Impact Evaluation of 2010 and 2011Rhode Island Custom Gas Installations

National Grid

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1. Introduction

This document summarizes the work performed by DNV KEMA and ERS during 2011 and 2012 to quantify the actual energy and demand savings due to the installation of ten Custom Gas measures installed through National Grid's Energy Initiative and Design2000 energy efficiency programs in 2010 and 2011 in Rhode Island (RI). This report also summarizes the sampling and analysis procedures used for developing the population level results.

1.1 Purpose of Study

The objective of this impact evaluation is to provide verification or re-estimation of natural gas savings estimates for a sample of Rhode Island Custom Gas projects through site-specific inspection, monitoring, and analysis, and to develop new realization rates for Custom Gas measures installed in Rhode Island.

This impact study consists of the following four tasks:

1. Develop Sample Design
2. Develop Site Measurement and Evaluation Plans
3. Data Gathering and Site Analysis
4. Report Writing and Follow-up

1.2 Scope

The scope of work of this impact evaluation covered the 2010 and 2011 Custom Gas installations, which include new equipment and/or control systems and strategies. This impact evaluation includes only measures which primarily reduce natural gas consumption.

2. Sampling Strategy

The primary focus of this effort was to examine possible scenarios and recommend sample sizes for the RI Custom Gas impact evaluation. The approach was to support the estimation of realization rates for National Grid's programs in RI. The primary variable of interest for the sample design was annual therms savings. The evaluation sample for this study was designed based on an 80% confidence level.

2.1 Population Analysis

Given the fact that this RI study was designed late in 2011, it was possible to include projects completed to date in 2011 as well as in part of 2010. This provided a larger pool of projects, and ensures that recent practices are reflected. Tracking system data for projects completed during the period July 1, 2010 through October 31, 2011 were included in the initial population for this study. Projects completed in the first half of 2010 were already evaluated as part of a prior study.

In order to be consistent with a concurrent MA impact evaluation, sites with savings less than 1,000 therms per year were eliminated from the population. This was done to make good use of evaluation resources by focusing on sites that are most likely to be custom installations with significant savings amounts. In RI, only 3 of 49 (about 6%) of the sites were dropped. However, they accounted for less than 0.1% of the total therms saved. These percentages are lower than those found in MA. The 2010-2011 population of projects in RI, after dropping the smaller measures, included 46 projects and a total of 1,110,420 annual therms saved.

The Custom Gas measure categories defined for the 2010-2011 impact evaluation cycle are: Hydronic/Steam, Controls, Envelope, Non-Boiler Heating, and Other. Though measure level results were not intended to be produced for this study, these measure groups were defined so that future impact evaluations may consider measure level impacts. As the program evolves, these four main categories are likely to provide the majority of savings, while the "Other" category may include different measure types that may not include enough projects to stand on their own from an evaluation stand point. The evaluation team recommended a site-based sample design where all measures at each site are verified, monitored, analyzed, and reported. Since this evaluation was designed to evaluate entire site savings, rather than individual measures, the final program realization rate will reflect the total system performance and interactivity.

2.2 Sample Design

The parameters considered in the sample design are the number of sample observations planned and the anticipated error ratio of quantity being estimated. The error ratio is a measure of the strength of the relationship between the known characteristic (e.g., tracking system savings) and the quantity being estimated (e.g., evaluated savings). Since the number of sample points required to achieve a desired level of precision depends upon the expected variability of the observed realization rates, KEMA looked at last year's Custom Gas evaluation study to determine a likely error ratio. The 2009-2010 Custom Gas evaluation included 12 RI sites and achieved a good precision level (±13.2%). The resulting error ratio for RI was 0.64. This error ratio was assumed for the 2010-2011 study.

Two potential sample designs were considered in an attempt to achieve the project goals of 80% confidence and ±20% relative precision overall. In the final design, which included 10 sites, the evaluation team expected to achieve this goal. Table 1 shows the stratum cut points and distribution of sample sites in this design.

Table 1: Final Sample Design

Stratum	Maximum Savings	Sites	Total Savings (Annual Therms)	Planned Sample	Inclusion Probabilities
1	14,725	28	185,542	3	0.1071
2	29,271	11	220,495	3	0.2727
3	83,527	6	301,372	3	0.5000
4	403,011	1	403,011	1	1.0000
Total		**46**	**1,110,420**	**10**	

Table 2 lists the calculated precision estimates for this design, following stratification.

Table 2: Estimated Precision for Final Sample Design

Sites	Total Savings (Annual Therms)	Error Ratio	Confidence Level	Planned Sample Size	Anticipated Relative Precision	Error Bound
46	1,110,420	0.64	80%	10	±18.25%	202,654

2.3 Final Sample

Following the final sample design, a set of 10 sample sites were selected. Of the initial 10 sites, one site was dropped due to the customer being unreachable after several attempts by the evaluator. Table 3 summarizes the final sites for which monitoring and verification activities were completed.

Table 3: Final Sample Selection

Application Number	Sample	Stratum	Number of Measures	Primary Measure Category	Tracking Savings (Therms)	Case Weight	Description
558283	Back-up	1	1	Controls	2,260	9.33	EMS Installation
643940	Primary	1	1	Controls	7,435	9.33	Boiler combustion controls
567673	Primary	1	1	Envelope	2,712	9.33	Energy efficient windows
588263	Primary	2	2	Hydronic/Steam	15,563	3.67	High efficiency condensing boilers
588342	Primary	2	1	Envelope	19,806	3.67	Energy efficient windows
632551	Primary	2	1	Controls	17,383	3.67	Installation of combustion controller
639281	Primary	3	1	Controls	40,908	2.00	Boiler combustion controls
705213	Primary	3	1	Controls	83,527	2.00	Expandable combustion controls
621106	Primary	3	4	Hydronic/Steam	43,444	2.00	High efficiency boilers
930837	Primary	4	1	Other	403,011	1.00	Thermal regenerative oxidizer

3. Description of Methodology

This section describes the site methodology generally for both the development of site evaluation plans, the execution of the plans, and the final process for producing program results.

3.1 Measurement and Evaluation Plans

Following the final sample selection of 2010 – 2011 Custom Gas applications and prior to beginning the site visits, the evaluation team developed detailed measurement and evaluation plans for each application. These plans outlined on-site methods, strategies, monitoring equipment placement, calibration, and analysis issues. National Grid provided comments and edits to clarify and improve the plans prior to them being finalized.

Evaluators utilized the savings analysis methodologies from the Technical Assistance (TA) study whenever possible. In some cases, adjustments to savings methodologies were presented and agreed upon in the measurement and evaluation plans.

The site evaluation plan played an important role in establishing approved field methods and ensuring that the ultimate objectives were met.

3.2 On-Site Data Gathering, Analysis, and Reporting

Data collection included physical inspection and inventory, interview with facility personnel, observation of site operating conditions and equipment, and short-term metering. At each site, the evaluator performed a facility walk-through that focused on verifying the post-retrofit or installed conditions of the energy efficiency measure. Some of the facilities utilized EMS controls which were either part of the application itself or controlled equipment that was included in the application. Evaluators viewed EMS screens to verify schedules and operating parameters where applicable. At times, the EMS was utilized to log key parameters, or previously trended data was extracted from the system.

Instrumentation such as current, motor status and temperature loggers were installed to monitor the usage of the installed HVAC equipment and associated affected spaces. At most sites which involved heating equipment, combustion efficiency measurements were taken. Gas bills were acquired from the gas distribution company and from customer records.

Weather sensitive measures were assessed using historical weather data from periods matching the metering period or the gas billing data. Savings estimates were normalized to a typical year using a typical meteorological year (TMY3). Weather stations located closest to each facility were used for all weather-sensitive calculations.

Each site report details the analysis methods used specific to each project including algorithms, assumptions, and calibration methods where applicable. The actual analytical techniques employed depended upon the applicant's methods, the measure, and site conditions. The methods included:

> **Hourly temperature spreadsheet models** Most condensing boiler, boiler, boiler controls, EMS, heat recovery, and water heater savings were estimated using an 8,760 hour model. Historical hourly weather data for a twelve month post installation period forms the basis of the model, permitting an hourly calculation of thermal load and equipment efficiency. The temperature and runtime logged measurements are utilized to identify a relationship between operation and outdoor air temperature. Operating schedules are also incorporated into the model. Boiler efficiency is based on the measured efficiencies extrapolated across the firing range of the boiler. For condensing boilers, the latent efficiency component was typically modeled as a function of the return water temperature. The final model is usually calibrated to actual customer bills.
>
> **Bin temperature spreadsheet models** A bin temperature model is a simplified version of the hourly model. While the thermal load and efficiency calculations are similar, the weather is represented by the number hours of occurrence of an outdoor temperature by temperature bin (usually in five degree increments).The bin model was used in cases where the applicant had also used a bin model and for some of the simpler measures.
>
> **Building simulation models** The envelope measures, which included window and insulation installations, were modeled using a simple eQUEST building simulation model. The building simulation model captures impacts of thermal mass and solar gains, which can be important for envelope measures. The building models incorporated field measurements and observations, such as size, location and number of windows; insulation levels; boiler efficiency and building schedules. Models were calibrated to customer monthly gas bills.

At almost all of the sites, customer billing usage was used to corroborate the savings. Engineers submitted draft site reports to National Grid upon completion of each site evaluation, which after review and comment resulted in the final reports. These are included in Appendix B.

3.3 Aggregate Analysis Procedures

In order to aggregate the individual site results from the Custom Gas sample, DNV KEMA applied the model-assisted stratified ratio estimation methodology.[1 2] The key parameter of interest is the population realization rate, i.e., the ratio of the evaluated savings for all population projects divided by the tracking estimates of savings for all population projects. This rate is estimated for the overall National Grid Custom Gas program in RI. Of course, the population realization rate is unknown, but it can be estimated by evaluating the savings in a sample of projects. The sample realization rate is the ratio between the weighted sum of the evaluated savings for the sample projects divided by the weighted sum of the tracking estimates of savings for the same projects. The total tracking savings in the population is multiplied by the sample realization rate to estimate the total evaluated savings in the population. The statistical precisions and error ratios are calculated for each level of aggregation.

[1] [1] The California Evaluation Framework, prepared for Southern California Edison Company and the California Public Utility Commission, by the TecMarket Works Framework Team, June 2005, Chapters 12-13.

[2] [2] Model Assisted Survey Sampling, C. E. Sarndal, B. Swensson, and J. Wretman, Springer, 1992.

4. Results

This section presents the site and population level results. The site level results include the estimates of savings and a quantitative breakdown of the factors that caused the realization rates to deviate from 100%. The population level analysis includes a presentation of the final case weights and the resulting realization rate.

4.1 Site Level Results

Figure 1 presents a scatter plot of evaluation results for annual therm savings plotted against the tracking savings. The dashed line represents a realization rate of one. The slope of the solid line in this graph is an indication of the overall realization rate and how it relates to a realization rate of 100%. These sample data are stay fairly close to the trend line, which is an indication that the error ratio of this study is lower than that used to design the sample.

Figure 1: Scatter Plot of Evaluation Results for Annual Energy Savings

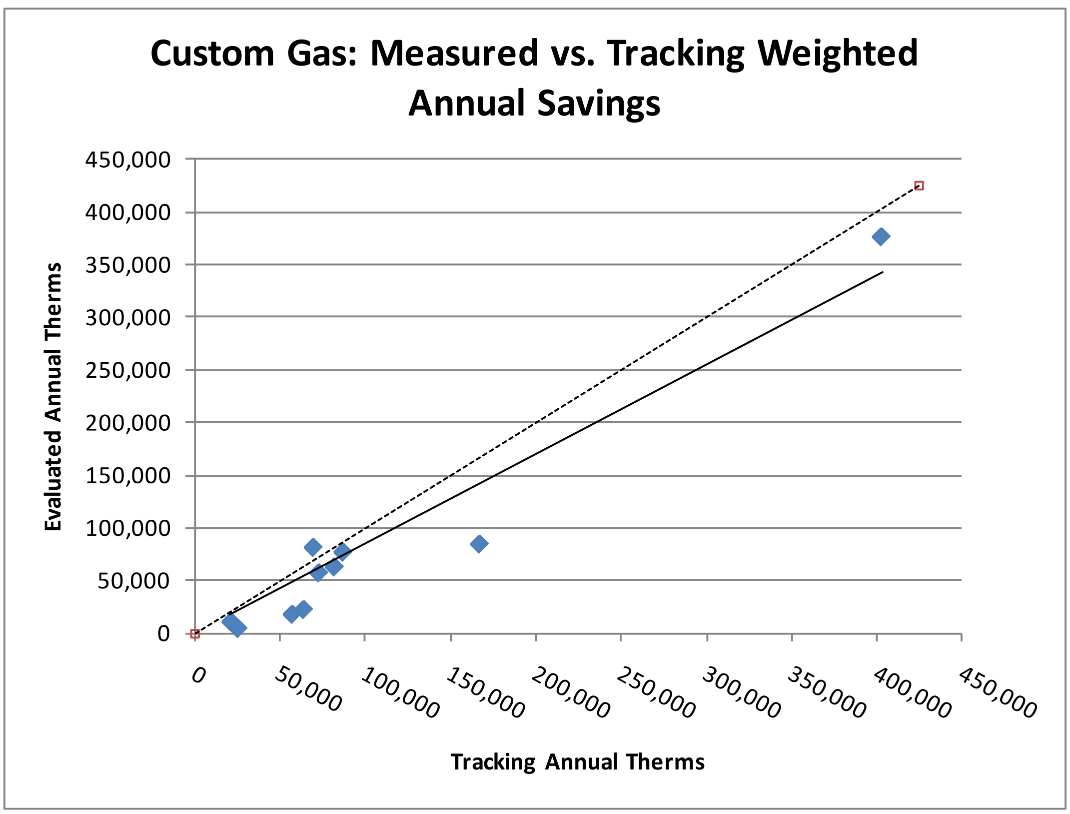


Table 4 presents the tracking and evaluated savings for each of the ten sampled sites, including the site realization rates. A brief description of the primary reasons for discrepancy between the tracking and evaluated savings are also provided for each site.

Table 4: Site Savings and Reasons for Discrepancies

Application Number	Primary Measure Category	Tracking Savings (Therms)	Evaluated Savings (Therms)	Realization Rate	Primary Reason for Discrepancy
558283	Controls	2,260	1,109	49%	The average internal temperature difference between the baseline and installed cases was 1.4°F, lower than the applicant's proposed 3.7°F difference.
643940	Controls	7,435	8,685	117%	The evaluation measured higher installed efficiencies than the applicant predicted which increased savings.
567673	Envelope	2,712	409	15%	Space heating is primarily served by electric heaters. Gas unit heaters provide minimal heat, which reduces the gas savings potential of the measure. Electric heating savings were also calculated as part of the evaluation.
588263	Hydronic/Steam	15,563	4,729	30%	Savings for the three heating hot water boilers calculated prescriptively using a deemed savings for each. This method did not account for site specific information including boiler staging, which resulted in the tracking savings overestimating run time.
588342	Envelope	19,806	15,500	78%	Differences in tracking baseline and proposed and evaluated baseline and installed infiltration rates.
632551	Controls	17,383	5,976	34%	Evaluation estimate of efficiency improvement was approximately 40% less than tracking estimate of efficiency improvement.
639281	Controls	40,908	31,258	76%	Actual operating combustion efficiency of installed system was lower than predicted in the tracking savings.
705213	Controls	83,527	42,124	50%	Evaluation results were less than tracking savings due to a reduction in operating hours.
621106	Hydronic/Steam	43,444	38,267	88%	Boilers fire in the mid to high range, where optimal combustion control savings occur at the lower ranges, which reduces savings.
930837	Other	403,011	376,831	94%	Applicant used 1,400°F RTO chamber temperature, EMS data showed it to be 1,519°F.

4.2 Program Realization Rate

In preparation for analyzing the evaluation results collected for the Custom Gas sample points, the original 2010 – 2011 population stratum boundaries were used to calculate case weights for each sample observation. These weights, as shown in Table 3, reflect the number of projects that each of the sample points represent in the population and allows for the aggregation of results across strata.

The site-level evaluation results were aggregated using stratified ratio estimation. Each site's tracking and measured savings values were multiplied by its case weight to expand its results to the population it represents. Then the weighted tracking and measured savings amounts were summed across sites to estimate total tracking and total measured savings. The program level realization rate is the ratio of the total measured savings to the total tracking savings. Table 5 summarizes the program level results of this analysis. The realization rate for Custom Gas measures was found to be 75.5%. The relative precision for this estimate was found to be ±8.7% at the 80% level of confidence. The error ratio was found to be 0.32, which is lower than the 0.64 used during the sample design.

Table 5: National Grid RI Custom Gas Results

Rhode Island	Annual Therms
Total Tracking Savings	1,110,420
Total Measured Savings	838,588
Realization Rate	**75.5%**
Relative Precision at 80% Confidence	±8.7%
Error Bound at 80% Confidence	73,066
Sample Size	10
Error Ratio	0.32

5. Conclusions and Recommendations

Overall, the Custom Gas program appears to be aggressively pursuing energy efficiency opportunities across a range of customers and measure types. Below are the major findings and recommendations.

5.1 Realization Rates

The impact evaluation of 2010 – 2011 Custom Gas installations in RI produced results that are reliable (±8.7%) at 80% confidence. The realization rate was found to be 75.5%. This is an improvement over the results from the previous impact evaluation of 2009 Custom Gas installations. which produced a National Grid RI realization rate of 43.6% with a relative precision of ±13.2% at 80% confidence.

Based on results of this year's evaluation, it was found that National Grid had made improvements to estimating savings as compared to the previous year's evaluation. In particular:

- Savings estimates were found to be better supported with back-up information, combustion measurements, and other site specific data.

- Four of the ten sites were for installation of combustion controls on boilers. The predicted savings were between 1-4% in gas usage for three of the sites which is within the expected range of savings. One site predicted a 16.7% savings, which is exceptionally high, however the re-evaluated savings rate was found to be 12%. The tracking analysis included pre-installation combustion efficiency across multiple firing ranges. In addition, the combustion controls savings were estimated using an algorithm which accounted for a firing rate profile, measured efficiency, and other site specific information. For one site, 705213, the realization rate was lower than projected because the boiler gas usage was significantly lower than had been used in the savings estimate, although the savings fraction was reasonable.

5.2 Program Improvement Recommendations

The evaluation team reviewed project files, conducted detailed analysis of the information provided in the files, and quantified discrepancies analysis to make the recommendations of this section. The recommendations are in summary:

- Project documentation should include savings estimates in their original form, ie Excel spreadsheets, not .pdf's of the spreadsheets and building simulation input files, not just output reports and support the claimed baseline.

- The baseline for replacement of older HVAC equipment will be building code in the large majority of cases. National Grid needs to document alternate baselines.

- Five vendors in the regenerative thermal oxidizer market were surveyed; the results were used to define a lowest cost, reasonable option baseline for this technology.

- When using billed usage to estimate savings, check whether other gas end-uses may be present that would remain unaffected by the installed measure. At two of the evaluated sites, National Grid had done a good job estimating the combustion controls savings fractions, but had not accounted for other non-boiler end-uses on the meter.

- When other non-gas heating systems are in place in addition to gas heating systems, ensure that predicted gas savings, particularly in building shell measures, reflects this to avoid overestimating gas savings estimates.

5.3 Individual Implementation and Technology Observations

The evaluators observed certain implementation practice and technology trends that are summarized in this section. These observations results in specific recommendations presented in the next section. Each section begins with an illustrative example shown in italics.

5.3.1 Boiler burner replacements and controls

Burner controls were installed at four of the ten sample sites and achieve savings by sensing the oxygen levels in the combustion exhaust and precisely trimming the fuel-air mix to maintain optimum combustion. One of the sites included conversion of oil-fired or dual-fired burners to gas fired burners. The combustion control vendors estimated usage savings which ranged between 2% and 17% while the evaluated reductions were in the 4% to 12% range.

The evaluation baseline for the boiler control measures was one of the following:

- An efficiency vs. firing rate curve derived by the evaluator, ERS, from multiple spot measurements of the boiler prior to installation of the controls. This is the preferred baseline when fuel switching has not occurred.

- An efficiency vs. firing rate curve from one spot measurement of the boiler prior to installation of the controls and an empirically derived curve fitted to that spot measurement;

- A code compliant combustion efficiency, using the empirically derived curve calibrated to the code efficiency. This is the baseline employed when fuel switching has occurred and reflects the fuel-switching policy.

The empirically derived curve was based on combustion measurements at multiple points in the firing range of 19 boilers at 12 different sites that were extracted from the evaluator's portfolio of linkage controlled boilers. The results show almost no variation in efficiency across the firing range.

The evaluator recommends that National Grid require a pre-installation boiler efficiency measurement, since the savings partly depends upon how the pre-existing boiler is controlled. Sites projecting more than a 5% efficiency improvements or greater should be carefully reviewed by the National Grid technical reviewer.

The evaluators observed an improvement in the combustion controls methodology which included pre-combustion measurements and an algorithm for predicting the impact of the improved control.

5.4 Savings Estimation Procedures and Initial Screening

The following recommendations are from the last evaluation, but still apply based on observations from the results of the current evaluation sample described above. This is not surprising, given the measures from the current sampled sites were installed before the findings of the last evaluation were published.

- **Calibrate models to weather-normalized billed usage.** Tracking calculation methodologies ranged from building simulations to single line calculations. Vendor proprietary software was also used for tracking estimates in a number of cases. Bin analyses, single line calculations, and proprietary software should be calibrated to weather-normalized billing usage where feasible. The use of TMY3 weather data as the standard in the calculations provides the most representative weather data for annualizing savings and should be used for all weather-sensitive savings calculations. This might impact the accuracy of the savings calculations by 5-10%.

- **Use current billed usage to "sanity check" savings estimates.** A simple screening to examine the measure savings as a percent of billed usage can help identify incorrect billing usage and applicant analysis that may require further scrutiny. Benchmarks should be assigned each measure type.

- **Include complete billing records in the files.** The project file should include a copy of an actual bill for the site (with the meter number) so that the measure location can be accurately appropriate bill. This is particularly important for multi-family housing complexes with multiple meters. The record should also include a 12-18 month billing history snapshot at the time of the original application and which also includes the time of the incentive payment.

- **Ensure TA studies and supporting calculations are stored for future evaluations.** In general, the evaluation team was provided with the TA savings spreadsheets or building simulations used to estimate the tracking savings for some projects. It is recommended that National Grid continue to obtain, and store the TA studies and savings calculations for future evaluations. When the tracking savings calculations are made available, the evaluation team can more clearly identify the source of the differences in energy savings estimates.

- **Consider commissioning procedures for control measures.** National Grid should consider instituting a Minimum Requirements Document (MRD) procedure that can be used by inspectors to verify that complex control measures, such as an EMS or heat recovery, are properly operating. A closer review of these projects after implementation would result in significant improvements in the overall realization rates for the program.

A. Site Reports

1. Project Summary and Results

The site is an athletic club with indoor tennis courts, weight and exercise rooms, locker rooms, and a lobby/entryway. The measure involved installing an energy management system (EMS) to control operation of the unit space heaters and air handling units (AHUs). Controls include nighttime setbacks based on the day of the week and location within the facility.

The evaluator visited the site, confirmed the system installation and operating parameters, installed loggers, trended additional points via the EMS, and conducted analysis resulting in the evaluated savings. An electric application was filed for this site, so electric savings are not estimated.

1.1 Savings

Measure ID	Measure Name		Gas Savings (Therms/yr)	Electric Savings (kWh/yr)
1		Tracked	2,260	N/A
		Evaluated	1,109	N/A
		RR[1]	49.1%	
[1] Realization rate				

1.2 Explanation of Deviations from Tracking

The main reason the savings were not achieved is that prior to the EMS, the site staff manually set back or turned off heating equipment as part of their regular closing routine. This impacted savings in two ways:

1. The average internal temperature difference between the baseline and installed cases was 1.4°F, lower than the applicant's proposed 3.7°F difference.
2. The baseline assumed no setback. However, the site already utilized manual setbacks reducing the number of potential hours for savings.

2. EVALUATED MEASURE

The measure was an installation of an EMS at an athletic club facility. The facility contains several indoor tennis courts, weight and exercise rooms, locker rooms, and a lobby/ entry area. There are a total of twenty AHUs, split AC units, and unit heaters that serve the various spaces. Although the facility had thermostats with digital displays, they were not programmable. The EMS controls the units to allow for nighttime setbacks based on the space location and day of the week.

2.1 Application Information and Analysis

The sections below detail the information contained in the applicant documents and program administrator files that were provided to the evaluators.

2.1.1 Application Description of Baseline

According to the applicant, there were twenty digital, non-programmable thermostats throughout the facility. There were seven split AC units, five AHUs, and eight unit heaters. The setpoints identified in the project documentation were 71°F for heating and 72°F for cooling. These setpoints were maintained 24/7. The application was identified as a retrofit measure.

2.1.2 Applicant Description of Installed Equipment and Operation

A TCS Basys Ubiquity Server EMS was installed to control the AHUs and unit heaters. During occupied periods, the setpoints were to remain at 71°F for heating and 72°F for cooling. During unoccupied periods, temperatures were to be set back to 60°F for heating and 80°F for cooling. Unoccupied periods as described in the project documentation are outlined in Table 2-1 below. Eighteen of the units were capable of providing heating.

Table 2-1. Applicant Description of Installed Schedules

Unit	Heating Setpoint		Weekly Hours	
	Occupied	Unoccupied	Occupied	Unoccupied
2 TCS stats	71°F	60°F	108	60
4 TCS stats	71°F	60°F	106.25	61.75
4 TCS stats	71°F	60°F	119.75	48.25
8 TCS stats	71°F	60°F	108	60
2 TCS stats	Cooling only.			

2.1.3 Applicant Energy Savings Algorithm

The applicant determined the average baseline and as-built temperature setpoints. For the pre-retrofit condition this temperature was 71°F, the constantly maintained space temperature. For the installed case, the weighted average of the occupied temperature (71°F), and unoccupied temperature (60°F) was calculated to be 67.3°F.

The following formula was used to find the as-built fuel use:

where,

= Estimated proposed gas use (therms)

= Billed baseline gas use (therms)

= Average space temperature setpoint of the proposed system (°F)

= Average space temperature setpoint of the baseline system (°F)

= Monthly average winter temperature

Energy savings is the difference between the baseline and installed fuel uses.

2.1.4 Analysis of Applicant Algorithm

The applicant used a simple method to estimate the savings of the EMS. The ratio of the average space temperature existing and proposed setpoints was multiplied by the existing fuel use to estimate the installed-case fuel use.

Since the average winter temperature is subtracted from the internal temperature, the effect of each degree of savings is magnified. The potential to overestimate savings can be seen by extrapolating setpoint toward the extreme. In the case of a 44.3°F average internal temperature, which is too low for this facility but perhaps reasonable for a garage or storage facility, the proposed fuel use would be 0 therms for heating. However, this would clearly not be the case. Providence, RI, has 3,265 hours below 44°F annually, during many of which heating would be required.

2.2 On-Site Inspection, Metering, and Analysis

This section provides the steps of the evaluation from initial site visit through the final results. Each step is described in detail to offer an in-depth reasoning behind the full process.

2.2.1 Summary of Site Visit Findings

The site was visited by the evaluators on March 14, 2012. Site personnel were interviewed about the system operation and facility schedules. The facility is used consistently throughout the year. Heating setpoints remain constant throughout the heating months. Table 2-2 presents a summary of the spaces and setpoint observed by the evaluators after reviewing the on-site data collection. These values were used in the analysis calculations for the installed system.

The trended setpoints showed that many of the spaces were kept at lower temperatures (both when occupied and unoccupied) than proposed by the applicant. However, discussions with the site contacts revealed that the baseline system was much more rigorously controlled than indicated in the application. During the baseline case, it was the responsibility of certain employees to turn down the thermostats each night when the facility closed. Therefore, a significant amount of the potential savings was already being captured by the system operators.

Table 2-2. Summary of EMS Programmed Setpoints and Occupancy Schedules

Unit	Location	Area Served (sq ft)	H/C	Heating Setpoint		Weekly Hours	
				Occupied	Unoccupied	Occupied	Unoccupied
1	Upstairs lounge	750	H+C	70°F	63.9°F	17.5	150.5
2	Upstairs locker room	750	H+C	60°F	56.1°F	126	42
3-10	Tennis courts	7,500 each	H	51°F	50°F	124.5	43.5
11	Entrance hallway	250	H	63.9°F	60°F	133	35
12	Downstairs locker room, lobby	2,500	H+C	72°F	60°F	128	40
13	Women's locker room	750	H+C	68°F	60°F	128	40
14	Free-weight rm.	1,600	H+C	68°F	60°F	152.5	15.5
15	Fitness center downstairs	3,200	H+C	58°F	55.1°F	102	66
16	Fitness center upstairs	3,200	H+C	58°F	55.1°F	98.5	69.5
17	Group exercise room	4,000	H+C	62°F	60°F	128.5	31.5
	Schedule 2			80°F			8
18	Group exercise room	4,000	H+C	62°F	60°F	125.5	34.5
	Schedule 2			80°F			8

Note: H = heating only, H+C = heating and cooling

2.2.2 Measured and Logged Data

The evaluators used both EMS trending capabilities as well as their own metering equipment to collect on-site data. EMS trended data, summarized in Table 2-3, was obtained from January 1 through January 31, 2012, and March 14 through April 14, 2012. The evaluators installed metering equipment from March 14 to April 13, 2012. Metered points are provided in Table 2-4.

Table 2-3. Summary of EMS Trended Data

Location	Parameters Monitored	Total Points	Time Interval	Duration*
Tennis courts	Unit heaters: heat, setpoint, space temperature	24	5 minutes	8 weeks
Entrance	AHU: heat, fan status, setpoint, space temperature	4	5 minutes	8 weeks
Upstairs locker room	AHU: heat, fan status, setpoint, space temperature	4	5 minutes	8 weeks
Upstairs lounge	AHU: heat, fan status, setpoint, space temperature	4	5 minutes	8 weeks
Women's locker room	AHU: heat, fan status, setpoint, space temperature	4	5 minutes	8 weeks
Downstairs fitness	AHU: heat 1 & 2, fan status, setpoint, space temperature	5	5 minutes	8 weeks
Upstairs fitness	AHU: heat 1 & 2, fan status, setpoint, space temperature	5	5 minutes	8 weeks
Main lobby/ locker room	AHU: heat 1 & 2, fan status, setpoint, space temperature	5	5 minutes	8 weeks
Free-weight room	AHU: heat 1 & 2, fan status, setpoint, space temperature	5	5 minutes	8 weeks
Group exercise room	AHU: heat 1 & 2, fan status 1& 2, setpoint 1 & 2, space temperature 1 & 2	8	5 minutes	8 weeks

Note: * Data was collected for two 4-week periods

Table 2-4. Summary of Evaluator Metered Data

Location	Parameter Monitored	Total Points	Time Interval	Duration
Main lobby/locker room	AHU: fan amperes	1	1 minute	4 weeks
Tennis courts	Unit heaters: fan amperes	3	1 minute	4 weeks
Upstairs fitness	AHU: fan amperes	1	1 minute	4 weeks
Upstairs fitness	Space temperature	1	1 minute	4 weeks
Downstairs fitness	Space temperature	1	1 minute	4 weeks
Men's locker room	Space temperature	1	1 minute	4 weeks
Tennis courts	Space temperature	2	1 minute	4 weeks

2.2.3 Evaluation Description of Baseline

The evaluators interviewed site contacts to determine the baseline temperature setpoints for individual spaces before the EMS was installed. Table 2-5 provides this information. These values were used in the evaluation calculations for the baseline system. The setback temperatures were manually set each day by the site staff. It is believed that compliance was very high.

Table 2-5. Summary of Evaluated Baseline Setpoints

Unit	Location	Area Served (sq ft)	H/C	Heating Setpoint		Weekly Hours	
				Occupied	Unoccupied	Occupied	Unoccupied
1	Upstairs lounge	750	H+C	70°F	55°F	17.5	150.5
2	Upstairs locker room	750	H+C	64°F	55°F	123	45
3-10	Tennis courts	7,500 each	H	55°F	45°F	123	45
11	Entrance hallway	250	H	70°F	55°F	123	45
12	Downstairs locker room, lobby	2,500	H+C	72°F	55°F	123	45
13	Women’s locker rm.	750	H+C	70°F	55°F	123	45
14	Free-weight rm.	1,600	H+C	70°F	55°F	123	45
15	Fitness center downstairs	3,200	H+C	64°F	55°F	123	45
16	Fitness center upstairs	3,200	H+C	64°F	55°F	123	45
17	Group exercise room	4,000	H+C	64°F	55°F	115	45
	Schedule 2			80°F		8	
18	Group exercise room	4,000	H+C	64°F	55°F	115	45
	Schedule 2			80°F		8	

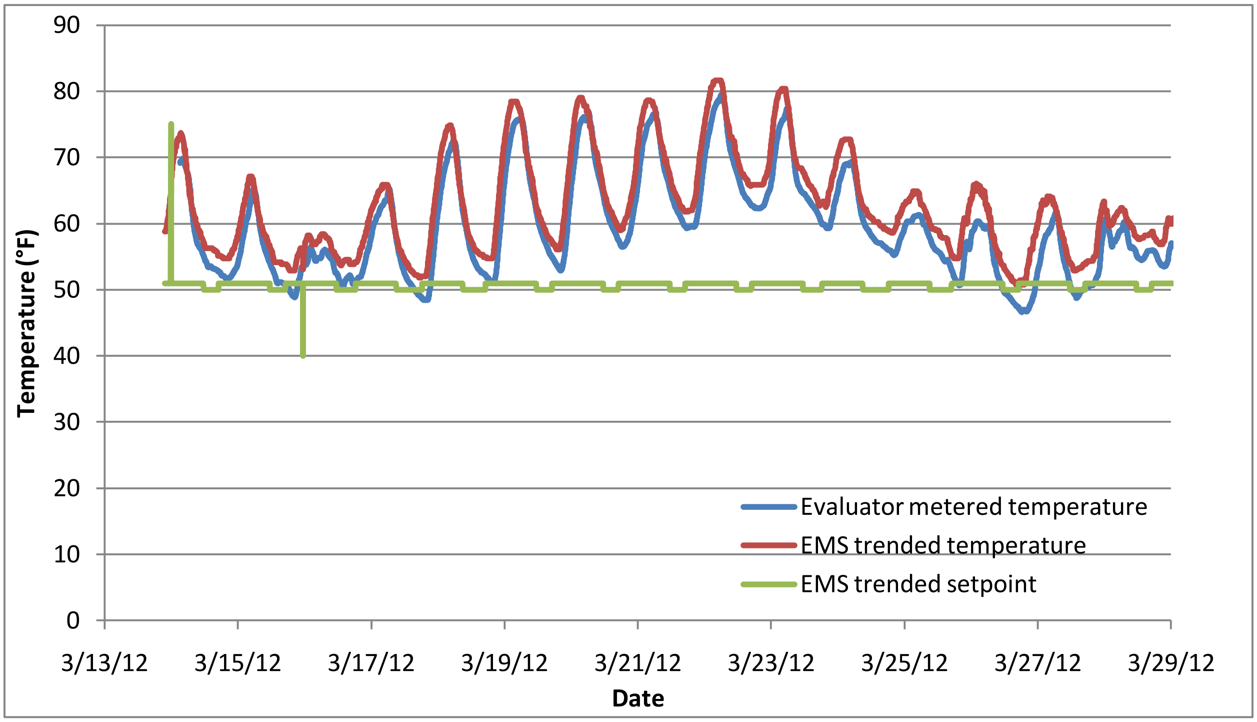
The applicant used a constant setpoint of 71°F for the baseline, since the facility had no programmable thermostats. However, the facility has two main types of space, an athletic club (exercise rooms, locker rooms, lounge, etc.) and indoor tennis courts. While the athletic club areas are typically set between a 65°F–71°F setpoint, the courts were set at only 51°F for the baseline, according to site contacts. Heating the courts to a higher temperature would have been extremely costly. In addition to the lower setpoint of the courts, the facility also had a rigorous system in place to manually turn back the thermostats each night at closing. In some areas, such as the court, heat was shut off completely. This significantly reduced the hours that the EMS could claim for savings. In general, the claimed baseline unoccupied setpoints are higher than the setpoints in the EMS and the unoccupied hours are very similar. The occupied temperatures claimed by the applicant were also generally higher than indicated by the site contact.

2.2.4 Evaluator Calculation Methodology

As part of the inspection and verification process, the evaluators confirmed the controls were operating as programmed in the system and the EMS trended data was accurately measuring field conditions. A summary of the evaluators’ findings was presented in Section 2.2.1.

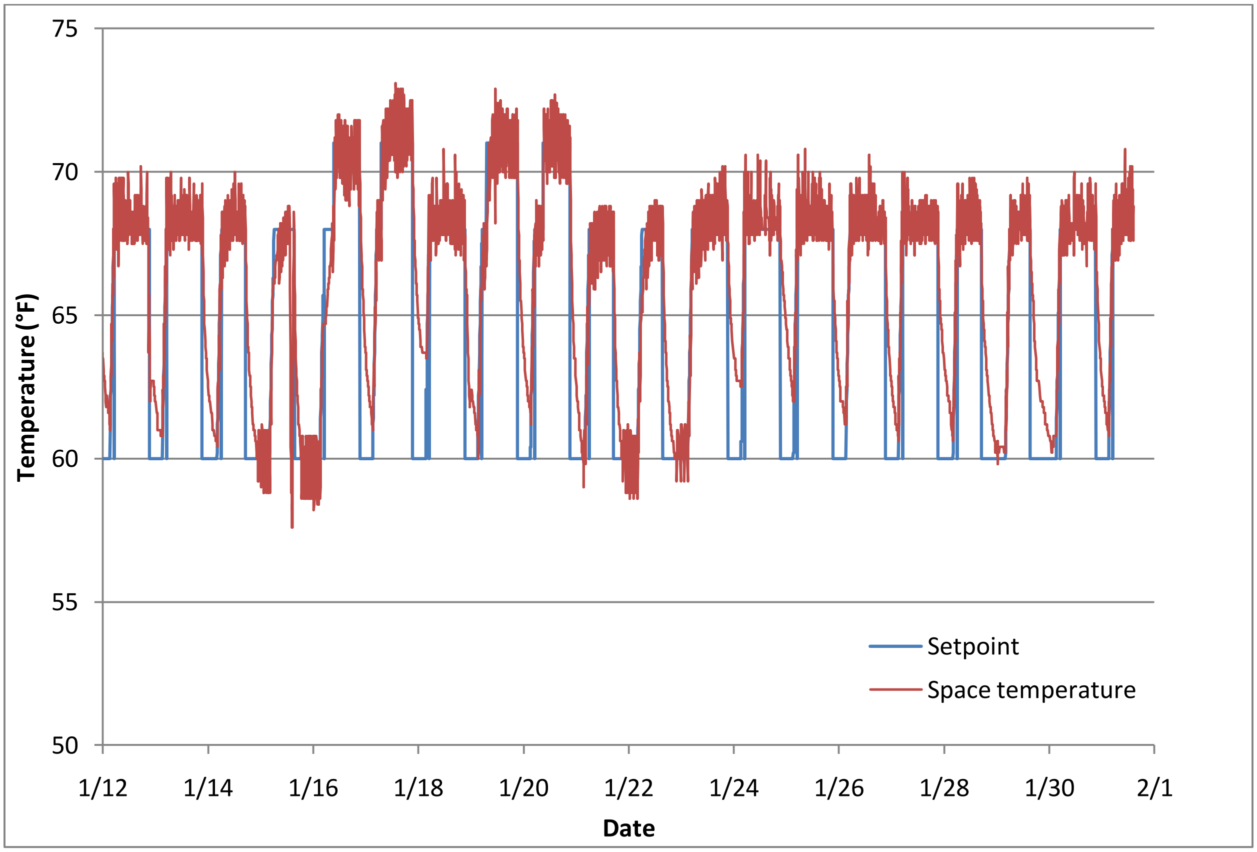
To verify that the EMS was properly controlling the equipment, the evaluators metered and trended several of the same points. Data from both sources was compared to check the accuracy of location labeling and calibration of sensors within the EMS. **Figure** 2-1 shows both the metered and trended data for the unit heater on court four. The temperatures of the logger and thermostat are very close, with the slight difference likely due to the logger being placed above the thermostat. In addition, when the logging equipment measures amperes, the EMS indicated the equipment was running, showing that the EMS is indeed displaying the correct information. Similar results were seen for the other trended and metered points.

