FINAL REPORT

Impact Evaluation of PY2016 Custom Gas Installations in Rhode Island

National Grid

Date: December 9th, 2019

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1 EXECUTIVE SUMMARY

This document summarizes the work performed by the DNV GL to quantify the natural gas savings of custom projects incentivized by National Grid in Rhode Island for the program year 2016 through the Large Commercial and Industrial New Construction and Retrofit Programs.

The custom gas segment includes custom projects that do not meet the criteria of National Grid's prescriptive or upstream program offerings. These projects generally use custom engineering analysis to generate ex-ante savings estimates rather than deemed savings estimates. The most recent custom gas impact evaluation was completed in 2016 and studied 2014 program participants.

The scope of work for this impact evaluation was all custom natural gas measures incentivized in 2016 (program year 2016, or PY2016) and included measures such as steam traps, pipe insulation, high efficiency heating equipment, heating systems controls, energy management systems (EMSs), boiler combustion controls, building shell measures, high efficiency gas industrial process equipment, and other measures.

1.1 Overview of Objectives

The primary objective of this evaluation was to provide verification and re-estimation of energy savings for a sample of statistically selected custom gas projects through site-specific inspection, monitoring, and analysis. The results of this study will be used to determine the gross realization rates for custom gas energy efficiency projects implemented in PY2020 and beyond.

Key objectives of this evaluation:

- **Evaluate savings impacts of custom gas projects implemented in PY2016**. The study determined the achieved natural gas gross energy savings for a sample of custom gas projects which can be used to calculate savings for all projects implemented in PY2016.
- **Ensure consistency with applicable protocols.** The DNV GL team's approach and methodology complied with the procedures and protocols developed for previous rounds of custom site-specific impact evaluations, as well as the protocols that have been developed or were developed for this round of impact evaluations.
- **Establishing a long-term staged M&V Approach** of RI only sampled sites and, after the evaluation of 2017 sites, achieve a relative precision of ±10% at a confidence interval of 80% by combining at least 3 program years.

1.2 Sampling Strategy

Based on the results achieved in the previous studies and concurrent Massachusetts (MA) study, this sample design assumed an error ratio of 0.6. The final error ratios of each of the prior custom gas impact evaluations have remained relatively consistent around this value, which is the basis for using 0.6 in this design. The primary sample design targeted ±15% relative precision for the entire National Grid territory in MA and RI's annual therms at the 80% confidence interval for PY2016. We used model-based statistical sampling (MBSS) techniques to develop the sample design.

In preparation for aggregate program analysis, the team used the design population stratum boundaries to calculate case weights for each final sample observation. PY2016 sample is considered to be year-2 in the staged (rolling) evaluation approach as mentioned above. Until three years of the rolling evaluation have been completed (PY2014, PY2016, and PY2017), final results for application to RI programs will be developed by combining with that year's sites in MA.

1.3 Conclusions and Findings

A new steam trap calculator was introduced in 2017, reducing average steam trap savings. The PY2016 steam trap projects were calculated using the old calculator, although there is an expectation that the new calculator will be used in PY2018 and going forward. As a consequence of this systematic change in practice, the evaluation team calculated a realization rate based on the results of the application of the new steam trap tool to the sampled PY2016 projects which will be applied beginning with the PY2020 program year.

The PY2016 steam trap projects were calculated using the old calculator, although it was verified that the new calculator was used beginning in PY2018 and going forward. For each site associated with steam traps measures, we calculated prospective results using the new tool, which we then aggregated to program-level realization rates. More details on the methods for calculating each set of results are provided in Section 2. The overall study results are summarized in Table 1-1.

Table 1-1. PY2016 National Grid territory results in MA and RI

Results by State	MA	RI	MA+RI
Tracking Savings (therms)	5,141,434	1,114,770	6,256,204
Evaluated Savings (therms)	4,534,668	795,000	5,329,668
Realization rate	88%	71%	85%
Relative Precision 80% CI	±9%	±11%	±8%
Error bound	8%	8%	7%
Sample size	21	8	29
Error ratio	0.35	0.27	0.34

The overall (MA+RI) PY2016 impact study realization rate is 4% lower than the 89% realization rate determined in the previous impact evaluation study conducted for PY2014 (MA+RI).

The evaluators determined that the program continues to generate significant natural gas savings. RI program participation consisted of 87 distinct accounts, saving 795,000 therms annually.

1.4 Recommendations and Considerations

This section presents the recommendations and considerations the evaluation team derived based on the study results.

1.4.1 Recommendations

The evaluation team reviewed sampled sites' project files; conducted site-level M&V; did detailed analyses of the information provided M&V to determine evaluated savings, and quantified discrepancies between tracking and evaluated savings. This overall process was used to make the following recommendations in RI specifically[1].

R-1. The 2016 National Grid sample in RI (only) has achieved the targeted precisions for this custom gas impact study without requiring the 2017 and 2018 samples as anticipated.

[1] MA specific considerations and recommendations can be found in the MA report. Some of these could overlap in both states due to the similarities in the programs. http://ma-eeac.org/wordpress/wp-content/uploads/MA-CIEC-P79-Custom-Gas-March-06.pdf

Therefore, DNV GL recommends National Grid to apply these RI only results for the next planning cycle unless results from the 2017 sample are available, which they are likely to be, in which case 2016 and 2017 RI only combined results should be applied, if they meet the precision targets. After the 2018 study is completed, DNV GL also recommends National Grid to use results from RI only sample from PYs 2016, 2017 and 2018 combined, as soon as possible.

R-2. The use of a 0.60 error ratio in the sample design may be adjusted in the subsequent evaluation, which yielded an overall (MA+RI) error ratio of 0.34. However, DNV GL recommends a conservative value of 0.50 for future evaluations.

R-3. DNV GL recommends the use of the new steam trap savings calculator for all steam trap projects, going forward.

R-4. For any RTO (regenerative thermal oxidizer) projects, DNV GL recommends using trend data to accurately estimate pre-, post- and also standby loads.

1.4.2 Considerations

Using the results of the study, the evaluation team generated a list of considerations that are summarized below. These considerations are for RI specifically.

C-1. Application review – The application reviewers should cross-check (with the customer) both pre- and post-retrofit steam boiler efficiencies and, steam system's operating hours for all steam traps and insulation measures. A convenient approach is to check the boiler system efficiency would be to request boiler combustion test receipts.

C-2. Installation commissioning – Approximately 15% of the realization rate discrepancy was due to overstating or understating the annual installed load of the equipment and 10% was due to the difference in hours of operating equipment impacted by the evaluated measures. One approach to prevent this difference would be to calibrate the measure savings based on post-installation metered or trend data and update the savings values.

C-3. Calculator-based measures – Nearly 1/3rd (32%) savings of the population in RI are steam trap measures and they rely on a deemed calculator to determine savings whereas non-steam trap projects use custom engineering calculations. Future RI evaluations may consider using different error ratios for the steam trap and non-steam trap projects to study the variability in savings between them.

2 METHODOLOGY

The evaluation team's approach and methodology were consistent with the procedures and protocols developed during the previous round of Custom Gas impact evaluation conducted on the program year 2014. As described in the next subsections, this impact evaluation consisted of on-site visits and metering of a randomly selected sample of projects at participating facilities.

2.1 Description of Sampling Strategy

Based on the results achieved in the previous studies, this sample design assumed an error ratio of 0.6. The final error ratios of each of the prior custom gas impact evaluations have remained relatively consistent around this value, which is the basis for using 0.6 in this design. The primary sample design targeted ±15% relative precision for the entire National Grid territory in MA and RI's annual energy (therms) at the 80% confidence interval for PY2016. We used model-based statistical sampling (MBSS) techniques to develop the sample design.

The initial population for this impact evaluation was the set of custom gas projects rebated in 2016, derived from tracking system data provided by National Grid. Table 2-1 shows the distribution of all tracking system records, based on annual tracking savings in therms.

Table 2-1. PY2016 Distribution of Population of Custom Gas Sites

State	Accounts	Savings (Therms)[2]
MA	301	5,057,389
RI	87	1,160,663
Grand Total	**388**	**6,218,052**

As was done in previous evaluations, small sites were excluded from the sample frame. These small sites account for about .01% of total tracking savings and do not warrant the expense of a site M&V. There were only 2 sites or unique gas accounts with annual savings of less than 1,000 therms that were removed, with a total savings of 971 therms.

2.1.1 Sample Design

The evaluation team developed a sampling population from program participation data provided by National Grid. Based on recent program history, it was assumed that the characteristics of the 2016 population would be equivalent to the expected characteristics of future populations, allowing the results of the study to be applied to in future years and preventing any need to adjust the sampled population for future program expectations.

Two sites[3] that were not fully paid by National Grid in 2016 (parent applications paid in 2016, but child applications not paid until the second half of 2017) were removed from the RI population. Other changes included an addition[4] of 1 child application that had been completed in the first 6 months of 2017 with a 2016 parent application. Table 2-1 presents the revised gas savings for the 2016 Custom Gas installations in the National Grid territory for both MA and RI. A total of 388 accounts participated in the program in 2016, producing an estimated 6,218,052 Therms of annual energy savings in the

[2] The savings values shown in this table are based on the original population (or sample design) which used old steam trap tool to calculate savings. But for the final program savings have been updated (both tracking and evaluated) in this report using the savings calculated with new steam trap tool.

[3] Applications 5771727 and 6236337 were removed as they were not fully paid in 2016 or before 6/30/2017.

[4] Child application 6808802 added to the parent 6447859 as it was completed before the National Grid evaluation threshold of 6 months from the project completion date (6/30/2017)

National Grid MA and RI combined territories. RI projects account for 19% of the total custom gas savings in the combined (MA+RI) National Grid custom gas population.

Table 2-2. Sample Design

State	Accounts (N)	Therms[2]	Error Ratio	Sample (n)	Expected Relative Precision
MA	301	5,057,389	0.6	20	±15.2%
RI	87	1,160,663	0.6	8	±26.8%
Total	**388**	**6,218,052**	**0.6**	**28**	**±13.4%**

Since the number of sample points required to achieve the desired level of precision depends upon the expected variability of the observed realization rates, DNV GL used the same error ratio that was used in MA for custom gas evaluation (P79) of 0.6 for Therms Savings at 80% confidence interval. First, both RI and MA gas population data were combined and then a stratified ratio estimation approach was used to develop a sample that is expected to meet an overall relative precision of ±15% at the 80% confidence as shown in Table 2-2. The RI sample design includes a total of 8 sample points compared to 20 sample points in MA evaluation. Table 2-2 also presents the expected realization overall (MA+RI) to be 13.4% while the RI only precision would be 26.8 % with 80% confidence. Sample case weights and their respective realization rates are shown in APPENDIX A.

Once National Grid agreed to the above sampling targets, the DNV-GL evaluation team selected a random primary and backup sample for the evaluation that minimizes the number of sample points required to meet the targets.

2.2 Site M&V Planning

The site evaluation plan played an important role in establishing approved field methods and ensuring that the ultimate objectives for each site evaluation were met. The M&V plan for each evaluated site provided detailed information on the procedures for accomplishing those objectives.

The DNV GL team submitted full, individual M&V plans for each evaluated site. These plans were reviewed by National Grid. Each site plan included the following sections:

Project description – A description of how the project saves energy
Tracking savings – A short description of how the tracking savings were estimated and their source, including:

- Analysis method used
- Identification of the key baseline assumptions
- Identification of the key proposed assumptions
- Evaluator assessment of tracking savings methods or assumptions, including program reported baseline

Project evaluation – A short description of the methods used to evaluate the project, including but not limited to:

- How a measure installation and current operation was verified
- How building use and occupancy was observed and/or assessed
- Identification of the tracking and expected evaluator baseline by measure
- Site staff interview questions (to understand the baseline operation and determine if any changes in the operation of the impacted system occurred after the project was installed)

- The list of data items that were requested by DNV GL during the site visit (e.g., EMS trends, production, pre-metering, etc.) and/or National Grid
- The expected evaluation analysis method to be used, including any deviations from the implementer savings estimation method. In general, the same methodology used to estimate tracking savings was to be used to estimate evaluated savings. The DNV GL team presented an alternative methodology only if the tracking methodology was flawed, unfeasible, or a more accurate methodology that utilized post-installation data was available.
- List of all key parameters that were used in the original savings estimate.

2.3 Data Collection

The DNV GL team scheduled a site visit to perform the tasks described in the site M&V plan.

2.3.1 Customer Outreach

Using the information provided in the project files, project engineers reached out to customer site contacts. During this initial outreach, the engineers discussed the purpose of the evaluation, the scope of measures installed, availability of on-site EMS trend/SCADA/production data, any other applicable parameters relevant to the evaluation, and confirmed that the site will allow the DNV GL team to conduct the site visits. To include the info gathered during discussions with the site, for most of the sites, the site engineers started the desk review of back material in the application after the initial discussion with the participant. The site-specific M&V planning effort did not commence until the customer site contact indicated they were willing to accommodate the ex-post on-site evaluation process.

2.3.2 Site Visit

Each initial site visit consisted of the verification of installed equipment, a discussion with facility personnel regarding the baseline characteristics of the measure, the installation of measurement equipment, and the collection of available trend data and/or the creation of a plan to gather trend data coinciding with the measurement period. Trend data beyond the measurement period was also requested and used when it improved the accuracy of the evaluation’s estimate of measure savings.

A second site visit to retrieve meters was scheduled for sites at which the evaluators installed meters during the initial visit.

2.3.3 M&V Plan Update

The DNV GL team submitted an updated site M&V plan to National Grid after the completion of the initial site visit if there were significant deviations from the approved plan. This updated plan included any deviations from the plan that occurred during the visit or were expected to occur. Deviations included cases where a portion of the proposed M&V plan was not feasible for unforeseen reasons. The update also shows the data requested from the customer and/or National Grid which were used to support the evaluation’s analysis/report.

The intention of the update was to keep National Grid current on the status of the site evaluation and communicate any anticipated or resultant deviations from the plan.

2.4 Site Analysis

The DNV GL team reviewed all data collected and then utilized the data to complete an evaluation analysis for each sampled project. The custom gas segment includes existing building retrofits, new construction, and major renovation projects and does not include comprehensive design assistance (CDA) projects.

For each project, the analysis generated evaluated savings estimates for all measures installed at each sampled site. Results were normalized to typical production or weather data. For weather-dependent measures, the site analysis involved normalizing the calibrated models to weather data using the Typical Meteorological Year 3 (TMY3) data in closest proximity to each site.

Steam trap evaluated savings were calculated using the calculator developed in P59 MA CIEC P59 Steam Trap Evaluation Phase 2 (Custom Steam Trap Savings Tool).

2.4.1 Steam Trap Prospective Methods

A new steam trap calculator that reduced the average measure savings was introduced in 2017. National Grid confirmed in April 2019 that all PY2018 projects used the new steam trap calculator, however, the PY2016 sites assessed in this study all used the old steam trap calculator.

As a consequence of this systematic change in practice, we calculated two realization rates for each steam trap project:

- A retrospective realization rate, which reflects the reduction in PY2016 steam trap savings using the new savings calculator
- A prospective realization rate for application once the new calculator is fully adopted by the Program. These are the results that were used in calculating the final evaluated realization rates since it was assumed that by the time these results will be applied in PY2020, all steam trap projects will utilize the new savings calculator.

Retrospective realization rate (RR) was calculated using the following formula:

$$RR_{retro} = \frac{Savings_{New\ Calculator,Ex\ post\ field\ conditions}}{Savings_{tracking}}$$

where,

RR_{retro} – Retrospective realization rate (%)

$Savings_{New\ Calculator,Ex\ post\ field\ conditions}$ - Evaluated first-year savings calculated using the Custom Steam Trap Savings Tool and the field conditions observed by the site engineer as part of the evaluation

$Savings_{tracking}$ – Program tracking first-year savings calculated using by the program (Therms) in this case using the old savings calculator

- Prospective realization rate (RR): calculated using the following formula:

$$RR_{pro} = \frac{Savings_{New\ Calculator,Ex\ post\ field\ conditions}}{Savings_{New\ calculator,Ex\ ante\ tracking\ conditions}}$$

where,

RR_{pro} – Prospective realization rate (%)

$Savings_{New\ Calculator,Ex\ post\ field\ conditions}$ Evaluated first-year savings calculated using the Custom Steam Trap Savings Tool and the field conditions observed by the site engineer as part of the evaluation

$Savings_{New\ calculator,Ex\ ante\ tracking\ conditins}$ – Adjusted first-year savings calculated using the new Custom Steam Trap Savings Tool and the ex-ante inputs (provided in the application savings calculator)

2.5 Site Reporting

The DNV GL team submitted draft site reports to National Grid. National Grid reviewed each site report and provided comments or questions to the engineer who led the site analysis. The engineer responded to comments and questions raised until a final agreement was reached on the analysis approach and results and the report itself. Each site report contains the following sections:

Project summary and results – This section provides a brief description of how the evaluated measures at the site save energy and a high-level summary of why the evaluation results may differ from the tracking estimates. The site results are also presented in this section.

Evaluated measures – This section provides a description of the evaluated measures, including but not limited to:

- Applicant baseline and proposed conditions
- Applicant savings calculations methods
- Evaluator's assessment of the applicant savings calculation methods
- How measures were verified
- The data collected by the DNV GL team summarized in graphical or tabular form for each data point collected
- The data provided by the site and/or their National Grid, with key data summarized in graphical or tabular form
- Evaluation baseline used
- The evaluation analysis method used, identifying any deviations from the original savings estimation method
- Key savings parameters determined through the evaluation, and a comparison to those used in the original savings estimate
- A summary of the evaluated savings calculated and the primary drivers for any differences between the tracking savings and evaluation savings estimates

3 RESULTS

This section presents the on-site and population-level results in RI[5]. These RI site-level results include the estimates of savings and a quantitative breakdown of the factors that caused the realization rates to deviate from 100%.

3.1 Comparison between Tracking and Evaluated Results in RI

In this section, the evaluation team will provide details that resulted from comparing tracking and evaluated results and the realization rates (and associated precision levels) for annual natural gas savings. The difference between the program-reported savings and the evaluated savings is due to factors that the evaluators associated with four main categories: administrative, application, installed measure verification, and installed measure performance as defined below.

Figure 3-1. Comparison of Reported and Evaluated Annual Natural Gas Savings in RI

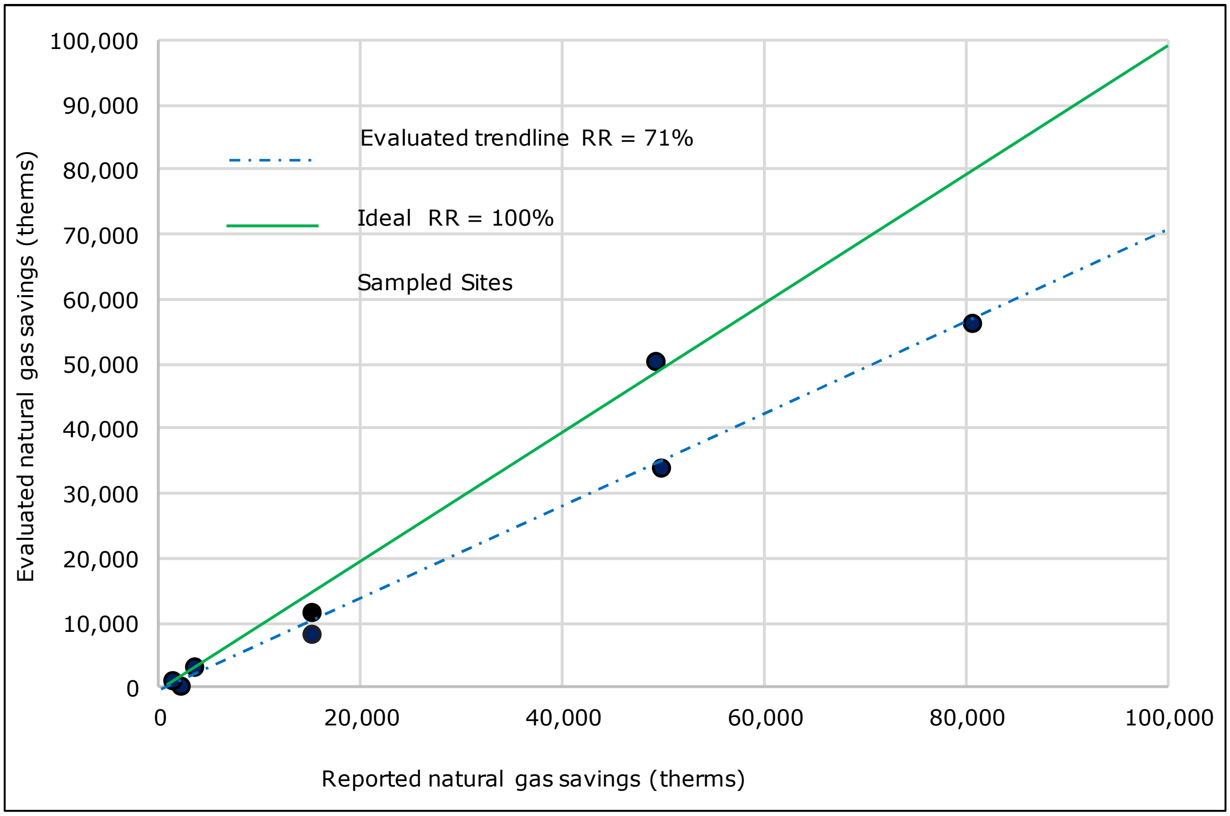

Figure 3-1 illustrates the comparison of evaluated (y-axis) and reported (x-axis) annual natural gas savings for the 8 RI sites. Ideally, the evaluated savings would always match the reported savings; this ideal is shown as a solid green line on the chart.

In RI, 10 measures (applications) at 8 sampled sites were studied through this project.

3 sites deviated from the tracking savings by more than 40%:

[5] This report excludes MA site-level results; They can be found at http://ma-eeac.org/wordpress/wp-content/uploads/MA-CIEC-P79-Custom-Gas-March-06.pdf.

- Site 2016RIN0032 installed heat timer at the boilers to regulate the temperature of supply water for space heating. The evaluation found that the heat timer was installed at the site but found to be non-operational. Therefore, evaluated savings have been adjusted to zero (0% RR).
- Site 2016RIN0024 installed new HVAC EMS controls software. The measure saves energy by adding a night time set-back to reduce airflow to an office building. The evaluation found the savings to be only 55% of the reported savings. The discrepancy was due to inaccuracies in savings calculation algorithms, baseline airflow assumptions and the use of outdoor air temperature instead of mixed air temperature in the savings calculation algorithm.
- Site 2016N0008 installed insulation jackets on bare steam and condensate pipes and repaired/replaced failed steam traps. The evaluation found that the realization rate of the steam traps portion of the saving is only 53% of the reported savings, and the realization rate of the insulation portion is 73%. The closing of most of the facility and the incremental shutdown of the steam systems is the primary reason for the deviation in savings.
- Regarding the issue of using the old steam trap tool in tracking estimate compared to the new steam trap tool: Overall the new tool has lower savings (therms) estimates when compared with the old tool estimates. However, both tracking and evaluated savings were calculated using the new tool producing realization results which were close, as shown in Table 3-1.
    - For site 2016N0008, the old tool steam trap savings realization rate was 57% as compared to 53% to the new[6] steam trap tool.
    - For site 2016N0060, the old tool steam trap savings realization rate was 105% as compared to 102% to the new[6] steam trap tool.
    - For site 2016N0088, the evaluation found no difference in realization rates between the 2 tools.

Table 3-1: Steam trap results comparison between old and new savings calculators

DNV GL ID	National Grid App#	Old Tool (retrospective)			New Tool (prospective)		
		Tracking	Evaluated	RR	Tracking	Evaluated	RR
2016RIN0088	6341835	1,949	1,561	80%	1,383	1,106	80%
2016RIN0060	6089981	87,573	92,369	105%	49,005	50,103	102%
2016RIN0008	6527347	21,512	12,231	57%	14,933	7,989	53%

3.1.1 Discrepancy Results (from RI sites)

For each of the 8 sites included in the study, the site engineers identified factors that led to differences between the program-reported (tracking) savings and the evaluated savings. The factors are classified into four main categories: administrative, application, installed measure verification, and installed measure performance. The evaluation team used the site-specific sampling weights and the site-specific impacts of discrepancy to calculate the impact of those factors that caused differences between the overall weighted tracking and evaluation results. Figure 3-2 presents the weighted discrepancy factors and their impacts.

[6] New steam strap tool savings have been used to report the program level realization rate.

Approximately -6.8% of the discrepancy comes from the operating hours found onsite. Out of the 8 sampled sites, 4 sites had higher operating hour estimates than reported values. The other major driver difference in the equipment annual load served by the measure resulted in a difference of approximately 17.7%. This is essentially coming from the differences in the baseline, installed and standby load assumptions used in the tracking analyses. Detailed information on site-specific differences is presented in the site reports attached in the appendix.

Figure 3-2. Discrepancy Factors between Tracking and Evaluated Results (RI only-weighted)

Category	Discrepancy sub-category	Counts	Impact on RR	Impact %
Admin error	Difference between the application and tracking savings	0		0.0%
Application	Operating hours	4		-6.1%
	Calculation based	2		-1.2%
	Savings Algorithm	3		-5.6%
	Efficiency	1		-0.6%
Measure Performance	Baseline load	1		-6.3%
	Installed load	5		-6.8%
	Standby load	1		-4.7%
	Pre/post trend data	3		2.5%
Measure verification	Difference in installed equipment/size/quantity	0		0.0%
Grand Total (rounded)				-29%

3.2 Evaluation Results

DNV GL applied the model-assisted stratified ratio estimation methodology to aggregate the individual site results from the RI Custom Gas sample. 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 program (MA and RI combined), as well as at the state level. The realization rate is the ratio between the weighted sums of the evaluated savings for the sample projects divided by the weighted sum of the tracking estimates of savings for the same projects. The statistical precisions and error ratios are calculated for each level of aggregation. The study results for RI are summarized in Table 3-2.

Table 3-2. RI PY2016 Program Expansion results

Results by State	RI
Tracking Savings (therms)	1,114,770
Evaluated Savings (therms)	795,000
Realization rate	71%
Relative Precision 80% CI	±11%
Error bound	8%
Sample size	8
Error ratio	0.27

The custom gas program in RI had a lower realization rate of 71% when compared with 98% (RI only) from the previous study[7] for PY2014. Study findings, recommendations, and considerations are provided below.

[7] http://rieermc.ri.gov/wp-content/uploads/2018/03/20160726_py2014_custom_gas_final_report.pdf

4 CONCLUSIONS AND FINDINGS

A new steam trap calculator was introduced in 2017, reducing average steam trap savings. The PY2016 steam trap projects were calculated using the old calculator, although there is an expectation that the new calculator will be used in PY2018 and going forward. As a consequence of this systematic change in practice, the evaluation team calculated a realization rate based on the results of the application of the new steam trap tool to the sampled PY2016 projects which will be applied beginning with the PY2020 program year.

The PY2016 steam trap projects were calculated using the old calculator, although it was verified that the new calculator was used beginning in PY2018 and going forward. For each site associated with steam traps measures, we calculated prospective (adjusted) results using the new tool, which we then aggregated to program-level realization rates. More details on the methods for calculating each set of results are provided in Section 2. The overall study results are summarized in Table 4-1.

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The evaluators determined that the program continues to generate significant natural gas savings. RI program participation consisted of 87 distinct accounts, saving 795,000 therms annually.

4.1 Recommendations and Considerations

This section presents the recommendations and considerations the evaluation team derived based on the study results.

4.1.1 Recommendations

The evaluation team reviewed sampled sites' project files; conducted site-level M&V; did detailed analyses of the information provided M&V to determine evaluated savings, and quantified discrepancies between tracking and evaluated savings. This overall process was used to make the following recommendations in RI specifically[8].

R-1. The 2016 National Grid sample in RI (only) has achieved the targeted precisions for this custom gas impact study without requiring the 2017 and 2018 samples as anticipated. Therefore, DNV GL recommends National Grid to apply these RI only results for the next planning cycle unless results from the 2017 sample are available, which they are likely to be, in which case 2016 and 2017 RI only combined results should be applied, if they meet

[8] MA specific considerations and recommendations can be found in the MA report. Some of these could overlap in both states due to the similarities in the programs. http://ma-eeac.org/wordpress/wp-content/uploads/MA-CIEC-P79-Custom-Gas-March-06.pdf

the precision targets. After the 2018 study is completed, DNV GL also recommends National Grid to use results from RI only sample from PYs 2016, 2017 and 2018 combined, as soon as possible.

R-2. The use of a 0.60 error ratio in the sample design may be adjusted in the subsequent evaluation, which yielded an overall (MA+RI) error ratio of 0.34. However, DNV GL recommends a conservative value of 0.50 for future evaluations.

R-3. DNV GL recommends the use of the new steam trap savings calculator for all steam trap projects, going forward.

R-4. For any RTO (regenerative thermal oxidizer) projects, DNV GL recommends using trend data to accurately estimate pre-, post- and also standby loads.

4.1.2 Considerations

Using the results of the study, the evaluation team generated a list of considerations that are summarized below. These considerations are for RI specifically

C-1. Application review – The application reviewers should cross-check check (with the customer) both pre- and post-retrofit steam boiler efficiencies and, steam system's operating hours for all steam traps and insulation measures. A convenient approach to check the boiler system efficiency would be to request boiler combustion test receipts.

C-2. Installation commissioning – Approximately 15% of the realization rate discrepancy was due to overstating or understating the annual installed load of the equipment and 10% was due to the difference in hours of operating equipment impacted by the evaluated measures. One approach to prevent this difference would be to calibrate the measure savings based on post-installation metered or trend data and update the savings values.

C-3. Calculator-based measures – Nearly 1/3rd (32%) savings of the population in RI are steam trap measures and they rely on a deemed calculator, whereas non-steam trap projects use custom engineering calculations. Future RI evaluations may consider using different error ratios for the steam trap and non-steam trap projects to study the variability in savings between them.

APPENDIX A. SAMPLE CASE WEIGHTS

Table 4-2: Final Achieved Sample and Site Results:

DNV GL ID	Stratum	Case Weight	Adjusted Tracking Savings (Therms)	Adjusted Evaluated Savings (Therms)
2016RIN0032	1	23	2,206	0*
2016RIN0052	1	23	3,386	2,977
2016RIN0088	1	23	1,383	1,106
2016RIN0002	2	4.3	49,606	34,001
2016RIN0007	2	4.3	15,052	11,408
2016RIN0024	2	4.3	14,983	8,204
2016RIN0008	3	2.5	80,620	56,056
2016RIN0060	3	2.5	49,005	50,103

** This site had zero savings; the measure was installed but not in use.*

APPENDIX B. SITE REPORTS

2016RIN002

- **Project Summary and Results**

This retrofit project installs a new 20,000 standard cubic feet per minute [SCFM] regenerative thermal oxidizer [RTO] at a packaging plant. This new RTO is required to meet increased volatile organic compound [VOC] generation from additional load from new printing operations. Existing thermal oxidizers had a maximum capacity of 15,000 SCFM. The new RTO has a 95% thermal energy recovery efficiency. A less efficient replacement recuperative thermal oxidizer is used as baseline equipment. That unit was rated with a 70% thermal energy recovery efficiency. The natural gas savings is achieved from the improved thermal energy recovery efficiency.

There are two application IDs. Incentives were paid out on an 80%/20% completion ratio. Application #6447859 is for the 20% incentive. Application #6808802 is for the 80% incentive. **Table 4-3** presents the total gas savings for this measure.

