FINAL

Impact Evaluation of 2017 Custom Gas Installations in Rhode Island

National Grid

Date: May 26, 2020

Table of Contents

List of figures

List of tables

List of acronyms used in this report

BAG – baseline advisory group

CDA – comprehensive design assistance

CHP – combined heat and power

C&I – commercial and industrial

CI – confidence interval

DR – desk review

EMS – energy monitoring system

EUL – effective useful life

HVAC – heating ventilation and air-conditioning

ISP – industry standard practice

M&V – measurement and verification

MBSS – model-based statistical sampling

PA – program administrator

PY2016 – program year 2016

PY2017 – program year 2017

PY2019 – program year 2018

PY2019 – program year 2019

RR – realization rate

RUL – remaining useful life

SCADA – supervisory control and data acquisition

TMY3 – typical meteorological year 3

1 EXECUTIVE SUMMARY

This Executive Summary provides a high-level review of the results for the Rhode Island (RI) Commercial and Industrial (C&I) Impact Evaluation of Program Year (PY) 2017 Custom Gas Installations. In this section, we state the study objectives, summarize the evaluation approach, and present key findings, conclusions, and recommendations. The scope of work of this impact evaluation covered the PY2017 Custom Gas impact category, which included HVAC, EMS, Steam Trap, Insulation, and Other measures. All the measures are commercial retrofit projects.

The work was completed between 2019 and 2020. DNV GL performed a site-based Measurement and Verification (M&V) impact evaluation to quantify the achieved natural gas energy savings for a sample of custom gas s projects completed in Program Year 2017 (PY2017).

1.1 Study Purpose, Objectives, and Research Questions

The objective of this Impact Evaluation of PY2017 Custom Gas Installations was to provide verification or re-estimation of energy (Therms) savings for a sample of Custom Gas projects through site-specific inspections, end-use monitoring, and analysis. The site-specific results were aggregated to determine realization rates separately for National Grid's custom gas installations in RI.

Starting with PY2017, custom gas studies in RI have shifted to a rolling/staged based evaluations. The goal of this approach was to produce updated RI specific results each year.

Even though PY2017 was the first study to be designed specifically to produce a rolling statewide RI only realization rate, results from the previous RI-only studies can be pooled with this year's results as there are no significant differences in the study methodology and the program. For the previous year's RI results, the PY2016 custom gas impact evaluation was combined with National Grid MA results to achieve the required precisions. This study achieved the required statistical relative precisions by combining results from RI only PY2016 and PY2017 studies.

This study:

- Achieved gross natural gas energy savings for custom gas projects at the statewide level, with targeted sampling precision of ±20% at 80% confidence when RI PY 2017 results are pooled with RI PY2016 results only

1.2 Key Findings and Results

The site-level evaluation results were aggregated using the final adjusted case weights. The realization rates were calculated and then applied to total tracking savings to determine their total evaluated savings. DNV GL developed realization rates (and associated precision levels) for annual therms savings of the program by combining 2 consecutive custom gas study results (conducted for PYs 2016 and 2017).

1.2.1 Rolling/Staged Sample: PY2016 and PY2017

The Rhode Island Piggybacking Diagnostic Study (finalized in January 2020) developed guidance on when it is appropriate to "piggyback" or combine RI evaluations efforts with MA studies or adopt MA results as a proxy for RI versus stand-alone RI studies. The "piggybacking" study report recommends which approaches National Grid RI should use for C&I measure groups and residential programs. For custom gas, it recommends using a RI Independent Sample approach.

A rolling/staged evaluation approach was planned to be used to effectively produce RI independent results by the end of a 3-year rolling cycle or, results from a 2-year rolling cycle, if reasonable relative precisions are achieved. And, the results presented in this report did achieve reasonable precisions by combining just two program years (PY2016 and PY2017) as shown in Table 1-1. Overall, the study achieved 85% RR with a relative precision (RP) of ±4.3% at 80% confidence interval. RR in PY2017 improved significantly to 92% from 71% in PY2016 with a far better RP.

Table 1-1: Yearly RI Specific Results and Pooled Results

Parameter	PY2016	PY2017	PYs 2016+2017
Tracking Savings	1,114,770	1,948,383	3,063,153
Sample Size	8	6	14
RR	71%	92%	85%
Relative precision @ 80% CI	±11.0%	±2.3%	±4.3%
Error Ratio	0.27	0.3	

CI = confidence interval

1.3 Conclusions, Recommendations and Considerations

This section presents the conclusions, recommendations, and of the impact evaluation study.

1.3.1 Conclusions

PY2017 Performance. The program continues to generate significant natural gas savings. In RI, PY2017 participation consisted of 98 distinct accounts, adjusted gross saving of 1.95 million therms annually with nearly 92% of the savings realized, based on the evaluation of the sample of RI PY2017 sites.

The original sample was designed to estimate the overall realization rate of the program by combining results from three program year evaluation studies (PYs 2014, 2016, and 2017) to achieve reliable relative precisions. But in this case reliable results were produced from combining results from just two programs years, 2016 and 2017.

Site-specific sample weights are shown in APPENDIX A. More details on the PY2017 results are presented in Section 6, below, and in each site-report included in APPENDIX B.

1.3.2 Recommendations

DNV GL reviewed project files, conducted detailed analyses of the information provided in the files, and quantified discrepancies to make the recommendations presented below.

1.3.2.1 R1: Realization Rate

DNV GL recommends National Grid to use the PY2016 and PY2017 combined RR of 85% for planning and program reporting, starting with PY2021 and continuing to subsequent years until a new impact evaluation study results are available. The applicable RRs are noted in Table 1-3 above. This recommendation was based on the following factors:

- When pooled with PY2016 results, the study produced state-wide results that are reliable (±4% at 80% confidence level).

1.3.2.2 R2: Research Methods for Steam Traps Estimation and Heat Load Reduction to Gas Savings Conversion

Steam traps constitute a large share of custom program savings and had a poorer realization rate in this evaluation when compared with other measures. Three out of 6 sampled sites in this study are steam trap projects as shown in APPENDIX A and the average weighted RR for steam traps projects is 78% compared to 105% for other measures (non-steam traps). This raises the issue of whether steam trap measures should be treated as a separate segment within the custom program or even evaluated separately entirely. The latest steam trap tool that is being used for all projects was vetted and calibrated using participant billing data in 2016. The evaluation observed major discrepancies in operating condition assumptions like Operating Hours, Steam Pressures, etc. used in the tracking analysis, and potentially, the steam trap calculator could benefit from another round of calibration incorporating additional sites from recent evaluations.

Measures such as insulation and steam traps reduce the heating load served by a boiler. Converting the heat load reduction from these measures to natural gas savings requires a boiler efficiency. There have been discussions with National Grid and not full agreement on how the boiler efficiency factor should be derived. MA is currently planning a study to understand more of these issues, DNV GL recommends National Grid in RI to follow MA and conduct similar research or piggyback with the MA effort to be cost-effective.

1.3.3 Considerations

Using the results of the study, the evaluation team generated a list of considerations, summarized below.

1.3.3.1 C1: Boiler Hours of Use Application Review

Rather than assuming a boiler and the heating distribution system operates year-round, site staff should be interviewed to determine if the specific distribution segments impacted by steam traps or pipe/fixtures insulation measures are operated only seasonally. This is considered as an operational discrepancy as shown in section 5.1.2.

For example:

2017RIG015: The applicant assumed higher operating hours for 2 water heaters compared to what the evaluator observed at this site that installed insulation on pipes and fittings. This decrease in operating hours reduced the overall savings by 14%. The site had an overall realization rate of 84% of the tracking savings.

2017RIG107: The applicant assumed the 4,837 hours for the boiler, but the evaluator found the actual hours of use to be 3,630 hours. This reduced the overall savings by 21% of the tracking estimate. The site had an overall realization rate of 73% of the tracking savings.

1.3.3.2 C2: Boiler Efficiency

The application reviewers should use site-specific information for the efficiency of the boilers impacted by steam traps or pipe/fixtures insulation measures where information is available. A convenient approach to determine the boiler system efficiency would be to request boiler combustion test receipts. This is considered as an operational discrepancy as shown in section 5.1.2.

For example:

2017RIG107: The evaluation performed boiler combustion tests onsite and estimated the efficiency of 84% while the tracking analysis assumed an industry-standard 80%. The decrease in savings was about 5% while the site had an overall realization rate of 73% of the tracking savings.

2017RIG053: The evaluation used the actual combustion efficiency of 83.2% found on-site while the tracking assumed an 80% efficiency system. The decrease in savings was about 4% while the site had an overall realization rate of 60% of the tracking savings.

1.3.3.3 C3: Pipe and Fitting Insulation Measure Calculator

The pipe/fitting insulation measure may benefit from a statewide calculator, like the steam trap calculator. The ex-ante savings methods were not transparent, and the evaluators could not always replicate them. A statewide deemed calculator could provide consistent and transparent estimates of savings.

1.3.3.4 C4: EMS or Control Based Projects

For EMS/Control Based projects, consider adding another level of verification such verifying the trend data showing that the control is operating as designed or capturing screenshots of the new control software interface that shows the actual setpoints, or some other meaningful form of documentation to ensure control based claimed savings are operational. Better documentation of the pre-existing conditions with pictures or trend data would help validate savings.

For example:

2017RIG097: The Majority (79%) of the tracking savings at this site come from the installation of Demand Control Ventilation (DCV) controls but no carbon dioxide ($CO_{2)}$ sensors were found on-site and without the signal from CO_2 sensors the DCV will not operate as intended. Therefore, zero savings have been assumed for this measure in the site analysis. The site had an overall realization rate of 25% of the tracked savings.

2 INTRODUCTION

This section presents the objectives for the DNV GL's Impact Evaluation of the Program Year (PY) 2017 Custom Gas Installations for National Grid in Rhode Island (RI). DNV GL performed a site-based Measurement and Verification (M&V) impact evaluation to quantify the achieved natural gas energy savings for a sample of custom gas projects from the Program Year 2017 (PY2017) population.

2.1 Study Purpose, Objectives and Research Questions

This evaluation performed a site-based M&V impact evaluation to quantify the achieved natural gas energy savings for 6 RI custom gas projects for PY2017. The results of this study were combined with the results from the PY2016 study to produce updated, statewide RRs.

2.2 Organization of Report

The remainder of this report is organized as follows:

- Section 3: Methodology and Approach. The methods associated with sampling and the M&V tasks will be described in this section.
- Section 4: Data Sources.
- Section 5: Analysis and Results. The rolling results and the results associated with the evaluation of PY2017 will be presented in this section.
- Section 6: Conclusions, Recommendations, and Considerations. Conclusions and recommendations from analyzing the M&V findings are presented in this section.

3 METHODOLOGY AND APPROACH

The evaluation team approach was consistent with the procedures and protocols developed during the previous round of custom gas impact evaluation conducted for PY2014 and PY2016[1]. As described in the next subsections, the impact evaluation consisted of on-site visits, and metering of a randomly selected sample of projects at participating facilities.

3.1 Description of Sampling Strategy

As discussed earlier, DNV GL designed the sample for the PY2017 impact evaluation to pool the annual evaluation results with PY2016 results to produce a rolling updated result. This allowed the sampling precision to meet the targets laid out in Table 3-1 at the statewide level.

For the next round of this evaluation, PY2016, PY2017, and PY2018[2] results will be pooled together to use in the PY2021 planning cycle. In subsequent years, the realization rate will reflect the pooling of the three most recent impact results.

Based on the results achieved in the previous studies, this sample design assumed the error ratios shown in Table 3-1 for the targets listed. The sample design for this round of study was developed assuming the results would be pooled with prior (and future) custom gas results. The general principle used in this design is that the results from each year would need to achieve ±35% precision at 80% confidence interval to maintain a three-year pooled result of ±20% precision at 80% confidence for gross therms savings RRs. DNV GL used Model-Based Statistical Sampling (MBSS) techniques to develop the sample design. The sampling unit is the sum of all projects installed in the evaluated program year at an account.

Table 3-1: Sampling Targets

Annual Sampling Target	Three-Year Pooled Sampling Target	Error Ratio
±35% expected relative precision - 80% CI	±20% expected relative precision - 80% CI	0.60

CI = confidence interval

3.1.1 PY2017 Sample Frame

The initial population for this impact evaluation was the set of custom gas projects rebated in 2017. Table 3-2 shows the distribution of all tracking records and the associated savings by National Grid.

Table 3-2: PY2017 Population Distribution of Custom Gas Accounts

Distribution	Number of Accounts	Gas Savings (Therms)	% Savings
Original Population Frame	102	2,242,372	96%
CDA projects	4	83,748	4%
Small Sites (<1,000 therms savings)	30	10,903	0.5%
Grand Total	**136**	**2,337,023**	**100%**

As was done in previous evaluations, small sites were excluded from the sample frame. These small sites account for less than 1% of total tracking savings and do not warrant the expense of site M&V. There were 30 such gas accounts with annual savings less than 1,000 therms that were removed from the population

[1] PY2016 study report was not finalized during the planning of this study.

[2] DNV GL has begun evaluating RI PY2018 (year 3) sample in January 2020 and was scheduled to have the results finalized by July 2020. In March 2020, National Grid has stopped all the field in response to the COVID-19 virus spread and this stoppage could potential cause some delays in the final deliverable date.

frame, with a total savings of 10,903 therms as shown in Table 3-2. There were 4 sites that completed CDA projects but were also removed from the population frame as the CDA projects are typically evaluated in a different study. Therefore, the original population included 102 unique customer accounts or sites. DNV GL in coordination with National Grid further split 3 accounts into 9 more different sites based on their location[3] making the total accounts to 111.

After this division, DNV GL noticed 13 accounts with prescriptive[4] measures with a savings of 293,990 therms. These sites were also removed and the final PY2017 population frame has a total of 98 accounts with savings of 1,948,383 therms. Table 3-3 shows the selected sample frame after dropping the small sites, increasing total accounts, and removing prescriptive measures.

Table 3-3: PY2017 Adjusted (Final) Project Sample Frame

Accounts	Tracking Savings (Therms)
98	1,948,383

3.1.2 PY2017 Sample Design

Table 3-4 shows the selected sample for this project. DNV GL estimated that 7 sampled sites would give reliable precisions to achieve the required target per Table 3-1. The table also shows that DNV GL completed 6 out of the designed 7 sites and the study did achieve the reliable statistical precision targets (±2.3%) at 80% confidence interval.

Table 3-4: PY2017 Project Sample

Accounts	Savings	Error Ratio	Sample (n)		Expected Relative Precision @ 90% CI	Achieved Relative Precision @ 90% CI
			Designed	Completed		
98	1,948,383	0.6	7	6	±30.0%	±2.3%

3.1.3 Rolling Sample Design

To calculate combined expected relative precision, the expected precision from the PY2017 sample design was combined with PY2016[5] study results. Table 3-5 provides the combined expected precision at the statewide level, based on this sample design.

Table 3-5: PY2016 and PY2017 Combined Expected Precision at 80% Confidence Interval

Program Year	Accounts (N)	Therms Savings	Error Ratio	Sample (n)		RP @80% CI	
				Designed	Completed	Design	Achieved
PY2016	87	1,160,663	0.6	8	8	±26.8%	±11.0%
PY2017	98	1,948,383	0.6	7	6	±30.0%	±2.3%
PYs (2016+2017)	**268**	**5,286,187**	**N/A**	**15**	**14**	**DNC[6]**	**±4.0%**

N/A = not applicable
DNC = Did not calculate;

[3] These 3 accounts were separated individually into 2, 4 and 6 accounts respectively based on their respective service addresses. These large customers have a single account numbers for their facilities located in different addresses and sometimes different cities.

[4] The population included "Custom Prescriptive" measures which were essentially radiator steam traps that uses a deemed savings calculation, therefore removed from the population frame and realization rates will not be applied to those sites.

[5] Expected RP; this study was not finalized during the designing stage of this study.

[6] The original design used results from 3 years, so this quantity was not calculated.

3.1.4 PY2017 Final Sample Disposition

One primary site refused to participate in the study and was replaced by a secondary site. Another primary site was non-responsive and was dropped[7] from the final sample. Therefore, the final (achieved) sample includes 6 sites as shown in Table 3-5. Appendix A summarizes the 6 sites for which M&V activities were completed and their respective post-stratified weights. The summary includes the site ID, the verified measure description, and the tracking savings and site RR.

3.2 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.

DNV GL submitted full individual M&V plans for each evaluated site. These plans were reviewed by the PA. 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:
  - Methods for verifying the measure installation and current operation.
  - Methods for observing and/or assessing building use and occupancy.
  - Identification of the tracking and expected evaluator baseline of each measure.
  - The data collected by DNV GL; where several similar items have been installed or are being controlled, the evaluation plan described and justified the sampling rate of the equipment to be monitored.
  - 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 data provided by the site (e.g., EMS trends, production, pre-metering, etc.) and/or the PA.
  - 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 used to estimate evaluated savings. DNV GL presented an alternative methodology only if the tracking methodology was flawed, unfeasible, or a more accurate methodology that utilized post-installation data was available.
  - Key parameters that were determined through the evaluation and compared to those used in the original savings estimate.

7 The replacement site was weather dependent and required some winter meeting which time did not allow, therefore dropped from the sample. DNV GL and National Grid had also discussed about adding an additional sample point to the next year's evaluation, based on the calculated overall relative precision for 3-year rolling/combined results.

DNV GL updated the M&V plan, responded to National Grid comments on the M&V plan, and in most of the cases submitted a revised M&V plan before the site visit. For some sites, the initial visit was scheduled within a couple of days or less and National Grid reviewers did not have the chance to approve the entire M&V plan before the site visit. For those sites, DNV GL evaluators emailed the plan for a quick review and response specifically for the tasks to be conducted on-site and the metering approach.

3.3 Data Collection

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

3.3.1 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 trend/EMS/production data, any other applicable parameters relevant to the evaluation, and confirmed that the site will allow DNV GL to conduct the site visits. 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. After the customer outreach discussion, if the engineer determined significant barriers were preventing M&V of substantial parts of the completed project, the site was flagged for review, and, if warranted, replaced with a backup site. This study had replaced only 1 primary site out of 6 in the original design with a backup site, due to customer refusal.

3.3.2 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, 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 measure savings estimates.

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

3.3.3 M&V Plan Update

DNV GL 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 the following information, based on the site visit:

- 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 intended to keep National Grid current on the status of the site evaluation and communicate any anticipated or resultant deviations from the plan.

3.4 Site Analysis

DNV GL reviewed all data collected and then utilized the data to complete an evaluation analysis for each sampled project. In general, the custom gas segment includes existing building retrofits, new construction, replacement on failure, and major renovation. It does not include the 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 the two weather-dependent measures (2 sites), the site analysis involved normalizing the models to weather data using Typical Meteorological Year 3 (TMY3) data for Providence to each site.

3.5 Site Reporting

DNV GL submitted draft site reports to National Grid and they 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, the results, and the report itself. Each site report contains the following sections:

- **Project summary and results** – 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 –** Describes the evaluated measures, including, but not limited to:
    - Applicant baseline and proposed conditions
    - Applicant savings calculation methods
    - Evaluator assessment of the applicant savings calculation methods
    - How measures were verified
    - The data collected by DNV GL, summarized in graphical or tabular form for each data point
    - The data provided by the site and/or their PA, 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 differences between the tracking savings estimates and evaluation savings estimates
    - Lifetime savings

A sample of site reports was reviewed by the team's independent quality assurance lead. This review determined if the reports complied with the requirements for this deliverable, and if the document communicates information clearly and consistently. The quality assurance lead reviewed the first report completed by each evaluation firm, as well as one additional report from each firm that was selected based on the characteristics of the site or analysis.

3.5.1.1 Measure Event Type and Baseline Review

A review of event measure types and baselines for each measure installed at sites in the primary and any replaced secondary (backup) sample selected for the evaluation was completed for this study.

DNV GL selected a measure baseline event type based on a preponderance of the evidence presented in the project file and the data gathered during the interview with the site contact. National Grid classified measures into two event types: new construction measures which include both new buildings and replace on failure and planned new measure purchases and retrofit measures. Evaluation observed only one measure event types: retrofit with a single baseline in the 6 sampled sites.

A summary of the measure event type completed for each sampled site is shown below.

Table 3-6 below shows the measure event types used in tracking and evaluation. Site 2017RIG015 had 2 different application numbers but were part of one site and are considered a Parent/Child[8] project.

Table 3-6: Measure event type in tracking and evaluation

Site Id	National Grid Application#	Tracking Event Type	Evaluation Event Type
2017RIG015	6342021	Retrofit	Retrofit with single baseline
2017RIG015	7599903	Retrofit	Retrofit with single baseline
2017RIG047	6480846	Retrofit	Retrofit with single baseline
2017RIG053	7031387	Retrofit	Retrofit with single baseline
2017RIG097	6480538	Retrofit	Retrofit with single baseline
2017RIG098	5685729	Retrofit	Retrofit with single baseline
2017RIG107	6808908	Retrofit	Retrofit with single baseline

After the measure event type was selected, the evaluator selected the evaluated baseline for the event type. Measures classified as retrofit or add-ons used pre-existing conditions as a baseline. The evaluation team completed an independent review of the baseline for each sampled project. And, using site data project documentation, and interviews at the facility, DNV GL assessed the reasonableness of the baseline for each sampled project.

For example: **Site 2017RIG097** application was supposed to install Demand Control Ventilation (DCV) system on the existing Energy Management System (EMS) but the evaluator did not find any DCV systems installed onsite. If it were installed, the evaluation event type would also include "add-on with a single baseline" with "retrofit with a single baseline" as they were other retrofit measures installed onsite.

[8] For some large projects, National Grid typically doesn't pay out the total incentive upfront but splits the payments into 2 as parent and child. And the child payment is made after the project is fully commissioned and completed

4 DATA SOURCES

To support the findings of the study, the evaluation team used the following data sources:

- PY2017 tracking data provided by National Grid
- PY2016 tracking data
- PY2016 impact evaluation results
- Project files, which typically include one or more of the following: original applications, BCR screenings, invoices, technical assistance studies, applicant savings calculations, and post-installation reports
- On-site observations and data collection including inspection and verifications of equipment, nameplate data, staff interviews, vendor interviews, spot measurements of various parameters including kW, longer-term measurements and combustion efficiency
- Metered and/or EMS trend data from each of the 6 sites that participated in the study.

5 ANALYSIS AND RESULTS

The RI PY2017 study achieved the target precisions by combining the latest 2 years (PY2016 and PY2017). PY2016 impact evaluation results have been finalized[9] in March 2019. The following subsections provide more details on the PY2017 results.

5.1 PY2017 Results

This section provides an overview of the results from comparing PY2017 tracking and evaluated results.

5.1.1 Site-Level Results

Figure 5-1 and Figure 5-2 illustrates the comparison of evaluated (y-axis) and reported (x-axis) annual natural gas savings for each of the 6 sites included in the evaluation sample for PY2017. Figure 5-1 shows the larger sites and Figure 5-2 shows the smaller sites which are hard to see when combined into one graph.

Ideally, the evaluated savings would always match the reported savings; this ideal is shown as a solid green line in each chart. Figure 5-1 shows the largest evaluated site which has tracking savings greater than 500,000 terms per year but over the ideal 100% RR line suggesting a realization rate higher than 100% (123%).

Projects installed at the remaining five sites deviated from tracking savings by at least 15% and therefore the sites lie below the ideal RR green line. Appendix A summarizes the 6 sites for which M&V activities were completed, with vital statistics such as the site ID, the verified measure description, tracking savings, and RR. Appendix A also presents a summary description for each evaluated site of the factors that led to differences between the program-reported (tracking) savings and the evaluated savings.