Figure 2-1. Court Four Logger and EMS Data Comparison



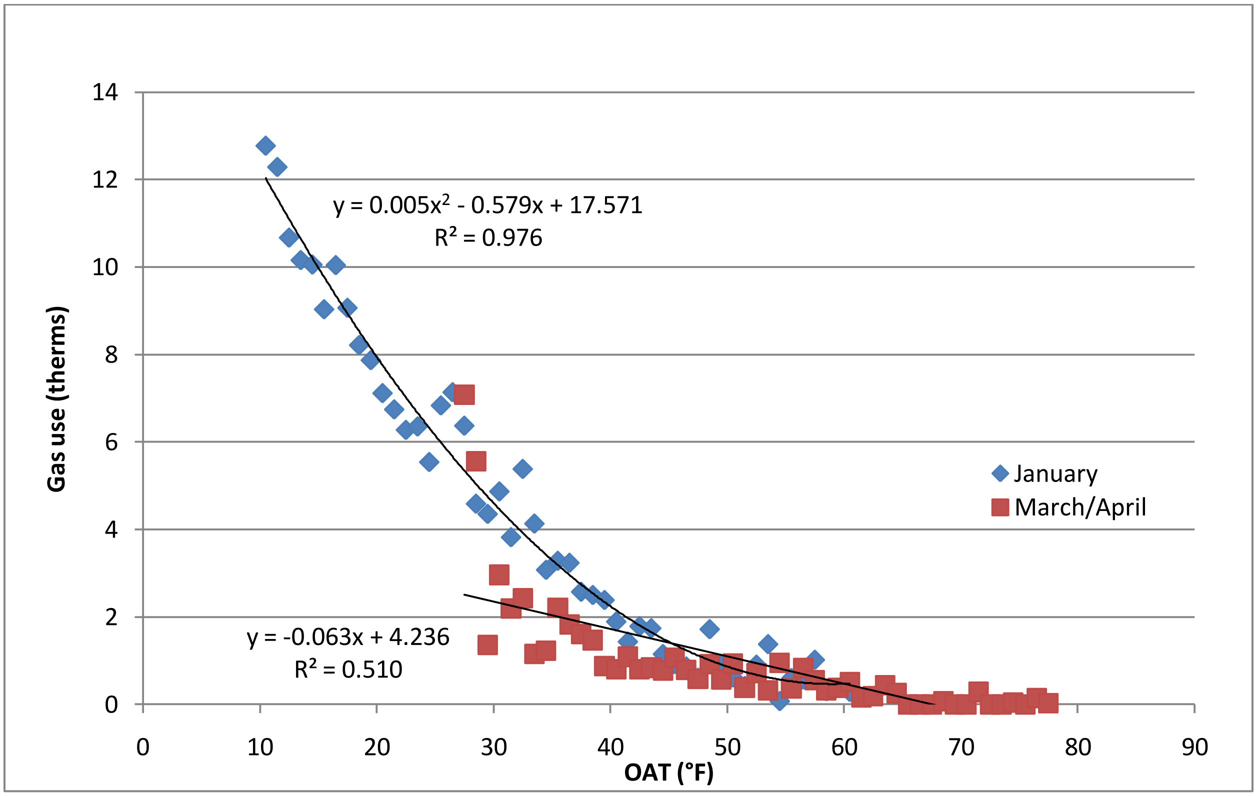
After verification that the EMS data was accurate, the evaluators verified the proposed schedules described in the application. The evaluators checked the trended setpoints, (the green line in **Figure** 2-1) to the applicant's proposed values. Changes were made as needed in the construction of Table 2-2, based on the trended data, which the evaluators used in their model. Figure 2-2 shows the trended space temperature and setpoint from the free-weight room. The space temperature tracks closely to the setpoint.

Figure 2-2. Space Temperature and Setpoint of Free-Weight Room



To determine savings between the baseline and installed cases for a full year, the evaluators created a regression of building gas use to the difference between the outdoor air temperature (OAT) and internal setpoint. This is similar in concept to regressing gas use to OAT provided in Figure 2-3.

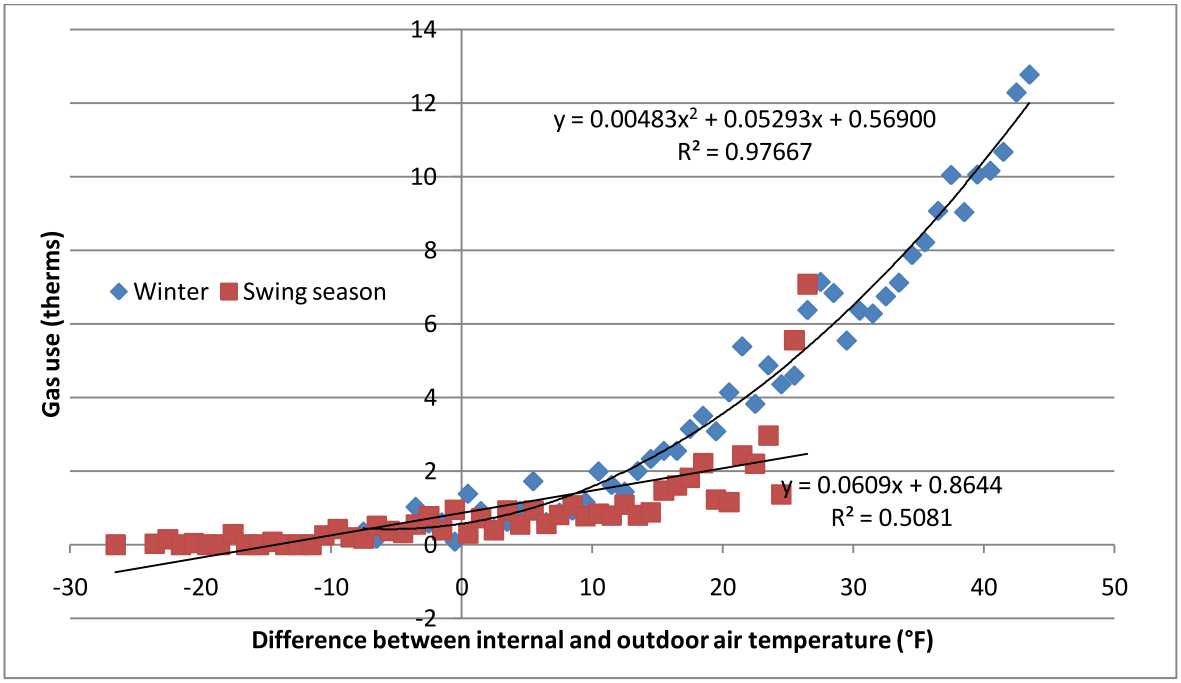
Figure 2-3. Regression of Hourly Building Gas Use to OAT



By regressing to a temperature difference (ΔT) rather than to OAT, the evaluators could modify the model to the baseline situation. The baseline gas use was unknown, and so the evaluators could not regress that to OAT. In addition, the baseline space temperatures were unknown. However, the setpoints were known. Since the setpoints were known for both the baseline and installed cases, the evaluators used the space setpoint rather than the space temperature to reduce error from introducing two temperature measurements. Using a ΔT model, the evaluators were able to run the same model (none of the equipment or system characteristics were changed) with the baseline information. This reduced any error present for algorithms, since the only parameter changed between the two model runs was the internal air temperature, the parameter that is responsible for all of the measure's savings. Building gas use was determined on an hourly timestep. EMS data including the on/off status of the units' burners was trended at 5-minute increments. Firing time was averaged for the hour and multiplied by the maximum hourly input from nameplate data. Gas use was summed for all units to determine the full building gas use.

Building Gas use was regressed against the temperature difference between the evaluator-measured indoor air temperature and OAT. National Oceanic and Atmospheric Administration (NOAA) weather data for Providence, RI, was used for the OAT. The regression is provided in Figure 2-4. As expected, the larger the difference between the outdoor and indoor air temperature (the colder the weather), the larger the building gas use. The resulting equation predicts building heating use as a function of the difference between the outdoor temperature and the indoor temperature, and can therefore be used to estimate the gas use for the outdoor and indoor temperature combinations in the base and installed cases. Two regressions were constructed, one for a cold season (month of January) and one for a swing season (mid-march through mid-April), in case the system behaved differently.

Figure 2-4. Regression of Hourly Building Gas Use to ∆T



The evaluators used an 8,760 analysis to extrapolate savings to the full year. Typical meteorological year (TMY3) weather data at hourly increments was used for Providence, RI. The installed gas use was calculated using the regressed equations, described above, and the hourly difference between the TMY3 OAT and internal setpoint temperature. The annual gas use model results were very close to the installed (billed) gas use (approximately a 4% difference), but were calibrated to the installed billed data by the ratio of the actual gas use to the modeled use. A heating lockout of ∆T of -7.5°F was used for the winter season since logged data showed that the heating system did not have a gas use above this point. A lockout of ∆T of -14.2°F was used to account for the point at which the swing season regression showed zero gas consumption. This prevented negative gas use from being modeled as the outdoor temperature continued to increase.

For baseline use, the difference between the baseline internal temperature and OAT was used with the regression to determine the baseline gas use. The calibration factor found in the installed case was used to calibrate the baseline gas use. Savings are the difference in gas use between the baseline and installed modeled scenarios.

2.2.5 Evaluator Calculation Results

The model resulted in a savings of 1,109 therms, or 7.3% of base use. Baseline space heating gas use was 15,290 therms, while the installed gas use was 14,181 therms.

3. Final Results

The site is an athletic club with indoor tennis courts, weight and exercise rooms, locker rooms, and a lobby/entryway. An EMS was installed to control all AHUs and space heaters throughout the facility. The EMS allowed for each space to have its own weekly schedule rather than rely on manual setbacks of the thermostats each night. The evaluators confirmed that the system was installed, and that temperatures were being set back accordingly.

The site savings were 1,109 therms, or 7.3% of the baseline space heating gas use of 15,290 therms.

Measure impact calculations are shown in Table 3-1.

Table 3-1. Applicant Algorithm Measure Impact Calculations

	Baseline	Installed
Billing		
Actual gas bills (Jan. 2009 – Dec. 2009, Jan. 2011 – Dec. 2011)	22,898	21,669
Heating degree days	5,421	5,227
TMY heating degree days	5,474	
Weather normalized billed usage (therms)	14,627	14,181
Weather-normalized billing difference		445
Tracking/Applicant		
Mean heating season setpoint	71.0°F	67.3°F
Average setpoint temperature reduction	3.7°F	
Gas usage	16,261	14,001
Savings (therms)		2,260
Evaluated		
Mean heating season setpoint	55.1°F	53.7°F
Average setpoint temperature reduction	1.4°F	
Gas usage (controlled equipment) – weather normalized)	15,290	14,181
Savings (therms)		1,109
Realization rate		
Final realization rate		49.1%

3.1 Cross Check with Billing Data

Billing data from the post-installation period was used to calibrate the model. This was to ensure that any error caused by unknown variables or logging equipment was reduced. However, the installed gas use predicted by the model was very close to the actual weather-normalized installed billed data (approximately a 4% difference). The billing analysis showed a savings of 445 therms. The modeled results show about double this savings. However, the billing analysis savings are only 1.9% of billed usage, within the noise of month-to-month billing fluctuations, and well below the 10% threshold usually deemed sufficient to rely on a billing analysis. Therefore, the evaluators preferred the hourly 8,760 building model that was used.

3.2 Recommendations for Program Designers & Implementers

The reduction in savings for this project was largely due to baseline assumptions. The applicant used a constant setpoint of 71°F for the baseline, since the facility had no programmable thermostats. However, the facility has two main types of space, an athletic club (exercise rooms, locker rooms, lounge, etc.) and indoor tennis courts. While the athletic club areas are typically set around the 71°F setpoint, the courts were set at only 51°F for the baseline, according to site contacts. Heating the courts to a higher temperature would have been extremely costly. In addition to the lower setpoint of the courts, the facility also had a rigorous system in place to manually turn back the thermostats each night at closing. In some areas, such as the court, heat was shut off completely. This significantly reduced the hours that the EMS could claim for savings. The evaluator recommends scrutinizing baseline assumptions and interviewing site contacts about how their systems currently run. Some facilities, such as this one, may have rigorous manual setback programs in place, while others may constantly operate their systems at the occupied setpoint.

3.3 Customer Alert

The customer has requested a copy of the final report.

3.4 Explanation of Deviations

Table 3-2 provides a summary of the key deviations between the tracking and evaluated savings.

Table 3-2. Summary of Key Factors and Deviations

Factor	Applicant	Evaluator	Impact of Deviation	Discussion of Deviations
Operational	168 hours	123 hours	-21.6%	Baseline (pre-EMS) hours at occupied setpoint
Operational	3.7°F	1.42°F	-51.4%	Average temperature difference between baseline and installed cases
Non-discernible			18.6%	Due in part to applicant's algorithms

1. PROJECT SUMMARY AND RESULTS

The site launders linen and uniform rentals. The facility operates 12 hours per day, 5 days per week. A 300 hp oil-fired steam boiler had the oil burner and associated hardware replaced with a gas-fired burner. In addition to the new burner, a parallel positioning control system with independent fuel and air actuators and O_2 trim was also installed as well as a variable frequency drive (VFD) on the blower motor. The boiler is used only to provide steam to heat water heat in the cleaning process.

The evaluator visited the site, interviewed site staff, took spot measurements, installed logging equipment, and conducted analysis to determine the evaluated savings.

1.1 Savings

Measure ID	Measure Name		Gas Savings (Therms/yr)	Electric Savings (kWh/yr)
1	Boiler controls	Tracked	7,435	N/A
		Evaluated	8,685	12,826
		RR[1]	116.8%	N/A
[1] Realization rate				

1.2 Explanation of Deviations from Tracking

There are several areas in which the evaluated savings vary from the tracking savings:

- Operational – The applicant applied the efficiency improvement to the site's total gas use. However, industrial gas powered dryers represent approximately 40% of the site's gas use. This decreased savings.
- Seasonal efficiency – The evaluators used a code baseline per National Grid's request and measured higher installed efficiencies while on-site than the applicant predicted. This increased savings

2. Evaluated Measure

The following sections present the evaluation procedure, including the findings from an in-depth study of the supplied application calculations and the evaluation methodology determined to best fit the measure based on the information available.

2.1 Application Information and Analysis

This measure included both fuel switching and boiler controls on an existing boiler serving the process load.

2.1.1 Application Description of Baseline

The applicant used the existing 300 hp oil-fired burner with a turndown ratio of 3 as the baseline. Only one oil-fired spot measurement efficiency was available. This was converted into a natural gas seasonal efficiency. Nameplate efficiency of the oil-fired boiler was 80%. A mean oil efficiency of 83.81% and a seasonal oil efficiency of 78.81% were converted to a 73.79% gas seasonal efficiency used in calculations. The hours of operation for the baseline and post-case scenarios were the same, 3,129 hours. Gas use was estimated at 22,000 therms per month per the applicant's natural gas supplier contract. The project documents identify this project as a retrofit measure.

2.1.2 Applicant Description of Installed Equipment and Operation

An existing 300 hp dual-fired (oil or natural gas) burner was to be replaced with a gas burner. The new burner would have a high-efficiency axial flow design and a fully modulating firing sequence with a turndown ratio of 5. All existing oil hardware components were to be removed and replaced with gas components. Several boiler control features were to be installed. The first was a parallel positioning control system with independent actuators for combustion air and fuel controlled by a PLC-based system. Actuator positioning is based on a preset combustion curve. The second control installed was an O_2 trim system to reduce excess air. Third, a VFD was installed on the burner blower motor. This allows for further trim of O_2. Excess O_2 was designed to be maintainable at 2.5% for high fire and 3.0% for low fire.

2.1.3 Applicant Energy Savings Algorithm

The applicant used a proprietary spreadsheet that calculates savings due to burner replacements, reductions in turndown ratios, sequencing controls, and implementation of parallel position controls with O2 trim. The applicant did not utilize the sequencing controls section of the spreadsheet. The savings identified in the spreadsheet are presented in Table 2-1.

Table 2-1 Summary of Applicant Savings Fractions

Savings mechanism	Combustion Efficiency	Efficiency Change	Seasonal Efficiency	Notes
Baseline	78.79%		73.79%	Based on an adjusted oil-fired combustion test
O2 Trim/PP	79.87%	1.68%	74.87%	O_2 from 4.3 to 2.5%
Replacement of the burner		0.92%		Appears to be deemed
Turn down ratio		0.14%		From 3 to 5
Final Seasonal			75.93%	
Seasonal efficiency change			2.14%	
Gas savings rate			2.82%	Evaluator calculated 2.9%

The 2.82% savings was applied to the contracted gas use of 22,000 therms.

2.1.4 Analysis of Applicant Algorithm

The applicant savings calculation spreadsheet is proprietary, providing summaries of inputs and outputs, but not the mechanics or sources of savings factors, although some can be deduced. Generally, the spreadsheet is a step forward in providing more rigorous and transparent savings estimates compared to the fixed savings fractions frequently typically used for savings estimates.

The combustion efficiency is improved by the new burner itself and the O_2 trim and parallel positioning controls. A 0.92% efficiency improvement is claimed by installation of the new burner itself. This appears to be a deemed value. The estimate of the improved efficiency due to the controls is reasonable, given a change in O_2 from 4.3 to 2.5%.

The applicant claimed the gas burner improved the turndown ratio from 3 to 5. The inverse of the turndown ratio is the lowest firing rate that can be maintained by the boiler. A higher turndown ratio permits a boiler to operate at a lower load without cycling off. Each time the boiler cycles off, the purge cycles forces hot air out of the stack, reducing the efficiency of the boiler. The algorithm appears to take into account a variety of appropriate factors, including operating temperatures, boiler radiant loss estimates, and typical cycling. The approach, as evidenced by the inputs and outputs, appears to be reasonable, although the exact algorithm cannot be discerned.

Both the burner replacement and turndown ratio results are presented as "% Savings", but they appear to be used as % efficiency improvements in the calculations.

The evaluators question the meaning of the baseline efficiency, however, since it is based on one spot-combustion measurement burning oil at an unknown firing rate converted to an 'equivalent' gas efficiency. Thus, the measurement needed to first be converted to an equivalent gas-fired efficiency, and then extrapolated across the firing range.

The applicant applied the savings to the contracted gas use since no baseline gas use was available. However, the site has three 2.8 MMBtu gas-fired dryers, so not all of the contracted gas would be used for the boiler, reducing the potential absolute savings in therms. This reduction in boiler usage was not accounted for.

2.2 On-Site Inspection, Metering, and Analysis

This section provides the steps of the evaluation from initial site visit through the final results. Each step is described in detail to offer an in-depth reasoning behind the full process.

2.2.1 Summary of Site Visit Findings

The site was visited on February 16, 2012, and personnel were interviewed regarding the system operation. The boiler plant consists of two gas-fired boilers. The lead boiler, which underwent the upgrades evaluated in this report, is a 300 hp steam boiler with parallel position controls, O_2 trim, and a VFD controlled blower motor. This boiler has a rated input of 12.5 MMBtu/h. The back-up gas-fired boiler is 250 hp with linkage controls. It generally only operates during startup in the early morning to get the system to temperature and occasionally during peak times when the lead boiler cannot meet the full load. The boilers reverse operation for approximately 3 to 4 days per month to ensure that all systems run properly. This finding was confirmed by logger data.

Both boilers were originally installed with dual fuel burners. About 7 to 8 years ago, the 250 hp burner was converted to natural gas only and became the primary boiler, with the 300 hp oil burner serving for back-up and peak demand times. According to the site contact, with its new upgrades, the 300 hp boiler now serves as the main boiler, with the 250 hp boiler operating occasionally to maintain the systems.

Logged data showed the boiler ran approximately 3-4 times per month. The project documentation assumed the 300 hp boiler meeting the full load.

The contact noted that the other significant end-use at the site was the gas-fired dryers. Three 2.8 MMBtu capacity units run for 9.5 hours per day five days a week, year round. These units pull in the combustion air from outside.

Production at the facility remains fairly consistent throughout the year with a slight uptick in the summer. Although production measurements were unavailable, the evaluators were able to obtain one year's worth of water consumption. Water consumption can be used as a proxy for production, and thus for gas use, but care should be taken since a variety of products, each with different water and heat demands, are laundered at the facility.

Using the customer provided water bills, the evaluators looked at the Btus of gas consumed per gallon of water used at a monthly time step. This value ranged from a low of 900 in May to a high of 1,500 in February, averaging about 1,200. The value during March 2011 was 1,200. Since the logging period represents an average month, the evaluators did not adjust production on a monthly basis.

2.2.2 Measured and Logged Data

The evaluators installed logging equipment on both boilers from February 16 through March 21, 2012. Table 2-2 shows the points that were metered.

Table 2-2. Summary of Metered Data

Boiler	Parameter Measured	Time Interval	Duration
Lead	Blower fan amps	1 minute	4 weeks
Lead	Stack temperature	1 minute	4 weeks
Back-up	Blower fan amps	1 minute	4 weeks
Back-up	Stack temperature	1 minute	4 weeks

The evaluators also took spot-combustion measurements across both boilers' firing ranges. The results for the lead boiler are presented in Table 2-3 and for the back-up boiler in Table 2-4.

Table 2-3. Spot Combustion Measurements (300 hp Boiler)

Percent Firing	Stack Temperature (°F)	Oxygen	Excess Air	Efficiency
25%	355	5.4%	31.0%	84.1%
50%	380	3.2%	16.2%	84.3%
75%	413	3.7%	19.2%	83.5%
100%	430	4.1%	21.4%	83.1%

Table 2-4. Spot Combustion Measurements (250 hp Boiler)

Percent Firing	Stack Temperature (°F)	Oxygen	Excess Air	Efficiency
25%	362	3.2%	15.9%	84.6%
50%	375	3.5%	17.6%	84.1%
75%	382	3.3%	16.4%	84.1%
100%	381	3.4%	17.0%	84.1%

Since the large boiler ran at a higher stack temperature, the efficiency was slightly lower than the smaller boiler. In addition, the back-up boiler was forced to fire from idle conditions and quickly brought through the firing range. Results may not be indicative of the way the boiler operates when loaded.

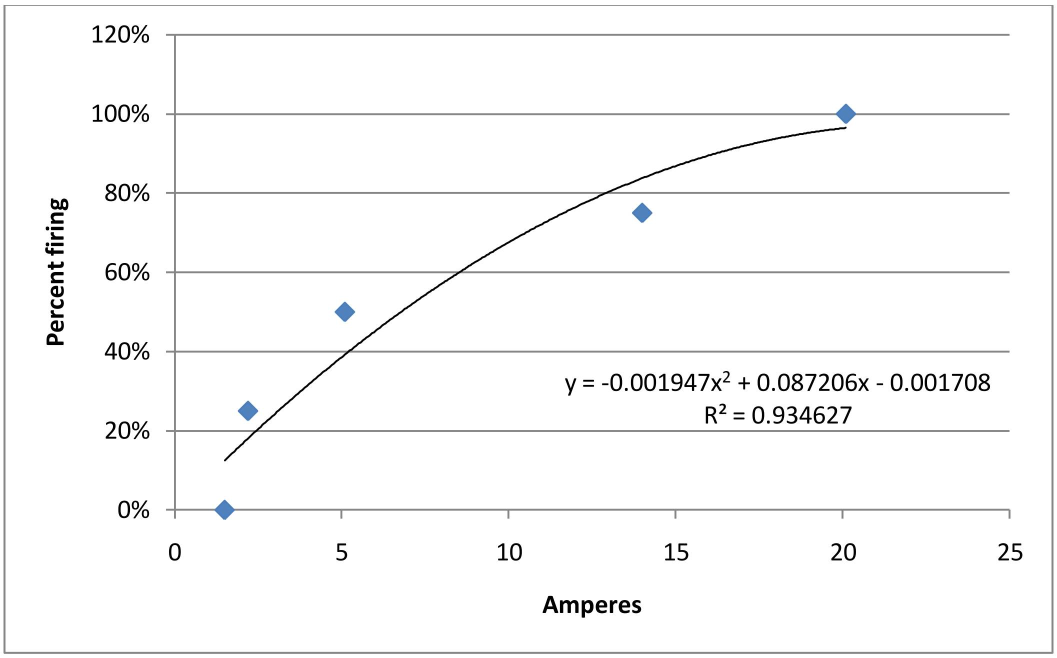
Both boilers operated in a manner consistent with the controls. The smaller boiler with linkage controls operates at an almost constant efficiency across the firing range, while the O_2 trim controlled boiler operates more efficiently as the firing range drops.

The blower motor fan amps were also recorded at each firing rate for the lead boiler, since it had a VFD installed. Therefore, amperage will increase as the firing rate increases. This allowed the evaluators to determine the firing rate each time the amperes were logged during the metering period. The results are presented in Table 2-5. These points were fit to regression so amperage values throughout the firing range could be translated to a firing rate. The regression is presented in Table2-6.

Table 2-5. Ampere Measurements at Sampled Boiler Firing Rates

Percent Firing	Amperes
25%	2.2
50%	5.1
75%	14.0
100%	20.1

Table2-6. Regression of Amps to Firing Rate



2.2.3 Evaluation Description of Baseline

This project involved the conversion of a dual-fired oil and gas burner to strictly gas. The boiler operated primarily on oil prior to the burner change out. National Grid has established a policy stating that the baseline for fuel switching projects is the building code. Since the project has a fuel switching component, the baseline efficiency is set by the Rhode Island building code. The offer letter was dated September, 2010, therefore the Rhode Island 11th edition applies. The Rhode Island state energy code dictates that gas-fired steam boilers must meet an 80% combustion efficiency. This burner replacement would have been expected to meet that requirement.

The applicant also claimed the burner itself improved efficiency about 1% over the old oil efficiency; however, since code is the baseline, this contribution will be captured by the measured combustion efficiency.

The change in combustion efficiency of the linkage controlled boiler across the boiler firing range is based on an empirically derived curve extracted from the evaluator’s portfolio of linkage controlled boilers. The curve is based on combustion measurements at multiple points in the firing range of 19 boilers at 12 different sites. The results show almost no variation in efficiency across the firing range with linkage control.

The applicant claims savings from a change in turndown ratio from 3 to 5, where 3 was the ratio of the existing oil-fired burner. A reasonable turndown ratio for a gas fired burner is in the 5-10 range according to a variety of sources, including DOE. A turndown ratio of 3 is not reasonable for gas-fired burner; therefore the evaluator has used a turndown of 5 for the new burner. Since the evaluator and the installed turndown ratios are both 5, no savings will be attributed to that strategy.

2.2.4 Evaluator Calculation Methodology

The evaluator calculated savings due to the improved combustion efficiency from the parallel position and O2 trim controls.

The evaluator used the metered data to create an 8,760 analysis of hourly boiler loads and efficiencies. First, the installed hourly boiler gas usage was estimated as a function of the observed firing rate and boiler capacity. Next the installed boiler combustion efficiency was calculated for each hour based on measured parameters, such as stack temperature and excess air. Multiplying the combustion efficiency by the estimated gas usage yields the combustion output (amount of available heat generated by the combustion of the fuel). The combustion load includes both the boiler output (useable heat energy sent to the process) and skin losses. The baseline efficiency was calculated for each hour using the code combustion efficiency adjusted for a linkage control profile and other factors. The calculated baseline efficiency was applied to the combustion load to calculate baseline gas usage. The annual savings was the difference between the sum of the hourly installed and baseline gas usage.

Hourly Boiler Gas Usage

The logged data was used to determine an hourly gas usage load profile. Since the load is dominated by the process and not space heating, the evaluators used time rather than outdoor air temperature as the basis for the firing rate load profile.

The evaluators calculated the firing rate for each minute during the logging. The results were binned hourly. This same profile is assumed constant throughout the year. The load profile is presented in Table2-7. The boiler operates at a fairly constant firing rate from 5 a.m. to 4 p.m on weekdays only. Table2-8 presents the hourly stack temperature profile, which is also fairly constant throughout the day.

Table2-7. Hourly Boiler Load Profile

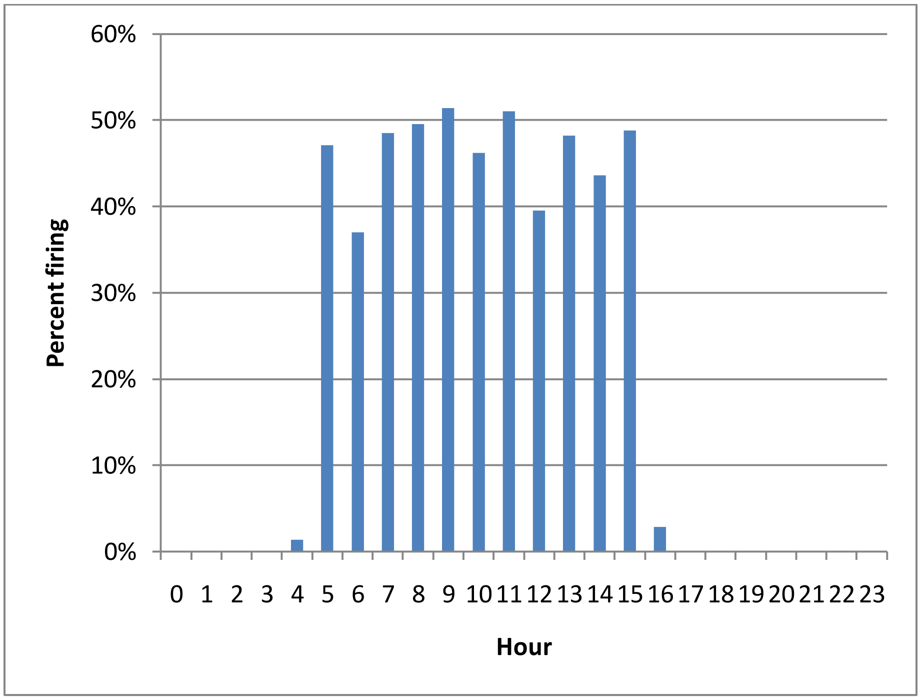
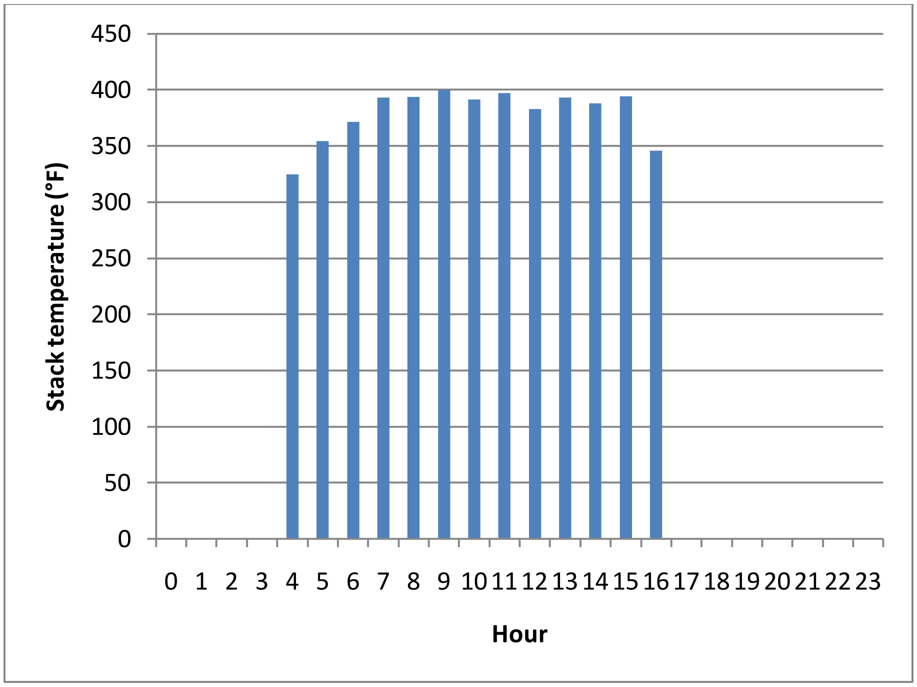


Table2-8. Hourly Stack Temperature Profile



The hourly installed gas usage is equal to the firing rate shown in Figure 2-1 for that hour times the boiler capacity.

Calculation of Installed Efficiency

The installed boiler thermal efficiency is the sum of the combustion minus the standby losses. The combustion efficiency has a sensible and latent component. The sensible efficiency can be calculated using stoichiometric equations with measured excess air, stack temperature, and ambient temperature as the primary inputs. The latent efficiency is a function of the return water temperature and stack temperature. Since the evaluated boiler is non-condensing, only sensible efficiency is of concern.

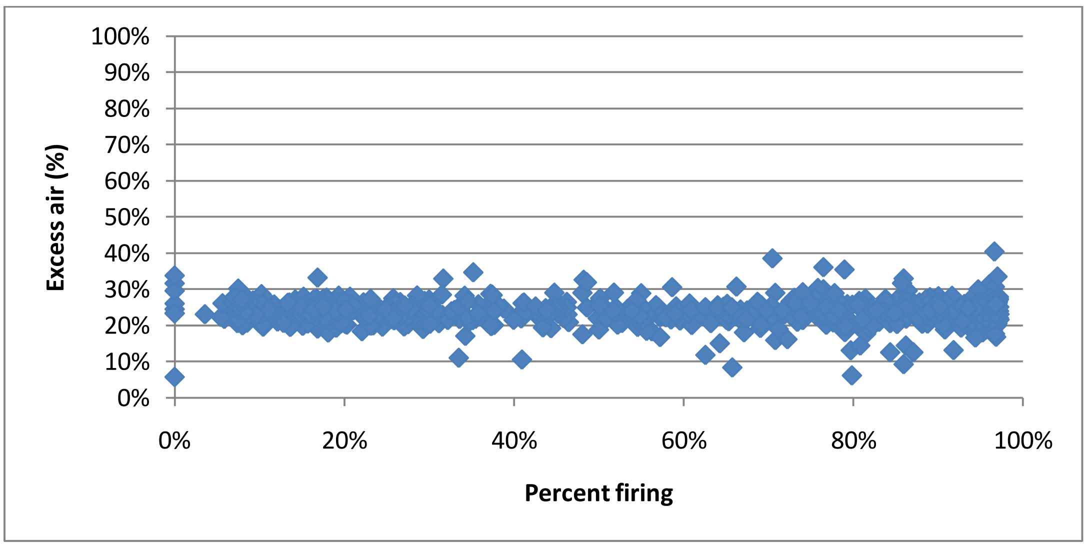
The sensible combustion efficiency and boiler standby losses were calculated on an hourly basis using ambient temperature for combustion air from Typical Meteorological Year (TMY3) data from Providence, RI, to determine the installed thermal efficiency for that hour.

<u>Combustion Efficiency</u>

The stack temperature and firing input were determined for each hour of the year using the hourly firing rate load profile described in the previous section.

For the measurement of excess air, the evaluators installed a logging combustion analyzer on the boiler from March 14–15, 2012. Spot measurements were also taken during the initial site visit. This was used to measure the excess air, which is the percentage of combustion air in excess of what is required stoichiometrically for full combustion. This is an important factor when determining efficiency. Excess air is heated and exhausted, wasting energy and reducing efficiency. Table2-9 shows excess air versus the firing rate. For this boiler, excess air is consistently in the 15%–30% range across all firing rates.

Table2-9. Excess Air vs. Percent Firing



The following equation was applied to calculate the sensible boiler efficiency for each hour, where the measured inputs include the excess air and hourly stack temperature:

where,

= Higher heating value of the fuel, equal to 23,797 Btu/lb for natural gas in this analysis

= The specific heat of the combustion products, estimated to be 0.26 Btu/lb-°F

= The temperature of the exhaust gases in °F

= The stoichiometric air-to-fuel ratio, equal to 17.2 for natural gas

= The excess air, in percentage

= The combustion temperature in °F, calculated according to the following equation:

where,

= The temperature of the combustion air before the burner, taken to be equal to the ambient room temperature (70°F) during the winter and the OAT during the summer

= The heat of reaction, equal to the HHV when the dew point temperature of the exhaust is less than 129°F and the lower heating value (LHV) [1] when the dew point temperature of the exhaust is greater than 129°F

Standby Losses

The standby losses consist of the heat loss through the shell of the boiler (skin losses) and purge losses which occur each time the boiler cycles. This boiler operates continuously once fired up for the week, so purge losses are inconsequential.

The skin losses are estimated based on field-collected data, including surface area from the equipment specifications, unit surface temperature, and boiler size. The absolute Btu valve of the skin loss is constant while the boiler is firing. However its relative percentage of total input changes depending on the firing rate. The skin loss is included as part of the combustion load and does not change between the pre and post-installation cases.

Skin losses are the convective and radiative losses from the boiler's hot surface to the cooler surrounding environment. They are determined by the temperature differential between the boiler skin and surrounding air as well as the boiler's size and shape. Losses are a constant Btu value whenever the boiler is firing. The losses are calculated as follows for each surface and summed:

where,

$=$ Emissivity

$A =$ Surface area, ft^2

$=$ Surface temperature, °F

$=$ Ambient (room) temperature, °F

where,

[1] LHV = 21,441 Btu/lbs for natural gas

= Surface area, ft^2

= Surface temperature, °F

= Ambient (room) temperature, °F

Calculation of Baseline Combustion Efficiency

The baseline combustion efficiency is calculated using the code combustion efficiency adjusted to account for linkage control and operational changes in efficiency. The linkage control factor is a linear function of firing rate and was empirically derived. The operational adjustment accounts for the variation in efficiency observed in the installed efficiency.

The equation is as follows:

where,

= RI code minimum combustion efficiency (80%)

= -0119* firing rate + 1.0099; empirically derived function of linkage control efficiency vs. firing rate.

= efficiency/maximum annual installed efficiency

Electric Savings

Electric savings were estimated as the hourly difference in blower electric usage between the baseline case, which assumes the intake air is modulated by dampers, and the installed VFD. The hourly estimates are summed through the metering period to estimate a daily average savings which was extrapolated to a yearly savings.

The base case motor usage is estimated as follows:

–

where,

rated volts for three phase power, 460 volts

=

The installed motor usage is estimated using the measured amps as follows:

–

where,

=

2.3 Evaluator Calculation Results

The hourly model can be used to estimate monthly and annual gas usage and boiler combustion efficiency (unweighted by firing rate) as shown in Table 2-10. . Table 2-11 includes annual dryer gas usage, which is estimated to consume about 40% of the gas usage, and the calculated lead and lag boiler gas use.

Table 2-10. Monthly Lead Boiler Gas Use, Efficiency, and Savings (therms)

	Baseline		Installed		Baseline
Month	**Use**	**Efficiency**	**Use**	**Efficiency**	**Savings**
January	12,880	78.03%	12,145	82.69%	735
February	11,709	78.03%	11,041	82.69%	668
March	13,466	78.03%	12,698	82.69%	768
April	11,709	78.03%	11,041	82.69%	668
May	13,466	78.09%	12,698	82.76%	768
June	12,880	78.11%	12,145	82.78%	735
July	12,295	78.21%	11,593	82.89%	702
August	13,466	78.14%	12,698	82.81%	768
September	12,295	78.09%	11,593	82.76%	702
October	12,880	78.03%	12,145	82.70%	735
November	12,880	78.03%	12,145	82.69%	735
December	12,295	78.03%	11,593	82.69%	702
Total	**152,223**	**78.1%**	**143,538**	**82.7%**	**8,685**

Table 2-11. Annual Gas Use by End Use (therms)

End Use	Baseline	Installed	Savings	Site Gas Use	Billed Use (installed period)
Lead boiler	152,223	143,538	8,685	53%	
Lag boiler	26,160	26,160	0	10%	
Dryers	102,600	102,600	0	38%	
Total	**280,983**	**272,298**	**8,685**	**100%**	**255,959**

Lead boiler gas use was calculated using the 8,760 analysis and metered percent firing data. Lag boiler use was calculated using the percent firing metered data for the one month metering period and multiplying by 12 months. Dryer gas use was estimated using information from the site contact, three 2.8 MMBtu dryers operating 9.5 hours per day. A 50% cycle factor was used to account for cooling and loading periods. The gas use from the lag boiler and dryers do not affect the lead boiler's evaluation results. Rather, they serve as a check to verify the ground-up approach of modeling gas use through the rated input and firing rate and provide a reasonable gas use.