Table 4-3: Savings

Measure ID	Measure Name		Gas Savings (Therms/year)
6808802 (pre-Cx) 6447859 (post-Cx)	Process Equipment	Tracked	49,606
		Evaluated	34,001
		RR[1]	69%
Totals		**Tracked**	**49,606**
		Evaluated	**34,001**
		RR[1]	**69%**

[1]Realization rate

- **Explanation of Deviations from Tracking**

The evaluated savings are 31% less than the applicant-reported savings, primarily due to the evaluation team's incorporation of a higher post gas usage rate during standby operation mode than the applicant's calculations, as well as incorporating a separate idle mode in the post operation, which has an inefficient gas usage rate. Further details regarding deviations from the tracked savings are presented in Section 2.1.4 and Section 3.3.

○ **Evaluated Measures**

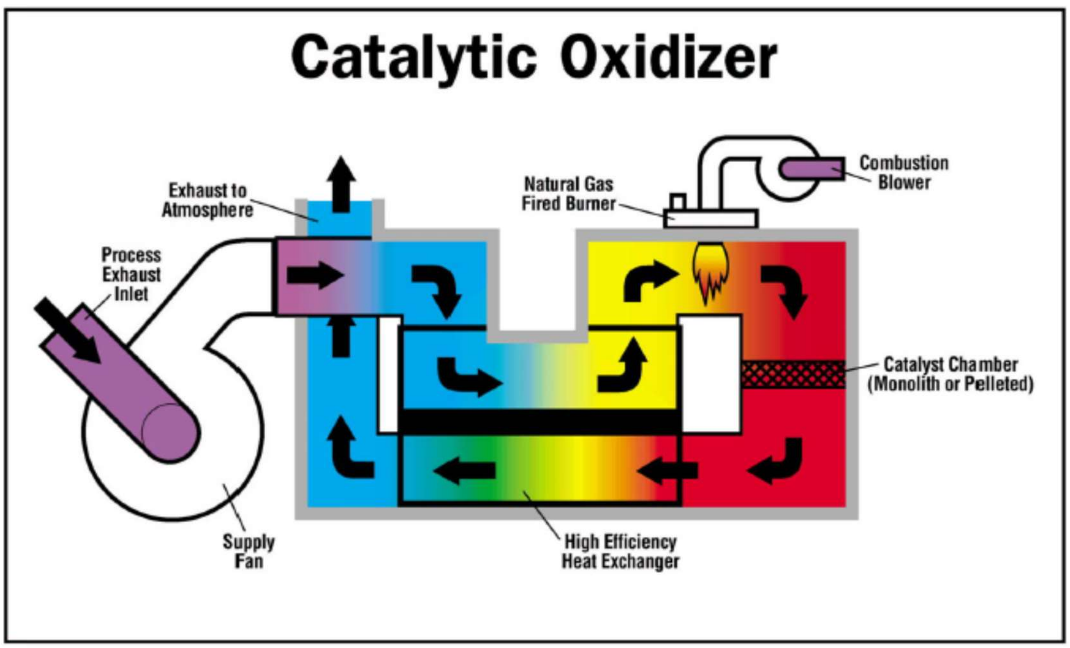
The following sections present the evaluation procedure, including the findings from an in-depth review of the supplied applicant calculations and the evaluation methodology determined to be the best fit for the site and information available.

▪ **Application Information and Analysis**

This section describes the information and analysis provided by the applicant.

▪ **Applicant Description of Baseline**

The baseline thermal oxidizer used in the calculations is a less efficient unit than the proposed regenerative thermal oxidizer. The existing thermal oxidizer was not the baseline unit. The new RTO is rated at 20,000 SCFM and is required to meet increased VOC generation from new printing machines. Existing thermal oxidizers could not handle this increased VOC load. This necessitated the selection of a new thermal oxidizer. The base case consists of a recuperative catalytic thermal oxidizer (CMM model C-20,000-M-60) using a precious metal catalyst at 600°F and with 70% thermal energy recovery efficiency[9].



The process exhaust air is forced into the inlet of the catalytic oxidizer and is directed through the "cold" side of the primary heat exchanger to be preheated. The preheated air then enters the burner chamber. The heated air stream then passes through the precious metal catalyst bed which is maintained at 600°F. VOC destruction takes place in the catalyst beds, where the VOCs are incinerated.

The clean (hot) air then passes from the catalyst beds through the "hot" side of the primary heat exchanger. In the heat exchanger, energy from the hot gas is used to preheat the incoming exhaust

[9] The vendor provided specifications for a 60% efficient recuperative catalytic thermal oxidizer, but this was increased to 70% in the applicant's calculations (both before and after commissioning), based on the National Grid Baseline Document, and discussions with oxidizer manufacturers.

stream with no cross contamination. The clean (cooled) air is then routed to the atmosphere through the exhaust stack.

Table 4-4 presents the baseline specifications of the regenerative thermal oxidizer.

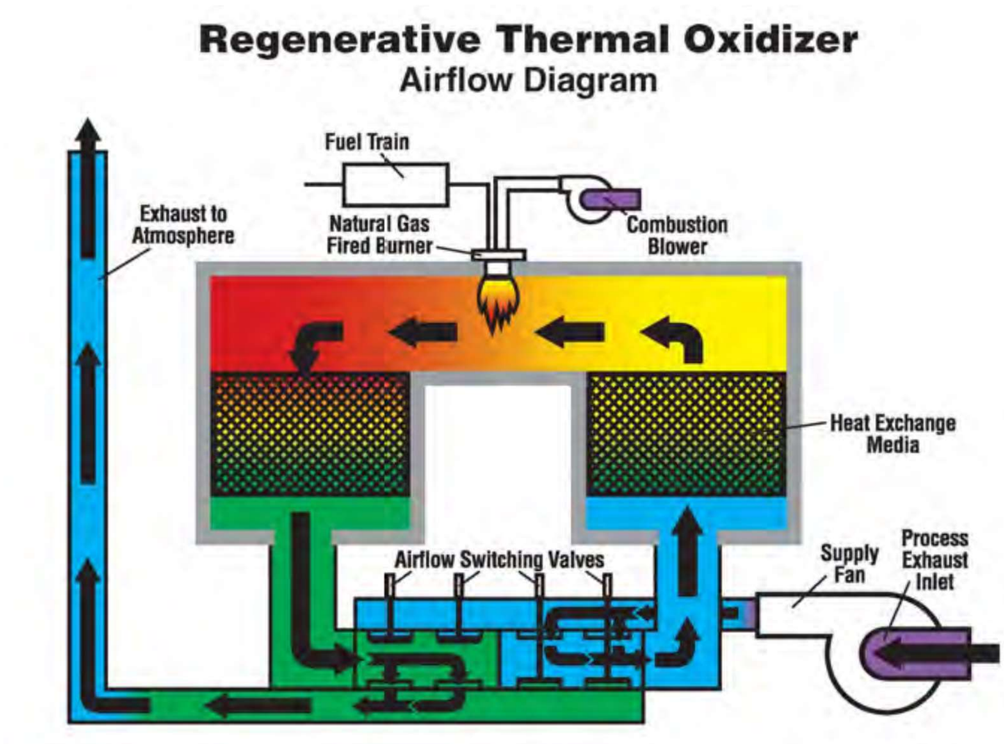
Table 4-4: Pre-retrofit Key Parameters

	BASELINE	
Parameter	**Value(s)**	**Source of Parameter Value**
Recuperative catalytic thermal oxidizer efficiency	70%	Commissioning memo, w/ reference to NGrid baseline document
Annual operating hours	4,134 hours	Supply fan trend data from 8/18/16 – 9/7/16, 30 second interval, annualized
Annual standby hours	4,626 hours	Supply fan trend data from 8/18/16 – 9/7/16, 30 second interval, annualized
Operating fuel usage rate	16.23 therms/hr	Sum of process, combustion, heat loss, and VOC contributions, provided by vendor at 60% efficiency, adjusted to 70% efficiency
Standby fuel usage rate	0 therms/hr	Calculations, no other reference provided
Maximum design air flow rate	20,000 ft^3/min	MRD & vendor proposal
Maximum observed operating air flow rate	15,682 ft^3/min	Calculated from post-kW measurements of supply fan trend data collected from 8/18/16 – 9/7/16, 30 second interval, annualized
Average observed operating air flow rate	11,461 ft^3/min	Calculated from post-kW measurements of supply fan trend data collected from 2/23/17 – 3/9/17, 5-minute interval, annualized
Maximum design standby air flow rate	4,000 ft^3/min	Vendor performance specifications
Average observed standby air flow rate	3,398 ft^3/min	Calculated from post-kW measurements of supply fan trend data collected from 2/23/17 – 3/9/17, 5-minute interval, annualized
Supply fan HP	125 HP	Vendor proposal

	BASELINE	
Parameter	**Value(s)**	**Source of Parameter Value**
Full load supply fan kW at full flow	79.35 kW	Vendor performance specifications
Process exhaust temperature supplied to RTO	110° F	Vendor proposal
Burner size	7,500,000 Btu/hr	Vendor proposal
Catalyst bed temperature	600° F	Vendor proposal
Input temperature to catalytic oxidizer	453° F	Calculated: 70%• (600° F - 110° F) + 110° F

- **Applicant Description of Installed Equipment and Operation**

The specified regenerative thermal oxidizer is a CMM unit, model# RTO-2000-M-95-2C. It is rated at 20,000 SCFM with a 95% thermal energy recovery efficiency and is designed to destroy the VOCs generated by the new printing press. Exhaust emissions from the process are collected in a common ductwork header and directed to the regenerative thermal oxidizer using the process exhaust fans and the main RTO supply fan. The VOC-laden air is directed into the energy recovery canisters. The polluted air passes through the first of the two heat exchanger canisters where it adsorbs heat from the ceramic media. The preheated air then enters the combustion chamber [1,500°F] where the VOCs are destroyed.



The hot air then passes from the combustion chamber vertically downward through the second energy recovery canister. Heat generated during VOC oxidation is then adsorbed by the ceramic media. This clean and cooled air is routed to atmosphere through the exhaust manifold and stack at approximately 245° F. Proposed parameters are shown in **Table 4-5**.

Table 4-5: Proposed Key Parameters

	PROPOSED	
Parameter	**Value(s)**	**Source of Parameter Value**
RTO thermal efficiency	95%	Manufacturer performance specifications
Annual operating hours	4,134 hours	Commissioning memo
Annual standby hours	4,626 hours	Commissioning memo
Operating fuel usage rate	1.56 therms/hr	Sum of process, combustion, heat loss, and VOC contributions, provided by vendor
Standby fuel usage rate	2.39 therms/hr	Sum of process, combustion, heat loss, and VOC contributions, provided by vendor
Maximum design airflow rate	20,000 ft^3/min	MRD & vendor proposal

Maximum observed operating air flow rate	15,682 ft^3/min	Calculated from post-kW measurements of supply fan trend data collected from 8/18/16 – 9/7/16, 30 second interval, annualized
Average operating SCFM	11,461 ft^3/min	Calculated from post-kW measurements of supply fan trend data collected from 2/23/17 – 3/9/17, 5-minute interval, annualized
Maximum design standby airflow	4,000 ft^3/min	Manufacturer performance specifications
Maximum design standby airflow	1,333 ft^3/min	Manufacturer performance specifications
Average observed standby airflow	3,398 ft^3/min	Calculated from post-kW measurements of supply fan trend data collected from 2/23/17 – 3/9/17, 5-minute interval, annualized
RTO supply fan HP	125 HP	MRD
Full load supply fan kW at full flow	79.35 kW	Vendor performance specifications
Combustion Blower HP	15 HP	Vendor proposal
Process exhaust temperature supplied to RTO	110° F	Vendor proposal
Burner Size Btu/Hr.	7,500,000 Btu/hr	Vendor proposal
Operating set point temperature (ceramic media)	1,500° F	Vendor proposal
Operating pre-heat temperature (no VOC)	1430.5° F	Manufacturer performance specifications
VOC destruction efficiency	98%	Vendor proposal

- **Applicant Energy Savings Algorithm**

Tracking savings are based on the post-commissioning savings that were finalized in a memo dated March 30th, 2017. Both the pre-commissioning savings and post-commissioning savings use a combination of manufacturer's specifications and monitoring data. The pre-commissioning savings use data from an existing 15,000 SCFM RTO operating at the facility. A power logger was installed to monitor the existing RTO supply fan. The logger monitored average power [kW] in 30 second intervals for a 20-day period from 08/16/2016 to 09/07/2016. The post commissioning savings use data from the newly installed 20,000 SCFM RTO. A power logger was installed to monitor the existing RTO supply fan. The logger monitored average power [kW] in 30 second intervals for a 14-day period from 2/23/17 to 3/9/17.

The differences between the pre-commissioning and post-commissioning data are as follows:

Table 4-6: Pre-Commissioning and Post-Commissioning Key Variables

Parameter	Pre-Commissioning Value	Post-Commissioning Value
Average operating SCFM	11,038 SCFM	11,461 SCFM
Average standby SCFM	3,167 SCFM	3,398 SCFM
Annual operating hours	4,134 hours	4,134 hours
Annual standby hours	4,626 hours	4,626 hours
Annual gas savings	46,192	49,606

A weekly operating schedule was created from the monitored data. The RTO did not operate during weekends and the average standby motor kW was created. The standby period is when no VOCs are being produced and combustion is not occurring. Defining the standby period also defines the RTO operating hours. All kW values above this standby average equated to operating conditions. All other hours were standby hours. The annualized operation included 240 hours of federal holidays when the facility is closed. These holidays were included in the standby hours.

In addition to estimating percent of operating and standby hours, the monitored power was used to estimate RTO SCFM using fan affinity laws. Maximum fan kW was estimated at 66.0 kW. The monitored kW was turned into the percent of the maximum. This percentage was turned into estimated percent flow using a ^2.5 exponent in the affinity law equation. The calculation is done for both the operating and standby periods. The standby period is defined when the RTO is on, but minimal VOCs are generated, which occurs between process runs. The airflow in the post-commissioning/tracking calculations was calculated as 57.3% [11,461 SCFM] during occupied hours and 17.0% [3,398 SCFM] during standby hours. The formula provided in fan monitoring data for SCFM is:

$$SCFM = \left(\frac{kWmon}{kWmax}\right)^{1/2.5} x\ SCFMdes$$

Where:

SCFM = Operating/standby hourly RTO SCFM

kW_{mon} = Monitored hourly kW of supply fan

kW_{max} = Maximum design supply fan kW

2.5 = Affinity law exponent used in documentation

$SCFM_{des}$ = RTO design SCFM

BTU per hour of gas usage for the base and installed cases are derived from the monitoring data and manufacturer's specifications. As described above, the power monitoring provides the estimate of the average operating and standby SCFM along with the corresponding annual hours.

A trend analysis is used to generate the base case natural gas usage rate during operating mode. The process air component of the trend includes the SCFM, heat recovery efficiency, catalyst bed temperature, and exhaust temperature. This is calculated for 20,000 SCFM and 10,000 SCFM. The equation used is:

Process air load, therms/h = SCFM X 1.08 X [$TEMP_{bed}$ -(EFF x ($TEMP_{bed}$ - $TEMP_{exhaust}$) + $TEMP_{exhaust}$)] / 100,000 Btu/therm

Where:

Process air load, therms/h = Total process air load, therms per hour

SCFM = Operating RTO airflow 20,000 SCFM or 10,000 SCFM

1.08 = Constant, BTU/h/(SCFM °F)

EFF = Heat recovery efficiency, 70%

$TEMP_{bed}$ = Catalyst bed temperature, 600°F

$TEMP_{exhaust}$ = Process exhaust temperature, 110°F

The process air load is added to manufacturer's specifications for heat loss, combustion air, and VOC contribution values to determine total load in therms/hour at 10,000 and 20,000 SCFM. A trend analysis is used to determine therms/hour at the base case operating SCFM. The trend hourly output is multiplied by the annual hours.

A separate but similar trend function is used to estimate the installed case usage during operating mode. The manufacturer's specifications for process heat, combustion air, heat loss, and VOC contribution are used with the annual operating hours to calculate usage.

For the base-case standby mode, the total gas usage rate is set to 0 therms/hour. A phone conversation with the vendor who supplied the new RTO confirmed that the theoretical baseline unit selected for this project, a recuperative catalytic thermal oxidizer, would indeed use 0 therms/hr, since these units only require approximately 1 hour to warm up, whereas a the installed regenerative thermal oxidizer requires approximately 8 hours to warm up from the off mode, so it would rarely get shut all the way down, and would instead run in standby mode during evening, weekend, and holiday shutdowns when no VOCs are being produced by the facility.

For the post-case standby mode, the total gas usage rate was estimated using ten evenings (11:01 PM to 6:01 AM) of gas meter data from a gas meter dedicated to the facility's in-situ baseline 15,000

SCFM RTO. These ten evenings of gas consumption rates resulted in 1.9691 therms/hr, that corresponded to the 15,000 SCFM RTO. To adjust for the new 20,000 SCFM RTO, this value of 1.9691 therms/hr was multiplied by 11,461 SCFM / 9,461 SCFM =1.21, for a final value of 2.39 therms/hr. The 11,461 SCFM is the estimated average operating flowrate, using baseline kW data collected between 8/18/16 and 9/7/16 on the in-situ 15,000 SCFM, adjusted to represent operation on the 20,000 SCFM RTO, while the 9,461 SCFM value is the estimated average operating flowrate on the in-situ 15,000 SCFM RTO itself.

- **Analysis of Applicant Algorithm**

The applicant's algorithm uses manufacturer's equipment specifications and monitored data from the smaller, 15,000 SCFM, in-situ baseline RTO to calculate savings. Monitored motor power is used as a proxy to estimate air flow. No temperature trending was done. The overall method is valid to estimate the savings achieved between the theoretical baseline unit of a 20,000 SCFM recuperative catalytic thermal oxidizer, and the installed 20,000 SCFM RTO. The VOCs become fuel in the oxidizer as they are destroyed in the process. VOC quantity and type are not monitored at the site and this heating contribution defaults to the manufacturer's data.

The following items describe the deviations between the applicant algorithm, and the evaluator algorithm:

- The applicant used the operating flow rates of the in-situ baseline and post-case RTOs, to scale the metered baseline standby gas usage rate [therms/hr] data to the post-case standby gas usage rate. The post-case standby gas usage rate that they determine using this method is 1.9691 therms/hr · 11,461 SCFM / 9,461 SCFM = 2.39 therms/hr. The evaluation uses the standby gas usage rate referenced in the performance specifications directly, and come up with a value of 4.08 therms/hr. The evaluation also looked at a similar approach of scaling the baseline value of 1.9691 therms/hr by the ratio of the average post standby SCFM rate to the average pre standby rate, which resulted in a post standby gas usage rate of 4.30 therms/hr, which is closer to the 4.08 therms/hr than the 2.39 value. The 4.08 value was selected because the SCFM data at the low kW loads is not very reliable, since the ^(1/2.5) transform function does not account for reduced motor and VFD efficiencies at low loads, which would tend to overestimate SCFM at low loads.
- The applicant did not distinguish the standby mode from the idle mode, and instead combined the two together in the analysis. The vendor's specification sheets for the new RTO indicate that the idling mode is the most inefficient mode of operation, using 7.97 therms/hr of gas (compared to 0.44 therms/hr while operating, and 4.08 therms/hr while in standby). During idling mode, the chamber temperature is 1,500° F and the flow rate is approximately 4,000 SCFM. The evaluation team found the RTO to be in idling mode 4.6% of the time.
- The applicant's algorithm does not incorporate the operational status of "off" for the RTO. The evaluation team incorporated an "off" status due to the evaluation finding that the post-case RTO was found to be completely shut off for 2.4 % of the monitoring period. This decreased the total number of annual operating hours in either "operation" , "idle", or "standby" mode by 211.

- **On-Site Inspection, Metering, and Analysis**

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

- **Summary of On-Site Findings**

The evaluators conducted a site visit on January 31, 2018. The RTO was installed and operating at that time. The facility engineer stated that the RTO was working well since it was installed without any operational issues. The contact also said that no major changes in facility or process operations have occurred since the RTO was installed.

The facility operates primarily from 5 am until 11 pm on Mondays through Fridays. The plant is closed, and the new RTO is in standby mode, on weekends and for 10 major holidays. However, contract work may occasionally require extended operation to meet production deadlines. But, the increased speed of the new presses and equipment has eliminated overtime for the foreseeable future.

Two power loggers were installed at the site visit. One logger monitored the kW of the RTO supply fan. The second logger monitored the operation of the burner motor.

Temperature and trending were discussed with the facility personnel. The RTO digital controls monitor chamber, process exhaust, and RTO stack exhaust temperatures. VOC production is monitored at the new press, but trends and reporting are not available. VOC readings are real time with limited historical records that are overwritten daily. RTO temperature trends were requested and received.

- **Evaluation Methods, Findings, and Results**

This section describes the evaluator methods, findings, and results.

- **Evaluation Description of Baseline**

Based on the project files and site visit findings, the evaluator determined the proposed, less efficient, recuperative catalytic thermal oxidizer is a valid option. A new printing press and expanded operation required the upgrade to a larger thermal oxidizer rated at 20,000 SCFM rather than their previous 15,000 SCFM unit. The incentive allowed the facility to install the regenerative unit.

- **Evaluator Calculation Methodology**

The evaluator used the same methodology and calculation spreadsheet that was utilized by the applicant, except for the adjustments described in section 2.1.4. Additionally, the spreadsheet input values were updated with the power data obtained during the site visit. The data obtained is shown in **Table 4-7**.

Table 4-7: Evaluation Data Collection

Source	Parameter	Interval	Duration
Elite power logger	RTO Blower volts, amps, pf, kW	15-minute	01/31/2018 - 05/22/18
Elite power logger	Burner Blower volts, amps, pf, kW	15-minute	01/31/2018 - 05/22/18
RTO digital controller	Process exhaust temperature (inlet to RTO) °F	1-minute	01/31/2018 - 05/22/18

RTO digital controller	Stack exhaust temperature (outlet from RTO) °F	1-minute	01/31/2018 - 05/22/18
RTO digital controller	Chamber temperature °F	1-minute	01/31/2018 - 05/22/18

The evaluation process took the same approach as the application analysis. The RTO monitored blower kW was reviewed to identify the maximum motor kW. The maximum monitored kW was 81.5 kW. The specified motor full load power of 79.35 kW was used to calculate the motor kW percentage, which corresponds to the specified full load scfm of 20,000 scfm. The same ^2.5 affinity power was applied to the motor kW to calculate the coincident blower SCFM. The calculation was performed for each 15-minute monitoring interval.

$$Percent\ Air\ Flow\ =\ (kWinterval/kWmaximum)\text{^}(1/2.5)$$

Where:

Percent Air Flow = Calculated air flow percentage/15-minute monitoring interval

$kW_{interval}$ = Average kW per 15-minute interval

$kW_{maximum}$ = Specified motor full load power of 79.35 kW, per specification sheets

2.5 = Affinity law exponent

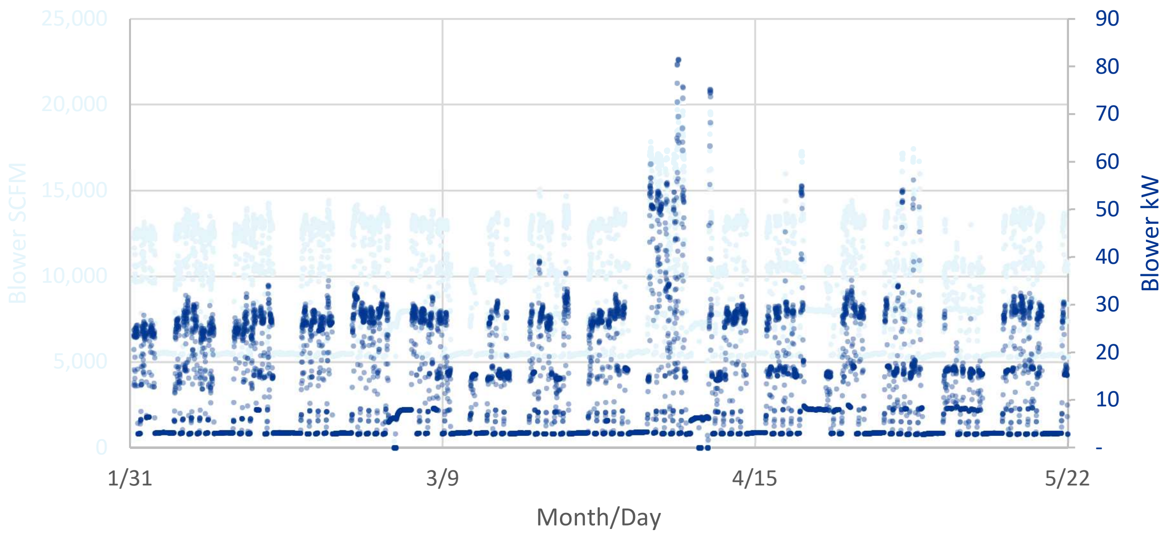
The average standby power during the monitoring period is 3.09 kW. This was obtained from the monitoring history when the facility was closed. All kW values above 4.0 kW usage were initially assigned to "operating" mode. Values between 6.0 kW and 8.0 kW that occurred consecutively for longer than four hours that occurred during evening and weekend hours were initially assigned to "idle" mode. Values below 2.0 kW were initially assigned to be in "off" mode, and values between 2.0 kW and 4.0 kW were initially assigned to be in "standby" mode. Some of these initial statuses were updated by incorporating chamber temperature data. The manufacturer specification sheets state that the chamber temperature is 1,500° F. For several hours surrounding periods where the status was assigned to "off", the chamber temperature was found to be less than 800° F, and these temperatures would go to values of around 230° F. These expanded periods where the temperature indicated temperatures too low for "idle" or "operating" mode, and which surrounded periods where the fan was almost completely off (which occurred twice during the evaluation monitoring period), were assigned to the "off status", even though the kW was sometimes higher than the 2 kW value that was originally used as the cut-off level for assigning the unit to "off" status. Similarly, hours which were found to have a chamber temperature of 1,000° were assigned to "standby" mode, even if the kW did not fall exactly within the 2.0 kW and 4.0 kW range, since the manufacturer specification sheets state that "standby" mode corresponds with a 1,000° F chamber temperature. Hours which were found to have a chamber temperature of 1,500° F, that occurred during evening or weekend periods, that had previously been assigned to another operating status based on kW, were assigned to "idle" status. For the most part, the initial categorization using the fan kW was consistent with the categorization using the temperature data, but the temperature data provided additional refinement.

The SCFM was then calculated as a percentage of the 20,000 design SCFM. The operating period has average operation of 57% [57% x 20,000 SCFM = 11,410 SCFM]. The average standby percent airflow is 27.4% [27.4% x 20,000 SCFM = 5,471 SCFM]. The average idle percent airflow is 39.6%, [39.6% x 20,000 SCFM = 7,927 SCFM]. This methodology is consistent with the baseline approach and equation.

The average weekend and evening monitored blower kW was used to estimate the standby, idle, off, and operating hours for the calculations. Annualized hours included the 10 federal holidays included in the standby period.

Figure 4-1 shows the monitoring period profile of the RTO blower. The chart shows that the blower operated nearly continuously over the 111-day monitoring period, except for a few periods where blower kW dropped to 0. The low (non-zero) points in the trend corresponds with weekend periods and time when the unit is in standby mode. In the chart, one can see a few weekends where the SCFM and kW values are consistently higher than during typical weekends. These are the periods that were assigned to "idling" mode. A value of 81.5 kW was the maximum power draw monitored during the 15-minute intervals, which corresponds to 20,218 SCFM.

Figure 4-1: Blower SCFM and kW Over Monitoring Period (1/31/18 – 5/22/18)



The average operating SCFM were used in the heating calculations. The average SCFM from the calculations replaced the applicant's estimated value.

The changes in the input variables are show in **Table 4-8**. The original spreadsheet equations and trend functions recalculated the energy savings.

Table 4-8: Calculation Variable Changes

	Tracking	Evaluation	Eval/Track
Maximum measured blower kW	66.0	81.5	124%
Maximum calculated blower SCFM - operating	15,682	20,218	129%
Average calculated blower SCFM - operating	11,461	11,410	99.6%
Process exhaust temperature °F	110	110	100%
Annual operating hours	4,134	3,771	91%
Hours in standby mode	4,626	4,374	95%
Hours in idle mode	0	405	NA
Hours in off mode (maintenance shutdown)	0	211	NA
Average percent flow – operating mode	63.1%	57.0%	90%

Baseline fuel therms/hour - operating	16.23	16.17	99.6%
Proposed operating therms/hour - operating	1.56	1.57	100.6%
Baseline therms/hr - standby	0	0	NA
Proposed standby therms/hour - standby	2.39	4.08	171%
Baseline therms/hr - idle	0	0	NA
Proposed therms/hr - idle	NA	7.97	NA

- **Final Results**

The project consisted of the installation of a new regenerative thermal oxidizer to accommodate increased VOC production. The applicant calculated savings for the measure using the vendor's spreadsheet analysis model.

The evaluators calculated savings for the measure using the same approach used by the applicant. The input variables were changed with data obtained from onsite power monitoring from the facility.

The evaluated savings for the project are 31% less than the reported values. The parameters impacting the analysis are summarized in **Table 4-9**.

Table 4-9: Summary of Key Parameters

Baseline	**Applicant**	**Evaluator**
Recuperative thermal oxidizer	A less efficient recuperative thermal oxidizer installed to handle increased VOC loads	A less efficient recuperative thermal oxidizer installed to handle increased VOC loads
As-Built	**Applicant**	**Evaluator**
Regenerative thermal oxidizer	An efficient regenerative thermal oxidizer installed	An efficient regenerative thermal oxidizer installed
Savings		
Annual natural gas savings (therms)	49,606	34,001
Natural gas realization rate	69%	

- **Recommendations for Program Designers & Implementers**

There are no recommendations for this project.

- **Customer Alert**

There are no customer requests at this time.

- **Explanation of Deviations**

Table 4-10 provides a summary of the key factors and deviations.

Table 4-10: Summary of Key Factors and Deviations

Factor	Applicant	Evaluator	Impact of Deviation	Discussion of Deviations
Tracked savings	49,606 therms	49,606 therms	No impact	**No impact** – Tracked savings were consistent with the application.
Decreased hours during operating mode, decreased hours during standby mode, and added idling mode and off modes as a result of examination of monitoring data.	Operating = 4,134 hrs standby = 4,626 hrs idling = 0 Off = 0 hrs	Operating = 3,771 hrs standby = 4,374 hrs idling = 405 hrs Off = 211 hrs pre-idling = 0 therms/hr post-idling = 7.97 therms/hr	-16%	**Decreased savings** – Fewer hours during operating mode, when the new RTO uses fewer therms/hr than the bassline RTO, reduces savings, and adding the idling mode, which uses more therms/hr in the post case than the base case also decreases savings.
Decreased baseline operating gas usage rate, which is a result of a lower measured average operating airflow rate. This adjustment is the result of using additional monitoring data.	Baseline operating gas usage rate = 16.23 therms/hr Average operating airflow rate = 11,461 SCFM	Baseline operating gas usage rate = 16.17 Average operating airflow rate = 11,410 SCFM	-0.6%	**Decreased savings** – The average baseline operating gas usage rate is interpolated from vendor specifications provided at 10,000 SCFM and 20,000 SCFM, with more process gas usage used at higher SCFM values. A lower average operating SCFM value corresponds with a lower baseline operating gas usage rate, resulting in decreased savings.