[9] Impact Evaluation of PY2016 Custom Gas Installations in Rhode Island

Figure 5-1: PY2017 Reported and Evaluated Annual Natural Gas Savings (large savings sites only).

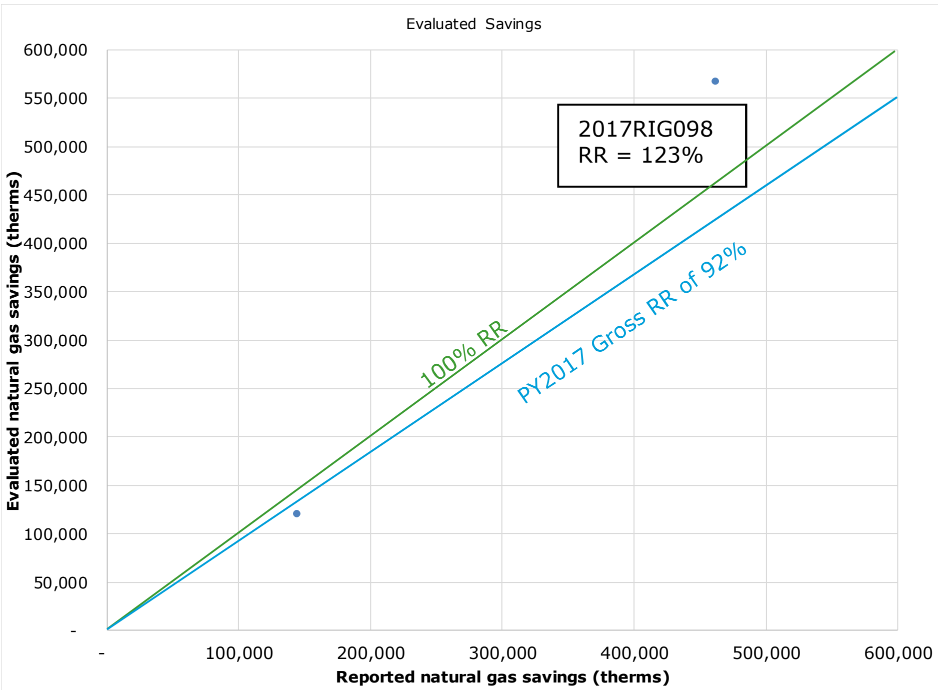
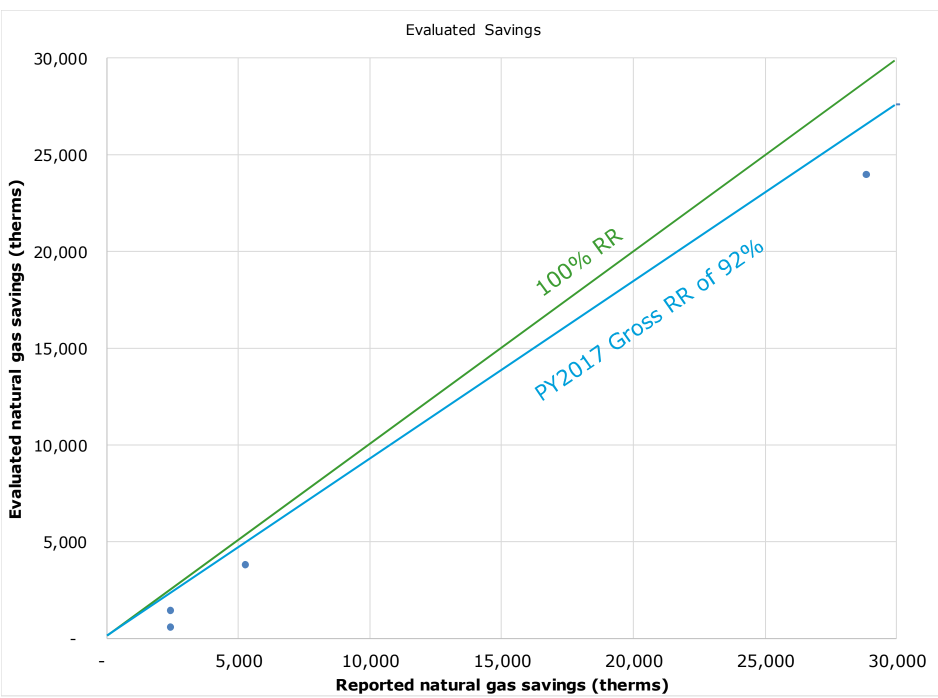


Figure 5-2: PY2017 Reported and Evaluated Annual Natural Gas Savings (low savings sites only).



5.1.2 Discrepancy Results

For each of the 6 sites included in the PY2017 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 six categories: tracking/administrative, baseline, quantity, methodology, failed or removed, and operational. A more discrete breakdown of differences is presented below in Table 5-1.

Table 5-1: PY2017 Discrepancy Factors and their Mapping to Major Categories

Major Discrepancy	Basic Discrepancy
Tracking/admin	Tracking savings
Baseline	Baseline
Quantity	Quantity of installed equipment
Methodology	Analysis methodology
Failed or removed	Failed traps
	Measure removed after one year
	Parts of the measure was removed
Operational	Boiler efficiency
	Difference in equipment hours of operation
	Equipment load profile
	Inaccurate pre-project characterization
	Steam operating pressure

The evaluation team used the site-specific sampling weights and the site-specific impacts of discrepancy to calculate the impact of factors that caused differences between the program and evaluated results. For steam traps measures, the evaluator's calculated program savings using the applicant inputs and the new steam traps savings calculator as the tool has changed since these applications were first claimed and going forward the new tool will be used for all applications.

Table 5-2 below presents the discrepancy factors and their impacts. There were no baseline discrepancies found in the sample.

Table 5-2: PY2017 Weighted Discrepancy Factors Between Tracking and Evaluated Results

Discrepancy	Site Counts	Impact on RR	Impact(%)
Tracking/Admin	1		-0.1%
Baseline	0		0.0%
Quantity	1		-4.2%
Methodology	1		-0.1%
Failed/Removed	1		-1.1%
Operational	6		-2.2%
Total			**-7.8%**

The largest discrepancy was due to quantity differences, with a negative impact of -4.2%. Site 2017RIG097 did not install DCV measures per the application and this was considered as a quantity discrepancy in the evaluation. This reduced the savings by nearly 79% of tracking savings (unweighted) for that one site. The impact of this reduction when normalized using the site weights (APPENDIX A) was estimated to be 4.2% of the over program savings as shown in Table 5-3.

This was followed by differences due to operational differences or uninstalled measures with a negative impact of approximately 2.2%. All 6 sites had operational adjustments as shown in Table 5-2 above due to change in boiler operating hours or change in temperature setpoints for the hot water boilers etc.

The largest and smallest tracking savings sites' discrepancies factors are discussed below:

2017RIG098 had a positive adjustment of savings due to the increased shutdown period of Absorption chillers at this hospital building. These chillers use steam generated in the boiler plant to provide cooling during the winter months and the measure was to repair/retrofit economizers to provide free cooling. (Site RR=123%).

2017RIG053 had an operating steam pressure adjustment from 40 PSI to 22.8 PSI in the evaluation analysis. This change reduced savings by nearly 40% of the site savings due to this operational change (Site RR=60%).

Table 5-3: Operational Discrepancies at 6 sampled sites

Site ID	Tracking Savings	Evaluated Savings	% discrepancy (weighted)	RR
2017RIG015	144,188	120,639	-14%	84%
2017RIG047	28,834	24,009	-17%	83%
2017RIG053	2,415	1,442	-40%	60%
2017RIG097	2,444	612	4%	25%
2017RIG098	461,862	567,496	23%	123%
2017RIG107	5,266	3,822	-18%	73%

Detailed information on site-specific differences is presented in Section 3 of each site report, which is included in Appendix B.

5.2 Combined Results

The evaluators calculated the gross RR using the results from PY2017 and PY2016. The results summary is presented in Table 5-4. PY2016 and PY2017 achieved much better precisions than what was estimated in the design (Table 3-5) primarily due to the low variance in large stratum site results. Site 2017RIG015 and 2017RIG098 tracking savings cover nearly 31% of the entire program savings and sampling both the large sites have reduced the error in the overall expanded results. And lower error ratios compared to the design's 0.60 estimate suggests that the sampled sites achieved better than expected realization rates.

Table 5-4: Statewide Summary Results

Parameter	PY2016	PY2017	PYs 2016+2017
Tracking Savings	1,114,770	1,948,383	3,063,153
Sample Size	8	6	14
RR	71%	92%	85%
Relative precision @ 80% CI	±11.0%	±2.3%	±4.3%
Error ratio	0.27	0.30	N.A.

CI = confidence interval

The relative precision of the RR ±4.3% meets the design precision targets proposed and presented in Section 3.1.3, above after combining just two years of results, not the three years originally thought needed.

6 CONCLUSIONS, RECOMMENDATIONS AND CONSIDERATIONS

This section presents the conclusions, recommendations, and of the impact evaluation study.

6.1.1 Conclusions

PY2017 Performance. The program continues to generate significant natural gas savings. In RI, PY2017 participation consisted of 98 distinct accounts, adjusted gross saving of 1.95 million therms annually with nearly 92% of the savings realized, based on the evaluation of the sample of RI PY2017 sites.

The original sample was designed to estimate the overall realization rate of the program by combining results from three program year evaluation studies (PYs 2014, 2016, and 2017) to achieve reliable relative precisions. But in this case reliable results were produced from combining results from just PY2016 and PY2017. Table 6-1 below shows the individual PY2016 and PY2017 results and the combined program results. Site-specific sample weights are shown in APPENDIX A.

Table 6-1: RI Only, Natural Gas Program Evaluations

Results	PY2016	PY2017	PYs 2016+2017
Tracked savings (therms)	1,114,770	1,948,383	3,063,153
Statewide evaluated savings (therms)	795,000	1,796,662	2,591,662
RR	71%	92%	85%
Relative precision-80% CI	±11.0%	±2.3%	±4.3%
Sample size	8	6	14
Error Ratio	0.27	0.3	

More details on the PY2017 results are presented in Section 6, below, and in each site-report included in APPENDIX B.

6.1.2 Recommendations

DNV GL reviewed project files, conducted detailed analyses of the information provided in the files, and quantified discrepancies to make the recommendations presented below.

6.1.2.1 R1: Realization Rate

DNV GL recommends National Grid to use the PY2016 and PY2017 combined RR of 85% for planning and program reporting, starting with PY2021 and continuing to subsequent years until a new impact evaluation study results are available. The applicable RRs are noted in Table 1-3 above. This recommendation was based on the following factors:

- When pooled with PY2016 results, the study produced state-wide results that are reliable (±4% at 80% confidence level).

6.1.2.2 R2: Research Methods for Steam Traps Estimation and Heat Load Reduction to Gas Savings Conversion

Steam traps constitute a large share of custom program savings and had a poorer realization rate in this evaluation when compared with other measures. Three out of 6 sampled sites in this study are steam trap projects as shown in APPENDIX A and the average weighted RR for steam traps projects is 78% compared to 105% for other measures (non-steam traps). This raises the issue of whether steam trap measures should be treated as a separate segment within the custom program or even evaluated separately entirely. The latest steam trap tool that is being used for all projects was vetted and calibrated using participant billing data in 2016. The evaluation observed major discrepancies in operating condition assumptions like Operating Hours, Steam Pressures, etc. used in the tracking analysis, and potentially, the steam trap calculator could benefit from another round of calibration incorporating additional sites from recent evaluations.

Measures such as insulation and steam traps reduce the heating load served by a boiler. Converting the heat load reduction from these measures to natural gas savings requires a boiler efficiency. There have been discussions with National Grid and not full agreement on how the boiler efficiency factor should be derived. MA is currently planning a study to understand more of these issues, DNV GL recommends National Grid in RI to follow MA and conduct similar research or piggyback with the MA effort to be cost-effective.

6.1.3 Considerations

Using the results of the study, the evaluation team generated a list of considerations, summarized below.

6.1.3.1 C1: Boiler Hours of Use Application Review

Rather than assuming a boiler and the heating distribution system operates year-round, site staff should be interviewed to determine if the specific distribution segments impacted by steam traps or pipe/fixtures insulation measures are operated only seasonally. This is considered as an operational discrepancy as shown in section 5.1.2.

For example:

2017RIG015: The applicant assumed higher operating hours for 2 water heaters compared to what the evaluator observed at this site that installed insulation on pipes and fittings. This decrease in operating hours reduced the overall savings by 14%. The site had an overall realization rate of 84% of the tracking savings.

2017RIG107: The applicant assumed the 4,837 hours for the boiler, but the evaluator found the actual hours of use to be 3,630 hours. This reduced the overall savings by 21% of the tracking estimate. The site had an overall realization rate of 73% of the tracking savings.

6.1.3.2 C2: Boiler Efficiency

The application reviewers should use site-specific information for the efficiency of the boilers impacted by steam traps or pipe/fixtures insulation measures where information is available. A convenient approach to determine the boiler system efficiency would be to request boiler combustion test receipts. This is considered as an operational discrepancy as shown in section 5.1.2.

For example:

2017RIG107: The evaluation performed boiler combustion tests onsite and estimated the efficiency of 84% while the tracking analysis assumed an industry-standard 80%. The decrease in savings was about 5% while the site had an overall realization rate of 73% of the tracking savings.

2017RIG053: The evaluation used the actual combustion efficiency of 83.2% found on-site while the tracking assumed an 80% efficiency system. The decrease in savings was about 4% while the site had an overall realization rate of 60% of the tracking savings.

6.1.3.3 C3: Pipe and Fitting Insulation Measure Calculator

The pipe/fitting insulation measure may benefit from a statewide calculator, like the steam trap calculator. The ex-ante savings methods were not transparent, and the evaluators could not always replicate them. A statewide deemed calculator could provide consistent and transparent estimates of savings.

6.1.3.4 C4: EMS or Control Based Projects

For EMS/Control Based projects, consider adding another level of verification such verifying the trend data showing that the control is operating as designed or capturing screenshots of the new control software interface that shows the actual setpoints, or some other meaningful form of documentation to ensure control based claimed savings are operational. Better documentation of the pre-existing conditions with pictures or trend data would help validate savings.

For example:

2017RIG097: The Majority (79%) of the tracking savings at this site come from the installation of Demand Control Ventilation (DCV) controls but no carbon dioxide ($CO_{2)}$ sensors were found on-site and without the signal from CO_2 sensors the DCV will not operate as intended. Therefore, zero savings have been assumed for this measure in the site analysis. The site had an overall realization rate of 25% of the tracked savings.

APPENDIX A. POST STRATIFIED SAMPLE WEIGHTS

This Appendix lists the weights that were used to calculate over realization rates for the program.

Table 6-2: Post-Stratified Sample Weights.

Site ID	App/s	Measure	Weight	Tracking Savings	Evaluated Savings	Realization Rate
2017RIG015	6342021, 7599903	Insulation	1.00	144,188	120,639	84%
2017RIG047	6480846	Steam Trap	13.00	28,834	24,009	83%
2017RIG053	7031387	Steam Trap	27.67	2,415	1,442	60%
2017RIG097	6480538	EMS	27.67	2,444	612	25%
2017RIG098	5685729	RCx and EMS	1.00	461,862	567,496	123%
2017RIG107	6808908	Steam Trap	27.67	5,266	3,822	73%

APPENDIX B. SITE REPORTS

1 Site 2017RIG015

Program Administrator	National Grid
Application ID(s)	6342021, 7599903
Project Type	Retrofit
Program Year	2017
Evaluation Firm	DNV GL
Evaluation Engineer	Ryan Brown
Senior Engineer	Srikar Kaligotla

1.1 Evaluated Site Summary and Results

The evaluated project was installed at a college campus and consisted of the installation of fitted insulation jackets on various sections of straight pipe, fittings, steam sleeves, and other heating equipment. The applicant calculated the measure savings due to the reduction in heat loss between bare and insulated pipes and fittings.

The evaluators modeled savings based on logged temperature data, temperature spot measurements using an infrared gun, and information gathered from on-site interviews. Boiler combustion efficiency tests were not performed on-site as there was construction surrounding the main mechanical building preventing access. Recent site combustion tests were also not provided. Gas savings were calculated using site data to determine the difference in heat loss between bare and insulated pipes and fittings. The evaluators determined the measure to be an add on single baseline considering the underlying steam distribution system is expected to outlive the installed insulation. The baseline is bare, uninsulated pipe and fittings. The savings were less than the tracking estimates primarily due to the difference in the oil/gas usage ratio, calculated heat loss values using 3EPlus, boiler combustion efficiency, and energized operating hours. The evaluated results are presented in Table 6-3.

Table 6-3. Evaluation Results Summary

PA Application ID	Measure Name		Savings (Therms/yr)	Measure Life (years)	Lifetime Savings (Therms)
NR160714	Fitted insulation jackets for pipes and fittings.	Tracked	144,188	15	2,162,823
		Evaluated	120,639	15	1,809,582
		Realization Rate	84%	N/A	N/A
Totals		**Tracked**	**144,188**	**15**	**2,162,823**
		Evaluated	**120,639**	**15**	**1,809,582**
		Realization Rate	**84%**	**N/A**	**N/A**

N/A = Not applicable

1.1.1 Explanation of Deviations from Tracking

The evaluated savings are 16% less than the applicant-reported savings primarily due to the difference in the oil/gas usage ratio, calculated heat loss values using 3EPlus, boiler combustion efficiency, and energized operating hours. Further details regarding deviations from the tracked savings are presented in Section 3-4.

1.1.2 Recommendations for Program Designers & Implementers

It is recommended for the program to use the default setting of “heat loss per hour” in 3EPlus to simulate heat loss. This setting produces outputs in proper units based on application type (straight pipe or tank shell). The method of “heat flow limitation” is not as consistent in providing heat loss values.

1.1.3 Customer Alert

There are no customer alerts for this project.

1.2 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 the installation of fitted insulation jackets on various sections of straight pipe, fittings, steam sleeves, and other heating equipment.

1.2.1 Application Information and Applicant Savings Methodology

This section describes the application information, savings methodology provided by the applicant, and the evaluation assessment of the savings calculation algorithm used by the applicant. Both applicant and evaluated approaches utilized 3EPlus simulation using on-site findings and assumptions to determine bare and uninsulated heat loss values for all insulated applications. Project savings were primarily based upon the reduction in heat loss between bare and insulated applications.

1.2.2 Applicant Description of Baseline

The applicant classified the measure as a retrofit with a single baseline. According to the savings analysis file provided by the applicant, the baseline is bare, uninsulated straight pipe, fittings, steam sleeves, and other heating equipment exposed to an indoor temperature of 70-110°F, dependent on building. The baseline steam system consisted of pre-existing boilers operating year-round except for maintenance shutdowns. The applicant used a boiler combustion efficiency of 80%.

Applicant Description of Installed Equipment and Operation

A vendor conducted a scoping audit in which they identified uninsulated steam pipes, fittings, steam sleeves, and other heating equipment that were allowing excess heat to escape to unconditioned mechanical spaces. The vendor took surface temperature spot readings of the uninsulated surfaces, collected surface pipe lengths and diameters to determine surface areas, and determined hours of operation for each system. Per the application documents, the vendor identified approximately 7,224 ft^2 equivalent of the distribution system totaling all hot surfaces that needed insulation. Insulation with thicknesses ranging between 0.39 and 4.5" were installed for all pipes and jackets other than most steam traps.

Applicant Energy Savings Algorithm

The project documents include a spreadsheet calculation file labeled "Insulation Measure - 144188 therms savings.xlsx". The applicant calculated the savings using a custom analysis spreadsheet aided by the 3EPlus energy modeling software to establish bare and insulated surface heat loss rates. The insulation energy savings were calculated for each insulated application using the following formula:

$$Svgs = \frac{SA_{fitting} \times (HLR_{\ bare} - HLR_{insulated}) \times Hours}{100{,}000 \times Eff_{burner}}$$

where,

$Svgs$	= Annual energy savings per year (therms)
$SA_{fitting}$	= Surface area of insulated fitting (ft^2)
HLR_{bare}	= Heat loss rate of bare pipe ($Btu/hr/ft^2$) calculated using 3EPlus
$HLR_{insulated}$	= Heat loss rate of insulated pipe ($Btu/hr/ft^2$), calculated using 3E Plus

$Hours$	=	Number of hours per year the pipe or fitting is energized
$100{,}000$	=	BTU to Therm conversion rate
Eff_{burner}	=	Boiler burner efficiency (80%)

Figure 6-1. Applicant Savings Calculations below shows a screenshot from the applicant savings calculations file.

Figure 6-1. Applicant Savings Calculations

Description	Component	Insul Thick	Flange Class	Nominal Pipe Size	Operating T	Ambient T	SF/component	Hrs in service/yr.	Bare BTU/hr/sf lost	Insul BTU/hr/sf lost	Insul Touch T ºF
6" Bonnet 125/150 2" (300°-425°F)	Bonnet	2	125/150	6.00	338	85	1.51	8640	736.10	29.56	103
3" Bonnet 125/150 2" (300°-425°F)	Bonnet	2	125/150	3.00	338	85	1.57	8640	759.70	56.64	116
1.5" Bonnet 125/150 2" (300°-425°F)	Bonnet	2	125/150	1.50	338	85	0.98	8640	791.80	18.73	97
1.5" Bonnet 125/150 2" (300°-425°F)	Bonnet	2	125/150	1.50	338	85	0.98	8640	791.80	18.73	97

The applicant post-installation inspection found that none of the steam traps in the proposal were insulated. Therefore, the applicant revised the calculation to remove the insulation savings associated with steam traps.

Additional details on the applicant algorithm could be found in the project files.

Evaluation Assessment of Applicant Methodology

The applicant used 3EPlus simulations based on site assumptions to determine heat loss values for bare and insulated fittings. The applicant 3EPlus values for bare and insulated heat loss were found to be calculated using non-default settings in the software. The default calculation type of "heat loss per hour" outputs heat loss units dependent upon the inputs given (BTU/hr/ft for linear pipe and BTU/hr/ft^2 for blanket applications). After performing some spot calculations, the evaluators were able to assume the applicant used "heat flow limitation" for the calculation type (although this could not be confirmed as 3EPlus screenshots were not provided in application data). This calculation type results in BTU/hr/ft^2 as the default unit regardless of the application type and if straight pipe parameters are used in the simulation. This method is not as consistent and overestimates heat loss compared to the heat loss per hour method.

1.2.3 On-Site Inspection and Metering

This section provides details on the tasks performed during the site visit and the gathered data.

Summary of On-site Findings

The evaluators conducted a site visit on April 19, 2019. During the site visit, the evaluators interviewed the facility maintenance manager and verified the applicant inputs by measuring surface area, taking spot temperature measurement using an infrared gun, and installing temperature meters for long term logging. Spot measurements included bare and insulated surface temperature as well as ambient space temperature for all accessible applications. A total of 6 buildings of varying use (lab, classroom, office, dorm, etc) were visited. Among these buildings a sum of 62 total unique steam applications were spot measured using an infrared gun. The spot measurements were used to confirm the insulated steam applications were energized. Considering the inaccurate variability of the infrared gun, the spot measurements were not used further in the analysis. Instead, the evaluator utilized long term measured data to make evaluated adjustments.