The gas use weighted boiler efficiency from the 8,760 analysis is 82.3%. This results in a savings of 8,685 therms from the 80% combustion efficiency, linkage-controlled code baseline. Savings account for the fact that the back-up boiler runs once per week as the lead boiler by multiplying the pre and post installation use by 0.85. (The boiler was observed to run 17 of the 20 production days metered). This savings represents 3.4% of the facility's installed gas use.

Table 2-12 summarizes the combustion, thermal, and seasonal efficiencies determined in this evaluation and compares them with those of the applicant. The applicant had estimated stack temperatures of about

500ºF, while the evaluator measured temperatures about 100ºF lower, which contributed to the higher installed boiler efficiency.

Table 2-12. Summary of Applicant and Evaluated Boiler Efficiencies

	Applicant Baseline	Applicant Installed	Evaluator Baseline	Evaluator Installed
Comb. efficiency, 80% firing rate	78.79%		80%	84.1%
Seasonal combustion efficiency			77.84%	82.55%
Standby loss			1.16%	1.23%
Seasonal thermal efficiency	73.79%	75.93%	76.67%	81.31%

Electric Impacts

Electric impacts were calculated using an analysis similar to the one applied to determine gas impacts. Evaluators determined savings for this measure by estimating the baseline electricity use for a dampered boiler air intake and the as-built electricity use for a variable speed fan. This resulted in annual impacts of 12,826 kWh/year.

3. Final Results

The site is launders linen and uniform rentals. The facility operates 12 hours per day, 5 days per week. A 300 hp oil-fired burner and associated oil burning related hardware was replaced with a gas-fired burner. In addition to the new burner, a parallel positioning control system with independent fuel and air actuators and O2 trim was also installed as well as a variable frequency drive (VFD) on the blower motor. The evaluators confirmed that the system was installed, operating as intended, installed metering equipment, and took spot measurements.

The site savings were 8,685 therms, or 3.4% of the installed facility gas use of 255,959 therms.

Measure impact calculations are shown in Table 3-1.

Table 3-1. Applicant Algorithm Measure Impact Calculations

	Baseline	Installed
Billing		
Actual gas bills (Jan. 2011 – Dec. 2011) (therms)	N.D.	255,959
Weather-normalized billing difference		N/A
Tracking/Applicant		
Boiler seasonal combustion efficiency	73.79%	75.93%
Average annual seasonal improvement in efficiency		2.14%
Gas usage (therms)	264,000	256,565
Savings (therms)		7,435
Evaluated		
Use-weighted boiler seasonal combustion efficiency	77.8	82.5
Average annual seasonal improvement in efficiency		4.7%
Boiler combustion output (therms)	118,484	118,484
Other gas usage (therms)	128,760	128,760
Boiler gas usage (therms)	152,223	143,538
Savings (therms)		8,685
Realization rate		
Final realization rate		116.8%

Note: N.D. = No data; boilers burned both oil and gas during the pre-retrofit period. No oil usage data was available.

3.1 Cross Check with Billing Data

In the baseline case, the boiler burners were dual firing, capable of burning both oil and gas. Oil billing data was not available, so comparing pre- and post-installation billing does not provide any insights to the gas savings.

3.2 Recommendations for Program Designers & Implementers

The new burner system at this facility appears to be operating very well and is experiencing much higher efficiencies than required by code. The baseline efficiency can be difficult to estimate, especially if the applicant has limited information about the boiler. For large boiler retrofit projects, it may be prudent to request combustion efficiency measurements across the firing range while firing natural gas, if possible, before the project is approved and the existing equipment removed.

3.3 Customer Alert

None.

3.4 Explanation of Deviations

Table 3-2 provides a summary of the key deviations between the tracking and evaluated savings.

Table 3-2. Summary of Key Factors and Deviations

Factor	Applicant	Evaluator	Impact of Deviation	Discussion of Deviations
Operational	264,000 therms	152,223 therms	57%	The applicant applied the efficiency improvement to the site's total gas use. However, approximately only 60% of the site's gas use is for the boiler.
Seasonal Efficiency	2.14% improvement	4.71% improvement	75%	The evaluator's calculated efficiency improvement was higher than the applicant's.
Baseline efficiency	*73.79%*	*77.84%*		The evaluators used a code baseline efficiency per National Grid's request that fuel switching projects are considered code replacements.
Installed efficiency	*75.93%*	*82.55%*		The evaluators used a combustion analyzer to determine key efficiency parameters such as excess air and stack temperature. The evaluated stack temperatures were about 100ºF than those that had been estimated by the applicant.
Non-discernible			- 1%	

1. PROJECT SUMMARY AND RESULTS

This project involves installation thirty nine energy efficient windows at one building in a large fabric mill complex with multiple buildings.This building serves as manufacturing facility for production of narrow fabrics which are used in various products. The total building area of the facility where the energy efficient windows were installaed is 22,000 square feet. The building is served by a single utility gas meter. The new energy efficient windows are low E with Argon gas between the glass sheets. This facility operates 9 hours per day, 5 days per week. New windows for this project are located in the manufacturing area of this building.

During the site visit, evaluators verified the installation of all thirty nine windows located in the manufacturing areas of the facility. Evaluation activities included on-site inspection, eQuest modeling, inspection of the HVAC units, collection of operating schedule information of the facility from the site contact and other data collection activities.

This project is considered as a retrofit measure for quantification of energy savings. The existing conditions are used as the baseline operating conditions for this facility.

1.1 Savings

Measure ID	Measure Name		Gas Savings (Therms/yr)	Electric Savings (kWh/yr)
1	Energy efficient windows	Tracked	2,712	N/A
		Evaluated	409	18,778
		RR[1]	16%	N/A
[1]Realization rate				

1.2 Explanation of Deviations from Tracking

The primary reason for discrepancy between the tracking savings and evaluated savings is that the final savings value for the 39 windows installed came from an analysis of a much larger project involving replacement of 299 windows for the entire complex. When the project was scaled back to only a small portion of the original project, the savings estimate was simply prorated proportionally and did not take into account key characteristics of the particular building such as the limited use of gas heating.

A second key reason for the discrepancy was that the new windows were installed in the manufacturing area of the building, which is primarily heated by electric heaters. Secondary space heating provided by gas unit heaters is minimal according to facility personnel, which was verified through examination of the gas billing data for the account serving this space. An estimated 18,778 kWh savings were calculated based on the use of electric heat in the space.

Another likely reason for the discrepancy between the tracking and evaluated savings were due to the difference in infiltration rates of the new windows between the two analyses. The original savings estimate used an infiltration rate of 0.01 cfm per square foot for the new windows. However, manufacturer’s data on the new windows showed that the actual infiltration rate was 0.1 cfm per square foot.

The use of an energy simulation building model makes it difficult to discern the individual impacts of these reasons quantitatively. However, the cumulative effect of these discrepancies led to the overall realization rate of 16% for this project.

2. Evaluated Measure: Energy Efficient Windows

The following sections present the evaluation procedure, an analysis of the application calculations, and the evaluation methodology determined to be the best fit for the site based on the information available.

2.1 Application Information and Analysis

The sections below detail the information contained in the applicant documents that were provided to the evaluators.

2.1.1 Application Description of Baseline

The baseline used in this analysis was the existing windows which had an estimated air infiltration rate of 0.5 cfm/sqft and U value of 1.12. The applicant initially used this baseline to calculate the energy savings for the replacement of 299 windows throughout the complex. This value was later pro-rated to a smaller project of 39 windows in one building.

2.1.2 Applicant Description of Installed Equipment and Operation

The new windows which are argon filled and low-E have an overall U factor of 0.35. And an infiltration rate of 0.01 cfm/ sqft.

2.1.3 Applicant Energy Savings Algorithm

The project file contains a preliminary site audit report that briefly explains the gas savings methodology used to quantify energy savings for 100 windows. Following that, a more thorough analysis was conducted which estimated the savings from replacing 299 windows at the site. The methodology used to evaluate these saving was based on basic heat transfer equations to calculate heat losses through fenestration. The audit report briefly lists the actual billing usage of three major utility gas accounts for this site. The cumulative usage for those three accounts is 8,823 therms. It is not clear from the report as which account reflects the heating energy to the specific area where the 39 windows were actually installed as part of the project and if the calculation was ever calibrated for the billing usage. The final savings for the 39 windows was simply a prorated value of the original estimate for the 299 windows originally estimated (39/299 x 20,794 therms = 2,712 therms)

The methodology used by the customer to estimate the energy savings is based on ASHRAE calculations. The model created by the applicant uses the temperature gradient difference between the inside and outside conditions of the facility. The U value and infiltration rates used in this calculation are taken from ASHRAE tables. The model uses the following formula to calculate the heat loss:

$$Q = U*A*(T_{out}-T_{in})$$

Where

U = Conductance of windows (Btu/hr ft^2 F)

A = Area of windows (square feet)

T_{out} = Outside temperature (F)

T_{in} = Inside temperature (F)

The equation used to quantify the heat loss through infiltration is:

Heat loss infiltration = H = Specific heat of air *Density of air *Air infiltration factor * Delta T

2.1.4 Analysis of Applicant Algorithm

The method used by the applicant to calculate energy savings for new energy efficient windows, is reasonable if calibrated against total heating usage from monthly gas billing data. It makes use of basic engineering principles of heat transfer to calculate the energy loss which takes into account the temperature differential across the building shell and infiltration. The vendor who conducted the analysis did not calibrate the estimated savings with the actual billing usage of the account which served the part of the facility which received the windows.

2.2 On-Site Inspection, Metering, and Analysis

This section provides the steps of the evaluation from initial site visit through the final results.

2.2.1 Summary of Site Visit Findings

The evaluators visited the site on March 18, 2012 and verified through inspection that thirty nine windows were installed on the east side of this facility. It was verified that the 39 windows were approximately 557 square feet in total area.

In order to build an eQuest model to calculate the energy savings, the evaluator team collected various data parameters including information on the building shell and heating and cooling system. The operating schedule of the facility and the details of new windows were also collected from the customer during the onsite visit. The various parameters that are collected are listed in Table 2-1.

Table 2-1. Data Collection Values for the eQuest Model

EQuest Parameter	Value or Description	Source
Ground floor construction	12-inch concrete wall	Site data
Roof construction	Built-up roof with metal frame	Site data
Floor to ceiling height	10 feet	Site data
Building footprint	220 feet x 100 feet	Site data
Heating system	Unit heaters	Site data
Heating efficiency	80%	Site data
Heating system location	Overhung units	Site data
Hours of operation	8am to 5pm;5 days a week	Site data
New Window type	Double pane	Site data
New Glass type	Low E	Site Data and Manufacturer's Spec
U value for new Windows	Argon gas (U:0.24)	Manufacturer's Spec
Frame width	0.11ft	Site data
Window Length	3.65 feet	Site data
Window Height	3.91 feet	Site data
Number of floors	2	Site data

2.2.2 Measured and Logged Data

The evaluation team did not perform any metering for this site. All the building shell and operational information of the facility was collect on-site by interviewing the site contact.

Some of the information that was not available from the customer regarding the new windows was collected from the window manufacturer.

2.2.3 Evaluation Description of Baseline

During the onsite audit of this facility, the customer verified that the existing old windows were single pane windows with metal frames. The customer also verified that the old windows had large cracks and other openings through which air flowed. Since the windows were confirmed to have maximum air leakage through them, the evaluation team makes use of infiltration rate of 0.4 cfm/square feet for this facility to quantify the energy savings. This number is based on ASHRAE standard 90.1 for the leakage through windows when there are considerable amount of openings. This infiltration rate is determined in accordance with the National Fenestration Rating Council (NFRC).

2.2.4 Evaluator description of installed equipment

The evaluators used an infiltration rate of 0.11 cfm/square foot and an overall U factor of 0.35 for the new window per the manufacturer's ratings. Note that the infiltration rate is higher than predicted in the original tracking savings estimate. The evaluation assumption comes directly from manufacturer's specifications.

2.2.5 Evaluator Calculation Methodology

The energy simulation program eQuest was used as the analysis tool. An as built installed model was constructed using data collected during the site visit (see Table 2- 1). For this site evaluation, the closest weather station for climate data as Pawtucket, RI which is 1.4 miles from the location of this site.

The evaluation team conducted a site visit which included the collection of building foot print and dimensions of each wall and section of building shell of this facility. This information was used in the eQuest simulation tool to create the sketch of the model that resembles the foot print of this building. The evaluation team identified the counts and dimensions of each installed window in each orientation of the building shell. This information was used to calculate the net percentage of window to wall area ratio. Along with the data points listed in table 2.1, the evaluation team designed the simulation model with various other inputs to the model such as the orientation of the building, lighting schedule, occupancy operating schedule, etc.

The mechanical system that provides heating energy to the school facility was also designed in the model. The mechanical system used is gas unit heaters that provide some heat to the space. The operating efficiency of the boiler used in the simulation is 80%. The retrofitted windows are installed in the manufacturing area of this facility which is mostly heated by electric heaters and are supplemented by the unit gas heaters. The use of gas heaters is very minimal for the manufacturing area. The customer confirmed that they relied on the electric heating for most of the space heating needs and very rarely will they use the space heaters, which explains the low gas usage in the billing.

With all the inputs provided to the simulation model an installed case model is run first and is calibrated to the annual billing data provided for the utility meter that is associated with this project. After that the baseline model is created and run to predict the baseline gas consumption. The difference in gas consumption between the baseline and proposed case simulations serve as the basis for energy savings.

To estimate expected electric savings from the use of electric heat, evaluators applied a similar methodology to the TA study to assess the estimated total heat savings. The gas savings predicted by the evaluator model was subtracted from this estimate, and the difference represents the electric savings. Site factors such as infiltration rate and U-value were used to update the TA methodology.

2.2.6 Evaluator Calculation Results

The monthly bills for the utility account were compared with the post usage consumption predicted by evaluator's model. A straight comparison of each month's consumption was made between the usage predicted by the model and the actual billing usage of the utility account. Various input parameters of the e-QUEST models were checked for their values in order to calibrate the consumption with the utility bills. Most of the input parameters of the model are based on the information provided by the customer and collected during the onsite audit, and were found to be reasonable enough to predict a relatively close match in usage of gas in the post case when compared to the utility bills. It should be noted that the total annual usage from the monthly bills is based on actual meter reads but most of the interim monthly billing data is based on estimated meter reads

Comparison made between the post installation usage of the model and the utility bill data shows a difference of only 1% validating the models use as a predictor of savings. The post installation usage predicted by the model was calculated as 653therms as compared with the actual billing data of 633 therms.

Table 2-2. Summarizes the results of evaluation simulation model

Table 2-2. Evaluation Model Results

Month	Usage (Therms)		Savings (Therms)
	Pre-Retrofit	Proposed	
January	226	162	64
February	215	153	62
March	151	106	45
April	70	27	43
May	13	2	11
June	0	0	0
July	0	0	0
August	0	0	0
September	0	0	0
October	36	4	32
November	141	61	80
December	210	138	72
Total	**1062**	**653**	**409**

3. FINAL RESULTS

This project involved installation of new energy efficient windows which provided lower infiltration and a reduced U value. The existing windows had large gaps between the window frame and the building shell which allowed outside air to infiltrate into the heated area of the building.. After conversation with the customer it was revealed that the area of this building where window retrofit project has taken place is mostly heated by electric heaters. The unit gas heaters that provide heating energy are seldom used which is evident from the low utility gas billed consumption. Use of the gas heaters compared to the electric heaters for this facility is very minimal. The customer also confirmed that the gas heaters are not the primary heating sources for this area of the building where the window project was completed.

The total area of windows retrofitted in this facility is 557 square feet. Because of the weather dependent nature of this measure, the eQuest simulation tool was used to quantify energy savings, which takes into consideration the local weather profile of Pawtucket, RI. Energy savings are (409 therms) per year, which represents a 16% realization rate when compared with estimated savings of 2,712 therms. In the calculation of energy savings provided by the applicant air infiltration rate of 0.01cfm/sqft was used for the proposed case which is very low compared to the rate used by the evaluation team, 0.1 cfm/sqft. The higher infiltration rate used in the evaluation is based on manufacturer's specifications for the new windows. Electric heat savings of 18,778 kWh were also calculated outside of eQuest.

Table 3-1 summarizes key parameters used in the analysis.

Table 3-1. Key Parameters

	Pre-Installation	Post-installation
Billing		
Actual billing usage (therms)	Not available	633
Tracking		
Base; Infiltration rate: 0.5 cfm/sq ft **Post; Infiltration rate: 0.01 cfm/sq ft**		
Savings are prorated from the savings of 299 windows (20,794 therms) to 39 windows (39/299*20,794 therms = 2712 therms)	2,712	
Evaluated		
Base; Infiltration rate: 0.4 cfm/sq ft **Post; Infiltration rate: 0.1 cfm/sq ft** **Window area (square feet)**	557	557

Savings (therms)	409
Realization rate	
Final Realization Rate(RR)	16%

3.1 Cross Check with Billing Data

The evaluator team compared the post measure installation utility bills for this facility with the post installation usage predicted by the evaluator's model. The total annual consumption is within 1% of annual billed gas usage.

3.2 Recommendations for Program Designers & Implementers

Energy modeling is an appropriate method for calculating temperature-sensitive and building shell dependent measures such as energy efficient windows. It should be used for building shell projects where cost effective.

3.3 Customer Alert

None.

3.4 Explanation of Deviations

The primary for the deviation between the tracking and evaluated savings is the fact that the applicant calculated savings for 299 windows which was then prorated to the 39 windows that were actually installed. These calculations did not take into consideration the usage of utility gas meters that are associated with this retrofit project and the limited use of gas for space heating in this building.

Evaluators found that the primary source of space heating in the location where the new windows were installed is electric heat. Gas unit heaters are also present, but only supply a relatively small amount of heat to this space. This is verified through discussions with facility personnel, and examination of the gas billing data.

In addition the applicant's methodology used different infiltration factors in their calculation compared to the ones used by the evaluator team. Specifically, the original savings analysis used an infiltration rate of 0.01 cfm per square foot for the new windows, where the evaluation's estimate of 0.1 cfm per square foot was taken from manufacturer's specifications.

Another likely reason for deviation is the difference between the tracking savings is due the methods used by applicant and the evaluation team. The evaluation team made use of a simulation technique whereas the original savings estimated used a standard heat loss calculation to quantify the savings which was not calibrated to actual building usage. The simulation takes into account factors like orientation of building, solar gain, height of building, wind effects etc into their method while the simplified calculations do not.

The use of an energy simulation building model makes it difficult to discern the individual impacts of these reasons quantitatively. However, the cumulative effect of these discrepancies led to the overall realization rate of 16% for this project.

Table 3-2. Summary of Key Factors and Deviations

Factor	Original Application	Evaluator	Discussion of Deviations
Baseline Assumptions	Infiltration rate of existing windows (0.5 cfm/sqft).	Infiltration rate of baseline windows (0.4 cfm/sqft)	This project is identified as retrofit project. TA study should have used the value of infiltration rate as 0.4 cfm/sqft for loosely pack windows but instead the study used 0.5 cfm /sqft.
Installed Assumptions	Infiltration rate of new windows (0.01 cfm/sqft).	Infiltration rate of new windows (0.1 cfm/sqft).	TA study assumed a very low infiltration rate for the new windows. However, manufacturer's data show that the infiltration rate for the new windows is higher than predicted.
Analysis approach	Uses custom tool to calculate energy savings	Uses eQuest simulation.	Evaluation model accounts for building specific factors, and is calibrated to post-installation billing data. TA study did not calibrate to billing data.
		Total	The cumulative effect of these discrepancies resulted in a realization rate of 16% on annual therms savings.

1 PROJECT SUMMARY AND RESULTS

This project consists of two measures. Measure 1 installs three new high efficiency condensing boilers to provide space heating. Measure 2 replaces two existing gas fired domestic hot water boilers with two condensing domestic hot water boilers. Though these measures replaced existing equipment it was assumed that the equipment replaced was at the end of its useful life. This facility is a multi-story apartment complex that contains a total of 201 units. These are 1 and 2 bedroom low income apartments.

The three new heating boilers and two domestic hot waters were installed at thesite and were fully operational. The project savings were evaluated using instantaneous combustion monitoring of the heating and domestic water boilers, trending of heating supply and return water temperatures, natural gas billing history review, and site data collection to identify facility operation and non-heating and water heating natural gas usage. Total gas savings for this project are 4,729 therms or 30 % of the value estimated before the installation.

There are no interactive electric savings for this project.

1.1 Savings

Measure ID	Measure Name		Gas Savings (therms/yr)	Electric Savings (kWh/yr)
1	Three heating condensing hot water boilers	Tracked	7,923	-
		Evaluated	3,278	-
		RR[1]	41%	-
2	Two condensing domestic water boilers	Tracked	7,640	-
		Evaluated	1,451	-
		RR[1]	19%	-
	Totals	**Tracked**	15,563	-
		Evaluated	4,729	-
		RR[1]	30%	-
[1]Realization rate				

1.2 Explanation of Deviations from Tracking

The tracking documentation provided few specific project details. Natural gas savings for the two domestic water boilers were submitted as a Custom Project application. No working spreadsheets were provided and there was no discussion of the existing domestic water heaters or the assumed baseline of the equipment that was assumed to have been installed absent the incentive program. The three space heating boilers were included in this Custom Project even though the savings were calculated using prescriptive program average savings values.

The review of the tracking documentation and the evaluation site analysis provided the following reasons for the savings variance:

- Savings for the three heating hot water boilers were calculated using the prescriptive measure values which did not take into account the specific site conditions, size or efficiency of the installed units. Prescriptive savings applies the same fixed annual savings value [2,641 therms per year] for each of the three boilers.
- The apartment complex uses natural gas for space heating, domestic hot water, and for commercial clothes dryers in the central laundry. The tracking savings did not account for dryer usage when estimating natural gas usage, overstating the amount of billed natural gas devoted to heat and domestic hot water.
- The tracking savings show pre-installation and post installation gas usage of 17,093 and 9,454 therms respectively for domestic hot water usage. Given no other work was done to save on domestic hot water usage, this 45% reduction is not reasonable particularly when the required baseline efficiency is 80% and the installed efficiency is estimated to be 91.4%.

2 EVALUATED MEASURES

The following sections present the evaluation procedure, including the findings from an in-depth study of the supplied application calculations and the evaluation methodology determined to be the best fit for the site and information available.

Both Measure #1 and Measure #2 applicant information and evaluator site findings will be separately discussed; however, the evaluation methodology will be combined into a single section. It should be noted that in some cases prescriptive and custom measures are combined into one custom application with a total prescriptive and custom incentive combined into one offering for the customer. In those cases, it is not clear how much documentation is required for the measures where the rebates and the savings are developed from the prescriptive offerings.

2.1 Measure #1: Install Condensing Space Heating Boilers

Three high-efficiency condensing boilers were installed in this 201 unit apartment building to provide space heating. They replaced existing hot water boilers that were at the end of their useful life. The site work also included new through-the-wall exhaust piping for the direct vented boilers, gas valve/gas train modifications to accommodate the new units, high and low voltage line rewiring for the new configuration, and new outside air reset controls.

2.1.1 Application Information and Analysis

The following sections detail the information that was provided by the site and in the application material provided as part of the project file provided by the PA.

Application Description of Baseline

The boiler make and model, quantity, capacity, or other data on the existing or assumed baseline equipment was not documented. Boiler controls, hot water reset schedules, and other operational factors were also not addressed. No estimates or discussion of baseline efficiency was provided. Note that since this measure was being treated as a prescriptive application, this information was not required.

Applicant Description of Installed Equipment and Operation

Three condensing boilers were installed at this site. The boilers are each rated at 1,300 MBH maximum input capacity. Output is rated at 1,240 MBH with a 95.4% thermal efficiency. The boilers are equipped with modulating burners that provide a 10:1 turndown ratio. The units also produce less than 200 ppm NOx.

An outdoor air reset controller was installed with the boilers. This controller adjusts heating hot water supply temperatures according to outside air temperature. The boilers operate in stages to provide heat. The burner of the lead unit modulates according to return water temperature and the supply water. A second boiler is brought online when the lead unit reaches 90% of rated capacity. The third boiler is brought on line accordingly. The boilers are on a rotating schedule to determine lead/lag operation.

Applicant Energy Savings Algorithm

Tracking documentation shows that savings for this measure were from the prescriptive program deemed savings. Prescriptive savings use a fixed annual savings value for different size groups. These three boilers fall into the 1000-1700 MBH size group. The annual savings factor for this group is 2,641 therms per boiler. The savings calculation is:

Analysis of Applicant Algorithm

These boilers fall within the prescriptive boiler size categories but more accurate savings could be attained if the boiler savings also used the custom approach.

2.1.2 On-Site Inspection, Metering, and Analysis

The following section details the evaluator's findings from the initial site visit, metered data, and other information collect as part of the evaluation.

Summary of Site Visit Findings

The evaluation team visited the site on March 14, 2012. The three new condensing boilers were installed and fully operational. The make, model, and capacity of the units matched tracking documentation. Boiler #2 was acting as the lead unit with the other two acting as back-up. The boiler display provided instantaneous readings that showed the lead unit was operating at 58% of capacity. The outside air temperature was approximately 58°F at that time.

The existing boilers were removed from the boiler room. New through-the-wall breeching was installed for direct venting. The boilers were tied into the main header feeding the distribution system. The existing heating hot water pump was retained working with the new boilers. The new boiler water reset controller was identified along with the mixing valve. It was not possible to access this controller to view the reset schedule.

2.1.3 Evaluation Description of Baseline

The baseline efficiency assumes compliance with the efficiency requirements as mandated by Rhode Island State Building Code. The minimum acceptable efficiency for hot water boilers is 80%.

Measure #2: Install Condensing Domestic Hot Water Boilers

The measure involves the installation of two condensing boilers to provide domestic hot water to the apartment building.

2.1.4 Application Information and Analysis

The following sections detail the information that was provided by the site and in the application material provided as part of the project file provided by the PA.

Application Description of Baseline

No text with descriptions or detailed specifications of the baseline equipment is provided in the tracking documentation. Tracking data shows a maximum boiler input of 3,800MBtu/hr, a 250 gallon/hour recovery rate, and 80% efficiency. The baseline units were greater than 12 years old according to the spreadsheet. Less efficient non-condensing boilers are used as the baseline domestic water heaters.

Applicant Description of Installed Equipment and Operation

The installed equipment was listed as two condensing boilers. The documentation lists 94.0% efficiency for the boilers and a 200 gallon per hour recovery rate. The combined maximum input is 1,600MBtu/hr. Cold water supply is 50°F. DHW is stored at 145°Fand circulated to the building at 110°F.

Applicant Energy Savings Algorithm

No working spreadsheet was provided in the tracking documentation. A .pdf file was included that provided a savings table and excel data entry pages for a Water Heater Calculator. It is not clear what entries are actually used in the calculations. The first screen is labeled with a school from New York but subsequent entries are for 201 units of senior housing. The number of units is correct but the facility consists of one and two bedroom apartments for low income individuals and families. The spreadsheet also includes 35 “hot water/unit/day”. The units for the hot water is not stated but presumed to be gallons. The baseline and installed equipment and conditions described above were taken from this worksheet. Other entries for laundry and shower are checked as no. The facility does have a laundry with 10 natural gas fired dryers. The data from the spreadsheet appears to calculate the monthly gas usage presented in the savings table. The savings table is presented in

Figure 1.

	Actual Facility Use	Percent Facility in Use	Old Boiler Predicted Use	Hours Which Boiler Cannot Meet Load	New Boiler Predicted Use	Hours Which Boiler Cannot Meet Load	Savings	% Savings
January	9113	100%	1452	0	803	0	649	44.7%
February	8256	100%	1311	0	725	0	586	44.7%
March	5224	100%	1452	0	803	0	649	44.7%
April	4730	100%	1405	0	777	0	628	44.7%
May	1502	100%	1452	0	803	0	649	44.7%
June	1297	100%	1405	0	777	0	628	44.7%
July	1380	100%	1452	0	803	0	649	44.7%
August	1618	100%	1452	0	803	0	649	44.7%
September	1900	100%	1405	0	777	0	628	44.7%
October	4754	100%	1452	0	803	0	649	44.7%
November	7530	100%	1405	0	777	0	628	44.7%
December	7731	100%	1452	0	803	0	649	44.7%
Totals	55035		17093		9454		7640	44.7%
Per Day			46.8		25.9		20.9	

Figure 1.DHW Savings Summary Table

The repetitive values in the old boiler, new boiler, and savings columns clearly show a per-day calculation approach. The per-day row at the bottom of the table shows the applicable value for each column. With the average daily value, it was possible to reverse engineer the old boiler predicted use in the table. That equation is:

The 63.9°F∆T is consistent with the difference between the 50°F ground water and a blended ratio of the 115°F supply water and145°F storage temperature. The 80% represents the stated efficiency of the baseline equipment.

A problem occurs when the formula is repeated using the new equipment efficiency.

The per-day savings using the 94% proposed efficiency is 39.8 therms and not the 20.9 therm value derived from the summary table. The efficiency is the only variable that should change between the two equations. The number of units and water usage per unit are constants. No water conservation measures were implemented but to achieve the 20.9 therms/day savings value the temperature differential would have to be reduced to 33.5°F or the water usage would have to be significantly reduced.

Analysis of Applicant Algorithm

The mass-flow approach is a valid approach to estimating usage and savings. It incorporates the anticipated usage, the properties of water, temperature differentials, and equipment efficiencies. This methodology can yield good results if properly applied and with sound input values. The maximum savings from the improved efficiency for this measure is 16.25% and not the 44.7% savings calculated in the summary table. More documentation of values and validity checking of the results would have provided clearer results and possibly discovered this discrepancy.

Summary of Site Visit Findings

Facility personnel were interviewed during the site visit. They stated that both the DHW boilers and heating boilers were working well with only minimal problems. There was a minor draft issue at the piping that would keep units from coming online but that problem has been resolved, The DHW boilers provide adequate hot water and the heating boilers are able to meet heating demands.

The hot water reset controller is working with the new boilers and lowers heating hot water supply temperature as the outside air temperature increases. The reset controller was considered essential in helping the condensing boilers operate at efficient levels.

Facility personnel stated that natural gas is used for space heating, domestic hot water, and for the 10 gas dryers in the laundry. Cooking in the apartments is electric and there are no other uses for natural gas in the facility.

Evaluation Description of Baseline

The baseline consisted of non-condensing domestic hot water boilers operating at 80% average efficiency. The DHW supply water is 5°F warmer than reported. The 145°F storage temperature matches the tracking documentation.

2.2 Measured and Logged Data

The evaluators installed metering equipment to verify the operation of the condensing boilers. The following points were logged on-site, as shown in Table 2-1 for the period of March 14 through April 13, 2012.

Customer Equipment	Parameter	Measurement	Observation	Metering

Monitored	Measured	Equipment	Frequency	Duration
Heating Hot Water Supply	Temperature	Hobo logger and J,K,S,T thermocouple	2 minute	4 weeks
Heating Hot Water Return	Temperature	Hobo logger and J,K,S,T thermocouple	1 minute	4 weeks

Table 2-1. Summary of Logged Data

Temperature loggers were installed to monitor heating hot water supply and return water temperatures. Thermocouples were installed under the insulation of the main distribution header. The 1 and 2 minute monitoring durations were set to capture temperature changes in the water streams. Figure 2-2 shows the temperatures over the monitoring period. The monitoring period coincides with an unusually warm period in March where some daily high temperatures were over 80°F. This explains the low readings at the start of the chart. Condensing boilers operate most efficiently when return water temperatures are below 140°F. This recorded temperature data shows that the installed controls optimize boiler operation. The outside air reset controller sets supply water temperatures accurately and keeps the return water temperatures mostly below140°F.

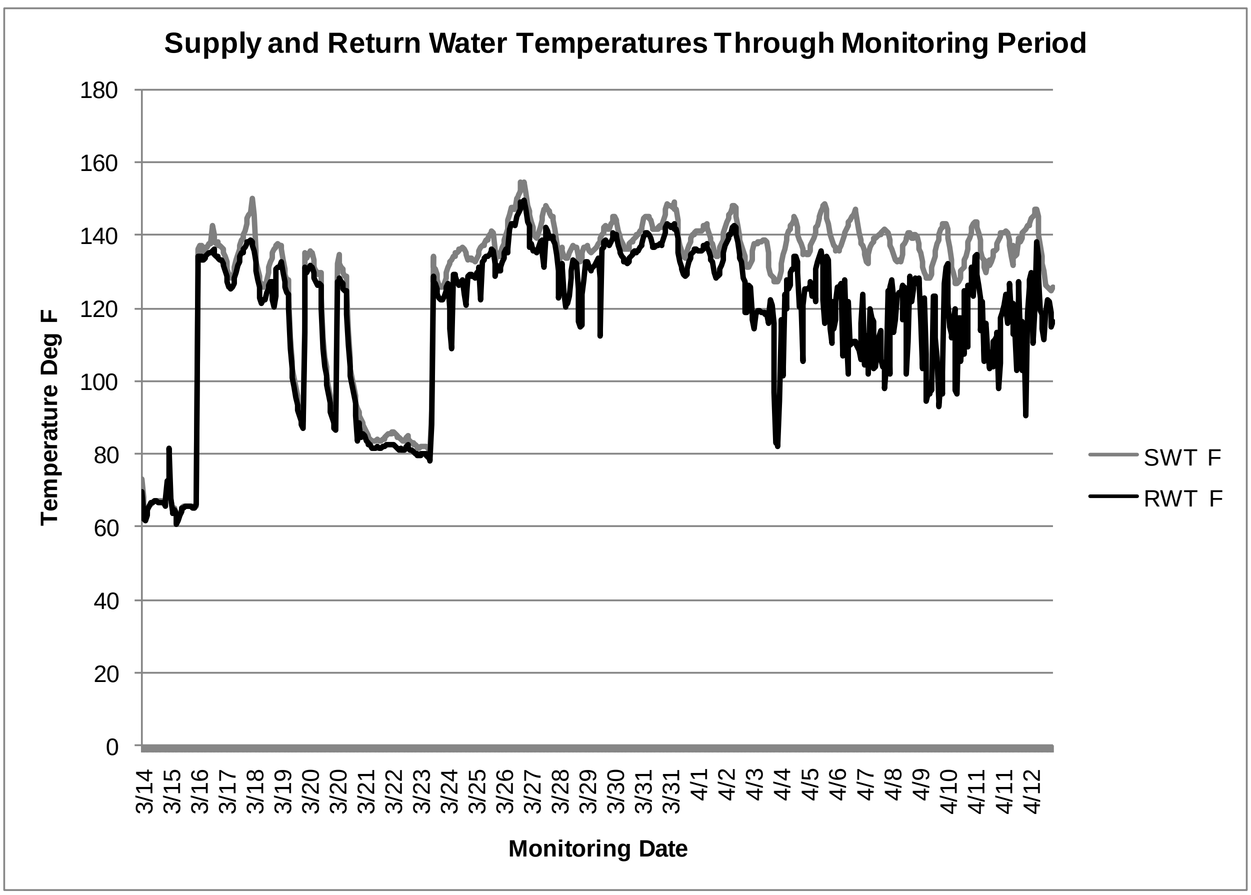


Figure 2-2. Supply and Return Water Temperatures During Monitoring Period

Spot combustion readings were taken during the site visit. One heating boiler was operating due to warm temperatures. One DHW boiler was operating at that time. Table 2-1 shows the combustion efficiency testing results.

Heating Boiler Flue gas testing results	
Efficiency %	91.0%
Excess Air %	0.90
Oxygen	4.0%
CO2 ratio	11.30%

DHW Boiler Flue gas testing results	
Efficiency %	90.5%
Excess Air %	0.90
Oxygen	3.8%
CO2 ratio	11.00%

Table 2-2. Summary of Logged Data

2.3 Evaluator Calculation Methodology

This section presents the methodology for computing the savings for both boiler replacement measures.

Measure 1: Install Condensing Heating Boilers

The evaluation savings were calculated in an analysis spreadsheet using the monitored return water temperature data, post installation gas billing history, monitoring period weather data, manufacturer's performance information, and the prescriptive baseline efficiency. Figure 2-3 provides an excerpt of that spreadsheet. The calculation methodology in each column is explained below.

		Col 1	Col 2	Col 3	Col 4	Col 5	Col 6	Col 7	Col 8	Col 9	Col 10	Col 11	Col 12	Col 13
		Max	83	95	74	53	50		271	285	143	97.7%	122.1%	24
		Min	12	16	4	0	0		0	0	0	0.0%	0.0%	0
			Totals or Average			5724	4632		24,936	30,814	123.55	89.6%	112.1%	3,278
			TMY3 Weather Data											
Month	Day	Heating Season	Avg OAT db	Max OAT db	Min OAT db	HDD	Evaluation HDD	HDD Adj Factor	Evaluation Therms	TMY3 Adjusted Therms	RWT	Installed Efficiency	Δ Efficiency	Therms Savings
1	1	1	29.92	36	19	38	21	1.79	113	202	136	87.63%	109.5%	19.25
1	2	1	35.17	39	32	30	24	1.22	130	159	132	88.16%	110.2%	16.20
1	3	1	28.50	32	24	37	40	0.92	216	199	136	87.51%	109.4%	18.70
1	4	1	27.67	37	20	37	46	0.80	245	196	137	87.45%	109.3%	18.29
1	5	1	28.58	37	23	35	35	0.99	190	188	136	87.52%	109.4%	17.71
1	6	1	29.63	37	22	36	26	1.36	141	191	136	87.60%	109.5%	18.16
1	7	1	39.92	45	32	27	19	1.42	101	143	128	88.80%	111.0%	15.69
1	8	1	30.33	35	24	36	27	1.32	144	191	135	87.66%	109.6%	18.30
1	9	1	31.75	42	24	32	34	0.94	184	172	134	87.79%	109.7%	16.78
1	10	1	36.29	43	29	29	28	1.02	153	156	131	88.30%	110.4%	16.19
1	11	1	36.21	43	33	27	29	0.94	155	145	131	88.29%	110.4%	15.05
1	12	1	35.54	38	32	30	26	1.16	139	161	131	88.20%	110.3%	16.56
1	13	1	34.42	39	29	31	28	1.12	150	167	132	88.07%	110.1%	16.84
1	14	1	37.21	48	25	29	36	0.79	195	153	130	88.41%	110.5%	16.14
1	15	1	47.54	51	43	18	50	0.36	271	97	120	90.18%	112.7%	12.33
1	16	1	37.58	45	28	29	44	0.66	234	153	130	88.46%	110.6%	16.23
1	17	1	22.96	28	18	42	25	1.70	133	226	139	87.16%	108.9%	20.23
1	18	1	27.29	34	20	38	28	1.36	150	205	137	87.42%	109.3%	18.98
1	19	1	31.83	36	26	34	41	0.84	218	183	134	87.80%	109.8%	17.85
1	20	1	25.29	31	19	40	38	1.05	205	215	138	87.29%	109.1%	19.62
1	21	1	26.46	35	19	38	44	0.86	238	205	138	87.36%	109.2%	18.83
1	22	1	29.13	38	21	36	42	0.85	226	191	136	87.56%	109.5%	18.06
1	23	1	30.92	41	16	37	29	1.27	155	196	135	87.71%	109.6%	18.95
1	24	1	13.58	19	10	51	16	3.12	87	272	142	86.85%	108.6%	23.27
1	25	1	16.63	25	6	50	27	1.82	146	266	142	86.92%	108.6%	23.03
1	26	1	18.75	21	15	47	29	1.62	156	253	141	86.98%	108.7%	22.08
1	27	1	16.13	27	8	48	21	2.24	114	256	142	86.90%	108.6%	22.06
1	28	1	17.17	29	4	49	25	1.92	136	261	142	86.93%	108.7%	22.62
1	29	1	21.63	34	9	44	27	1.61	146	234	140	87.10%	108.9%	20.77
1	30	1	26.13	34	11	43	31	1.39	164	229	138	87.34%	109.2%	21.00
1	31	1	33.04	35	31	32	25	1.30	133	172	133	87.92%	109.9%	17.06

Figure 2-3. Evaluation

The spreadsheet calculates energy savings for each day of the year. The heating season months are defined in Col 1. An entry of 1 includes that day in the heating season. The typical heating season is from October 1st to June 1st.

TMY3 weather data is reported in an hourly format [8760 hourly temperatures per year]. The average daily outdoor air temperature is calculated in Col 2. This is the average of the 24 hourly temperatures for each day.