Factor	Applicant	Evaluator	Impact of Deviation	Discussion of Deviations
Increased post operating gas usage rate, which is a result of a lower measured average operating airflow rate (provides less VOCs to burn). This adjustment is the result of using additional monitoring data.	Post operating gas usage rate = 1.56 therms/hr Average operating airflow rate = 11,461 SCFM	Post operating gas usage rate = 1.57 therms/hr Average operating airflow rate = 11,410 SCFM	-0.1%	**Decreased savings** – The average post operating gas usage rate is interpolated from vendor specifications provided at 10,000 SCFM and 20,000 SCFM, with less process gas usage used at higher SCFM values (due to lower VOC contribution). A lower average operating SCFM value corresponds with a higher post operating gas usage rate, resulting in decreased savings.
Increased post standby gas usage rate by referencing performance specifications of new equipment, rather than using applicant approach of scaling the measured standby gas usage rate on the old 15,000 SCFM RTO by multiplying this rate by the average post-case calculated operating SCFM over the average baseline calculated operating SCFM	Post standby gas usage rate = 2.39 therms/hr = 1.969 therms / hr · [11,461 SCFM / 9,461 SCFM]	Post standby gas usage rate = 4.08 therms/hr (based on performance specifications of new equipment)	-18%	**Decreased savings** – The post case standby gas usage rate increased from 2.39 therms/hr to 4.08 therms/hr, resulting in increased post annual therms, and reduced savings.

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- **Project Summary and Results**

Two measures were implemented at this 154,450 square foot middle school in Providence, RI. The entire space is conditioned and heated via the central steam boiler plant with two steam boilers. These boilers are used solely for heating the spaces. The following two measures were completed in 2016 as Custom Gas measures.

6423075 – Vacuum condensate return system: The main function of these systems is to remove air from the steam and condensate return lines. Instead of using the steam to "push" the air out of the system, the air is evacuated via electric vacuum pumps. This allows the system to warm up faster during boiler start-up, decreasing the amount of time the boiler must remain in high fire. There are also savings associated with lowering the required steam pressure when the boiler is firing during the colder months. Since the vacuum condensate return system is creating a negative pressure on the system, the steam pressure on the boiler can be reduced. This will result in less natural gas required for steam production throughout the heating season.

6733502 – Efficient steam boiler: A new fire tube steam boiler was installed to work in tandem with an existing steam boiler. The tracking analysis assumed the new boiler to run constantly throughout the year, but evaluation found that it runs alternatively (every other month) with the less efficient existing boiler.

The boiler measure was classified as New Construction and Vacuum condensate return system (VCRS) as retrofit measures by National Grid. The evaluators agree with National Grid's classification. Evaluation also considered VCR measure to be completed before the boiler measure and removed the savings from VCR in boiler usage to avoid any double counting of savings.

Table 4-11: Savings Results

Measure ID	Measure Name		Gas Savings (Therms/yr)
6423075	Vacuum condensate return system	Tracked	6,256
		Evaluated	6,041
		RR[1]	96%
6733502	Efficient steam boiler	Tracked	8,796
		Evaluated	5,367
		RR[1]	61%
Totals		**Tracked**	**15,052**
		Evaluated	**11,408**
		RR[1]	**76%**

[1]Realization rate

○ ***Explanation of Deviations from Tracked Savings***

The source of the tracking gas history was undocumented, and the annual usage according to the tracking analysis was 64,133 therms less than billed histories obtained by evaluators. The savings from the additional gas billing was offset by reductions in steam heat loss estimates.

The reduction in savings for the efficient steam boiler is primarily attributed to a reduction in annual operating hours. The new boiler was installed to operate with an existing twin steam boiler that was installed previously. Only one boiler is required to meet the heating load. The boilers are manually switched monthly between primary and backup roles. Tracking savings are based upon the new boiler handling the entire heating load throughout the heating season but in reality (in evaluated case) it operates only 50% of the time.

▪ **Evaluated Measures**

The measures implemented at this site upgrade the condensate collection system of the existing steam heating system by installing a vacuum return pump. The second measure installs an efficient steam boiler to work in tandem with an existing identical steam boiler.

○ ***Application Information and Analysis***

This section describes the information and analysis provided by the applicant.

○ **Applicant Description of Baseline**

6423075 – Vacuum condensate return system

The baseline for this measure is an existing gravity-fed condensate system. Steam is fed through the piping and gravity draws the condensate into a receiving tank. Float driven condensate pumps then pump the water back to the boilers. The original steam system was designed to operate with a vacuum condensate system. The vacuum pumps failed at some unknown time in the past. The conversion to a gravity system was the low-cost replacement solution at that time. The steam pressure was increased to 7-psig when the gravity system was installed.

6733502 – Efficient steam boiler

The baseline for this measure is a less efficient new steam boiler [79% efficiency], which aligns with IECC 2012 minimum requirements. The original boiler was a coal-fired steam boiler that was retrofitted with a natural gas burner. The evaluator found that one existing boiler is being used in conjunction with the boiler installed in this project, but this was not incorporated into the tracking analysis. In the tracking analysis, existing boilers are not part of the baseline (in terms of operating hours). The boiler installed in this project is identical to the existing steam boiler that remained in place after the retrofit. In the tracking analysis, the baseline boiler is assumed to serve the entire heating load.

○ **Applicant Description of Installed Equipment and Operation**

6423075 – Vacuum condensate return system

The existing condensate receiver and pump was removed and one Skidmore model #JVC-42-370-101 duplex vacuum boiler feed unit was installed in its place. The vacuum system is equipped with two 5.0-HP vacuum pumps and a 375-gallon receiving tank. The vacuum system operates and feeds both steam boilers. The vacuum pump operation is linked with boiler operation and runs continuously when there is a call for heat to return required condensate. Both pumps are off when there is no call for heat.

<u>6733502 – Efficient steam boiler</u>

A non-condensing Cleaver Brooks 150-HP firetube steam boiler, Model CBLE 700-150 – 015ST was installed in the boiler room. The new boiler was installed to operate with an existing twin steam boiler and is tied into a common distribution header. Both boilers are fed by the vacuum condensate return system. Only one boiler is required to meet the heating load of the school. The boilers operate as primary/standby. The boilers are manually switched over between primary and standby monthly. The steam pressure was set to 3-psig with the installation of the vacuum condensate system.

○ **Energy Savings Algorithms**

<u>6423075 – Vacuum condensate return system</u>

The TA used a custom calculator to estimate savings for the measure at this school. The analysis used third-party best practices manual in building this custom tool. Due to the reduction of the steam pressure from 7-psig to 3-psig, the savings calculated were based on the steam properties shown in Table 4-12 below. The values in parentheses are steam properties at 3-psig adjusted for a steam mass of 0.993 lb. (i.e. 957.2 BTU/lb ÷ 964.2 BTU/lb).

Table 4-12: Steam Properties

Parameter	7-psig (Baseline)	3-psig
Saturation Temperature (˚F):	232	222; (220.5)
Specific Enthalpy of Water (hf) (BTU/lb): Sensible heat	200.69	189.78; (188.40)
Specific Enthalpy of Evap. of Steam (BTU/lb): Latent heat	957.2	964.22; (957.2)
Specific Enthalpy of Steam (hg) (BTU/lb): Total	1,157.89	1,153.99; (1145.60)
Boiler stack temperature(˚F):	346.6	338.6; (338.6)

Savings were calculated using best practices estimated steam losses obtained from an engineering website. The best practices average steam system thermal cycle efficiency is 56.3%, which means that 43.7% of the energy that is consumed in the boilers is wasted or lost. These losses were considered to be applicable to a school and steam system that is greater than 70 years old. Figure 4-2 shows estimated losses used in the TA study. Savings for the new condensate system are based upon the lower temperatures associated with the reduction in steam pressure. Conduction losses and steam losses at 3-psig will be at lower temperatures when compared with the 7-psig baseline pressure.

Figure 4-2: Steam Thermal Cycle Losses from Best Practices Manual

A	Boiler flue gasses	16.4%
B	Boiler outer shell or casing	0.5%
C	Continuous blow down (boiler)	1.5%
D	Bottom blowdown (boiler)	0.2%
E	Insulation (steam and condensate)	6.4%
F	Steam leaks	7.5%
H	Steam Trap Station Failures	3.6%
G	Condensate Losses	3.8%
H	Steam Loss to Atmosphere	7.4%
	Total	47.3%

Site specific steam system savings were created using the average system losses identified above, adjusting them based on the change from 7 psig to 3 psig.

Table 4-13: Site Loss and Savings

Site Loss	Savings %	Savings Source
Steam leaks from components (e.g. valves and piping)	1.4%	Line F
Combustion loss	0.0%	Equipment Estimate
Boiler blowdown loss	0.1%	Lines C+D
Condensate Losses	0.0%	Line H
The enthalpy savings effect.	1.1%	Steam enthalpy difference
Flash steam loss through condensate receiver vents	1.1%	Steam enthalpy difference
Boiler radiation and convection loss	0.0%	Line B
Steam piping heat loss	0.3%	Line E
Steam trap leakage	0.7%	Line G
Warm-up / Start-up	2.2%	Estimate run time reduction
Total	**7.02%**	

75,654 annual therms of natural gas are listed as the heating therms used. This value is normalized against 30-year average heating degree-days to obtain 89,078 adjusted heating therms. The monthly natural gas data has no heating usage from April through October. It is not clear from the documentation as to why the tracking analysis used billing data from various years (2011 through 2014) to calculate Normalized heating use as shown in the Table 4-14 below. Total annual savings are obtained by multiplying the annualized heating therms by the 7.02% savings factor from Table 2-2

Table 4-14: VCR Tracking Analysis Billing Data Normalization

Date	# Days	Therms Use	HDD	30Yr HDD	Normalized Heating Use
Jan-14	31	15,812	956	1125	18,607

Feb-11	28	16,892	829	965	19,663
Mar-11	31	6,394	580	817	9,007
Apr-14	30	0	408	494	0
May-13	31	0	147	221	0
Jun-13	30	0	61	122	0
Jul-11	31	0	0	3	0
Aug-11	31	0	0	9	0
Sep-13	30	0	79	101	0
Oct-11	31	8,018	267	377	11,321
Nov-13	30	12,324	684	637	11,477
Dec-13	31	16,214.00	820	961	19,002
Total	**365**	**75,654**	**4,831**	**5,832**	**89,078**

The estimated savings are driven by the reduction in heat and pressure between 7-psig and 3-psig steam. The rows referencing lines refer to the lines listed in Figure 4-2. The Figure 4-2 loss factor is modified by the percentage difference in enthalpy between 7-psig and 3-psig [1.1%] to calculate savings. Steam leaks account for 7.5% of the listed Best Practice losses. In the documentation, absolute pressure for 7-psig steam is 20.7 PA. It is 16.7 PA for 3-psig steam. 16.7 PA is 80.7% of 20.7 PA [16.7/20.7 = .807]. At 3-psig, the losses are reduced to 6.1% [7.5% x .807]. The reduction in pressure results in savings of 1.4% for the steam leaks [7.5% - 6.1%]. Other factors' equations are shown in Table 4-15 below.

Table 4-15: Methodology/Equations

Saturated Steam Properties	**% Savings**	**Pre-retrofit (7 psig) from Figure 4-2**	**Post-retrofit (3 psig)**	**Post- calculation methodology ***
Steam Losses	1.4%	7.5%	6.1%	$\frac{\text{Absolute Pressure of 16.7 @ 3 psig}}{\text{Absolute Pressure of 20.7 @ 7 psig}} * 7.5\% = \left(\frac{16.7}{20.7}\right) * 7.5\% = 6.1\%$
Boiler blowdown losses	0.11%	1.70%	1.59%	
Condensate Losses	0.03%	3.80%	3.77%	$\frac{\text{CR Heat @ 3 psig}}{\text{CR Heat @ 7 psig}} * 3.80\% = \left(\frac{110.91}{111.72}\right) * 3.80\% = 3.77\%$ Where, CR Heat = (1-%total condensate loss) *mass lb*enthalpy of condensate) @ 3 psig = (1-0.24) *0.993*147=110.91btu @ 7 psig = (1-0.24) *1.000*147=111.72btu
Enthalpy Savings Effect	1.1%	1039.6 btu	1028.2 btu	$\frac{\text{Total heat supplied to boiler (@ 7psig} - \text{@ 3p}}{\text{Total heat supplied to boiler @ 7psig}}$ $\frac{1039.6 - 1028.2}{1039.6} = 1.1\%$ Where, Total heat supplied to boiler = Sensible heat + latent heat = (heat energy req'd at Sat Temp − heat in CR − heat in MUW) + (heat energy req'd to vaporize) @7psig =200.69-111.72-6.58+957.2=1039.6 @3 psig =188.40-110.91-6.53+957.2=1028.2

Flash Steam through condensate receiver	1.1%	9.3%	8.2%	$\frac{\text{Sensible Heat at Sat temp} - \text{Sensible heat of co}}{\text{Latent heat}}$ @ 7psig: $\frac{200.69-11\ .72}{957.2}$=9.3% @ 3psig: $\frac{189.78-111.72}{957.2}$=8.2%
Boiler Outer Shell Losses	0.012%	0.5%	0.488%	$\frac{\text{stack emperature (@ 7psig−@ 3psig)}}{\text{Stack temperature @ 7psig}} = \frac{346.6-338.6}{346.6} * 0.5\% = 0.488\%$
Steam piping insulation losses	0.3%	6.4%	6.1%	$\frac{Absolute\ pressure\ @\ 3\ psig * 6.4\%}{Absolute\ pressure\ @\ 7\text{psig}}$ = $\frac{16.7*6.4\%}{20.7}$=6.1%
Steam trap leakage	0.7%	3.6%	2.9%	$\frac{Absolute\ pressure\ @\ 3\ psig * 3.6\%}{Absolute\ pressure\ @\ 7\text{psig}}$ = $\frac{16.7*3.6\%}{20.7}$=2.9%
Warm-up/Startup	2.2%	6.89%	4.72%	Savings calculated based on a revised start-up time of 1.75 hours in proposed condition compared to 2.5 hours in baseline. Gas consumption = (Enthalpy*startup time*heating days*1000)/1000 therms
Total	7.02% savings of the total gas usage (89,078 Therms[10]).			6,256 therms (rounded)

<u>6733502 – Efficient steam boiler</u>

Tracking savings were generated using weather normalized monthly billing usage data and estimated firing rate for both base and proposed cases. The TA study normalizes monthly gas heating therms by creating a ratio between the 30-year average heating degree days for Providence against heating degree days for the billing month. Non-heating natural gas usage is estimated at 324 therms per month [3,888 annual therms] and is the average of June through September monthly natural gas billing. Non-heating natural gas usage is for domestic hot water (DHW). The DHW therms are subtracted from the annual normalized usage. This results in 134,767 annual heating therms.

$$Therms\ savings\ monthly = Normalized\ Therms\ Usage * \frac{Baseline\ Eff - Proposed\ Eff}{Baseline\ Eff}$$

This savings equation is incorrect. The therms savings should be the difference in load to efficiency ratios of baseline and proposed boilers. This has been updated in the evaluation as shown in ***On-Site Inspection and Metering*** section below.

[10] Gas usage was calculated using billing data normalized using the HDD and 30yr HDD values.

Analysis of Applicant Savings Algorithms

6423075 – Vacuum condensate return system

The vacuum condensate return system tracking savings are based upon average best practice steam losses and total annual natural gas billing usage. Savings are attributed to the reduced enthalpy and temperature associated with the reduction in steam pressure. No site-specific values are provided in the TA documentation. Table 4-16 shows the site loss assumptions referenced by the best practices to the physical attributes linked with the actual baseline condition that the evaluation determined has to be used for savings calculations. The best practices and billing approach provided a savings estimate. But, all the best practices were accepted as being in place in the installed case and were not verified or quantified in the TA study.

Table 4-16: Baseline Data Comparison

Site Loss	Baseline Condition
Steam leaks from components (e.g. valves and piping)	No equipment, temperatures, insulation values
Combustion loss	Same of base and installed - no impact
Boiler blowdown loss	No boiler blowdown rates
Condensate Losses	No estimates of % condensate leakage
The enthalpy savings effect.	Enthalpy of steam at 7-psig and 3-psig
Flash steam loss through condensate receiver vents	No notation of leaks or interaction with vacuum system
Boiler radiation and convection loss	No surface area or temperatures
Steam piping heat loss	No insulation values, dimensions, or temperatures
Steam trap leakage	No count of leaking traps
Warm-up / Start-up	0.75 hours pre day - no documentation

6733502 – Efficient steam boiler

The tracking calculations are based upon the difference in gas usage using the baseline and installed boiler efficiencies. Tracking analysis did not specify the reasons for varying efficiencies at different loads, but they seem to be reasonable assumptions.

The tracking analysis does not appear to take into account any interactive effects between these two measures.

- ***On-Site Inspection and Metering***

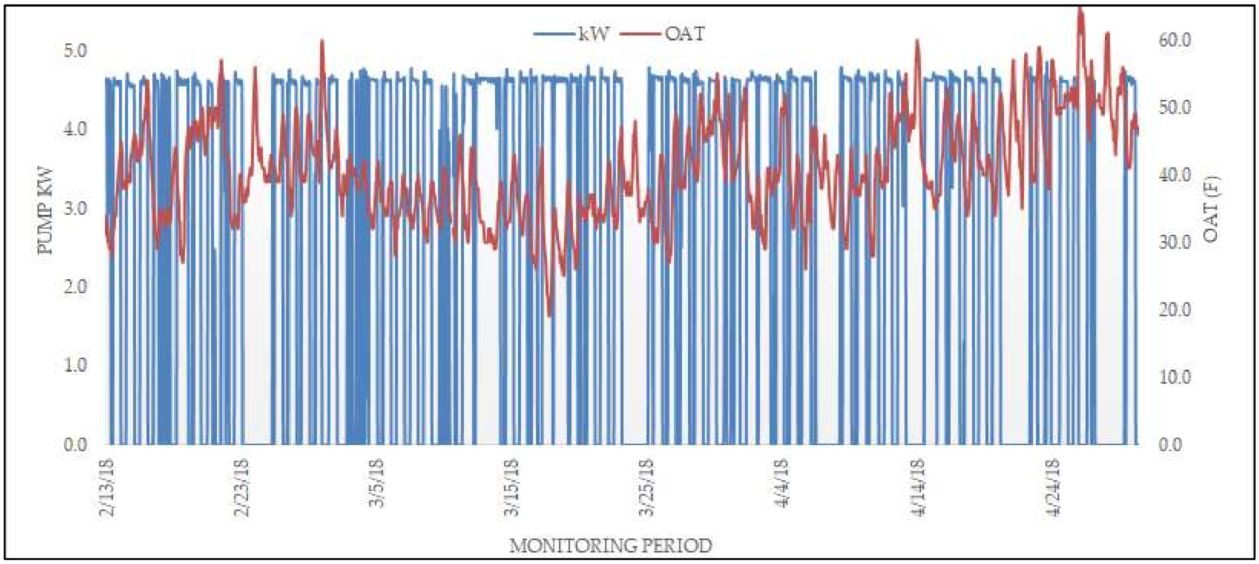
This section provides the findings identified during the site visit and includes the results of onsite monitoring.

- **Summary of On-Site Findings**

The evaluators conducted a site visit on February 13, 2018. The evaluator verified that a new duplex vacuum condensate system was installed at the site and was operating at that time. The evaluator verified that the new non-condensing fire-tube boiler described in the tracking estimate was also installed at the site. The observed pressure was 3-psig at the boiler. The new boiler operates in a primary/backup mode with a twin boiler that was installed earlier. Boilers are manually switched between primary and backup mode every 30 days. Only one boiler is required to meet the heating load. The lead boiler provides the required steam and the backup boiler will come on if the primary boiler fails. Alternating the boilers as the primary unit keeps equal runtime on the equipment.

Two Elite power loggers were installed during the site visit. One logger monitored the operation of the duplex vacuum pumps. The monitoring period was from February 13, 2018 to May 15, 2018. The logger data showed that the vacuum pumps operated for 1,001 hours or 54% of the time at an average of 4.5 kW. Figure 4-3 shows the average hourly monitored kW of the vacuum pump operating over the monitoring period.

Figure 4-3: Monitored Vacuum Pump kW vs Providence OAT (˚F)



The second Elite power logger was installed to monitor the operation of the new boiler's burner. The downloaded logger data consisted of 1 entry and provided no usable data. The voltage clip that powers the logger became undone after the logger was launched and the panel closed.

A Hobo temperature logger was installed at the site to monitor steam and condensate piping temperatures. The logger was installed at the pipe station that feeds a piping chase in the boiler room. That logger was missing at the retrieval date and could not be located. Instantaneous temperature readings were taken at three locations using an infrared thermometer. The temperature at the main header off the boilers was 225.3°F, the feed to the vacuum system measured 222.5°F, and the steam branch pipe to the tunnel was 220.5°F. The average steam temperature was 222.8°F.

The site contact stated that the 7-psig pre-case estimate was accurate and that the system is currently generating 3-psig steam. He went on to say that the original steam system was designed to operate with a vacuum condensate system. At some unknown time in the past, major repairs were required and, for unknown reasons that were probably cost related, the current condensate pumping system was installed. Steam pressures were increased to 7-psig at that time. The vacuum system installed with this measure brings the system back to the original design. He believed that the system could operate at 2-psig, but that reduction has not been tried and is not scheduled in the near term.

Five of the rows citing Best Practice losses in Figure 4-2 contribute to total condensate loss in the system. These rows are condensate losses, boiler blowdown, steam trap station failures, steam leaks, and steam loss to atmosphere. There is an energy content for these losses individually and collectively. The vacuum pump measure achieves savings by reducing the operating pressure. The lower steam pressure also lowers the temperature in the boiler shell, pipes, and devices. The losses are also occurring at a reduced temperature and become a source of savings for the measure. Below are observations made during the evaluation that either confirmed the tracking analysis use of typical values or suggested they should be updated to match site-specific conditions.

Condensate Losses: The site engineer is aware of the benefits of a tight system and works at minimizing steam losses. The site contact claimed that 95% of condensate is recovered and returned to the boiler. The more condensate that is recovered reduces the losses that were included in the tracking savings.

Boiler Blowdown: The site contact stated that a continuous blowdown was never part of the school's boiler operation. Continuous blowdown uses boiler steam to keep the boiler clean and eliminate sediment buildup in the boiler. It is also a continuous source of steam loss. In place of continuous blowdown, a boiler water treatment program was implemented, and the mud drum and legs are cleaned at the end of each season during maintenance. Samples are drawn periodically through the year for inspection and he cannot recall a midseason blowdown requirement. The continuous blowdown losses were not present in the system as it is operated, but tracking analysis claimed savings from this effect so, the evaluator adjusted savings claimed from this source.

Steam Trap Station Failures: There is a steam trap maintenance program in place and failed traps are repaired/replaced annually. This maintenance program reduces steam leaks and the associated energy loss. This is an old school with multiple tunnels and chases. Some areas are difficult to access. There may be some failed open traps that have yet to be identified. All easy-access traps at appliances and drip legs are routinely maintained. These savings were claimed in the tracking savings but adjusted in the evaluation

Steam Leaks and Steam Loss to Atmosphere: It was difficult for the site contact to differentiate between "steam leaks" and "steam loss to atmosphere". The contact said the system is well maintained and that condensate return is almost 95%. One steam leak was visible, but no others. Steam leaks are at a minimum, so the evaluator adjusted this factor.

Combustion efficiency testing was not performed at the site. The site contact said it was policy to only have licensed operators and technicians handle the equipment. This is required as part of their safety policy and to protect equipment warrantees. The site contact was to arrange for combustion testing when the boiler was serviced at the end of the heating season. However, the site contact left before the boilers were serviced and the testing results were not available.

- ***Evaluation Information and Analysis***

This section describes the baseline and savings calculation methodology used by the evaluator.

- **Baseline**

The gravity condensate system, condensate pumps and tanks, have been removed from the facility. The site contact confirmed that the gravity system was in place. He also confirmed that the system was operating at 7-psig for the baseline.

The site contact said that the less efficient steam boiler was considered for the installation and the lower efficiency [79%] seems reasonable for a 7-psig system and it meets the code (IECC 2012 standard).

- **Energy Calculation Methodology**

The metered VCR pump data essentially shows that the boiler operated mostly during the business hours (6 AM through 8 PM daily) and when the OAT is <65°F (HDD setpoint) which matches the tracking analysis assumptions for operating hours. Therefore, the evaluator used the original calculation spreadsheet and methodologies to calculate both VCR and non-condensing boiler savings.

VCRS

Table 4-17: Methodology differences between tracking and evaluation savings analyses

Parameter	Tracking	Evaluation
Adjustment Methodology (for Normalization)	30-year average	TMY3
Annual Billed Baseline Usage (therms)	134,767	131,904
Number of boilers used in Installed case	1	2

In the tracking analysis, vacuum condensate pump savings were calculated using 89,078 therms (from Table 4-14) of natural gas usage for the account that served that boiler compared to 137,943 therms shown in the Table 4-18. Tracking analysis assumed that the heating was turned OFF in April and turned back ON in October, but evaluation extended the heating season months based on onsite interview and billing data. That data was then normalized using TMY3 weather data converted to base 65¯F heating degree days. Evaluation used 2015 natural gas billing therms usage to calculate savings, while the tracking analysis used billing data from various months of 2011 through 2014. The tracking analysis also did not remove DHW usage from billing data before performing the weather normalization.

Table 4-18: Evaluated Heating Usage

Month	Days	Usage	HDD	Non-Heating	Heating Therms	TMY3 HDD	Adjusted Heating Therms
Jan-15	31	19,560	1,012	324	19,236	1,122	21,327
Feb-15	28	25,770	902	324	25,446	921	25,982
Mar-15	31	10,445	650	324	10,121	803	12,504
May-15	30	12,111	475	324	11,787	512	12,705
May-15	31	2,347	125	324	2,023	240	3,885
Jun-15	30	393	73	324	69	52	49
Jul-15	31	288	0	324	0	6	0
Aug-15	31	242	0	324	0	7	0
Sep-15	30	372	23	324	48	82	171
Oct-15	31	14,203	348	324	13,879	387	15,435

Nov-15	30	15,483	517	324	15,159	677	19,836
Dec-15	31	20,869	838	324	20,545	1,063	26,049
Totals	**365**	**122,083**	**4,963**	**3,885**	**118,316**	**5,870**	**137,943**

Steam system heat loss assumptions derived from best practices were modified to reflect the change in temperature and enthalpy between 7-psig steam and 3-psig steam. For example, calculating the vacuum system savings for the loss through steam piping uses the following approach.

Average steam system losses for piping from the best practices is 6.4% of total usage. Ambient temperature in the boiler room and mechanical spaces is estimated at 70°F in the tracking documentation. Site space room temperatures were not taken and the 70°F is used as the default. The three instantaneous pipe temperatures take during the site visit average 222.8°F The adjusted pipe temperatures at the site [pipe temperature minus room temperature] are calculated at 7-psig [158.5°F] and 3-psig [150.5°F]. Savings from the reduction in steam pressure for the piping losses are 0.32% of total annual natural gas used for space heating.

$0.32\% = 6.4\% - ((150.5°F/158.5°F) * 6.4\%$

Evaluation updated 3 variables from the tracking calculation.

1. Steam Leaks = 0; No steam leaks found on site.
2. Boiler blowdown loss = 0.01%; There is no continuous blowdown at the site and mud drums are purged during maintenance.
3. The Enthalpy Savings Effect = 0; The change in the specific enthalpy of steam between the baseline and installed scenarios is small. The baseline value is 1,157.89 hg [BTU/LB.} The proposed enthalpy is 1,153.99 hg [BTU/LB.]. All the savings/losses are temperature and enthalpy driven. It is the reduction in pressure/temperature/enthalpy that is the source for all the other savings. The reduction in steam enthalpy results in the savings at the boiler jacket and in the piping. The reduction in enthalpy is also the driver for the condensate loss values. Without identifying specific areas or devices that are affected by the pressure reduction in addition to the ones listed, the enthalpy reduction as a stand-alone line was duplicating savings.

Figure 4-4 shows the changes that were made in the calculation variables. The only steam leak that was visible in the boiler room was near the condensate receiver vents and is covered by the same variable in the table below. The enthalpy of steam row was also eliminated.

Figure 4-4: Changes in Heat Loss Variables

	Tracking	Evaluation
Steam leaks from components (e.g. valves and piping)	1.45%	0.00%
Combustion loss	0.00%	0.00%
Boiler blowdown loss	0.11%	0.01%
Condensate Losses	0.03%	0.03%
The enthalpy savings effect.	1.10%	0.00%
Flash steam loss through condensate receiver vents	1.14%	1.14%
Boiler radiation and convection loss	0.01%	0.01%
Steam piping heat loss	0.32%	0.32%
Steam trap leakage	0.70%	0.70%
Warm-up / Start-up	2.17%	2.17%
Totals	**7.02%**	**4.38%**

Therefore, VCR measure savings = Adjusted evaluated heating therms*%Total heat loss

= 137,943*4.38%

= 6,041 therms

Non-Condensing Boiler Savings:

As mentioned in the previous section evaluation used the tracking savings spreadsheet and methodology to calculate savings but using as-built and operating conditions found during the site visit.

Tracking analyst used efficiency of 79% and 84% for baseline and installed boilers respectively. Evaluation confirmed the baseline efficiency to be 79% using IECC 2012 code (per RI 2016 TRM) and used manufactured rated efficiency for the installed case.

Evaluation also found that the non-condensing boiler was operating only 50% of the time in summer based on the customer interview. The savings equation in evaluation has been corrected from tracking analysis as shown below.

Therms Savings $_{\text{Evaluated}}$

$$= \sum_{alternate\ heating\ month} \left(\frac{Evaluated\ Normalized\ Therms\ Usage}{Baseline\ Eff} - \frac{Evaluated\ Normalized\ Therm\ \ Usage}{Installed\ Eff}\right)$$

Where,

Evaluated Normalized therms usage = (Monthly Billing Usage – DHW usage) *($\frac{TMY3\ HDD}{HDD}$)

DHW usage = Average therms usage during non-heating months = 324 therms

Baseline Efficiency = 79% (IECC 2012)

Installed Efficiency = 85% (load <50% of max); 84% (load >50% of max)

per the manufacturer specifications.

But, there was no information on which boiler is turned ON first during the beginning of a heating season in September. Therefore, to be conservative the evaluation has used an averaged savings value calculated from both the scenarios as shown in Table 4-19 below.

Table 4-19: Evaluated Savings (therms) due to efficient non-condensing boiler

Month of Use	Billing Usage (Therms)	Tracking Baseline Usage (normalized)	Evaluated Baseline Usage (normalized)	Tracking Savings Therms	Evaluated Savings (Therms)	
			Adjusted for VCR savings	1 Boiler	Efficient Boiler Start	Inefficient Boiler Start
Jan	19,560	21,384	20,393	1,409	0	1,660
Feb	25,770	27,224	24,844	1,768	2,009	0
Mar	10,445	12,722	11,956	892	0	983
Apr	12,111	12,259	12,149	860	997	0
May	2,347	3,577	3,714	243	0	308
Jun	393	116	47	0	0	0
Jul	288	0	0	0	0	0
Aug	242	0	0	0	0	0
Sep	372	212	163	0	0	14
Oct	14,203	15,036	14,759	1,007	1,208	0
Nov	15,483	18,678	18,967	1,237	0	1,550
Dec	20,869	23,561	24,908	1,380	2,117	0
Totals	**122,083**	**134,767**	**131,901**	**8,796**	**6,221**	**4,514**
Evaluated Savings (therms)					**5,367**	

- **Final Results**

The project consisted of replacing a gravity fed condensate recovery system with a duplex vacuum pump unit. Savings came from the lowering of the system steam pressure by 4 psig. Evaluated savings are 4.0% less than the estimated tracking savings. This is due to a reduction in percent savings by the VCRS coupled with an increased estimate of baseline load; the two discrepancies offset each other.