To perform the analysis, the evaluator developed bins to divide the large sample of data. Bins were developed based on temperature and application type (straight pipe/jackets). Averages were taken for pipe size and insulation thicknesses that fell in these bins. Temperature bins are shown below in Table 6-4. .

Table 6-4. Evaluated Temperature Bins

		Application			Evaluation		
Bins	**Count**	**Operating Temp [⁰F]**	**Ambient Temp [⁰F]**	**Surface area per component [sqft/unit]**	**Operating Temp [⁰F]**	**Ambient Temp [⁰F]**	**Surface area per component [sqft/unit]**
Jacket Bin 1	828	185	85	3.91	200	89	4.52
Jacket Bin 2	117	227	85	4.30	227	89	4.38
Jacket Bin 3	345	239	85	3.02	240	89	3.33
Jacket Bin 4	183	250	85	2.16	250	89	2.40
Jacket Bin 5	8	252	85	8.59	252	89	8.59
Jacket Bin 6	26	275	85	3.64	275	89	6.18
Jacket Bin 7	110	285	85	1.73	285	89	1.52
Jacket Bin 8	94	298	86	2.40	298	89	2.67
Jacket Bin 9	13	307	88	3.08	307	89	3.79
Jacket Bin 10	12	320	89	1.61	320	89	1.96
Jacket Bin 11	267	338	84	3.79	338	89	3.89
Jacket Bin 12	34	350	85	1.31	350	89	1.31
Pipe Bin 13	84	185	83	1.66	200	89	1.56
Pipe Bin 14	73	239	82	1.41	240	89	1.41
Pipe Bin 15	6	298	85	1.08	298	89	1.06

An average evaluated ambient temperature of 89 ⁰F was captured by long-term logging and used for the evaluated heat loss calculations.

Site steam is generated from a central boiler and CHP[10] (Combined Heat & Power) system at 100 psi 8,760 hours annually. There are multiple PRV (pressure reducing valves) throughout the campus to reduce pressure to optimal points based on end use. Dorms are typically serviced at 6-8 psi, lecture halls at 10 psi, while labs vary. Generally, buildings are provided with steam heat from the second

10 DNV GL confirmed that CHP plant is not incentivized by any National Grid EE programs.

weekend of October to the second weekend of May. After steam heat is no longer provided, the steam system still provides steam to areas such as labs for process use and hot water.

Duel Fuel

The system runs dual fuel during periods of high demand. The site was unable to provide logs to show how often oil was used compared to natural gas. Instead, the evaluator was able to find utility logs and annual usage history for 2017 from the University's website. These logs were used to compare the use of oil to gas. After converting gallons of No. 2 fuel oil to ccf, it was found that 12% of overall ccf consumption is due to oil. This adjustment factor was applied to the final therm calculations to determine savings only associated with gas usage. The boiler combustion efficiencies were not provided by the site, and efficiency tests could not be performed as there was construction around the plant preventing access to the main mechanical building. The site CHP was mentioned but details were not provided for the system. The contact who escorted the evaluators through the campus was a new employee at the time and did not know details on the CHP. The contact who escorted the evaluators on the return visit also did not know details on the system. The evaluators forwarded a questionnaire to the site after the visits were conducted to answer some overall questions on the CHP system, which have gone unanswered. The evaluator was able to find detailed notes and news on the utilities of the campus on the University's website. Under the gas and steam section (updated in 2017), 4 boilers of varying sizes were listed. There was no mention of a CHP. From this information the evaluator assumed the boilers were the main steam generator, and used a standard combustion efficiency of 83.2%, which is a value established by the Baseline Advisory Group to account for stack heat losses.

The evaluator took spot measurements for bare and insulated surface temperatures as well as ambient temperatures in different areas using an infrared temperature gun. Multiple temperature probes were installed to accessible insulated applications to capture both bare pipe and ambient temperatures for each metered building. Ambient pendent loggers were also hung in multiple buildings. Temperature fluctuations were captured over a one-month period.

Measured and Logged Data

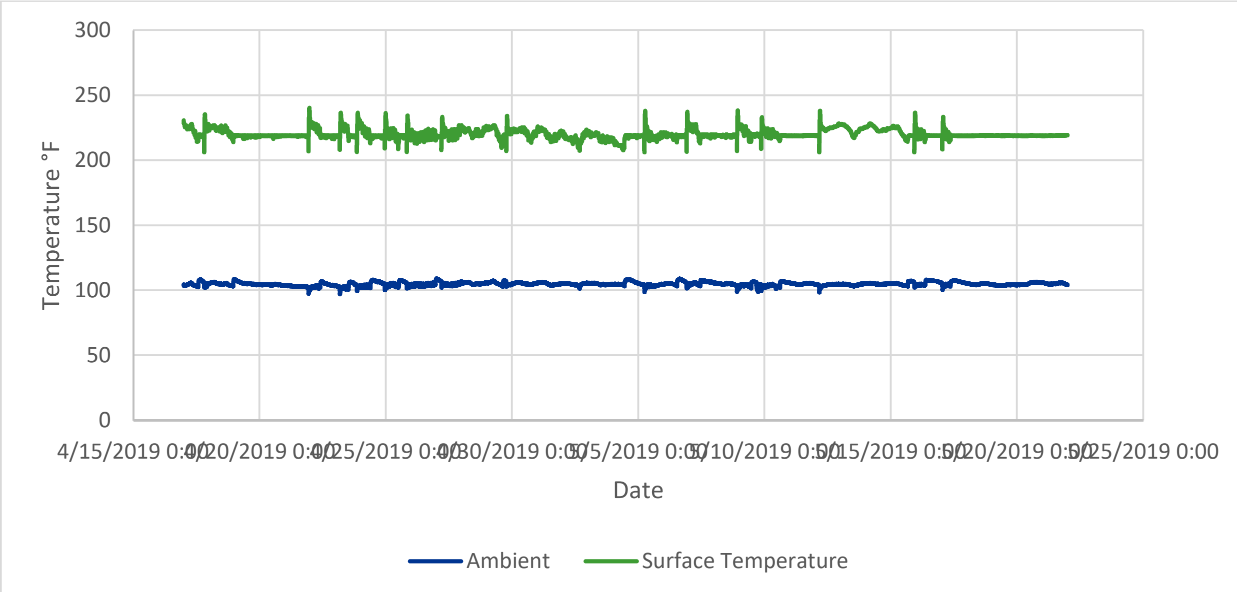
The evaluator deployed data loggers to characterize the temperature profiles for a number of pipes and fittings from April 17, 2019, through May 21, 2019. Table 6-5. Data Logger Deployment Details presents the logger deployment details.

Table 6-5. Data Logger Deployment Details

Data Logger Type	Parameter	Time Interval	Duration	Quantity
HOBO MicroStation with Temperature Sensors	Pipe and Ambient Temperature	1 minute	6 weeks	9
HOBO High Temperature Logger	Pipe and Ambient Temperature	1 minute	6 weeks	1
HOBO Pendant Temperature Logger	Ambient Temperature	2-3 minutes	6 weeks	4

An example of logged temperature data is shown below in Figure 6-2. Logged Temperature Data

Figure 6-2. Logged Temperature Data – HXXX Dorm (PII Removed) Heat Exchanger



The evaluator used the metered temperature data to calculate an operating profile to show when steam was supplied to the insulated applications during the metered period. The data was adjusted to show operation above an established baseline (212 °F in this case). Metered hourly data was expanded to fit a weekly profile. The profile depicts an hourly percent on value that shows the supplied steam operation compared to the max temperature observed in the adjusted sample. Table 6-6. Steam Supplied to HXXX Dorm (PII Removed) Heat Exchanger - % On below presents the weekly operating profile for the heat exchanger depicted in Figure 6-2. Logged Temperature Data – HXXX Dorm (PII Removed) Heat Exchanger

Table 6-6. Steam Supplied to HXXX Dorm (PII Removed) Heat Exchanger - % On

Hour	Sun	Mon	Tue	Wed	Thu	Fri	Sat
1	29%	42%	37%	44%	46%	31%	22%
2	28%	42%	36%	43%	36%	30%	20%
3	29%	41%	37%	41%	37%	33%	20%
4	27%	40%	37%	41%	34%	26%	20%
5	33%	39%	38%	37%	34%	27%	19%
6	35%	40%	47%	39%	33%	25%	24%
7	41%	38%	45%	39%	33%	25%	26%
8	36%	39%	42%	39%	32%	26%	20%
9	33%	33%	38%	34%	29%	25%	23%
10	28%	30%	37%	27%	23%	27%	20%
11	27%	26%	31%	27%	24%	25%	22%
12	29%	24%	35%	24%	24%	25%	24%
13	29%	21%	30%	21%	24%	21%	25%
14	30%	20%	29%	19%	26%	22%	25%
15	30%	21%	29%	20%	24%	22%	26%

Hour	Sun	Mon	Tue	Wed	Thu	Fri	Sat
16	30%	24%	27%	20%	25%	23%	25%
17	29%	27%	26%	23%	24%	24%	25%
18	28%	28%	27%	24%	25%	22%	26%
19	29%	27%	25%	24%	25%	25%	26%
20	30%	36%	27%	24%	26%	22%	28%
21	32%	31%	28%	34%	29%	24%	27%
22	35%	30%	40%	29%	37%	22%	29%
23	34%	37%	37%	39%	31%	23%	27%
24	49%	37%	38%	50%	28%	22%	29%

From the expanded data set, the evaluator was able to determine an estimated energized profile for the as-built insulated applications. Table 6-7. below depicts the evaluated energized hours extrapolated from metered data compared to applicant hours. These hours were applied to un-metered area by determining the space type of the area. A campus key was provided where buildings were categorized under residential, classroom, lab, offices, gym, etc. Evaluated hours were applied to the specific building types listed below, in tandem with the heat loss bin values determined from Table 6-8 to determine application specific savings.

Table 6-7. Annual Energized Operating Hours

Building	Building Type	Applicant Hours	Evaluated Hours
Center for Biotech	Lab	5,040	4,225
HXXX (PII Removed) Dorm	Residential	5,040	4,194
Pharmacy	Classroom	5,040	4,446
Unspecified building	Unspecified	1,500, 5,040, 8,640	1,500, 5,040, 8,640

1.2.4 Evaluation Methods and Findings

This section describes the evaluator methods and findings.

Evaluation Description of Baseline

The evaluator reviewed the project files and interviewed the site contact to gather information on the baseline. The evaluator determined the measure is an add on with a single baseline measure because the underlying steam distribution system is expected to outlive the installed pipe and fitting insulation jackets. The baseline is the preexisting steam system with bare pipes and fittings, supplying steam at 100 psi.

Evaluation Calculation Method

The evaluator modeled energy savings using 3EPlus simulations to determine bare and insulated heat loss values for each unique application using the input parameters confirmed on-site. These parameters include pipe size, insulation thickness, as well as operating and ambient temperatures.

In 3EPlus the default calculation type of “heat loss per hour” was used for all applications. Under the system application drop down, “Pipe – Horizontal” was used for straight pipe applications while “tank shell – horizontal” was used for blanket applications. For material selection, “850F Mineral Fiber PIPE, Type I” was used for straight pipe applications while “850F MF Blanket, Type IV” was used for blanket applications. An example of a 3EPlus output is shown below in and Figure 6-3. 3EPlus: Blanket Insulation

Figure 6-3. 3EPlus: Blanket Insulation

Heat Loss Per Hour Report

System Application:	Tank Shell - Horizontal	
Dimensional Standard:	ASTM C 585 Rigid	
Calculation Type:	Heat Loss Per Hour	
Process Temp:	224.4	°F
Ambient Temp:	89	°F
Wind Speed:	0.0	mph
Jacket Material:	All Service Jacket	
Jacket Emittance:	0.9	
Insulation Layer 1:	850F MF BLANKET, Type IV, C553-13	Varied

Variable Insulation Thickness	Surface Temp (°F)	Heat Loss (BTU/hr/ft^2)	Efficiency (%)
Bare	224.2	299.80	
0.5	125.0	63.18	78.92
1.0	110.9	35.54	88.14
1.5	104.9	24.78	91.73
2.0	101.6	19.04	93.65
2.5	99.4	15.46	94.84
3.0	97.9	13.02	95.66

The evaluated savings for the insulation measure were calculated for each unique insulated application using the following formula:

$$Svgs = \frac{Qty \times \left(SA_{fitting} \text{ or } L_{pipe}\right) \times \left(HLR_{bare} - HLR_{insulated}\right) \times Hours}{100{,}000 \times \eta}$$

where,

$Svgs$	= Annual energy savings per year (therm/yr)
$SA_{fitting}$	= Surface area of fitting being insulated (ft^2)
L_{pipe}	= Length of the pipe (ft)
HLR_{bare}	= Heat loss rate of bare pipe (Btu/hr/ft^2 or Btu/hr/ft), calculated using 3EPlus
$HLR_{insulated}$	= Heat loss rate of insulated pipe (Btu/hr/ft^2 or Btu/hr/ft), calculated using 3EPlus
$Hours$	= Annual energized hours of use

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

η = Boiler combustion efficiency, 83.2%

Table 6-8 compares the calculated results for the equipment bins corresponding to Table 6-4. Savings shown were determined using the heat loss bins below, as well as the building specific hours of use shown in Table 6-7. Annual Energized Operating Hours.

Table 6-8 Comparison of Applicant and Evaluation Calculated Results

			Application		Evaluation		
Bins	**Count**	**Bare heat loss [BTU/hr/sf]**	**Insulated heat loss [BTU/hr/sf]**	**Total Savings [Therm]**	**Bare heat loss [BTU/hr/sf]**	**Insulated heat loss [BTU/hr/sf]**	**Total Savings [Therm]**
Jacket Bin 1	828	233	17.7	37,148	225	29.5	29,257
Jacket Bin 2	117	354	24.7	8,862	299	33.7	6,171
Jacket Bin 3	345	395	28.9	20,051	343	42.3	15,703
Jacket Bin 4	183	437	32.0	8,445	377	52.3	6,649
Jacket Bin 5	8	446	43.3	595	383	44.4	370
Jacket Bin 6	26	589	31.7	3,102	432	50.0	2,350
Jacket Bin 7	110	563	39.9	5,245	488	60.7	3,252
Jacket Bin 8	94	642	45.8	6,428	529	63.9	4,635
Jacket Bin 9	13	661	26.6	1,304	572	50.4	1,178
Jacket Bin 10	12	689	31.5	672	599	55.7	530
Jacket Bin 11	267	766	34.8	49,829	915	74.0	49,040
Jacket Bin 12	34	824	42.1	1,820	742	60.4	1,367
Pipe Bin 13	84	240	16.4	485	228	30.2	83
Pipe Bin 14	73	418	38.7	65	343	44.0	24
Pipe Bin 15	6	775	54.2	138	484	52.7	31

1.3 Final Results

The project consisted of the installation of fitted insulation jackets on various sections of straight pipe, fittings, steam sleeves, and other heating equipment. The evaluator used field parameters to calculate heat loss through 3EPlus simulations. The evaluated savings are less than the reported values. The parameters impacting the analysis are summarized below in Table 6-9. Summary of Key Parameters

Table 6-9. Summary of Key Parameters

As-Built	Applicant	Evaluator
Energized annual operating hours	Classroom: 5,040 Lab: 5,040 Residential: 5,040 Unspecified: 1,500, 5,040, 8,640	Classroom: 4,446 Lab: 4,225 Residential: 4,194 Unspecified: 1,500, 5,040, 8,640
Average combustion efficiencies	80%	83.2%
Ambient temperature	70-110°F	89°F
Operating temperature	185-350°F	200-350°F
Gas/Oil usage ratio	85%	88%
Savings		
Annual natural gas savings (therms)	144,188	120,639
Natural gas realization rate	84%	

1.3.1 Explanation of Differences

The evaluated savings are less than the tracked savings primarily due to the difference in the oil/gas usage ratio, calculated heat loss values using 3EPlus, boiler combustion efficiency, and energized operating hours. Table 6-10 provides a summary of the differences between tracking and evaluated values.

Table 6-10. Summary of Deviations

End-use	Discrepancy	Parameter	Impact of Deviation	Discussion of Deviations
Process	Other	Oil/Gas Ratio	+3%	**Increased savings** – due to the difference in usage between oil and gas.
Process	Other	Heat Loss	+1%	**Increased savings** – due to the difference in calculated heat loss values based on gathered field parameters, primarily operating and ambient temperatures.
Process	Other	Quantity adjustment	-<1%	**Decreased savings** – due to an error in documented savings where some applications were considered twice.
Process	Other	Boiler Efficiency	-4%	**Decreased savings** – due to the difference in boiler efficiency
Process	Operational	Boiler operating hours	-14%	**Decreased savings** - the evaluated operating hours of hot water heaters 3 and 4 are less than the values used by the applicant to calculate the measure savings.

1.3.2 Lifetime Savings

Because the steam distribution system will outlive the installed measure, the evaluators classified this measure as an add-on with a single baseline.

The evaluated lifetime savings are smaller than the tracking lifetime savings because the evaluated first year savings are smaller than the tracking first year savings. Table 6-11 provides a summary of key factors that influence the lifetime savings.

Table 6-11. Lifetime Savings Summary

Factor	Tracking	Applicant	Evaluator
Lifetime savings	2,162,823 therms	2,162,823 therms	1,809,582 therms
First year savings	144,188 therms	144,188 therms	120,639 therms
Measure lifetime	15 years	15 years (project BCR)	15 years (MA TRM for jacket insulation)
Baseline classification	Retrofit	Retrofit	Add-on single

Ancillary impacts

There are no ancillary impacts for this site as the space isn’t cooled.

2 Site 2017RIG053

Program Administrator	National Grid
Application ID(s)	7031387
Project Type	Retrofit
Program Year	2017
Evaluation Firm	DNV GL
Evaluation Engineer	Ryan Brown
Senior Engineer	Srikar Kaligotla

2.1 Evaluated Site Summary and Results

The evaluated project was implemented at a manufacturing plant and consisted of the repair of failed steam traps under this retrofit measure. The applicant calculated the measure savings due to the reduction in steam losses from the repair of failed traps.

The evaluators modeled savings based on temperature spot measurements using an infrared temperature gun, logged temperature data, logged boiler run-time hours, and information gathered from on-site interviews. A boiler combustion efficiency test was not performed by the evaluator. Gas savings were calculated using site data to determine the impact on associated steam losses. The evaluators determined the measure is a retrofit with a single baseline. The evaluated baseline is pre-existing conditions as identified when the vendor conducted a steam trap survey, which is the same as the applicant baseline. The evaluator calculated the project savings using the newly revised 2018 Custom Express steam trap tool with input parameters observed on site. The older tool was used for the tracking estimate. The evaluated savings were less than the tracking values using the older tool and less than the savings that would have been reported by the program if they would have been calculated using the revised 2018 Custom Express tool.

The evaluation results are presented in Table 6-3.

Table 6-12. Evaluation Results Summary

PA Application ID	Measure Name		Savings (Therms/yr)	Measure Life (years)	Lifetime Savings (Therms)
7031387	Steam traps	Tracked	2,081	6	12,487
		Tracking savings calculated with the new tool[1]	2,415	6	14,490
		Evaluated	1,442	6	8,652
		Realization rate[2]	60%	N/A	N/A
Totals		**Tracked**	**2,081**	**6**	**12,487**
		Tracking savings calculated with the new tool[1]	**2,415**	**6**	**14,490**
		Evaluated	**1,442**	**6**	**8,652**
		Realization rate[2]	**60%**	**N/A**	**N/A**

N/A = Not applicable

[1]Program savings calculated using the new tool are calculated using the applicant inputs applied to the 2018 Custom Express Tool

[2]The realization rate is the ratio of evaluated savings to program savings calculated using the new tool

2.1.1 Explanation of Deviations from Tracking

The evaluated savings are 40% less than the savings the program would have been reported if the savings would have been calculated using the new 2018 Custom Express tool primarily due to the difference in operating pressure, energized hours, and boiler efficiency. Further details regarding deviations from the tracked savings are presented in Section 3-4.

2.1.2 Recommendations for Program Designers & Implementers

The evaluator recommends that savings for all steam trap projects going forward, be calculated using the newly revised 2018 Custom Express tool.

2.1.3 Customer Alert

There are no customer alerts for this project.

2.2 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 the repair or replacement of 7 failed steam traps identified in the vendor scoping audit.

2.2.1 Application Information and Applicant Savings Methodology

This section describes the application information, savings methodology provided by the applicant, and the evaluation assessment of the savings calculation algorithm used by the applicant. Both applicant and evaluated approaches calculated system steam losses based on steam properties calculated via on-site findings and assumptions. Project savings were primarily based upon the reduction in steam losses.

2.2.2 Applicant Description of Baseline

The applicant classified the measure as a retrofit with a single baseline. According to the savings analysis file provided by the applicant, the baseline is the pre-existing steam system identified through a third-party scoping audit. In the survey, each trap was classified as working, plugged, leaking, or blowing through. The vendor performed temperature and ultrasonic testing to determine the working status of the steam traps. Per the project documents, the vendor identified 23 steam traps where 7 were found to need repairs. The results of the survey can be seen in Table 6-13. Steam Trap Survey Results with the corresponding loss factors associated with each classification. The applicant used a boiler combustion efficiency of 80%.

Table 6-13. Steam Trap Survey Results

Trap Status	Loss Factor	Quantity Surveyed	Gas Savings (Therms)	% of Gas Savings
Fully operational	0%	16	0	0%
Partial leak	25%	7	2,081	100%
Grand total		**23**	**2,081**	**100%**

Applicant Description of Installed Equipment and Operation

The vendor replaced the 7 steam traps that were leaking

Table 6-14. Measure Level Details

Location	Trap Quantity	Gas Savings (Therms)	Average Operating Hours	Average Steam Pressure at Trap (psig)
Dryer room	7	2,081	2,000	40
Grand Total	**7**	**2,081**	**2,000**	**40**

Applicant Energy Savings Algorithm

he applicant calculated the savings using a custom analysis spreadsheet provided by the Program Administrators using the findings from the steam trap survey as inputs. 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 the 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 the latent heat of trap steam not serving boiler loads (Btu/hr) see below

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

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

A 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 the latent heat of steam not being used to serve boiler loads throughout the 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 the 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%)

Evaluation Assessment of Applicant Methodology

The applicant correctly used the 2010 Custom Express tool, and the evaluator determined the application calculation methodology reasonable.

2.2.3 On-Site Inspection and Metering

This section provides details on the tasks performed during the site visit and the gathered data.

Summary of On-site Findings

The evaluators conducted a site visit on February 19, 2019. During the site visit, the evaluators interviewed the facility maintenance manager and verified the applicant inputs by taking spot temperature measurements using an infrared gun, performing ultrasonic testing, and installing some temperature and motor loggers for long term metering. A summary of the on-site spot verification and metered data compared with the inputs used by the applicant in the tracking savings calculations is provided in Table 6-15. Note that in addition to the seven replaced traps, the evaluator also verified three other traps to confirm they are not leaking. The evaluator steam pressure was extrapolated from the steam tables based on measured temperature data.