The maximum and minimum daily temperatures are reported in Col 3 and Col 4 respectively. These are the maximum and minimum of the 24-hour temperatures for each TMY3 day.

TMY3 Heating Degree days are calculated in Col 5 from the TMY minimum and maximum data. Heating degree days are 65°F based. The HDD creation formula is:

The evaluation heating degree days in Col 6 are the daily post-installation HHDs obtained from the weather station at Green Airport in Warwick RI. Together with the HDDs in Col 6 they are used to generate the HDD adjustment factor in Col 7. The evaluation period HDDs are nearly 1100 less than the TMY3 HDD data. This adjustment factor is used to normalize monitoring period weather performance to TMY3 weather standards.

Evaluation therms are provided in Col 8. A one year post-installation natural gas billing history was identified. The project was completed in February 2011. The one year gas billing history is from May 1, 2011 through April 30, 2012. The evaluation HDDs are also from this time period. The gas billing history is presented in Table2-3 below:

Bill Date From	Bill Date To	Therm	
04/30/2011	05/31/2011	1,811	Heating Season
05/31/2011	06/30/2011	1,027	Non-Heating Usage
06/30/2011	07/31/2011	948	Non-Heating Usage
07/31/2011	08/31/2011	966	Non-Heating Usage
08/31/2011	09/30/2011	1,019	Non-Heating Usage
09/30/2011	10/31/2011	2,685	Heating Season
10/31/2011	11/30/2011	3,883	Heating Season
11/30/2011	12/31/2011	5,304	Heating Season
12/31/2011	01/31/2012	6,230	Heating Season
01/31/2012	02/29/2012	5,470	Heating Season
02/29/2012	03/31/2012	4,330	Heating Season
03/31/2012	04/30/2012	3,143	Heating Season
		36,816	12 Month Gas Usage - Post Installation
Billing days		3,960	Total Non-Heating Gas June through Sept
365		990	Avg Non-Heating Gas Usage June through Sept
		11,880	Annual Non-Heating Gas Usage
		24,936	Heating Gas Usage

Table2-3. Post-Installation Natural Gas History

The shaded areas represent the non-heating season and is the source of the Total [3,960 therms] and Average [990therms] non-heating use values. The annual non-heating gas usage is calculated as:

The calculated total non-heating gas usage is subtracted from the total 12-month gas usage to obtain the heating natural gas usage. The total heating gas therms are converted to daily usage by calculating the daily HDD percentage of total heating degree days.

Daily evaluation therms=Total heating therms x Daily evaluation HDD/Total evaluation HDD

The heating natural gas therms are adjusted to TMY3 heating degree days in Col 9.

TMY3 adjusted therms= Daily evaluation therms Col 8 x HDD adjustment factor Col 7

Condensing boiler efficiency is related to the return water temperature. A regression analysis was performed against evaluation period weather data and the monitored return water temperatures.Figure2-4 provide the scatter plot of the regression analysis and the R^2 formula. There were no data points below 28°F in the monitoring period due to the mild winter. The performance points were estimated below that temperature. The new hot water reset controller is working with the new system and the site personnel indicated that the controller was included as an important part of the project. A 150°F return water temperature was set at 10°F outside air. The lowest TMY3 OAT is 12°F. The controller was installed to keep water temperatures in optimum ranges for the condensing boilers to maximize efficiency.

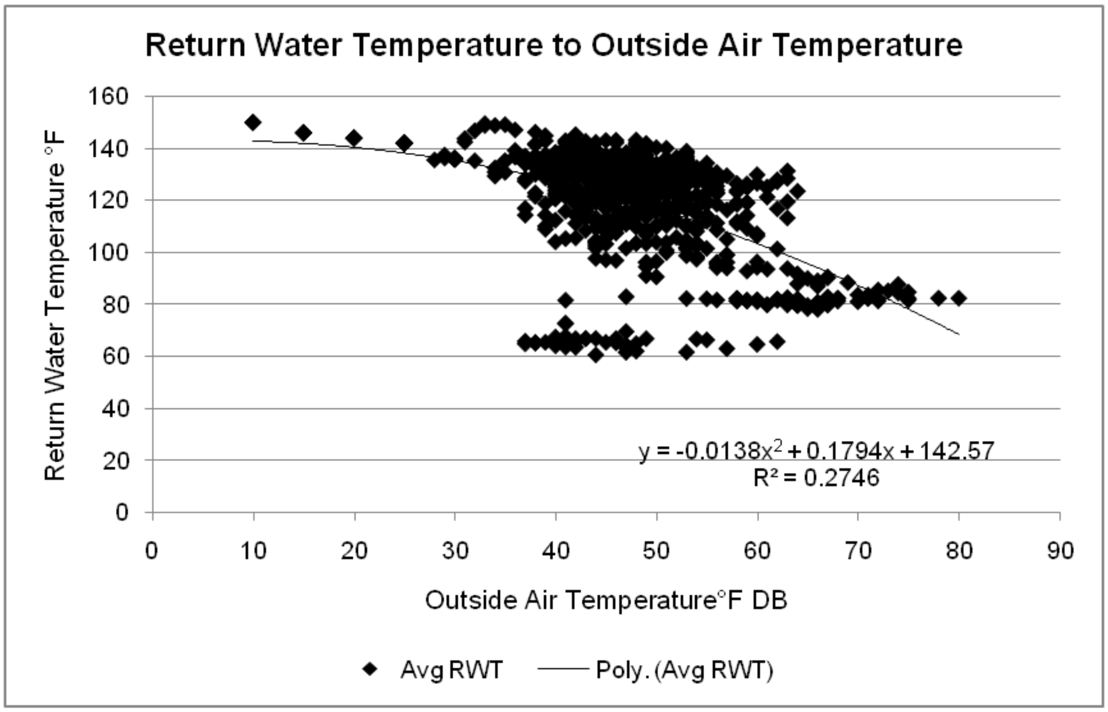


Figure 2-4. Return Water Regression Analysis

The regression formula was expanded and used to estimate the return water temperature in each heating day according to the daily average outdoor air temperature. The mild winter temperatures contribute to the low R^2. The expanded values are presented in Table2-4.

SUMMARY OUTPUT - RWT to OAT DB	
Regression Statistics	
Multiple R	0.524046449
R Square	0.27462468
Adjusted R Square	0.272685174
Standard Error	18.44254298
Observations	751
ANOVA	
	df
Regression	2
Residual	748
Total	750
	Coefficients
Intercept	142.571463
TEMP DB	0.179410267
TEMP DB^2	-0.013820078

Table2-4.Expanded RWT Regression Statistics

The formula for estimating return water temperature in Col 10 is:

$$\textit{Return Water Temp °F} = (\textit{Avg } OAT^2 \times DB^2 \textit{Coeff}) + (\textit{Avg OAT} \times \textit{DB Coeff}) + \textit{Intercept}$$

A performance curve was obtained from Lochinvar for the condensing boiler. Efficiency is plotted according to return water temperature. The manufacturer's curve is presented in Figure 2-5.

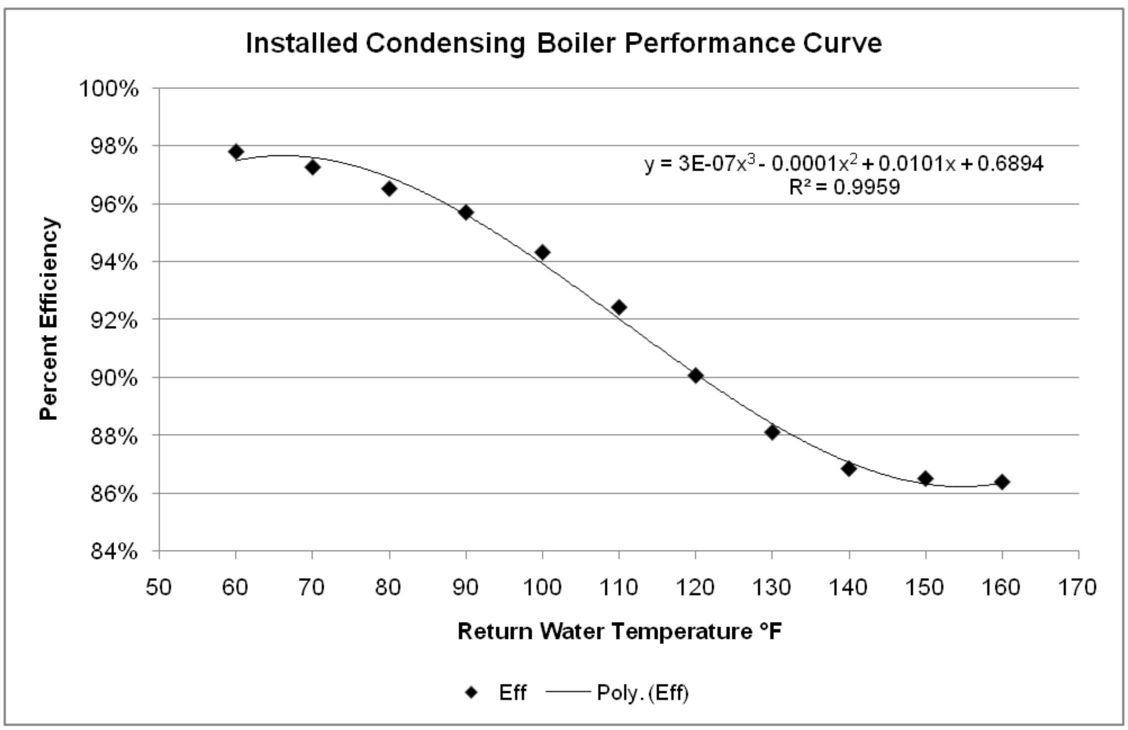


Figure 2-5. Condensing Boiler Performance Curve

Table 2-5 provides the expanded regression analysis coefficients for the performance curve.

Output - Installed Efficiency	
Regression Statistics	
Multiple R	0.997943059
R Square	0.995890349
Adjusted R Square	0.994129069
Standard Error	0.003498023
Observations	11
ANOVA	
	df
Regression	3
Residual	7
Total	10
	Coefficients
Intercept	0.689441026
RWT	0.010121088
RWT^2	-0.000109091
RWT^3	3.28982E-07

Table 2-5. Expanded Efficiency Regression Statistics

The formula for estimating installed efficiency from return water temperature [RWT] in Col 11 is:

$$Efficiency = (RWT^3\ RWT^3Coeff) + (RWT^2 \times RWT^2Coeff) + (RWT \times RWT\ Coeff) + Intercept$$

The installed efficiency is divided by the prescriptive baseline efficiency of 80%calculate the improvement in efficiency. The change in efficiency is calculated in Col 12.

$$\Delta\ Efficiency = Installed\ efficiency\ Col\ 11\ /\ 80\%\ baseline\ efficiency$$

The annual savings in therms is calculated in Col 13. Thisis a function of the TMY3 adjusted therms and the calculated improvement in efficiency. Daily savings values are summed to obtain the annual heating savings..

$$Annual\ savings\ therms = (TMY3\ adjtherms\ Col\ 9 \times \Delta\ efficiency\ Col\ 12) - TMY3\ adjtherms\ Col\ 9$$

Measure 2: Install Condensing Domestic Hot Water Boilers

The domestic hot water savings are calculated from the post-installation billing histories. Non-heating gas usage was estimated from the June, July, August, and September gas histories. Natural gas is used for space heating, domestic hot water, and in commercial dryers in the laundry. Non-heating gas usage was calculated from the post-installation billing history in Measure 1. This usage had to be adjusted to account for the gas dryer operation. Facility personnel estimated that there are about 60 dryer loads per day and the average dryer cycle is about 20 minutes at full dryer output. The savings calculations and assumptions are presented in the following worksheet – Figure 2.6. The calculation methodology is explained below.

Figure 2-5. Domestic Hot Water Savings Calculations

The formula to calculate the dryer portion component of the non-heating gas usage is:

Annual dryer therms = (60 loads/day x 365 days/year x (20min/60 min per hour)/load x 24,000 Btu/hrs)/103000 BTUs per therm

This value is subtracted from the total annual non-heating therms calculated in Measure 1 to estimate the natural gas used by the DHW boilers.

The tracking documentation used a baseline efficiency of 80%. This was retained for the evaluation analysis. A 91.4% efficiency was obtained from combustion test performed on the operating DHW boiler. This was considered as a “typical” average operating efficiency. The DHW is stored in a holding tank maintained at 145°F. The circulated supply water is fed to the building at 115°F through a mixing valve. DHW circulation is constant to feed the far end units. The combustion test was done mid-day away from early morning or evening usage. The 91.4% efficiency is only slightly lower that the 94% rated efficiency of the new boilers. The savings are calculated as:

Annual DHW savings therms = Adjusted non-heating therms x (evaluation eff / baseline eff)

3 FINAL RESULTS

This project consisted of installing three new condensing boilers to replace existing heating boilers, and the installation of two condensing boilers to replace existing domestic hot water heating boilers. The measures were properly installed and are working as intended. A hot water temperature reset controller was installed with the heating boilers. This controller works with the boilers by providing supply water at the lowest possible temperatures while meeting the heating loads on the facility. This results in lower return water temperatures. These lower temperatures have the condensing boilers operating at greater efficiency for longer periods of time.

The total evaluated savings for both measures is 4,729 therms/year. The final site realization rate is 30%.

Table 3-1.Evaluated Savings Impact Calculations

Evaluated	Base Case	Installed
Measure #1: Condensing Heating Boilers		
Efficiency	80%	89.6%
Gas usage – weather normalized	N/A	27,563
Savings	3,278	
Measure #2: Condensing DHW Boilers		
Efficiency	80%	91.4%
Gas usage – non-weather sensitive	9,454	8,729
Savings	1,451	
Total Gas Savings and Realization rate		
Total Annual Gas Savings	4,729	
Final site realization rate	30%	

3.1 Cross Check with Billing Data

Natural gas billing history was used directly in the savings analysis. Adjusting post-installation gas usage to TMY3 heating degree day equivalents are discussed the analysis methodology in Measure 1.

3.2 Recommendations for Program Designers & Implementers

The project consisted of two measures. Savings for the condensing heating boilers were calculated using the average values from the prescriptive program. The savings for the condensing domestic hot water boilers were calculated as a custom measure. Calculation methodologies should be the same for all measures in a project.

The DHW savings were calculated using mass flow calculations. However, the resulting savings percentage exceeded the maximum possible percent improvement in boiler efficiency. This mistake could have been caught with better documentation and a more thorough review.

3.3 Customer Alert

The facility personnel stated that there no major problems with either installed system. A minor boiler shutdown issue linked to the new breeching appears to have been resolved. The facility personnel are happy with the new systems.

3.4 Explanation of Deviations

The evaluators and the applicant both utilized billing information to determine the savings for this project. Additionally, the evaluators used logged data to supplement the billing information and estimate several key parameters of the system, including the operating efficiency. The key reasons for deviations between the evaluation and tracking results are:

- Savings for the three heating hot water boilers were calculated using the prescriptive measure values which did not take into account the specific site conditions, size or efficiency of the installed units. Prescriptive savings applies the same fixed annual savings value [2,641 therms per year] for each of the three boilers. The prescriptive deemed savings value assumes equal full load operating hours for each boiler. The installed boilers modulate according to heating load and need. The prescriptive full load operating hours exceed the actual operation of the boilers in the facility.
- The apartment complex uses natural gas for space heating, domestic hot water, and for commercial clothes dryers in the central laundry. The tracking savings did not account for dryer usage when estimating natural gas usage, overstating the amount of billed natural gas devoted to heat and domestic hot water.
- The tracking savings show pre-installation and post installation gas usage of 17,093 and 9,454 therms respectively for domestic hot water usage .Given no other work was done to save on domestic hot water usage, this 45% reduction is not reasonable particularly when the required baseline efficiency is 80% and the installed efficiency is estimated to be 94%.The evaluators were able to reverse engineer the pre-installation natural gas usage for domestic hot water usage. The usage for the installed boilers could not be replicated within the realm of practical operation was likely due to calculation error. The domestic water heating savings difference is due primarily to calculation error.

1. Project Summary and Results

This project involves the installation of energy efficient windows at a high school in Rhode Island. The total area of retrofitted windows is 9,432 square feet. These windows are scattered on all the four orientations of the building shell. The total area of the main building shell of this high school where the window retrofit has taken place is 166,000 square feet. The space heating needs of the school is served by a single utility gas meter. There are other gas meters for this site which are assigned to the kitchen and domestic hot water usage, the field house and a back-up generator.

Though the new windows replaced older windows at the school, this project was considered a time-of-replacment project by the Program Administrator due to the age and the very poor condition of the existing windows., The existing windows had very large openings, which allowed a large amount of air to infiltrate the building shell. Note that, despite the project being considered a time-of-replacement project by the Program Administrator, the TA vendor’s savings estimates were based on the characteristics of the existing windows.

The existing windows were single pane windows. The glass used in new windows is a double pane glass with, ¼ inch thick clear glass on inside and ¼ inche annealed green glass sheet on the outside. The new windows have ½ inch space between the two glass layers which act as thermal insulators. The total thickness of the glazing material used in the new windows is 1 inch. The school facility is operational for 10 months a year excluding July and August. During the operational months, the heating system and the school itself is operational for 10 hours per day. During the non operational period of this school, the heating system is shut off completely.

During the site visit, evaluators verified the installation of all energy efficient windows. Evaluation activities included on-site inspection, building simulation modeling using eQuest, inspection of the HVAC units, collection of operating schedule information of the facility from the site contact and other data collection activities.

Based on the site audit findings and conversations with the site contact it was concluded that the existing windows at the school facility were at the end of their useful life and needed to be replaced. Therefore this project is treated as a time of replacement project in this evaluation, and the appropriate code-compliant baseline window charactaristics were applied to the evaluation results.

Analysis conducted by the evaluation team shows annual gas energy savings of 15,500 therms compared to the savings estimate of 19,806 therms reported in the original application.

1.1 Savings

Measure ID	Measure Name		Gas Savings (Therms/yr)	Electric Savings (kWh/yr)
1	Energy efficient windows	Tracked	19,806	N/A
		Evaluated	15,500	
		RR[1]	76%	
[1]Realization rate				

1.2 Explanation of Deviations from Tracking

One reason for the difference between the tracking savings reported by the customer and the evaluated savings estimate is the infiltration factor used by each party for their base case models. The original application made use of a baseline infiltration factor of 0.55 cfm per square foot in their calculation whereas the evaluation estimate used 0.3 cfm per square foot to quantify the savings. Since this project is considered a time of replacement project, the value used by the evaluation team is consistent with the minimum code requirement for infiltration rate for windows for the State of RI if the project was completed before 2010. This requirement is consistent with IECC 2009 codes and standards.

A second reason for the discrepancy between the tracking and evaluated savings were due to the difference in infiltration rates of the new windows between the two analyses. The original savings estimate used an infiltration rate of 0.008 cfm per square foot. However, manufacturer's data on the new windows showed that the actual infiltration rate was 0.1 cfm per square foot.

A third reason for the discrepancy between the energy savings estimate provided in the original application and calculated by the evaluation is the two different methods used to quantify these savings. The original savings estimate made use of ASHRAE heat loss calculations, whereas the method used by the evaluation team used an energy simulation. The simulation estimates the building's gas usage in the installed case by creating a model which is calibrated to the gas consumption of the installed case. The applicant's method does not reveal if it was calibrated to the actual energy consumption of the facility.

The use of an energy simulation building model makes it difficult to discern the individual impacts of these reasons quantitatively. However, the cumulative effect of these discrepancies led to the overall realization rate of 76% for this project.

2. EVALUATED MEASURE: ENERGY EFFICIENT WINDOWS

The following sections present the evaluation procedure, an analysis of the application calculations, and the evaluation methodology determined to be the best fit for the site based on the information available.

2.1 Application Information and Analysis

The sections below detail the information contained in the application documents that were provided to evaluators.

2.1.1 Application Description of Baseline

For the calculation of the baseline gas energy savings, the customer used an infiltration rate of 0.55 cfm per square foot and overall U-value of existing windows as 0.95. The U value used by the customer in baseline is taken from ASHRAE standard tables for loosely fit windows. Similarly, the infiltration rate is also taken from ASHRAE.

2.1.2 Applicant Description of Installed Equipment and Operation

The proposed windows with aluminum frames used glass with a U value of 0.29 and an infiltration rate of 0.008 cfm per square foot. The proposed windows have a double layer of glass; the outer layer is green annealed glass which is ¼ inches thick and the inner layer is clear glass with ¼ inches thickness as well. The space between the two glass layers is ½ inches which makes the entire windows glazing assembly 1 inch thick.

2.1.3 Applicant Energy Savings Algorithm

The methodology used by the customer to estimate the energy savings is based on ASHRAE calculations, which estimates heat loss through transmission and infiltration. The model created by the applicant uses the temperature gradient difference between the inside and outside conditions of the facility. The U value and infiltration rates used in this calculation are taken from the ASHRAE tables. The U value used was 0.95 and the infiltration rate used for the calculation was 0.55 cfm per square foot. The model uses the following formula to calculate the heat loss:

$$Q = U*A*(T_{out}-T_{in})$$

Where

U = Conductance of windows (Btu/hr ft^2 F)

A = Area of windows (square feet)

T_{out} = Outside temperature (F)

T_{in} = Inside temperature (F)

The equation that is used to quantify the heat loss through infiltration is:

Heat loss infiltration = H = Specific heat of air *Density of air *Air infiltration factor * Delta T

The infiltration factor used in above equation by the customer is 0.65 cfm/linear foot, which is used to calculate the infiltration rate of 0.55 cfm per square foot.

2.1.4 Analysis of Applicant Algorithm

The method used by the customer to calculate energy savings for the new energy efficient windows lacks calibration of their results against total heating usage from monthly gas billing data. Also the method does not take into consideration the mechanical behavior of the equipment that provides heating energy to the facility such as their operation, sequencing, and flow rate of heat energy supplied to the system boundary which is directly related to the gas consumption of the facility. Evaluators believe that this method is not the most accurate for quantifying energy savings due to the lack of consideration of these building characteristics.

2.2 On-Site Inspection, Metering, and Analysis

This section provides the steps of the evaluation from initial site visit through the final results. Each step is described in detail to offer an in-depth reasoning behind the full process.

2.2.1 Summary of Site Visit Findings

The evaluators visited the site on July 17, 2012 and verified that the windows on each side of the building had been installed. The evaluators collected the actual dimensions of each side wall and the dimensions of windows and doors at this facility. A visible inspection of the installed windows was conducted and it was verified that a total of approximately 9,432 square feet of windows were installed.

In order to build an eQuest model to calculate the energy savings, the evaluation team collected various data parameters, including information on the building shell and heating and cooling systems. The operating schedule of the facility and the details of new windows were also collected from the customer during the on-site visit. The various parameters that were collected are listed in Table 2-1.

Table 2-1. Data Collection Values for the eQuest Model

EQuest Parameter	Value or Description	Source
Wall construction	Brick walls	Site data
Roof construction	Built-up roof with metal frame	Site data
Floor to ceiling height	10 feet	Site data
Heating system	Boilers(3.2 MBtu)	Site data
Boiler efficiency	80%	Site data
Heating system location	Central boiler plant	Site data
Hours of operation/day	10 hours ; 7am – 5pm; 5 days/week	Site data
New Window type	Double pane	Site data
New Glass type	Clear glass	Site Data and Manufacturer’s Spec
Insulation for new Windows	½ inch air space	Manufacturer’s Spec
New Window frames	Aluminum	Manufacturer’s spec
Total area of retrofit windows	9,432 square feet	Site data and project documents
Number of floors	1 and 2 floors	Site data

2.2.2 Measured and Logged Data

The evaluation team did not perform any metering for this site. All building shell data and operational information of the facility was collected on-site by inspection and through interviewing the site contact. The window and glass information that was not available from the customer was collected from the glass manufacturer and local supplier of the windows.

2.2.3 Evaluation Description of Baseline

During the on-site audit of this facility, the customer verified that the existing windows were single pane windows with metal frames. The customer also verified that the old windows had numerous cracks and other such openings. The cracks and other opening were present between the window frame and the building shell. The existing windows, which were 25 years old, were at the end of their useful life, which was confirmed by the customer who stated that they needed replacement due to their condition. Based on this discussion with the customer, the evaluation team considered this project as a time of replacement project for evaluation purposes. Since this work was completed before July 2010, the 10^{th} edition of the RI building code, which is derived from IECC 2009 code requirement for the state of RI, is used as the baseline for this project. The 2009 code allows an infiltration rate of 0.3 cfm per square foot and a U value of 0.35. The evaluation team used these values as the baseline in quantifying the energy savings.

2.2.4 Evaluator description of installed equipment

The evaluators used an infiltration rate of 0.1 cfm/square foot for the installed windows, which is specified by the manufacturer. This value is higher than assumed in the TA study. The installed windows have an overall U factor of 0.29.

2.2.5 Evaluator Calculation Methodology

The energy simulation program, eQuest, was used as the analysis tool. A proposed model was constructed using data collected during the site visit (Table 2- 2-1). For this site, evaluators used climate data from Providence, RI, which is the closest weather station to the school.

The evaluation team conducted a site visit which included collection of building foot print and dimensions of each wall and section of building shell of this school. This information was used in the eQuest simulation tool to create the sketch of the model that resembles the foot print of the school. The evaluation team identified the counts and dimensions of each installed window on each building orientation. This information was used to calculate the net percentage of window to wall area ratio. for each orientation.

Along with the data points listed in table 2.1, the evaluation team designed the simulation model with various other inputs to the model such as the orientation of the building, lighting schedule, occupancy operating schedule, etc. The mechanical system that provides heating energy to the school facility was also included in the model. The mechanical system used is hot water boilers with hot water loops connected to air handling units which are situated on various locations of the building roof. The operating efficiency of the boiler used in the simulation is 80%.

With all the inputs provided to the simulation model an energy efficient run was created with the new windows that include a lower infiltration rate and lower U value. This run is called as “energy efficient run” which depicts the post installation condition of the facility. A baseline run was then created which depicts the baseline conditions of the school facility. The difference in gas consumption between these two runs serves as the basis of the gas savings.

2.2.6 Evaluator Calculation Results

The energy simulation model results are tabulated in below table 2-2. The estimated savings for the project are 15,500 therms per year.

The evaluation team calibrated their post installation simulation model with the post installation utility gas consumption data provided for this facility. The total gas consumption for the post installation period predicted by the evaluation model is 62,400 therms which match closely with the actual billing consumption of 66,798 therms provided in the utility bills. The slight difference is due to the fact that the eQuest simulation is done based on the actual historic average weather data file a particular weather region whereas the gas consumption from utility bills is for one particular year and it may reflect some minor operational differences between the simulation and actual conditions. Post installation utility data is for the period October 2010 through September 2011.

The evaluation team had received the pre and post installation utility gas consumption data for this facility. It was noted that the pre installation usage of 64,945 therms) was lower than the post installation usage of 66,798 therms. After contacting the customer it was revealed that many of the air handling units providing space heat to the facility during the pre-installation phase were not operational and they needed to be fixed. In the post installation period, the AHUs were fixed. The customer also confirmed that after the new windows were installed, some occupants experienced a “stuffy nose” feeling, which was solved by injecting more air flow into the rooms and running the fans for longer period of time. Because of the increasing fan operation time and flow rate, the post installation gas consumption of this facility was higher than that of the pre installation period. In an ideal situation, all the fans of the heating supply system should have been operational during the pre-installation phase. But it was confirmed from the customer that only a portion of the fans were operational prior to the installation of the new windows, which led to less gas consumption. Due to this under operation of supply fans, the gas consumption shown in the utility bills during the pre-installation phase is not quite the correct representation of gas usage. Following the windows retrofit project, the school facility fixed all the fans and made them completely operational. The gas consumption shown on the utility bills after the windows retrofit project was completed had already taken into consideration the normal operation of all fans. Because of this adjustment in operation, the billing data from pre 64,945 therms to post 66,798 therms installation phase is not representative of the change in the window performance.

The evaluation team, while creating their simulation model, built the model based on the assumption as if all the fans were operational during the pre-existing phase and kept them unchanged to the post installation phase. From a modeling perspective, the only change that took place was the upgrade of the baseline windows to new windows, which essentially reduced the heat conduction through the glass and the infiltration of outside air into the building’s heating space. This change serves as the basis of the energy savings estimated by the model.

Table 2-2. Evaluation Model Results

Month	Usage (Therms)		Savings (Therms)
	Pre-Retrofit	Proposed	
January	17500	14700	2300
February	14900	12400	2100
March	11200	9000	2000
April	5900	4500	1900
May	1400	800	1400
June	300	100	400
July	0	0	0
August	0	0	0
September	300	100	600
October	3500	2300	1300
November	8200	6500	1300
December	14500	11800	1900
Total	**77,700**	**62,200**	**15,500**

3. Final Results

This project involved replacement of existing windows at the end of their useful life with new energy efficient windows.

The total area of windows retrofitted in this facility is 9,432 square feet. Because of the weather dependent nature of this measure, the eQuest simulation tool was used to quantify energy savings, which takes into consideration the local weather profile of Providence, RI. Energy savings are 15,500 therms per year, which represents a 76% realization rate when compared with original savings estimate of 19,806 therms.

Table 3-1 summarizes key parameters from the analysis.

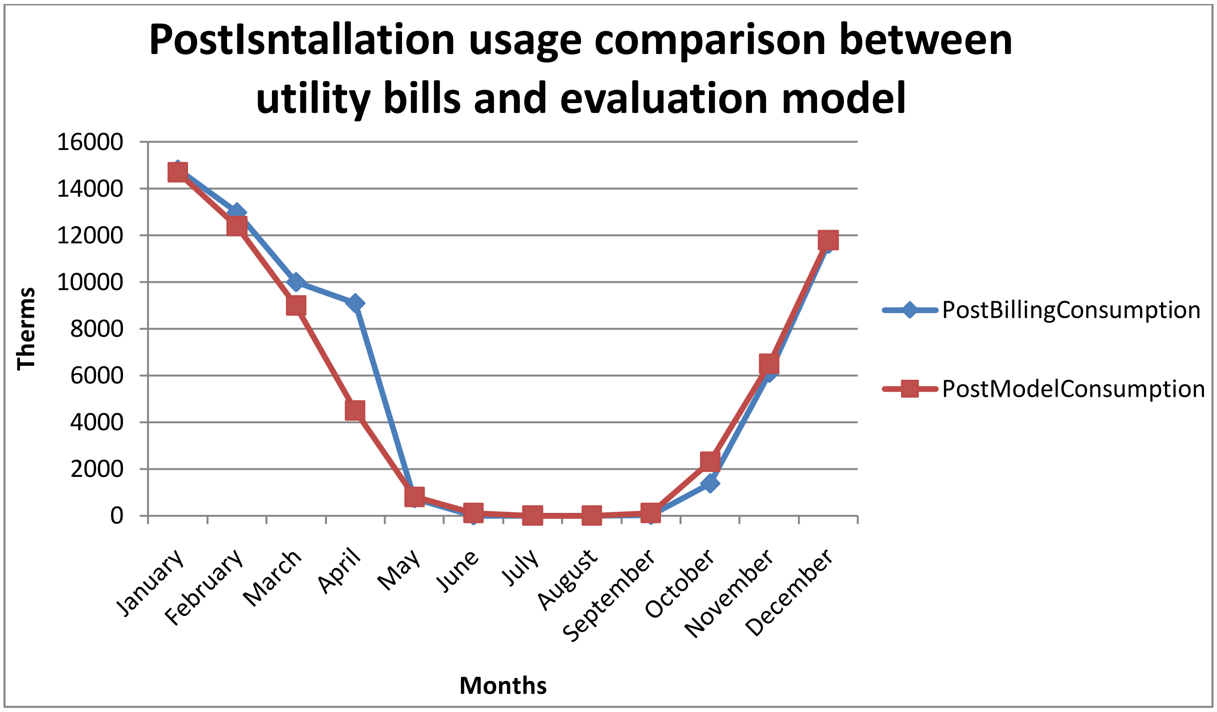
Table 3-1. Key Parameters

	Pre-Installation	Post-installation
Billing		
Actual billing usage (therms)	64,945	66,798
Tracking		
Savings (therms	19,806	
Evaluated		
Window area (square feet)	9,432	9,432
Savings (therms)	15,500	
Realization Rate (RR)	76%	

3.1 Cross Check with Billing Data

The evaluation team compared the post measure installation utility bills for this facility with the post installation usage predicted by the evaluator's model. The following figure illustrates comparison between post case actual billing usage and the usage predicted by evaluator's model.

The site contact confirmed that the facility did incorporate the changes in their usage pattern for the month of April which can be seen from the below graph. Also the facility supervisor clarified that for few months out of the year, the gas meter readings had been adjusted in next month's billing cycles because the bills for previous months would show no usage and they had to be adjusted in subsequent months.



3.2 Recommendations for Program Designers & Implementers

Energy modeling is an appropriate method for calculating savings for temperature-sensitive and building shell dependent measures such as energy efficient windows.

3.3 Customer Alert

None.

3.4 Explanation of Deviations

The most likely reason for deviation is the difference between the tracking savings is due the methods used by applicant and the evaluation team. The evaluation team made use of a simulation technique whereas the original savings estimated used a standard heat loss calculation to quantify the savings which was not calibrated to actual building usage. Second, the factors used for infiltration and heat conduction are different from applicant's number to the evaluator's number as explained in above sections. The applicants most likely used the original windows as the baseline, not the code required values as appropriate for a time of replacement project,

Table 3-2. Summary of Key Factors and Deviations

Factor	Original Application	Evaluator	Discussion of Deviations
Baseline Assumptions	Infiltration rate of existing windows (0.55 cfm/sqft).	Infiltration rate of baseline windows (0.3 cfm/sqft)	Though project was characterized as time-of-replacement, the TA study used the existing window infiltration rate, rather that code infiltration rate.
Installed Assumptions	Infiltration rate of new windows (0.008 cfm/sqft).	Infiltration rate of new windows (0.1 cfm/sqft).	TA study assumed a very low infiltration rate for the new windows. However, manufacturer's data show that the infiltration rate for the new windows is higher than predicted.
Analysis approach	Uses custom tool to calculate energy savings	Uses eQuest simulation.	Evaluation model accounts for building specific factors, and is calibrated to post-installation billing data. TA study did not calibrate to billing data.
		Total	The cumulative effect of these discrepancies resulted in a realization rate of 76% on annual therms savings.

1. PROJECT SUMMARY AND RESULTS

The site launders linen and uniform rentals. The facility operates 4 a.m. through 8:30 p.m. Monday through Friday. Combustion controls were added to a 600 hp gas-fired steam boiler recently converted from oil to gas. Controls included a parallel positioning control system with independent fuel and air actuators and O_2 trim as well as a variable frequency drive (VFD) on the blower motor. The boiler is shut off during nights and weekends. There is an additional back-up 250 hp gas-fired boiler onsite that does not have advanced combustion controls and was not part of the incentive.

The evaluator visited the site, interviewed site staff, took spot measurements, installed logging equipment, and conducted analysis to determine the evaluated savings.

1.1 Savings

Measure ID	Measure Name		Gas Savings (Therms/yr)	Electric Savings (kWh/yr)
1	Boiler controls	Tracked	17,383	NA
		Evaluated	5,976	NA
		RR[1]	34%	NA
[1] Realization rate				

1.2 Explanation of Deviations from Tracking

There are several areas in which the evaluated savings vary from the tracking savings:

- Operational – The applicant applied the efficiency improvement to an estimated lead boiler gas use that was larger than the actual amount used by that boiler. This decreased savings.
- Efficiency – The evaluators used combustion equations with variables measured by the applicant and onsite for the baseline and installed cases respectively. Although efficiencies were higher in both cases, the magnitude of the improvement was less resulting in lower savings.

2. Evaluated Measure

The following sections present the evaluation procedure, including the findings from an in-depth study of the supplied application calculations and the evaluation methodology determined to best fit the measure based on the information available.

2.1 Application Information and Analysis

This measure included only boiler controls on an existing boiler serving the process load. The oil to gas burner replacement had already been completed at the time of the application and was not incentivized.

2.1.1 Application Description of Baseline

The applicant used the existing 600 hp gas-fired burner with a turn down ratio of 3 as the baseline. Four spot measured efficiencies were measured across the boiler's firing range, as shown in Table 2-1. A mean gas-fired efficiency was calculated to be 77.94% assuming equal boiler loads at the firing rates shown. The hours of operation for the baseline and post-case scenarios were the same at 4380 hours. Annual gas usage was estimated to be 513,519 therms annually from existing oil billing data. The applicant allocated 77.57% of gas use to the lead 600 hp boiler, and 22.43% to the backup boiler. The project documents identify this project as a retrofit measure.

Table 2-1. Applicant Measurements of Baseline

Percent Firing	25%	50%	75%	100%
Stack temperature (°F)	390	456	510	543
Combustion air temperature (°F)	80	80	80	80
CO2 (%)	6.9	7.2	7.9	8.2
Excess air (%)	39	35	31	27
Oxygen (%)	10.0	8.0	7.0	5.4

2.1.2 Applicant Description of Installed Equipment and Operation

An existing 600 hp gas-fired burner was to be upgraded with several controls features. The first was a parallel positioning control system with independent actuators for combustion air and fuel controlled by a PLC-based system. Actuator positioning is based on a preset combustion curve. The second control installed was an O_2 trim system to reduce excess air. Third, a VFD was installed on the burner blower motor. This allows for further trim of O_2.

2.1.3 Applicant Energy Savings Algorithm

The applicant used a proprietary spreadsheet that calculates savings due to burner replacements, reductions in turndown ratios, sequencing controls, and implementation of parallel position controls with O_2 trim.

The applicant did not utilize the sequencing controls section of the spreadsheet. The savings identified in the spreadsheet are presented in Table 2-2.

Table 2-2 Summary of Applicant Savings Fractions

Savings mechanism	Combustion Efficiency	Efficiency Change	Seasonal Efficiency	Notes
Baseline	77.94%		72.94%	Based on gas-fired combustion test
O_2 Trim/PP		3.16%		O_2 from 7.6% to 3.0%
Purge Losses		0.17%		
Turn down ratio		N/A		No change
Final Seasonal			76.27%	
Seasonal efficiency change			3.33%	
Gas savings rate			3.39%	Of total billed use

Savings was the difference between the usage in the existing and proposed cases using the seasonal efficiencies above.

2.1.4 Analysis of Applicant Algorithm

The applicant savings calculation spreadsheet is proprietary, providing summaries of inputs and outputs, but not the mechanics or sources of savings factors, although some can be deduced. Generally, the spreadsheet is a step forward in providing more rigorous and transparent savings estimates compared to the fixed savings fractions frequently used for savings estimates.

The combustion efficiency is improved by the O_2 trim and parallel positioning controls. The estimate of the improved efficiency due to the controls is reasonable, given a change in O_2 from 7.6% to 3.0%.

The applicant also claims a reduction in purge losses, thought the mechanism for achieving this savings is not apparent, as the turndown ratio is equivalent in the pre and post case.

2.2 On-Site Inspection, Metering, and Analysis

This section provides the steps of the evaluation from initial site visit through the final results. Each step is described in detail to offer an in-depth reasoning behind the full process.

2.2.1 Summary of Site Visit Findings

The site was visited on February 16, 2012, and personnel were interviewed regarding the system operation. The boiler plant consists of two gas-fired boilers. The lead boiler, which underwent the upgrades evaluated in this report, is a 600 hp steam boiler with parallel position controls, O_2 trim, and a VFD controlled blower motor. The boiler has a rated input of 2.52 MMBtu/hr input. The back-up gas-fired boiler is 250 hp with linkage controls. It generally only operates during startup in the early morning to get the system to temperature and occasionally during peak times when the lead boiler cannot meet the full load. It also runs for space heating during nights and weekends.

Both boilers were originally installed with oil-fired burners. About 7 to 8 months prior to the combustion controls, the burners were changed to fire gas. The burner changes were not part of the incentives. Only the lead 600 hp boiler received the advanced combustion controls.

The contact noted that the other significant end-use at the site was the gas-fired dryers. Three 2.73 MMBtu capacity units run for 17–18 hours per day five days per week, year round. These units pull in the combustion air from outside. In addition there are small rooftop units which serve the offices and conference room space heating needs.

2.2.2 Measured and Logged Data

The evaluators installed logging equipment on both boilers from February 16 through March 17, 2012. Table 2-3 shows the points that were metered.