Additional savings came from the installation of an efficient non-condensing steam boiler. The baseline unit was a less efficient than the new boiler that has been installed in its place. Savings for the new boiler are 38% less than the tracking estimate. The savings shortfall is due to a reduction in annual operating hours for the efficient boiler. The new boiler operates in a primary/backup mode with a second twin steam boiler. The boilers are switched as the primary operating unit every 30 days. There was a 2% increase in usage in the evaluated analysis from the use of TMY3 HDD. About 1.2% savings from the double counting of VCRS savings in tracking has also been removed in the evaluation.

The evaluators' analyses found that savings for both measures combined is 24% less than anticipated.

Table 3-1 summarizes the key parameters used to calculate the energy savings for the measure.

Table 3-1. Summary of Key Parameters

Parameter	Applicant	Evaluator
Vacuum system savings percentage	7.02%	4.38%
Total annual pre-installation gas therms – vacuum system	89,078	137,943
Total annual pre-installation gas therms – boiler	134,757	131,902
Efficient boiler percent of load served	100%	50%
Estimated boiler EFLH	1,870	2,702

Two different annual gas usages were used in the calculations. 89,078 is the 30-year HDD adjusted therms from October through March based on various months of 2011 through 2014 and not accounting for DHW usage; this value was the basis of the tracking VCRS savings. 137,723 is the total TMY3 adjusted heating therms based on 2015 billing data and accounting for DHW usage; this value was the basis of the evaluated VCRS savings. Both the tracking analysis and the evaluation used the 2015 billing data adjusted for DHW usage as the basis for the boiler savings calculations, but weather normalization was performed slightly differently between the two and VCRS savings interaction was not accounted for in the tracking analysis, leading to slightly different baseline usage.

- ***Cross Check with Billing Data***

The evaluation annual natural gas savings was compared with the TMY3 adjusted heating therms. The annual savings of 12,564 therms is 9.1% of the 137,732 adjusted therms. The savings include the interactive effects of the two measures where the savings from the efficient vacuum system is not included in the savings for the new boiler. The 9.1% value is not excessive and logical for this project.

- ***Recommendations for Program Designers and Implementers***

When best practices are used as a savings source it is important to compile a list of baseline conditions and values that correspond with the best practices. No site-specific temperatures, insulation values, steam trap discussions, steam leaks identified, system losses, or other values were included in the baseline discussion that referred to the best practices.

Natural gas billing histories and gas usage was not uniform between the two measures. Each measure had a different annual therms of gas. The history used to calculate the vacuum system savings was incomplete and April, May and September possible usage. The same billing history should be used for all measures.

The boiler tracking savings did not take into account the savings from the installed vacuum system. These measures are interactive. Interactive impacts should be addressed.

- ***Explanation of Deviations***

The evaluated savings were 24% less than the tracked savings because of changes in the variables contributing to losses, annual natural gas billing usage history errors, and anticipated run hours of the efficient steam boiler. Table 3-3 provides a breakdown of the change in savings due to each of the input variables.

Table 3-3 Discrepancy Summary

Factor	Applicant	Evaluator	Impact of Deviation	Discussion of Deviations
Vacuum condensate system heat loss percentage	7.02%	4.38%	-4%	Savings factors associated, and the best practices were reduced and resulted in less savings.
Annual natural gas usage history - Therms	89,078	137,723	7.0%	Vacuum system savings were based on natural gas history that was 64,133 Therms less that billing. Using the proper history increased annual savings
Boiler annual run percentage	100%	50%	~35%	Installed boiler runs alternatively with the baseline/pre- boiler and reduced total project savings.

o

2016RIN008

- **Project Summary and Results**

Two natural gas measures are installed across th multi-building hospital campus. Project #5895857 adds 1.5” insulation to 408 bare steam and condensate system pipes and fittings in 33 areas across the campus. Project #6527347 repairs or replaces 25 failed steam traps in the steam system.

The site contact informed the evaluator that since the project was installed the hospital will likely be closing. Parts of the campus were closed and unoccupied during the site visit. Medical process steam lines are shutoff in closed areas and HVAC operation is reduced to caretaker status. According to the site contact, the entire hospital is slated for shutdown, but the precise fate of the building is uncertain. Due to this uncertainty, evaluation used a conservative approach and calculated measure lifetime savings (therms) first and then annualized each measure based on their respective TRM specified measure lives (years). Evaluation also used both old and newly developed steam trap calculation tools, Savings are summarized in Table 4-20. Shutting down the hospital over time and taking steam systems offline is the major source of the savings discrepancy.

Table 4-20 Project Summary of Savings

Measure ID	Measure Name	TRM measure life	Measure life for unused measures	Parameter	Gas Savings (Original Steam Trap Tool)	Gas Savings (New Steam Trap Tool)
		years	years		therms	therms
5895857	Insulation	13	2	Tracked annual savings	65,687	
				Evaluated measure life savings	624,867	
				Evaluated annual savings	48,067	
				RR[1]	73%	
301710	Repair Failed Steam Traps	6	2	Tracked annual savings	21,512	14,933
				Evaluated measure life savings	73,388	47,934
				Evaluated annual savings	12,231	7,989
				RR[1]	57%	53%
Totals				**Tracked Annual Savings**	**87,199**	**80,620**
				Evaluated Annual Savings	**60,298**	**56,056**
				RR[1]	**69%**	**70%**

[1]Realization rate

- **Explanation of Deviations from Tracking**

The total evaluated savings are 30% less than the applicant-reported savings. Due to the uncertainty in building operation in the future, evaluation calculated total measure life savings assuming that the as-found conditions are to be present throughout the life of the measure (as shown in section o) and annualized savings based on their respective TRM measure lives for reporting purposes.

For reporting purposes, the building was assumed as 2 different areas:

Area 1- Operating or As-found (during the site-visit): Only 40% of repaired steam traps and 62% of insulated pipe areas are in operation. These areas have a full measure life of 6 and 13 years respectively.

Area 2- Non-operating (during the site visit): 60% of repaired steam traps and 38% of insulated pipe areas are not in use. This area of the building was operated for only 2 years after the install, therefore both the measures have been given only 2 years of life.

Steam trap savings are estimated at 53% of the tracking savings. This estimate is based on the new steam trap tool, which will be used by the program going forward; this is discussed in more detail later in the report. This shortfall is due to 15 of the 25 repaired traps being in area 2.

Piping insulation savings are 73% of the tracking estimates. The savings reduction is primarily due to insulated piping and devices being taken out-of-service and no longer carrying steam or condensate loads. 154 [38%] of the 408 insulated devices are no longer in service.

- **Evaluated Measures**

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

The project consisted of repairing failed steam traps and insulating bare steam piping.

- **Application Information and Analysis**

This section describes the information and analysis provided by the applicant.

- ***Applicant Description of Baseline***

Repair Failed Steam Traps

The vendor performed a survey of all steam traps throughout the facility which involved determining the operating status of each trap by way of spot measurements on trap entering and leaving temperatures and ultrasonic testing. The baseline status for each trap was established to be the operating condition identified by the vendor during the survey.

The baseline for steam traps replaced during Project #6527347 is failed open. 25 of the facility's 286 traps were identified as failed across the campus. Another 5 traps were reported to be plugged. These traps were repaired or replaced. There are no savings attributed to the repair of a plugged trap. Annual operating hours range from 1,700 hours to 8,760 hours depending upon location and task. Steam pressures range from 10-psi to 100-psi. Average steam pressure is 46-psi and average annual operation is 6,642 hours. Table 4-21 details the findings of the Custom Express Savings Tool submitted with the application.

Table 4-21: National Grid Custom Express Screening Tool Claims

Trap Status	No Action	Repair	Replace	Total
No Status	0	0	0	0
Fully operational	256	0	0	256
Plugged	0	3	2	5
Partially leaking	0	16	3	19
Full leak	0	0	0	0
Partially blowing by	0	4	2	6

Total	256	23	7	286

○ ***Insulate Bare Steam Piping and Devices***

The baseline for Project #5895857 is uninsulated piping and devices. These 408 bare devices include bare pipes, welded elbows, flanges, bonnets, fittings, valve bodies, strainers and other devices. Steam is produced all year in the hospital for HVAC and medical process usage. 8,424 annual hours are assigned for continuous usage. Heating only HVAC devices are rated at 2,928 annual operating hours. Device surface temperatures ranged from 160°F for condensate systems to a maximum of 336°F in boiler room systems. The average temperature for all devices is 247°F. The average annual operation is 8,072 hours. There is a slight deviation in annual operating hours from steam trap and insulation calculations. This could be due to the use of different vendors calculating savings for each measure.

Table 4-22: Uninsulated Piping and Device Quantities

Device	Total
Angle Valve	1
Ball Valve	5
Bonnet	32
Butterfly Valve	8
Control Valve	7
Elbow	39
Fitting	87
Flange	29
Gate Valve	33
Globe Valve	3
Heat Ex	16
Manway	4
Pipe	64

Device	Total
PRV	2
Pump Body	10
Reducer	4
Regulating Valve	6
Strainer	21
Tank	6
Tee	1
Trap	3
Union	3
Unknown	8
Valve Cap	13
Flex Hose	2
LWCO	1

○ ***Applicant Description of Installed Equipment and Operation***

Repair Failed Steam Traps

Project #6527347. The 25 failed-open traps are either repaired or replaced. The 5 plugged steam traps are also repaired or replaced. 256 of the existing traps are fully functional. There are no changes in operating hours or steam pressures from the baseline conditions.

○ ***Insulate Bare Steam Piping***

Project #5895857. Insulating jackets are installed on all 408 existing bare devices. The insulation is 1.5” fiberglass with solid vinyl cladding across all devices. Operating hours, system temperatures, and device area do not change from the baseline conditions.

○ ***Applicant Energy Savings Algorithm***

Repair Failed Steam Traps - Project #6527347

For the repaired and replaced traps, the applicant used the National Grid Custom Express Screening Tool to calculate savings. The tool was developed by National Grid in 2010 and uses the findings from the steam trap survey as inputs to calculate energy savings. The tool determines energy savings by calculating theoretical steam flow through the trap orifice using the Grashof formula and then applying several factors to account for trap-specific and system-level operating characteristics. Steam flow through the orifice for each trap is calculated using the formula below.

$$SF = 41.58 \times \pi \times \left(\frac{Diam}{2}\right)^2 \times (Pres + 14.7)^{0.97} \times LF$$

where,

SF = Estimated steam flow through trap orifice (lbs/hr)

41.58 = Grashof equation coefficient

$Diam$ = Trap orifice diameter (inches)

$Pres$ = Trap operating pressure (psig)

LF = Leak factor as determined from steam trap survey testing

Applicant steam trap savings are then calculated using various loss mechanisms that are selected based on the system configuration (for example, savings for a trap venting directly to atmosphere are calculated with a different loss mechanism than those used for a trap venting into a closed condensate return system). Since all the traps from this project are associated with a single configuration (traps venting to a closed condensate return system), only the loss mechanisms for this configuration will be explained. Applicant steam trap savings are calculated using the following formula:

$$Svgs = \frac{TCF \times Hours}{100{,}000} \times \left(\frac{(LM_{Flash} + LM_{LatentLost})}{\eta} + LM_{Excess}\right)$$

where,

$Svgs$ = Annual energy savings per year (therms)

TCF = Total correction factor (see below)

$Hours$ = Number of hours per year the valve or fitting is energized

$100{,}000$ = Therms to Btu conversion

LM_{Flash} = Loss mechanism for flash steam savings (Btu/hr), see below

$LM_{LatentLost}$ = Loss mechanism for latent heat of trap steam not serving boiler loads (Btu/hr), see below

LM_{Excess} = Loss mechanism for excess steam in boiler cycle (Btu/hr), see below

η = Total boiler efficiency, includes system line losses (75%)

Total correction factor (TCF) is calculated as the product of two factors described below.

$$TCF = RRF \times PAF$$

where,

RRF = Repair/replace factor. For repaired traps, a value of 70% is applied to the savings equation while replaced traps use a value of 100%.

PAF = PA savings adjustment factor to be used by PA's engineering staff to adjust savings if needed based on system uncertainty.

The loss mechanism for flash steam savings is calculated using the formula below.

$$LM_{Flash} = SF \times \frac{(h_{f,trap} - h_{f,atm})}{(h_{g,atm} - h_{f,atm})} \times (h_{g,atm} - h_{f,cw})$$

where,

LM_{Flash} = Loss mechanism for flash steam savings (Btu/hr)

SF = Estimated steam flow through trap orifice, calculated above (lbs/hr)

$h_{f,trap}$ = Steam trap saturated liquid enthalpy, based on trap pressure (Btu/lb)

$h_{f,atm}$ = Atmospheric saturated liquid enthalpy, constant (180.07 Btu/lb)

$h_{g,atm}$ = Atmospheric saturated steam enthalpy, constant (1,150.4 Btu/lb)

$h_{f,cw}$ = City water enthalpy, constant (28.1 Btu/lb)

The loss mechanism for the latent heat of trap steam not used to serve boiler loads is calculated using the formula below.

$$LM_{LatentLost} = SF \times (h_{g,trap} - h_{f,trap}) \times Constant$$

where,

$LM_{LatentLost}$ = Loss mechanism for latent heat of steam not being used to serve boiler loads throughout facility (Btu/hr)

SF = Estimated steam flow through trap orifice, calculated above (lbs/hr)

$h_{g,trap}$ = Steam trap saturated steam enthalpy, based on trap pressure (Btu/lb)

$h_{f,trap}$ = Steam trap saturated liquid enthalpy, based on trap pressure (Btu/lb)

$Constant$ = Percent of latent heat in steam which is not returned to the steam loop in a useful manner such as heating condensate in DA tank or heating conditioned space through condensate return line. (30%)

The loss mechanism for the excess steam lost in the boiler cycle is calculated using the formula below.

$$LM_{Exce} = SF \times (h_{g,trap} - h_{f,trap}) \times (1 - \eta)$$

where,

LM_{Excess} = Loss mechanism for excess steam lost in boiler cycle (Btu/hr)

SF = Estimated steam flow through trap orifice, calculated above (lbs/hr)

$h_{g,trap}$ = Steam trap saturated steam enthalpy, based on trap pressure (Btu/lb)

$h_{f,trap}$ = Steam trap saturated liquid enthalpy, based on trap pressure (Btu/lb)

η = Total boiler efficiency, includes system line losses (75%)

○ ***Insulate Bare Steam Piping - Project #5895857***

Insulation savings were generated using spreadsheet calculations and vendor-generated heat loss values thought to come from the 3EPlus model. The MMBTU/hour heat loss values per Ft^2 of device is provided for the bare and 1.5" insulated scenarios. These MMBTUH values are hard copy pasted numbers from the vendor. The heat loss values were modified by a 3rd party engineering firm that used 3EPlus to create a deration factor from a sample of fitting that adjusts the savings. The basic insulation savings equation is the summation of the savings from each device insulated using the following formula:

$$THERMSannual = \sum[((MMBTUHbare - MMBTUinsulated)\left(\frac{Original\ Operating\ hours}{Revised\ Operating\ hours}\right)) * \ Deration\ Factor * \ 10]$$

Where:

$THERMS_{annual}$ = Therms of natural gas saved per year

$MMBTUH_{bare}$ = Heat loss per square foot of uninsulated device per year

$MMBTUH_{insulated}$ = Heat loss per square foot of insulated device per year

Deration factor = Savings adjustment [3EPlus generated therm savings/ original therm savings/]

10 = Conversion factor to MMBTUh to Therms

The tracking savings are based on revisions were made by a commissioning firm to the original vendor study. The original operating hours were the annual operation estimated by the TA engineering firm. The TA study estimated annual operation at 8,760 hours for continuous service and 4,000 hours for HVAC and incremental usage. Continuous operation was reduced to 8,424 annual operating hours by the commissioning firm to account for system downtime and annual maintenance. HVAC and non-continuous system operation were reduced from 4,000 hours to 2,928 annual hours by the commissioning firm. The hours were lowered to reflect a greater diversity in system operation at the hospital. The breakout showing the weighted average estimates were not presented.

The deration factor is a calculated factor that adjusts the TA estimated bare and insulated heat loss values to bare and uninsulated values from 3EPlus. Adjustments are made for high temperature systems (>250°F) and low temperature systems (<=250°F).

Table 4-23: High and Low Temperature Deration Factors

Sample Equip.	Sample Area (SqFt)	Sample Temp (*F)	Tracking uninsulated energy use	Tracking insulated energy use	Tracking savings	3EPlus uninsulated energy use	3EPlus insulated energy use	3EPlus Savings	Deration Factors	Average Deration Factors
30'-1.5" Pipe	15.0	220	6,720.0	319.1	6,400.9	4,599.0	353.6	4,245.5	0.66	72.48%
6" 150# SRV FLG Cap	5.5	236	2,539.4	251.9	2,287.4	1,946.5	147.6	1,798.9	0.79	
9'-.75" Pipe	2.4	305	1,749.6	83.1	1,666.5	1,424.0	103.2	1,320.8	0.79	81.72%
10" Valve,Gate,300#	18.0	312	13,017.6	1,283.4	11,734.2	11,019.6	796.1	10,223.5	0.87	
15'-2.5" Pipe SP	11.3	302	7,992.0	379.5	7,612.5	6,467.6	469.6	5,998.1	0.79	

The low temperature deration factor for low temperature components is 72.5%. This is based upon the average difference between the TA and 3EPlus values for a 1.5" diameter pipe and a 6" safety relief valve flange cap. The 81.7% high temperature average deration factor is based upon the comparison of ¾" piping, a 10" gate valve, and 2.5" piping.

○ ***Analysis of Applicant Algorithm***

Repair Failed Steam Traps

While the applicant approach for calculating steam trap savings is reasonable except for the repair/replace factor, the evaluators found the applicant's multilayered approach to calculating steam trap savings to be unnecessarily complex. The repair/replace factor used by the applicant discounts savings calculated for repaired traps by 30% based on an assumption that the measure life for repaired traps is shorter than that of replaced traps. It is worthwhile to note that since the savings for this project were reported, a revised version of the custom express tool has been adopted by the PAs which no longer applies this factor to trap savings in addition to several other changes to the applicant algorithm described above.

The evaluators agreed that the various input parameters used in steam trap savings calculations (trap operating pressure, hours of operation, boiler efficiency, etc.) were reasonable.

○ ***Insulate Bare Steam Piping***

The analysis is a composite of site-specific data and performance data for the piping that provide the heat losses for the bare and uninsulated scenarios. The equation itself is a basic heat loss calculation approach which is appropriate. The annual operating hours were reduced from the initial TA estimates to account for potential system downtime, maintenance hours, and system diversity. This adjustment provided a more conservative estimate for annualized savings.

▪ **On-Site Inspection, Metering, and Analysis**

○ ***Summary of On-Site Findings***

The evaluators conducted a site visit on February 8, 2018. The installed measures were reviewed with the facility personnel. All the components and measures that were installed in Area-2 were deemed as zero savings for the remaining measure life. For the insulation measure, the identified exclusions accounted for 125 of the 408 devices in the measure or about 31% of the total. The tracking calculation temperatures, operating hours, and steam pressures for the remaining areas were discussed with facility operators, and since there was no operation in those closed areas changes were made to the analysis.

The same discussion and review were conducted during the July 24, 2018 logger retrieval site visit. The insulation measure device list was reviewed again during the second site visit. Facility personnel estimated that an additional 29 devices or about 7% of the 408 insulation measure devices had been removed from service. This brings the total devices shutdown to 154 (38%) out of 408 installed jackets.

Individual components and branches may have been removed from service in the remaining areas (Area-1), but those were difficult to identify in the documentation. Facility personnel estimate that about 40% of the steam components have either been completely or partly closed since the measures were installed.

Insulating jacket installations were observed in the field during the walk through. Evaluation verified a sample of 4 dozen insulation jackets in various areas during the site visit. This was not expanded to the entire population of the jackets because with no steam running through the affected areas, evaluation assumed zero savings for those, even with the jackets installed.

During the initial site visit 15 of the 25 repaired or replaced traps were in the Area-2. Six of the 10 operational repaired steam traps were identified and were shot with a thermal thermometer to gauge operation. These traps were in the main boiler room (3) and in the primary care mechanical room (3). All 6 inspected traps were fully operational. Three Hobo loggers were installed to verify line temperatures. The loggers monitored high and low temperature lines in the main boiler room, condensate and steam lines in the field, and supply lines to two areas that were taken offline.

Boiler operation was discussed with central heating plant operators. They estimated that winter peak operating efficiency is 84.5%. Average summer efficiency drops to an average of 82.0% due to oversizing of boilers to the minimum summer loads. The contacts also stated that the hospital had a significant non-heating baseload, with condensate recovery over 95%, and that the system was well maintained, and steam trap maintenance was a high priority for them. They also said that there was heat recovery from blowdown and from the stack. During the visit, these efficiencies couldn't be verified. Therefore, evaluation used the same 75% (total) efficiency that was used in tracking analysis.

- ***Measured Data***

Evaluators took temperature spot measurements on piping of six steam traps before and after the steam traps. The traps were located in the main boiler room and in the primary care mechanical room. Facility personnel believed that these were the best representatives for longest remaining operation. The residual heat on both sides of the earliest measured traps indicate a differential that is consistent with an operating trap. The results are found in the Table 4-24 below.

Table 4-24: Steam Trap Survey Findings

Tag #	Application	Steam Pressure at Trap (psig)	Orifice Size (in)	Temp 1 (°F)	Temp 2 (°F)
83268	Drip Leg	100	3/32	341	322
83269	Drip Leg	100	5/32	347	323
171792	Drip Leg	100	3/32	335	320
83310	Drip Leg	10	7/32	244	229
83312	Drip Leg	100	3/32	345	325
83315	Drip Leg	10	7/32	248	237

- Two lines that feed areas of the facility that are closed were monitored. Over the 166-day monitoring period average temperatures were 71°F and 80°F. No temperature >100°F was monitored. This provides verification that the identified lines and areas are not in service.
- Over the same 166-day period, the high-pressure steam line in the main boiler room had an average temperature of 338°F. A condensate line average temperature was 147°F. Two low pressure steam lines recorded average temperatures of 207°F and 248°F.

- **Evaluation Methods, Findings, and Results**

○ ***Evaluation Description of Baseline***

Based on the project files and discussions with facility personnel, the evaluator determined that the identified devices were uninsulated prior to the measure. They also confirmed that the steam trap repair/replace list was consistent with their recollection. Boiler operators were maintaining the same steam pressures as baseline conditions. Operating schedules have not changed in the parts of the facility that were still open.

○ ***Evaluator Calculation Methodology***

2.3.2.1 Repair Failed Steam Traps

The evaluated savings for this site were calculated using the newly revised Custom Express tool with input parameters observed in the field. At the onset of the steam trap site work for this larger evaluation effort, the decision was made to calculate the realization rate by comparing the evaluated steam trap savings with savings calculated using the new Custom Express methodology with applicant baseline data. This was done because the realization rate will be applied prospectively, and future projects will use the new steam trap tool to calculate savings.

Evaluated savings. A revised version of the custom express tool was adopted by the PAs following the completion of the Phase 2 Steam Trap Evaluation[11] completed in March 2017. The intent of revising this tool was to develop a more consistent methodology for calculating steam trap savings, which involved a combination of methodological simplifications to the approach in addition to the empirical derivation of relatively unknown parameters used to calculate savings. The custom savings equation developed through the referenced study has been adopted by the evaluators and is described below.

$$Svgs = \left(60 \times \frac{\pi}{4} D^2 \times (P + 14.7)^{0.97}\right) \times \frac{LF \times C_D \times (h_g - h_f) \times CR \times Hours}{100{,}000 \times \eta}$$

where,

$Svgs$ = Annual energy savings per year (therms)

60 = Empirically derived factor in Grashof equation ($lb_m/(in^{0.06}\text{-}lb^{0.97}\text{-}hr)$)

D = Diameter of steam trap orifice (inches)

P = Pressure of steam in line at trap (psig); add 14.7 to get psia

0.97 = Empirically derived factor in Grashof equation

LF = Leak factor is determined through field testing and accounts for partially obstructed orifices or non-ideal steam flow. Plugged traps use a value of 0% (i.e. no savings result from fixing a plugged trap), leaking traps use a value of 26% and blowing by traps use a value of 55%

C_D = Discharge coefficient (70%) due to trap hole not being a perfect orifice

h_g, h_f = Enthalpy of saturated steam and liquid, respectively; associated with specified trap operating pressure (Btu/lb)

[11] http://ma-eeac.org/wordpress/wp-content/uploads/Steam-Trap-Evaluation-Phase-II.pdf

CR = Condensate return factor accounting for energy returned from leaking/blowing by traps via a condensate return line. (36.3%)

$Hours$ = Hours per year that a trap is pressurized and operating

$100{,}000$ = Therms per Btu conversion

η = Boiler plant efficiency

The evaluators used the revised custom savings equation along with a collection of original and revised input parameters to calculate savings. The evaluators used the same trap orifice sizes and operating pressure used by the applicant as they were verified on site using spot checks.

A sample of 6 steam traps were inspected of the 10 remaining operational repaired steam traps. Temperatures were measured to verify upstream and downstream pipe temperatures.

The evaluators updated the operating status (leak factor) to reflect the picklist options of the revised method rather than the options from the applicant approach. This involved updating statuses like "partially leaking" and "partially blowing by" to "leaking" and "blowing by", respectively, based on guidance from the Phase 2 study results. With these updated statuses, the evaluators applied the revised leak factors to the custom savings equation.

Comparison with old methodology. Based on their on-site findings, the evaluators changed the old method calculator to reflect the evaluator's observed parameters without modifying the actual methodology. The applicant methodology updated to reflect applicant inputs yields measure level savings of 14,933 therms versus the tracking estimate with the old methodology of 21,512 therms. The primary reason why the evaluated savings are lower than the reported values is due to the difference in the inputs that were employed by the applicant and evaluator.

- ***2.3.2.2 Insulate Bare Steam Piping***

The site contact confirmed that the piping and devices listed in the tracking documentation were uninsulated prior to the program. Because a significant part of the facility was already closed, and the entire facility was scheduled for closure, an extensive field review of the insulated devices was not performed. The site visit looked at insulation installed in the main boiler room [29 devices], the tunnel off boiler room 1 [4 devices], the care center mechanical room [7 devices], and a mechanical room off the laundry [4 devices]. The identified devices matched tracking data. Observed insulation was clad 1.5" fiberglass which is consistent with the installed description. These 44 devices make up 11% of the total project and 17% of the fixtures in the area still in use.

Evaluated savings: The same spreadsheet used to generate the tracking savings was used for the evaluation. The tracking hours, heat loss values, and deration factors were retained.

$$THERMSannual = \sum[((MMBTUHbare - MMBTUHinsulated)\left(\frac{Original\ Operating\ hours}{Revised\ Operating\ hours}\right)) * Deration\ Factor * 10]$$

Where:

$THERMS_{annual}$ = Therms of natural gas saved per year

$MMBTUH_{bare}$ = Heat loss per square foot of uninsulated device per year

$MMBTUH_{insulated}$ = Heat loss per square foot of insulated device per year

10 = Conversion factor to MMBTUh to Therms

○ ***Annualized Measure Life Savings***

Due to the uncertainty in the building use of the future, the evaluation used a conservative approach of calculating the measure life savings for two measures and then annualized the therms savings based on the actual life of used and unused areas. Per RI TRM, the measure lives are 6 and 13 years for steam trap and insulation respectively. 100% of the installed measures were operating for 2 years, therefore the evaluation considers full savings for 2 years and partial savings for remaining life of the measure.

<u>Steam Traps:</u>

Only 10 out 25 steam traps have full life of 6 years (Area-1), the remaining 15 steam traps had 2 years of life (Area-2).

Therefore: (new tool)

Steam Trap Measure life savings = 2*10,416 Therms + 6*4,517 therms = 47,934 therms

Steam trap annual savings = 47,934/6 = **7,989 therms**; RR = 53%

<u>Insulation:</u>

254 jackets out 408 will have full life of 13 years (Area-1), the remaining 154 had only 2 years of life (Area-2).

Therefore,

Insulation measure life savings = 13*44,863 therms + 2*20,824 Therms = 624,867 therms

Insulation annual savings = 624,867/13= **48,067 therms**; RR = 73%

Total Annual savings = 7,989 + 48,067 therms = 56,056 Therms; RR = 70%

▪ **Final Results**

The project consisted of the repair of broken steam traps and the installation of 1.5" fiberglass insulation with vinyl cladding on bare steam piping and devices.

The applicant calculated savings for the steam trap measure using the custom express screening tool with inputs provided from the results of a recently completed steam trap survey.

The evaluators calculated savings for the steam trap measure using a revised version of the custom express savings equation along with additional information gathered during the site visit.

For the steam piping insulation measure the evaluators used the applicant spreadsheet to estimate savings. Annual operating hours for the areas removed from service identified during the site visits were reduced to zero.

The evaluated savings for the project is less than the reported values. The parameters impacting the analysis are summarized in Table 4-25.

Table 4-25: Summary of Key Parameters

Baseline	Applicant	Evaluator

Steam traps measure	25 leaking steam traps	10 leaking steam traps
Uninsulated device quantity	408	254
Uninsulated device Ft^2	2,391	2,391
As-Built	**Applicant**	**Evaluator**
Steam traps measure	25 repaired steam traps	10 repaired steam traps in areas currently operating
Insulated device quantity	408	254 in areas currently operating
Insulated device Ft^2	2,391	1,529 in areas currently operating
Savings	**Applicant**	**Evaluator**
Annual natural gas savings (therms)	80,620	56,056
Natural gas realization rate	70%	

- **Recommendations for Program Designers & Implementers**

There are no recommendations.

- **Explanation of Deviations**

The closing of the facility and incremental shutdown of the steam systems is the primary reason for the deviation in savings. This reduces the annual operation to zero hours for these systems and devices. Steam pressures and bare/insulated heat loss values remain unchanged.

Table 3-2 provides a summary of the key factors and deviations.

Table 3-2. Summary of Key Factors and Deviations

Factor	Applicant	Evaluator	Impact of Deviation	Discussion of Deviations
Change in number of operating repaired steam traps	25	10	-37%	**Decreased savings** – Reduces the number of devices operating
Change in number of operating insulated steam piping and devices – Quantity	408	254	-27%	**Decreased savings –** Reduces the number of insulated devices

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○ **Project Summary and Results**

The project was implemented in an office building at a biotechnology facility and consisted of the installation of EMS HVAC controls software. The HVAC system serves an office building divided into

North and South sections, each measuring 18,000 square feet. The measure saves energy by adding a night time set back to reduce air flow to both sides of the building.

The evaluator verified the installation of the EMS controls, collected information on the boiler and AHU systems as well as EMS trending data, and updated the savings analysis model accordingly. **Table 4-3** presents the gas savings for this measure.

Table 26: Savings

Measure ID	Measure Name		Gas Savings (Therms/yr)
6735010	EMS Controls	Tracked	14,983
		Evaluated	8,204
		RR[1]	55%
Totals		**Tracked**	**14,983**
		Evaluated	**8,204**
		RR[1]	**55%**

[1]Realization rate

- **Explanation of Deviations from Tracking**

The evaluated savings are 45% less than the applicant-reported savings. Several errors were identified and corrected in the applicant's calculations which had to do with misplaced parentheses, swapping the order of the outdoor air temperature and the discharge air temperature, the use of outdoor air temperature rather than mixed-air temperature in the heating load calculation, and the use of a constant VAV box discharge temperature of 70° F, rather than a more typical VAV box discharge air temperature that varies with the building's heating load. Additionally, the evaluation team made other adjustments to the calculations, such as eliminating the step used by the applicant of filtering out a handful of CFM and amp data points that fell below expected, and using the utility motor supply voltage (480), rather than the motor nameplate supply voltage (460). The evaluation team also incorporated a longer post-data collection period, which has an increasing effect on the savings estimate, due to the evaluation post-data set showing lower unoccupied CFM rates than the applicant's post-data set. Further details regarding deviations from the tracked savings are presented in Section 3-3.