Table 6-15. Summary of Applicant's and Verified Parameters

	Applicant		Evaluator				
Tag #	Annual Hours of Operation	Steam Pressure at Trap (psig)	Ultrasonic Readings (dB) In	Ultrasonic Readings (dB) Out	Ultrasonic Readings (dB) Orifice	Temp (°F)	Steam Pressure at Trap (psig)
290	2,000	40	16	28	11	263	22.6
291	2,000	40	19	20	22	253	16.7
292	2,000	40	16	17	17	255	17.8
293	2,000	40	16	17	17	264	23.2
294	2,000	40	22	21	23	255	17.8
295	2,000	40	32	34	30	254	17.3
962	2,000	40	22	26	21	253	16.7
963	2,000	40	23	16	15	254	17.3
969	2,000	40	14	24	16	254	17.3
Unknown	2,000	40				252	16.2
Unknown	2,000	40				273	29.3

Steam traps listed as "unknown" were monitored long term for temperature. The evaluator did not note the trap tags. An ultrasonic leak detector with dB level measurements was used to listen to the steam trap operation to determine if steam was leaking. Ultrasonic dB measurements were taken within 6 in. of the inlet and outlet of the steam trap for baseline operation. If the ultrasonic dB measurements at the orifice were equal to or lower than the baseline, then the trap was fully operational. If not, the steam trap was leaking within 10% of the baseline dB level and blowing by if greater than 10%. Based on the on-site results, the steam traps measured were found to be on the border of fully operational.

The site is equipped with one natural gas-fired boiler estimated to operate at 40 psi and maintain energized steam to the traps for 2,000 annual hours. Two high-temperature HOBO loggers with thermocouples were installed to bare trap surfaces to capture temperature fluctuations over a period of four months. One DENT motor logger was installed to the boiler motor to capture and estimate annual run-time hours. The evaluator was not able to perform a boiler combustion efficiency test due to safety constraints on-site. Historic efficiency tests were not provided either. Instead, the evaluator used a boiler efficiency of 83.2% for the boilers with linkage control, which is a value derived from the MA baseline advisory group for this specific boiler configuration.

Measured and Logged Data

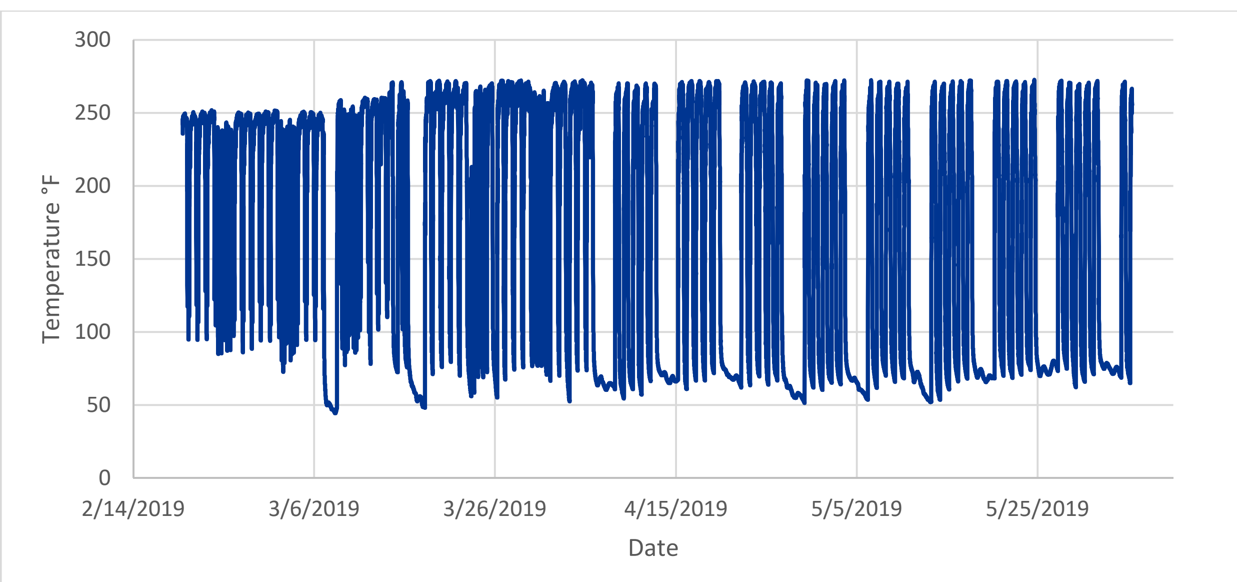
The evaluator deployed data loggers to characterize the temperature profiles for a couple of steam traps from February 19, 2019, through June 4, 2019. Table 6-16 presents the logger deployment details.

Table 6-16. Data Logger Deployment Details

Data Logger Type	Parameter	Time Interval	Duration	Quantity
HOBO high-temperature logger with thermocouple	Temperature	5 minute	17 weeks	2
DENT motor logger	Annual Operating Hours	15 minutes	17 weeks	1

An example of logged temperature data is shown below in Figure 6-4. Logged Temperature Data.

Figure 6-4. Logged Temperature Data – Other



The evaluator did not note the boiler operating discharge pressure or the observed pressure readings at the pressure-reducing valves (if applicable). Instead, long term temperature samples were used to extrapolate pressure from the steam tables by using the max observed value. The evaluator decided not to include spot measurements taken from IR gun samples as those could be inconsistent. The average calculated pressure from the two traps that were metered long term was used as a proxy for the remaining sample of traps, as all were shown to operate on the same pressure.

Temperature loggers were deployed on two traps to determine annual energized hours of use. Logger data from one of the traps is shown in Figure 2-1, depicting temperature fluctuations during the metered period. The evaluator used the metered temperature data to calculate an operating profile to show when steam was supplied to the as-built steam traps during the metered period. Metered hourly data was expanded to fit a weekly profile. The profiles depict an hourly percent on value that shows the supplied steam operation over baseline (212°F) compared to the max temperature value seen in the data. The max value shown in the metered data correlates to a pressure less than the estimated operating pressure shown in the application. It is possible that the application over estimated trap operating pressure for this steam system. Table 6-17. Steam Supplied to Process Trap - % On presents the weekly operating profile for the sampled trap.

Table 6-17. Steam Supplied to Process Trap - % On

Hour	Sun	Mon	Tue	Wed	Thu	Fri	Sat
1	3%	4%	5%	6%	7%	2%	5%
2	5%	3%	3%	5%	4%	3%	5%
3	3%	1%	1%	1%	2%	0%	0%
4	3%	2%	2%	1%	2%	2%	2%
5	10%	8%	7%	9%	13%	11%	4%
6	8%	13%	10%	14%	17%	15%	3%
7	11%	27%	35%	37%	38%	40%	8%
8	17%	51%	55%	58%	57%	53%	16%
9	11%	68%	68%	67%	67%	66%	9%
10	9%	72%	72%	68%	70%	69%	4%
11	4%	75%	73%	72%	71%	70%	1%
12	5%	75%	76%	75%	73%	71%	5%
13	0%	78%	76%	75%	74%	72%	1%
14	1%	78%	77%	76%	73%	73%	0%
15	3%	81%	79%	79%	76%	78%	1%
16	4%	71%	69%	70%	66%	70%	6%
17	0%	50%	53%	56%	47%	52%	1%
18	2%	37%	45%	51%	36%	41%	1%
19	9%	35%	44%	50%	36%	41%	8%
20	6%	32%	38%	44%	30%	36%	10%
21	3%	26%	29%	35%	25%	26%	4%
22	11%	24%	28%	33%	25%	24%	9%
23	7%	12%	16%	18%	13%	16%	9%
24	2%	4%	5%	5%	2%	3%	2%

The operating profile from the logged temperature data depicts average operation weekdays between 8 AM and 4 PM. Morning, evening, and weekends seem to be shut down. The logged boiler runtime data corroborate these findings as the boiler seems to mainly operate between 8 AM and starts to ramp down after 4 PM. The boiler looks to be typically off during early mornings and weekends.

From the expanded temperature data set, the evaluator was able to determine an estimated annual operation for the as-built steam traps. Table 6-18 below depicts the estimated annual operation for both metered traps compared to the applicant assumed operating hours.

Table 6-19 Evaluated Steam Trap Operating Hours by Application

Steam Trap	Applicant Annual Hours	Evaluation Annual Hours
Other – Logger 20550129	2,000	936
Other – Logger 20550137	2,000	2,611
Average	2,000	1,774

2.2.4 Evaluation Methods and Findings

This section describes the evaluator methods and findings.

Evaluation Description of Baseline

The evaluator reviewed the project files and interviewed the site contact to gather information on the baseline. The evaluator determined the measure is a retrofit with a single baseline measure, where the baseline would be the pre-existing traps as identified in the steam trap survey.

Evaluation Calculation Method

The evaluator calculated the savings using a revised version of the Custom Express tool that was adopted by the National Grid subsequent to the program year of this application. The 2018 revised Custom Express tool includes a different leak factor and no longer applies the repair/replace factor to the trap savings calculation. 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 also compare the evaluated steam trap savings with the savings calculated using the 2018 Custom Express methodology updated with the original applicant inputs.

Evaluated savings. A revised version of the custom express tool was adopted by National Grid 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 ($lb_m/(in^{0.06}\text{-}lb^{0.97}\text{-}hr)$)

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

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)

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 by the applicant as they were verified on-site using spot checks and site contact interviews. The evaluator corrected the pre-retrofit operating status to reflect the updated inputs. Specifically, "partially leaking" and "partially blowing-by" was updated to "leaking" and "blowing-by" respectively, based on guidance from the Phase 2 study results. With these updated statuses, the evaluators were able to apply the revised leak factors to the custom savings equation.

Program savings calculated using the new tool. The evaluator calculated the program savings that would have been reported if the 2018 Custom Express tool had been used to model the measure savings. The savings calculated using the ex-ante assumptions resulted in savings of 2,415 therms per year. Table 2-7 compares the reported tracking estimates, program savings calculated using ex-ante assumptions and the 2018 Custom Express tool, and the evaluated savings.

Table 6-20. Steam Trap Survey Findings

Method	Savings (therms)
Tracked	2,081
Tracking savings calculated with the new tool[1]	2,415
Evaluated	1,442

[1]Program savings calculated using the new tool are calculated using the applicant inputs applied to the 2018 Custom Express tool

Cross-Check with Utility Billing Data

The evaluators conducted billing analysis to verify the evaluated savings for this site as well as analyze the pre-existing gas usage which is difficult to be accurately modeled otherwise. However, the evaluated savings is only 2.2% of the post-retrofit annual usage. Due to the embedded error in the weather normalization, DNV GL determined the billing anlaysis would not yield meaningful results given the small amount of the savings for this measure.

2.3 Final Results

The project consisted of the repair of failed steam traps discovered through a vendor study for the steam traps located in the dryer room. The applicant calculated savings for the steam trap measure using the older 2010 Custom Express tool with inputs collected from the steam trap survey conducted in 2017. The evaluator calculated savings for the steam trap measure using the 2018 revised version of the Custom Express tool with inputs collected from metered and measured data. The evaluated savings for the project were smaller than the savings the program would have been reported if the savings would have been calculated using the 2018 Custom Express tool. The parameters characterizing the analysis are depicted in Table 6-21. Summary of Key Parameters.

Table 6-21. Summary of Key Parameters

Baseline	**Applicant**	**Evaluator**
Impacted system	Existing boiler plant and steam distribution system with 7 failed steam traps	Existing boiler plant and steam distribution system with 7 failed steam traps
Boiler plant efficiency	Combustion efficiency: 80% System line losses: 0%	Combustion efficiency: 83.2 System line losses: 0%
Steam operating pressure	40 psi	22.8 psi
Steam trap operating hours	2,000	1,774
As-Built	**Applicant**	**Evaluator**
Impacted system	Existing boiler plant and steam distribution system with 7 steam traps that were repaired by this measure	Existing boiler plant and steam distribution system with 7 steam traps that were repaired by this measure
Boiler plan efficiency	Combustion efficiency: 80% System line losses: 0%	Combustion efficiency: 83.2 System line losses: 0%
Steam operating pressure	40 psi	22.8 psi
Steam trap operating hours	2,000	1,774
Savings		
Annual natural gas savings (therms)	2,415	1,442
Natural gas realization rate	60%	

2.3.1 Explanation of Differences

The evaluated savings are 40% less than the savings the program would have been reported if the savings would have been calculated using the 2018 Custom Express tool. Table 6-22. Summary of Deviations below provides a summary of the differences between tracking and evaluated values.

Table 6-22. Summary of Deviations

End-use	Discrepancy	Parameter	Impact of Deviation	Discussion of Deviations
Process	Operational	Steam operating pressure	-28%	**Decreased savings** - due to a difference in observed boiler discharge pressure.
Process	Operational	Energized steam operating hours	-8%	**Decreased savings** - due to the reduction in evaluated energized steam operating hours.
Process	Operational	Boiler efficiency	-4%	**Decreased savings** - due to a difference in boiler efficiency.

2.3.2 Lifetime Savings

The evaluator determined the measure is a retrofit with a single baseline measure, where the baseline would be the pre-existing traps as identified in the steam trap survey conducted at the facility.

The evaluated lifetime savings are smaller than the tracking lifetime savings because the evaluated first-year savings are smaller than the tracking first-year savings. Table 6-11 provides a summary of key factors that influence the lifetime savings.

Table 6-23. Lifetime Savings Summary

Factor	Tracking	Program Savings using the 2018 Custom Express Tool	Evaluator
Lifetime savings	2,081 therms	2,415 therms	1,442 therms
First year savings	12,487 therms	14,490 therms	8,652 therms
Measure lifetime	6 years	6 years (project BCR)	6 years (MA TRM for steam traps)
Baseline classification	Retrofit	Retrofit	Retrofit

The equivalent measure life for this project is 6 years.

Ancillary impacts

There are no ancillary impacts for this site as space isn't cooled.

3 Site 2017RIG098

Project ID	5685729
Program admin	National Grid
Lead evaluation engineer	Chris Williams, DNV GL
Report author	Chris Williams, DNV GL

Project Description

This project performed “phase 5” improvements at a hospital campus with approximately 450,000 square feet of conditioned space. The hospital campus consists of eight major buildings. The evaluation scope is limited to one building: building D. One of the evaluated measures is a chilled water plant optimization which consists of two sub-measures. The other evaluated measures included a number of HVAC controls and re-commissioning/repair measures that are summarized below.

- EEM 1.00: Improve the existing hot water temperature reset schedule by lowering the minimum loop temperature during mild weather. Reducing the hot water temperature reduces heat loss from pipes, valves and pumping equipment, and can also improve temperature control.
- EEM 2.00: Improve economizer control on AC-5 and AC-6. This included damper repair and re-programming/re-commissioning. Since AC-5 and AC-6 have CHW coils that are served by steam absorption chillers, gas savings are realized.
- EEM 3.00: This measure retrofitted existing VAV air handler with VFDs and locked the existing inlet guide vanes in the open position. A total of three VFDs were installed, one each on AC-1 supply and return fans and one on AC-4 supply fan. The VFDs modulate to maintain static pressure similar to the inlet guide vane operation. Energy savings are created by using a VFD to modulate the airflow, which reduces airflow more efficiently than inlet guide vanes. An unoccupied static-pressure setback was also added to AC-4 and the occupied schedule for AC-1 was modified.
- EEM 5.00: This measure consists of two sub-measures.
    - 5C: Optimize Condenser Water Temperature. This measure is a condenser water supply temperature reset schedule based on outside air wet-bulb temperature. This schedule will reset the supply temperature from 84 °F down to a minimum of 75 °F. The plant used to operate at a constant temperature of 84 °F whenever the old absorbers were running.
    - 5D: Repair Bridge – Repair ED AHU Economizers and Shut off Plant During Economizer Weather. This measure repaired 10 air handlers in the “B–ED” building to allow them to properly economize. These AHUs are served by the building D chiller plant, and repairing the economizers will allow the plant to be shut down when the outside air temperature is less than 45 °F.

The building D central plant is the only central chiller plant involved in this project. It contains one 700-ton water-cooled centrifugal chiller and four single-effect steam absorption chillers totaling 1,600 tons (two rated at 550 tons, two rated at 250 tons).

The campus space heating is achieved with a central steam plant with two 16 MMBTU/hr natural gas-fired boilers. There are three steam HHW converters and HHW is supplied to AHU preheat and reheat coils. The hospital uses approximately 12 GWh electricity, 8 million Therms, and 680,000 gallons of #6 fuel oil annually.

Table 24: Project tracking savings by measure

Measure	Energy savings (Therms)	% of total savings
EEM 1.00 – Optimize Hot water reset on building D converters	7,313	1.6%
EEM 2.00 – Repair AC-5 & AC-6 economizer controls	8,289	1.8%
EEM 3.00 Retrofit VFDs on AHUs	18,135	3.9%
EEM 5.00 – CHW plant optimization and AHU economizer repair	428,125	92.7%
Total	**461,862**	**100%**

The table above summarizes the project's individual measures savings as reported in tracking and the table below summarizes evaluation results, aggregated to the application ID. Evaluation results for the individual measures are presented later in the report.

Table 25: Project results for 5685729

Measure	Tracking energy savings (Therms)	Evaluated energy savings (Therms)	Realization rate (%)
EEM 1.00 – Optimize Hot water reset on building D converters	7,313	4,930	67%
EEM 2.00 – Repair AC-5 & AC-6 economizer controls	8,289	2,920	35%
EEM 3.00 Retrofit VFDs on AHUs	18,135	7,069	39%
EEM 5.00 – CHW plant optimization and AHU economizer repair	428,125	552,577	129%
Total	**461,862**	**567,496**	**123%**

The bullets below explain some key discrepancy findings:

- EEM 1.00 did not realize 33% of savings because while the hot water (HW) temperature reset was implemented, the schedule was less aggressive than estimated in the tracking savings calculation. The tracking calculation assumed that the HW temperature would reset with a high/low HW/OAT schedule of 180 °F/0 °F and 130 °F/40 °F. The observed schedule had shifted the low HW/OAT set points to 130 °F / 70°F.

- EEM 2.00 realized 35% of the tracking savings mostly due to a change in the estimated supply air volume being conditioned by the AHUs affected by the economizer repairs. Trend data collected (for AC-5) by the evaluator were used to reduce the tracking supply air volume estimates (based on supply fan speed and design cfm) with measured supply airflow using calibrated flow stations. The reduction in estimated supply air volume reduced the cooling load to be saved.

- The largest discrepancy in savings realization for EEM 3.00 came about from the proposed unoccupied supply fan speed for AC-1. The applicant proposed that the AC-1 fan would be off during unoccupied periods. The evaluation found that the AC-1 fan was on during unoccupied periods, but at a reduced speed. This observation had a negative impact on savings. The observed fan speeds for AC-4 during heating periods were also lower than what was assumed in the tracking calculation. This observation for AC-4 had a positive impact on savings.

- Savings for EEM 5.00 increased because the measured loop loads were higher than what had been modeled, and the evaluator verified and accepted the additional savings modeled to represent AHU economizers offsetting chiller load in shoulder temperatures 40 °F < OAT < 60 °F. The model was also adjusted to schedule the chillers off (December through March) to match the observed chiller operation.

1.1 Tracking Savings

This section summarizes the methodology and assumptions used to estimate the tracking savings claimed for the project.

1.1.1 Baseline Condition

The baseline equipment and conditions for each project are summarized below. Details on baseline equipment loads and energy consumption are explained in the calculation methodology section.

EEM 1.00 – Optimize Hot water reset on building D converters

Two hot water systems serving perimeter radiation and VAV reheat coils are monitored but not controlled by the existing EMS system. Both systems have HW supply temperature set points between 175-180 °F. No automatic reset controls exist, but the HW supply temperatures are manually adjusted by plant operators.

EEM 2.00 – Repair AC-5 & AC-6 economizer controls

AC-5 economizer had two operating sequences. One was a dry-bulb high limit of 60 °F; the other was a comparative enthalpy control that was not working properly and overriding the high limit dry bulb temperature. AC-5 economizer damper was observed to be fully open (100%) when the outside air temperature was 90 °F. At this outside air temperature, the damper should have been at its minimum position (30%). AC-6 damper modulation was observed to be disabled (at 30% open) and not responding to outside air temperature or comparative enthalpy.

EEM 3.00 Retrofit VFDs on AHUs

AC-1 and AC-4 are equipped with inlet guide vanes (IGVs) but they are stuck in place, allowing ~72% design flow for AC-1 and ~100% design flow for AC-4. AC-1 has supply and return fans; AC-4 is a 100% outside air unit. Both operate 24/7 and both are served by an absorption chiller.

EEM 5.00 – CHW plant optimization and AHU economizer repair

The condenser water supply temperature setpoint for the plant is 84 °F year-round.

Building B is served by 10 AHUs that require the building D chiller plant to operate year-round to provide the necessary cooling. The AHUs were observed to have broken or inoperable economizers. The building B AHUs are capable of having cooling requirements satisfied by outside air during cooler months if the economizers are operable.

2.1.1 Proposed condition

The proposed conditions are summarized below. Details on proposed equipment loads and energy consumption are explained in the calculation methodology section.

EEM 1.00 – Optimize Hot water reset on building D converters

Both interior and perimeter HW converters had automatic temperature reset schedules implemented to maintain HW temperatures according to the following range.

Table 26: EEM 1.00 reset schedule

Outside air temperature	Hot water temperature
40 °F	130 °F
0 °F	180 °F

EEM 2.00 – Repair AC-5 & AC-6 economizer controls
Economizer operating sequences for AC-5 and AC-6 are repaired, allowing the AC-5 outside air dampers to close when the outside air is not suitable for intake and made the AC-6 economizer damper modulation functional. AC-5 and AC-6 economizers now remain at their minimum position (30%) during outside air temperatures not suitable for air conditioning (above 65 °F and below 25 °F). For outside air temperatures suitable for cooling (between 25 °F and 65 °F), the economizers modulate from their minimum position to fully open (100%) to try to satisfy the discharge air temperature set point (55 °F).

EEM 3.00 Retrofit VFDs on AHUs
AC-1 and AC-4 fans were retrofitted with VFDs and their IGVs were completely removed. The VFDs modulate fan speed to maintain duct static pressure. In addition, AC-1 fans are scheduled off during unoccupied periods, and AC-4 duct static pressure is reduced during unoccupied periods.

EEM 5.00 – CHW plant optimization and AHU economizer repair
The condenser water temperature setpoint accepts the following reset schedule.

Table 27: Condenser water reset schedule

Outside air wet bulb temperature	Condenser water temperature
68 °F	75 °F
77 °F	84 °F

The building B AHU economizers are functional allowing the building D chilled water plant to shut down during colder temperatures (< 40 °F). Additional cooling savings (i.e., reduced absorber chiller energy usage) can occur during the economizing period (40 °F < OAT < 60 °F) due to the repaired economizers.

3.1.1 Tracking calculation methodology

The applicant used different savings methods depending on the measure. The savings method and a brief description of the inputs and assumptions used for each measure are described below.

All temperature bin calculations (except for EEM 1.00) use a similar calculation spreadsheet that uses some key calculation equations to estimate cooling and fan energy. The equations that are used in the spreadsheets are summarized in the equations below.

Cooling (coil) load:

$$E_{cooling} = 4.5 \times CFM_{supply,bin} \times \Delta H_{MA-CD,bin} + Heat_{SFmotor}$$

Where,

$E_{cooling}$ = total energy from cooling, kBtu/hr

$CFM_{supply,bin}$ = The supply airflow for each bin, cfm

$\Delta H_{MA\text{-}CD,bin}$= difference between mixed air enthalpy and cooling coil discharge enthalpy, Btu/lb

$Heat_{SFmotor}$ = Supply fan heat gain added to the air stream, Btu/hr

4.5 = unit conversion coefficient

Chilled water (absorber chiller) cooling energy:

$$EC_{therms} = \frac{E_{\ cooling} \times BinHrs}{100000 \times Eff}$$

Where,

$E_{cooling}$ = total energy from cooling, kBtu/hr

BinHrs = annual hours within the temperature bin

Eff = chiller or cooling efficiency. Assumed to be 75% for steam generation and 0.6 COP for absorption chiller

100000 = unit conversion coefficient

Fan energy:

$$E_{fan} = VFD_{\%,bin}^{2.5} \times kW_{fan,full\ speed} \times BinHrs$$

Where,

E_{fan} = total energy from fan, kWh

$VFD_{\%,bin}^{2.5}$ = The VFD fan speed, %, raised by the assumed fan law exponent of 2.5

$kW_{fan,\ full\ speed}$= the assumed full speed power of the fan

BinHrs = annual hours within the temperature bin

Almost all measures (except for the measure that uses eQUEST) had supplemental trend data, spot power measurements, and EMS screenshots to provide input for the equations and temperature bin calculations.