Table 2-3. Summary of Metered Data

Boiler	Parameter Measured	Time Interval	Duration
Lead	Blower fan amps	1 minute	4 weeks
Backup	Blower fan amps	1 minute	4 weeks

The evaluators we unable to take spot measures due to limited access to the boiler stacks. However, the site contact was able to modulate the boiler across its firing range allowing the evaluators to record efficiency information displayed on the PLC. The results are presented in Table 2-4. These efficiency measurements were taken ‘wet’, that is the moisture is not condensed prior to measurement, which raises the measured efficiency compared to a ‘dry’ measurement. The equivalent dry measurement is provided in the table.

Table 2-4. Combustion Readout Values (600 hp Boiler)

Percent Firing	Stack Temperature (°F)	Oxygen - Wet	Oxygen - Dry
10%	405	4.3%	5.1%
10%	391	3.4%	4.0%
25%	408	4.3%	5.1%
30%	417	2.7%	3.3%
40%	422	2.4%	2.9%
50%	418	3.6%	4.3%
60%	427	3.2%	3.8%

The boiler operated in a manner consistent with the controls.

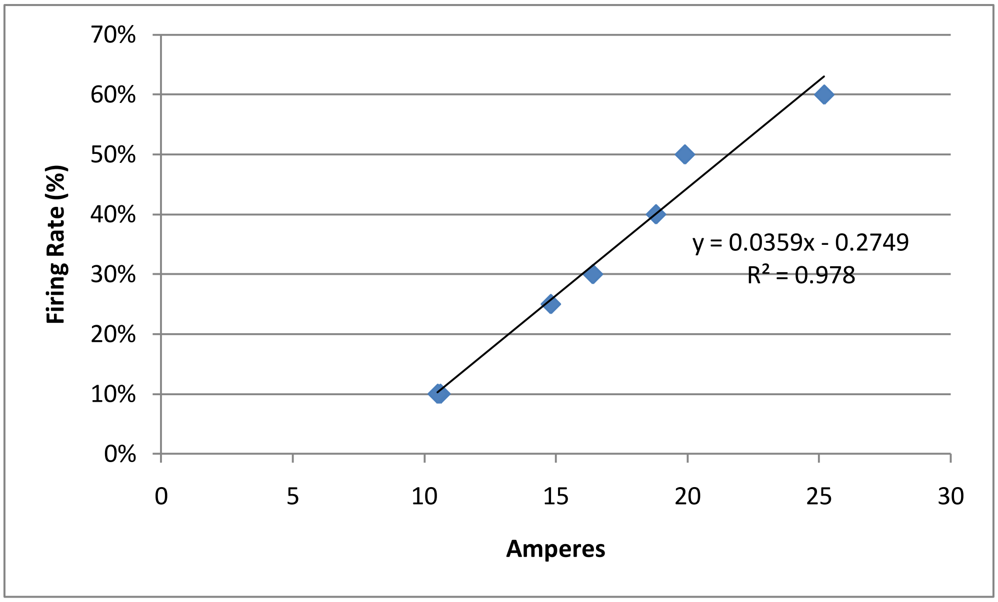
The blower motor fan amps were also recorded at each firing rate for the lead boiler, since it had a VFD installed. Fan amperage will increase as the firing rate increases. This allowed the evaluators to determine the firing at each amperage rating that was logged during the metering period.

The results are presented in Table 2-5. These points were fit to regression so amperage values throughout the firing range could be translated to a firing rate. The regression is presented in Figure 2-1.

Table 2-5. Ampere Measurements at Sampled Boiler Firing Rates

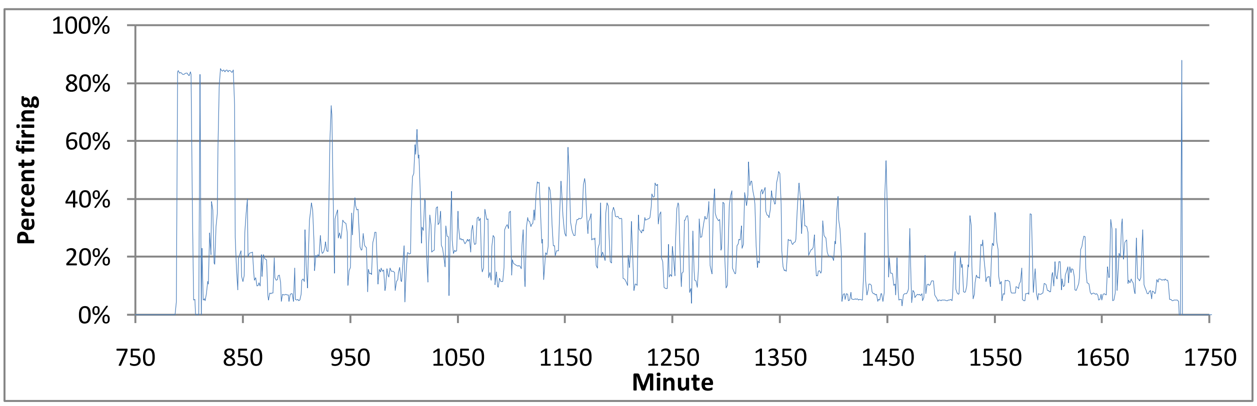
Percent Firing	Amperes
10%	10.6
25%	14.8
30%	16.4
40%	18.8
50%	19.9
60%	25.2

Figure 2-1. Regression of Amps to Firing Rate



A sample of the firing rate at a one minute resolution is shown in Figure 2-2. Note that the boiler did not cycle off once it was fired up at the beginning of the day.

Figure 2-2. Typical Boiler Daily Firing Profile



2.2.3 Evaluation Description of Baseline

This project involved the addition of advanced boiler controls to a gas-fired burner. The baseline boiler was linkage controlled. The burner was not changed out as part of this upgrade.

The baseline is based on the combustion efficiencies calculated using the equation listed below with spot measurements of stack and ambient temperatures and CO2 and O2 measured across the firing range taken prior to the retrofit. The measured values and calculated efficiencies are provided in Table 2-6.

Table 2-6. Applicant Provided Baseline Measurements and Combustion Efficiency

Percent Firing	25%	50%	75%	100%
Stack temperature (°F)	390	456	510	543
Combustion air temperature (°F)	80	80	80	80
CO2 (%)	6.9	7.2	7.9	8.2
Excess air (%)	39	35	31	27
Oxygen (%)	10.0	8.0	7.0	5.4
Calculated efficiency	81.66%	80.15%	79.04%	78.54%

2.2.4 Evaluator Calculation Methodology

The evaluator calculated savings due to the improved combustion efficiency from the parallel position and O_2 trim controls.

The evaluator used the metered data to estimate the firing rate profile. The profile was used to calculate annual usage as a function of the observed firing rate and boiler capacity. Next, best fit curves were developed for combustion efficiency vs. the firing rate for the base case and installed case using pre and post spot measurements of the boiler. Annualized pre and post combustion efficiencies were produced based using the firing rates of the high resolution firing rate profile. Equation 1 was used in calculating all efficiencies.

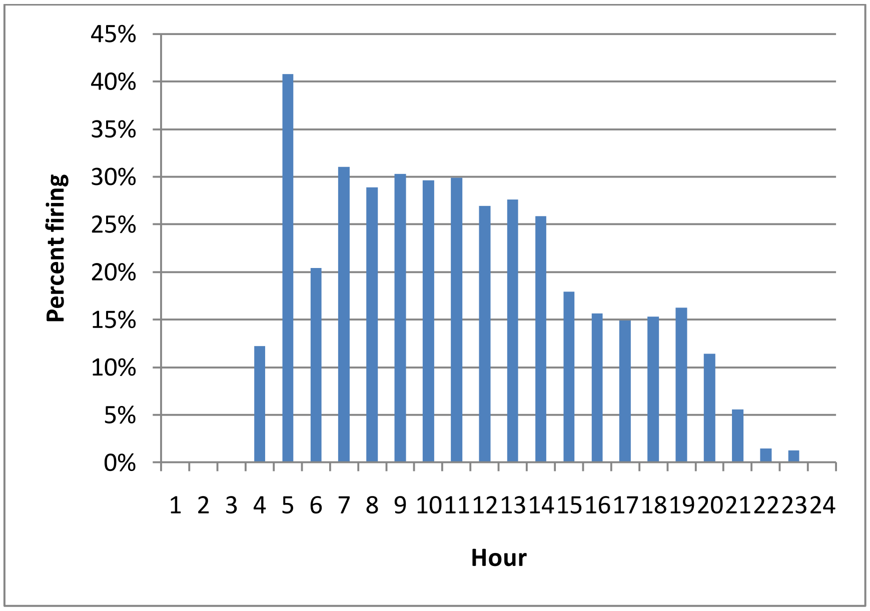
The savings is computed from a ratio of the annualized combustion efficiencies applied to the estimated gas use as follows:

Boiler Firing Rate Profile

The logged data was used to determine an hourly gas usage load profile. Since the load is for process, the evaluators used time of day rather than outdoor air temperature as the basis for the firing rate load profile.

The evaluators calculated the firing rate for each hour during the logging period. The results were binned hourly. The average hourly load profile is presented in Figure 2-3. The boiler firing rate typically ramps up from 4 a.m. to 7 a.m., levels off through the midday, and tapers off after noon before being shut off around 8–10 p.m. The boiler is shut off on weekends. This was confirmed through logged data. Figure 2-3 was used to confirm the overall boiler profile, but was not used directly in any calculations.

Figure 2-3. Hourly Boiler Load Profile



As can be seen in Figure 2-2, the boiler firing rate changes rapidly and since difference in efficiency changes with firing rate, a shorter calculation period is required to capture this effect. Using the logged blower fan ampere data, the minute by minute logged data was separated into firing rate bins to develop a profile for calculating the average change in efficiency. Table 2-7 shows the percent of time the boiler fired at each firing rate bin. This was the profile used to calculate the weighted annual combustion efficiency.

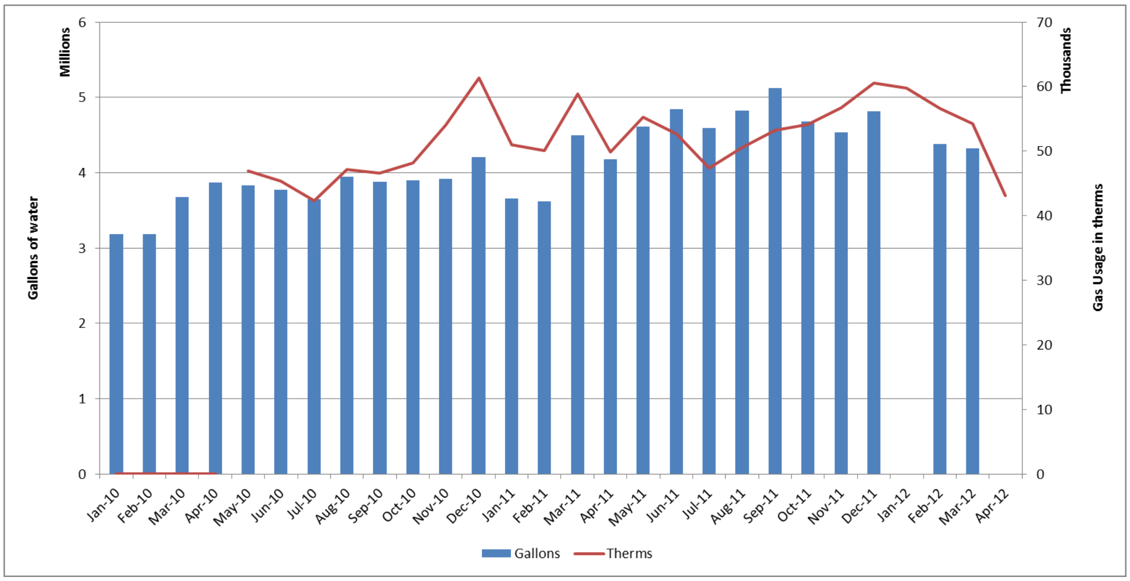
Table 2-7. Percent of Time at Each Firing Rate Bin

Firing Bin	Average Percent Firing	Percent of Time at Firing Bin
0% - <15%	9.6%	14.1%
15% - <25%	19.9%	17.0%
25% - <35%	30.2%	26.2%
35% - <45%	38.6%	21.2%
45% - <55%	48.6%	5.8%
55% - <65%	59.3%	1.3%
65% - <75%	70.8%	1.0%
75% - <85%	82.2%	5.8%
85% - <95%	86.9%	7.5%
95% - 100%	98.5%	0.0%

Production at the facility remains fairly consistent throughout the year with a slight uptick in the summer and an early winter down tick. Although production measurements were unavailable, the evaluators were able to obtain one year's worth of water consumption. Water consumption can be used as a proxy for production, and thus for gas use, but care should be taken since a variety of products, each with different water and heat demands, are laundered at the facility.

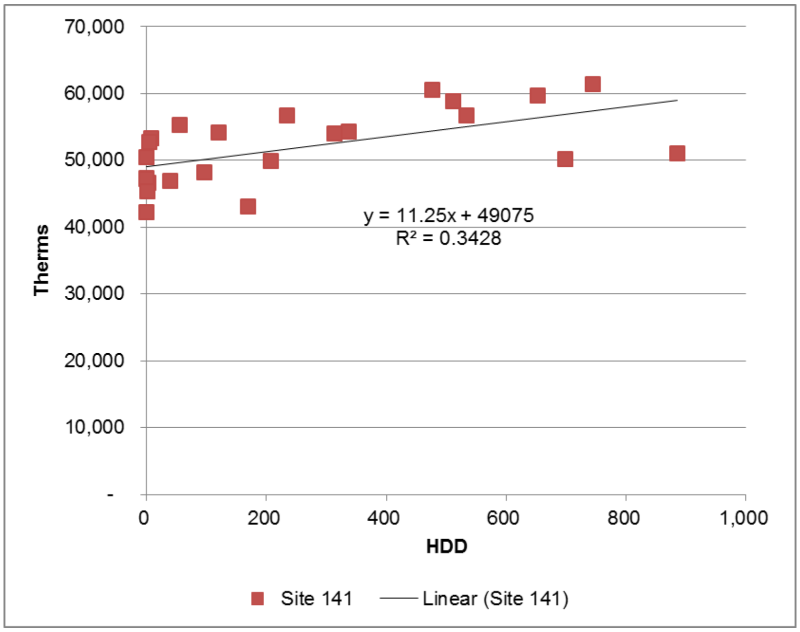
Using the customer provided water bills, the evaluators looked at the Btus of gas consumed per gallon of water used at a monthly time step. This value ranged from a low of 1,100 in July to a high of 1,400 in December, averaging about 1,250. In addition, the evaluator looked at the variation in water usage by month and noted that the February and March (the metering period) average water use was about 7% lower than the average use in the prior ten months with water usage. As this appears to be a consistent pattern and is likely to reflect lower production than in other months, the annual production gas use (for dryers and the boilers) was adjusted upward by 7%, for the ten months with higher levels of production. A graph of water and gas usage follows in Figure 2-4. Using this 7% reduction in water usage for the two months for which the metering was done compared to rest of the year results in an annual adjustment of 1.06

Figure 2-4. Water and Gas Usage History



The gas usage is process dominated, although there is a weak weather sensitive component to the bills, as shown in Figure 2-5. A space heating load was added to the boiler load using the equation in Figure 2-5, which is equal to about 7% of the billed usage and allocated to each boiler proportional to their annual gas usage.

Figure 2-5. Monthly HDD vs. Gas Usage

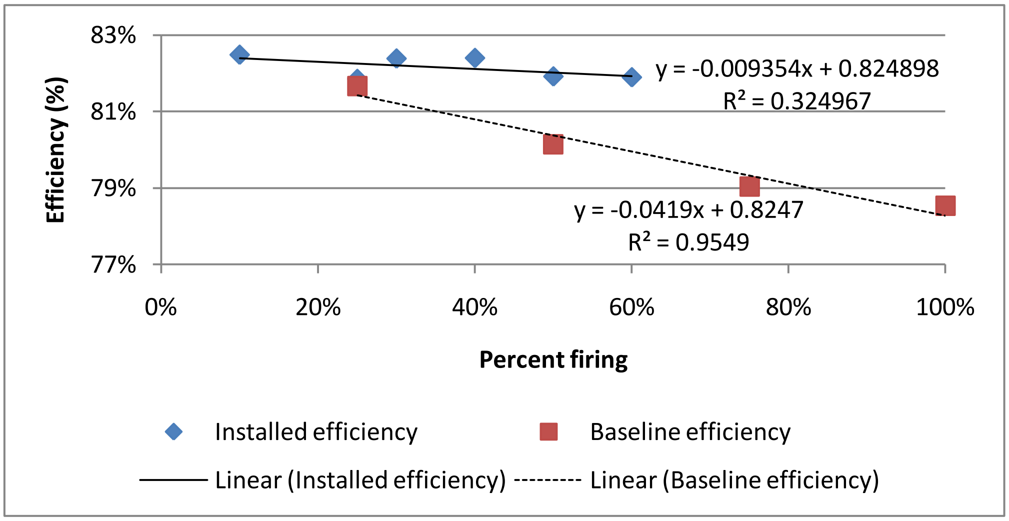


Calculation of Combustion Efficiency

Best fit curves were developed for combustion efficiency vs. the firing rate for the base and installed case using pre and post spot measurements of the boiler.

Stack temperature, O_2, and ambient temperature readings from spot measurements were used as inputs to calculate combustion efficiencies in Equation 1 described in the next section. The applicant measurements shown in Table 2-1 were used to calculate baseline efficiencies. The evaluator recorded measurements in Table 2-4 were used to calculate the installed efficiencies. The calculated combustion efficiencies were regressed against firing rate to produce two equations, as shown Figure 2-6.

Figure 2-6. Baseline and Installed Efficiency



Combustion Efficiency Calculation

The following equation[1] was applied to calculate the sensible boiler efficiency, where the measured inputs include the excess air and stack temperature:

(1)

where,

= Higher heating value of the fuel, equal to 23,797 Btu/lb for natural gas in this analysis

= The specific heat of the combustion products, estimated to be 0.26 Btu/lb-°F

= The temperature of the exhaust gases in °F

= The stoichiometric air-to-fuel ratio, equal to 17.2 for natural gas

= The excess air, in percentage

= The combustion temperature in °F, calculated according to the following equation:

where,

= The temperature of the combustion air before the burner, taken to be equal to the ambient room temperature (70°F) during the winter and the OAT during the summer

= The heat of reaction, equal to the HHV when the dew point temperature of the exhaust is less than 129°F and the lower heating value (LHV) [2] when the dew point temperature of the exhaust is greater than 129°F

Final Calculation of Savings

The average percentage of time at each firing rate by bin, illustrated in Table 2-7, was used to calculate the annual boiler gas usage as the sum of the product of the firing rate and boiler capacity in each bin. The analysis assumes fifty weeks of production per year, as described by the site contact.

The average pre and post combustion efficiency were calculated using the firing rate distribution shown in the high resolution boiler profile shown in Figure 2-2. The average baseline efficiency is the sum of the product of the baseline efficiency and the percent of time at a firing rate. Likewise, the installed efficiency is the sum of the product of the installed efficiency and the percent of time at a firing rate.

2.3 Evaluator Calculation Results

Table 2-8 provides the applicant and evaluator efficiencies for both the baseline and installed cases.

[1] "Quantifying Savings From Improved Boiler Operation," Kissoc, University of Dayton IAC, http://academic.udayton.edu/kissock/http/Publications/QuantSaveFromImpBoilerOp_IETC2005.pdf

[2] LHV = 21,441 Btu/lbs for natural gas

Table 2-8. Applicant and Evaluator Combustion Efficiencies

Firing Bin	Average Percent Firing	Percent of Time at Firing Bin	Applicant Efficiency		Evaluator Efficiency	
			Baseline	Proposed	Baseline	Installed
0% - 15%	9.6%	14.1%	79.22	83.8	82.1	82.4
15% - 25%	19.9%	17.0%	78.97	83.3	81.6	82.3
25% - 35%	30.2%	26.2%	78.72	82.8	81.2	82.2
35% - 45%	38.6%	21.2%	78.52	82.3	80.8	82.1
45% - 55%	48.6%	5.8%	78.28	81.8	80.4	82.0
55% - 65%	59.3%	1.3%	78.02	81.3	80.0	81.9
65% - 75%	70.8%	1.0%	77.75	80.7	79.5	81.8
75% - 85%	82.2%	5.8%	77.47	80.1	79.0	81.7
85% - 95%	86.9%	7.5%	77.36	79.8	78.8	81.7
95% - 100%	98.5%	0.0%	77.08	79.2	78.3	81.6

The annual usage of Boiler # 1 and the lag boiler was estimated as the average weekly gas usage, determined during the metering period, times 50 weeks of production. The gas usage was adjusted to account for increased production during the rest of the year compared to the metering period by multiplying by the 1.06 adjustment factor discussed above and shown in Table 2-9. The estimated weather normalized space heating usage was estimated using the regression listed in Figure 2-5.

After the boilers, the next highest end use at the facility was the dryers. Dryer gas use was estimated using information from the site contact that three 2.7 MMBtu/h dryers operated 17–18 hours per day. A 50% cycle factor was used to account for cooling and loading periods. The dryer use was also adjusted for annual production using the 1.06 adjustment factor. A summary of all the gas consumption is shown in Table 2-9.

As a check on the estimated boiler load, all the estimated gas end uses were summed and compared to the weather normalized billed use. Table 2-9 shows that the final estimated usage was within 1% of the weather normalized billed usage.

Table 2-9. Reconciliation Factor

Gas end use	Modeled Use	Adjusted Modeled Use
600 hp boiler use	338,697	359,357
250 hp boiler use	28,254	29,978
Normalized space heating	43,666	43,666
Dryer use	179,156	190,084
Production Adjusted Model	589,774	623,085
Production Adjustment	106%	
Weather adjusted billed use	629,926	99%

The final estimated monthly scaled usage of the lead boiler, the lag boiler, the space heating load served by the boilers, and the dryers is compared to the monthly weather adjusted bills in Table 2-10.

Table 2-10. Monthly Gas Use by End Use (therms)

Month	Lead Boiler	Lag Boiler	Dryer	Space Heating	Modeled	Weather Adjusted Billed Usage
January 2012	30,186	2,518	15,967	9,720	58,391	58,575
February	27,311	2,278	14,446	7,764	51,800	56,619
March	30,186	2,518	15,967	6,103	54,775	54,958
April	30,186	2,518	15,967	3,159	51,830	52,014
May 2011	30,186	2,518	15,967	972	49,644	49,827
June	31,623	2,638	16,727	109	51,098	48,964
July	30,186	2,518	15,967	0	48,671	48,855
August	30,186	2,518	15,967	2	48,673	48,857
September	30,186	2,518	15,967	260	48,931	49,115
October	30,186	2,518	15,967	1,843	50,514	50,698
November	28,749	2,398	15,207	4,741	51,094	53,596
December	30,186	2,518	15,967	8,994	57,665	57,849
Total	**359,357**	**29,978**	**190,084**	**43,666**	**623,085**	**629,926**

The gas usage of Boiler #1 was determined to be the sum of the 359,356 process therms listed in Table 2-9 and 2-10 and the proportion of the space heating load which was supplied by Boiler #1. That portion of the 43,666 therm space heating load that is served by Boiler 1 is proportional to the usage of Boiler 1 versus the total load usage of Boiler #1 and the lag boiler which is 92%. The sum of 359,356 therms and 92% of 43,666 therms is the 399,661 therms listed in Table 2-11.

The efficiencies identified in Table 2-8 were then applied to total therms used by Boiler #1 to calculate the savings shown Table 2-11.

Table 2-11. Evaluated Weighted Efficiency and Savings

	Baseline	Installed
Usage	405,636	399,661
Efficiency	80.94%	82.15%
% Savings	1.50%	
Savings (therms)	5,976	

Electric Impacts

A separate electric incentive application was submitted so electrical impacts were not evaluated.

3. Final Results

The site launders linen and uniform rentals. The facility operates 17 hours per day, 5 days per week. A 600 hp gas-fired boiler received controls upgrades including a parallel positioning controls system with independent fuel and air actuators and O_2 trim, as well as a variable frequency drive (VFD) on the blower motor. The evaluators confirmed that the system was installed, operating as intended and installed metering equipment.

The site savings were 5,373 therms, or 0.8% of the installed facility gas use Measure impact calculations are shown in Table 3-1.

Table 3-1. Applicant Algorithm Measure Impact Calculations

	Baseline	Installed
Billing		
Actual gas bills (May. 2011 – Apr. 2012) (therms)	N.D.	644,452
Weather-normalized billing difference		626,332
Tracking/Applicant		
Boiler seasonal combustion efficiency	77.94%	81.10%
Annual hours of operation	4,380	4,380
Average annual seasonal improvement in efficiency		4.05%
Gas usage (therms)	513,519	496,136
Savings (therms)		17,383
Evaluated		
Use-weighted boiler seasonal combustion efficiency	80.94%	82.15%
Annual hours of operation	4,034	4,034
Average annual seasonal improvement in efficiency		1.21%
Boiler gas usage (therms)	405,636	399,661
Savings (therms)		5,976
Realization rate		
Final realization rate		34%

Note: N.D. = No data; a full year of pre-retrofit billing data was not available.

3.1 Cross Check with Billing Data

A full year of billing data was not available for the pre-retrofit case. In addition the boiler is capable of burning both gas and oil so gas billing may not capture the full baseline energy use.

3.2 Recommendations for Program Designers & Implementers

The boiler is operating at a higher efficiency than predicted by the applicant. However, the baseline efficiency also appears to have been higher than stated by the applicant. The applicant may have been over ambitious in the efficiency improvement provided by the O_2 trim. As more controls projects are evaluated, TAs and PAs may have a better idea of typical efficiency improvements resulting from these projects.

3.3 Customer Alert

None.

3.4 Explanation of Deviations

Table 3-2 provides a summary of the key deviations between the tracking and evaluated savings.

Table 3-2. Summary of Key Factors and Deviations

Factor	Applicant	Evaluator	Impact of Deviation	Discussion of Deviations
Operations	513,519therms	405,636 therms	-46%	The applicant applied the efficiency improvement to an estimated breakdown between boilers and end uses.
Baseline efficiency	*77.94%*	*81.10%*	-60%	The evaluators calculated efficiency based on the applicant's inputs.
Installed efficiency	*80.94%*	*82.15%*	40%	The evaluators used a combustion analyzer to determine key efficiency parameters such as percent oxygen and stack temperature.

1. PROJECT SUMMARY AND RESULTS

This project involves replacing the linkage combustion controls for one 600-hp and two 300-hp steam boilers with parallel positioning oxygen (O_2) trim control packages and variable speed drives (VFDs) on each of the boilers' combustion blowers to operate the boilers efficiently. The boiler burners were converted from oil-fired to dual fuel fired, although the burners have been fired on gas exclusively since the burner replacement. The steam boilers support the manufacturing of specialty synthetic fabric at the facility. The facility operates 24 hours per day, 5 days per week.

The evaluator visited the site, interviewed site staff, took spot measurements, installed logging equipment, and conducted analysis to determine the evaluated savings.

1.1 Savings

Measure ID	Measure Name		Gas Savings (Therms/yr)	Electric Savings (kWh/yr)
1	Boiler controls	Tracked	40,908	N/A
		Evaluated	31,258	23,883
		RR[1]	76%	N/A

[1] Realization rate

1.2 Explanation of Deviations from Tracking

There are several areas in which the evaluated savings vary from the tracking savings:

- The applicant used what appears to be non-weather adjusted billing data which slightly understated the savings.
- The applicant projected improved combustion efficiencies of 86% with the combustion controls. The evaluator never measured efficiency above 85% efficiency with the mid-range efficiency for the large boiler operating at about 84% efficiency. This was the largest source of discrepancy.

2. Evaluated Measure

The following sections present the evaluation procedure, including the findings from an in-depth study of the supplied application calculations and the evaluation methodology determined to best fit the measure based on the information available.

2.1 Application Information and Analysis

This measure included boiler controls on three existing high pressure steam boilers serving the process load in a manufacturing facility

2.1.1 Application Description of Baseline

The applicant describes the baseline system to be a constant speed combustion fan with combustion air modulated with linkage and damper controls for the 600-hp boiler and both 300-hp boilers. The boilers had previously fired only oil, but had been converted to dual gas and oil firing prior to and not part of the controls upgrades. Fuel switching was not included in the application. Several spot measurements were taken of the baseline boilers. However, these appear to be taken when the boiler was firing on oil, since the efficiencies range from 87-89%, very high for gas and more typical of the stoichiometric properties of oil.

2.1.2 Applicant Description of Installed Equipment and Operation

The three existing boilers discussed above were retrofitted with new variable speed drive combustion blowers with parallel positioning capabilities and oxygen (O_2) trim controls. The combustion fan speed, thus the combustion air load, is modulated to maintain a 3-5% oxygen content of the effluent combustion products.

2.1.3 Applicant Energy Savings Algorithm

The applicant used a proprietary spreadsheet that calculates savings due to implementation of parallel position controls with O_2 trim. However, the spreadsheet does not provided any inputs or calculations to show how the old or new boiler efficiencies were determined. The baseline and installed efficiencies identified in the savings summary are presented in Table 2-1.

Table 2-1. Summary of Applicant Efficiencies

	Steady State Efficiency		Seasonal Efficiency		
Boiler	**Baseline**	**Installed**	**Baseline**	**Installed**	**Portion of Load Served**
1 (300 hp)	81.8%	83.4%	76.8%	78.4%	16.7%
2 (300 hp)	82.9%	84.1%	77.9%	79.1%	16.7%
3 (600 hp)	81.3%	86.5%	76.3%	81.5%	66.7%
Weighted Average			76.7%	80.7%	

One year of billed gas consumption was multiplied by the baseline weighted efficiency to determine the load. Load was then divided by the proposed weighted efficiency to calculate the proposed gas use. The difference between the base and the proposed usage was the savings.

2.1.4 Analysis of Applicant Algorithm

The applicant savings calculation spreadsheet is proprietary and provides limited information of inputs and outputs, or the mechanics and sources of savings factors.

Unlike some other applications, there were no measurements 'receipts' recording the results of a combustion measurement test with recorded stack temperatures, O2, or ambient temperatures. In addition, the algorithm input and output documents did not include any of these values. The evaluators question the meaning of the baseline efficiency, since the source of the inputs is unknown. Other project documentation includes several spot measurements that appear to be taken when the boiler was firing oil. If these oil-fired values were converted to gas-fired values, the mechanics are not documented.

Finally, while all three boilers have similar baseline combustion efficiencies between 81.3% and 82.9%, the projected increase in efficiency varies by boiler by a factor of three with largest boiler projected to have 5.3% increase in efficiency and the smaller boilers only a 1.6% and 1.2% improvement. There was no reason offered why the larger boiler would have a larger improvement.

The billed gas usage was reasonable.

2.2 On-Site Inspection, Metering, and Analysis

This section provides the steps of the evaluation from initial site visit through the final results. Each step is described in detail to offer an in-depth reasoning behind the full process.

2.2.1 Summary of Site Visit Findings

The site was visited on February 13, 2012, and personnel were interviewed regarding the system operation. The boiler plant consists of three dual gas and oil-fired boilers. According to the site contact they have been and plan to continue to fire gas only due to economics and maintenance considerations. The lead boiler is a 600 hp steam boiler with parallel position controls, O_2 trim, and a VFD controlled blower motor. The two lag steam boilers are 300 hp with similar controls. They typically fire during peak periods when the lead boiler cannot meet the plant's load, and weekends during the heating season when the lead boiler is shut down. The lag boilers rotate operation weekly.

All three boilers were originally oil-fired boilers. In 2008 their burners were replaced to accommodate both oil and natural gas firing. Natural gas firing is preferred by the site. All three boilers were fitted with combustion controls.

Production at the facility remains fairly consistent throughout the year according to the site contact. In April of 2010 the facility was closed for several weeks due to flooding. This is reflected in the billing data.

The portion of the plant which includes the three boilers is served by a single gas meter. An additional meter at the site serves other process loads, including a dryer process.

2.2.2 Measured and Logged Data

The evaluators installed logging equipment on both boilers from February 13 through March 14, 2012. Table 2-2 shows the points that were metered.

Table 2-2. Summary of Metered Data

Boiler	Parameter Measured	Time Interval	Duration
600 hp boiler	Blower fan amperes	1 minute	4 weeks
600 hp boiler*	Stack temperature	1 minute	4 weeks
600 hp boiler**	Blower fan amperes	15 seconds	2 days
300 hp boiler #1	Blower fan amperes	1 minute	4 weeks
300 hp boiler #1	Stack temperature	1 minute	4 weeks
300 hp boiler #2	Blower fan amperes	1 minute	4 weeks
300 hp boiler #2	Stack temperature	1 minute	4 weeks

Note: *The thermocouple malfunctioned so no data was available

**This data was recorded during the combustion analyzer deployment

The evaluators also took spot-combustion measurements using a combustion analyzer (CA), across the 600 hp and one 300 hp boilers' firing range. The results for the lead boiler are presented in Table 2-3 and for the lag boiler in Table 2-4. The evaluator also noted the efficiency reading from the combustion control panel output (PLC) for combustion efficiency, which is included in the table as well. The difference between the PLC and spot measurements is evident. Typically, PLC efficiencies read high, because the gas measurements are taken without condensing out the water first (a so called 'wet' measurement). The differences could be due to calibration issues with the PLC (the evaluator combustion analyzer had been calibrated in the previous month at the factory) or the variability in the boiler performance from minute to minute. The evaluator uses the CA recorded efficiencies and did not use the PLC efficiencies in any calculations.

Table 2-3. Spot Combustion Measurements (600 hp Boiler)

Percent Firing	Stack Temperature (°F)	Oxygen	Excess Air	CA Recorded Efficiency	PLC Recorded Efficiency
25%	346	10.2%	86.1%	84.4%	80.90%
50%	355	6.2%	33.3%	82.7%	80.70%
75%	363	9.0%	65.8%	82.6%	80.30%
100%	365	8.7%	62.0%	82.3%	79.60%

Table 2-4. Spot Combustion Measurements (300 hp Boiler)

Percent Firing	Stack Temperature (°F)	Oxygen	Excess Air	CA Recorded Efficiency	PLC Recorded Efficiency
25%	328	13.6%	160.9%	84.1%	80.80%
50%	354	7.1%	45.7%	83.1%	82.10%
75%	373	7.7%	55.0%	82.9%	80.90%
100%	384	7.8%	43.8%	82.9%	80.40%

The blower motor fan amps were also recorded at each firing rate for both boilers, since it had a VFD installed. Amperage will increase as the firing rate increases. This allowed the evaluators to determine the firing rate each time the amperes were logged during the metering period. The results are presented in Table 2-5 and Table 2-6 for the 600 and 300 hp boilers respectively. These points were fit to regression so amperage values throughout the firing range could be translated to a firing rate. The regressions are presented in Figure 2-1 and Figure 2-2 respectively.

Table 2-5. Ampere Measurements at Sampled Boiler Firing Rates (600 hp Boiler)

Percent Firing	Amperes
25%	8.4
50%	13.7
75%	16.7
100%	18.7

Table 2-6. Ampere Measurements at Sampled Boiler Firing Rates (300 hp Boiler)

Percent Firing	Amperes
25%	6.3
50%	8.8
75%	9.9
100%	10.6

Figure 2-1. Regression of Amps to Firing Rate (600 hp Boiler)

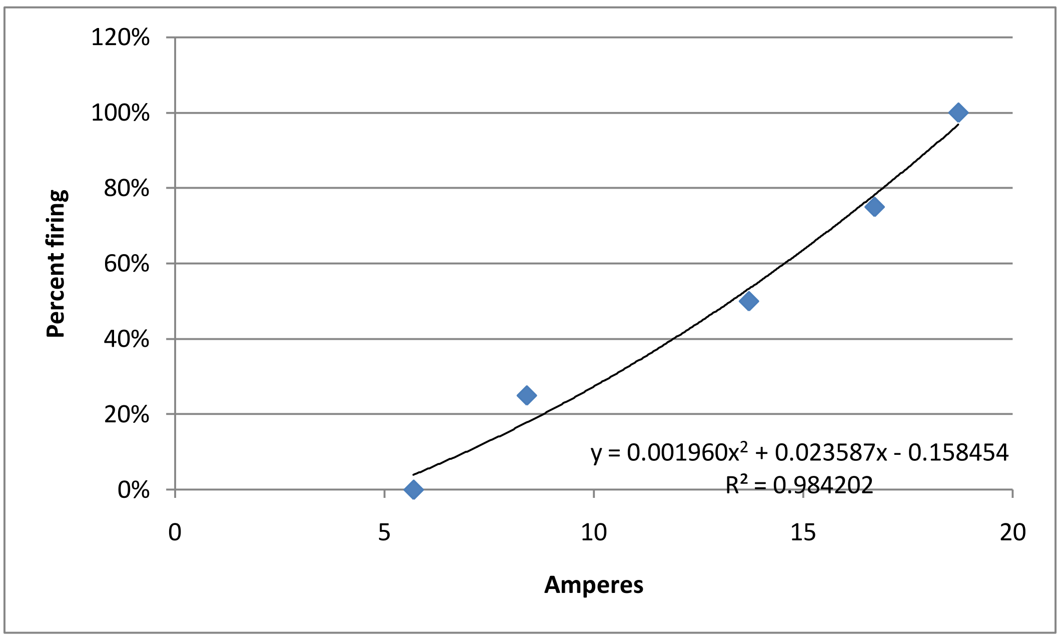
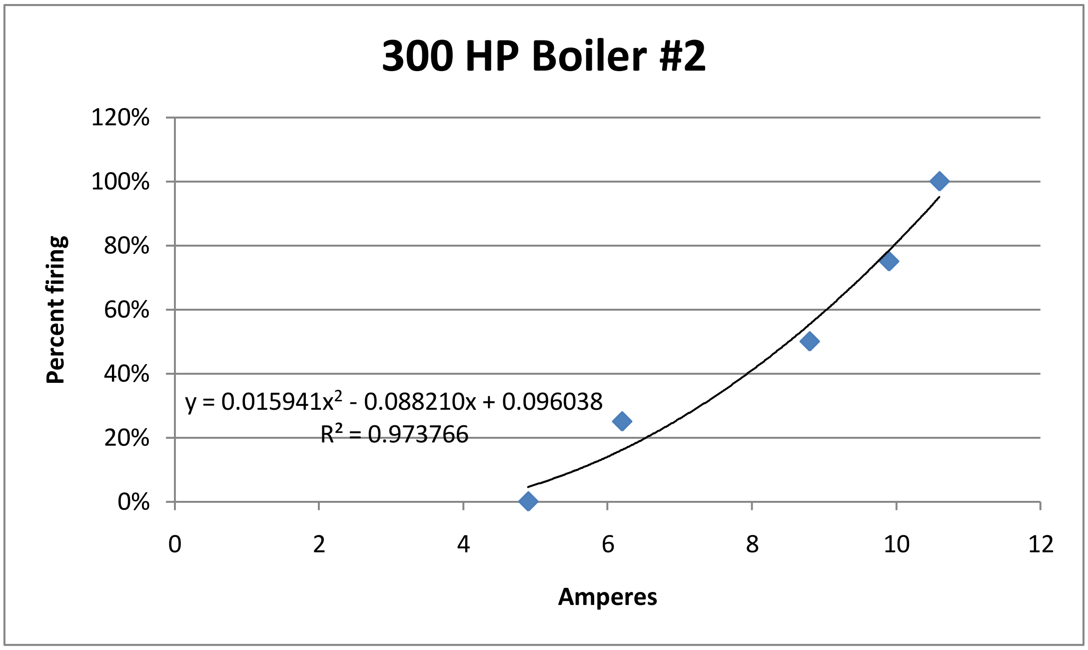


Figure 2-2. Regression of Amps to Firing Rate (300 hp Boiler)



The daily average hourly load profile of the boiler was fairly regular, as can be seen in Figure 2-3. However, on a smaller time scale, the boiler firing rate changed rapidly, as can be seen in Figure 2-4.