○ **Evaluated Measures**

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

▪ **Application Information and Analysis**

This section describes the information and analysis provided by the applicant.

▪ **Applicant Description of Baseline**

The applicant baseline condition for this project assumed the same air flow in both sections of the office building even when the building was not occupied. The pre-retrofit system operated continuously at the same flow rate because the facility was occupied 24 hours per day, 7 days per week and had no set-back controls.

There are supply and return fans that supply equal space areas of 18,000 square feet in the North and South sections of the office building. The VAV boxes were set to maintain the same air flow, regardless of building occupancy. Outdoor air was controlled based on an outdoor air temperature (OAT) of 55˚F, where the damper was closed above the temperature set point and open below that set point. The hourly CFM values did not decrease at night in the pre-retrofit condition, and so were not considered separately from occupied schedule operation. **Table 4-4** presents the pre-retrofit parameters and assumptions used in the tracked savings calculations. These averages represent only the night time setback data points for the two weeks during which the new EMS controls were trialed in September 2016.

Table 27: Pre-retrofit Key Parameters

	PRE-RETROFIT		
Parameter	**Value(s)**	**Source of Parameter Value**	**Note**
Relative Humidity (RH)	45%	TA study	Assumption from previous study at this facility
Boiler Efficiency	80%	TA study	Assumption from previous study at this facility
Reheat Discharge Temp	70˚F	TA study	Assumption from previous study at this facility
Fan Motor Efficiency	93%	TA study	Assumption
Fan Supply Voltage	460	TA study	Assumption
Power Factor	0.9	TA study	Assumption
Supply CFM (South Section)	14,752.9	TA study	Customer EMS averaged value

Supply CFM (North Section)	14,806.1	TA study	Customer EMS averaged value
Return CFM (South Section)	10,487.7	TA study	Customer EMS averaged value
Return CFM (North Section)	10,954.9	TA study	Customer EMS averaged value
Supply Fan Amperage (South Section)	28.8	TA study	Customer EMS averaged value
Supply Fan Amperage (North Section)	28.2	TA study	Customer EMS averaged value
Return Fan Amperage (South Section)	8.6	TA study	Customer EMS averaged value
Return Fan Amperage (North Section)	8.1	TA study	Customer EMS averaged value
Return Air Above 55˚F (South)	72.12	TA study	Customer EMS averaged value
Return Air Below 55˚F (South)	58.48	TA study	Customer EMS averaged value
Return Air Above 55˚F (North)	71.56	TA study	Customer EMS averaged value
Return Air Below 55˚F (North)	58.79	TA study	Customer EMS averaged value
DB Mid-Point ˚F	7,9,11…83 ˚F	TA study	Outdoor Dry Bulb Mid-Point values

- **Applicant Description of Installed Equipment and Operation**

The applicant as-built configuration for the EMS controls measure consisted of a software implementation to set back the supply and return fans at 52% when not occupied and sets the duct static high limit to 1.5 in wc. The site contact is not aware of a pre-retrofit high limit for the duct static pressure. All VAV boxes are set to a minimum position from the hours of 9 PM to 6 AM. The occupancy schedules for the office building are 6 AM to 9 PM Monday through Sunday. These controls effectively reduce fan usage, cooling, heating and reheating energy, which consequently reduces gas consumption.

- **Applicant Energy Savings Algorithm**

Bin analysis for Providence temperature data was used to estimate the savings for this measure. Table 3 shows assumptions consistent with other studies at the facility in 2014. The purpose of the table is to show discharge air temperatures at various outside air temperatures. Using the least squares method, the Discharge Air Temperature (DAT) table values act as the known Y-values and the OAT values act as known X-values. Each dry bulb (DB) midpoint value, referenced in Table 2, acts as the new X value. With these three known values, the new discharge air temperature can then be determined.

Table 28: Bin Data Linear Analysis Parameters per the TA analysis

Discharge Air Temp Reset	
OAT (F)	**DAT at Air Handler (F)**
80	55
65	65
55	55
0	68

The AHU uses discharged return air via a mixing box with return air to help reheat the fresh air from the dampers and lessen the heating load on the system. The OAT set point is 55°F. The system damper is closed above this temperature with no heating to the building and open when the OAT dropped below the set point. Each section of the office building has identical conditions, and so the following set of calculations considers only the South section of the building.

The tracked saving combines reheat savings and heating load savings. Reheat savings rates in terms of therms/hr for each temperature bin are calculated by the applicant as follows:

$$Reheat\ Savings\left(\frac{Therms}{hr}\right) = \frac{1.08\ \cdot \left(T_{rehea}\ - T_{discharge}\right) \cdot Q_{savings}}{\eta_{boiler} \cdot 100{,}000}$$

Where:

$$1.08 = 0.24\frac{Btu}{lb\ {}^{\circ}F} \cdot 0.075\frac{lb}{ft^3} \cdot \frac{60\ min}{hr} = \ heat\ capacity\ \cdot\ dry\ air\ density \cdot 60\ min/hr$$

$T_{discharge} = Discharge\ air\ temperature\ after\ reheat\ element({}^{\circ}F), as\ calculated\ in\ Table\ 3\ description$

$T_{rehe}\ \ = Discharge\ air\ temperature\ after\ AHU\ cooling\ coil = 70\ {}^{\circ}F$

$Q_{savings} = Airflow\ savings\ during\ unoccupied\ periods\ , (\frac{ft^3}{min})$

$\eta_{boiler} = Boiler\ efficiency = 80\%$

$100{,}000 = conversion\ constant, 100{,}000\frac{Btu}{therm}$

The total reheat savings are then calculated and totaled across all outdoor air temperature bins as follows:

$$Reheat\ savings\ (therms) = \sum_{Hour\ _{Unocc} = MinOAT}^{Hour\ _{Unocc} = MaxOAT} Reheat\ Savings\ \cdot Hours_{Unocc}$$

Where:

$$Hours_{unocc} = hours\ in\ each\ temperautre\ bin, which\ sum\ to\ 9\frac{hrs}{day}\cdot 365\frac{days}{yr} = 3{,}285\frac{hrs}{year}$$

$$MinOAT\ = Lowest\ temperature\ bin = 7^{\circ}\ F$$

$$MaxOAT\ = Highest\ temperature\ bin\ = 83^{\circ}\ F$$

The dry bulb temperature from outdoor weather bin data is placed into one of three discharge air temperature reset bins (Table 3) each with fixed assumptions based on a previous 2014 National Grid study at this facility. The supply CFM savings during unoccupied hours is calculated as:

$$Supply\ CFM\ Savings = Baseline\ Supply\ Avg\ CFM\ - Proposed\ Supply\ Avg\ CFM$$

Pre-retrofit Supply Avg. CFM is averaged from occupied and unoccupied hourly data directly from the BMS from Jan 2015 - Dec 2015, which is shown below in Figure 1.

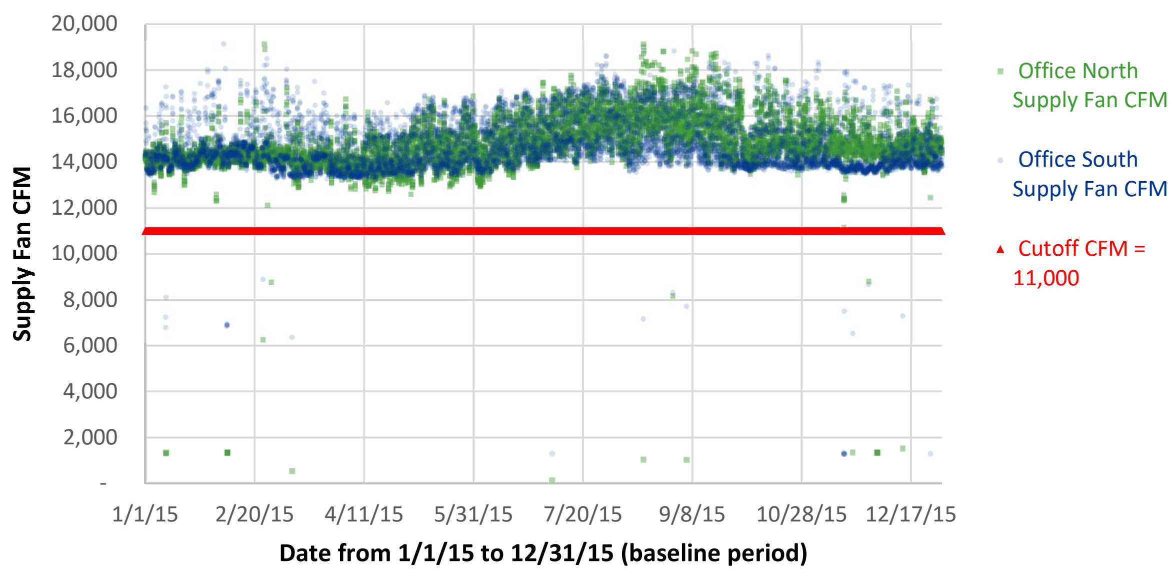

Figure 1. *Baseline Supply Fan CFM for North and South AHUs Showing No Unoccupied Setback*

The tracking analyst also set a minimum CFM value of 11,000 to eliminate outliers from the data used to calculate the average baseline flowrates. There are 47 out of 17,492 points below this cutoff CFM value (0.27%) so not including this parameter has a negligible effect on the final savings estimates (< 0.1%).

Proposed Supply Avg. CFM is averaged from a two-week testing period in September 2016 after the new HVAC controls were implemented; only data during the setback hours from 9 PM to 6 AM was used in this calculation. Heating savings rates in terms of therms/hr for each temperature bin is calculated by the applicant as follows

$$Heating\ Savings\left(\frac{\text{therms}}{hr}\right) = \frac{(T_{OA}\ -\ T_{DA}) * 1.08 * \left(Q_{savings}\ (CFM) - Fan\ Heat\ \left(\frac{BTU}{\text{hr}}\right)\right)}{Boiler\ Eff * 100{,}000\,\frac{BTU}{therm}}$$

Where:

$T_{OA} = Outdoor\ air\ temperature\ (^{\circ}F), midpoint\ of\ particular\ bin$

$T_{DA} = Discharge\ air\ temperature\ after\ heating\ coil = 70\ ^{\circ}F$

$Fan\ Heat = Heat\ added\ to\ air\ by\ fan, see\ calculation\ below$

$Q_{savings} = Airflow\ savings\ during\ unoccupied\ periods\ , (\frac{ft^3}{min})$

$\eta_{boiler} = Boiler\ efficiency = 80\%$

$100{,}000 = conversion\ constant, 100{,}000\,\frac{Btu}{therm}$

$1.08 = 0.24\,\frac{Btu}{lb\ ^{\circ}F} \cdot 0.075\,\frac{lb}{ft^3} \cdot \frac{60\ min}{hr}\ =\ heat\ capacity\ \cdot\ dry\ air\ density \cdot 60\ min/hr$

Where:

$Fan\ Heat\ \left(\frac{BTU}{\text{h}}\right) = Fan\ Power\ Savings\ (KW) * 3412\,\frac{BTU/\text{h}}{kW}$

Where:

$$Fan\ Power\ Savings\ (kW) = \frac{(Amps_{Baseline} - Amps_{Proposed})\ * Volts *\ \sqrt{3} * Power\ Factor}{\eta_{motor} \cdot 1000\,\frac{Watts}{kW}}$$

Where:

$Amps_{Baseline} = Average\ of\ measured\ baseline\ amps\ of\ supply\ fan\ motors$

$Amps_{Proposed} = Average\ of\ measured\ proposed\ amps\ of\ supply\ fan\ motors$

$Volts = Nameplate\ motor\ voltage = 460\ ^{\circ}F$

$\sqrt{3} = Factor\ for\ three\ phase\ power\ calculation$

$Power\ Factor = 0.9\ , stipulated\ by\ TA$

$\eta_{motor} = Motor\ efficiency = 93\%, stipulated\ by\ TA$

The total heating savings are then calculated and totaled across all outdoor air temperature bins as follows:

$$Heating\ savings\ (therms) = \sum_{Hours_{Unocc}= MinOAT}^{Hours_{Unocc}= ChangeOverT} Heating\ Load\ \cdot Hours_{Unocc}$$

Where:

$Hours_{unocc} = hours\ in\ each\ temperautre\ bin, which\ sum\ to\ 9\,\frac{hrs}{day} \cdot 365\,\frac{days}{yr} = 3{,}285\,\frac{hrs}{year}$

$MinOAT\ = Lowest\ temperature\ bin = 7^\circ F$

$ChangeOverTemp\ = Outdoor\ temperature\ at\ which\ heating\ is\ enabled\ = 55^\circ F$

If the outdoor air dry bulb temperature is less than changeover temperature , then heating load is calculated as follows.

$$Heating\ Load\ \left(\frac{Therms}{Hour}\right) = \frac{\left(Dry\ Bulb\ Mid\ Point\ (°F)\ -\ Discharge\ Air\ (DAT\ °F)\right) * 1.08 * \left(Supply\ CFM\ Savings\ (CFM) - Fan\ Heat\ \left(\frac{BTU}{\text{h}}\right)\right)}{Boiler\ Eff * 100000\frac{BTU}{therm}}$$

The formula for *Heating Load* (therms/hr) is inaccurate, as the units do not match in the airflow portion of the calculation (BTU/hr and CFM inside the parenthesis above). Additionally, the applicant's algorithm subtracts the discharge air temperature from the outdoor air temperature to calculate the instantaneous heating load, rather that subtracting the outdoor air temperature from the discharge air temperature, which would be the correct way to calculate the heating load if the air-handler had to heat 100% outdoor air. However, these air-handlers are not 100% outside air units, and instead mix outdoor air with return air, which reduces the total amount of heat required at the AHU coil. Rather than outdoor air temperature, the applicant's algorithm should have used mixed air temperature. The evaluator has made the proper changes to the forumla as shown in Section 2.3.2.

Pre-retrofit amperage is an averaged conditional value directly from hourly customer trend data from January through December 2015. If the office supply fan CFM meets the minimum threshold (11,000 CFM) to eliminate any outliers, then it is included as an amperage point and averaged across the year.

Proposed Avg. Amps is an averaged value directly from the two-week testing period of customer data for night setback hours only, following the implementation of the HVAC controls. Figure 2 below shows that the setbacks were working during the applicant's post monitoring period, and that the flow rates decreased from around 15,000 CFM to around 9,000 CFM during the nine unoccupied hours between 9:00 PM and 6:00 AM.

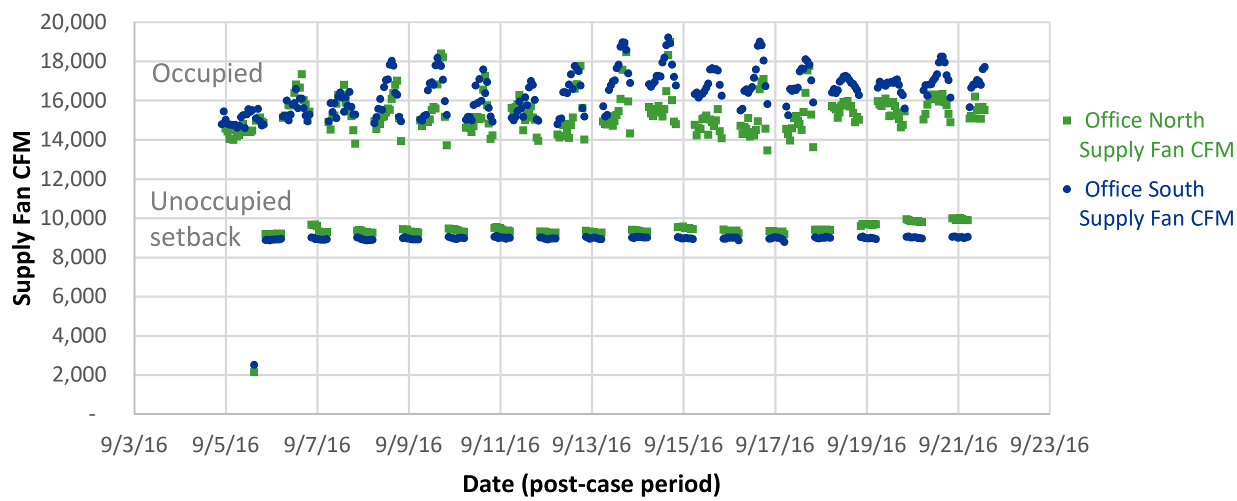

Figure 2. *Post-Case Supply Fan CFM for North and South AHUs Showing Unoccupied Setback*

▪ Analysis of Applicant Algorithm

The applicant algorithm for calculating savings is reasonable with the following exceptions:

- Heating load calculation containing a parenthesis placement error. Within the same set of parentheses, fan heat was improperly subtracted from ventilation airflow. This order of operations error in the tracking calculation leads to a reduction in savings. While it is important to subtract fan heat from heating load savings equation, this must be done correctly in the appropriate units throughout the calculation.
- Heating load calculation error due to incorrect temperature differential calculation. The applicant calculated the heating load by subtracting discharge air temperature from outdoor air temperature, rather than the other way around. This resulted in a positive number in the applicant's analysis coincidentally only because of the parentheses placement error described in the first bullet above. Correcting for the parentheses placement without correcting the temperature differential error results in the negative heating savings and does not accurately reflect what is physically happening with the system. The applicant used the temperature differential between outdoor air temperature and the discharge air temperature after the AHU's heating coil, to calculate the heating savings at the AHU heating coil, rather than the temperature differential between the mixed air temperature and the AHU discharge air temperature. Using the outdoor air temperature, as the applicant did, assumes a 100% outdoor unit, which is not the case.
- The applicant's algorithm calculated the reheat savings by taking the temperature differential between the temperature leaving the air handler before entering the VAV box, and the average reheat temperature leaving the VAV box, where the temperature leaving the VAV box is set at a constant value of 70°F, which is based on a reference to a 2014 study done at the facility. The temperature leaving a VAV box depends on the instantaneous heating or cooling

loads for a zone, and although the annual average discharge air temperature from a VAV box may be close to 70°, this temperature is going to be different during different times of the year (higher during colder months, and lower during warmer months).

- The applicant's algorithm interpolated between four sets of OAT and DAT temperatures, to develop the discharge air temperature from the AHUs as a function of the OAT (see Table 3 above). The evaluator found the average DAT for each 2° F temperature bin between 6°F and 64° F based on post-installation customer data collected between 12/1/17 and 4/12/18, which provides a more granular and accurate DAT as a function of OAT for use in the bin calculation. For temperatures above 64°, (where DAT is only used in the reheat savings calculation, not the heating savings calculation), the evaluator estimated the DAT using a linear relationship between OAT and DAT for the other temperatures.
- The applicant's calculation approach filtered out 0.27% of the baseline CFM and amp data points, for the hours during which the EMS trending system showed that the CFM usage was below 11,000, indicating outlier behavior. These data points were included in the evaluation team's methodology, since they reflect actual distribution of values. A plot of the data also shows outliers on the high end, so removing the outliers solely from the low-side does not appear to be the most accurate approach. Overall, this adjustment had a negligible effect on the end-result due to the very small number of points that met this criterion.
- The applicant's calculation approach estimated the baseline average unoccupied CFM usage by taking the average CFM usage during both the occupied and unoccupied periods. The evaluator's updated approach estimated the baseline average unoccupied CFM usage by only incorporating baseline data from unoccupied hours.
- The applicant used the motor nominal voltage of 460, rather than the utility nominal supply voltage of 480 associated with this 460 motor voltage[12].
- The applicant used outdoor air temperature sensor data from their building automation system (BAS), whereas the evaluator chose to use outdoor air temperature data from the nearest airport (T.F. Green, PVD). Although the applicant's use of outdoor air temperature data from their BAS instead of outdoor air temperature data from the airport sensor data behind the Typical Meteorological Year (TMY) data upon which the energy savings were annualized had a minimal impact on the savings estimate overall (1%), the evaluator chose to use the airport data due to finding that the average discrepancy between the BAS data and the PVD airport data was about five times larger than the average discrepancies between the PVD airport data, and the temperature data at the next nearest distance from the site (Quonset State Aiport, OQU).

The evaluation team believes that the applicant EMS data is reliable and paints a clear picture of EMS night time setbacks regarding supply CFM values and amperages.

[12] See the following website for additional information on this common error that occurs when estimating motor power demand: http://romtecutilities.com/faq/why-is-the-motor-nameplate-voltage-rating-460v-when-the-utility-supply-voltage-is-480v/ Additional information related to the distinction between nominal utility supply voltage and nominal motor voltage can be found through a web search on the topic of 480 vs. 460 volts.

The evaluator agreed that the various other input parameters used in the bin analysis (outside air temperatures, discharge air temperatures, dry bulb mid-point temperatures) are reasonable.

- **On-Site Inspection, Metering, and Analysis**

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

- **Summary of On-Site Findings**

The evaluators conducted a meeting with the site contact on February 7, 2018, to describe the preliminary metering plan for the evaluation. The evaluation team was not permitted to enter any part of the biotechnology facility, due to custom proprietary data confidentiality concerns and was prohibited from using external electrical contractors.

The site contact did allow the team to observe the industrial boilers, which were confirmed to be operating at approximately 80% efficiency based on review of nameplate information. Each section (North and South) of the building contains VAV boxes for each area/room to control room temperature through VAV box reheat coils. The basic configuration is shown in Figure 3.

It was also confirmed that no changes to the building or BMS system, nor any energy savings measures, have been implemented since the installation of the EMS controls.

The site contact verified that the project work was completed and discussed the project history with the evaluators. The primary reason for the implementation of EMS night setback controls is due to the removal of a third shift at the facility. As previously mentioned, the facility previously operated 24 hours per day, 7 days per week. In the post-retrofit condition, the site contact confirmed there are now unoccupied hours from 9 PM to 6 AM every day.

The evaluators also gathered more information on the general operation of the boilers and AHUs. The boilers have risers that extend up to the respective AHUs, which are located on the roof. The outside air comes in and mixes with return air from the conditioned space in a mixing box before it is again sent through the heating and cooling cools back into the supply fan of the AHU. The air-handler discharge air temperature, mixed air temperature, return air temperature and outside air temperature sensor locations are presented in Figure 3 below to further clarify the tracking bin analysis.

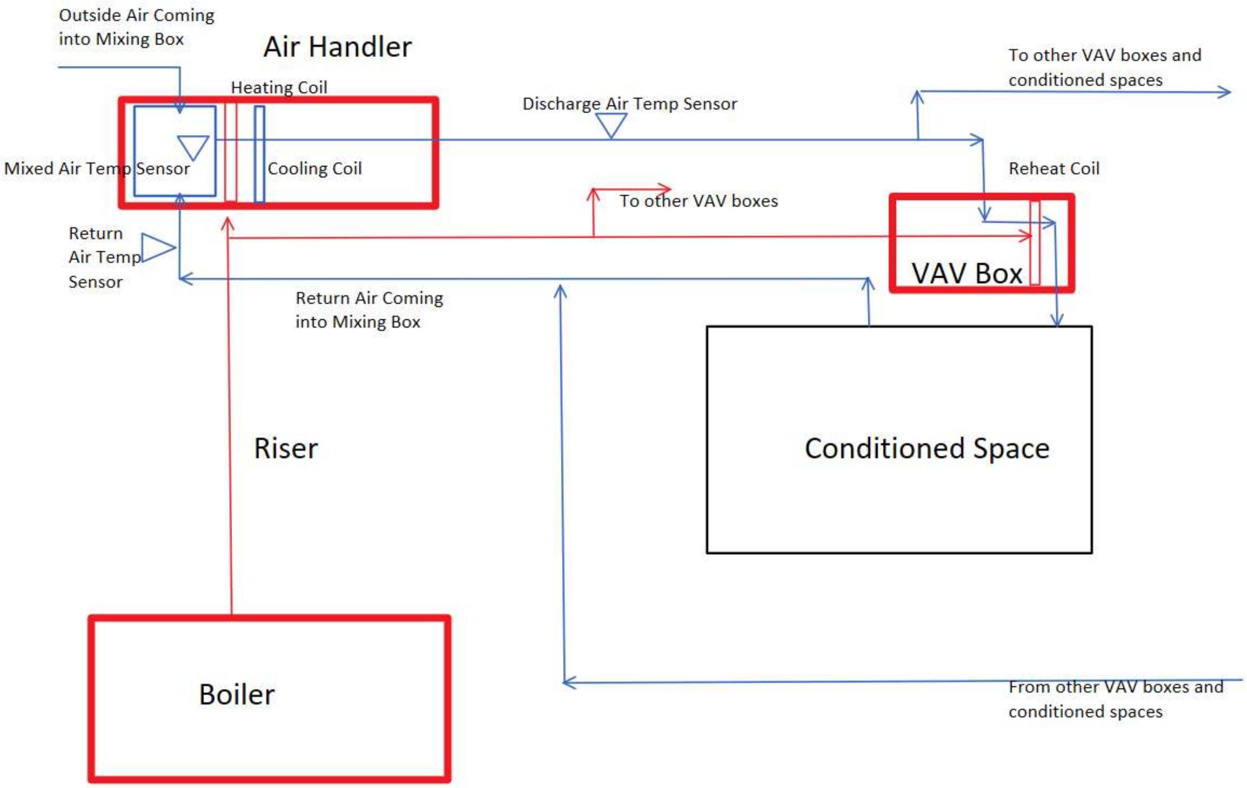

Figure 3: *Boiler and AHU Operation*

- **Evaluation Methods, Findings, and Results**

This section describes the evaluator methods, findings, and results.

- **Evaluation Description of Baseline**

Based on the project files and site visit findings, the evaluator determined the measure is an add-on with a single baseline. Through discussions with the site contact, the evaluator confirmed the baseline for the EMS controls measure is the preexisting condition. The baseline is the preexisting condition with no setback feature of the EMS controls in place and the AHUs supplying air at full flow throughout the entire year with no setback.

- **Evaluator Calculation Methodology**

The evaluator used the same methodology as was utilized by the applicant. The applicant conducted a bin temperature analysis and considered reheating and heating loads within the tracking calculations. Aside from the calculation discrepancies in mentioned in Section 2.1.4, the tracking calculation methodology is used in the final analysis.

Due to the inability to perform spot measurements or meter installations for short term monitoring, the evaluators gathered the trending EMS data points presented in Table 4-7.

Table 29: Evaluation Data Collection – Data Received

Source	**Parameter**	**Interval**	**Duration**
EMS Trending Data	Supply CFM	1-hour interval	12/1/17-4/12/18
EMS Trending Data	Supply Fan Amperage	1-hour interval	12/1/17-4/12/18
EMS Trending Data	Mixed Air Temperature	1-hour interval	12/1/17-4/12/18
EMS Trending Data	Return Air Temperature	1-hour interval	12/1/17-4/12/18
EMS Trending Data	Discharge Air Temperature	1-hour interval	12/1/17-4/12/18
EMS Trending Data	Outdoor Dry Bulb Air Temperature	1-hour interval	12/1/17-4/12/18
AR7 Office Building	Floor Plan Schematic	NA	NA
Site Contact	Occupancy Schedules	1-hour interval	
AR7 Office Building Gas Sub-meter	Therms usage for the building	Monthly	12 months

The evaluated savings for the EMS controls utilize the tracking methodology calculations as presented in Section 2.1.3. The discrepancy in the heating load formula is addressed with the following formula, where T_{OA} is replaced with T_{MA}, where T_{MA} is the mixed air temperature:

$$Heating\ Savings\left(\frac{\text{therms}}{hr}\right) = \frac{\left[(T_{MA} - T_{DA}) * 1.08\left(\frac{BTU * min}{ft^3 * {}^\circ F * \text{hr}}\right) \cdot Q_{savings}\ (CFM)\right] - \left[Fan\ Heat\ \left(\frac{BTU}{\text{hr}}\right)\right]}{\eta_{boiler} * 100{,}000\frac{BTU}{therm}}$$

The evaluated savings for the EMS controls measure using the method described above resulted in annual energy savings of 8,204 therms, yielding a measure level realization rate of 55%.

The evaluators also deemed the assumptions of boiler efficiency, motor efficiency, and motor power factor as reasonable and therefore used them in the final analysis. The motor supply voltage of 460 used by the applicant was updated in the evaluator's approach to 480, which is a more accurate characterization of the voltage supplied to the motor. The evaluators used EMS trending data from December 2017 through April 2018 in the final analysis. Because this post-retrofit dataset contains the same data points as the dataset used in the applicant tracking methodology, the evaluators were able to confidently compare the baseline condition to that of the post-retrofit condition. This data is also consistent with occupancy schedules, temperature setpoints and AHU supply and return fan operational values.

○ **Final Results**

The project consisted of the installation of EMS controls in the North and South sections of an office building. The applicant calculated savings for the measure using the vendor's spreadsheet analysis model.

The evaluators calculated savings for the measure using the same approach used by the applicant, but with the following differences:

- Subtract fan heat separately from the supply CFM values in the heating load algorithm
- Use mixed air temperature rather than outdoor air temperature in the heating load calculation
- Use VAV box reheat discharge air temperatures that vary with heating load, rather than a single VAV box reheat temperature of 70°
- Use utility supply voltage of 480 volts for fan heat calculation, rather than motor nameplate value of 460
- Inclusive of the full data range for the unoccupied hours for calculation of post-case unoccupied average CFM, rather than excluding some outliers
- Use longer duration (132 days instead of 15 days) of post-installation CFM data, which shows lower unoccupied CFM values than applicant's calculations (~7,000 CFM instead of ~9,000)
- Use of outdoor air temperature data from the nearest airport weather station, instead of the temperature sensor that is part of the customer's building automation system.

The evaluated savings for the project are less than the reported values. The parameters impacting the analysis are summarized in **Table 4-9**. The major discrepancies are primarily due to adjustments to the algorithms themselves, rather than the values used in the algorithms, as indicated in Section 3.3.

Table 30: Summary of Key Parameters

Baseline	**Applicant**	**Evaluator**
EMS Controls Measure	AHUs maintain constant air flow in both sections of office building 24/7 throughout entire year regardless of occupancy. Total average baseline unoccupied CFM	AHUs maintain constant air flow in both sections of office building 24/7 throughout entire year regardless of occupancy Total average baseline unoccupied CFM =
As-Built	**Applicant**	**Evaluator**
EMS Controls Measure	Night time setbacks are applied to AHUs, reducing supply and return fans to 52%, VAV boxes set to minimum positions from 9 PM to 6 AM Total average as-built unoccupied CFM = 18,406	Night time setbacks are applied to AHUs, reducing supply and return fans to 52%, VAV boxes set to minimum positions from 9 PM to 6 AM Total average as-built unoccupied CFM = 14,839
Savings		
Annual natural gas savings (therms)	14,983	8,204

Natural gas realization rate	55%

- **Recommendations for Program Designers & Implementers**

The evaluators believe the post-installation trended EMS data provided an accurate representation of the EMS night time setback controls. The evaluation team recommends that in the future, for building load calculations, that applicants use the mixed air temperature when appropriate, rather than outdoor temperature, and that the heating algorithms which account for fan heat are correct. The evaluation team also recommends that for motor power calculations that rely on nameplate information rather than measured values, the nameplate utility supply voltage be used. This is often seen in calculations involving the common 460-volt motor, which operate at 480 volts. Additionally, the evaluation team recommends including all data points when generating an average value used in an analysis, and in cases where excluding outliers is warranted, the evaluation team recommends that the applicant include a description of the rationale and impact of excluding outliers in a calculation workbook.