EEM 1.00 – Optimize Hot water reset on building D converters

Temperature bin analysis assuming a particular hot water supply temperature (HWST) setpoints based on outside air temperature. Conductive heat losses through HW pipes are calculated for each bin. The measure lowers the HWST set point thus lowers conductive heat loss. Conductive heat loss is assumed to be made up of the steam boiler. The following parameters are assumptions that feed into the savings calculation.

1. Ambient temperature heat is lost to: 70 °F
2. Pipe outer diameter = 1.5”
3. Insulation thickness = 1”
4. Insulation conductivity = 0.023 Btu/hr-ft-°F
5. Estimated pipe length = 6,021’
6. Boiler efficiency = 75%
7. Converter efficiency = 96%
8. Base case perimeter HWST SP when OAT > 65 °F = 150 °F
9. Base case perimeter HWST SP when OAT < 65 °F = 180 °F
10. Base case interior HWST SP when OAT > 60 °F = 150 °F
11. Base case interior HWST SP when OAT > 80 °F = 120 °F
12. Base case interior HWST SP when OAT < 60 °F = 180 °F
13. Proposed case (perimeter and interior) HWST SP when OAT > 40 °F = 130 °F
14. Proposed case HWST SP when OAT < 40 °F = linear reset from 130 °F to 176 °F

EEM 2.00 – Repair AC-5 & AC-6 economizer controls

The temperature bin model assumes a % outside air damper position (% of design supply air at outside air enthalpy) for each temperature bin. The key savings parameters and assumptions are:

1. AC-5 base case OA damper % is 100% for OAT above 55 °F. The damper position then modulates down to a minimum of 30%. AC-6 base case damper position is fixed at 30%.
2. AC-5 and AC-6 proposed case OA damper position fixed the minimum position at 30% for OAT above 65 °F. It then modulates between 100% and 30% to maximize free cooling.
3. The final discharge air temperature is 55 °F. This set point dictates how much free cooling (i.e., %OA) can be made available by the OA damper.
4. Design fan supply flow rate of 34,000 cfm. When OA% is equal to 100%, the economizer is drawing 34,000 cfm from outside.
5. Return air temperature is assumed to be a maximum of 74.2 °F (at the >90 °F temperature bin) and drops by 0.4 °F per bin.
6. Heating efficiency = 75%
7. Cooling efficiency = 0.6 COP

EEM 3.00 Retrofit VFDs on AHUs

The temperature bin model calculates supply airflow and fan power using fan power measurements, TSP measurements, and fan/motor efficiency assumptions. The gas energy savings assumes a profile that varies VFD speed based on bin temperature. The gas energy savings are based on the assumed VFD profile, corresponding supply airflow calculated by bin, and the calculated enthalpy differential between the mixed air and the discharge air. Gas energy savings are effectively based on a schedule change for AC-1 (from 24/7 to M-F 6a-9p), as the proposed airflow profile does not result in any savings for this unit. The key savings parameters and assumptions are:

1. Proposed condition: During the occupied period SF and RF speed at 50% for OAT < 35 °F and increases at 5% increment as OAT increases up to 100%
2. Proposed condition: During the unoccupied period both SF and RF remain off.
3. Heating efficiency = 75%
4. Cooling efficiency = 0.6 COP (absorption chillers)

EEM 5.00 – CHW plant optimization and AHU economizer repair

The measure savings are estimated using an eQUEST model with two parametric runs. Each parametric run represents one sub-measure of EEM 5.00.

EEM 5.00C is the condenser water reset measure. The eQUEST model simulates the measure by using the following key assumptions:

1. Base case condenser water loop setpoint control is fixed
2. Base case condenser water setpoint temperature is 84 °F
3. Proposed case condenser water loop setpoint control is schedule-based.
4. The proposed case condenser water loop setpoint schedule varies based on a custom entered the daily schedule. The schedule varies the condenser water set point from 75 °F to 81 °F. The daily schedules are shaped where colder morning and evening months and hours are set at 75 °F and gradually increase to 81 °F for mid-day hours where the OAT is expected to be warmer. The evaluator believes the schedule was made to emulate a temperature reset schedule but does not understand why a specific temperature reset schedule was not entered into eQUEST.

EEM 5.00D is the chiller plant optimization measure where the economizers of building B AHUs (12 in total, over 400,000 design supply cfm) are re-commissioned such that building D chillers can be shut down during colder winter weather. The eQUEST model simulates this measure by modifying the custom base case secondary chilled water load schedule to have effectively no load (i.e., chillers shut down) during the winter months. The custom secondary chilled water loop load schedule is a composition of 365 individual daily schedules that have hourly fractional loads ranging from 0 to 1. The full load secondary chilled water loop capacity is equivalent to the full load capacity of the chillers that are assigned to the secondary chilled water loops, as listed in the table below.

Table 28: Building D chiller schedule

Chiller	Capacity (tons)
Electric centrifugal VFD	700
Single-stage steam absorption	550
Single-stage steam absorption	550
Single-stage steam absorption	250
Single-stage steam absorption	250

The base case and proposed case secondary chilled water loop schedules are reportedly developed from analyzing base case trend data. The modeled base case and proposed case secondary chilled water loop loads are shown in the figures below. Notice how the proposed secondary chilled water loop loads drop when OAT drops below approximately 55 °F.

Figure 5: Base case secondary chilled water loop load versus outside air temperature

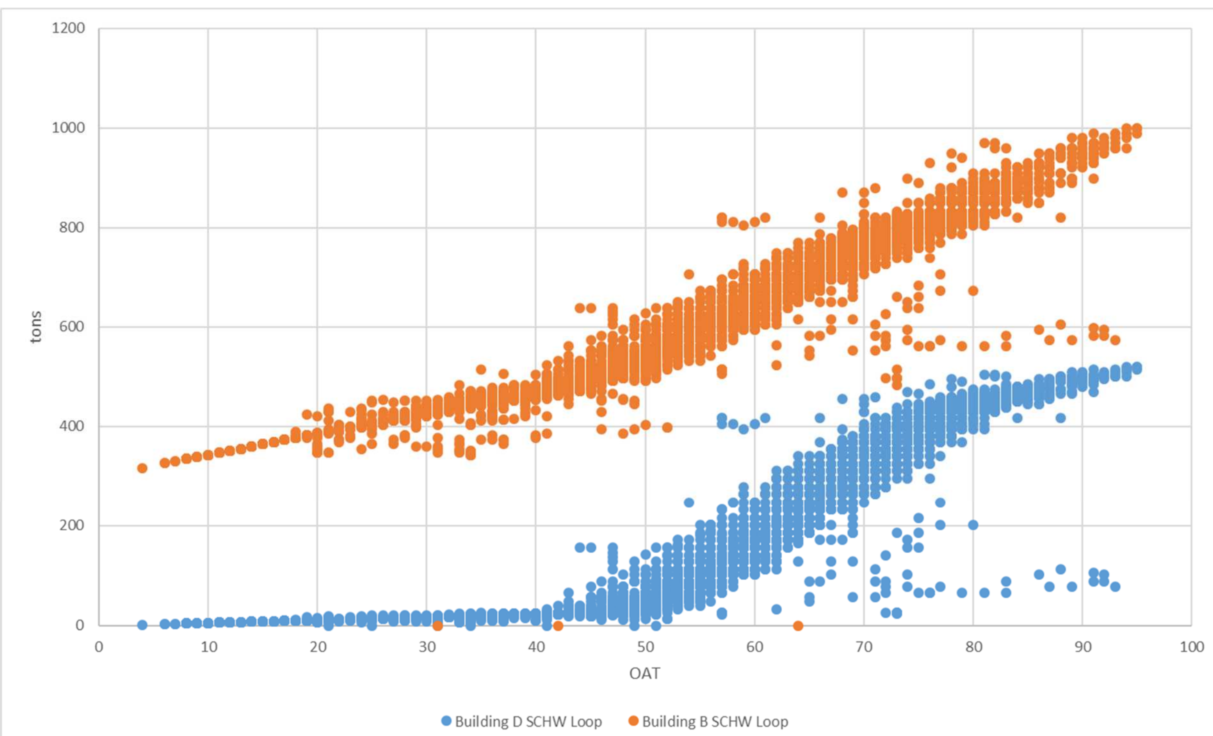
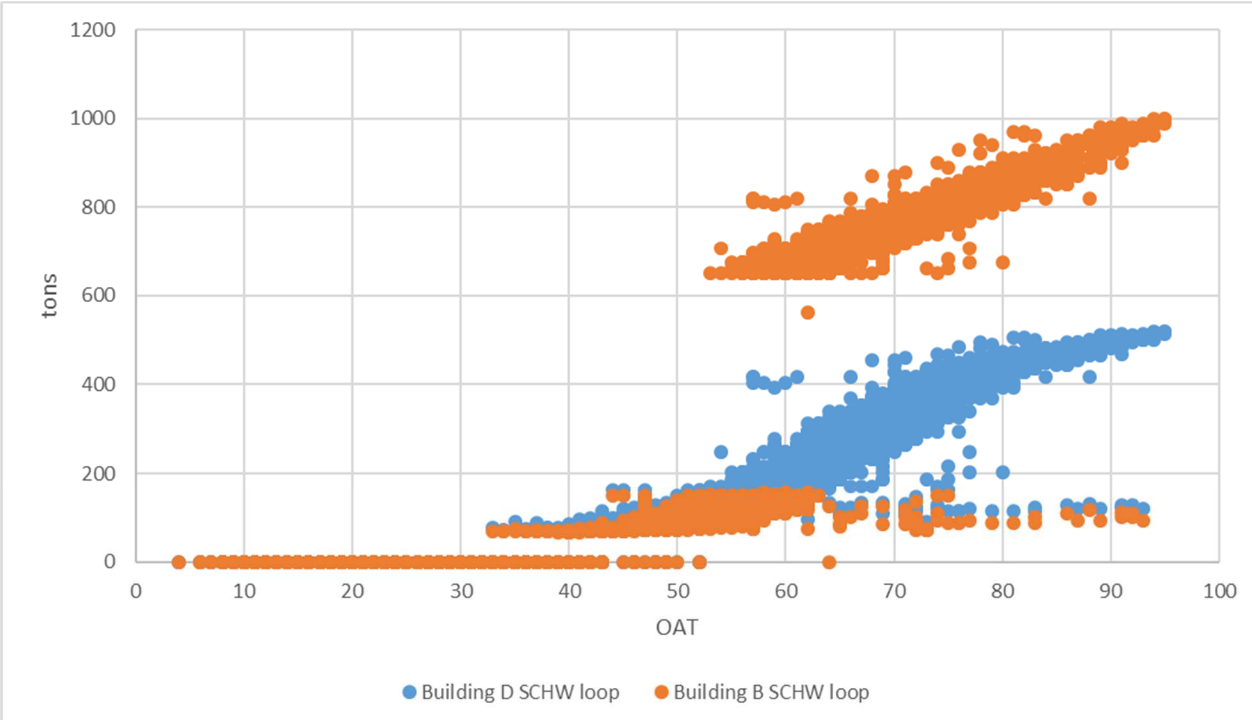


Figure 6: Proposed case secondary chilled water loop load versus outside air temperature



2.1 Project Evaluation

Table 29 shows how each measure was verified to be installed and operating. If a measure was found to not be installed or installed but not operating correctly, it is noted in this table.

Table 29: Measure verification

Measure Name	Verification Method	Verification Result
EEM 1.00 – Optimize Hot water reset on building D converters	EMS and trend data	Functionality programmed into EMS but with different setpoints than proposed by applicant
EEM 2.00 – Repair AC-5 & AC-6 economizer controls	EMS and trend data	Functionality programmed into EMS; however, EF-2A exhibited near full speed
EEM 3.00 Retrofit VFDs on AHUs	EMS and trend data	Functionality programmed into EMS
EEM 5.00 – CHW plant optimization and AHU economizer repair	EMS, trend data, and fuel data	Functionality programmed into EMS; however, manual operator control is warranted

The M&V plan and project evaluation were generally conducted as planned. A site visit was performed to collect EMS screenshots, collect trend data, and interview the site contact.

Due to the size of the hospital campus, the limited time the site contact had to accommodate the evaluation, and the specificity of some of the measures, all measures were verified from EMS screenshots and trend data. Trend reports had already been generated that gathered specific trend points to corroborate measure verification. For example, trend reports were already generated for "phase 5 chiller" measures. The trend report recorded data points (chiller status, chilled water pump status and speed, chilled water loop flow, supply/return chilled water temperature, etc.) that would assist in verifying that measures were functioning as intended. The reports could also be used to update specific data fields that were used in the temperature bin analyses.

The evaluation savings methodologies that are explained in later sections were implemented as planned. For all measures, the evaluation utilized the existing tracking calculation methods and updated them with observed operating conditions and profiles.

4.1.1 Data collection

The evaluator's data collection approach outlined in the M&V plan was implemented as planned. The following table describes data points utilized in analysis for the affected equipment. Most other data points that were mentioned in the M&V plan were also collected but did not need to be used for measure verification and evaluation. All data points were collected in 1-hour intervals.

Table 30: Data collection

Measure Name	Equipment	Data points	Duration
EEM 1.00 – Optimize Hot water reset on building D converters	Hot water loop converters	• HW reset set points (OAT/HWST) • HWRT • HWST • HW pump status • Steam valve position • OAT	12 months
EEM 2.00 – Repair AC-5 & AC-6 economizer controls	AC-5; AC-6	• AC-5/AC-6 return air enthalpy • AC-5/AC-6 Discharge air temperature • AC-6 discharge air humidity • AC-5/AC-6 Supply fan speed % • AC-5 supply fan cfm • AC-6 Outside air damper position • AC-5/AC-6 heating/cooling coil valve position • AC-6 economizer and enthalpy enable status • Outside air temperature	11 months
EEM 3.00 Retrofit VFDs on AHUs	AC-1; AC-4	• AC-1/AC-4 supply fan speed % • AC-1/AC-4 supply fan status (on/off)	2-14 months
EEM 5.00 – CHW plant optimization and AHU economizer repair	EW AHU 2-5	• Outside air temperature/humidity • Chiller status (all chillers) • CHWST • CHWRT • SCHWST (both loops) • SCHWRT (both loops) • SCHW Pump speed (all pumps) • SCHW Pump status (all pumps) • CT fan status (all CT fans) • CT fan speed (all CT fans) • CWST • CWRT • CWST set point • CT bypass valve positions (all CTs) • AHU (1,2,3,6,8) cooling valve position • AHU (1,2,3,6,8) outside air damper position	12 months

The evaluator did not collect all data points for EEM 1.00 described in the Evaluator Metering Approach section. EEM 1.00 accounted for only 1.6% of the project savings so the missed collection points were de-prioritized due to time constraints during the site visit. The following points were not collected:

- Pipe insulation thickness, average
- Pipe inner/outer diameter

- An estimate of total pipe length exposed to ambient (conditioned) space

5.1.1 Evaluation savings analysis

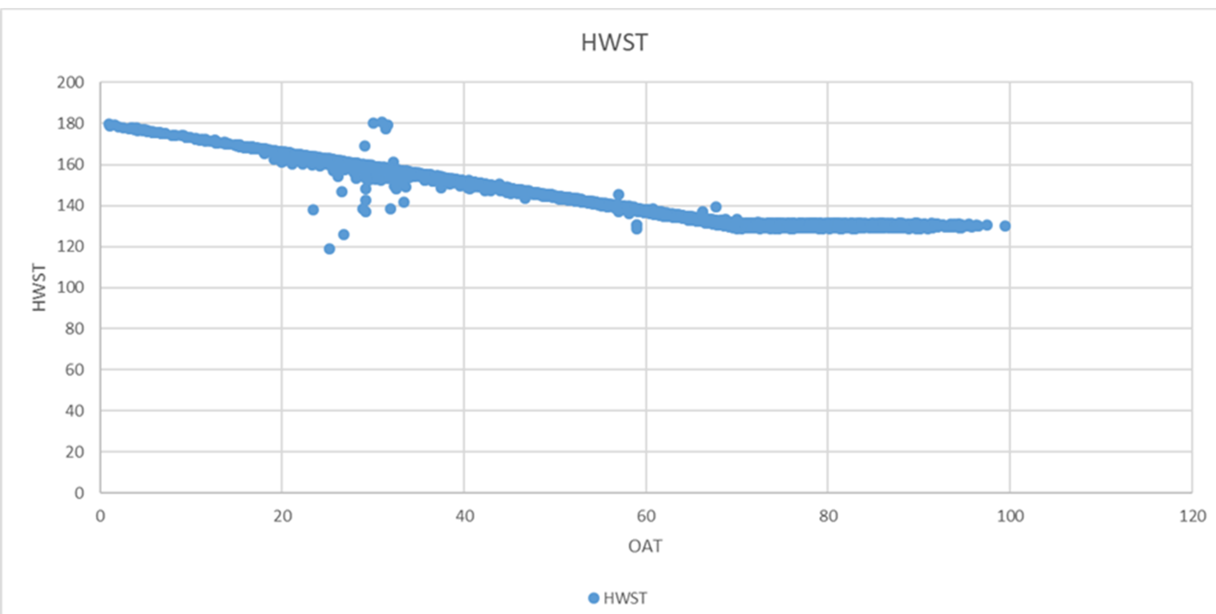
The evaluation of each measure began with determining how reasonable the tracking savings methods were and how to reasonably update the existing savings workbooks with current operating conditions. The evaluation found that existing savings methods were reasonable to use as starting points for the evaluation. In some cases, the savings output could be converted to an 8,760-hour format. However, most savings calculations used a temperature bin format that could not reasonably be converted to an 8,760-hour format.

Details of the individual project savings analyses are presented below.

EEM 1.00 – Optimize Hot water reset on building D converters

The evaluator used the existing calculation method as the starting point to estimate savings. Trend data were analyzed to determine if the reset schedule was implemented and operating as intended. One year of hourly interval data comparing the hot water supply temperature of the hot water loop converters to outside air temperature (see Figure 7) confirmed that the loop converter temperature was resetting supply temperature based on outside air temperature.

Figure 7: HWST (of loop converter) versus outside air temperature



The trend data also showed specific high and low-temperature set points for the hot water and outside air. The comparison of the observed schedule to the reset schedule assumed in the tracking calculation is shown in the table below.

Table 31: Comparison of observed and tracking HWST reset schedules

Observed Outside air temperature	Observed Hot water temperature	Tracking Outside air temperature	Tracking Hot water temperature
70 °F	130 °F	40 °F	130 °F
0 °F	180 °F	0 °F	180 °F

The evaluator used the observed hot water reset schedule to update the calculation's proposed hot water supply temperature reset schedule. The tracking proposed schedule was assumed by the implementor and does not appear to have been updated with post-implementation data. The evaluator also included in the savings estimate the heat loss from the return hot water pipes. Previously, the tracking savings calculation had accounted only for the supply of hot water pipes. Since both lengths of pipe (supply and return) lose heat to the ambient air, the evaluator considered the return hot water pipe heat loss appropriate to include in the savings estimate.

The changes to the temperature bin reset schedules are shown in the table below.

Table 32: Comparison of evaluated and tracking proposed HWST

	Perimeter					Interior				
		Evaluated		Tracking			Evaluated		Tracking	
Weather Bin	Bin Hours	Existing HWST (F)	Proposed HWST (F)	Existing HWST (F)	Proposed HWST (F)	Bin Hours	Existing HWST (F)	Proposed HWST (F)	Existing HWST (F)	Proposed HWST (F)
Deg F	Hrs	Deg F	Deg F	Deg F	Deg F	Hrs	Deg F	Deg F	Deg F	Deg F
> 90	44	150	130	150	130	44	120	130	120	130
85 - 90	76	150	130	150	130	76	120	130	120	130
80 - 85	2	150	130	150	130	298	120	130	120	130
75 - 80	12	150	130	150	130	475	150	130	150	130
70 - 75	21	150	130	150	130	556	150	130	150	130
65 - 70	75	150	**131**	150	130	813	150	**131**	150	130
60 - 65	165	180	**135**	180	130	904	150	**135**	150	130
55 - 60	294	180	**139**	180	130	647	180	**139**	180	130
50 - 55	410	180	**143**	180	130	604	180	**143**	180	130
45 - 50	615	180	**146**	180	130	770	180	**146**	180	130
40 - 45	656	180	**149**	180	130	740	180	**149**	180	130
35 - 40	778	180	**153**	180	133	921	180	**153**	180	133
30 - 35	804	180	**157**	180	140	805	180	**157**	180	140
25 - 30	535	180	**160**	180	146	387	180	**160**	180	146
20 - 25	374	180	**163**	180	152	375	180	**163**	180	152
15 - 20	205	180	**167**	180	158	224	180	**167**	180	158
10 - 15	97	180	**172**	180	166	96	180	**172**	180	166
5 - 10	44	180	174	180	171	24	180	174	180	171
< 5	1	180	177	180	176	1	180	177	180	176
TOTAL	**5,208**					**8,760**				

Conductive heat loss equations, ambient temperature, and pipe length estimations were reviewed and considered to be reasonable; their values were retained in the measure savings calculation workbook.

The table below provides the evaluation results for EEM 1.00. The measure did not realize all savings estimated by the applicant because while the hot water (HW) temperature reset was implemented, the schedule was less aggressive than estimated in the tracking savings calculation. The tracking calculation assumed that the HW temperature would reset with a high/low HW/OAT schedule of 180 °F/0 °F and 130 °F/40 °F. The observed schedule had shifted the low HW/OAT set points to 130 °F / 70°F. With this shift, the hot water supply temperature remained hotter for more operating hours than what was assumed in the tracking calculation.

Table 33: Evaluation results for EEM 1.00 – Optimize Hot water reset on building D converters

Savings Quantity	Tracking Estimate	Evaluation Estimate	Realization Rate
Natural gas energy (Therms)	7,313	4,930	67%

EEM 2.00 – Repair AC-5 & AC-6 economizer controls

The evaluator verified that the economizers for AC-5 and AC-6 were repaired and were operating as intended. Both AC-5 and AC-6 were observed through trend data to modulate outside air dampers depending on outdoor air conditions and mixed air temperature setpoints. However, the outside air dampers did not modulate to fully open (100%) during specific outside air temperature ranges as assumed in the tracking calculation. The table below shows a comparison between tracking and evaluated estimates for outside air damper (OAD) position for a specific set of outside air temperature bins. These bins are shown because they are the bins where Therms savings exist (absorber chillers are active).

Table 34: Comparison of tracking and evaluated OAD % for AC-6 and AC-5

Outside air °F	Tracking Estimate for OAD%, AC-6	Evaluation Estimate for OAD%, AC-6	Tracking Estimate for OAD%, AC-5	Evaluation Estimate for OAD%, AC-5
65 to 70	30%	24%	30%	35%
60 to 65	100%	57%	100%	100%
55 to 60	100%	64%	100%	100%

The evaluation estimate for the OAD position was developed from averaging hourly OAD positions for all hours where the outside air temperature fell within the corresponding bins ranges. 11 months of data were available to construct these average values.