Figure 2-3. 600 HP Boiler Hourly Profile

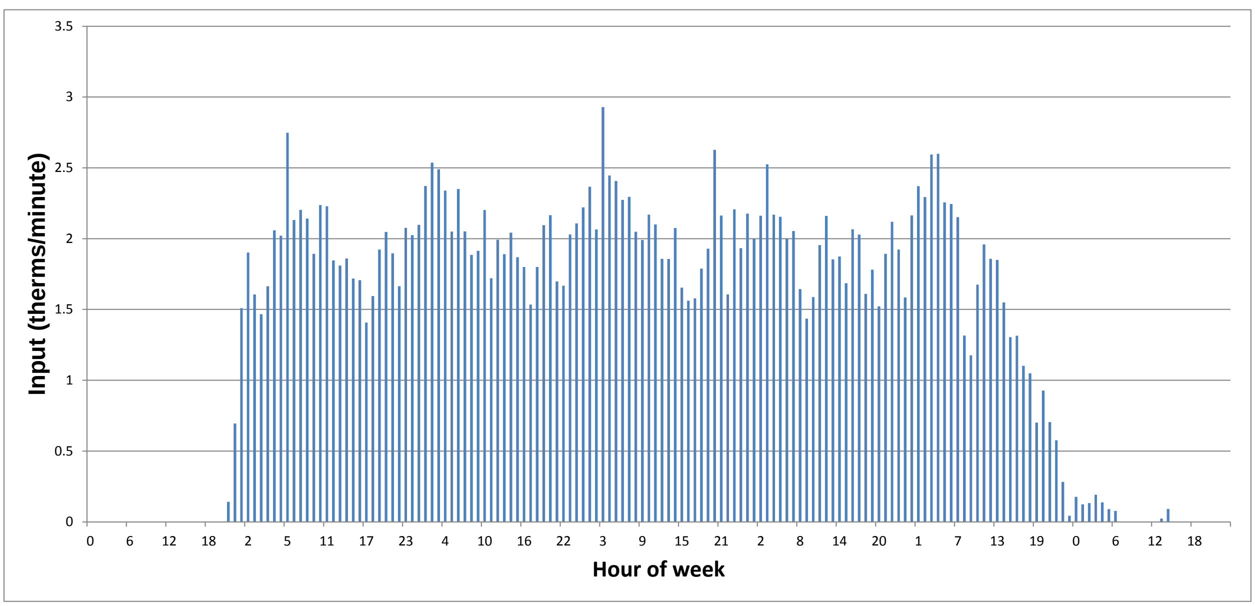
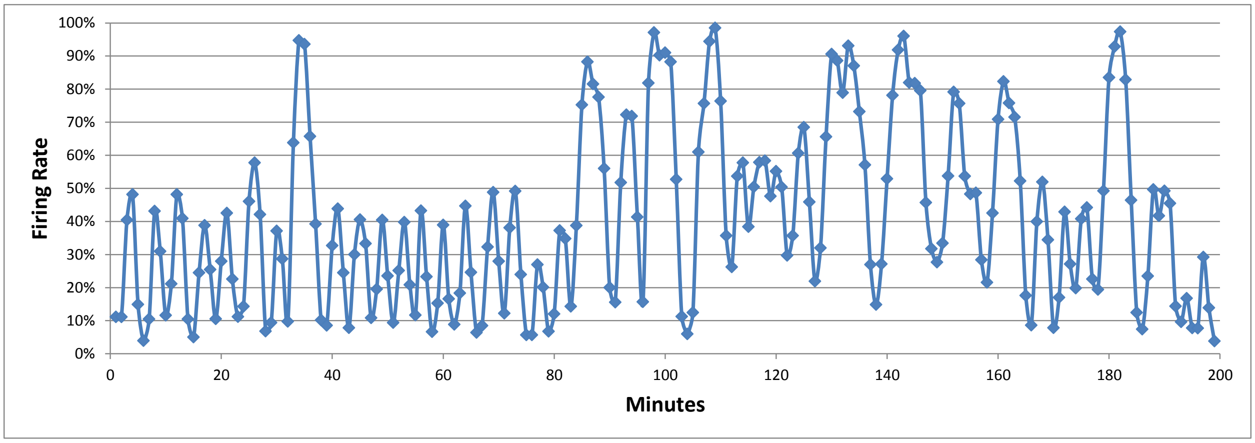
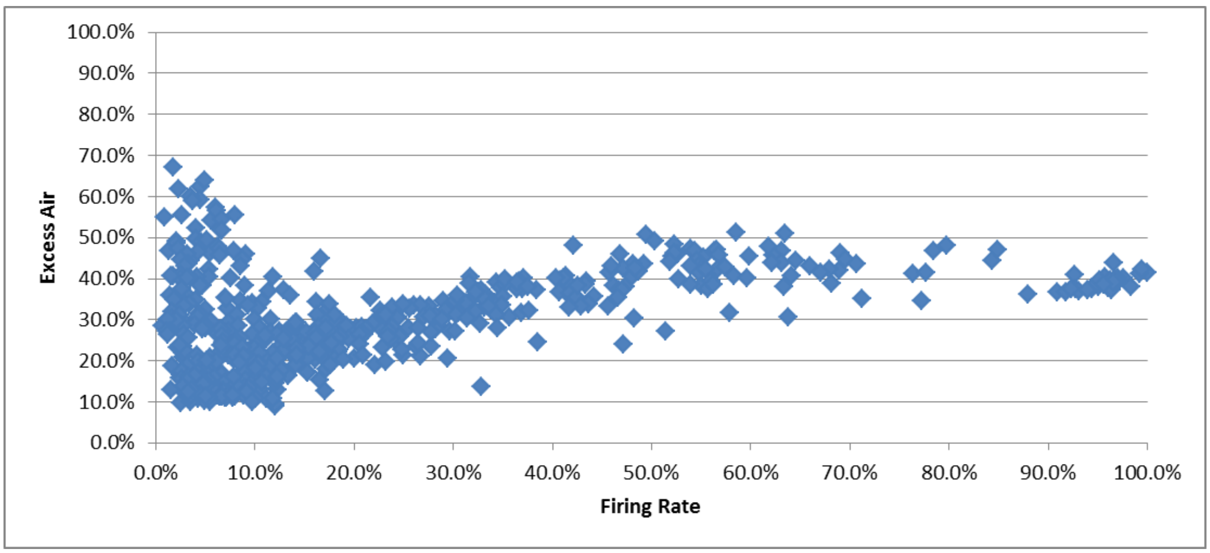


Figure 2-4. 600 HP Boiler Firing Rate, By Minute



Not only was the boiler firing rate changing rapidly, but the excess air was changing as the boiler firing rate changed. Typically, the excess air rate stays fairly constant across the firing range. As can be seen in Figure 2-5, the excess air rate varies from 10 to 70%.

Figure 2-5. 600 hp Boiler Excess Air



Evaluation Description of Baseline

This project involved the addition of advanced boiler controls to a gas-fired burner. Since there were no pre-implementation combustion efficiency measurements, the evaluators used the applicant baseline steady state efficiencies as a reference combustion efficiency. A combustion efficiency vs. firing rate for a linkage control baseline was produced using an empirically developed curve. The curve was developed from a data set of combustion measurements at multiple points in the firing range of 19 boilers at 12 different sites extracted from the evaluator's portfolio of linkage controlled boiler combustion tests.

2.2.3 Evaluator Calculation Methodology

The evaluator calculated savings due to the improved combustion efficiency from the parallel position and O_2 trim controls.

The evaluator used the metered data to determine a boiler firing rate profile and efficiencies. First, the installed boiler gas usage was estimated as a function of the observed firing rate and boiler capacity and trued up to the weather normalized bills. The boiler firing rate was a bin model arranged in 10% firing rate intervals. Next the installed boiler combustion efficiency was calculated based on a relationship between firing rate and combustion efficiency from the combustion analyzer logged data for each of the firing rate bins. The baseline efficiency was calculated using the applicant defined combustion efficiency adjusted for a linkage control profile. The calculated baseline efficiency was applied to the combustion load to calculate baseline gas usage.

Since the boilers were the same both before and after the installation of the controls, the thermal losses remained constant and were ignored. This method used the applicant reported baseline efficiency and the evaluator combustion instrument reading in the calculation because they were the best 'apples-to-apples' equivalents. Usually, the evaluator will use combustion instrument inputs of temperature and gas saturations to recalculate a combustion efficiency for both the baseline and installed efficiencies to eliminate methodological differences, but no such data was provided by the applicant.

The annual savings was the difference between the sum of the hourly installed and baseline gas usage.

where:

= Twelve months of weather adjusted billed usage

= From the applicant and as determined from measurement and analysis.

Boiler Firing Rate Profile

The logged data was used to determine an average firing rate for each of the boilers. Since the load is dominated by the process and not space heating, the evaluators used time rather than outdoor air temperature as the basis for the firing rate load profile.

The evaluators calculated the firing rate for each minute during the logging for each boiler. The results were binned into 10% interval firing rate bins. Table 2-7 summarizes the average firing rates by bin interval for the three boilers. The table shows the percent of the time the boilers are off-line (where firing rate is zero) in the first row. The next ten rows show the boiler performance when the boiler is on-line, expressed as an average firing rate by firing rate interval and the time duration in that bin; these figures are used to calculate combustion efficiencies. The last row presents the average firing rate throughout the period; this figure was used to calculate annual gas usage and is the sum of the product of the bin firing rates and the time duration percentage. Note that exactly four weeks of data were used to produce these profiles so that weekends and weekdays are proportionally represented.

Table 2-7. Boiler Firing Rate Bins

		600 hp Boiler		300hp #1 Boiler		300hp #2 Boiler	
		Average Firing Rate	Pct of Time	Average Firing Rate	Pct of Time	Average Firing Rate	Pct of Time
Boiler off-line		**0.0%**	**28.4%**	**0.0%**	**87.0%**	**0.0%**	**73.2%**
Boiler On-line							
Boiler On-line Firing Interval	0+% to <10%	6.5%	9.7%	8.4%	26.1%	4.3%	31.5%
	10% to <20%	14.8%	12.6%	12.0%	27.4%	17.2%	29.6%
	20% to <30%	25.0%	11.0%	25.5%	3.8%	22.3%	5.6%
	30% to <40%	35.1%	11.0%	36.0%	5.4%	35.6%	2.0%
	40% to <50%	45.0%	13.7%	44.9%	5.9%	45.3%	2.8%
	50% to <60%	54.7%	12.6%	55.2%	7.2%	55.2%	3.2%
	60% to <70%	64.8%	8.1%	64.8%	6.0%	65.3%	6.1%
	70% to <80%	74.6%	6.4%	74.9%	3.2%	75.3%	4.4%
	80% to <90%	85.2%	5.1%	84.3%	2.5%	84.8%	8.0%
	90% to 100%	96.3%	9.8%	98.4%	12.5%	95.0%	6.8%
Seasonal firing rate			32.9%		4.7%		8.6%

Boiler Annual Usage

The modeled boiler annual usage is the product of the boiler capacity and the annual weighted average firing rate for each boiler from Table 2-7.

As a first approximation, the annual usage of each boiler was estimated as the product of the seasonal firing rate and the boiler input capacity times the number of hours in the month. This is the ‘unadjusted model’ estimate in Table 2-8 and yields an annual usage of 871,937therms which can be compared to the annual billed usage of 808,088 therms. The adjusted model is within 10% of the actual bills which indicates the boiler usage is reasonably modeled and that the metering period happened to represent a typical period of production, combined with weather.

Production figures were available for the 2011 and were regressed with heating degree days against gas usage resulting in the following relationship show in Figure 2-6. This regression was used to estimate the production levels for January through April in 2012 in Table 2-8.

Figure 2-6. Regression Results: Gas and Production vs. Heating Degree Days

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.95599166
R Square	**0.91392005**
Adjusted R Sq	0.89240006
Standard Erro	7751.51256
Observations	11

Gas usage as a function of heating degree days and production:
Monthly gas use = 21,423 + Production/month * 0.1430 + HDD/month * 42.31
HDD base 55F

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 90.0%*	*Upper 90.0%*
Intercept	21423.6859	7,142	2.99963579	0.01708116	4,954	37,893	8,143	34,705
Production	0.1430	0.0267	5.3620	0.0007	0.0815	0.2045	0.0934	0.1926
HDD	42.31	8.59	4.92	0.00	22.49	62.12	26.33	58.29

The weather and production normalized bills predict a usage of 888,609 therms during a typical weather year. This model was developed using the regression from Figure 2-6 applied to monthly TMY3 heating degree days. A final adjustment of 101.9% was applied to the unadjusted model to weather and production normalize the results by applying the ratio of the weather and production normalized usage divided by the unadjusted model usage.

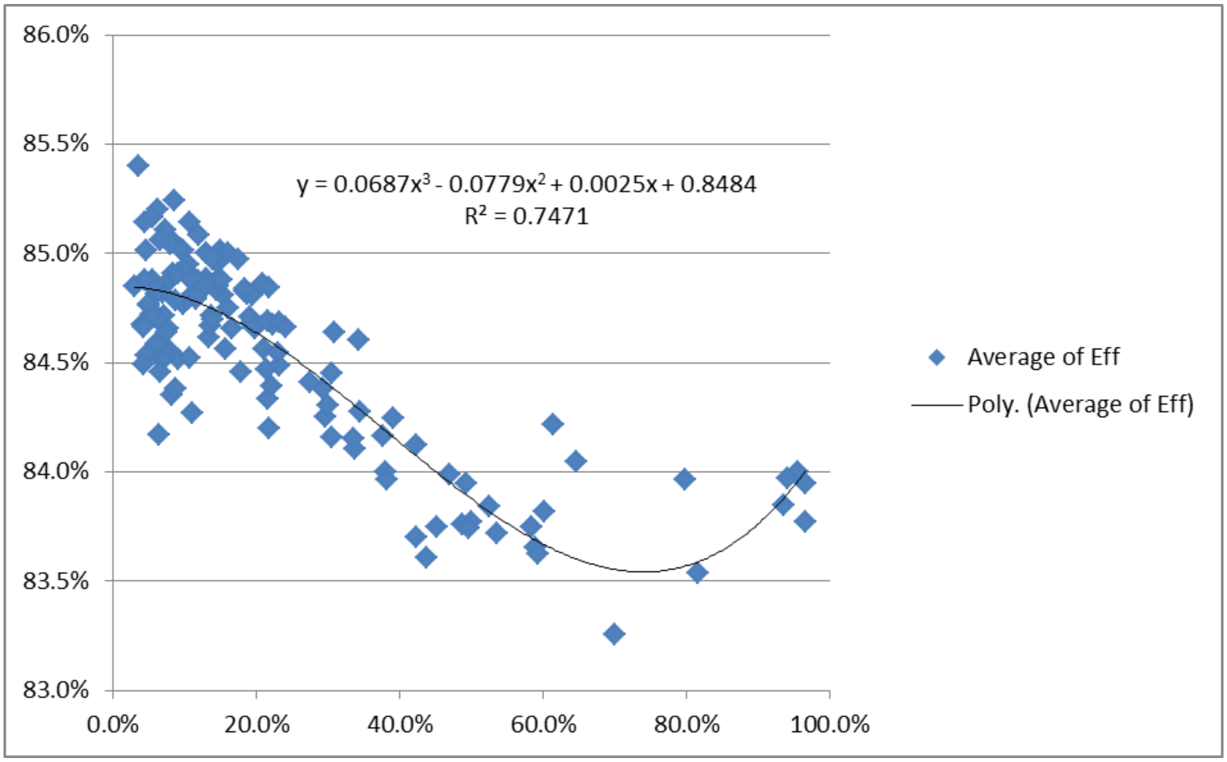
Table 2-8. Adjustments to Model for Actual Billed Use and Weather Normalization

Month	Days	Pro-duction	HDD-55F Actual	HDD-55F TMY3	Billed Used	Unadjusted Model	Weather Normalized Billing & Production
					Therms		
January -2012	31	306,113	594	997	90,337	73,853	107,376
February-2012	29	294,087	503	907	84,767	69,088	101,853
March-2012	31	353,230	319	550	85,442	73,853	95,235
April-2012	30	257,013	162	377	65,038	71,470	74,134
May -2011	31	324,035	50	170	83,295	73,853	74,975
June-2011	30	382,750	6	44	77,010	71,470	78,020
July-2011	31	157,569	0	14	47,466	73,853	44,571
August-2011	31	304,552	0	15	63,452	73,853	65,615
September-2011	30	177,406	8	68	41,913	71,470	49,657
October-2011	31	159,676	117	269	42,127	73,853	55,645
November-2011	30	189,270	215	398	57,885	71,470	65,331
December-2011	31	193,194	446	642	69,356	73,853	76,196
Total					**808,088**	**871,937**	**888,609**
					Model adjustments for weather		**101.9%**

Installed Combustion Efficiency

The boiler efficiency was estimated using a firing rate vs. combustion efficiency curve developed from combustion efficiency values taken by the evaluator's logging combustion analyzer. The analyzer was left in place on the 600 hp boiler for about 36 hours and continuously measured and recorded boiler temperatures, gas saturations, and a calculated efficiency. The firing rate vs. combustion efficiency curve produced from this data is shown in Figure 2-7 and was used to calculate the installed combustion efficiency.

Figure 2-7. Firing Rate vs. Efficiency Curve



The analyzer was only installed on the 600 hp boiler. As can be seen in Table 2-4, the smaller boilers show a similar spot combustion profile to that of the large boiler, so the same equation was used to estimate the 300 hp boiler installed combustion efficiencies.

Note that this approach is not the typical methodology used for boiler combustion efficiency evaluations. Usually, the recorded measured inputs for both the baseline and installed cases are used as inputs to a combustion equation so that the efficiencies are calculated using the same methodology in the pre and the post case. As noted previously, however, the applicant only provided final efficiencies and not the measured inputs. In addition, an examination of the combustion analyzer data showed an unusual amount of variance in excess air and that although firing rate was a good predictor of efficiency; it was not a good predictor of stack temperature or excess air alone.

Calculation of Baseline Combustion Efficiency

The only source of baseline combustion efficiency is from the applicant steady state efficiency identified in the applicant's savings summary. This was a mid-range value. With linkage control, the combustion efficiency will change across the firing range in a characteristic manner which is described by an empirically developed linkage control curve. The curve was developed from a data set of combustion measurements at multiple points in the firing range of 19 boilers at 12 different sites extracted from the evaluator's portfolio of linkage controlled boiler combustion tests.

The relationship of firing rate calculated using the applicant's steady state baseline efficiency as a reference point for a linkage control curve. The linkage control factor is a linear function of firing rate and was empirically derived.

The equation is as follows:

where,

Electric Savings

Electric savings were estimated as the hourly difference in blower electric usage between the baseline case, which assumes the intake air is modulated by dampers, and the installed VFD. The hourly estimates are summed through the metering period to estimate a daily average savings which was extrapolated to a yearly savings.

The base case motor usage is estimated as follows:

–

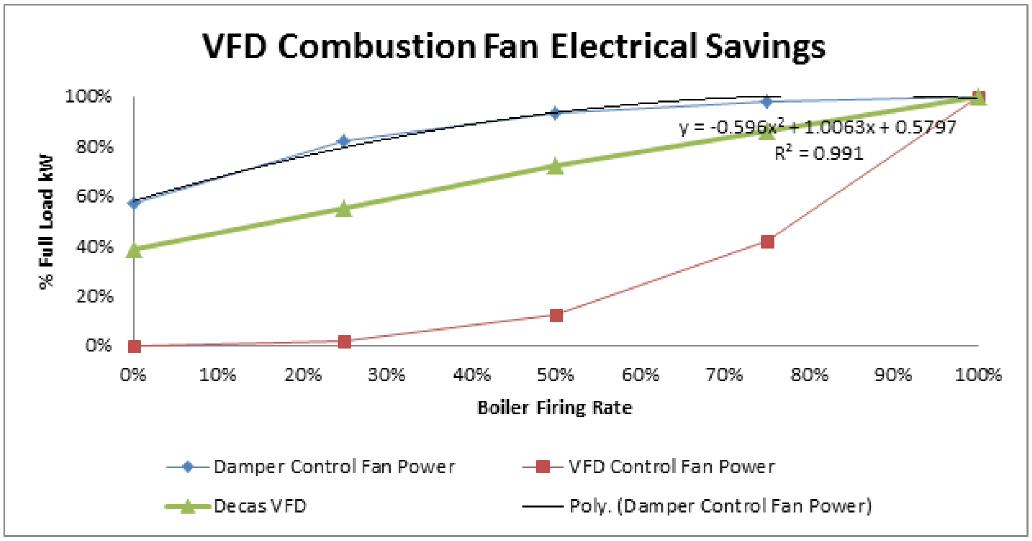
where,

volts for three phase power, 460 volts

= -

Figure 2-8 was developed from fan curves and accounts for the loading as a function of fire rate.

Figure 2-8. Firing Rate vs. VFD Percent of Full Load



The installed motor usage is estimated using the measured amps as follows:

–

where,

=

2.3 Evaluator Calculation Results

The estimated installed and baseline combustion efficiencies are presented in Table 2-9. The installed efficiencies are calculated using the efficiency vs. firing rate curve at the average firing rate for that bin. The baseline efficiencies are calculated using the applicant steady state baseline efficiencies and a linkage control curve.

Table 2-9. Boiler Installed and Baseline Combustion Efficiencies by Firing Rate

		600 hp Boiler			300hp #1 Boiler			300hp #2 Boiler		
		Firing Rate	Installed	Base	Firing Rate	Installed	Base	Firing Rate	Installed	Base
Boiler On-line Firing Interval	0+% to <10%	6.5%	84.8%	81.7%	8.4%	84.8%	82.2%	4.3%	84.8%	83.3%
	10% to <20%	14.8%	84.7%	81.6%	12.0%	84.8%	82.1%	17.2%	84.7%	83.2%
	20% to <30%	25.0%	84.5%	81.5%	25.5%	84.5%	82.0%	22.3%	84.6%	83.1%
	30% to <40%	35.1%	84.3%	81.4%	36.0%	84.2%	81.9%	35.6%	84.3%	83.0%
	40% to <50%	45.0%	84.0%	81.3%	44.9%	84.0%	81.8%	45.3%	84.0%	82.9%
	50% to <60%	54.7%	83.8%	81.2%	55.2%	83.8%	81.7%	55.2%	83.8%	82.8%
	60% to <70%	64.8%	83.6%	81.1%	64.8%	83.6%	81.6%	65.3%	83.6%	82.7%
	70% to <80%	74.6%	83.5%	81.0%	74.9%	83.5%	81.5%	75.3%	83.5%	82.6%
	80% to <90%	85.2%	83.6%	80.9%	84.3%	83.6%	81.4%	84.8%	83.6%	82.5%
	90% to 100%	96.3%	84.0%	80.8%	98.4%	84.1%	81.3%	95.0%	83.9%	82.4%
Seasonal efficiency			84.1%	81.3%		84.4%	81.9%		84.4%	83.0%

The final estimate of installed monthly gas usage was calculated as the product of the average firing rate which included off-line operating hours, the boiler input capacity, the hours in the month, and a weather normalization factor. The savings was equal to the difference in gas usage between the baseline and installed usage. The monthly results are summarized in Table 2-10.

Table 2-10. Boiler Installed Gas Usage and Savings

	Installed Boiler Usage (therms)				Boiler Savings- therms		
Month	Blr-600 hp	Blr 1 - 300	Blr 2 - 300	Total Boiler	Blr-600 hp	Blr 1 - 300	Blr 2 - 300
March	62,680	4,425	8,159	75,265	2,205	156	287
April	60,658	4,282	7,896	72,837	2,134	151	278
May	62,680	4,425	8,159	75,265	2,205	156	287
June 2011	60,658	4,282	7,896	72,837	2,134	151	278
July	62,680	4,425	8,159	75,265	2,205	156	287
August	62,680	4,425	8,159	75,265	2,205	156	287
September	60,658	4,282	7,896	72,837	2,134	151	278
October	62,680	4,425	8,159	75,265	2,205	156	287
November	60,658	4,282	7,896	72,837	2,134	151	278
December	62,680	4,425	8,159	75,265	2,205	156	287
Annual	**740,033**	**52,242**	**96,334**	**888,609**	26,032	1,838	3,389
						Savings:	31,258

A final summary of the applicant and installed combustion efficiencies is provided in Table 2-11 for the lead 600 hp boiler.

Table 2-11. Comparison of Applicant and Evaluator Installed Combustion Efficiencies.

	Applicant Baseline	Applicant Installed	Evaluator Baseline	Evaluator Installed
Combustion efficiency, 50% firing rate	81.3%	86.5%	Same as applicant at 50% firing rate	84.0% at 50% firing rate

Electric Impacts

Electric impacts were calculated using an analysis similar to the one applied to determine gas impacts. Evaluators determined savings for this measure by estimating the baseline electricity use for a dampered boiler air intake and the as-built electricity use for a variable speed fan. This resulted in annual impacts of are presented in Table 2-12.

Table 2-12. VFD Electrical Savings Estimate

	Metering period usage			
Boiler	Baseline kWh	Installed kWh	Daily savings	
600 hp	6,565	4,997	52.1	kWh
300-1 hp	583	412	5.7	kWh
300-2 hp	1,203	1,009	6.4	kWh
		Annual savings	23,883	kWh

3. Final Results

The site produces synthetic specialty fabrics and operates twenty-four hours per day, five days per week. Three steam boilers, which had been retrofitted prior to this project with a dual-fuel fired burners, were upgraded with combustion controls providing VFD motors, parallel positioning, and O2 trim. The facility operates twenty-four hours per day, five days per week. The boilers are currently firing exclusively on natural gas.

Since there were no pre-implementation combustion efficiency measurements (stack temperature and excess air or gas saturations), the evaluators used the applicant baseline steady state efficiencies as reference combustion efficiency for the baseline. The installed efficiency was based on the logged efficiency measurements of a logging combustion analyze.

The applicant had projected that the steady state efficiency of the lead 600 hp boiler would be about 86%, while the evaluator measured mid-firing range efficiency of about 84%, which reduced the savings.

Measure impact calculations are shown in Table 3-1.

Table 3-1. Key Parameter Summary

	Baseline	Installed
Billing		
Actual gas bills (May-11 to April-12) (therms)	N.D.	808,088
Weather and production normalized billing		888,609
Tracking/Applicant		
Combustion Efficiency - 600 hp boiler	81.30%	86.50%
Load share of 600 hp boiler		66.70%
Gas usage (therms)	825,066	784,158
Savings percent of baseline and therms	5.0%	40,908
Evaluated		
Replacement boiler seasonal combustion efficiency	81.65%	82.51%
Load share of 600 hp boiler		84%
Gas usage (therms), weather normalized	919,867	888,609
Savings (therms)	3.4%	31,258
Realization rate		
Final realization rate		76%

3.1 Cross Check with Billing Data

A ‘two-sided’ billing analysis using pre and post billing data was not possible, since there was insufficient billing in the baseline case and also the projected savings was on the edge of what could be discernible in a billing analysis. However, the model estimated usage was compared to billing, as shown in Table 2-8.

3.2 Recommendations for Program Designers & Implementers

The baseline efficiency can be difficult to estimate, especially if the applicant has limited information about the boiler. For large boiler projects, it may be prudent to request combustion efficiency measurements across the firing range while firing natural gas, if possible, before the project is approved and the existing equipment removed or upgraded.

3.3 Customer Alert

None.

3.4 Explanation of Deviations

Table 3-2 provides a summary of the key deviations between the tracking and evaluated savings.

Table 3-2. Summary of Key Factors and Deviations

Factor	Applicant	Evaluator	Impact of Deviation	Discussion of Deviations
Operation	**825,066**therms	**888,609**therms	6%	The applicant used non-weather adjusted billing usage.
Baseline efficiency	*81.3%*	*81.3*	0%	The evaluator used the applicant base steady state efficiency.
Installed efficiency	*86.5%*	*82.51%*	-30%	The evaluators used a combustion analyzer to determine the actual operating combustion efficiency which was lower than projected by the applicant.

1. PROJECT SUMMARY AND RESULTS

This project involves replacing the linkage combustion controls for one 600-hp steam boiler with a parallel positioning oxygen (O_2) trim control package and a variable speed drive (VFD) on the boiler's combustion blower to operate the boiler efficiently. The steam boiler supports the manufacturing process and space heating loads at the facility

The evaluator visited the site, interviewed site staff, took spot measurements, installed logging equipment, and conducted analysis to determine the evaluated savings.

1.1 Savings

Measure ID	Measure Name		Gas Savings (Therms/yr)	Electric Savings (kWh/yr)
1	Boiler controls	Tracked	83,527	N/A
		Evaluated	42,124	7,081
		RR[1]	51%	N/A
[1] Realization rate				

1.2 Explanation of Deviations from Tracking

The primary reason the evaluated savings vary from the tracking savings was a reduction in the operating hours. Initially, one boiler with all of the run hours was incentivized. However, after the initial installation, the site installed controls on the second boiler and split the load, effectively reducing potential savings for the boiler control incentivized by approximately 50%

2. Evaluated Measure

The following sections present the evaluation procedure, including the findings from an in-depth study of the supplied application calculations and the evaluation methodology determined to best fit the measure based on the information available.

2.1 Application Information and Analysis

This measure included boiler controls on an existing boiler serving the process load. The boiler plant consists of two identical boilers. One boiler was assumed to serve as the lead and carry the entire facility load. The installation of controls on the lead boiler was incentivized.

2.1.1 Application Description of Baseline

The applicant describes the baseline boiler plant to consist of two 600-hp steam boilers of the same make and model that serve the facility's steam load. The applicant described the two baseline boilers to be water-tube steam boilers with an input capacity of 25.1 MMBtu/h each with a constant speed combustion fan with combustion air load modulated with linkage and damper controls. Only Boiler #1 received the incentive for the controls upgrade. According the applicant Boiler #1 serves the entire load and runs for 7,509 hours. Boiler #2 serves as a backup only and does not run. The baseline boilers were dual fuel and the system did operate partially on natural gas and fuel oil #6.

2.1.2 Applicant Description of Installed Equipment and Operation

A control system with parallel position and O_2 trim was to be installed on the lead boiler. Any existing linkage controls were to be removed.

2.1.3 Applicant Energy Savings Algorithm

The applicant used a proprietary spreadsheet that calculates savings due to combustion air preheaters, blow down heat recovery, and implementation of parallel position controls with O_2 trim. Only the parallel positioning O_2 trim section was used. The savings identified in the spreadsheet are presented in Table 2-1.

Table 2-1 Summary of Applicant Savings Fractions

Savings mechanism	Combustion Efficiency	Efficiency Change	Seasonal Efficiency
Baseline	70.88%		65.88%
O_2 Trim/PP	81.69%	10.81%	76.69%
Seasonal efficiency change			10.81%
Gas savings rate			14.1%

The 14.10% savings was applied to the 2010 year of billed gas use of 592,529 therms.

2.1.4 Analysis of Applicant Algorithm

The applicant savings calculation spreadsheet is proprietary, providing summaries of inputs and outputs, but not the mechanics or sources of savings factors, although some can be deduced. Generally, the spreadsheet is a step forward in providing more rigorous and transparent savings estimates compared to the fixed savings fractions frequently typically used for savings estimates.

The combustion efficiency is improved by the O_2 trim and parallel positioning controls. The estimate of the improved efficiency due to the controls is reasonable, given a change in O_2 from 12.94% to 3.0%. The applicant inputs appear to be from actual combustion test data, including stack temperature, gas saturations, and ambient temperatures at various firing rates, although no equipment 'test receipts' were included in the file.

2.2 On-Site Inspection, Metering, and Analysis

This section provides the steps of the evaluation from initial site visit through the final results. Each step is described in detail to offer an in-depth reasoning behind the full process.

2.2.1 Summary of Site Visit Findings

The site was visited on February 17, 2012, and personnel were interviewed regarding the system operation. The boiler plant consists of two dual fuel gas or oil fired boilers. The boilers are identical 600 hp boilers. Although only one boiler was given controls during the incentivized upgrade, both boilers had the control system when the evaluators visited the site. The facility is served by a single gas meter. The boilers account for almost all of the gas use except for several small gas-fired RTUs which are used to heat the office spaces.

The evaluators used logged data and interviews with site contacts to determine that the boilers operated in a weekly lead/backup rotation, rather than have one boiler continuously serve as the lead boiler as indicated in the project documentation. Contacts also indicated that during the metering period, schedules and production levels were typical.

2.2.2 Measured and Logged Data

The evaluators installed logging equipment on both boilers from February 17 through March 18, 2012. Table 2-2 shows the points that were metered.

Table 2-2. Summary of Metered Data

Boiler	Parameter Measured	Time Interval	Duration
600 hp boiler #1	Blower fan amperes	1 minute	4 weeks
600 hp boiler #2	Blower fan amperes	1 minute	4 weeks

The evaluators we unable to take spot combustion measurements on the boilers due to limited access to the stacks. Site contacts were also unable to modulate the boiler on demand.

2.2.3 Evaluation Description of Baseline

This project involved the addition of advanced boiler controls to a gas-fired burner. The baseline boiler was linkage controlled. The burner was not changed out as part of this upgrade.

The baseline is based on the combustion efficiencies calculated using Equation 1 listed below with spot measurements of stack and ambient temperatures and O_2 measured across the firing range taken prior to the retrofit. The measured values and efficiencies are provided in Table 2-3. The 'Calculated Efficiencies' were calculated using Equation 1 described later.

Table 2-3. Applicant Provided Baseline Measurements and Calculated Combustion Efficiency

Percent Firing	Stack Temperature (°F)	Oxygen	Excess Air	Ambient Air Temperature	Calculated Efficiency
25%	477.4	13.3%	2.6%	84.3 ºF	63.4%
50%	477.3	12.9%	2.4%	85.5 ºF	64.4%
75%	477.0	12.3%	2.3%	85.5 ºF	65.6%
100%	477.0	12.2%	2.3%	85.6 ºF	65.8%

2.2.4 Evaluator Calculation Methodology

The evaluator calculated savings due to the improved combustion efficiency from the parallel position and O_2 trim controls.

The evaluator used the metered data to estimate the firing rate profile. The profile was used to calculate annual usage as a function of the observed firing rate and boiler capacity. The annual usage was adjusted to equal the weather normalized billing, since a single meter accounts for only the boiler use. Annualized pre and post combustion efficiencies were produced based using the firing rates of the high resolution firing rate profile. Equation 1 was used in calculating all efficiencies.

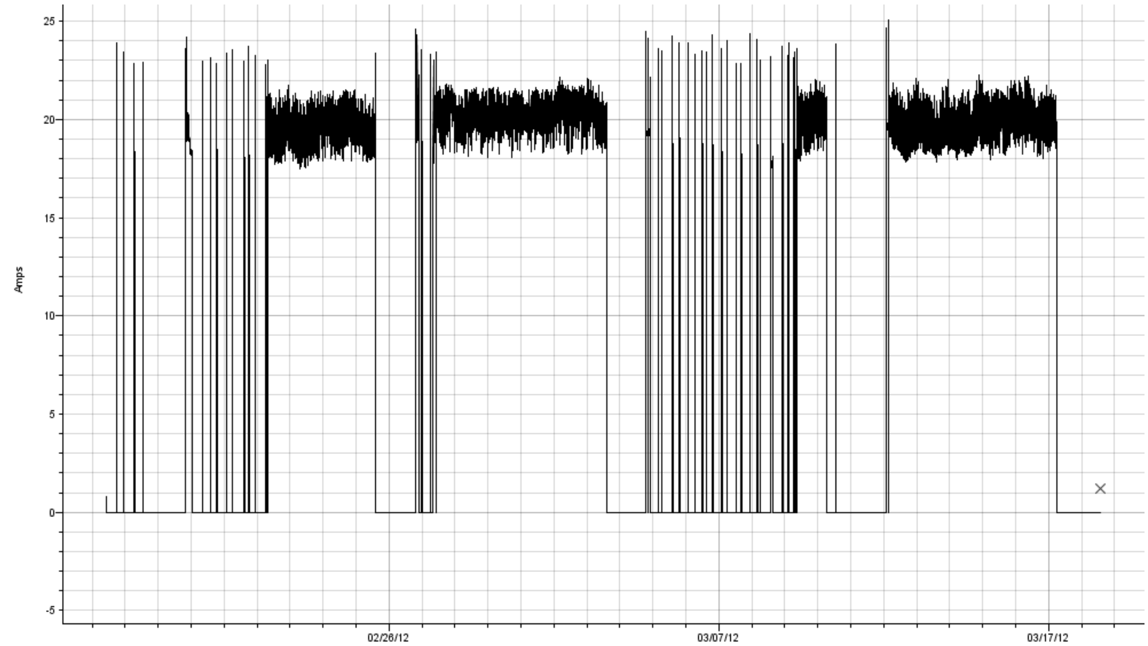
The savings is computed from a ratio of the annualized combustion efficiencies applied to the estimated gas use as follows:

Boiler Firing Rate Profile

There was no blower kW vs. firing rate observations directly available, so this relationship had to be inferred from other data. Points A, B, C, and D shown in Figure 2-2 were used as the endpoints of three lines describing the firing rate vs. blower demand as follows:

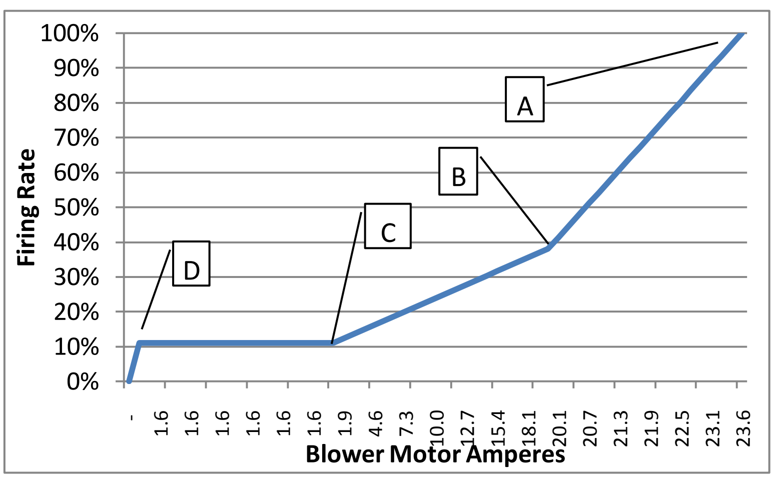
- Point A. The blower motor was a 25 hp motor; it would draw 23.6 amperes (18.6 kW) at 100% design load. The maximum draw of the blower motor observed in the logged data was about 24 amperes. Point A is defined as a 100% firing rate when the blower motor is at a 23.6 ampere load.
- Point B. The blower motor operated fairly constantly over the metering period from mid-February through mid-March. A monthly firing rate of 38% was calculated by dividing the billed February/March usage by the number of hours in the month divided by the boiler rated input capacity. The average blower motor operation of 19.9 amperes over this period was assumed to produce this average firing rate of 38%. Point B is defined as 38% firing rate when the blower motor is at 19.9 amperes. Figure 2-1 shows the boiler ampere profile from the logged data.

Figure 2-1. Boiler Ampere Profile



- Point C. With a turn down ratio of nine, the minimum firing rate for the boiler is 11%. The boiler only operated for about 12 hours during month of metering below 1.6 amperes. The evaluator assumed that the blower motor draws 1.6 ampere at an 11% firing rate, defining Point C.
- Point D. The blower motor will be at zero when the boiler is at 0% firing rate, establishing the last point.

Figure 2-2. Combustion Blower Fan Curve



Using the logged blower fan ampere data, the minute by minute logged data was separated into firing rate bins to develop a profile for calculating the average change in efficiency. Table 2-4 summarizes the average firing rates by bin interval for the two boilers. The table shows the percent of the time the boilers are off-line (where firing rate is zero) in the first row. The next ten rows show the boiler performance when the boiler is on-line, expressed as an average firing rate by firing rate interval and the time duration in that bin; these figures are used to calculate combustion efficiencies. The last row presents the average firing rate throughout the period; this figure was used to calculate annual gas usage and is the sum of the product of the bin firing rates and the time duration percentage. Note that exactly four weeks of data were used to produce these profiles so that weekends and weekdays are proportionally represented.