- **Customer Alert**

There are no customer requests at this time.

- **Explanation of Deviations**

Table 4-10 provides a summary of the key factors and deviations. The primary differences between the applicant and evaluator savings are due to updates to the calculation algorithm, as well as other differences outlined below.

Table 31: Summary of Key Factors and Deviations

Factor	Applicant	Evaluator	Impact of Deviation	Discussion of Deviations
Tracked savings	14,983 therms	14,983 therms	No impact	**No impact** – Tracked savings were consistent with the application.
Difference in heating load calculation algorithm	Subtracted fan heat from supply CFM with incorrect order of operations, and calculated heat load as a function of (discharge air temp - outdoor air temp).	Subtracted fan heat separately from CFM values, and calculated heat load as a function of (outdoor air temp - discharge air temp).	-24%	**Decreased savings** – The correct order of operations in the evaluator's calculation proved to be a significant impact, ensured proper units in the final answer (therms/hour)
Difference in treatment of outlier data points	Calculates baseline CFM and amp data after excluding hours where CFM < 11,000. This represents 0.27% of records.	Calculates baseline CFM and amp data including all hours, including hours where CFM < 11,000	-0.5%	**Decreased savings** – The inclusion of the few outlier baseline points with lower CFM values reduces the CFM savings, resulting in marginally fewer savings overall.
Difference in calculation of baseline CFM rates and amp data.	Calculates baseline CFM and amp draws from both occupied an unoccupied time periods.	Calculates baseline CFM and amp draws solely during unoccupied periods.	-9%	**Decreased savings** – The baseline occupied CFM is approximately 6% higher than the baseline unoccupied CFM, and the occupied amperage is 2% higher than unoccupied amperage, so including the occupied CFM and amperage in the baseline overestimates savings.

Factor	Applicant	Evaluator	Impact of Deviation	Discussion of Deviations
Difference of voltage being used in motor power calculation (for fan heat correction)	Uses motor nameplate of 460 volts.	Uses utility nominal value of 480 volts.	-0.3%	**Decreased savings** – A higher motor voltage results in an overall larger motor power draw for the baseline and post-case fan power. This results in additional heat being added to the air stream, requiring less heat from the boiler in both the base case and the post case, resulting in slightly lower savings.
Difference in post-data collection timeframe	Post data spans 9/5/16 - 9/21/16, average post CFM during unocc times = 9,000 CFM, average post amps = 23	Post data spans 12/1/2017 - 4/12/18, average post CFM during unocc times = 7,000 CFM, average post amps = 25	40%	**Increased savings -** The additional post unoccupied supply fan CFM and amperage data increased savings, primarily because of the lower post-case CFM data (~7,000 CFM), as opposed to the applicant's findings from their three weeks of post monitoring (~9,000 CFM). Increased savings occur from the increased flow reduction.
Difference in heating load calculation algorithm	Heating load = 1.08 · CFM · (Outdoor Air Temp - AHU Discharge Air Temp)	Heating load = 1.08 · CFM · (Mixed Air Temp - AHU Discharge Air Temp)	-56%	**Decreased savings -** The applicant's heating savings algorithm overestimated savings, because it did not consider the energy being recovered by mixing the return air with the outdoor air before being heated by the heating coil at the air handler, and instead assumed that the AHU was a 100% outdoor-air unit.

Factor	Applicant	Evaluator	Impact of Deviation	Discussion of Deviations
Difference in reheat load calculation algorithm	Reheat load = 1.08 · CFM · (AHU Discharge Air Temp - VAV Discharge Air Temp) Where VAV Discharge Air Temp = 70° for all hours	Reheat load = 1.08 · CFM · (AHU Discharge Air Temp - VAV Discharge Air Temp) Where, VAV Discharge Air Temp = (Return Air Temp + 15) at minimum Outdoor Air Temp, and = (Return Air Temp) at Building Balance Point Temp of 55°, and linear interpolated for points between minimum Outdoor Air Temp and 55°.	27%	**Increased savings -** The applicant's reheat savings algorithm underestimated savings, because it used a constant discharge air temperature of 70° after the VAV box, rather than a more typical discharge air-temperature value that varies between room temperature and room temperature plus 15 °F during the heating season.
Difference in outdoor air temperature data source	Outdoor air temperature data during evaluation monitoring period is from building automation system (BAS). TMY outdoor air temperature for performing savings annualization is from T.F. Green Airport (PVD)	Outdoor air temperature data during evaluation monitoring period is T.F. Green Airport (PVD). TMY outdoor air temperature for performing savings annualization is from T.F. Green Airport (PVD)	1%	**Increased savings** - The use of the T.F. Green Airport (PVD) outdoor air temperature data in place of the data from the customer's outdoor air temperature sensor within their buidling automation system (BAS) increased savings by 1%.

2016RIN032 & 52

1.1 Project Description

These energy measures were completed in a high school in the Providence area. The facility is broken into two sections served by separate boilers, East and West Plants, with a total of 186,000 sqft in the facility. Each plant has a separate account, hence two applications. The system provides space heating to the building through a radiant heated water system and is supplied by two boilers at each plant. Both the applications are identical but the difference in savings is due to size of the buildings that they are serving. The west plant serves 86,000 sqft, and the east plant serves 100,000 sqft.

The measure installed a new heat timer at the boilers to regulate the temperature of supply water for space heating (140-180°F, based on the outside temperature). In pre-retrofit condition the supply water temperature is reported to have run at a constant temperature of 180°F without regard to outside air conditions, resulting in overheated spaces, and did not schedule unoccupied setback temperatures. The new system regulates a valve to combine the outlet boiler temperature water with a return water line that bypasses the boilers to achieve the set temperature regulated by the outside air reset controller. Therefore, savings are achieved by reducing the amount of cycles the boiler is placed in standby and reheated to provide heat to the system by operating the boiler at a lower capacity over longer periods of time. Additional savings are achieved by reducing over-heated spaces. Setpoints for the building were changed from a constant 68°F to an occupied setpoint of 70°F and unoccupied of 60°F. Table 32 below shows the tracking and evaluated gas savings of the measures and the realization rates of the measures.

Table 32: Project Results

App ID	Savings Quantity	Tracking Estimate	Evaluation Estimate	Realization Rate
2016RIN0032/6342135	West Plant Annual Savings	2,206	0	0%
2016RIN0052/6342134	East Plant Annual Savings	3,386	2,977	87.9%

1.2 Tracking Savings

The TA used a weather bin-analysis with unverifiable weather data[13] to calculate annual savings. The retrofitted control measure monitors the outside air temperature and reduces gas consumption by lowering the supply water maximum temperature for space heating. The reset controls will reduce the supply water temperature by mixing a percentage of return water to provide the optimal heat necessary to heat the space and reduce overheating scenarios. Boilers run at the maximum design temperature of 180°F when the outside air temperature is less than 0°F and full supply temperature is provided to the space. As the temperature rises outside, the boiler can provide lower outlet temperatures to adequately heat the served spaces.

1.2.1 Pre-retrofit Condition

There are two hydronic boilers installed to provide hot water for a radiant space heating system. The boilers run at a constant outlet temperature of 180°F. Documentation shows the boilers are capable of 160°F setback for hotter winter months, but the boilers were never setback. Due to the constant

[13] Tracking Weather Source not verified. Heating & Cooling Design Day verified as Providence, RI. Evaluation to use TMY3 in 8,760-hour analysis.

temperature, the boilers output higher temperature water than necessary and overheat some spaces during hotter winter months. Table 2 shows the pre-retrofit parameters used in the tracking savings calculations

Table 33: Pre-retrofit condition Key Parameters

PRE-RETROFIT			
Parameter	**Value(s)**	**Source of Parameter Value**	**Note**
Boiler Seasonal Efficiency	70%	TA Assumption	
Building Set Temperature	68°F	TA Assumption	No Setbacks when unoccupied
Historical Temperature Data	Bins	Weather Data	Not verifiable

1.2.2 Post-Retrofit Condition

The post-retrofit boiler operation involves a new controller for the boiler outlet temperature programmed with a linear setback based on the outside air temperature. In the binning analysis of the TA, the max supply water temperature reached is 180°F when the OAT is coldest and the minimum supply water temperature before shut-off at 70°F OAT is 135°F.

Table 34: Post-retrofit Key Parameters

POST-RETROFIT			
Parameter	**Value(s)**	**Source of Parameter Value**	**Note**
OA temperature ranges	Low Set point: 0°F High Set point: 70°F	TA analysis	Boiler locked out when OA>70°F;
Hydronic Loop Temperature ranges	Low Set point: 180°F High Set point: 133°F	TA analysis	Loop temperature =180 °F when OA temperature is below 0°F.
Occupied Heating Set point	Pre-= 68 °F Post-= 70 °F	TA analysis	
Unoccupied Heating Set point	Pre-= 68 °F Post-= 60°F	TA analysis	
Heating Design Temperature	10.8°F	TA analysis	The lower temperature bound that 99% of total hours in a year have a higher average

			temperature. (This value is from 2005 ASHRAE Fundamentals. 2013 ASHRAE Fundamentals – Providence, RI is 12.9˚F)

1.2.3 Tracking Calculation Methodology

For ease of understanding, all the calculations below are for one bin at the West Plant. The methodology is the same for East plant but with a different square footage and building heat load.

The tracking estimated savings start with a bin analysis of an undetermined location's temperature data (5˚F increments). Heating Design temperature matches values Providence, RI, however, the bin data does not match Providence TMY3 data. Hydronic Loop temperatures were calculated using a slope from the temperature assumptions in Table 34 and a linear regression analysis of the bin temperatures.

Hydronic Circulating Temperature, the supply water temperature, is regulated based on the outside air temperature through the outside air reset controller. The supply water temperature linear equation is based on two points, 60˚F OAT returns 140˚F supply water temperature and 0ºF OAT returns 180˚F supply water temperature. The maximum temperature is reached at 0ºF and maintained for temperatures below 0ºF. The outlet temperature is increased by 3.33ºF for every bin (5˚F increments) until reaching the limit of 133˚F boiler temperature. The radiant heat system is shut off at 70ºF.

The Pre-retrofit Heat Load is the sum of the heat loads while the building is occupied and unoccupied and accounts for boiler efficiency. Both values are calculated using the same method only changing the number of hours for either condition. The Heat Load equation is the ratio between the set point temperature of the space/bin midpoint temperature and the set point temperature of the space/heating design temperature. The ratio accounts for lower heating needs during high outside air temperatures and higher heating needs during low outside air temperatures.

Table 35: Tracking Calculations

Variable Name	Example Variable Value	Verification Result
Regression Analysis Binning Range	67.5˚F (±2.5˚F)	
Hydronic Circulating Temperature	135 ˚F	$Bin\ Midpoint * \left(\frac{Min\ Boiler\ Outlet\ Temp - Maximum\ Boiler\ Outlet\ Temp}{Outside\ Air\ @\ Min\ Boiler\ Temp - Outs\quad Air\ @\ Max\ Boiler\ Temp}\right) + Max\ Boiler\ Outlet\ Temp\ = 67.5\left(\frac{140-180}{60-0}\right) + 180$
Total Occupied Heat Load for Binning Range	20.85 therms	$\frac{(\text{Occupied Existing Heat Setpoint °F} - \text{Bin Temperature Midpoint °F})}{\text{Occupied Existing Heat Setpoint °F} - \text{Heating Design Temperature °F}}) * \left(\text{Heat load}\frac{\text{Btu}}{\text{hr}}\right) * (\frac{Occ\ hours}{100000\ \frac{BTU}{therm}}) * \frac{1}{Seasonal\ Eff}$

		$=(68\ ^{\circ}\mathrm{F} - 67.5\ ^{\circ}\mathrm{F}) * \frac{\left(888{,}215\frac{\mathrm{Btu}}{\mathrm{hr}}\right)}{68\ ^{\circ}\mathrm{F} - 10.8\ ^{\circ}\mathrm{F}} * \left(\frac{188\ Occupied\ Hours}{100000\ \frac{BTU}{therm}}\right) * \frac{1}{0.70}$
Total Unoccupied Heat Load for Binning Range	62.00 therms	$\left(\frac{\text{Unoccupied Existing Heat Setpoint }^{\circ}\mathrm{F} - \text{ Bin Temperature Midpoint }^{\circ}\mathrm{F}}{\text{Unoccupied Existing Heat Setpoint }^{\circ}\mathrm{F} - \text{Heating Design Temperature }^{\circ}\mathrm{F}}\right) * \left(\text{Heat load}\frac{\mathrm{Btu}}{\mathrm{hr}}\right) * \left(\frac{Unocc\ hours}{100000\ \frac{BTU}{therm}}\right) * \frac{1}{Seasonal\ Eff}$ $=(68\ ^{\circ}\mathrm{F} - 67.5\ ^{\circ}\mathrm{F}) * \frac{\left(888{,}215\frac{\mathrm{Btu}}{\mathrm{hr}}\right)}{68\ ^{\circ}\mathrm{F} - 10.8\ ^{\circ}\mathrm{F}} * \left(\frac{559\ Unoccupied\ Hours}{100000\ \frac{BTU}{therm}}\right) * \frac{1}{0.70}$
Pre-Retrofit Total Building Heat Load for Binning Range	82.85 therms	$\text{Occupied Load} + \text{Unoccupied Load} = 20.85 \text{ therms} + 62.00 \text{ therms}$
Pre-Retrofit West Plant Heat Load	882,215 btu/hr	$86{,}000 \text{ sq. ft.} * 10.3280 \frac{btu/_{hr}}{sqft} = 882{,}215 \text{ btu/hr}$
Hydronic Savings Percentage	11%	$Coefficient * \left(\frac{Max\ Retrofit\ Circulating\ Temp - Bin\ Retrofit\ Circulating\ Temp}{PreRetrofit\ Max\ Setpoint - PreRetrofit\ Setback\ Temperature}\right) =$ $5\% * \left(\frac{180-135}{180-160}\right)$
Retrofit Building Heat Load	73.74 therms	$\text{PreRetrofit Heat Load} * (1 - \%\text{ Hydronic Savings})$ $= 82.85 * (1 - 0.11) \text{ therms}$
Gas Savings	9.32 therms	$\text{PreRetrofit Heat Load} * (\%\text{ Hydronic Savings}) = 82.85 * (0.11) \text{ therms}$

The Pre-Retrofit Heat Load is assumed the product between the square footage of the space served by the plant and the $^{btu}/_{hr}$ per square foot necessary to heat the space. The $^{btu}/_{hr}$ per square foot likely came from a billing analysis of historical data. The btu/hr per square foot value provided for the sample calculation from the TA is to assure the total annual building heating load is equal to the total space heating from gas (therms). For the East plant, adjustment factor = 13.63385. Source for the total heating load is shown in the TA analysis.

The % Hydronic Savings percentage regulates the amount of gas savings claimable by reducing the pre-retrofit heat building load. The percentage reduction both calculates the gas savings and post-retrofit building load. The savings are found from a percentage of the ratio between the pre- and post-retrofit setback temperatures multiplied by the required heat load within the bin.

The result is the total therms saved by switching to the new reset controller and the remaining proportion is the post-retrofit building heat load.

1.3 Project Evaluation

Metering took place from mid-February to the end of April. Main data collection was centered around boiler outlet temperatures and boiler operating hours:

Recruitment of the site was established through a phone call on 1/16/18.

The monitoring period is the winter and spring of 2018 between 2/13/18 and 4/30/18.

Table 36: Measure Verification

Measure Name	Verification Method	Verification Result
Boiler Heat Timers	Gather Outside Air Temperatures from local weather stations and compare with supply water temperature readings. Compare schedules from tracking with monitored boiler operating schedules.	Boiler Heat Timers were installed and verified on site. Upon verification of the supply water temperatures, the West plant did not vary the temperature as documented to achieve savings. East plant functions with slight differences outlined in Section 1.3.2.

1.3.1 Data Collection

The main goal of data collection is to validate the control mechanism and its ability to adjust boiler outlet temperature based on the outside air temperature. The measurable objectives are outlined in Table 37 and Table 38.

The installation of the heat timer corresponded with the cooling season in 2016. The project began in May 2016 and finished in the beginning of August 2016. Billing data was collected for the 2015-2017 annual calendars.

The East and West plant are operated by two space heating boilers each. The two boilers operated in the West plant are Weil-McLain 88 Boilers – 1388 Model with 3.27MBtu/hr capacity. The East plant boilers are H.B. Smith Co. 640 Mills Boilers with 3.78MBtu/hr capacity. The East plant boilers were adapted to operate on natural gas from fuel oil before the installation of the heat timer.

The plant boilers are operated under a lead/lag operation depending on the load and capacity of the primary boiler. In the pre-retrofit case, boilers responded to the return temperature and calls for heat from the system. In the post-retrofit case, the OAT heat timer controls boiler runtime to bring the return water temperature up to a temperature based on a linear scale of the outside air temperature. The OAT heat timer performs this operation by regulating a valve to mix return water and boiler supply water.

Loggers were placed on the boiler outlet pipes to monitor water temperature and in spaces to monitor space temperature setbacks. This data is verified and supplemented with trending data for the supply temperature, pump statuses, and mixing valve percentage. Outside air temperature is acquired from NOAA Weather Station Hourly data. Data point specifics are outline in Table 37 and Table 38.

Table 37: Evaluation Data Collection – Installed Equipment

Parameter	M&V Equipment Brand and Model	Quantity	Metering Start/Stop Dates	Metering Interval

Boiler Outlet Temperatures	HOBO Micro Station H21-002 with Temperature Probes	4	2/13/18 – 4/30/18	5 min
Space temperature	Temperature Sensors	4	2/13/18 – 4/30/18	5 min

Table 38: Received data from outside source

Parameter	Source	Metering Start/Stop Dates	Metering Interval
Constant Flow Pump Status (6 pumps)	BMS	3/23/18 – 4/30/18	15 min
Hot Water Supply Temperature	BMS	3/23/18 – 4/30/18	15 min
Percent Mixing of Boiler Outlet and Return Water	BMS	4/9/18 – 4/30/18	15 min
Outside Air Temperature	Local Weather Station	2/13/18 – 4/30/18	1 hour

1.3.2 Evaluation Savings Analysis

The evaluation team uses an 8,760-hour spreadsheet (heating season only) to calculate the savings for the project. The savings are extrapolated to the entire heating year using regression analysis. The non-monitored periods in the 8,760-hour spreadsheet during the typical heating season are filled based on the regression line calculated from monitored data points. Savings are adjusted based on correlation between real-time outside dry bulb temperature and boiler outlet temperatures.

$$Supply\ Temperature(^{O}F) = -OAT\ Regulating\ Slope * Outside\ Air\ Temperature(^{O}F) + Base\ Intercept\ (^{O}F)$$

The monitored temperature period provides an accurate estimation of the supply temperature at specific outside air temperatures as shown with the occupied supply temperature in Figure 5 for the East plant.

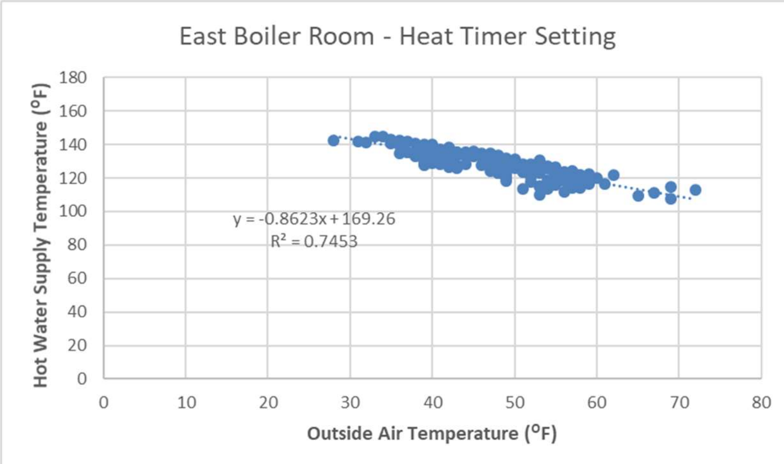

Figure 5: Evaluator Occupied East Supply Temperature in Response to OAT

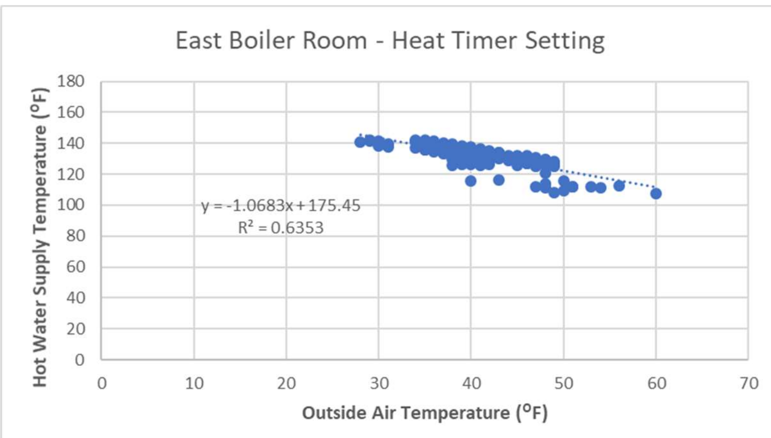

Figure 6: Evaluator Unoccupied East Supply Temperature in Response to OAT

Based on conversations with onsite personnel, evaluators found that the pre-retrofit supply temperature was a constant 160°F, in contrast to the 180°F pre-retrofit supply temperature reported in the Evaluators found the West plant does not control the supply temperature based on a mixing valve between return and boiler outlet temperatures. The OAT Heat Timer is supposed to regulate the boiler output temperature to a lower setting based on OAT. However, the data does not support the proper function of the OAT Heat Timer. The East plant has a clear drop in supply temperature when compared with the OAT and contains a few outlying points during operation of the OAT Heat Timer, Figure 5 and Figure 6. The West plant supply water temperature, as shown in Figure 7, stays constant around 160°F (the pre-retrofit supply temperature) until around 45°F OAT dry bulb. The OAT Heat Timer should begin reducing the temperature of the supply water around 32°F OAT.

After 45°F OAT, the same supply temperature of 160°F continues except with some logged values below 160°F. Metered supply temperature data combined with pump status trend data shows that the supply temperature begins to drop during operation of the heat timer because the boiler shuts off more periodically than in winter and the system logs a small drop in the supply temperature for that period.

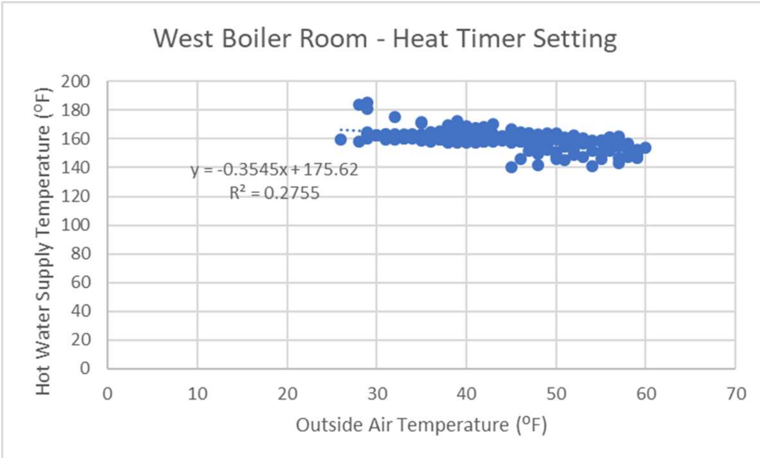

Figure 7: Evaluator West Supply Temperature in Response to OAT

Collected data comparing OAT and supply temperature for the East and West plants are found in

Table **39**. There is a clear difference between the tracking equation and the installed equation from the vendor equation programmed in the heat timer. Comparing the equations, the programmed vendor equation predicts more savings than the equation found in the evaluation by further reducing the supply temperature for warmer outside weather. The evaluation found that in the West plant, though the vendor had programmed a reset equation into the heat timer, it was not operational. Tracking equations are more conservative and would not have lowered the temperatures as aggressively as the vendor equation as the outside temperature increased.

A regression was performed on the data collected from the supply temperature and NOAA Weather Station data to determine the equation governing operation of the boiler. The two evaluation equations were determined, based on occupied and unoccupied times provided by the site technician. The equations support the programmed vendor installation equation. Occupied periods of the day increase the heating and decrease savings for the building due to occupancy setpoints listed versus unoccupied times on nights and weekends that will achieve more savings.

Table 39: East and West Plant Boiler Room OAT Regulating Equations

Source		Trendline Points (°F)	Equation
Tracking		Outside Air: 0°F, Supply: 180°F Outside Air: 60°F, Supply: 140°F	$HW\ Supply\ Temperature, °F = -0.67 * OAT, °F + 180°F$
Programmed in Heat Timer		Outside Air: 0°F, Supply: 180°F Outside Air: 70°F, Supply: 110°F	$HW\ Supply\ Temperature, °F = -OAT, °F + 180$
East Plant Evaluation	Occupied	Regression Trendline	$HW\ Supply\ Temperature, °F = -0.83 * OAT, °F + 169; R^2 = 0.75$ (0°F OAT is 169°F Supply; 60°F OAT is 119°F Supply)
	Unoccupied	Regression Trendline	$HW\ Supply\ Temperature, °F = -1.06 * OAT, °F + 175; R^2 = 0.63$ (0°F OAT is 175°F Supply; 60°F OAT is 111°F Supply)
West Plant Evaluation		Regression Trendline	$HW\ Supply\ Temperature, °F = -0.35 * OAT, °F + 175; R^2 = 0.27$ (0°F OAT is 175°F Supply; 60°F OAT is 154°F Supply)

Temperature loggers installed throughout the school verify set back temperatures for the spaces by corresponding unoccupied times with a reasonable reduction in temperature compared to set back levels. **Figure 8** and **Figure 9** show the setbacks for East and West Plant. The East plant has clearly controlled and verifiable setback temperatures. West Plant is not controlled, and setbacks do no operate properly.

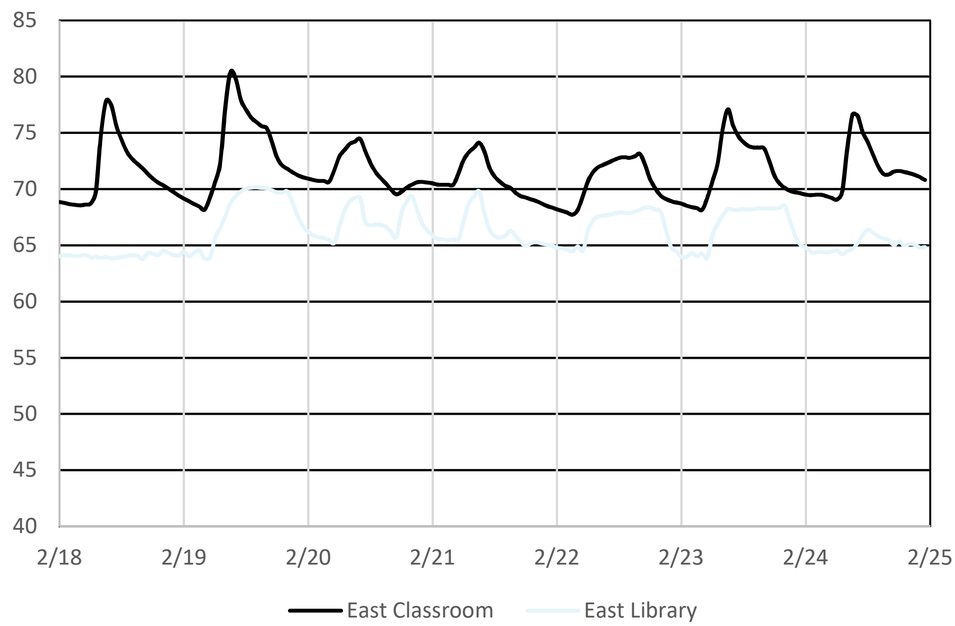

Figure 8: East Plant Typical Winter-Week Space Temperatures Demonstrating Setpoints

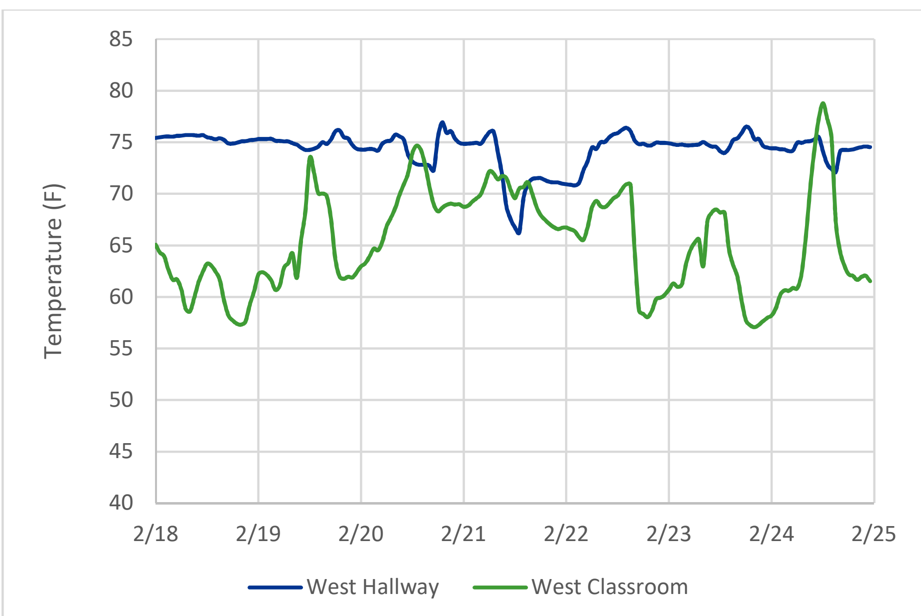

Figure 9: West Plant Typical Winter-Week Space Temperatures Demonstrating Setpoints

Energy savings are calculated using the method outlined below in Table 40. This method calculates the total therms usage by the boiler systems to heat the return water temperature to 160ºF for water needed in the mixture valve and provide the supply temperature set by the OAT Heat Timer. The boiler combustion efficiency is documented as 70% and is changed to 75% per the nameplate for the boilers.

Table 40: Step-by-step analysis approach for evaluation estimation of energy savings

Savings Formula	Equation
Return Water Temperature	$T_{return}, {}^{o}F = T_{supply}, {}^{o}F - \frac{m_{boiler\ outlet}}{m_{bypass}}, \%\ Mix * \left(T_{boiler\ outlet} - T_{supply}\right), {}^{o}F$
Average Boiler Reheat Rate	$h\ , \frac{BTU}{hr} = C_1 *\ q, \frac{gal}{min} *\ (T_{boiler\ outlet} - T_{return}), {}^{o}F$
Therm Usage	$therms =\ h, \frac{BTU}{hr} * t\ , hr * \left(\frac{1\ therm}{100{,}000\ BTU}\right)\left(\frac{1}{\varepsilon_{boiler\ eff}, \%}\right)$
Realization Rate	$RR\ (\%) = \frac{\sum 8760\ Evaluated\ PreMeasure\ Therm\ Usage - \sum 8760\ Evaluated\ PostMeasure\ Therm\ Usage}{Tracking\ Data\ Claimed\ Therm\ Savings}$

Table 41: Therms savings calculation parameters and assumptions

Parameter	Value(s)	Source of Parameter Value	Note
Heat Flow Rate Conversion Factor	$C_1 = \frac{\rho_{water}, \frac{lb_m}{ft^3} \cdot \frac{BTU}{lb_m {}^oF} \cdot 60 \frac{min}{hr}}{7.48 \frac{gal}{ft^3}}$	Unit Conversion	
Boiler Efficiency	$\varepsilon_{boiler\ eff}$	TA analysis	Boiler efficiency is the same for the East Plant boiler pairs and for the West Plant boilers.