The evaluator believes that the OAD for AC-6 does not fully open because given the return air and outside air conditions, and mixed air setpoint requirements, the OAD did not need to fully open to meet the mixed air set point.

The evaluator utilized the tracking savings method and updated key input parameters in the temperature bin analysis with observed measurements using trend data. Many of the updated input parameters previously had used values assumed on arbitrary and typical values (e.g., return air temperature & humidity, actual discharge air temperature, supply fan speed)

The temperature bin analysis parameter values that were updated by the evaluator are:

AC-5

- Proposed supply fan speed (affects supply fan kW), all-temperature bins
- Proposed AHU supply cfm (affects mass/enthalpy flow), all-temperature bins
- Proposed return air temperature, all-temperature bins
- Proposed return air humidity, all-temperature bins
- Proposed discharge air temperature, all-temperature bins
- Proposed OA damper position (%), all-temperature bins
- Base case supply fan speed, temperature bins below 65 °F. Temperature bins above 65 °F were also adjusted but used assumptions and not trend data
- Base case AHU supply cfm, temperature bins below 65 °F. Temperature bins above 65 °F were adjusted as a result of changing the supply fan speed
- Base case return air temperature (equal to proposed)
- Base case return air humidity (equal to proposed)
- Base case discharge air temperature (equal to proposed)

AC-6

- Proposed supply fan speed, all-temperature bins
- Proposed return air enthalpy, all-temperature bins
- Proposed outside air damper position (%), all-temperature bins
- Proposed discharge air temperature, all-temperature bins
- Proposed discharge air humidity, all “cooling” temperature bins
- Base case return air enthalpy (equal to proposed)
- Base case discharge air temperature (equal to proposed)
- Base case discharge air humidity (equal to proposed)

The table below provides the evaluation results for EEM 2.00. The evaluation savings were less than the tracking savings (35% realized) mostly due to a change in the estimated supply air volume being conditioned by the AHUs affected by the economizer repairs. Trend data collected by the evaluator were used to adjust the tracking supply air volume estimates (based on assumed supply fan speed and design cfm) with measured supply airflow or measured supply fan speed[12]. The reduction in estimated supply air volume reduced the cooling load to be saved.

Table 35: Evaluation Results for EEM 2.00 – Repair AC-5 & AC-6 economizer controls

Savings Quantity	Tracking Estimate	Evaluation Estimate	Realization Rate
Natural gas energy (Therms)	8,289	2,920	35%

EEM 3.00 Retrofit VFDs on AHUs

This measure was verified using trend data and EMS screenshots. AC-1 and AC-4 were observed to have functional VFDs controlling the fan speed of the supply and return fans (for AC-1). In addition to the VFD implementation, the AHUs were observed to have occupied and unoccupied schedules, as proposed in the tracking documentation. AC-1 has an occupied schedule of M-Sun 5a-9p and AC-4 has an occupied schedule of M-Sun 6a-10p.

AC-1 trend data had conflicting results for its fan status during unoccupied periods. The TA report claims that AC-1 has its fans turned off during unoccupied periods. This claim was supported with trend data collected (as part of the post-implementation verification) for roughly 14 days in November/December 2016. However, the evaluator collected more trend data that covers November 2017 through October 2018. During that time period, the fan status remains on at all times while the duct static pressure enters the unoccupied status. AC-4 also enters a reduced flow schedule during unoccupied periods.

These findings were determined by analyzing trend data including:

- AC-1/AC-4 fan speed
- AC-1/AC-4 duct static pressure
- AC-1/AC-4 fan status (on/off)

The evaluator used the trend data to develop average fan VFD speed values to replace the assumed values in the tracking temperature bin analysis spreadsheet for both occupied and unoccupied periods. The AC-1 unoccupied period was updated to reflect that the fans were operating at reduced speeds (instead of being off).

The updates had a net reduction in estimated savings compared to tracking estimates. The observed unoccupied VFD speeds for AC-1 were 60% instead of being off as assumed in the tracking calculation. This finding for AC-1 had a negative impact on savings. There was an increase in savings for AC-4 because the observed fan speeds during heating periods were lower than what was assumed in the tracking calculation. The table below summarizes the evaluation findings for EEM 3.00.

Table 36: Evaluation results for EEM 3.00 Retrofit VFDs on AHUs

Savings Quantity	Tracking Estimate	Evaluation Estimate	Realization Rate

[12] Measured supply fan speed was available via trend data for AC-6, supply air flow (cfm) data was available for AC-5

Natural gas energy (Therms)	18,135	7,069	39%

EEM 5.00 – CHW plant optimization and AHU economizer repair

There are two sub-measures associated with EEM 5.00 – a condenser water reset component and a chilled water plant shutdown component. The chilled water plant shutdown was proposed to be made possible by repairing economizers of 12 AHUs that required chilled water during colder weather. With the AHU economizers repaired, the AHUs would no longer be dependent on the chilled water to provide adequate cooling.

Both sub-measures were verified to be implemented but both are operating differently than how they were modeled in the post-implementation TA report. Each sub measures evaluation analysis is explained below.

Condenser water reset

The condenser water reset sub-measure was verified to be implemented and appeared to be working as intended. The specific condenser water reset schedule appeared to have been modified by the plant operators to satisfy their operating requirements. The operators also appear to modify the reset schedule throughout the year as ambient conditions change; however, the changes are not dramatic, and the reset schedule is always enabled (rather than a manual setpoint). The condenser water is kept between a temperature range of 76 °F and 84 °F for the corresponding outside the wet bulb temperature range of 68 °F and 77 °F (an approach of 7-8 °F). The condenser water temperature appears to be reasonably maintained when outside wet-bulb temperature is greater than 68 °F. This is evident from approximately 5 months of trend data (May through October) showing average approach temperature (CWST – WBT) of 10 °F.

The evaluator generally accepts the method used by the PA of modeling the condenser water reset measure. A specific condenser water temperature schedule (hourly setpoint changes) was used as a proxy to a fixed reset schedule. However, the evaluator adjusted the modeling method by using specifically the reset schedule option in eQUEST. The following reset schedule was entered into eQUEST.

Table 37: Evaluated condenser water reset schedule

Outside wet bulb temperature	Condenser water supply temperature
68 °F	76 °F
77 °F	84 °F

This adjustment had a marginal and negligible change to total measure savings, decreasing savings by 0.3%.

AHU economizer re-commissioning and chilled water plant shutdown

This sub-measure was also verified to be implemented as planned. AHU economizers appear (through trend data) to be functional and operating an intended. One year (March 2017-2018) of trend data was analyzed for several AHUs to determine economizer functionality. The figures below illustrate the outside air damper positions changing over a range of outside air temperature. The AHU cooling valve position is also shown to verify that the AHU is not calling for chilled water during colder weather and its discharge air temperature setpoint is being satisfied using outside air.[13]

[13] 40 °F was the temperature threshold given by the TA report for the chiller shutdown. This threshold will later be shown in the report to be manually determined by plant operators. The AHU cooling valve position may report being open even when the chillers are inactive.

Figure 8: Damper and cooling valve position for building B AHU 3-1

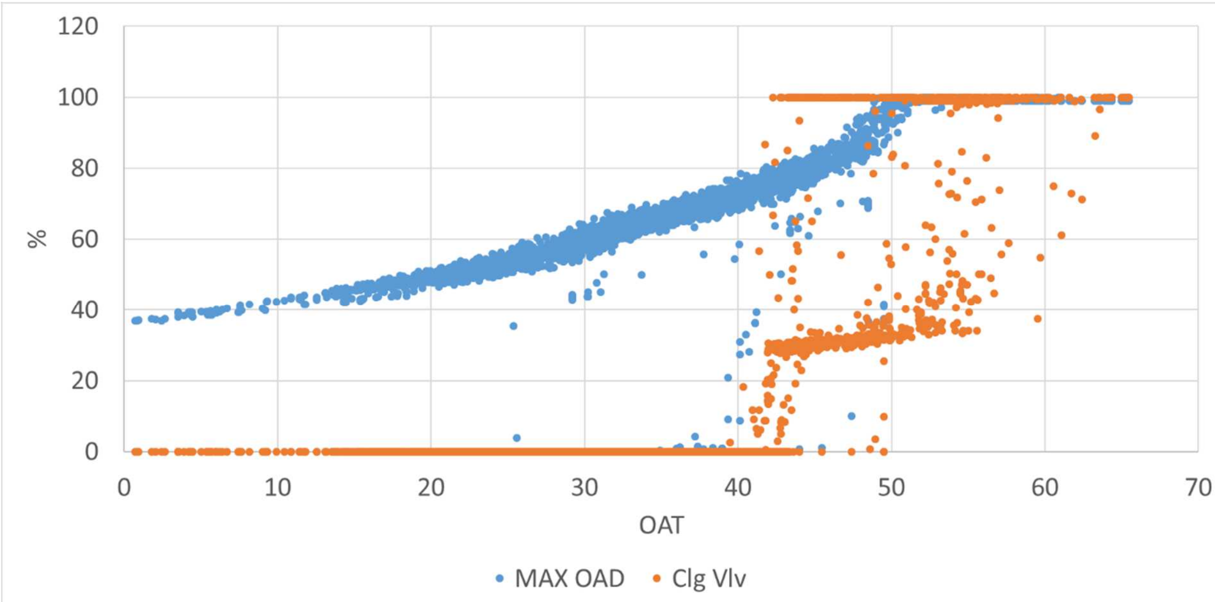


Figure 9: Damper and cooling valve position for building B AHU 3-2

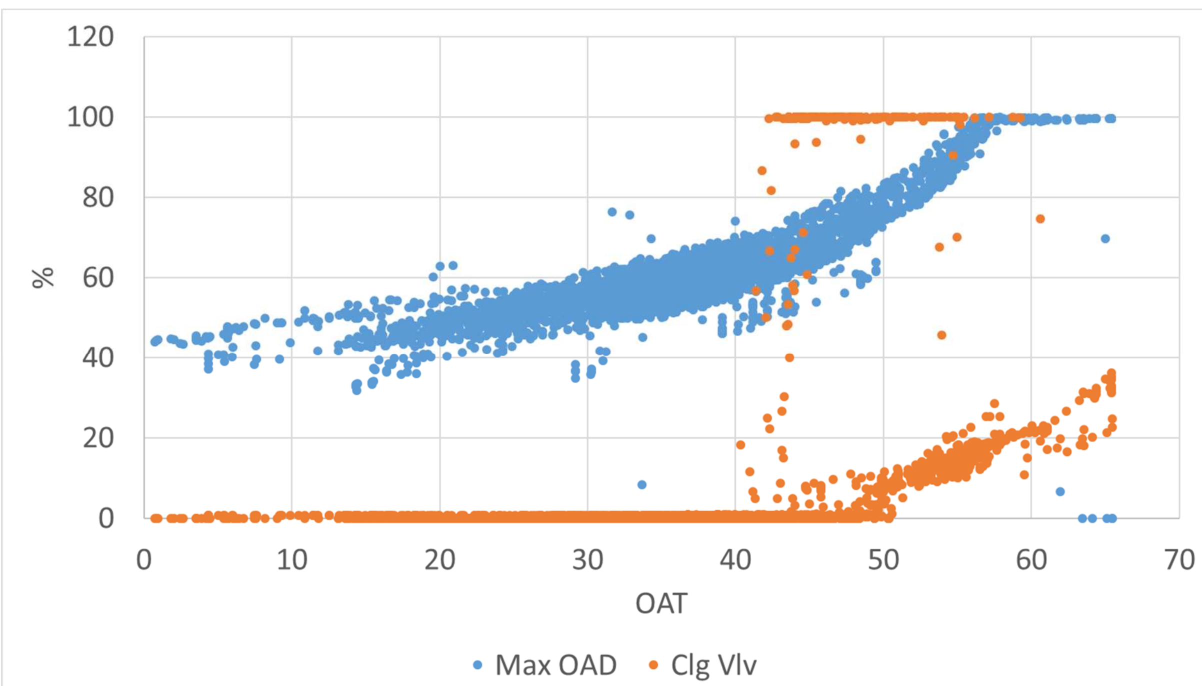
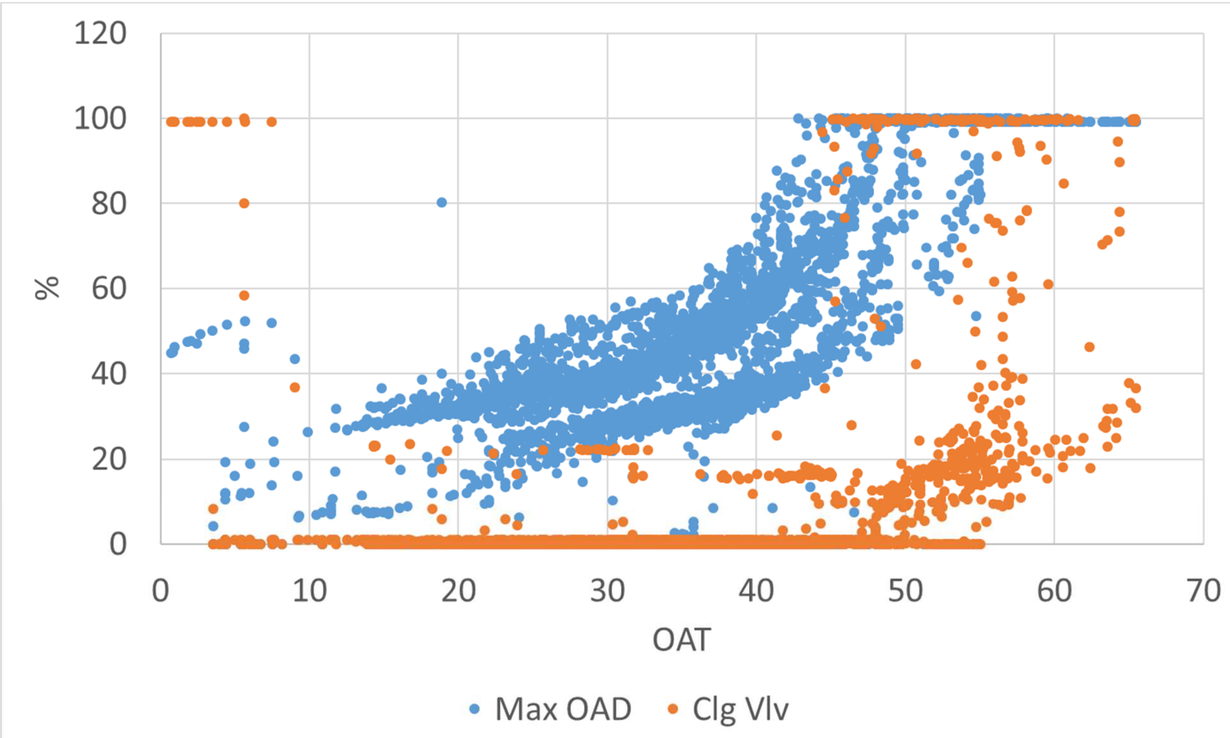
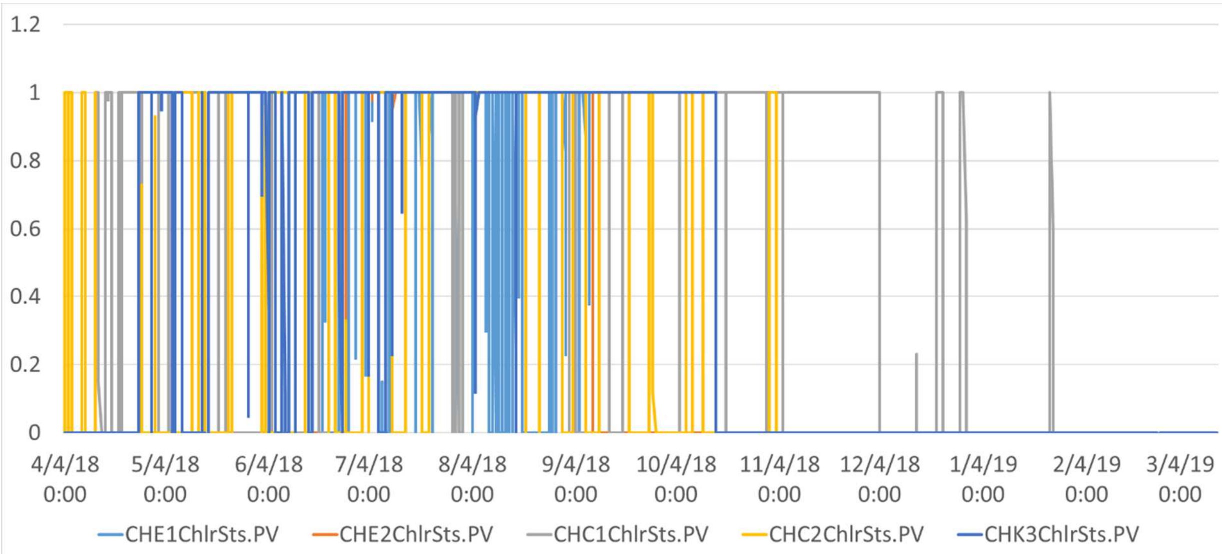


Figure 10: Damper and cooling valve position for building B AHU 3-3



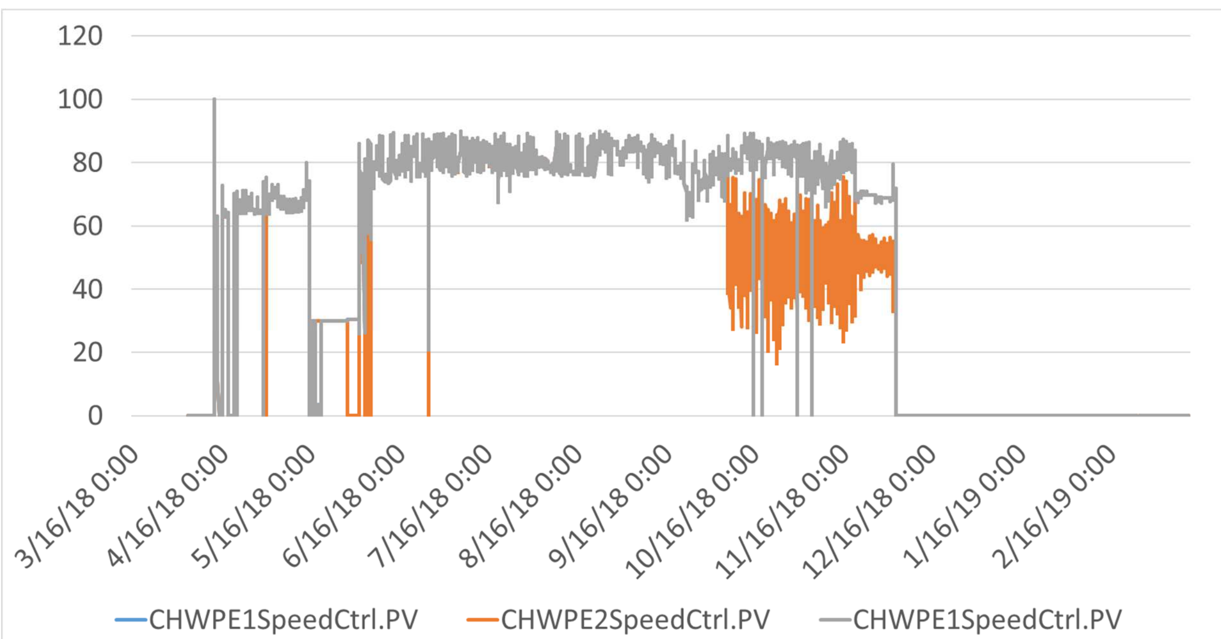
The chiller shutdown component of this sub-measure was verified by analyzing trend data that tracked chiller status over approximately one year. The data shows (see Figure 11) that all chillers except "CHC1" (one of the 550-ton absorption chillers) are inactive starting in early November. Chiller "CHC1" then shuts down in early December with a very intermittent short-term activity until all chillers remain off from January through March.

Figure 11: Chiller Status (offline ~December through March)



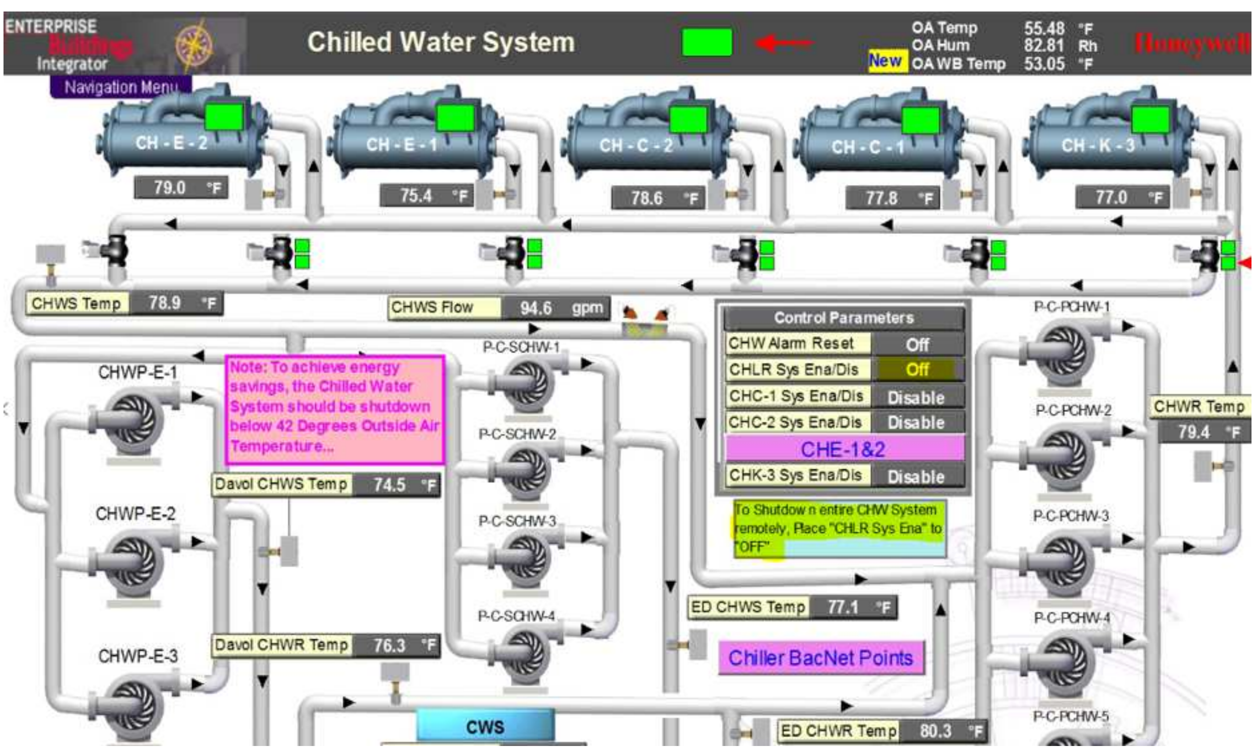
Similarly, trend data for a sample of secondary chilled water pumps for the building B and building D secondary loops show that the pumps remain inactive (0% speed) from December through March.

Figure 12: SCHW pump status (offline ~December through March)



Finally, EMS dashboards show that operators maintain the ability to manually enable the chillers remotely and remind the operators that energy savings are possible when the outside air temperature is below 42 °F. The figure below shows an EMS screenshot that was taken on March 15, 2019. The OAT was 55 °F and all the chillers were off.