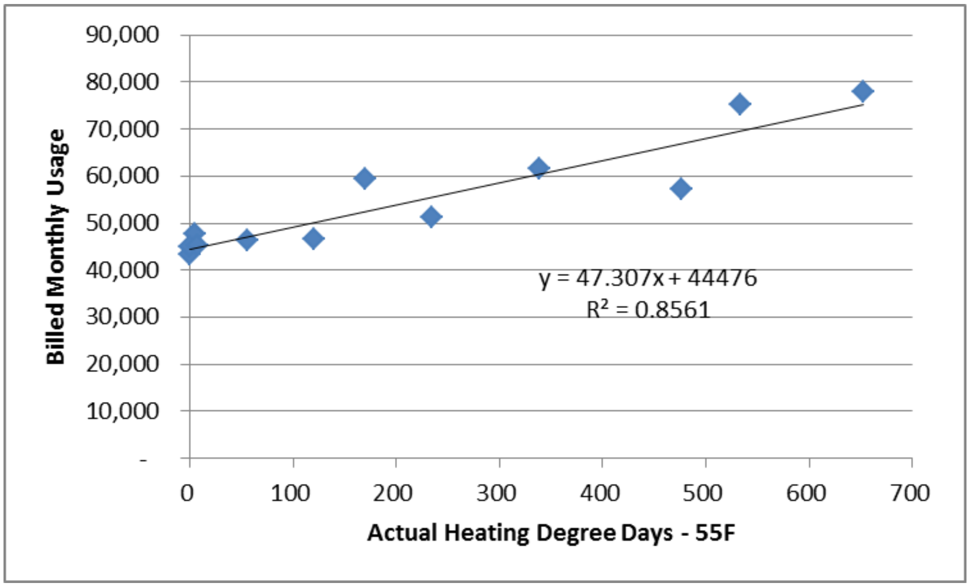
Table 2-4. Percent of Time at Each Firing Rate Bin

		#1 Boiler		#2 Boiler	
Firing Interval		Average Firing Rate	Pct of Time	Average Firing Rate	Pct of Time
Boiler off-line		**0.0%**	**48.5%**	**0.0%**	**66.4%**
Boiler On-line					
Boiler On-line	1%-15%	0.0%	0.0%	11.2%	0.6%
	15%-25%	0.0%	0.0%	20.8%	0.1%
	25%-35%	0.0%	2.0%	33.8%	10.4%
	35%-45%	34.1%	70.4%	37.8%	79.2%
	45%-55%	38.4%	22.6%	50.3%	6.8%
	55%-65%	50.4%	4.5%	60.2%	2.4%
	65%-75%	59.4%	0.3%	69.0%	0.5%
	75%-85%	69.1%	0.1%	78.9%	0.1%
	85%-95%	81.9%	0.1%	90.2%	0.0%
	95%-100%	90.6%	0.0%	0.0%	0.0%
Seasonal firing rate:			18.2%		13.0%

Weather Normalized Billing Usage

The boiler load is served by a single meter and the meter serves only the boiler load. The actual usage of the boiler, therefore, is equivalent to the actual bills. The weather normalized usage can be estimated by first determining the relationship between billed usage and heating degree days, as shown in Figure 2-3. A base of 55ºF was selected, since this is an industrial facility with a relatively low balance point. The weather normalized usage is calculated by using the typical meteorological year (TMY3) heating degrees to the equation for each month.

Figure 2-3. Regression of Billed Usage vs. Heating Degree Days



Calculation of Installed Efficiency

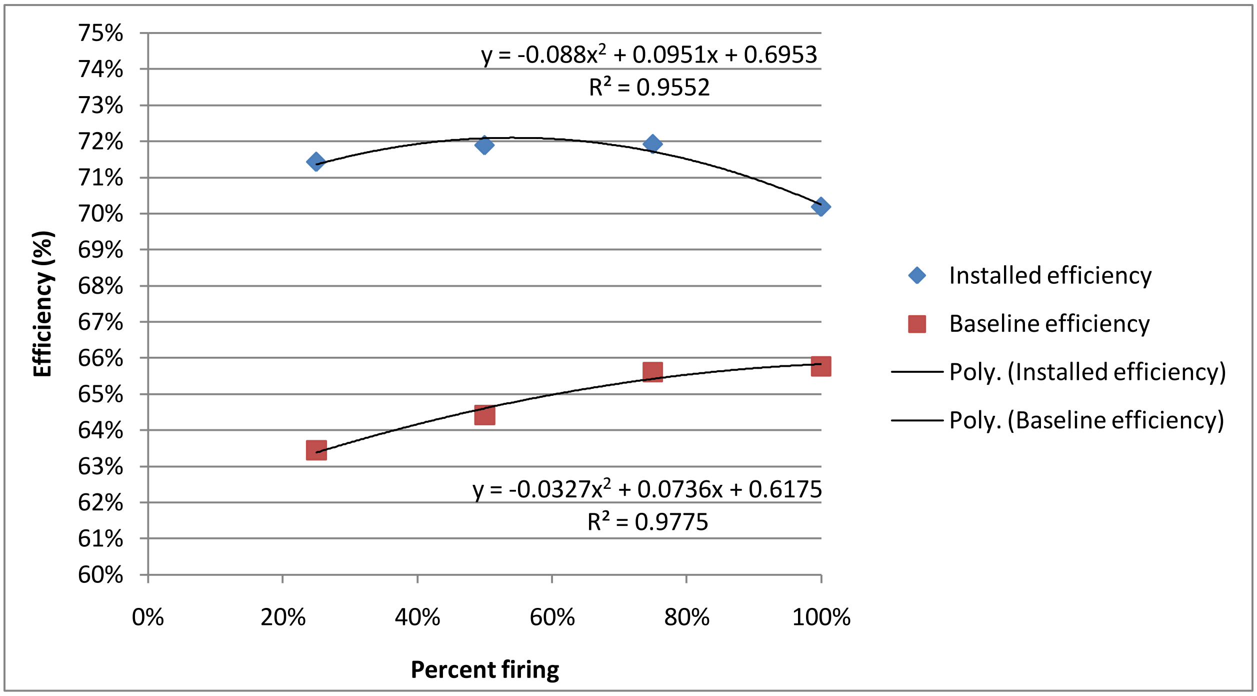
Best fit curves were developed for combustion efficiency vs. the firing rate for the base and installed case using pre and post spot measurements of the boiler.

Stack temperature, O_2, and ambient temperature readings from spot measurements taken by the installer were used as inputs to calculate combustion efficiencies in Equation 1 described in the next section. The applicant measurements shown in Table 2-3 were used to calculate baseline efficiencies. The installer recorded measurements in Table 2-5 were used to calculate the installed efficiencies. The calculated combustion efficiencies were regressed against firing rate to produce two equations, as shown Figure 2-4.

Table 2-5. Installer Provided Post-installation Measurements and Calculated Combustion Efficiency

Percent Firing	Stack Temperature (°F)	Oxygen	Excess Air	Ambient Air Temperature (°F)	Efficiency
25%	444.5	8.1%	1.7%	82.9	71.4%
50%	442.3	7.7%	1.6%	83.1	71.9%
75%	444.1	7.6%	1.6%	82.8	71.9%
100%	510.5	5.1%	1.4%	70.3	70.2%

Figure 2-4. Baseline and Installed Efficiency



Combustion Efficiency Calculation

Measured inputs of stack temperature, ambient temperature, excess air or gas saturations are used to calculate combustion efficiency using the equations described in this section. While combustion test equipment estimates a combustion efficiency which is often recorded, the exact calculation method is usually unknown. Use of the same equation for both the pre and post-installation efficiency calculations using the same measurement inputs eliminates one source of error between these measurements.

The following equation[1] was applied to calculate the sensible boiler efficiency, where the measured inputs include the excess air and stack temperature:

Equation 1

(1)

where,

= Higher heating value of the fuel, equal to 23,797 Btu/lb for natural gas in this analysis

= The specific heat of the combustion products, estimated to be 0.26 Btu/lb-°F

= The temperature of the exhaust gases in °F

= The stoichiometric air-to-fuel ratio, equal to 17.2 for natural gas

[1] "Quantifying Savings From Improved Boiler Operation," Kissoc, University of Dayton IAC http://academic.udayton.edu/kissock/http/Publications/QuantSaveFromImpBoilerOp_IETC2005.pdf

= The excess air, in percentage

= The combustion temperature in °F, calculated according to the following equation:

where,

= The temperature of the combustion air before the burner, taken to be equal to the ambient room temperature (70°F) during the winter and the OAT during the summer

= The heat of reaction, equal to the HHV when the dew point temperature of the exhaust is less than 129°F and the lower heating value (LHV) [2] when the dew point temperature of the exhaust is greater than 129°F

Electric Savings

Electric savings were estimated as the hourly difference in blower electric usage between the baseline case, which assumes the intake air is modulated by dampers, and the installed VFD. The hourly estimates for both boilers are summed through the metering period to estimate a daily average savings which was extrapolated to a yearly savings. The yearly savings was divided by two, to account for the fact that only one boiler received the incentive.

The base case motor usage is estimated as follows:

where,

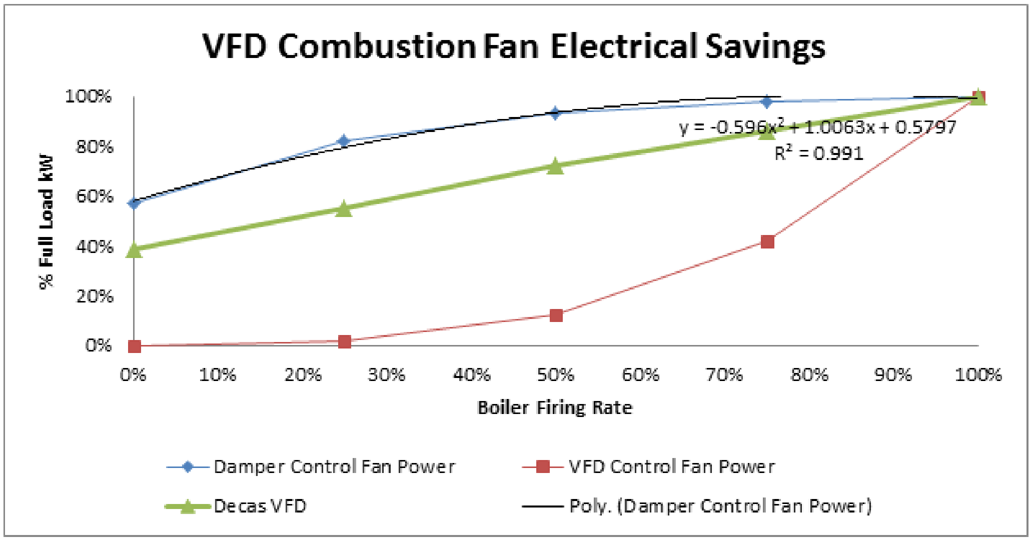
volts for three phase power, 460 volts

= -

Figure 2-5 was developed from fan curves and accounts for the loading as a function of fire rate.

[2] LHV = 21,441 Btu/lbs for natural gas

Figure 2-5. Firing Rate vs. VFD Full Load Percentage



The installed motor usage is estimated using the measured amps as follows:

–

where,

=

2.3 Evaluator Calculation Results

Table 2-6 provides the evaluator average firing rate and efficiencies for both the baseline and installed cases. Efficiency and savings were calculated separately for each boiler and then averaged. Although a single combustion vs. firing rate equation was used for both boilers, the efficiencies for each boiler vary slightly because the average firing rate within each bin varies.

Table 2-6. Evaluator Firing Rate and Combustion Efficiencies

		#1 Boiler				#2 Boiler			
Firing interval		Average Firing Rate	Pct of Time	Installed	Base	Average Firing Rate	Pct of Time	Installed	Base
Boiler off-line		**0.0%**	**48.5%**			**0.0%**	**66.4%**		
Boiler On-line									
Boiler On-line Intervals	1%-15%	0.0%	0.0%	70.5%	62.5%	11.2%	0.6%	70.5%	62.5%
	15%-25%		0.0%	71.1%	63.1%	20.8%	0.1%	71.1%	63.1%
	25%-35%		2.0%	71.7%	63.9%	33.8%	10.4%	71.7%	63.9%
	35%-45%	34.1%	70.4%	71.9%	64.1%	37.8%	79.2%	71.9%	64.1%
	45%-55%	38.4%	22.6%	72.1%	64.6%	50.3%	6.8%	72.1%	64.6%
	55%-65%	50.4%	4.5%	72.1%	65.0%	60.2%	2.4%	72.1%	65.0%
	65%-75%	59.4%	0.3%	71.9%	65.3%	69.0%	0.5%	71.9%	65.3%
	75%-85%	69.1%	0.1%	71.6%	65.5%	78.9%	0.1%	71.6%	65.5%
	85%-95%	81.9%	0.1%	70.9%	65.7%	90.2%	0.0%	70.9%	65.7%
	95%-100%	90.6%	0.0%	70.4%	65.8%		0.0%	70.4%	65.8%
Average seasonal		18.2%		71.9%	64.2%	13.0%		71.9%	64.1%

The average seasonal firing rate, highlighted in the last row of Table 2-6 was used to estimate a monthly usage for each month as the product of the number of hours in the month, the boiler input capacity and the average seasonal firing rate. The results of this calculation are shown in Table 2-7 in the Unadjusted Model column. On an annual basis, this result is within 5% of the billed use, which demonstrates that the model is a reasonable representation of the boiler performance.

Since this result must be weather normalized, the billing has been weather normalized, also shown in Table 2-7 in the last column. This annual usage is the usage of the two boilers.

Table 2-7. Monthly Billing Analysis for Weather Normalized Usage

Month	Days	HDD-55F Actual	HDD-55F TMY3	Billed Used	Unadjusted Model	Weather Normalized Billing
				Therms		
January-12	31	652	802	77,844	58,288	82,407
February-12	29	533	640	75,232	54,527	74,775
March-12	31	338	504	61,545	58,288	68,295
April-12	30	170	261	59,324	56,407	56,805
May-11	31	56	80	46,203	58,288	48,271
June-11	30	5	9	47,682	56,407	44,903
July-11	31	0	0	43,262	58,288	44,476
August-11	31	0	0	44,981	58,288	44,483
September-11	30	8	21	45,240	56,407	45,489
October-11	31	120	152	46,599	58,288	51,667
November-11	30	235	391	51,196	56,407	62,977
December-11	31	476	742	57,276	58,288	79,576
Total				**656,385**	**688,171**	**704,123**
Model adjustments for weather						**102.3%**

The final monthly usage and savings for the two boilers is shown in Table 2-8. The boiler usage for each month was estimated as the product of the number of hours in the month, the average firing rate, the boiler input capacity, and the weather normalization factor of 102.3%. Note that the total boiler usage is equivalent to the weather normalized billed usage due to the weather normalization factor.

Table 2-8. Monthly Gas Use

Month	Installed Boiler Usage (therms)			Boiler Savings(therms)	
	Boiler #1	Boiler #2	Total Boiler	Boiler #1	Boiler #2
January -12	34,751	24,888	59,639	4,158	2,978
February	32,509	23,282	55,791	3,890	2,786
March	34,751	24,888	59,639	4,158	2,978
April	33,630	24,085	57,715	4,024	2,882
May	34,751	24,888	59,639	4,158	2,978
June 2011	33,630	24,085	57,715	4,024	2,882
July	34,751	24,888	59,639	4,158	2,978
August	34,751	24,888	59,639	4,158	2,978
September	33,630	24,085	57,715	4,024	2,882
October	34,751	24,888	59,639	4,158	2,978
November	33,630	24,085	57,715	4,024	2,882
December	34,751	24,888	59,639	4,158	2,978
Annual	**410,284**	**293,838**	**704,123**	49,090	35,157
				Savings:	84,247

The boiler usage in Table 2-8 represents the usage and savings for both boilers. However, the incentives were only provided for a single boiler. At the time of the application, the owner had intended to run one boiler as the primary boiler. Since then, controls were installed on the second boiler and now the boilers run alternating the lead boiler. Since the intent of the owner is to run each boiler equally, the savings have been halved to represent the saving due to the incentive for a single boiler. The final savings for the project is shown in Table 2-9.

Table 2-9. Evaluated Weighted Efficiency and Savings

	Baseline	**Installed**
Usage, single boiler	394,185	352,061
Efficiency	64.18%	71.90%
% Savings	12.03%	
Savings (therms)	42,124	

Electric Impacts

Electric impacts were calculated using an analysis similar to the one applied to determine gas impacts. Evaluators determined savings for this measure by estimating the baseline electricity use for a dampered boiler air intake and the as-built electricity use for a variable speed fan. This resulted in annual impacts of 7,081kWh/year.

Table 2-10. Variable Speed Drive Savings Summary

Boiler	Metering period usage			
	Baseline kWh	Installed kWh	Daily savings	
Boiler #1	5,189	4,605	19.4	kWh
Annual savings			7,081	kWh

3. Final Results

This project involves replacing the linkage combustion controls for one 600-hp steam boiler with a parallel positioning oxygen (O_2) trim control package and a variable speed drive (VFD) on the boiler's combustion blower to operate the boiler efficiently. The steam boiler supports the manufacturing process and space heating loads at the facility.

At the time of the application, the facility steam load was served almost entirely by Boiler #1 with Boiler #2 as back-up. The incentive and savings were calculated accordingly. Subsequent to the installation of the controls, the second boiler was equipped with combustion controls and the sequence of operation has been changed so that the boilers both operate in alternate periods, halving the load and the savings of Boiler #1. The second boiler was not incentivized.

The actual seasonally adjusted combustion efficiency improvement of 12% was impressive, but still below the 16.7% projected in the application. However, the applicant had underestimated the usage of the boiler plant, which increased the savings.

Measure impact calculations are shown in Table 3-1.

Table 3-1. Key Parameter Summary

	Baseline	Installed
Billing		
Actual gas bills (May. 2011 – Apr. 2012) (therms)	N/A	656,385
Weather normalized installed billing	N/A	704,123
Tracking/Applicant		
Boiler seasonal combustion efficiency	66%	77%
Average annual seasonal improvement in efficiency		16.7%
Lead boiler hours	7,509	7,509
Gas usage (therms)	592,529	509,002
Savings (therms)		83,527
Evaluated		
Use-weighted boiler seasonal combustion efficiency	64.18%	71.90%
Average annual seasonal improvement in efficiency		12.0%
Lead boiler hours	3,734	3,734
Boiler gas usage (therms), weather normalized	394,185	352,061
Savings (therms)		42,124
Realization rate		
Final realization rate		50.60%

3.1 Cross Check with Billing Data

A year of post-installation billing data was used to determine the typical process use (The average gas use during the summer months of June, July, and August). The process use, along with the TMY3 normalized space heating use was used to determine the facility load. In this way the actual billed use is an inherent part of the analysis.

3.2 Recommendations for Program Designers & Implementers

The boiler controls have improved the efficiency of the boiler substantially. However, the full impact of the savings was not realized because the two boilers shared the facility's load. Many sites with multiple boilers will use a lead lag rotation on a daily, weekly, or monthly basis to reduce the wear and tear on a particular boiler and extend operational life. Applications that show the full facility load on only one boiler should be a sign for extra scrutiny of an application.

3.3 Customer Alert

None.

3.4 Explanation of Deviations

Table 3-2 provides a summary of the key deviations between the tracking and evaluated savings.

Table 3-2. Summary of Key Factors and Deviations

Factor	Applicant	Evaluator	Impact of Deviation	Discussion of Deviations
Operation	592,529 therms	394,185 therms	-40%	The applicant assumed the incentivized boiler would serve the load, but both boilers equally served the load.
Baseline efficiency	66%	64%	17%	The evaluators used the combustion test measurements in a standardized combustion equation.
Installed efficiency	77%	72%	-28%	The evaluators used a combustion analyzer to determine key efficiency parameters such as excess air and stack temperature.

1. Project Summary and Results

This project replaced two existing gas-fired high pressure steam boilers with two new higher efficiency gas fired steam boilers of the same size equipped with combustion controls. The older boilers did not have combustion controls. The boiler plant serves essentially the entire heating load at a community hospital, consisting of space heating, DHW, and process. The boiler plant operates year round and except in the coldest weather, operates with a single boiler. The project was separated into two identical applications.

The evaluator visited the site, interviewed site staff, took spot measurements, installed logging equipment, and conducted analysis to determine the evaluated savings.

1.1 Savings

Measure ID	Measure Name		Gas Savings (Therms/yr)	Electric Savings (kWh/yr)
1	Steam boiler replacement (2)	Tracked	32,146	NA
		Evaluated	32,147	NA
		RR[1]	98%	NA
2	Boiler controls (2)	Tracked	11,298	NA
		Evaluated	6,922	NA
		RR[1]	61%	NA
	Total	Tracked	43,444	NA
		Evaluated	38,267	NA
		RR[1]	88%	NA

[1] Realization rate

1.2 Explanation of Deviations from Tracking

There are several areas in which the evaluated savings vary from the tracking savings:

- The applicant had assumed lower baseline efficiencies, but had expected lower installed efficiencies for the boiler replacement component. In addition, the applicant had assumed slightly higher standby losses assuming the old boiler as the baseline. The net impact was a net reduction in savings.
- The combustion controls saving were lower than the applicant estimate. The boiler operates almost exclusively in the mid to high range of the firing rate, while combustion efficiency controls typically provide a higher efficiency margin in the lower end of the firing range.

2. EVALUATED MEASURE

The following sections present the evaluation procedure, including the findings from an in-depth study of the supplied application calculations and the evaluation methodology determined to best fit the measure based on the information available.

2.1 Application Information and Analysis

This measure included the replacement of two existing 30 year old Kewanee steam boilers (Boilers #1 and #2) with two new high efficiency boilers with combustion controls. A third boiler (Boiler #3) remained as a back-up boiler. All of the old and new boilers were identically sized at 250 hp.

The project evolved from early March 2009 through the installation in mid-2010. The original offer letter dated March 2009 was for the replacement of the burners and controls on all three boilers. The Custom Audit Report dated September 2009, identified two measures: a higher efficiency new boiler replacement for boiler #2 and an upgrade of boiler #1's controls. The final project consisted of the replacement of both Boilers #1 and #2 with higher efficiency boilers equipped with combustion controls. Boiler # 3 was left in place as is, as a back-up unit. The measure also included savings based on the elimination of a control sequence which held the back-up boiler on hot standby.

2.1.1 Application Description of Baseline

The applicant savings were calculated assuming the replaced boilers were 23 years old and 8 years old and had seasonal thermal efficiencies of 76% and 79.9% respectively based on a calculation of efficiency vs. age from a US Army Corp study for similar boilers. The applicant also assumed the new boilers would not have combustion controls. Based on the age cited, the baseline appears to assume that boiler #2 and #3 would be replaced.

The savings also noted the designated back-up boiler was on hot standby during the entire year.

2.1.2 Applicant Description of Installed Equipment and Operation

The applicant ultimately replaced Boilers #1 and #2 with two 250 hp steam boilers with combustion controls. The control sequence was altered to provide cold stand-by capability for the lag and back-up boilers. The #3 boiler was left in place with no upgrades as a back-unit.

2.1.3 Applicant Energy Savings Algorithm

The applicant calculated savings using a spreadsheet which identified three savings mechanisms:

- Installation of high efficiency boilers
- Elimination of hot standby of the back-up boiler, which was added with high efficiency boiler savings in tracking
- Implementation of combustion controls.

The high efficiency boiler savings was calculated using the following equation:

where:

= Twelve months of billed usage, Aug-08 to Jul-09

= Per the following table

The efficiencies used to calculate savings are summarized in Table 2-1. These were reported as FTSE or fuel to steam seasonal efficiencies.

Table 2-1. Summary of Applicant Efficiencies for Boiler Replacement

	Boiler #1	Boiler #3
Age of boiler	23 years	8 years
Baseline FTSE efficiency	76%	79.9%
Installed FTSE efficiency	87.7%	81.7%
Base gas usage	571,117 therms from August 2008 to July 2009	

The elimination of **hot standby** of the back-up boiler was calculated assuming the old #2 boiler was running in hot standby for eight months of the year and the # 3 boiler was in standby for 4 months of the year. The calculation assumes a standby loss rate from ABMA tables which is applied to the boiler capacity times the number of hours on standby per year. The sum of the loss is assumed to be the energy that is saved in the installed case.

The savings calculation for the **combustion controls assumes** the controls will only be placed on the existing #3 boiler, which is a Cleaver-Brook unit installed in 2009, however, it would serve almost all of the load. The calculations reference spot combustion measurements (stack and O2), averages the results across the firing range, and then uses these average values to derive a boiler efficiency from a combustion efficiency look-up table. The baseline efficiency is calculated to be 80.3% with an expected efficiency of 82% by reducing the O2 level by 4%. This efficiency improvement is applied to the estimated gas usage after the installation of the new boilers.

2.1.4 Analysis of Applicant Algorithm

The calculation methods are reasonable, except that the applicant references combustion efficiencies based on an algorithm developed by the US Army Corp of engineers based on the age of the boiler rather than using the combustion measurement data that was available from multiple sources – and was even referenced in the applicant’s savings algorithms. Two of the combustion data sets are summarized in Table 2-2.

In addition, the calculations appear to have been devised for boilers #1 and #3 and not the boilers that were replaced, boiler #1 and #2. However, this would not have had a significant impact since the calculations assumed the boilers served the entire load.

Table 2-2. Project File Combustion Measurements for Boiler #1

	March 2009			July 2008		
Percent Firing	Low	Med	Hi	Low	Med	Hi
Stack temperature (°F)	338	355	367	299	311	317
Combustion air temperature (°F)	94	86	95	86	86	86
Excess air (%)	31	29	42	31	42	29
Oxygen (%)	5.4	5.2	6.7	5.4	6.7	8.8
Reported efficiency	85.5	85.7	85.5	85.5	85.5	85.7

2.2 On-Site Inspection, Metering, and Analysis

This section provides the steps of the evaluation from initial site visit through the final results. Each step is described in detail to offer an in-depth reasoning behind the full process.

2.2.1 Summary of Site Visit Findings

The site was visited on March 23, 2012, and personnel were interviewed regarding the system operation. The boiler plant consists of three gas-fired boilers. Two of the boilers, Boilers #1 and #2 were identical new 250 hp boilers rated at 10.2 MMBtu/h input with a nominal 82% efficiency. Both boilers are equipped with parallel position controls, O_2 trim, and a 10 horse power VFD controlled blower motor. The back-up gas-fired boiler is 250 hp boiler, although about 10 years old and is equipped with linkage controls. The boilers are dual fuel fired with oil used as an emergency back-up fuel only.

The boilers are sequenced with Boilers #1 and #2 operating lead/lag. The lag boiler is only brought on line when the load exceeds the capacity of the lead boiler. The lag boiler is kept in cold stand-by. During the metering period, Boiler 2 was operated as the lead boiler almost exclusively. According to the site contact, however, the boilers are rotated over the year resulting in equivalent hours over the long term.

The boilers supply high pressure steam (100 psi) for space heating, domestic hot water, and process loads related to sterilization. The boilers are served by a gas meter which includes a small kitchen load. Two other gas meters serve minor loads.

The plant is in good condition and the distribution system has recently been checked for steam leaks and trap repairs.

2.2.2 Measured and Logged Data

The evaluators installed logging equipment on both boilers from March 19 through June 27, 2012. Table 2-3 shows the points that were metered

Table 2-3. Summary of Metered Data

Boiler	Parameter Measured	Time Interval	Duration
Boiler #1	Blower fan kW	15 minute	14 weeks
Boiler #2	Blower fan kW	15 minute	14 weeks

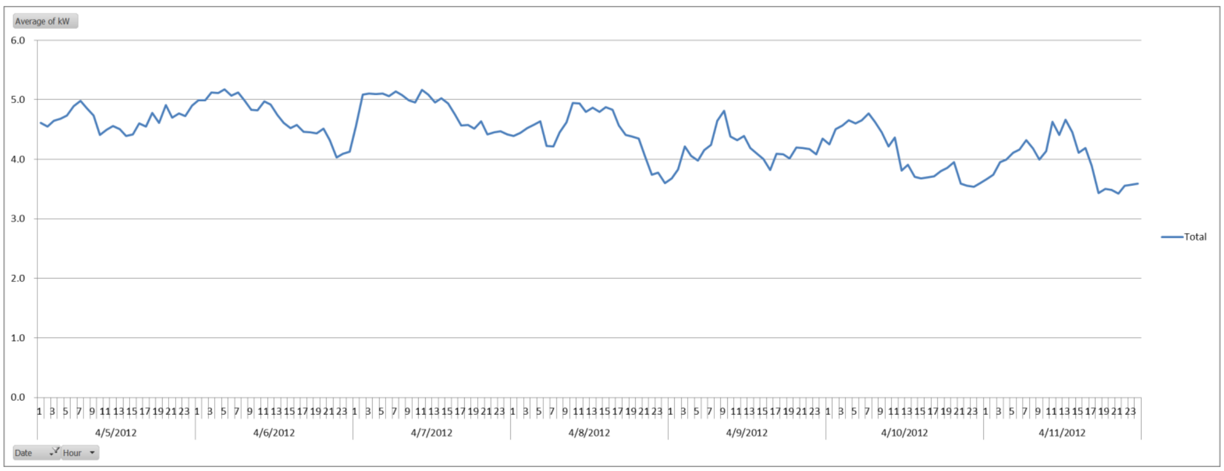
The evaluators were able to take only a single spot measure, due to the plant operator’s reluctance to modify the firing rate of the boiler. The evaluator was also given permission to measure the blower motor only and was not allowed to leave a probe in the stack. The result of the single point measurement is summarized Table 2-4.

Table 2-4. Combustion Measurements – Boiler #2

Percent Firing	Stack Temperature (°F)	O2	CO2
Read #1	334	3.1%	5.1%
Read # 2	391	3.4%	4.0%
Ambient	96		
Firing rate	50%		
Average efficiency reading	85.1%		

The boiler operates continuously over a fairly narrow range. During this period, Boiler #2 ran for most of the time, with boiler #1 operating for only about three days. There was almost no overlap in operation between the two boilers. Boiler #3 was shutdown. A typical weekly profile of the blower motor is shown in Figure 2-1.

Figure 2-1. Typical Boiler Weekly Firing Profile



2.2.3 Evaluation Description of Baseline

The documentation indicates that the customer thinking had evolved over the course of the project. The original offer letter of March 2009 was for the installation of three combustion control systems, one for each of the boilers. Subsequent documentation indicates the customer had funding set aside for the replacement of one of the boilers. The site contact indicated that the replaced boilers, at thirty years old, were clearly at the end of their lives and needed to be replaced in the near term

While there appeared to be some consideration to keep the old boilers, the evidence indicates the boilers were in need of replacement and had reached the end of their useful lives. The code in force at the time of the offer letter dated July 2010 was the 11th edition Rhode Island building code. The code requires a minimum 80% combustion efficiency for a gas-fired steam boiler >2.5 mmBtu/hr; this was used as a reference point in the baseline efficiency calculations.

The baseline of the combustion controls measure used was a linkage control profile referencing the efficiency of the new boilers. The baseline for the boiler replacement was a linkage control profile referencing the code efficiency standard. The baseline for the standby control sequence change was the estimated standby loss of the code compliant baseline boilers kept in hot standby.

2.2.4 Evaluator Calculation Methodology

The evaluator calculated savings due to the combustion controls, the replacement of the two existing boilers with high efficiency equivalents, and the elimination of hot standby losses, in that order to account for interactive effects.

The evaluator used the metered data to create an 8,760 analysis of hourly boiler loads to estimate the hourly average firing rates and the hourly boiler gas usage as a function of the observed firing rate and boiler capacity of the installed boilers with TMY3 weather data. This established the current weather normalized installed gas usage of the boilers.

Next, a best fit curve was developed for combustion efficiency vs. the firing rate for the installed case based on the post spot measurements of the boiler. A combustion efficiency vs. firing rate for a linkage control baseline was produced using an empirically developed curve of the relationship between firing rate and efficiency with linkage control. Two curves were developed, one for the high efficiency boilers with linkage control and a second with a code compliant boiler with linkage controls.

The following general equation was applied to calculate the savings for each case:

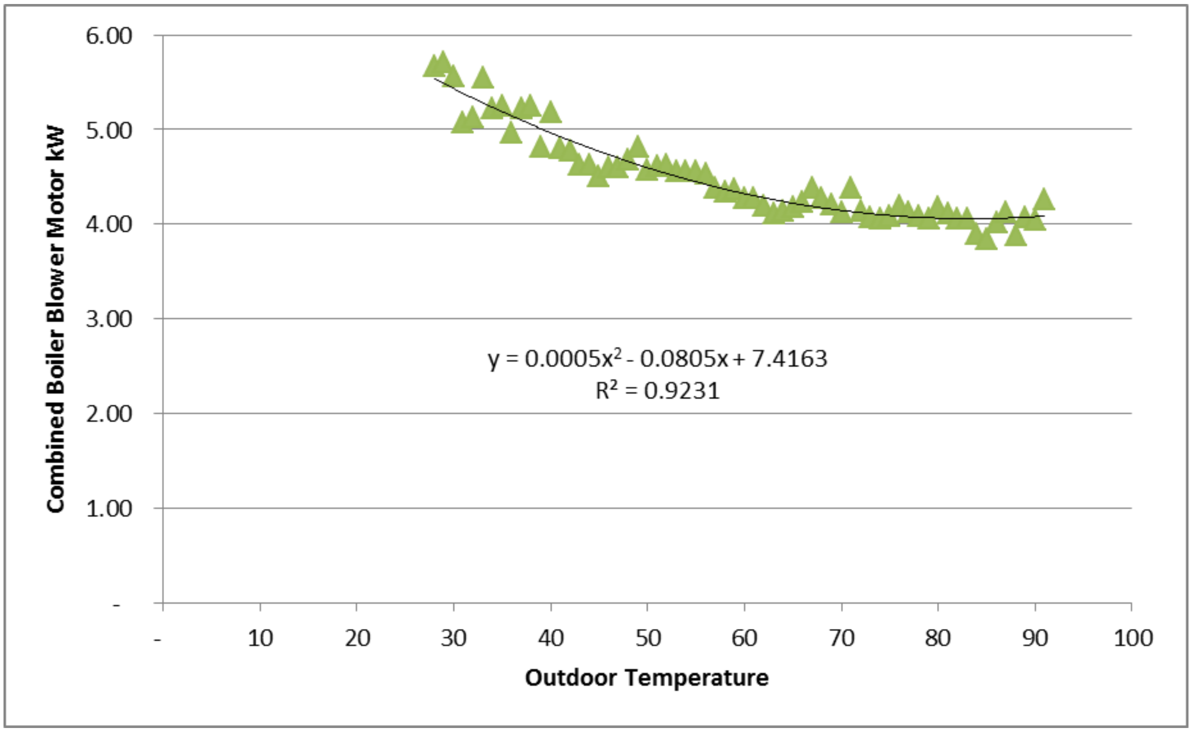
The hot standby loss was calculated last using the baseline efficiency of the boilers replacements applied to the shell loss load. A shell loss rate was estimated and then applied for the hours of the year when only a single boiler is required to serve the load.

Boiler Firing Rate Profile

The evaluators used metered combustion fan kW to determine the usage of the boilers. The evaluator developed a relationship of fan kW vs. firing rate using billing and other data.

The blower motor logger data was processed for each boiler to create hourly demand profiles. The blower demand was regressed against concurrent outdoor air temperature (OAT) data from a local weather station. Figure 2-2 presents the average hourly blower motor demand as a function of dry-bulb temperature.

Figure 2-2. Blower motor kW vs. Outdoor Air Temperature

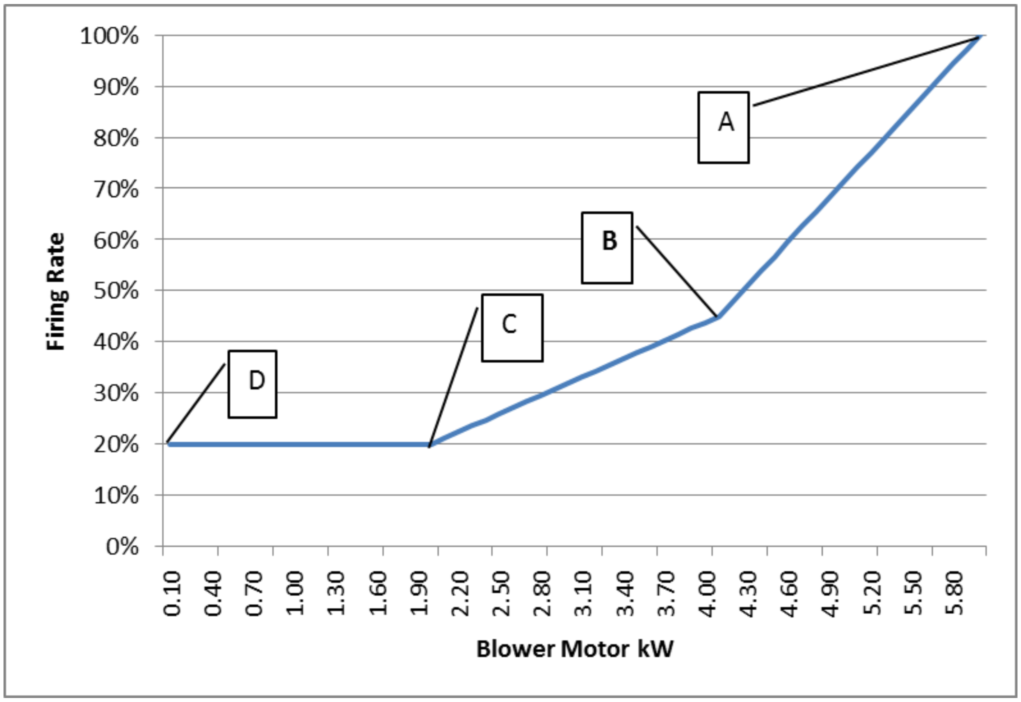


There was no blower kW vs. firing rate observations directly available, so this relationship had to be inferred from other data. Points A, B, C, and D shown in Figure 2-3 were used as the endpoints of three lines describing the firing rate vs. blower demand as follows:

- Point A. The blower motor was a 10 hp motor; with an 80% load factor it would draw 6 kW at 100% design load. The maximum sustained draw of the blower motor observed in the logged data was 6 kW. Point A is defined as a 100% firing rate when the blower motor is at a 6kW load.
- Point B. The blower motor operated with very little variation over the month of June implying a constant firing rate (4.1 kW ±6% standard deviation). A monthly firing rate of 45% was calculated by dividing the billed June usage by the number of hours in the month divided by the boiler rated input capacity. Since the blower motor operated at 4.1 kW with little variation, the 4.1 kW was assumed to produce this average firing rate of 45%. Point B is defined as 45% firing rate when the blower motor is at 4.1 kW.
- Point C. With a turn down ratio of five, the minimum firing rate for the boiler is 20%. The boiler only operated for about 45 minutes during three months of metering below 2 kW. The evaluator assumed that the blower motor draws 2 kW at a 20% firing rate, defining Point C.
- Point D. The blower motor will be at zero when the boiler is at 0% firing rate, establishing the last point.

While some judgment had to be applied in producing the model of Figure 2-3, the model matched the weather adjusted billing data extremely well, which gives confidence in the model.

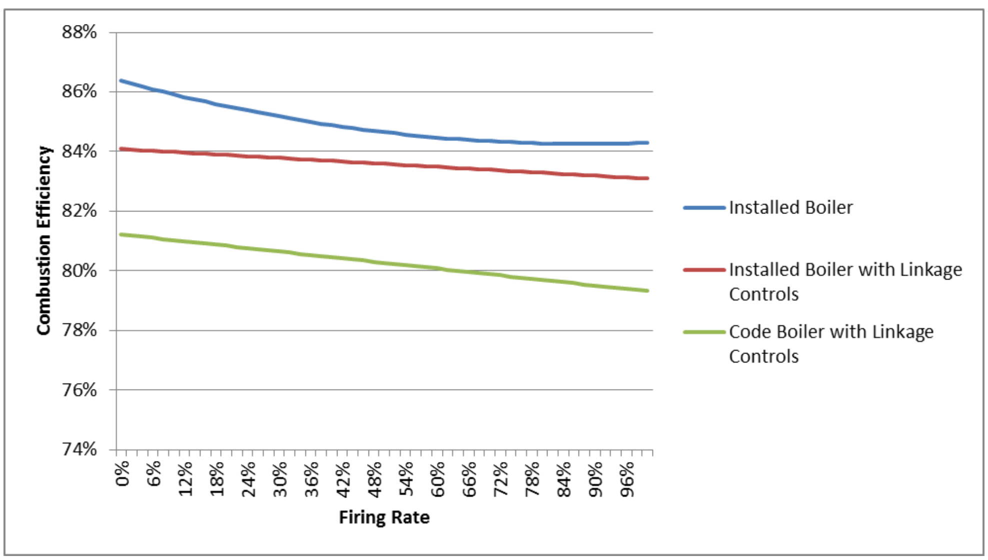
Figure 2-3. Relationship of kW to Firing Rate



Calculation of Combustion Efficiency

Combustion curves relating efficiency to firing rate were developed for the installed case and each of the base cases. The curves are presented in Figure 2-4 and discussed in the following sections. The efficiency curves are used in the 8760 model to compute efficiency as a function of firing rate.