An 8,760 model of pre-retrofit operation will follow the steps outlined above using the regressions analysis for outside air temperature and maintaining the pre-retrofit conditions, found in Figure 10 and previously discussed in Section 1.2.1. The pre-retrofit conditions are operation of the West Plant mixing valve as discussed in further sections. The realization rate is the difference between the evaluated therm usage for pre- and post-retrofit divided by the tracking claimed therm savings.

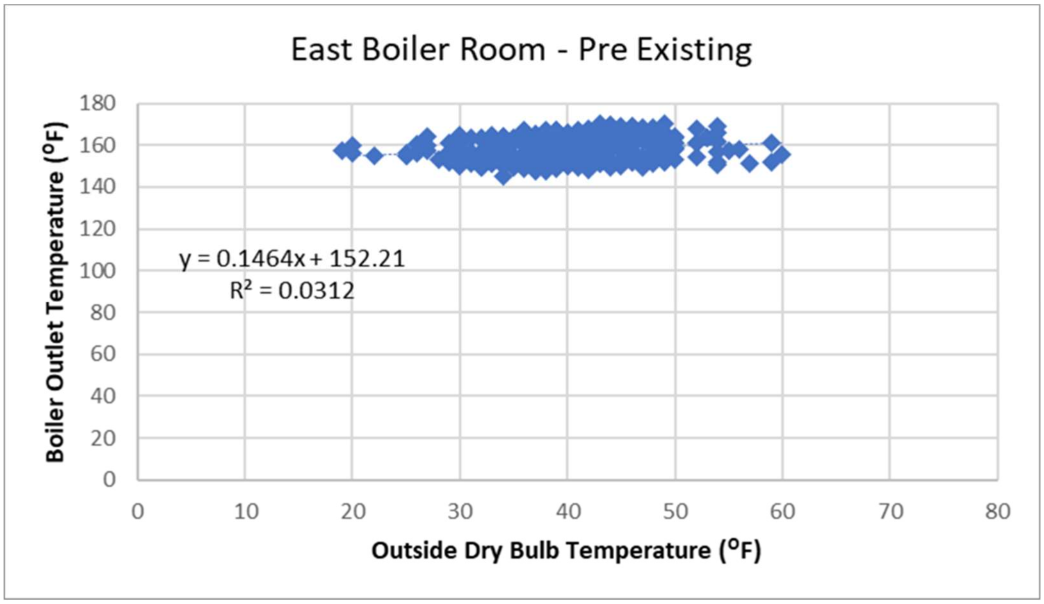

Figure 10: Regression for Pre-Retrofit Supply Temperature

A separate regression analysis calculates the temperature of return water based on supply water temperature for values not monitored during the typical heating season. This will be used to calculate boiler reheat delta temperatures.

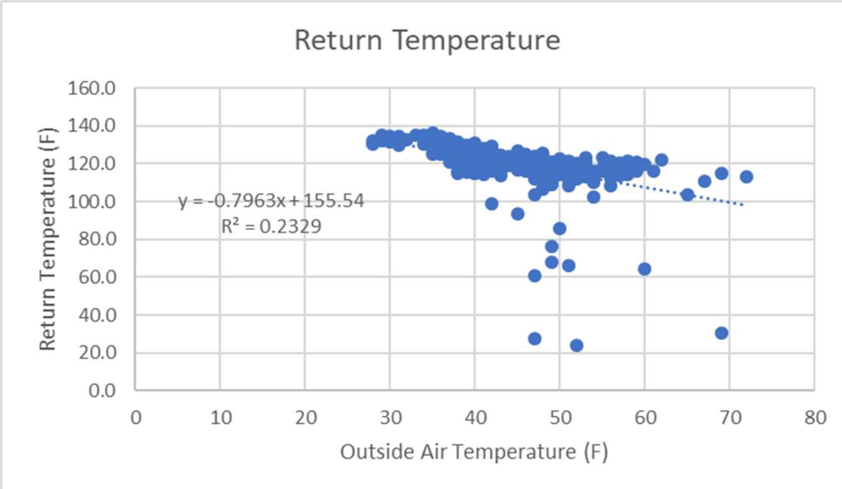

Figure 11: Evaluator Return Temperature for East Plant

The evaluation team could not monitor return water temperature due to tightly wrapped, thick white vinyl pipe cladding. The return water temperature is then found by calculating the difference between hot water supply temperature, the boiler outlet temperature, and the percent mixing of boiler heated water and return water. The average boiler reheat rate calculates the BTU/hr based on the water flow rate through the boiler, determined by the constant flow pumps and mixing valve percentage reading. This provides the total therms consumed at the specific boiler efficiency in operation. The therm usage is extrapolated to the typical heating season times based on the regression analysis for outside air temperatures and return water temperatures.

The supply temperatures for an 8760 schedule (created with TMY3) shows the savings potential of this type of measure. The supply temperatures drop during the shoulder months of the year and perform similar during cold winter months. The site contact confirmed the heating schedule runs from mid-October until mid-May. As Figure 12 shows, the largest ranges in supply temperature happens during the spring and fall months when temperatures vary greatly from day to day or during the day compared to at night.

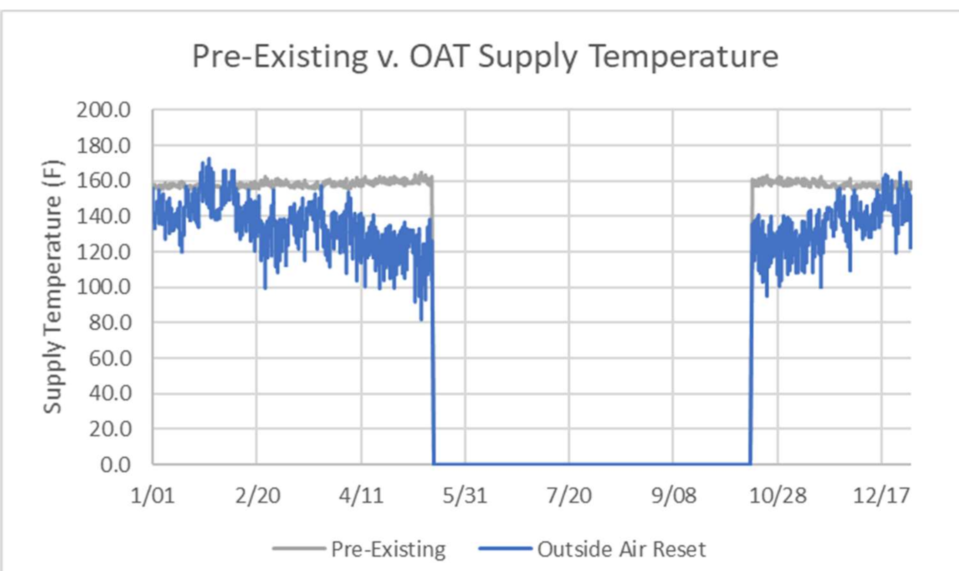

Figure 12: East 8760 Pre-Existing Supply Temperature vs. OAT Heat Timer Supply Temperature

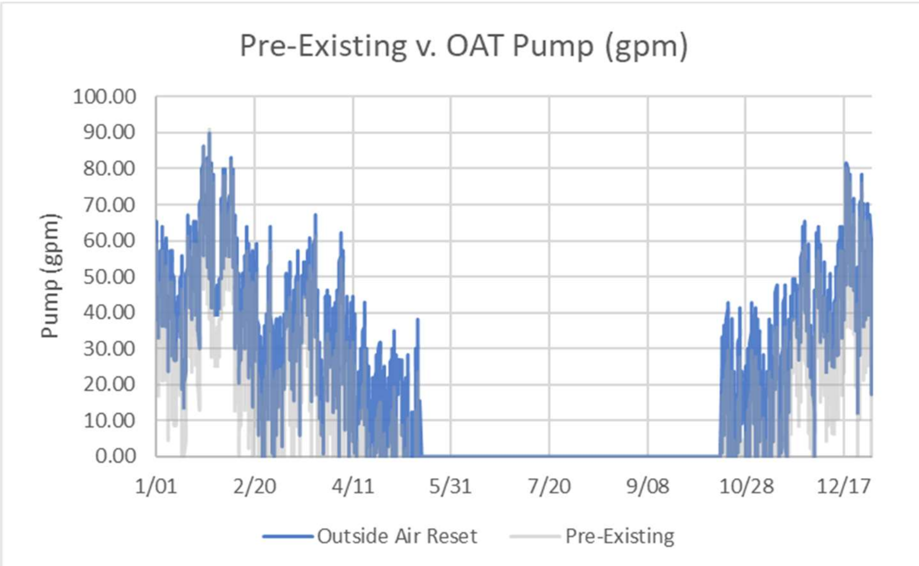

Figure 13: Mass Flow Rate Through East Plant Boiler

The therm savings calculation depends greatly on the water flow through the boiler. Figure 13 shows the pump activity for the 8760-schedule calculated from the East plant pump for the OAT Heat Reset Timer and with the West plant pump for pre-existing condition. Since the change in temperature from return and boiler outlet can vary greatly, the pumps must lower the amount of water flow through the boiler in the pre-existing operation. This is the main driver for savings as the OAT Heat Timer will run the boiler more often but reduce cycling and boiler reheat. The West plant serves as a model for pre-existing pump operation due to the higher supply temperature and serves the same envelope with similar heat loss and load.

1.4 Evaluation Results

This section summarizes the evaluation results determined in the analysis above.

The savings found in Table 42 summarize the changes from tracking to evaluation results. The West plant OAT Heat Timer is not operating and evaluated data does not support the West Plant regression equation of

Table **39**. The East plant has a realization rate of 87.9% due to reductions in savings discrepancies outlined in Section 1.4.2.

Table 42: Project Results by Measure.

Savings Quantity	2016RIN0032 West Plant Annual Savings (therms)	2016RIN0052 East Plant Annual Savings (therms)
Tracking Estimate	2,206	3,386
Evaluation Estimate	0	2,977
Realization Rate	0%	87.9%

The West plant does not reduce the supply temperature as the OAT climbs above 55ºF in a conservative estimate, and a slight trend is apparent in Figure 7 above 55ºF but the supply temperature does not drop as programmed to guarantee proper operation by the OAT Heat Timer. However, at this temperature, the savings associated with the small reduction in supply temperature does not provide enough change to validate savings in the evaluation analysis estimate and instead, the reduction in supply temperature aligns with times the boiler had cycled off. There is also a possibility the sampling of data occurred during periods that the boiler was operating and might have slightly lower supply temperatures before the boiler turned off after 55ºF. Most checks in the data have a majority of the samples of the supply temperature to occur between 157ºF - 160ºF. This operation is consistent with pre-retrofit behavior of the East plant found in Figure 10 The current operation of the West plant, therefore, does not validate enough change to provide savings from this measure.

The East plant savings were reduced by 12.1% due to actual, metered changes in operation of the OAT Heat Timer equations, change in analysis method, and updated boiler combustion nameplate efficiency.

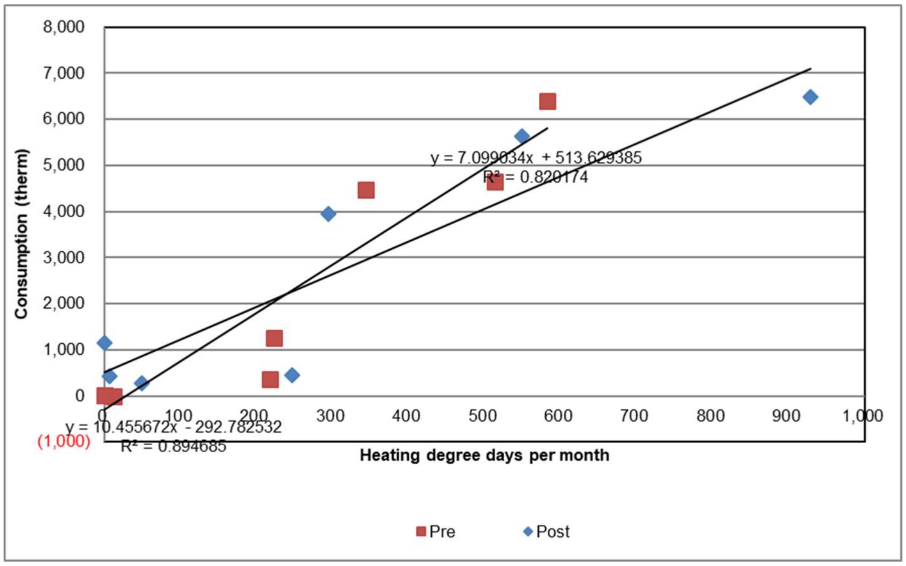

Figure 14: East Plant Billing Analysis Pre- & Post-Retrofit Normalized Trends

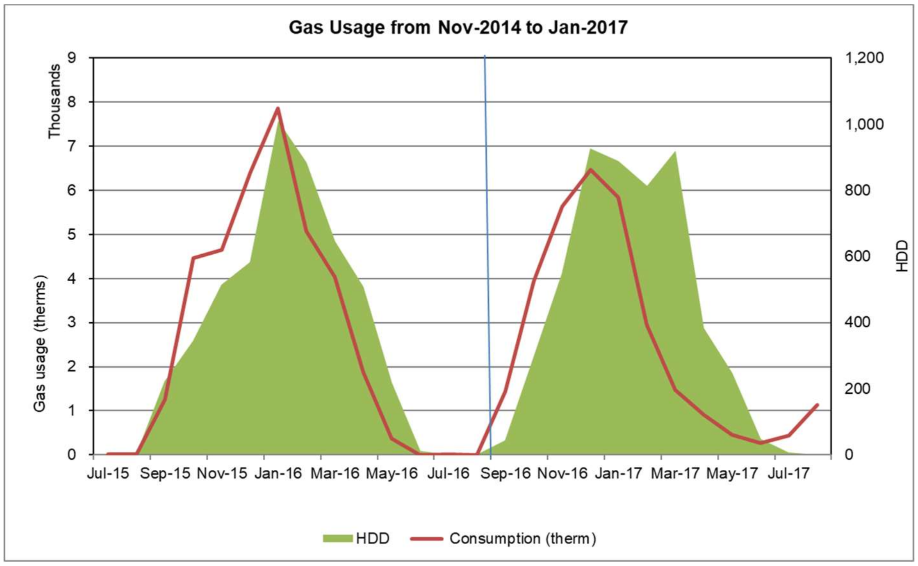

Figure 15: East Plant Billing Analysis HDD and Consumption Trends

A pre/post billing analysis was done which shows the total therms savings from the East plant at 4,803 therms. The Heating Degrees Days for March of 2017 has a large spike that may increase the total savings from the OAT Heat Timer shown in the billing data. However, the billing data shows the savings are within the same magnitude as the savings calculated from metered data. Figure 14 shows the difference in pre- and post-retrofit billing data to estimate annual savings.

The total evaluated savings are 8% of the total consumption for the year of 2016 and total billing evaluated savings are 13% of total consumption for 2016. For this site it was determined that the billing data analysis was not as reliable due to other implemented measures shown as an increase in consumption between 2016 and 2017.

1.4.1 Comparison of Assumptions

The purpose of this table is to show how different values changed as a result of the evaluation.

Table 43: Comparison of Key Parameters for East Plant

	PRE-RETROFIT		POST-RETROFIT / INSTALLED	
Parameter	Tracking Value(s)	Evaluation Value(s)	Tracking Value(s)	Evaluation Value(s)
Boiler Thermal Efficiency	70%	75%	70%	75%
Post-Supply Reset Schedule	N/A	N/A	$HW\ Supply\ Temperature, = -0.67 * OAT, °F + 180°F$	$Occupied\ HW\ Supply\ Temperature, = -0.83 * OAT, °F + 169; R^2 = 0.75$

				$Unoccupied\ HW\ Supply\ Temperatur$ $= -1.06 * OAT, °F + 175; R^2 = 0.63$
Unoccupied/Occupied Time	5pm-7am/ 7am-5pm	4pm-6am/ 6am-4pm	5pm-7am/ 7am-5pm	4pm-6am/ 6am-4pm
Unoccupied Temperature Setpoints	68	68	60	60
Occupied Temperature Setpoints	68	68	70	70
OA Temp/Boiler Outlet Temp	180ºF	160ºF	≤0ºF/180ºF; ≥60ºF/140ºF	Between 120ºF and 170ºF
Weather Data	Not Verifiable	Providence, RI	N/A	Providence, RI

Table 44: Comparison of Key Parameters for West Plant

	PRE-RETROFIT		POST-RETROFIT / INSTALLED	
Parameter	**Tracking Value(s)**	**Evaluation Value(s)**	**Tracking Value(s)**	**Evaluation Value(s)**
Boiler Thermal Efficiency	70%	75%	70%	75%
Post-Supply Reset Schedule	N/A	N/A	$HW\ Supply\ Temperature, °F = -0.67 * OAT, °F + 180°F$	Post- Supply Reset Equation Insufficient for Proper Operation
Unoccupied/Occupied Time	5pm-7am/ 7am-5pm	4pm-6am/ 6am-4pm	5pm-7am/ 7am-5pm	4pm-6am/ 6am-4pm
Unoccupied Temperature Setpoints	68	68	60	60

Occupied Temperature Setpoints	68	68	70	70
OA Temp/Supply Temp	180ºF	160ºF	≤0ºF/180ºF; ≥60ºF/140ºF	160ºF
Weather Data	Not Verifiable	Providence, RI	N/A	Providence, RI

1.4.2 Discrepancy Analysis

This section describes the **key drivers** behind any difference in the tracking and evaluation estimates of therms savings. Table 45 and 14 summarize these differences.

Table 45: Discrepancy Summary for East Plant

Parameter(s)	Discrepancy	Impact on Results
Operational Differences & Evaluation Analysis Method	Distinct regulating OAT Heat Timer Equations and savings analysis method calculates savings from heat transfer equation shifting away from heat load fraction method found in tracking analysis method.	-5.8%
Boiler Combustion Efficiency	Efficiency is taken from the boiler nameplate information	-6.3%

Table 14: Discrepancy Summary for West Plant

Parameter(s)	Discrepancy	Impact on Results
Evaluation Analysis Method	The West plant OAT Heat Timer does not operate as intended and evaluated collected data for boiler operation does not validate savings for this measure.	-100%

1.4.3 Customer Alerts

Despite confirmation from the vendor that the heat timer had been installed in both the East and West buildings, there is no evidence of any setback in the West building, while the heat timer is operating as intended in the East building. It is recommended that the customer request a return visit from the vendor to review boiler operating in the West building.

1.4.4 Improvement Opportunities

A better post installation inspection procedure could have discovered that the heat timer in the West Plant was not operating as intended. Future installations of this measure should have a formal commissioning requirement to ensure proper operation.

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- **Project Summary and Results**

This project consisted of replacing one and repairing 13 existing steam traps that had failed at a manufacturing facility. Failed traps were classified as full blow by, partial blow by, or plugged. The facility operates 24 hours, 7 days a week with no observed holidays. Steam to the system is provided on-site by two 700 PSI steam boilers. The repaired steam traps are primarily on drip leg steam lines used to discharge condensate with a negligible loss of steam.

During the site visit, the evaluator conducted a walkthrough of the facility; interviewed the site contact; verified the installation of the incentivized equipment; and tested a sample of the steam traps that were repaired or replaced using an infrared temperature gun to verify that the traps were operating correctly. Boiler combustion efficiency testing could not be performed due to facility safety procedures.

The applicant estimated the project savings using the appropriate Custom Express tool for steam traps at the time based on the steam trap survey results. Evaluators estimated the project savings by recreating the Custom Express tool, used at the time of installation, as well as through an updated Custom Express spreadsheet tool populated with the findings from the steam trap test sample results and spot measurements taken on-site.

The evaluated savings are higher than reported for both versions of the Custom Express tool because steam trap pressures and annual hours of operation were higher in some traps than estimated in the tracking savings.

The realization rate to be applied prospectively was calculated using the evaluated savings associated with the new tool compared to the tracking savings associated with the new tool; it does not account for differences between the two tools. This is because the results are applied prospectively only, and the new tool will be the only tool in use going forward.

Table 46: Savings Results

Application ID	Measure Name	Gas Savings [Therms/yr] (Old Tool)		Gas Savings [Therms/yr] (New Tool)	
6089981	Repair/Replace Failed Steam Traps	Tracked	87,573	Tracked	49,005
		Evaluated	92,369	Evaluated	50,103
		RR[1]	105%	RR[1]	102%

[1]Realization rate

- **Explanation of Deviations from Tracking**

The evaluated savings using the 2018 Custom Express tool are 102% of the tracked savings and 103% using the old Custom Express tool. The difference in savings were due to hours of operation adjustments to four steam traps and pressure adjustments made to three steam traps. The hours for the four traps were adjusted up from 8,424 hours to 8,760 based on the site visit. It is unknown why 8,424 hours were used in the applicant calculations, but the difference (336 hours) was exactly 14 days and with no holidays DNV GL assumed the difference in hours was to account for change in process heating loads.

Steam pressure for one of the traps was boosted from 75 to 650 PSI, and two of the traps were dropped from 250 to 75 PSI. The final evaluated savings for this project are being calculated using the 2018 Custom Express Steam Trap Screening Tool, while the applicant savings were calculated using the previous version of the Custom Express Steam Trap Spreadsheet.

- **Evaluated Measures**

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

The project consisted of repairing and replacing 14 failed steam traps. The purpose of steam traps is to remove condensate from the steam system. When steam traps fail open they remove both condensate and live steam from the steam system and this increases the load on the steam boilers. The following sections present the applicant and evaluator approaches for determining the gas savings resulting from repairing or replacing the failed steam traps.

- **Application Information and Analysis**

This section describes the information and analysis provided by the applicant.

- **Applicant Description of Baseline**

This measure was classified as a retrofit measure. The pre-existing condition was based on a steam trap survey conducted by a third party steam specialist. In the survey, each trap was classified as working, plugged, leaking (full or partial), or blowing by (full or partial).

The applicant used a code-compliant boiler combustion efficiency of 80% (includes 5% line losses for a system efficiency of 75%). The applicant assumes that the steam system operates at 650 psi which is the maximum steam pressure at any repaired/replaced trap. The operating hours of the central steam plant are assumed to be 8,760 because the manufacturing facility operates 24 hours, 7 days a week with no observed holidays. Steam traps repaired and replaced under this application are strictly for process and are not on any space heating elements. Although the facility operates 24/7, some steam traps are assumed to operate 8,424 hours annually, perhaps because the process heating load varies and steam control valves will cycle between open and closed to satisfy the manufacturing process.

The baseline status for each trap was established to be the operating condition identified by the vendor during the survey. The vendor survey shows that testing was conducted and identified 14 steam traps that were categorized as full blow by, partial blow by, or plugged of steam passing through their trap mechanism. **Table 47** below details the findings of the vendor steam trap survey.

Table 47: Steam Trap Survey Findings

Trap Status	No Action	Repair	Replace	Total
Fully operational	543	0	0	543
Plugged	0	1	0	1
Partial blow by	0	5	1	6
Full blow by	0	7	0	7
Total	**543**	**13**	**1**	**557**

- **Applicant Description of Installed Equipment and Operation**

The steam trap survey was conducted in April 2015 and identified 14 failed traps. The applicant's installed case for this measure assumes that all of the traps on-site are in good working condition. The trap operating pressure and hours of operation used for the as-built case matched those of the baseline configuration.

- **Applicant Energy Savings Algorithm**

The applicant used the National Grid Custom Express Screening Tool to calculate savings. The tool was developed by National Grid in 2010 and uses the findings from the steam trap survey as inputs to calculate energy savings. The tool determines energy savings by calculating theoretical steam flow through the trap orifice using the Grashof formula and then applying a number of factors to account for trap-specific and system level operating characteristics. Steam flow through the orifice for each trap is calculated using the formula below.

$$SF = 41.58 \times \pi \times \left(\frac{Diam}{2}\right)^2 \times (Pres + 14.7)^{0.97} \times LF$$

where,

SF = Estimated steam flow through trap orifice (lbs/hr)

41.58 = Grashof equation coefficient

$Diam$ = Trap orifice diameter (inches)

$Pres$ = Trap operating pressure (psig)

LF = Leak factor as determined from steam trap survey testing

Applicant steam trap savings are then calculated using various loss mechanisms that are selected based on the system configuration (for example, savings for a trap venting directly to atmosphere are calculated with a different loss mechanism than those used for a trap venting into a closed condensate return system). Since all of the traps from this project are associated with a single configuration (traps venting to a closed condensate return system), only the loss mechanisms for this configuration will be explained. Applicant steam trap savings are calculated using the following formula:

$$Svgs = \frac{TCF \times Hours}{100{,}000} \times \left(\frac{(LM_{Flash} + LM_{LatentLost})}{\eta} + LM_{Excess}\right)$$

where,

$Svgs$ = Annual energy savings per year (therms)

TCF = Total correction factor (see below)

$Hours$ = Number of hours per year the valve or fitting is energized

$100{,}000$ = Therms to Btu conversion

LM_{Flash} = Loss mechanism for flash steam savings (Btu/hr), see below

$LM_{LatentLost}$ = Loss mechanism for latent heat of trap steam not serving boiler loads (Btu/hr), see below

LM_{Excess} = Loss mechanism for excess steam in boiler cycle (Btu/hr), see below

η = Total boiler efficiency (80%) - system line losses (5%) = 75%

Total correction factor (TCF) is calculated as the product of two factors described below.

$$TCF = RRF \times PAF$$

where,

RRF = Repair/replace factor. For repaired traps, a value of 70% is applied to the savings equation while replaced traps use a value of 100%.

PAF = PA savings adjustment factor to be used by PA's engineering staff to adjust savings if needed based on system uncertainty.

The loss mechanism for flash steam savings is calculated using the formula below.

$$LM_{Flash} = SF \times \frac{(h_{f,trap} - h_{f,atm})}{(h_{g,atm} - h_{f,atm})} \times (h_{g,atm} - h_{f,cw})$$

where,

LM_{Flash} = Loss mechanism for flash steam savings (Btu/hr)

SF = Estimated steam flow through trap orifice, calculated above (lbs/hr)

$h_{f,trap}$ = Steam trap saturated liquid enthalpy, based on trap pressure (Btu/lb)

$h_{f,atm}$ = Atmospheric saturated liquid enthalpy, constant (180.07 Btu/lb)

$h_{g,atm}$ = Atmospheric saturated steam enthalpy, constant (1,150.4 Btu/lb)

$h_{f,cw}$ = City water enthalpy, constant (28.1 Btu/lb)

The loss mechanism for the latent heat of trap steam not used to serve boiler loads is calculated using the formula below.

$$LM_{LatentLost} = SF \times (h_{g,trap} - h_{f,trap}) \times Constant$$

where,

$LM_{LatentLost}$ = Loss mechanism for latent heat of steam not being used to serve boiler loads throughout facility (Btu/hr)

SF = Estimated steam flow through trap orifice, calculated above (lbs/hr)

$h_{g,trap}$ = Steam trap saturated steam enthalpy, based on trap pressure (Btu/lb)

$h_{f,trap}$ = Steam trap saturated liquid enthalpy, based on trap pressure (Btu/lb)

$Constant$ = Percent of latent heat in steam which is not returned to the steam loop in a useful manner such as heating condensate in DA tank or heating conditioned space through condensate return line. (30%)

The loss mechanism for the excess steam lost in the boiler cycle is calculated using the formula below.

$$LM_{Excess} = SF \times (h_{g,trap} - h_{f,trap}) \times (1 - \eta)$$

where,

LM_{Excess} = Loss mechanism for excess steam lost in boiler cycle (Btu/hr)

SF = Estimated steam flow through trap orifice, calculated above (lbs/hr)

$h_{g,trap}$ = Steam trap saturated steam enthalpy, based on trap pressure (Btu/lb)

$h_{f,trap}$ = Steam trap saturated liquid enthalpy, based on trap pressure (Btu/lb)

η = Total boiler efficiency, includes system line losses (75%)

- **Analysis of Applicant Algorithm**

While the applicant approach for calculating steam trap savings is reasonable with the exception of the repair/replace factor, the evaluators found the applicant’s multilayered approach to calculating steam trap savings to be unnecessarily complex. The repair/replace factor used by the applicant discounts savings calculated for repaired traps by 30% based on an assumption that the measure life for repaired traps is shorter than that of replaced traps. It is worthwhile to note that since the savings for this project were reported, a revised version of the Custom Express tool has been adopted by the PAs which no longer applies this factor to trap savings in addition to a number of other changes to the applicant algorithm described above.

The evaluators agreed that the input parameters used in the steam trap savings calculations (pipe size, orifice size, trap operating pressure, hours of operation, boiler efficiency, etc.) were reasonable assumptions, with the exception of changes discussed in section 1.1.

- **On-Site Inspection, Metering, and Analysis**

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

- **Summary of On-Site Findings**

A site visit was conducted on January 26th, 2018 to confirm that a sample of the 14 steam traps identified as needing replacement or repair in the steam trap survey were in working condition. The facility performs annual steam trap maintenance and because of that, tag numbers which would otherwise be the primary identifier in locating the traps repaired or replaced could not be found. Evaluators relied on documented trap locations, elevations, and site contact knowledge to locate the traps. A combination of visual inspection and temperature readings were used to determine if the traps operate as intended. Additionally, the key inputs to the savings calculations were confirmed as part of the site visit such as pipe size and steam pressure.

Evaluators performed a walkthrough of the facility and were able to visually inspect and record temperature measurements on seven of the 14 steam traps to make sure they were working as intended and to make sure there was no physical damage to the trap. The visual inspection was limited in usefulness because the existing traps marked as needing repair are likely internally rebuilt.

An infrared thermometer was used check the temperature of pipe entering and leaving the steam trap. Insulation on the pipes surrounding the steam traps forced measurements to be taken directly at the steam trap inlet and outlet. For working traps evaluators assumed a temperature drop of 20-30°F (depending on operating pressure) between the inlet and outlet. If the inlet and outlet temperatures are the same, the trap is likely failed open. If the entering temperature is hot and the leaving temperature is cold (temperature difference over 30°F), the trap could be failed closed. If the temperature difference is small (<10°F), the trap could be partially failed open, however, this is not conclusive. These temperatures are used as a general rule of thumb for low pressure steam applications (<15 PSI) primarily used for space conditioning. This does not necessarily apply for these high pressure process steam applications as higher inlet temperatures and pressures will naturally lead to larger temperature differentials between the inlet and outlet. In high pressure process steam applications, the evaluator first identified if there was a temperature drop. If a temperature drop occurs, it can be concluded that the trap is not failed open. In process steam applications, a failed closed steam trap would disrupt the process.

Site contact interviews led the evaluator to believe all steam traps operated 8,760 hours annually instead of some operating at 8,424 hours annually. There was no quantifiable indication of variances in operating hours based on process load, maintenance, or other factors.

The evaluator recorded steam pressure by observing pressure gauge readings on steam trap pipe lines where available. Steam lines at the site also had pressures marked on the insulation surrounding the pipe when a gauge was not present. These markings are assumed to be accurate as they are similar to measurements indicated on the tracking steam trap survey. Boiler combustion efficiency testing was not permitted by the facility due to safety protocols but boiler nameplate data was collected to determine average combustion efficiency. **Table 48** below details the traps inventoried, temperature and pressure data collected, as well as the evaluators working assessment of the trap.