Figure 13: EMS dashboard (chillers are off March 15, 2019; 55 °F OAT)

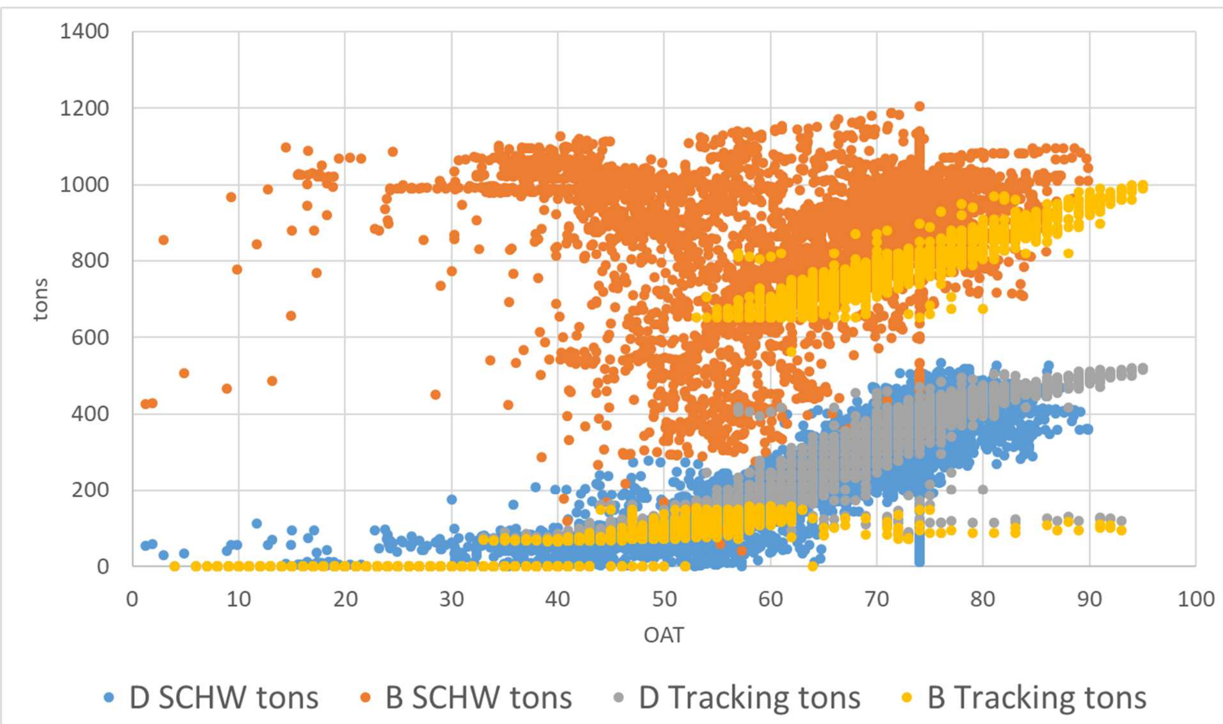


With the evidence presented above, the evaluator verified with high certainty that the plant operators maintain diligence to shutdown chiller operation during colder weather, particularly in the months of December through March. Further, the data suggests that the chillers can be disabled when the outside air temperature is above 42 °F, exceeding the threshold temperature that was recommended and estimated by the PA.

The eQUEST model that was available to the evaluator is known as the "Cx" model.[14] This model accounts for additional savings attributed to functional AHU economizers during shoulder season weather (40 °F < OAT < 60 °F). The model appears to account for these additional savings by adjusting the secondary chilled water (SCHW) loop load schedule. The SCHW loop load schedule effectively drives how much chiller usage is simulated by the energy model[15]. The SCHW loop load schedules, for both the baseline and measure models, appear to have been estimated using chiller loads measured from trend data.

The SCHW loop load (in tons) modeled in the "Cx" model was compared (see Figure 14) to the SCHW loop loads estimated using roughly 10 months of trend data. The trend data was a combination of SCHW pump speed, SCHW supply and return temperatures, and known design pump capacities (in GPM). These were used to approximate SCHW loop load in tons.

Figure 14: Comparison of tracking and observed SCHW loop loads



The blue and orange loads are the "measured" SCHW loop loads while the yellow and gray loads are the "tracking" SCHW loop loads. The blue "measured" and gray "tracking" loop loads agree reasonably

---

[14] The tracking savings uses outputs from two models, the "TA" model and the "Cx" model. The "TA" model was not available to the evaluator. It appears to be the first version of the model that was later revised in to the "Cx" model. The tracking savings uses the savings estimated in the "TA" model + 50% of the difference in savings between the "Cx" model and "TA" model. The TA report reasons that this was done because "the trends reveal additional chilled water savings due to repaired economizer mode on the AHUs. These additional savings were not included in the TA (model) study savings calculations because, while the TA model accounted for shutting the plant off when the OAT is less than 40oF, the reduced loads during economizer weather (40oF<OAT<60oF) resulting from implementing this measure were not modeled. These additional savings (50% of difference between Cx and TA models) are included" in the final tracking savings.

[15] Normally, a building model might use a sum of zonal cooling loads to determine chiller load. Zonal cooling loads are calculated using a combination of characteristics like zonal thermostat schedules, internal heat gain like occupancy, lighting, and equipment, and radiant heat gain from zonal exposure to sun and ambient weather

well and correspond to the same "building D" SCHW loop. The orange "measured" and yellow "tracking" loop loads do not align as well. The measured loop load does not correlate as cleanly with outside air temperature as the tracking loop load (for building B) and appears to have some constant loop load from 30 °F to 50 °F. Looking more closely at the trend data for these points presents some ambiguity because some groups of supply and return temperatures (over several hours) have identical values. This could indicate some inaccuracy in the chilled water temperature which could over or underestimate the chilled water load; however, the SCHW pumps are active and their data appear less questionable. Without more specific evidence to prove contrary to the trend data, the evaluator took the above representation of measured SCHW loop loads to be reasonable.

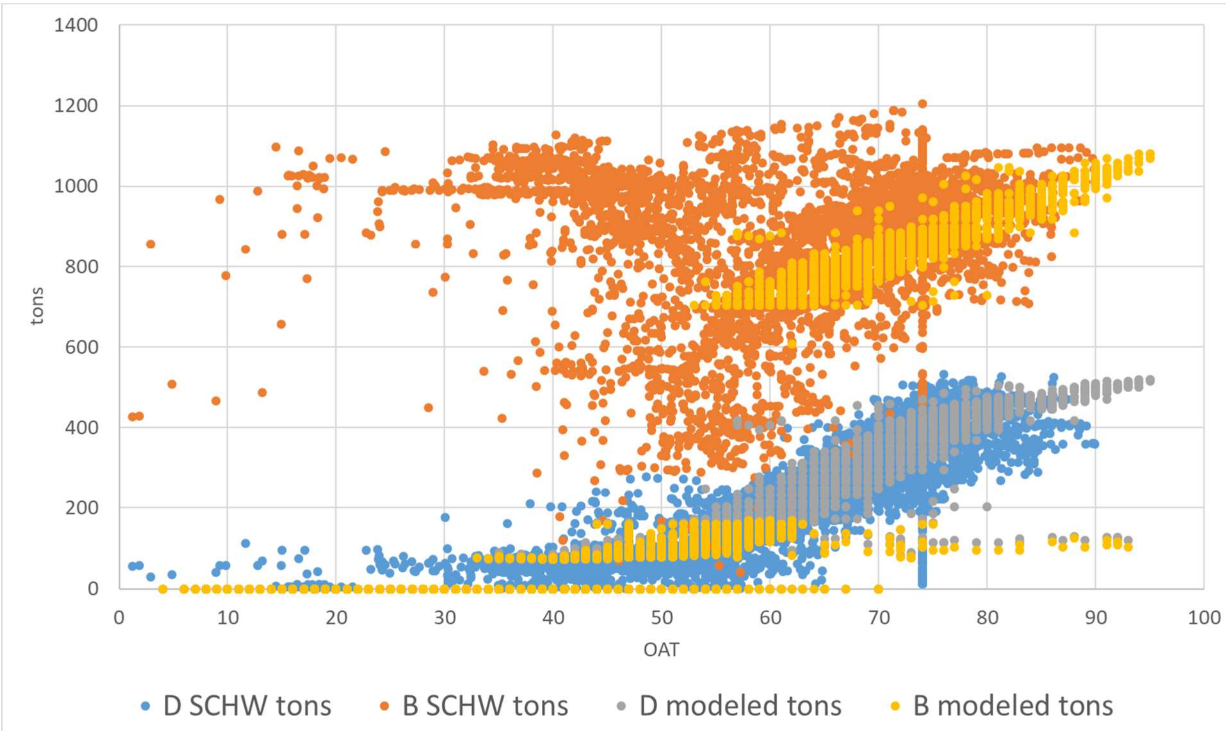
The evaluator chose to modify the modeled building B SCHW loop load to more closely resemble the measured building B SCHW loop load. This was done by modifying the following:

- The SCHW loop load nominal capacity was multiplied by a factor of 1.08 to bump up the modeled load for all hours[16]. This raised the modeled peak load from approximately 1,000 tons to 1,080 tons.
- The PCHW and SCHW loops were assigned an on/off flag schedule instead of operating on standby. The flag schedule dictates when the chillers operate. This change was meant to simulate the chillers being manually shut down during the periods that were observed through trend data. The flag schedule turns the chillers off from December 16 through March 31. The chillers are on standby from April 1 through December 15.

These changes adjusted the modeled loop loads to more closely resemble the measured loop loads. The figure below shows the results of the adjustments.

[16] The nominal process load capacity was adjusted in the model from 13.512 MBH to 14.593 MBH (increased by a factor of 1.08)

Figure 15: Comparison of modeled and observed SCHW loop loads



Finally, there were slight adjustments made to the ratio of natural gas to oil fuel usage. The facility purchases both natural gas from the utility and #6 oil to operate the steam boilers which in turn allow the absorber chillers to operate. The tracking estimate used oil purchase and usage data from 2011 to 2014 to determine that there was a 21% #6 oil usage for the plant. Since only natural gas savings can be claimed by the program, this percentage of modeled savings was removed so that the claimed program savings reflected only natural gas savings.

The evaluator used average oil and natural gas use from 2017-18 and determined that oil use had increased slightly to 26%. This ratio was applied in the same manner to modeled savings to remove the portion attributed to #6 oil.

The table below presents the final evaluation results for EEM 5.00.

Table 38: Evaluation results for EEM 5.00 – CHW plant optimization and AHU economizer repair[17]

Savings Quantity	Tracking Estimate	Evaluation Estimate	Realization Rate
EEM 5.00C condenser water reset - Natural gas energy (Therms)	**428,125**	79,210	N/A
EEM 5.00D chilled water shutdown - Natural gas energy (Therms)		473,367	
EEM 5.00 Total natural gas energy (Therms)		**552,577**	**129%**

The final evaluated savings for EEM 5.00 (~55,000 MMBTU) accounts for approximately 6.5% of the average annual natural gas usage (~850,000 MMBTU for 2017 and 2018) of the hospital. The evaluator considered this sanity check for overall natural gas usage and measure savings to show a reasonable level of savings. The measure is effectively shutting down four absorber chillers totaling 1,600 tons for up to 4 months. While the chillers operate at low load during these months, the measure offsets up to approximately 500 tons of cooling that the chillers would have otherwise needed to support.

6.1.1 Evaluation Results

The evaluated savings are presented in this section by measure. Specific measure discrepancies are described under the measure evaluation sections.

Table 39: Evaluation results for project ID 5685729

Project/Measure	Savings Quantity	Tracking Estimate	Evaluation Estimate	Realization Rate
EEM 1.00 – Optimize Hot water reset on building D converters	Natural gas energy (Therms)	7,313	4,930	67%
EEM 2.00 – Repair AC-5 & AC-6 economizer controls	Natural gas energy (Therms)	8,289	2,920	35%
EEM 3.00 Retrofit VFDs on AHUs	Natural gas energy (Therms)	18,135	7,069	39%
EEM 5.00 – CHW plant optimization and AHU economizer repair	Natural gas energy (Therms)	428,125	552,577	129%
Total project (5685729)	**Natural gas energy (Therms)**	**461,862**	**567,496**	**123%**

[17] Individual sub-measure savings cannot be broken down for the tracking savings because the "TA" model which the tracking savings is primarily based on was not available to the evaluator

4 Site 2017RIG107

Project ID	2017RIG107
Program admin	National Grid
Lead evaluation engineer	Jerry Song, DNV GL
Report author	Jerry Song, DNV GL

4.1.1 Project Summary and Results

The project was implemented at a fabric manufacturing facility and consisted of the repair or replacement of nine steam traps that were blowing through. 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 and process heating which requires the steam system to be available for the entire year.

The evaluator visited the facility, verified the operation of the steam traps using an IR gun and ultrasonic tester, 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 a failed steam trap and fewer annual pressurized hours.

Table 40: 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	8,810	Tracked	5,266
		Evaluated	6,394	Evaluated	3,822
		RR[1]	73%	RR[1]	73%

[1]Realization rate

Explanation of Deviations from Tracked Savings

The evaluated savings found a 73% realization rate when comparing evaluated savings to tracked savings using the new tool. The difference in savings between the tracked and evaluated savings is primarily due to two factors. 1) 1 steamtrap was not operating 2) the operating hours were reduced for the traps that are connected to the space heating equipment and process equipment based on the facility's holiday schedule and metered data and 3) the verified boiler efficiency was 84%, higher than the 80% efficiency assumed in the tracking analysis.

4.1.2 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. The operating hours of the drip leg steam traps were assumed to be 8,760 and unit heaters and radiator traps operating 1,700 hours per year. Unit heater and radiator traps 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 the MA59 Phase 2 Steam Trap Evaluation and implemented in both the original and new custom express tools.

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 9 steam traps that were categorized as partial blow-by and 5 categorized as plugged. 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	0	0	0	0
Partial Blow By	8	1	0	9
Plugged	3	2	0	5
Total	11	3	42	56

Applicant Description of Installed Equipment and Operation

The steam trap survey conducted in 2017 identified 9 partial blow-by steam traps and five plugged steam traps, which were repaired or replaced. 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 the 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 the 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 the latent heat of steam not being used to serve boiler loads throughout the 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 the 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 2017 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 in-depth reasoning behind the full evaluation and savings calculation process.

Summary of On-Site Findings

The evaluators conducted a site visit on April 9, 2019. 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 2017 are still operating properly.

The evaluator conducted a walkthrough of the facility to verify the installation of the steam traps. The evaluator visually confirmed six of the nine steam traps. Two of the steam traps were unable to be found. Based on the interview with the site contact it was determined that the two that could not be located were indeed installed the evaluator give credit for the two traps that were not found.

The evaluator performed IR gun temperature measurements and ultrasonic testing to verify the operating status of the steam traps for the steam traps that were in operation.

An IR gun was used to perform temperature verification of trap operation by taking temperature readings directly at the steam trap inlet and outlet. If the measured temperature is over 212°F (saturated steam temperature at 0 psig), then the trap is operating. Traps 79332 and 79236 were off because they are only used in winter for space heating. Trap 175922 shows abnormal temperature based on the IR gun measurement. Since this trap is supposed to operate for the whole year, the evaluator treated this trap as non-operating and removed the savings associated with this trap.

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	Site Status	Operating Temp [°F]	Temp In	Temp Trap	Temp Out	dB In	dB Trap	dB Out
130437	Radiator Trap	Thermostatic Angle	Not found	250	-	-	-	-	-	-
79332	Unit Heater	Inverted Bucket	Off	338	-	-	-	-	-	-

79236	Unit Heater	Inverted Bucket	Off	338	-	-	-	-	-	-
79335	Unit Heater	Inverted Bucket	Operating	338	263	248	246	22	21	21
79371	Radiator Trap	Thermostatic Angle	Operating	239	206	186	202	20	20	20
175922	Drip Leg	Thermostatic Angle	Non-operating	239	125	125	125	11	11	9
79319	Drip Leg	Inverted Bucket	Not found	324	-	-	-	-	-	-
79315	Drip Leg	Inverted Bucket	Operating	274	264	264	214	33	22	33
175928	Drip Leg	Float & Thermostatic	Operating	239	264	262	246	31	24	32

A boiler combustion test was performed and found a boiler efficiency of 84%, 4% higher than the assumed 80% boiler efficiency. In speaking with the site contact, it was found that the facility runs 24/7 outside of two weeklong shutdowns during the week of July 4th and between Christmas and New Year. This was captured in the installed loggers, showing the shutdown during the Independence Day week. There are two types of traps repaired/replaced under this measure. There are five traps that are connected to space heating equipment will show weather sensitive load and the other four traps are connected to process equipment and will run all-yearlong except for the facility holiday.

There were no pressure gauges available for either the boiler or anywhere along the steam line to verify steam pressure at the traps. However, the site contact believed the steam pressures used during the initial analysis are accurate.

Logged data

In addition to the spot measurement, the evaluator also installed a temperature logger to steam trap #79335 for the unit heater to meter the steam trap usage. The metering equipment and metering information are shown in Table 2-3.

Table 2-3 Summary of Steam Trap Findings

Data Logger Type	Parameter	Time Interval	Duration	Quantity
HOBO high-temperature logger with thermocouple	Temperature	1 minute	4/9/2019 to 7/8/2019	1

Figure 2-16 shows the metered trap temperature. The trap temperature remained around 230 °F except the week of Independence Day, during which the temperature dropped to room temperature, due to extended shut off.

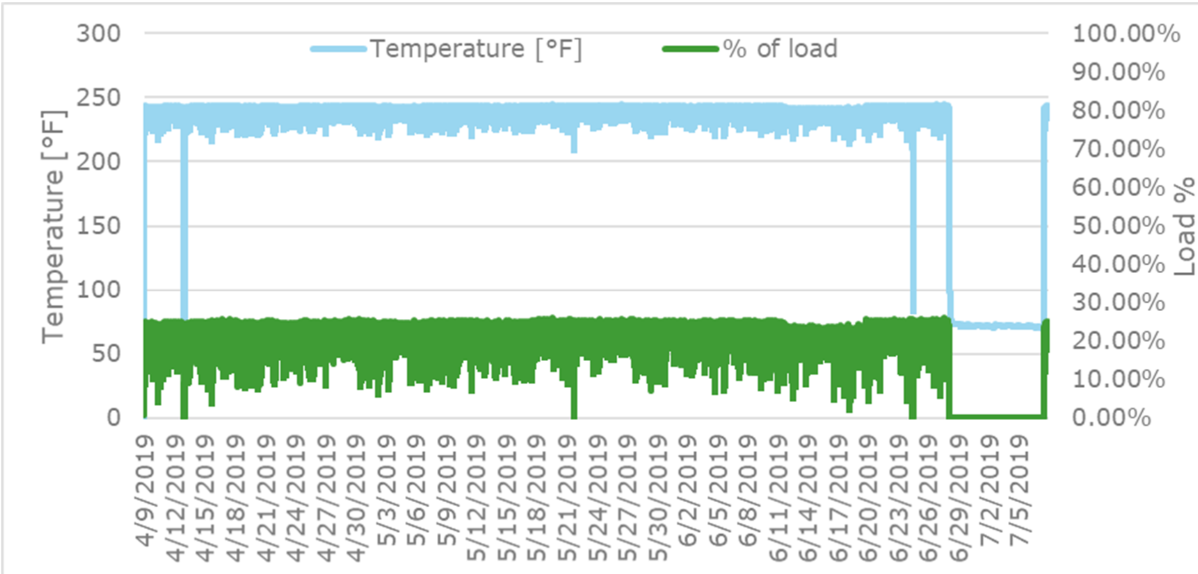


Figure 2-16 Metered Steam Trap Temperature

To calculate the trap usage during the metering period, the evaluator uses the metered temperature and steam table to calculate the hourly trap load percentage as

Hourly Steam Trap Load % =

If metered temperature > 212°F (Steam Saturation Temperature at 0 psig)

$$\frac{Metered\ Temperature\ [°F] - 212\ °F}{Steam\ Saturation\ Temperature\ at\ normal\ operating\ condition\ 100\ psig\ (338°F) - 212\ °F}$$

Else,

Hourly Steam Trap Load % = 0

The evaluator tried to plot the metered steam trap load % with the temperature/HDD. However, since the metering period is the transitional and early summer season, the trap usage does not show a good correlation with the low heating load condition. Therefore, DNV GL used the following approach to determine the load on the weather sensitive steam trap

1. DNV GL used the metered data to determine the balance point temperature to be 51°F, corresponding to the outdoor air temperature during the period when the trap load was smaller than 2%.
2. The evaluator assumed the steam trap will be at 100% load at the ASHRAE 90.1 heating design temperature for Providence Airport (5°F)
3. The load will increase linearly from 0% to 100% when the outdoor air temperature drops from the 51°F to 5°F and remain at 100% when the outdoor temperature is smaller than 5°F
4. Calculate the equivalent full load hour for the trap using TMY3 weather data
5. The annual equivalent full load hour (EFLH) is the summation of the load percentage for each hour

The calculated the EFLH for the metered steam trap is 1,480 hours. The evaluator assumes other weather sensitive steam traps will have the same EFLH. For the all-yearlong steam traps, the evaluator removed the 2-week holiday periods and assumed the traps would not operate during this time, as indicated by the site contact and metered data (week of Independence Day). Table 2-4 shows the evaluated EFLF versus the applicant's assumption. Trap 175922 was not operating during the site visit, since it is suppoed to operate year long, the evaluator treated it as non-operating and assigned zero savings to this trap.

Table 2-4. Comparison of EFLH Between Tracking and Evaluation

Trap Tag #	Trap Application	Tracking Hours of Operation [hrs/yr]	Evaluated Hours of Operation [hrs/yr]

130437	Radiator Trap	1,700	1,480
79332	Unit Heater	1,700	1,480
79236	Unit Heater	1,700	1,480
79335	Unit Heater	1,700	1,480
79371	Radiator Trap	1,700	1,480
175922	Drip Leg	8,760	0
79319	Drip Leg	8,760	8,424
79315	Drip Leg	8,760	8,424
175928	Drip Leg	8,760	8,424

Evaluation Information and Analysis

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

Baseline

The conducted steam trap survey identified nine failed or blowing through 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 were adjusted lower based on site findings. The boiler efficiency was revised upward from 80% to 84% based on combustion testing. 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[18] 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

[18] 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 for all drip legs and 1,700 annual operating hours for the unit heater and radiator traps. The evaluator modified the system operating hours based on the site findings. Logger data indicated the facility had a weeklong shutdown during the Independence Day week. This was corroborated by the site contact, who also indicated a similar shutdown in the week between Christmas and New Year. The evaluator modified the system operating hours for the drip legs from 8,760 hours to 8,424 annual hours to reflect this. The weather sensitive traps EFLH were reduced from 1,700 to 1,480 based on the metered data.

Comparison with original methodology: The new methodology yielded significantly lower savings than the old methodology in both the tracking and evaluated cases. The evaluated conditions yielded a 61% realization rate for the new methodology when compared with the old methodology.

4.1.3 Final Results

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

The evaluators' analyses show less savings than were projected by the applicant using both the original tool and the new tool. The evaluation found an overall decrease in operating hours and higher boiler efficiency than the applicant's estimate.

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
Average Steam Plant Operating Hours	4,837	3,630
Boiler Efficiency	80%	84%

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 are lower than that of the old tool. As mentioned in the MA report, 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 picklist. Some additional changes to the calculation algorithm were made to increase savings accuracy, resulting in lower savings than in the old tool as outlined in the MA report.