Figure 2-4. Baseline and Installed Efficiency



The points used to develop the combustion curves are from combustion test measurements of stack temperature, ambient air temperature, and excess air. The actual efficiencies at these points are calculated using Equation 1 described below, so the baseline and installed efficiencies are computed in the same manner eliminating a potential methodological difference.

Installed combustion efficiency. The stack temperature, O2, and ambient temperature readings from spot measurements shown in Table 2-2 were used as inputs to calculate combustion efficiencies using Equation 1 described in the next section. These measurements were in the project file and were taken at the time the new unit was commissioned. As a comparison, the single firing point measured by the evaluator is included in the table as well. In this particular case, the evaluator field measurement was close to the earlier recorded efficiencies. Once the efficiencies were calculated, the efficiencies were regressed against the firing rate. Since the firing rates were not specified, the evaluator assumed rates of 25%, 50%, and 100% for these points.

Table 2-5. Post-Installation Project File Combustion Measurements

	October 2010			March 2012
Percent Firing	**Low**	**Med**	**Hi**	**Med**
Stack temperature (°F)	293.1	289.2	271.6	334
Combustion air temperature (°F)	90	90	90	96
Excess air (%)	18.9	39.7	64.2	17.4
Oxygen (%)	3.66	6.46	8.77	3.1
Calculated efficiency	85.3	84.7	84.3	84.6%

Linkage control efficiency curve. The baseline for the combustion controls is the high efficiency boiler with linkage controls. Combustion efficiency is estimated using an empirically derived linkage control curve. The curve was developed from a data set of combustion measurements at multiple points in the firing range of 19 boilers at 12 different sites extracted from the evaluator’s portfolio of linkage controlled boiler combustion tests.

Code boiler efficiency curve. The baseline for the high efficiency boiler is a code compliant boiler that meets the minimum required rating of 80% combustion efficiency and has linkage controls. Combustion efficiency vs. firing rate is estimated using the empirically derived linkage control curve described above, but referencing the code compliant efficiency. A further adjustment is applied to the code baseline to account for operational changes in efficiency. This adjustment is calculated each hour as the ratio of the calculated hourly efficiency of the installed boiler divided by the maximum observed installed boiler efficiency.

Combustion Efficiency Calculation

Measured inputs of stack temperature, ambient temperature, excess air or gas saturations are used to calculate combustion efficiency using the equations described in this section. While combustion tests equipment estimate a combustion efficiency which is often recorded, the exact calculation method is usually unknown. Use of the same equation for both the pre and post-installation efficiency calculations using the same measurement inputs eliminates one source of bias between these measurements.

The following equation[1] was applied to calculate the sensible boiler efficiency, where the measured inputs include the excess air and stack temperature:

Equation 1

where,

= Higher heating value of the fuel, equal to 23,797 Btu/lb for natural gas in this analysis

= The specific heat of the combustion products, estimated to be 0.26 Btu/lb-°F

= The temperature of the exhaust gases in °F

= The stoichiometric air-to-fuel ratio, equal to 17.2 for natural gas

= The excess air, in percentage

= The combustion temperature in °F, calculated according to the following equation:

where,

= The temperature of the combustion air before the burner, taken to be equal to the ambient room temperature (70°F) during the winter and the OAT during the summer

= The heat of reaction, equal to the HHV when the dew point temperature of the exhaust is less than 129°F and the lower heating value (LHV) when the dew point temperature of the exhaust is greater than 129°F. Steam boilers do not condense so the LHV is used.

Hot Standby Calculations

In the sequence of operation with hot standby, a boiler is kept at very low fire so that it can be brought up quickly. Although the boiler is not generating any output, the boiler shell is at production temperature and losses occur. Since a boiler was always maintained in standby prior to the installation, these losses were constant when a single boiler was operating.

The skin losses are estimated based on field-collected data, including surface area from the equipment specifications, unit surface temperature, and boiler size. The absolute Btu valve of the skin loss is constant while the boiler is firing or in standby.

Skin losses are the convective and radiative losses from the boiler's hot surface to the cooler surrounding environment. They are determined by the temperature differential between the boiler skin and surrounding air as well as the boiler's size and shape. Losses are a constant Btu value whenever the boiler is firing. The losses are calculated as follows for each surface and summed:

[1] "Quantifying Savings From Improved Boiler Operation," Kissoc, University of Dayton IAC,http://academic.udayton.edu/kissock/http/Publications/QuantSaveFromImpBoilerOp_IETC2005.pdf

where,

= Emissivity

$A =$ Surface area, ft^2

= Surface temperature, °F

= Ambient (room) temperature, °F

where,

= Surface area, ft^2

= Surface temperature, °F

= Ambient (room) temperature, °F

The result of the calculation is a constant shell loss value which is expressed as a percentage of the rated input. The shell loss savings were calculated as the sum of the hours the second boiler was in standby multiplied by the loss in MMBtu/h and divided by the baseline efficiency.

Final Calculation of Savings

The general equation was applied to calculating savings for the combustion controls and the high efficiency boiler, in turn on an hourly basis:

The sum of the hourly usages is the annual usage. The shell losses of the hot standby practice were calculated last.

2.3 Evaluator Calculation Results

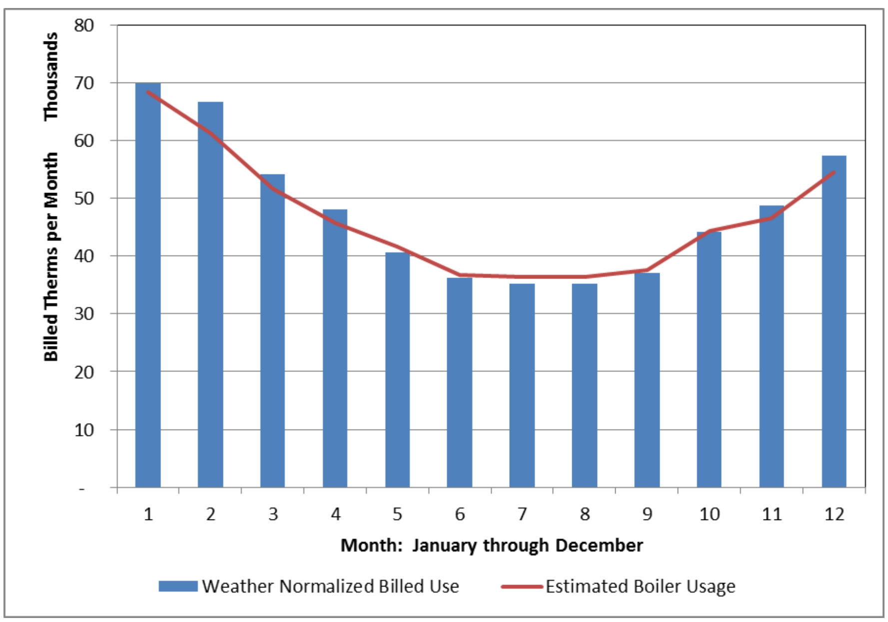
The modeled annual estimated gas use is compared to the weather adjusted billing in Table 2-6. The table shows the actual billed usage for the period of June 2011 through January 2012, the weather adjusted gas usage and the modeled gas usage. There is good agreement between the billed usage and the model. The modeled gas usage was used as the installed gas usage with no further adjustments since there are other small end-uses on the meter.

Table 2-6. Estimated Annual Gas Usage

	TMY3	Billed Used	Weather Normalized	Modeled Usage
Month	HDD	Therms		
January -12	997	61,854	69,843	68,359
February	907	58,207	66,674	61,299
March	550	51,030	54,109	51,620
April	377	45,910	47,993	45,638
May	170	40,282	40,705	41,587
June 2011	44	40,291	36,244	36,751
July	14	34,131	35,209	36,426
August	15	33,468	35,227	36,405
September	68	34,370	37,083	37,660
October	269	40,291	44,187	44,316
November	398	45,228	48,731	46,518
December	642	52,630	57,318	54,484
Total		**537,692**	**573,324**	**561,061**
Model variance			**98%**	

A plot of weather normalized billing and modeled gas usage is shown in Figure 2-5.

Figure 2-5. Weather Normalized Billing and Modeled Gas Usage



The 8760 model was used to calculate the gas usage of the high efficiency boiler with linkage controls and then finally the gas usage of a code compliant boiler with linkage controls. The gas usage and weighted average combustion efficiency are shown in Table 2-7.

Table 2-7. Gas Usage and Savings by Measure

	Gas Use (therms)	Seasonal Thermal Efficiency	Savings (therms)
Installed Case	561,061	83.50%	
High Efficiency Boiler, Linkage	567,984	82.63%	6,922
Code Boiler, Linkage	592,697	79.19%	24,713
Code Boiler, Linkage, Hot standby	599,329		6,632
Final project savings:			**38,267**

3. Final Results

This project replaced two existing gas-fired high pressure steam boilers with two new higher efficiency gas fired steam boilers of the same size equipped with combustion controls at a hospital. The boiler plant serves essentially the entire heating load consisting of space heating, DHW, and process. The boiler plant operates year round and except in the coldest weather, operates with a single boiler. The two boilers that were replaced were about twenty-five years old and at the end of their useful lives according to the site contact. Boiler #3, which was only eight years old was not upgraded and operates as a back-up unit.

The evaluator visited the site, interviewed site staff, took spot measurements, installed logging equipment, and conducted analysis to determine the evaluated savings. The applicant derived the baseline boiler efficiency using an algorithm based on the boiler age, although there were multiple series of combustion measurements available that could have been used. These actual baseline combustion efficiencies were higher than the age-based efficiency and also higher than required by code. Because the applicant's projected installed efficiency was lower than the actual installed efficiency, the net impact reduced savings by only about 10%. The boiler plant operates at a relatively steady firing point at the mid to high range of the boiler, missing the 'sweet spot' for combustion controls at the lower end of the range, leading to a slight decrease in combustion control savings. Finally, the elimination of the hot standby operation produced additional savings, however, at the loss rate of the installed boiler rather than the loss rate of the old boiler.

Measure impact calculations are shown in Table 3-1.

Table 3-1. Key Parameter Results

	Baseline	Installed
Billing		
Actual gas bills (Jun-11 to May-12) (therms)	N.D.	537,692
Weather-normalized billing difference		573,324
Tracking/Applicant		
Replacement boiler seasonal combustion efficiency	77.50%	81.70%
Combustion control efficiency change		1.70%
Standby loss rate		0.65%
Gas usage (therms)	598,369	554,924
Savings (therms)		43,445
Evaluated		
Replacement boiler seasonal combustion efficiency	79.01%	82.44%
Combustion control efficiency change		0.84%
Standby loss rate		0.63%
Standby loss seasonal efficiency impact		1.01%
Gas usage (therms)	599,329	561,061
Savings (therms)		38,267
Realization rate		
Final realization rate		88 %

3.1 Cross Check with Billing Data

The project was estimated to save almost 8% of the pre-installation billing, which could be observable in the bills. However, the site experienced metering difficulties for many months in the pre-installation phase of the project making a billing analysis impossible. The results section, however, presented an analysis of the modeled usage against current billing showing very good agreement between the model and the weather normalized billed usage.

3.2 Recommendations for Program Designers & Implementers

The applicant savings calculations should avail themselves of combustion measurements when they are available.

Large capital equipment purchases are usually end-of-life measures and not retrofit measures, this case being no exception according to the site contact and also according to at least some of the notes in the project file. However, in this case, that factor increased the project savings since the combustion efficiency measurements of the pre-installation boiler were higher than the code compliant combustion efficiency standard.

3.3 Customer Alert

None.

3.4 Explanation of Deviations

Table 3-2 provides a summary of the key deviations between the tracking and evaluated savings.

Table 3-2. Summary of Key Factors and Deviations

Factor	Applicant	Evaluator	Impact of Deviation	Discussion of Deviations
Efficiency improvement – Combustion controls	1.7%	.9%	-18%	The boiler does not fire in the lower range where the combustion controls have the most savings.
Efficiency improvement – Shell losses	*0.65%*	*0.51%*	-8%	The applicant included shell losses from the old existing boiler. The evaluator losses are based on the code compliant boiler losses.
Baseline efficiency	*77.50%*	*79.1%*	-12%	The applicant estimated a baseline efficiency using an algorithm based on the age of the boiler. Measured efficiencies were higher. Because this was an end of life measure, the evaluator used a code baseline efficiency
Installed efficiency	*81.70%*	*83.43%*	26%	The applicant used boiler ratings to estimate the installed efficiency. The actual seasonal thermal efficiency based on combustion measurements was higher.

1. Project Summary and Results

This project involves the installation of a regenerative thermal oxidizer (RTO) at a 140,000 sq ft manufacturing facility that produces aerogel-impregnated insulation blankets. The process exhaust stream contains volatile organic compounds (VOCs). Per EPA requirements, the facility must incinerate the VOC-laden exhaust at a temperature of at least 1,500ºF to prevent harmful emissions. The project claims savings from a higher efficiency RTO with ceramic media, compared to a less efficient thermal recuperative oxidizer (TRO) and heat exchanger.

1.1 Savings

Measure ID	Measure Name		Gas Savings (Therms/yr)	Electric Savings (kWh/yr)
1	Regenerative thermal oxidizer (RTO)	Tracked	403,011	
		Evaluated	376,831	
		RR[1]	93.5%	
[1] Realization rate				

1.2 Explanation of Deviations from Tracking

There are several areas that the evaluated savings vary from the tracking savings:

- RTO chamber temperature – the applicant used a temperature of 1400°F. The EMS trended average temperature was 1519°F
- VOC heat contribution – the applicant did not include the combustion heat from the VOCs in the installed case which offset the oxidizer's gas use.

2. Evaluated Measure

The following sections present the evaluation procedure, including the findings from an in-depth study of the supplied application calculations and the evaluation methodology determined to be the best fit for the site based on the information available.

2.1 Application Information and Analysis

An RTO was installed at a manufacturing plant during an expansion to add new production capacity. The RTO serves the new capacity and also replaces an existing TRO which served the original production capacity.

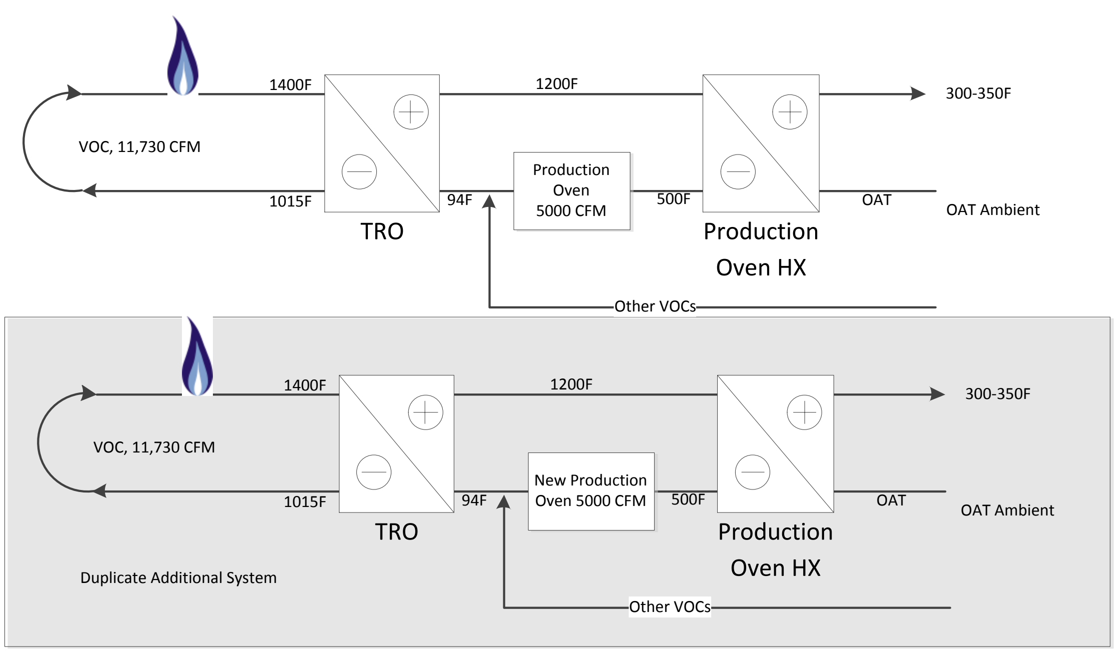
The sections below detail the information contained in the applicant documents and program administrator files that were provided to the evaluators.

2.1.1 Application Description of Baseline

The existing TRO utilized two heat exchangers in series. The first preheated in incoming VOC-laden air before combustion. The second was used to heat outdoor air entering the continuous production oven line eliminating the need for any further thermal inputs to the ovens. This dual heat exchanger system setup provided more heat recovery than a typical TRO because the site had a use for the lower quality heat leaving the first heat exchanger. In most facilities the exhaust airstream would be vented to the outdoors after the first heat exchanger.

The site anticipated a doubling of capacity, due to new production. The applicant baseline retained the existing system and added a duplicate system to meet the additional capacity. Figure 2-1 illustrates the existing system and the proposed duplicate system with the temperatures provided by the applicant.

Figure 2-1 Applicant Baseline Schematic

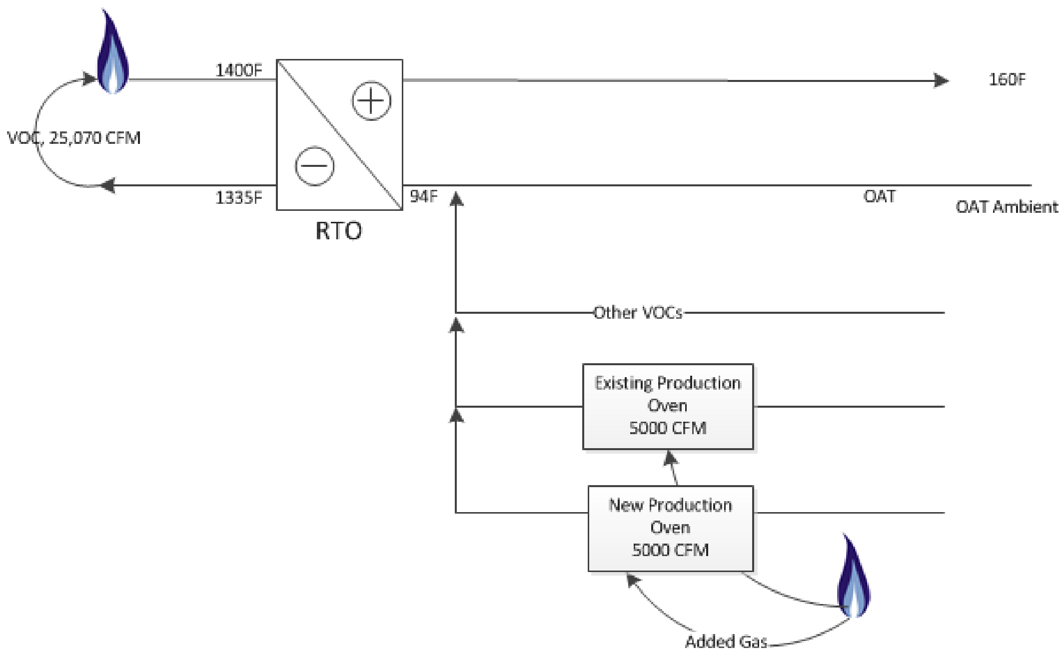


The site also used an 8 MMBtu boiler to meet its process hot water needs.

2.1.2 Applicant Description of Installed Equipment and Operation

The existing TRO and both heat exchangers were to be removed. A new production oven line (identical to the existing line) was to be installed. A new RTO would be installed to serve both production oven lines. In addition, since the secondary heat exchanger had been removed, both ovens would have a burner installed to provide the necessary heat. The existing TRO was sized for 11,730 cfm of exhaust air. The increase of the second oven line (doubling of production) increased the new design capacity to approximately 25,000 cfm. Figure 2-2 is a schematic of the applicant's proposed system with temperatures.

Figure 2-2 Applicant Installed System Schematic



Due to the increase in production capacity, the 8 MMBtu hot water boiler was upgraded to 12 MMBtu. The boiler was not part of the incentive package.

2.1.3 Applicant Energy Savings Algorithm

The applicant calculated existing and proposed gas use with an adjustment for the production capacity increase. The difference between the scaled up baseline and estimated proposed use was the energy savings.

Existing Baseline Consumption

The applicant baseline assumed that the facility would install a second TRO system identical to the first, including the second heat exchanger, thereby doubling the amount of gas currently used by the existing TRO.

The applicant calculated the savings through inspection of the pre-existing oxidizer's fuel use. The consumption of the pre-existing oxidizer was modeled according to the billed consumption for the entire facility for a summer month. The applicant reported the pre-existing oxidizer's consumption to be

The boiler calculations were based on a trended period from July 6, 2010-August 17, 2010 during a non-space heating period in the summer so that process use could be isolated.

The process boiler load was calculated based on trended supply and return piping and an estimated hot water (HW) flow rate based on the pump operating point and an average pump speed of 98% (the pump is VSD controlled). Thus the average hot water flow rate was estimated to be 98% of the total flow rate. The average process boiler load was determined by the applicant through the following expression:

where,

= Conversion constant from to therms/hr

= Average HW flow rate at 98% full load (gpm)

= Supply water temperature (°F)

= Return water temperature (°F)

The process boiler efficiency was calculated based on measured parameters on April 29, 2010 to be 87.9% and the average boiler gas input was determined to be 41 therms/hr. The whole facility gas consumption for the trended period was 102 therms/hr. Thus the total thermal oxidizer consumption was tabulated to be 61.0 therms/hr.

The applicant then calculated the temperature of the exhaust stream after the recuperator and prior to introduction to the flame in the combustion chamber of the oxidizer through the use of this load and thermal oxidizer specifications. This inlet temperature will be used to determine the energy input of the proposed oxidizer.

where,

= Temperature at outlet of combustion chamber before recuperator (1,400°F)

= Energy consumption of pre-existing oxidizer (61.0 therms/hr)

= Conversion constant

= Pre-existing oxidizer flow rate (11,730 scfm)

The applicant then used these calculated conditions and the specifications of the applicant's baseline system to determine the baseline system's consumption. Using the airflow of the proposed system at 25,070 scfm and the same inlet and outlet conditions the applicant calculated the consumption of the baseline system with the following equation:

where,

= Baseline airflow (25,070 scfm)

= Temperature at inlet of combustion chamber, calculated previously (1,015°F)

The burner input was calculated with the tabulated baseline load and the estimated incinerator burner efficiency of 80% to produce a total hourly consumption of 130.0 therms per hour.

Essentially, the previous two equations scale up the gas use from the existing flow rate of 11,730 cfm to the proposed flow rate of 25,070 cfm. The following is an alternative method, presented by the evaluators, may provide a simpler approach:

Proposed Installed Consumption

The proposed RTO was calculated by the applicant through the use of the manufacturer specifications. According to manufacturer specs, the RTO has a 95% thermal efficiency. Thus, the applicant used this to calculate a few of the system's temperature points based on the following equation:

where,

= Temperature after the heat recovery device, temperature entering the burner, (1,335°F)

= Temperature entering the RTO (94°F), same as baseline

= Temperature leaving the burner (1,400°F)

The applicant calculated the new temperature of the airstream before the burner (to be 1,335°F. The applicant then subsequently calculated the new RTO load and consumption with the following equations.

where,

= Combustion efficiency of the gas burner, same as baseline at 80%

The hourly consumption of the proposed RTO was determined to be 22.1 therms/hr by the applicant.

Oven consumption

The applicant then accounted for the increase in consumption from the ovens. The original oven line required a new gas burner since its heat exchanger was removed. Additionally, the new oven will also need a gas burner when compared to the heat exchanger baseline. Each oven is rated at 5,000 cfm, totaling 10,000 cfm, and raises the outdoor air temperature to 500°F. The applicant determined the average annual outdoor air temperature (OAT) to be 51°F for Providence, RI and determined the annual oven heating load to be 48.5 therms per hour using a similar equation to the ones shown previously. Using the estimated combustion efficiency of 80%, the ovens were estimated to consume 60.6 therms per hour between the two ovens (30.3 therms/hr each).

Analysis conclusion

The applicant then used the hours of operation for the manufacturing process to determine the total savings for the project. The results are as follows:

The slight difference between the calculated savings of 403,262 therms and the tracking savings of 403,011 is likely due to rounding.

2.1.4 Analysis of Applicant Algorithm

The applicant's analysis uses a top down approach starting with the facility gas use to estimate the baseline TRO's gas use. The supply temperature, return temperature, and flow rate of the process boiler were metered to determine boiler load. The load was used with the efficiency to determine boiler gas use. All other facility gas use was attributed to the TRO since the metering period occurred during a non-space heating period. Although this method does not directly meter the equipment of interest, the principle behind the method is sound. The applicant assumes the current TRO gas use would double with the new production, in effect assuming that the existing system would be duplicated. The evaluators agree with this assumption of the expanded capacity baseline. A "carbon copy" system would include a new 11,730 cfm TRO with an additional heat exchanger to heat the incoming outdoor air to the oven.

The proposed case gas use is a more difficult calculation since there is no equipment yet installed to be metered. The applicant used first principle calculations to determine the temperature rise between the inlet and outlet of the RTO. The gas use was estimated using the proposed flow rate, efficiency and temperature rise. However, the applicant did not include the contribution from the combustion of the VOC's. The removal of the harmful VOC's is achieved through combustion. As the VOC's burn they produce heat which lessens the load on the RTO burner. According to the facility contact, the facility's permit allows for the production of 103 lb/hr of VOC's, 99% of which must be destroyed. The primary VOC entering the RTO is ethanol, with a heating value of 11,500 btu/lb. This is a potential source of 1.17 MMBtu/hr of heat. However, it is important to note that the permitted amount of VOC's is the maximum allotted, and may not be the actual VOC content. Actual VOC content may change based on the production level and product mix. Building calculations from gas use rather than inlet and outlet temperatures intrinsically accounts for the VOC levels eliminating this issue.

2.2 On-Site Inspection, Metering, and Analysis

This section provides the steps of the evaluation from initial site visit through the final results. Each step is described in detail to offer an in-depth reasoning behind the full process.

2.2.1 Summary of Site Visit Findings

The site was visited by the evaluators on March 6, 2012 and personnel were interviewed regarding the system operation. The facility maintains a fairly consistent production level throughout the year. The RTO and new oven line (bringing the total to two) were installed as planned. The facility also uses a 12 MMBtu boiler for process hot water. The facility has several AHU's for space heating in the production and office areas, with some areas requiring as many as 6 air changes per hour to maintain proper ventilation levels.

2.2.2 Measured and Logged Data

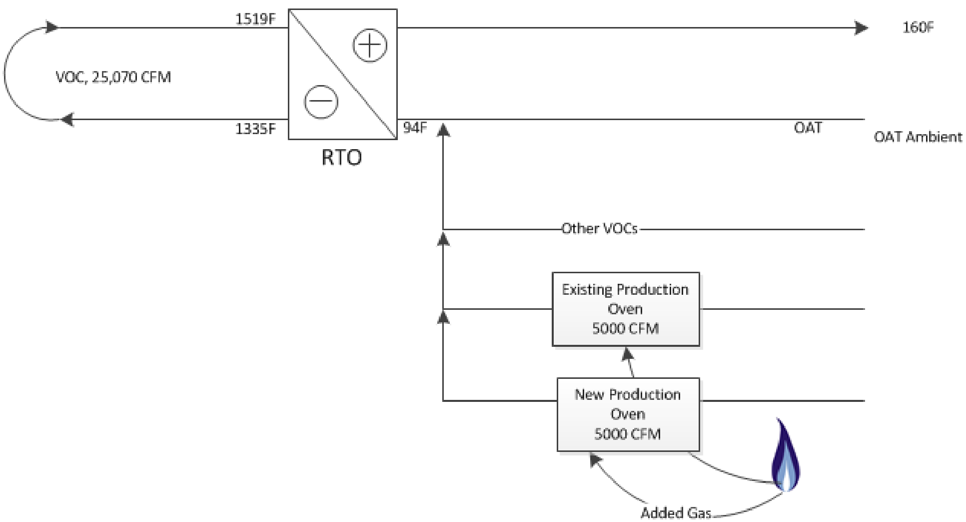
Due to difficulty accessing the RTO and ovens, the evaluators did not install loggers at the site. However, the site had a robust energy management system (EMS) with real-time data from the equipment. The site contact was able to provide evaluators with data from the RTO and ovens from March 16, 2012 through April 30, 2012. Table 2-1 lists the points that were trended. Values were recorded every 36 minutes.

Table 2-1. Points Trended with EMS

Description	Parameter Monitored	Total Points	Interval	Duration
Oven temperature	Temperature	2	36 minutes	6 weeks
Oven heater setpoint	Temperature	2	36 minutes	6 weeks
RTO chamber temperature	Temperature	2	36 minutes	6 weeks
RTO gas valve	% of maximum gas	1	36 minutes	6 weeks

Figure 2-3 is the installed system schematic, updated with the temperatures observed and calculated in the course of the evaluation.

Figure 2-3. Evaluator Updated Installed Schematic



2.2.3 Evaluation Description of Baseline

The evaluators agree with the applicant's baseline. The lowest cost option would have been to install a second TRO system, identical to the first, concurrent with the installation of their second oven line which doubled their production capacity. In this scenario the baseline gas use by the TRO would be expected to double. Lending further credence to this baseline are the results of a survey conducted by the evaluators with several manufactures and installers active in the oxidizer market. The general consensus among the market players was that RTOs become more economical at larger sizes due to economies of scale. For systems with less than 10,000 cfm of flow, the TRO is usually the better option. For sites with airflows larger than 30,000 cfm, RTOs are a more cost effective option. For sites with airflows between this range, 10,000 – 30,000 cfm, there is not clear cost advantage to either system.

In addition, this site also had a use for the rejected TRO heat. By adding a second heat exchanger, they were able to offset oven gas usage, increasing the overall system efficiency. For sites that cannot use the oxidizer rejected heat, the higher efficiency RTO may be the more economical choice over an even greater range of airflow rates.

2.2.4 Evaluator Calculation Methodology

The evaluated savings for the RTO was calculated as:

RTO savings = baseline system gas usage –(RTO gas consumption + production oven gas use)

Where:

- Baseline system gas usage was identical to that of the applicant and is based on duplicating the gas usage of the existing TRO .
- RTO gas consumption is a direct measurement of the RTO gas consumption using the unit rated input and the firing rate determined from the gas valve position.
- Production oven gas use is estimated from logged temperatures and rated airflows.

The site was able to trend the percent of maximum gas use of the RTO for the 6 week metering period. Since the maximum input of the RTO was known, the evaluators could determine the gas input at each recorded data point. According to site contacts, this 6 week period was typical for production levels. The site generally does not experience any seasonal trends in production. Annual RTO gas use was calculated with the follow equation:

where,

= Percent of maximum gas input, six week average per hour of operation

= Rated capacity of RTO, 103 therms/hr

= Operation time during period (hours)

Since the baseline case utilized a second heat exchanger to heat the ovens, no additional gas input was needed. However, with the more efficient RTO, both ovens now require a gas-fired heat source. The oven gas use must be considered as a penalty and added to the RTO gas use to determine the total installed gas use. The ovens are each sized for 5,000 cfm and use only outdoor air. The site was able to trend the temperature of each oven. The evaluators used the following equation to calculate the oven gas use:

where,

= Outdoor air temperature, NOAA data (°F)

= Airflow through ovens, 10,000 cfm

= Efficiency of oven heating furnace, 80%

As a sanity check, the evaluators estimated the other end gases uses to determine the total facility gas use over the metering period. This value was compared to the bills to ensure the results for the RTO gas use were reasonable. The estimated contribution of the process hot water boilers and space heat did not affect the calculated RTO and oven use described above. The equation for the hot water boiler gas use followed the applicant's methodology but scaled up proportional to the new boiler that was installed:

where,

= Conversion constant from ———— to therms/hr

= Average HW flow rate at 98% full load (gpm)

= Supply water temperature (°F)

= Return water temperature (°F)

= Increase of boiler size to supply new load, 12 MMBtu/8 MMBtu

Gas use for space heat was estimated using a temperature rise, cubic footage of the building, and air changes per hour:

where,

= ————, 18,667 cfm

= Volume of conditioned space, (ft^2)

= Air changes per hour, 5changes/hr

2.2.5 Evaluator Calculation Results

Table 2-2 presents the installed gas use for each gas end use. RTO use varies slightly depending on the number of days per month. Oven gas use varies due to average outdoor air temperature and days per month. Note the installed gas use is estimated using TMY data and that the billed use has not been weather normalized so differences should be expected. However, the comparison does show that the estimates of RTO and oven use are a reasonable fraction of the billed monthly use.

Table 2-2. Gas Use by End Use (Installed)

	Installed Gas Use					
Month	**RTO**	**Ovens**	**Boiler**	**Space Heat TMY-Based**	**Total**	**Billed Use***
January	17,982	45,928	45,756	57,868	167,534	94,531
February	16,183	41,061	41,328	47,055	145,627	134,557
March	17,982	44,984	45,756	39,665	148,386	133,959
April	17,382	42,696	44,280	23,727	128,085	103,906
May	17,982	43,005	45,756	0	106,743	110,591
June	17,382	40,880	44,280	0	102,542	103,361
July	17,982	41,579	45,756	0	105,317	93,166
August	17,982	41,877	45,756	0	105,614	87,725
September	17,382	41,033	44,280	0	102,696	95,196
October	17,982	43,567	45,756	15,237	122,541	93,061
November	17,382	43,139	44,280	31,923	136,724	114,473
December	17,982	45,737	45,756	54,191	163,666	145,658
Total	**211,583**	**515,487**	**538,740**	**269,664**	**1,535,475**	**1,310,184**

Note: *Billed use is from April 2011 to March 2012 and has not been adjusted for weather

Table 2-3 provides the baseline gas use per month. This baseline assumes the production capacity increase. TRO gas use varies depending on the number of days per month. There is no oven gas use since the ovens would have been heated solely by the heat rejected from the TROs.

Table 2-3. Gas Use by End Use (Baseline)

	Baseline Gas Use				
Month	**TRO**	**Ovens**	**Boiler**	**Space Heat**	**Total**
January	93,816	0	45,756	57,868	197,440
February	84,434	0	41,328	47,055	172,817
March	93,816	0	45,756	39,665	179,237
April	90,689	0	44,280	23,727	158,696
May	93,816	0	45,756	0	139,572
June	90,689	0	44,280	0	134,969
July	93,816	0	45,756	0	139,572
August	93,816	0	45,756	0	139,572
September	90,689	0	44,280	0	134,969
October	93,816	0	45,756	15,237	154,809
November	90,689	0	44,280	31,923	166,891
December	93,816	0	45,756	54,191	193,763
Total	**1,103,902**	**0**	**538,740**	**269,664**	**1,912,306**

A summary of the evaluator's installed use, baseline use, and savings is presented in Table 2-4. Table 2-5 contains this information as provided in the applicant's (tracking) documentation. The baseline for both cases is the same. The evaluators saw 13% higher gas use than expected from the RTO and 0.4% more gas use from the ovens.

Table 2-4. Summary of Evaluated Gas Use

Month	TRO	RTO	Ovens	Total
Baseline	1,103,902	N/A	0	1,103,902
Installed	N/A	211,583	515,487	727,070
Savings				376,831

Table 2-5. Summary of Tracking Gas Use

Month	TRO	RTO	Ovens	Total
Baseline	1,103,902	N/A	0	1,103,902
Installed	N/A	187,231	513,403	700,634
Savings*				403,267

Note: *Tracking savings of 403,011 therms, difference likely due to rounding

This results in an evaluated savings of 376,831, or 93.5% of tracked savings.

3. Final Results

This project involves the installation of a regenerative thermal oxidizer (RTO) at a 140,000 sqft manufacturing facility that produces aerogel-impregnated insulation blankets. The process exhaust stream contains volatile organic compounds (VOCs). Per EPA requirements, the facility must incinerate the VOC-laden exhaust at a temperature of at least 1,500ºF to prevent harmful emissions. The evaluators confirmed that the system was installed, operating as intended, and used onsite trended data to verify the savings.

The site savings were 376,831 therms, or 47% of the baseline installed facility gas use of 805,119 therms. The baseline system had an overall efficiency of 83.8% using information from the project documents and site contact. The installed system had an efficiency of 95.4%. Table 3-1 shows the estimated temperatures used for the calculation.

Table 3-1. System Temperatures and Efficiency

	Baseline	Installed
Inlet (°F)	94	94
Chamber (°F)	1519	1519
Final discharge (°F)	325	160
Efficiency	83.8%	95.4%

Measure impact calculations are shown in Table 3-2.

Table 3-2. Applicant Algorithm Measure Impact Calculations

	Baseline	Installed
Billing		
Actual gas bills (Jul. 2009 – Jun. 2010, May 2011 - Apr. 2012) (therms)*	805,119	1,310,184
Weather-normalized billing difference		N/A
Tracking/Applicant		
TRO/RTO gas use (therms)	1,103,902	187,231
Oven gas use (therms)	0	513,403
Savings (therms)		403,011
Evaluated		
TRO/RTO gas use (therms)	1,103,902	211,583
Oven gas use (therms)	0	515,487
System efficiency	83.8%	95.4%
Savings (therms)		376,831
Realization rate		
Final realization rate		93.5%

Note: *Facility doubled production capacity between the baseline and installed cases

3.1 Cross Check with Billing Data

During the 6 week evaluation metering period, the evaluators calculated 196,863 therms of use. Scaling this to two full months, (March and April) yields 271,292 therms of use. Billed use during that period was

268,516 therms, about 2% lower. This gives the evaluators confidence that the evaluation methods used fully and accurately capture all major drivers of gas use at the facility.

Table 2-2 compares twelve months of billed use to the model estimates of usage. However, the billed use has not been weather normalized so differences are expected. The comparison does show that the estimates of RTO and oven use are a reasonable fraction of the billed monthly use and do not exceed the billed use.

3.2 Recommendations for Program Designers & Implementers

The RTO is operating very similarly to its designed intent. However, RTOs pose several complications that can drastically affect realized savings. Perhaps most critical are the assumptions for the baseline. The evaluator's market research indicates that there is a certain tipping point at which economies of scale make RTOs the more economic choice over TROs. The range of this point was between 10,000 and 30,000 cfm based on survey results. As technology advances, this range may continue to shift downward. Beyond the evaluation baseline, understanding this dynamic and changing market is important to preventing other program issues such as free ridership.

VOC's also present an additional challenge when determining oxidizer efficiency. When these compounds are combusted, they release heat that would otherwise be generated by burning gas, reducing the total gas use. Although knowing the rate of VOC was not critical for this evaluation since gas use was driver of calculations in both the baseline and installed cases, there may be other sites which determine savings though inlet and outlet temperatures of the oxidizer. In these scenarios knowing the exact VOC content is critical. Requiring applicants to submit additional information on actual VOC loads may help to alleviate this potential problem.

When timing and funds permit for large projects, additional baseline measurements may improve evaluation results. Ultimately, oxidizer savings are generated from a reduced atmospheric discharge temperature (the temperature at which air is exhausted from the facility to the outdoors). The difference in temperature between the baseline and installed cases multiplied by the airflow rate provides a simple, yet accurate way to evaluate savings. However, in order to have confidence in the results, one would prefer several weeks of pre/post temperature data. This relies on cooperation and foresight between the Program Administrator, Technical Assistant, and applicant which may not be practical for all projects.

3.3 Customer Alert

None.

3.4 Explanation of Deviations

Table 3-3 provides a summary of the key deviations between the tracking and evaluated savings that could be identified.

Table 3-3. Summary of Key Factors and Deviations

Factor	Applicant	Evaluator	Impact of Deviation	Discussion of Deviations
Operational – chamber temperature	1400°F	1519°F	-15%	Applicant used 1400°F RTO chamber temperature, EMS data showed it to be 1519°F
Non-discernible			9%	A non-discernible discrepancy resulted in an increase, this is likely the contribution of the VOCs in the air stream. However, without field measurements of VOCs the exact contribution is not known