Table 48: Evaluated Steam Traps

Tag #	Pipe Temperature [˚F] (Inlet/Outlet)	Trap Temperature [˚F]	Pressure [PSI]	Evaluator Assessment
221	293/238	250	75	Fully Operational
222	478/300	380	650	Fully Operational
225	185/140	159	75	Fully Operational
317	273/240	260	200	Fully Operational
909	245/217	227	145	Fully Operational
1060	354/309	320	250	Fully Operational
7451	351/296	310	250	Fully Operational

Figure 16: Repaired Drip Leg Steam Trap

It was concluded that all seven inventoried steam traps were in working condition. Based on the temperature readings, Trap #222 could be potentially plugged. The temperature difference between the inlet and outlet of this trap was 178°F which raises concern about the operability of the trap. However, the steam pressure at this trap was the highest observed on-site and because of this, the temperature drop between inlet and outlet could be greater than the lower observed pressures. In addition, the process for which the steam line served was in full operation. Based on this, the evaluator assumed this trap was in working condition. The remaining seven traps were assumed to be repaired and in working condition based on the evaluator's observed findings.

- **Evaluation Methods, Findings, and Results**

This section describes the evaluator methods, findings, and results.

- **Evaluation Description of Baseline**

Based on the project files and site visit findings, the evaluator determined the measure is an add-on with a single baseline. The baseline is the preexisting boiler plant and steam distribution system with traps in condition they were identified to be operating during the survey conducted by the applicant. While boiler efficiency was kept the same, the revised tool removes 5% line losses from the calculation, impacting the efficiency values in the calculation.

- **Evaluator Calculation Methodology**

The evaluated savings for this site were calculated using the newly revised Custom Express tool with input parameters observed in the field. At the onset of the steam trap site work for this larger evaluation effort, the decision was made to compare the evaluated steam trap savings with savings calculated using the original Custom Express methodology revised with site specific observations as well as recreating tracking and evaluated savings using the new tool.

Evaluated savings. A revised version of the Custom Express tool was adopted by the PAs following the completion of the Phase 2 Steam Trap Evaluation[14] completed in March 2017. The intent of revising this tool was to develop a more consistent methodology for calculating steam trap savings, which involved a combination of methodological simplifications to the approach in addition to the empirical derivation of relatively unknown parameters used to calculate savings. The custom savings equation developed through the referenced study has been adopted by the evaluators and is described below.

$$Svgs = \left(60 \times \frac{\pi}{4} D^2 \times (P + 14.7)^{0.97}\right) \times \frac{LF \times C_D \times (h_g - h_f) \times CR \times Hours}{100{,}000 \times \eta}$$

where,

$Svgs$ = Annual energy savings per year (therms)

60 = Empirically derived factor in Grashof equation ($lb_m/(in^{0.06}\text{-}lb^{0.97}\text{-}hr)$)

D = Diameter of steam trap orifice (inches)

P = Pressure of steam in line at trap (psig); add 14.7 to get psia

0.97 = Empirically derived factor in Grashof equation

LF = Leak factor is determined through field testing and accounts for partially obstructed orifices or non-ideal steam flow

C_D = Discharge coefficient (70%) due to trap hole not being a perfect orifice

h_g, h_f = Enthalpy of saturated steam and liquid, respectively; associated with specified trap operating pressure (Btu/lb)

CR = Condensate return factor accounting for energy returned from leaking/blowing by traps via a condensate return line. (36.3%)

$Hours$ = Hours per year that a trap is pressurized and operating

100,000 = Therms per Btu conversion

η = Boiler plant efficiency

The evaluators used the revised Custom Express savings equation along with a collection of original and revised input parameters to calculate savings. The evaluators used the same trap orifice sizes. The operating pressure and hours of operation were verified on site using spot checks and metered data and were modified as necessary. The evaluators updated the operating status (leak factor) to reflect the picklist options of the revised method rather than the options from the applicant approach. This involved updating statuses like "partially leaking" and "partially blowing by" to "leaking" and "blowing by", respectively, based on guidance from the Phase 2 study results. With these updated statuses, the evaluators applied the revised leak factors to the Custom savings equation.

The energy savings for the steam trap measure using the new methodology described above are 50,103 therms per year, yielding a measure level realization rate of 102%.

14 http://ma-eeac.org/wordpress/wp-content/uploads/Steam-Trap-Evaluation-Phase-II.pdf

Comparison with old methodology. Based on their on-site findings, the only revisions made were to the operating hours and steam pressure at the traps. The original model was updated by using the site specific findings, which yielded savings of 92,940 therms per year, a realization rate of 105%.

The new methodology yielded significantly lower savings than the old methodology in both the tracking and evaluated cases. The savings using the new methodology were only 56% and 54% of those calculated by the old methodology for the tracking and evaluated cases, respectively.

- **Final Results**

The project consisted of repairing or replacing 14 steam traps that had failed partially or fully blown open at the site. The evaluators took inlet and outlet temperature measurements on seven out of 14 steam traps to determine if the steam traps are operating properly. It was determined that all evaluated traps were in working condition. It is assumed by the evaluators that the remaining seven steam traps included in this measure are in working condition.

The applicant calculated savings for the steam trap measure using the Custom Express screening tool with inputs provided from the results of a recently completed steam trap survey.

The evaluators calculated savings for the steam trap measure using a revised version of the Custom Express savings equation along with additional information gathered during the site visit.

The evaluated savings were greater than the tracking savings both when using the old tool and the new tool. The new tool's tracked and evaluated savings were significantly lower than the values using the old tool, however. The parameters impacting the analysis using the new Custom Express savings tool are summarized in **Table 49**.

Table 49: Summary of Key Parameters

Parameter	Applicant	Evaluator
Steam Trap 109 Annual Hours of Operation	8424	8760
Steam Trap 144 Annual Hours of Operation	8424	8760
Steam Trap 225 Annual Hours of Operation	8424	8760
Steam Trap 317 Annual Hours of Operation	8424	8760
Steam Trap 7451 Annual Hours of Opeation	8424	8760
Steam Trap 221 Operating Pressure [PSI]	250	75
Steam Trap 222 Operating Pressure [PSI]	75	650
Steam Trap 225 Operating Pressure [PSI]	250	75

Table 50 compares the reported, modified applicant (old tool) and evaluated savings (new tool) for the steam trap measure. Note that the tracking savings from the new tool is significantly lower than the old tool. As detailed in Phase 2 Steam Trap Evaluation[14], methodological simplifications were made

to the revised tool in an effort to reduce the chance of field staff misinterpreting the operating status of an individual trap. These simplifications include reducing the number of variables and respective options for selected variables. In particular, the reduction of leak factor options from 4 to 2 non-zero options in the tool's pick list. Some additional changes to the calculation algorithm were made to increase savings accuracy, resulting in lower savings than in the old tool, such as eliminating 5% line losses in the new tool.

Table 50: Steam Trap Analysis Results

Gas Savings [Therms/yr] (Old Tool)		Gas Savings [Therms/yr] (New Tool)	
Tracked	87,573	Tracked	49,005
Evaluated	92,940	Evaluated	50,103
RR[1]	105%	RR[1]	102%

1.1 Cross Check with Billing Data

While sufficient utility billing data was provided to perform a billing analysis, the evaluator determined billing analysis would not provide details about the performance of the evaluated measures and the natural gas usage at the facility is too large relative to the impacts of the installed measure to observe any discernible impacts using a billing analysis. As a percentage of the post-retrofit therms, the results using the new tool and original tool account for less than 1% of the total facility consumption for both.

- **Recommendations for Program Designers & Implementers**

Calculating steam trap operating hours based on site-specific operating parameters would provide more accurate results. Providing additional tracking details with regards to steam pressure requirements for process measures would assist in evaluation efforts.

- **Customer Alert**

There are no customer requests at this time.

- **Explanation of Deviations**

The evaluated savings using both tools are more than the tracking savings because the steam pressure and steam trap operating hours were found to be greater than assumed by the applicant. These changes to the savings calculations lead to an increase in the energy savings for both models. The revised calculation tool resulted in a substantial decrease in savings over the original calculation tool. **Table 51** provides a breakdown of the change in savings due to each of the input modifications. The realization rate to be applied was calculated using the evaluated savings associated with the new tool compared to the tracking savings associated with the new tool; it does not account for differences between the two tools. This is because the results will be applied prospectively only, and the new tool will be the only tool in use going forward. As shown in the table, there was an additional 46% difference based on changing between the original calculation tool and revised calculation tool. The revision in methodology is derived from the Phase 2 Steam Trap Evaluation (MA59) effort. This decrease in savings is not reflected in the realization rates that compare only the results of the old tool together and new tool together.

Table 51: Discrepancy Summary

Factor	Applicant	Evaluator	Impact of Deviation	Discussion of Deviations
Drip Leg Steam Trap Operating Hours	4 steam traps with 8,424 operating hours	All steam traps operate 8,760 hours	3%	Five of the steam traps operated 8,424 hours each in the tracking calculations. Evaluators determined that these traps operate 8,760 hour annually.
Steam pressure at steam trap	2 steam traps at 250 PSI and 1 trap at 75 PSI	2 steam traps at 75 PSI and 1 trap at 650 PSI	2%	2 steam traps in the tracking were listed at operating at 250 PSI and 1 trap operating at 75 PSI. Evaluators observed operating pressure of 75 PSI for the two traps listed at 250, and 650 PSI for the trap listed at 75 PSI.
Difference in analysis methodology	Original calculation tool	Revised calculation tool	-46%	The evaluator used the revised calculation tool methodology to incorporate the approach generated from Phase 2 Steam Trap Evaluation (MA59) effort. This resulted in a 46% decrease in savings when comparing the results of the original calculaton tool to the rivesed calculation tool. Note these values are not shown in the realization rates comparing only the results of the old tool together and new tool together

2016RIN088

○ **Project Summary and Results**

The project was implemented at a manufacturing facility and consisted of the repair or replacement of ten failed open steam traps. The measure is expected to save energy by reducing losses associated with the facility's steam distribution system. The steam traps were on lines serving space heating, running only during the heating season.

The evaluator visited the facility, verified the operation of the steam traps via an IR gun, and collected information on typical boiler operation, and updated the savings analyses models accordingly. The evaluated savings were lower than the reported values, primarily due to fewer annual pressurized hours and one of the ten steam traps was not working.

Table 52: Savings Results

Application/Measure ID	**Measure Name**	**Gas Savings [Therms/yr] (Original Tool)**		**Gas Savings [Therms/yr] (New Tool)**	
6341835	Repair/Replace Failed Steam Traps	Tracked	1,949	Tracked	1,383
		Evaluated	1,561	Evaluated	1,106
		RR[1]	80%	RR[1]	80%

[1]Realization rate

- **Explanation of Deviations from Tracked Savings**

The evaluated savings using the revised calculation tool are 80% of the tracked savings using both the new and original calculation tool. The difference in savings between the tracked and evaluated savings using the two tools were due to two changes. 1) The annual trap hours were adjusted down from 1,700 hours to 1,486 hours for unit heaters and from 5,110 to 4,457 for the drip legs. This adjustment was made based on site's claimed balance point temperature. 2) One of the ten steam traps had failed based on the temperature readings and a non-functioning unit heater, resulting in zero savings for the steam trap.

○ **Evaluated Measures**

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

The measure implemented by the site to identify and then repair and replace failed steam traps was evaluated. The purpose of steam traps is to remove condensate from the steam system. When steam traps fail open they remove both condensate and live steam from the steam system and this increases the load on the steam boilers. The following sections present the applicant and evaluator approaches for determining the gas savings resulting from repairing or replacing the failed steam traps.

▪ **Application Information and Analysis**

This section describes the information and analysis provided by the applicant.

▪ **Applicant Description of Baseline**

The measure was classified as a retrofit. The preexisting condition was based on a steam trap survey conducted by a third party steam specialist. In the survey, each trap was classified as working, plugged, leaking (full or partial), or blowing by (full or partial).

The applicant assumed a code-compliant boiler combustion efficiency of 80% with 5% system line losses and the steam system operates at 5 psi. The operating hours of the central steam plant are assumed to be 5,110 by assuming 24/7 boiler operation during the October through April heating season. Steam traps that serve the unit heaters are assumed to operate 1,700 hours annually because the heating load varies and steam control valves will cycle between open and closed to satisfy the space temperature setpoint. This assumption was based on standards set during MA59 Phase 2 Steam Trap Evaluation and implemented in both the the original and new custom express tool.

The baseline status of each steam trap was determined by the applicant through an on-site survey of all the traps at the site. The vendor survey shows that testing was conducted and identified 11 steam traps that were categorized as full blow by, partial blow by, or plugged of steam passing through their trap mechanism. Table 2-1 below details the findings of the vendor steam trap survey.

Table 2-1 Steam Trap Survey Findings

Trap Status	Repair	Replace	No Action	Total
Fully Operational	0	0	42	42
Partial Leak	5	1	0	6
Partial Blow By	3	1	0	4
Plugged	0	1	0	1
Total	4	7	42	53

▪ **Applicant Description of Installed Equipment and Operation**

The steam trap survey conducted in 2016 identified 10 failed or partially failed open steam traps, which were replaced or repaired. The installed case assumes that all of the traps on-site are in working condition. Energy savings are only considered for the steam traps that have failed open (or defined as leaking by) as these traps waste live steam and the traps that have failed closed do not pass live steam from the steam header to the condensate line. Boiler efficiency, operating hours, and steam pressure are not impacted by this measure and match the baseline values.

- **Energy Savings Algorithms**

The applicant used the original National Grid Custom Express Screening Tool (Original Tool) to calculate the savings for repairing the failed traps. The tool was developed by National Grid in 2010 and uses the findings from the steam trap survey as inputs to calculate energy savings. The tool determines energy savings by calculating theoretical steam flow through the trap orifice using the Grashof formula and then applying a number of factors to account for trap-specific and system level operating characteristics. Steam flow through the orifice for each trap is calculated using the formula below.

$$SF = 41.58 \times \pi \times \left(\frac{Diam}{2}\right)^2 \times (Pres + 14.7)^{0.97} \times LF$$

where,

SF = Estimated steam flow through trap orifice (lbs/hr)

41.58 = Grashof equation coefficient

$Diam$ = Trap orifice diameter (inches)

$Pres$ = Trap operating pressure (psig)

LF = Leak factor as determined from steam trap survey testing

The savings are then calculated using various loss mechanisms that are selected based on the system configuration (for example, savings for a trap venting directly to atmosphere are calculated with a different loss mechanism than those used for a trap venting into a closed condensate return system). Since all of the traps from this project are associated with a single configuration (traps venting to a closed condensate return system), only the loss mechanisms for this configuration will be explained. Applicant steam trap savings are calculated using the following formula:

$$Svgs = \frac{TCF \times Hours}{100{,}000} \times \left(\frac{(LM_{Flash} + LM_{LatentLost})}{\eta} + LM_{Excess}\right)$$

where,

$Svgs$ = Annual energy savings per year (therms)

TCF = Total correction factor (see below)

$Hours$ = Number of hours per year the valve or fitting is energized

$100{,}000$ = Therms to Btu conversion

LM_{Flash} = Loss mechanism for flash steam savings (Btu/hr), see below

$LM_{LatentLost}$ = Loss mechanism for latent heat of trap steam not serving boiler loads (Btu/hr), see below

LM_{Excess} = Loss mechanism for excess steam in boiler cycle (Btu/hr), see below

η = Total boiler efficiency (80%) - system line losses (5%) = 75%

Total correction factor (TCF) is calculated as the product of two factors described below.

$$TCF = RRF \times PAF$$

where,

RRF = Repair/replace factor. For repaired traps, a value of 70% is applied to the savings equation while replaced traps use a value of 100%.

PAF = PA savings adjustment factor to be used by PA's engineering staff to adjust savings if needed based on system uncertainty.

The loss mechanism for flash steam savings is calculated using the formula below.

$$LM_{Flash} = SF \times \frac{(h_{f,trap} - h_{f,atm})}{(h_{g,atm} - h_{f,atm})} \times (h_{g,atm} - h_{f,cw})$$

where,

LM_{Flash} = Loss mechanism for flash steam savings (Btu/hr)

SF = Estimated steam flow through trap orifice, calculated above (lbs/hr)

$h_{f,trap}$ = Steam trap saturated liquid enthalpy, based on trap pressure (Btu/lb)

$h_{f,atm}$ = Atmospheric saturated liquid enthalpy, constant (180.07 Btu/lb)

$h_{g,atm}$ = Atmospheric saturated steam enthalpy, constant (1,150.4 Btu/lb)

$h_{f,cw}$ = City water enthalpy, constant (28.1 Btu/lb)

The loss mechanism for the latent heat of trap steam not used to serve boiler loads is calculated using the formula below.

$$LM_{LatentLost} = SF \times (h_{g,trap} - h_{f,trap}) \times Constant$$

where,

$LM_{LatentLost}$ = Loss mechanism for latent heat of steam not being used to serve boiler loads throughout facility (Btu/hr)

SF = Estimated steam flow through trap orifice, calculated above (lbs/hr)

$h_{g,trap}$ = Steam trap saturated steam enthalpy, based on trap pressure (Btu/lb)

$h_{f,trap}$ = Steam trap saturated liquid enthalpy, based on trap pressure (Btu/lb)

$Constant$ = Percent of latent heat in steam which is not returned to the steam loop in a useful manner such as heating condensate in DA tank or heating conditioned space through condensate return line. (30%)

The loss mechanism for the excess steam lost in the boiler cycle is calculated using the formula below.

$$LM_{Excess} = SF \times (h_{g,trap} - h_{f,trap}) \times (1 - \eta)$$

where,

LM_{Excess} = Loss mechanism for excess steam lost in boiler cycle (Btu/hr)

SF = Estimated steam flow through trap orifice, calculated above (lbs/hr)

$h_{g,trap}$ = Steam trap saturated steam enthalpy, based on trap pressure (Btu/lb)

$h_{f,trap}$ = Steam trap saturated liquid enthalpy, based on trap pressure (Btu/lb)

η = Total boiler efficiency, includes system line losses (75%)

- **Analysis of Applicant Savings Algorithms**

The evaluator agrees with the applicant calculation methodology because the Custom Express tool in use during 2016 was appropriate for this application (original tool). Note, however, the Custom Express tool has been revised and the 2018 version of the tool (revised tool) was used to determine evaluated savings.

The evaluators agreed that the input parameters used in the steam trap savings calculations (pipe size, orifice size, trap operating pressure, hours of operation, boiler efficiency, etc.) were reasonable assumptions, with the exception of changes discussed in section 1.1.

While the applicant approach for calculating steam trap savings is reasonable with the exception of the repair/replace factor, the evaluators found the applicant's multilayered approach to calculating steam trap savings to be unnecessarily complex. The repair/replace factor used by the applicant discounts savings calculated for repaired traps by 30% based on an assumption that the measure life for repaired traps is shorter than that of replaced traps. It is worthwhile to note that since the savings for this project were reported, a revised version of the Custom Express tool has been adopted by the PAs which no longer applies this factor to trap savings in addition to a number of other changes to the applicant algorithm described above.

- **On-Site Inspection and Metering**

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

- **Summary of On-Site Findings**

The evaluators conducted a site visit on February 2, 2018. The evaluator had two primary goals while on site: to verify the assumptions used by the applicant to calculate gas savings using the Custom Express tool: and, to evaluate if the steam traps that were replaced or repaired in 2016 are still operating properly.

The evaluator conducted a walkthrough of the facility to verify the installation of the steam traps. The evaluator visually confirmed seven of the ten steam traps. Three of the steam traps were inaccessible due to being too high up to verify the steam trap tags. For the three inaccessible steam traps, the documented location information was used to locate the trap. While the tag number could not be confirmed, IR temperature readings were taken for the steam traps to verify they were working.

An IR gun was used to perform temperature verification of trap operation by taking temperature readings directly at the steam trap inlet and outlet. Of the ten traps, one trap (153270) had either failed or was not repaired. Pipe size were confirmed to be correct and steam pressure was verified to be reasonable based on discussions with the site contact.

A summary of the data collected on the steam traps is shown in Table 2-2.

Table 2-2 Summary of Steam Trap Findings

Tag #	Application	Type	Evaluated Annual Trap Hours of Operation (hrs/yr)	Steam Trap Status	Repair/ Replace	Notes	Temp 1	Temp 2
140705	Unit Heater	Float & Thermostatic	1292	Plugged	Replace	Could not find this trap. 140706, -07, and -08 were found, but not this one. All steam traps in this area were visibly older and remained unreplaced	-	-
153290	Unit Heater	Float & Thermostatic	1292	Partial Blow By	Replace	Verified	180	160
153292	Drip Leg	Float & Thermostatic	3875	Partial Leak	Replace	Verified	185	165
153272	Drip Leg	Float & Thermostatic	3875	Partial Blow By	Repair	Unable to verify tag #. Attempted to find / made best guess based on trap location description.	185	165
153274	Drip Leg	Float & Thermostatic	3875	Partial Blow By	Repair	Unable to verify tag #. Attempted to find / made best guess based on trap location description. This may be connected to a faulty and disconnected unit heater.	185	165
153284	Unit Heater	Float & Thermostatic	1292	Partial Leak	Repair	Unable to verify tag #. Attempted to find / made best guess based on trap location description.	210	190
153264	Unit Heater	Float & Thermostatic	1292	Partial Leak	Replace	Verified	190	170
153266	Unit Heater	Float & Thermostatic	1292	Partial Leak	Replace	Verified	190	170
153267	Unit Heater	Float & Thermostatic	1292	Partial Leak	Replace	Verified	185	170
153268	Unit Heater	Float & Thermostatic	1292	Partial Leak	Replace	Verified	185	170
153270	Unit Heater	Float & Thermostatic	1292	Partial Blow By	Repair	Failed steam trap	165	165

Boiler combustion tests could not be performed because there was no accessible combustion testing port. Photos were taken of the boiler nameplate, but the nameplate did not indicate any efficiency value or even a model number. The manufacturer was contacted in the hopes of obtaining an efficiency value via the manufacturer serial number but was unable to provide an efficiency value. The boiler efficiency was kept at the assumed value of 80% with 5% line losses, for a system efficiency of 75%.

Per the site contact, boiler and unit heater operation is controlled by a single thermostat at the facility. All the heaters are in the same zone with an occupied and unoccupied schedule. The occupied schedule is M-F 4AM-Midnight and has a setpoint of 70F. Unoccupied hours include weekends and 12AM-4AM running at a setpoint of 66F. The site contact estimated the balance point temperature for the building is about 55F. The site contact was unable to give a definitive response as to how the balance point temperature changes between occupied and unoccupied time, but does not believe the balance point temperature would change much. He believed internal processes and occupancy should make up for the temperature differences between occupied and unoccupied setpoints. The estimated balance point temperature of 55 degrees was used to determine the operating hours for the steam traps.

There were no pressure gauges available for either the boiler or anywhere along the steam line. However, the site contact as well as two engineers verified the steam pressure at the boiler is about 10-15PSI. The PSI given is viable as the system is only used for heating. From this value, the assumed 5 PSIG steam pressure at the trap was deemed feasible.

- **Evaluation Information and Analysis**

This section describes the baseline and savings calculation methodology used by the evaluator.

- **Baseline**

The steam trap survey conducted in January 2016 identified 10 failed or partially failed open steam traps. The baseline status of each steam trap was determined by the applicant through an onsite inventory of all the traps at the site. Based on the evaluator site visit findings, the annual operating hours was adjusted lower. While boiler efficiency was kept the same, the revised tool removes 5% line losses from the calculation, impacting the efficiency values in the calculation. All other baseline values were kept consistent with the applicant baseline.

- **Energy Calculation Methodology**

The evaluated savings for this site were calculated using the newly revised Custom Express tool with input parameters observed in the field. However, at the onset of the steam trap site work for this larger evaluation effort, the decision was made to compare the evaluated steam trap savings with savings calculated using the original custom express methodology revised with site specific observations, so tracking and evaluated savings are presented for both the original and the new tool.

Evaluated savings. A revised version of the Custom Express tool was adopted by the PAs following the completion of the Phase 2 Steam Trap Evaluation[15] completed in March 2017. The intent of revising this tool was to develop a more consistent methodology for calculating steam trap savings, which involved a combination of methodological simplifications to the approach in addition to the empirical derivation of relatively unknown parameters used to calculate savings. The custom savings equation developed through the referenced study has been adopted by the evaluators and is described below.

$$Svgs = \left(60 \times \frac{\pi}{4} D^2 \times (P + 14.7)^{0.97}\right) \times \frac{LF \times C_D \times (h_g - h_f) \times CR \times Hours}{100{,}000 \times \eta}$$

where,

$Svgs$ = Annual energy savings per year (therms)

60 = Empirically derived factor in Grashof equation ($lb_m/(in^{0.06}\text{-}lb^{0.97}\text{-}hr)$)

D = Diameter of steam trap orifice (inches)

P = Pressure of steam in line at trap (psig); add 14.7 to get psia

0.97 = Empirically derived factor in Grashof equation

[15] http://ma-eeac.org/wordpress/wp-content/uploads/Steam-Trap-Evaluation-Phase-II.pdf

LF = Leak factor is determined through field testing and accounts for partially obstructed orifices or non-ideal steam flow

C_D = Discharge coefficient (70%) due to trap hole not being a perfect orifice

h_g, h_f = Enthalpy of saturated steam and liquid, respectively; associated with specified trap operating pressure (Btu/lb)

CR = Condensate return factor accounting for energy returned from leaking/blowing by traps via a condensate return line. (36.3%)

$Hours$ = Hours per year that a trap is pressurized and operating

$100{,}000$ = Therms per Btu conversion

η = Boiler plant efficiency

The evaluators used the revised Custom Express savings equation along with a collection of original and revised input parameters to calculate savings. The evaluators used the same trap orifice sizes and operating pressure used by the applicant. The evaluator updated the operating status (leak factor) to reflect the picklist options of the revised method rather than the options from the applicant approach. This involved updating statuses like "partially leaking" and "partially blowing by" to "leaking" and "blowing by", respectively, based on guidance from the Phase 2 study results. With these updated statuses, the evaluators applied the revised leak factors to the custom savings equation.

The original calculations assumed 24/7 operation throughout the heating season of October through April (5,110 hours). Standard practice used in the MA59 Phase 2 Steam Trap evaluation as well as the revised custom express tool assumes the steam line will remain pressurized ~1/3 of the heating season, or 1,700 hours for the unit heater steam traps. The evaluator modified the system operating hours based on the site findings. TMY3 data from October through April and a 55F balance point temperature was used to determine the typical annual heating hours. 55F was used for both the occupied and unoccupied times as the site contact does not believe the balance point changes much between occupied and unoccupied times due to process loads and occupancy. The change resulted in the operating hours for the drip leg and unit heater steam traps to decrease from 5,110 (standard heating season) to 4,457 (site heating season) hours and 1,700[16] to 1,486 hours, respectively. The drip leg steam trap operation is equal to all heating hours during the heating season, while the unit heater steam traps were assumed to run at 1/3 of the heating season, the methodology used in the revised custom express tool for such heating applications.

The energy savings for the steam trap measure using the methodology described above are 1,106 and 1,561 therms per year using the new and original calculation tool with the evaluation site level findings, respectively.

Comparison with original methodology. Based on their on-site findings, the only revisions made were to the operating hours and updating one trap to failed. The applicant methodology (original tool) updated to reflect site specific findings yielded savings of 1,561 therms per year. The primary reason why the evaluated

[16] Based on the past experience, experts and experts and stakeholder both recommended retaining pick list of hours associated with specified trap applications rather than direct entry of hours, which would be theoretically more precise. See page A-2 in the MA steam trap report (link to report), 1700 hr/year (for unit heaters) which is 1/3rd of the heating season of 5,100 hours.

savings are lower than the reported values is due to the reduction in the operating hours and the finding of one failed trap.

The new methodology yielded significantly lower savings than the old methodology in both the tracking and evaluated cases. The savings using the new methodology were both only 71% of the value calculated by the old methodology for the tracking and evaluated cases

○ **Final Results**

The project consisted of repairing or replacing ten steam traps that had failed open at the site. The evaluators took measurements of all steam traps to determine if the steam traps are operating properly.

The evaluators' analyses show lower savings than were projected by the applicant using both the original tool and the new tool. This is because one of the sampled steam traps had failed and lower operating hours.

Table 3-1 summarizes the key parameters used to calculate the energy savings for the measure that were updated as a result of the evaluation.

Table 3-1. Summary of Key Parameters

Parameter	Applicant	Evaluator
Steam Plant Operating Hours	5,110	4,457
Traps Failed After Repairs/Replacements	-	1/10

Table 3-2 compares the reported, modified applicant and evaluated savings for the steam trap measure.

Note that the tracking savings from the new tool is lower than the old tool. As mentioned in the MA report14, methodological simplifications were made to the revised tool in an effort to reduce the chance of field staff misinterpreting the operating status of an individual trap. These simplifications include reducing the number of variables and respective options for selected variables. In particular, the reduction of leak factor options from 4 to 2 non-zero options in the tool's pick list. Some additional changes to the calculation algorithm were made to increase savings accuracy, resulting in lower savings than in the old tool as outlined the the MA report.

Table 3-2. Steam Trap Analysis Results

Gas Savings [Therms/yr] (Original Tool)		Gas Savings [Therms/yr] (New Tool)	
Tracked	1,949	Tracked	1,383
Evaluated	1,561	Evaluated	1,106
RR[1]	80%	RR[1]	80%

1.2 Cross Check with Billing Data

While sufficient utility billing data was provided to perform a billing analysis, the evaluator determined billing analysis would not provide more details about the performance of the evaluated measures and the natural gas usage at the facility is too large relative to the impacts of the installed measure to observe any discernible impacts using a billing analysis. As a percentage of the post-retrofit therms, the results using the new tool and original tool account for only 1.4% and 2% of annual therms, respectively.

- **Recommendations for Program Designers and Implementers**

Operating hours should be calculated using site-specific temperature setpoints and balance points rather than an assumption of 24/7 operation.

- **Explanation of Deviations**

The evaluated savings are less than the tracked savings because the evaluators are using the revised calculation tool, the steam trap operating hours were lower, and one of the steam traps failed since being repaired. Each of these changes to the savings calculations lead to a decrease in the energy savings. Table 3-3 provides a breakdown of the change in savings due to each of the input modifications. As shown in the table, there was an additional 29% difference based on changing between the original calculation tool and revised calculation tool. The revision in methodology is derived from the Phase 2 Steam Trap Evaluation (MA59) effort. This decrease in savings is not reflected in the realization rates that compare only the results of the old tool together and new tool together.

Table 3-3 Discrepancy Summary

Factor	Applicant	Evaluator	Impact of Deviation	Discussion of Deviations
Drip Leg Steam Trap Operating Hours	3 steam traps with 5,110 operating hours	3 steam traps with 4,457 operating hours	-8%	The 3 steam traps operated at 5,110 hours each in the applicant calculations versus 4,457 hours in the evaluator calculations
Unit Heater Steam Trap Operating Hours	6 steam traps with 1,700 operating hours	6 steam traps with 1,486 operating hours	-4%	The 6 unit heater steam traps operated at 1,700 annual hours in the applicant calculation versus 1,486 hours in the evaluator calculations
Failed Steam Trap	Partial blow-by unit heater trap	Steam trap failed	-8%	One of the ten steam traps failed

Factor	Applicant	Evaluator	Impact of Deviation	Discussion of Deviations
Inaccurate estimation from applicant model	Original calculation tool	Revised calculation tool	-29%	The evaluator used the revised calculation tool methodology to incorporate the approach generated from Phase 2 Steam Trap Evaluation (MA59) effort. This resulted in a 29% decrease in savings when comparing the results of the original calculaton tool to the rivesed calculation tool. Note these values are not shown in the realization rates comparing only the results of the old tool together and new tool together