a large office building with a primary-secondary boiler staging design. the primary and secondary boiler banks never run at the same time. Additionally the 18 story building is currently at 1/4 occupancy.

Capacity

For the TRM, capacity was recorded as a single representative value for each stratum. Engineering nameplate savings show the manufacturers listed capacity multiplied by the number of installed units shown in the tracking database. The phone survey verified the number of units, capacity and make/model for each participant over the phone and the On-site survey visually confirmed the same data. shows all capacity adjustments made to the sites included in the on-site sample. In the cases where there is a discrepancy between the tracking data (engineering capacity) and the phone or on-site recorded capacities there is a comment explaining what caused the discrepancy.

Table B-4: **Capacity**

Site ID	TRM	Namplate	Phone	Onsite	Comments
1	165	80	80	80	
26	165	215	215	215	
27	330	400	400	400	
28	330	598	598	598	
19	330	490	490	490	
3	165	125	124	125	
29	165	106	106	106	
22	165	210	210	210	
13	165	161	161	161	
31	330	600	600	600	
4	1,200	1,197	1,197	1,197	
32	400	310	310	620	Adjusted because the participant stated that 2 of the three identical boilers on site had been incentivized. Not one as was represented in the database.
34	965	997	997	997	
16	800	798	798	798	
10	400	310	310	310	
2	1,200	1,197	1,197	1,197	

Site ID	TRM	Namplate	Phone	Onsite	Comments
14	1,600	1,596	798	798	Half of the incentivized capacity was found to be in use at this site.
12	800	798	798	798	
30	400	399	399	399	
8	1,500	1,600	1,600	1,100	The application was for two boilers size 800 Mbtuh, but the onsite revealed that one boiler was 800 Mbtuh and the other was 300 Mbtuh
18	2,250	1,500	1,500	1,500	
25	1,500	1,600	1,600	1,600	
33	1,500	1,400	1,400	1,400	
17	1,500	1,400	1,400	1,400	
21	3,000	2,000	2,000	2,000	
24	750	600	600	600	
23	750	600	600	600	
36	2,700	2,000	2,000	2,000	
15	2,700	2,142	2,142	2,142	
5	2,700	3,000	3,000	3,000	
7	2,700	2,120	2,120	2,120	
6	2,700	3,000	3,000	3,000	
11	1,865	2,405	2,405	2,405	
9	5,400	4,200	4,200	4,200	
35	3,400	4,000	4,000	4,000	
20	11,900	23,527	23,527	23,527	

Appendix C **Building Load Calculation**

KEMA estimated thermal efficiency, EFLH (equivalent full load hours), and capacity for all sampled sites in both the phone survey and on-site survey samples. EFLH estimation was aided by KEMA's billing analysis which provided Normalized Annual Consumption and Normalized Annual Heating to the engineer when available. If unavailable or if the billing analysis was inappropriate because of site considerations, than KEMA estimated EFLH by taking into consideration the building characteristics to estimate heating load. In the event that too little information was available to estimate load than the average EFLH in the stratum was applied to the site.

Due to the brief nature of both the phone/on-site survey and limited budget it was not possible to construct complex building models to estimate building load for each site. However, when enough data was available a simplistic model was used to estimate EFLH. The engineer's were able to customize and expand on the standard equations at will to suite the individual site needs. Following is the most basic standardized tool used for estimating load.

Space heat

Space Heat is calculated based on the surface area between the conditioned space and the atmosphere, insulating value of the walls and heating degree days.

$$SpaceHeat = HDD * 24 \frac{hours}{day} * AREA * \frac{1}{R}$$

Where,

- $Spaceheat$ is the annual load in units of btu,
- HDD is the total heating degree days during the reported heating season,
- $AREA$ is the total surface area between conditioned and unconditioned space and
- R is the average insulating value of the building

Domestic Hot Water

Domestic hot water is calculated based on a gallon/unit rating provided by Table 7 of the ASHRAE 2007 handbook - HVAC Applications 49.14. This table provides average gallons/unit broken out by type of building.

$$DHW = \frac{gallons}{unit} * units * \Delta T * Cp * \frac{g}{gal} / \frac{joules}{btu}$$

Where,

- *DHW* is the annual load in btu,
- *Gallons/unit* is referenced from the ASHRAE handbook,
- *Units* is entered from the interview,
- ΔT is the difference between feed and supply water temperatures in degrees Kelvin,
- *Cp* is the specific heat of water equal to 4.1813 joules/(gram-kelvin),
- There are 3785.4 grams per gallon and,
- 1055.056 joules/btu

Load to EFLH

The total load is the sum of space heat load and domestic hot water load. Total load divided by full load capacity in units of btu/h is equal to EFLH.

$$EFLH = \frac{SH + DHW}{CAP}$$

Example: Site 19

Site 513311579 is a condominium space of 14,000sqft, 9ft ceilings and approximately R-5 average insulation. Capacity is equal to 490,000btu/h.The space is heated from September through March which correlates to 5197 heating degree days in eastern Massachusetts according to www.degreedays.net.

$$AREA = 18259.6\, sqft = 14{,}000 + \sqrt{14{,}000} * 4 * 9$$

$$SpaceHeat = 455{,}496{,}115\, btu = 5197 * 24 \frac{hours}{day} * AREA * \frac{1}{5}$$

Site 19 also has 14 units which the ASHRAE handbook correlates to 42gal/unit, and water supplied at 125 degrees F.

$$DHW = 367{,}549\ btu$$

$$= 42\frac{gallons}{unit} * 14units * (325k - 283k) * 4.1813\frac{j}{g * K} * 3785.4\frac{g}{gal}/1055.1\frac{joules}{btu}$$

$$EFLH = 1{,}203h = \frac{455{,}496{,}115\ btu + 367{,}549\ btu}{490{,}000btu/h}$$