Table 3-2. Steam Trap Analysis Results

Gas Savings [Therms/yr] (Original Tool)		Gas Savings [Therms/yr] (New Tool)	
Tracked	8,810	Tracked	5,266
Evaluated	6,394	Evaluated	3,822
RR[1]	73%	RR[1]	73%

Cross Check with Billing Data

The evaluator determined billing analysis would not provide more details about the performance of the evaluated measures and the natural gas usage as the facility is too large relative to the impacts of the installed measure to observe any discernible difference using a billing analysis.

Recommendations for Program Designers and Implementers

Operating hours for climate-dependent manufacturing spaces should be modified to take into account non-standard operating hours. In addition, scheduled facility shutdowns should be taken into account for drip leg steam traps.

Explanation of Deviations

The evaluated savings differed from the tracking savings because of the use of the revised calculation tool, an increase in boiler efficiency, and an overall increase in steam trap operating hours.

Table 3-3 provides a breakdown of the change in savings due to each of the input modifications using the new steam trap calculation tool.

Table 3-3 Discrepancy Summary

Factor	Applicant	Evaluator	Impact of Deviation	Discussion of Deviations
Drip Leg Steam Trap Operating Hours	4 steam traps with 8,760 operating hours	3 steam traps with 8,424 operating hours 1 with zero operating hours.	-9%	The three steam traps operated at 8,760 hours each in the applicant calculations versus 8,424 hours in the evaluator calculations. One trap was found not operating during the site visit and assigned zero savings.
Unit heater/radiator steam trap in climate-dependent space operating hours	5 steam traps with 1,700 operating hours	5 steam traps with 1,480 operating hours	-13%	The evaluator revised the operating hours to 1,480 based on the metered data and TMY3 weather.

Factor	Applicant	Evaluator	Impact of Deviation	Discussion of Deviations
Boiler Efficiency	80%	84%	-5%	Since the savings come from the reduction in wasted steam through the steam trap, with higher boiler efficiency, less natural gas is needed to generate the same amount of wasted steam compared to the applicant's calculation, which essentially reduce the measure savings.

5 Site 2017RIG015

Program Administrator	National Grid	
Application ID(s)	6342021, 7599903	
Project Type	Retrofit	
Program Year	2017	
Evaluation Firm	DNV GL	DNV·GL
Evaluation Engineer	Ryan Brown	
Senior Engineer	Srikar Kaligotla	

5.1 Evaluated Site Summary and Results

The evaluated project was installed at a college campus and consisted of the installation of fitted insulation jackets on various sections of straight pipe, fittings, steam sleeves, and other heating equipment. The applicant calculated the measure savings due to the reduction in heat loss between bare and insulated pipes and fittings.

The evaluators modeled savings based on logged temperature data, temperature spot measurements using an infrared gun, and information gathered from on-site interviews. Boiler combustion efficiency tests were not performed on-site as there was construction surrounding the main mechanical building preventing access. Recent site combustion tests were also not provided. Gas savings were calculated using site data to determine the difference in heat loss between bare and insulated pipes and fittings. The evaluators determined the measure to be an add on single baseline considering the underlying steam distribution system is expected to outlive the installed insulation. The baseline is bare, uninsulated pipe and fittings. The savings were less than the tracking estimates primarily due to the difference in the oil/gas usage ratio, calculated heat loss values using 3EPlus, boiler combustion efficiency, and energized operating hours. The evaluated results are presented in Table 6-3.

Table 6-41. Evaluation Results Summary

PA Application ID	Measure Name		Savings (Therms/yr)	Measure Life (years)	Lifetime Savings (Therms)
NR160714	Fitted insulation jackets for pipes and fittings.	Tracked	144,188	15	2,162,823
		Evaluated	120,639	15	1,809,582
		Realization Rate	84%	N/A	N/A
Totals		**Tracked**	**144,188**	**15**	**2,162,823**
		Evaluated	**120,639**	**15**	**1,809,582**
		Realization Rate	**84%**	**N/A**	**N/A**

N/A = Not applicable

5.1.1 Explanation of Deviations from Tracking

The evaluated savings are 16% less than the applicant-reported savings primarily due to the difference in the oil/gas usage ratio, calculated heat loss values using 3EPlus, boiler combustion efficiency, and energized operating hours. Further details regarding deviations from the tracked savings are presented in Section 3-4.

5.1.2 Recommendations for Program Designers & Implementers

It is recommended for the program to use the default setting of "heat loss per hour" in 3EPlus to simulate heat loss. This setting produces outputs in proper units based on application type (straight pipe or tank shell). The method of "heat flow limitation" is not as consistent in providing heat loss values.

5.1.3 Customer Alert

There are no customer alerts for this project.

5.2 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 the installation of fitted insulation jackets on various sections of straight pipe, fittings, steam sleeves, and other heating equipment.

5.2.1 Application Information and Applicant Savings Methodology

This section describes the application information, savings methodology provided by the applicant, and the evaluation assessment of the savings calculation algorithm used by the applicant. Both applicant and evaluated approaches utilized 3EPlus simulation using on-site findings and assumptions to determine bare and uninsulated heat loss values for all insulated applications. Project savings were primarily based upon the reduction in heat loss between bare and insulated applications.

5.2.2 Applicant Description of Baseline

The applicant classified the measure as a retrofit with a single baseline. According to the savings analysis file provided by the applicant, the baseline is bare, uninsulated straight pipe, fittings, steam sleeves, and other heating equipment exposed to an indoor temperature of 70-110°F, dependent on building. The baseline steam system consisted of pre-existing boilers operating year-round except for maintenance shutdowns. The applicant used a boiler combustion efficiency of 80%.

Applicant Description of Installed Equipment and Operation

A vendor conducted a scoping audit in which they identified uninsulated steam pipes, fittings, steam sleeves, and other heating equipment that were allowing excess heat to escape to unconditioned mechanical spaces. The vendor took surface temperature spot readings of the uninsulated surfaces, collected surface pipe lengths and diameters to determine surface areas, and determined hours of operation for each system. Per the application documents, the vendor identified approximately 7,224 ft^2 equivalent of the distribution system totaling all hot surfaces that needed insulation. Insulation with thicknesses ranging between 0.39 and 4.5" were installed for all pipes and jackets other than most steam traps.

Applicant Energy Savings Algorithm

The project documents include a spreadsheet calculation file labeled "Insulation Measure - 144188 therms savings.xlsx". The applicant calculated the savings using a custom analysis spreadsheet aided by the 3EPlus energy modeling software to establish bare and insulated surface heat loss rates. The insulation energy savings were calculated for each insulated application using the following formula:

$$Svgs = \frac{SA_{fitting} \times (HLR_{\ bare} - HLR_{insulated}) \times Hours}{100{,}000 \times Eff_{burner}}$$

where,

$Svgs$	= Annual energy savings per year (therms)
$SA_{fitting}$	= Surface area of insulated fitting (ft^2)
HLR_{bare}	= Heat loss rate of bare pipe (Btu/hr/ft^2) calculated using 3EPlus
$HLR_{insulated}$	= Heat loss rate of insulated pipe (Btu/hr/ft^2), calculated using 3E Plus

$Hours$ = Number of hours per year the pipe or fitting is energized
$100{,}000$ = BTU to Therm conversion rate
Eff_{burner} = Boiler burner efficiency (80%)

Figure 6-1. Applicant Savings Calculations below shows a screenshot from the applicant savings calculations file.

Figure 6-17. Applicant Savings Calculations

Description	Component	Insul Thick	Flange Class	Nominal Pipe Size	Operating T	Ambient T	SF/component	Hrs in service/yr.	Bare BTU/hr/sf lost	Insul BTU/hr/sf lost	Insul Touch T ºF
6" Bonnet 125/150 2" (300°-425°F)	Bonnet	2	125/150	6.00	338	85	1.51	8640	736.10	29.56	103
3" Bonnet 125/150 2" (300°-425°F)	Bonnet	2	125/150	3.00	338	85	1.57	8640	759.70	56.64	116
1.5" Bonnet 125/150 2" (300°-425°F)	Bonnet	2	125/150	1.50	338	85	0.98	8640	791.80	18.73	97
1.5" Bonnet 125/150 2" (300°-425°F)	Bonnet	2	125/150	1.50	338	85	0.98	8640	791.80	18.73	97

The applicant post-installation inspection found that none of the steam traps in the proposal were insulated. Therefore, the applicant revised the calculation to remove the insulation savings associated with steam traps.

Additional details on the applicant algorithm could be found in the project files.

Evaluation Assessment of Applicant Methodology

The applicant used 3EPlus simulations based on site assumptions to determine heat loss values for bare and insulated fittings. The applicant 3EPlus values for bare and insulated heat loss were found to be calculated using non-default settings in the software. The default calculation type of "heat loss per hour" outputs heat loss units dependent upon the inputs given (BTU/hr/ft for linear pipe and BTU/hr/ft^2 for blanket applications). After performing some spot calculations, the evaluators were able to assume the applicant used "heat flow limitation" for the calculation type (although this could not be confirmed as 3EPlus screenshots were not provided in application data). This calculation type results in BTU/hr/ft^2 as the default unit regardless of the application type and if straight pipe parameters are used in the simulation. This method is not as consistent and overestimates heat loss compared to the heat loss per hour method.

5.2.3 On-Site Inspection and Metering

This section provides details on the tasks performed during the site visit and the gathered data.

Summary of On-site Findings

The evaluators conducted a site visit on April 19, 2019. During the site visit, the evaluators interviewed the facility maintenance manager and verified the applicant inputs by measuring surface area, taking spot temperature measurement using an infrared gun, and installing temperature meters for long term logging. Spot measurements included bare and insulated surface temperature as well as ambient space temperature for all accessible applications. A total of 6 buildings of varying use (lab, classroom, office, dorm, etc) were visited. Among these buildings a sum of 62 total unique steam applications were spot measured using an infrared gun. The spot measurements were used to confirm the insulated steam applications were energized. Considering the inaccurate variability of the infrared gun, the spot measurements were not used further in the analysis. Instead, the evaluator utilized long term measured data to make evaluated adjustments.

To perform the analysis, the evaluator developed bins to divide the large sample of data. Bins were developed based on temperature and application type (straight pipe/jackets). Averages were taken for pipe size and insulation thicknesses that fell in these bins. Temperature bins are shown below in Table 6-4. .

Table 6-42. Evaluated Temperature Bins

		Application			Evaluation		
Bins	Count	Operating Temp [ºF]	Ambient Temp [ºF]	Surface area per component [sqft/unit]	Operating Temp [ºF]	Ambient Temp [ºF]	Surface area per component [sqft/unit]
Jacket Bin 1	828	185	85	3.91	200	89	4.52
Jacket Bin 2	117	227	85	4.30	227	89	4.38
Jacket Bin 3	345	239	85	3.02	240	89	3.33
Jacket Bin 4	183	250	85	2.16	250	89	2.40
Jacket Bin 5	8	252	85	8.59	252	89	8.59
Jacket Bin 6	26	275	85	3.64	275	89	6.18
Jacket Bin 7	110	285	85	1.73	285	89	1.52
Jacket Bin 8	94	298	86	2.40	298	89	2.67
Jacket Bin 9	13	307	88	3.08	307	89	3.79
Jacket Bin 10	12	320	89	1.61	320	89	1.96
Jacket Bin 11	267	338	84	3.79	338	89	3.89
Jacket Bin 12	34	350	85	1.31	350	89	1.31
Pipe Bin 13	84	185	83	1.66	200	89	1.56
Pipe Bin 14	73	239	82	1.41	240	89	1.41
Pipe Bin 15	6	298	85	1.08	298	89	1.06

An average evaluated ambient temperature of 89 ºF was captured by long-term logging and used for the evaluated heat loss calculations.

Site steam is generated from a central boiler and CHP[19] (Combined Heat & Power) system at 100 psi 8,760 hours annually. There are multiple PRV (pressure reducing valves) throughout the campus to reduce pressure to optimal points based on end use. Dorms are typically serviced at 6-8 psi, lecture halls at 10 psi, while labs vary. Generally, buildings are provided with steam heat from the second

[19] DNV GL confirmed that CHP plant is not incentivized by any National Grid EE programs.

weekend of October to the second weekend of May. After steam heat is no longer provided, the steam system still provides steam to areas such as labs for process use and hot water.

Duel Fuel

The system runs dual fuel during periods of high demand. The site was unable to provide logs to show how often oil was used compared to natural gas. Instead, the evaluator was able to find utility logs and annual usage history for 2017 from the University's website. These logs were used to compare the use of oil to gas. After converting gallons of No. 2 fuel oil to ccf, it was found that 12% of overall ccf consumption is due to oil. This adjustment factor was applied to the final therm calculations to determine savings only associated with gas usage. The boiler combustion efficiencies were not provided by the site, and efficiency tests could not be performed as there was construction around the plant preventing access to the main mechanical building. The site CHP was mentioned but details were not provided for the system. The contact who escorted the evaluators through the campus was a new employee at the time and did not know details on the CHP. The contact who escorted the evaluators on the return visit also did not know details on the system. The evaluators forwarded a questionnaire to the site after the visits were conducted to answer some overall questions on the CHP system, which have gone unanswered. The evaluator was able to find detailed notes and news on the utilities of the campus on the University's website. Under the gas and steam section (updated in 2017), 4 boilers of varying sizes were listed. There was no mention of a CHP. From this information the evaluator assumed the boilers were the main steam generator, and used a standard combustion efficiency of 83.2%, which is a value established by the Baseline Advisory Group to account for stack heat losses.

The evaluator took spot measurements for bare and insulated surface temperatures as well as ambient temperatures in different areas using an infrared temperature gun. Multiple temperature probes were installed to accessible insulated applications to capture both bare pipe and ambient temperatures for each metered building. Ambient pendent loggers were also hung in multiple buildings. Temperature fluctuations were captured over a one-month period.

Measured and Logged Data

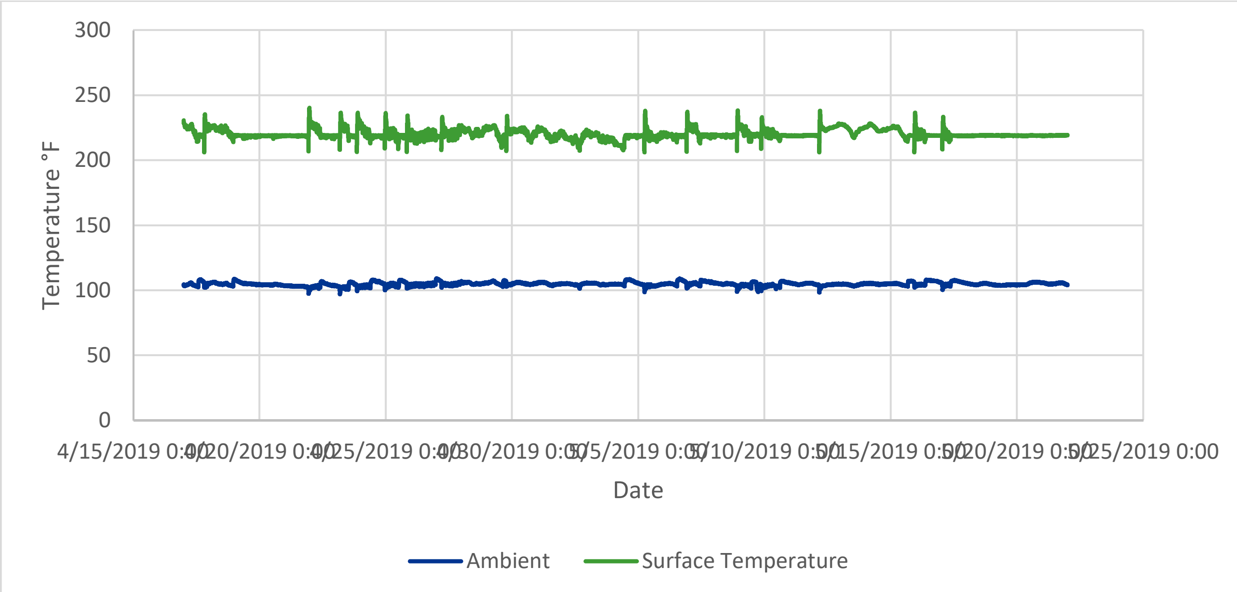
The evaluator deployed data loggers to characterize the temperature profiles for a number of pipes and fittings from April 17, 2019, through May 21, 2019. Table 6-5. Data Logger Deployment Details presents the logger deployment details.

Table 6-43. Data Logger Deployment Details

Data Logger Type	Parameter	Time Interval	Duration	Quantity
HOBO MicroStation with Temperature Sensors	Pipe and Ambient Temperature	1 minute	6 weeks	9
HOBO High Temperature Logger	Pipe and Ambient Temperature	1 minute	6 weeks	1
HOBO Pendant Temperature Logger	Ambient Temperature	2-3 minutes	6 weeks	4

An example of logged temperature data is shown below in Figure 6-2. Logged Temperature Data

Figure 6-18. Logged Temperature Data – HXXX Dorm (PII Removed) Heat Exchanger



The evaluator used the metered temperature data to calculate an operating profile to show when steam was supplied to the insulated applications during the metered period. The data was adjusted to show operation above an established baseline (212 °F in this case). Metered hourly data was expanded to fit a weekly profile. The profile depicts an hourly percent on value that shows the supplied steam operation compared to the max temperature observed in the adjusted sample. Table 6-6. Steam Supplied to HXXX Dorm (PII Removed) Heat Exchanger - % On below presents the weekly operating profile for the heat exchanger depicted in Figure 6-2. Logged Temperature Data – HXXX Dorm (PII Removed) Heat Exchanger

Table 6-44. Steam Supplied to HXXX Dorm (PII Removed) Heat Exchanger - % On

Hour	Sun	Mon	Tue	Wed	Thu	Fri	Sat
1	29%	42%	37%	44%	46%	31%	22%
2	28%	42%	36%	43%	36%	30%	20%
3	29%	41%	37%	41%	37%	33%	20%
4	27%	40%	37%	41%	34%	26%	20%
5	33%	39%	38%	37%	34%	27%	19%
6	35%	40%	47%	39%	33%	25%	24%
7	41%	38%	45%	39%	33%	25%	26%
8	36%	39%	42%	39%	32%	26%	20%
9	33%	33%	38%	34%	29%	25%	23%
10	28%	30%	37%	27%	23%	27%	20%
11	27%	26%	31%	27%	24%	25%	22%
12	29%	24%	35%	24%	24%	25%	24%
13	29%	21%	30%	21%	24%	21%	25%
14	30%	20%	29%	19%	26%	22%	25%
15	30%	21%	29%	20%	24%	22%	26%

Hour	Sun	Mon	Tue	Wed	Thu	Fri	Sat
16	30%	24%	27%	20%	25%	23%	25%
17	29%	27%	26%	23%	24%	24%	25%
18	28%	28%	27%	24%	25%	22%	26%
19	29%	27%	25%	24%	25%	25%	26%
20	30%	36%	27%	24%	26%	22%	28%
21	32%	31%	28%	34%	29%	24%	27%
22	35%	30%	40%	29%	37%	22%	29%
23	34%	37%	37%	39%	31%	23%	27%
24	49%	37%	38%	50%	28%	22%	29%

From the expanded data set, the evaluator was able to determine an estimated energized profile for the as-built insulated applications. Table 6-7. below depicts the evaluated energized hours extrapolated from metered data compared to applicant hours. These hours were applied to un-metered area by determining the space type of the area. A campus key was provided where buildings were categorized under residential, classroom, lab, offices, gym, etc. Evaluated hours were applied to the specific building types listed below, in tandem with the heat loss bin values determined from Table 6-8 to determine application specific savings.

Table 6-45. Annual Energized Operating Hours

Building	Building Type	Applicant Hours	Evaluated Hours
Center for Biotech	Lab	5,040	4,225
HXXX (PII Removed) Dorm	Residential	5,040	4,194
Pharmacy	Classroom	5,040	4,446
Unspecified building	Unspecified	1,500, 5,040, 8,640	1,500, 5,040, 8,640

5.2.4 Evaluation Methods and Findings

This section describes the evaluator methods and findings.

Evaluation Description of Baseline

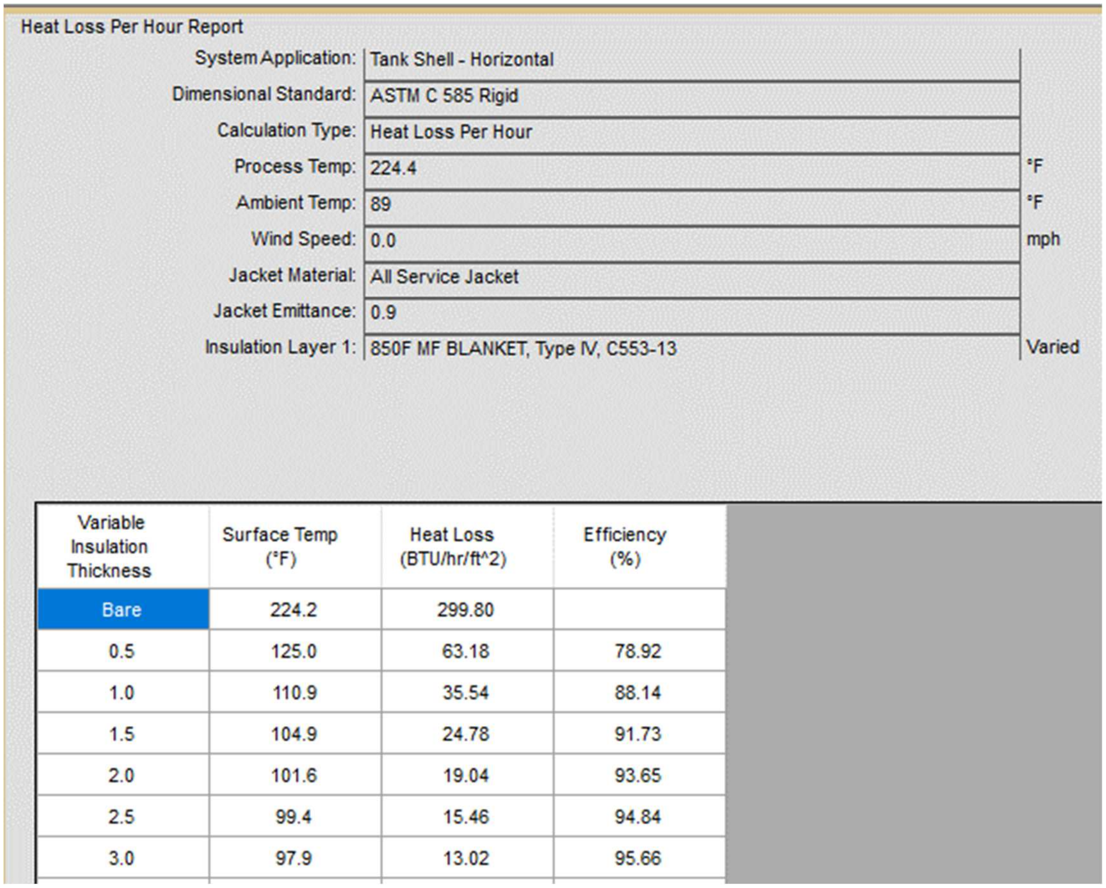
The evaluator reviewed the project files and interviewed the site contact to gather information on the baseline. The evaluator determined the measure is an add on with a single baseline measure because the underlying steam distribution system is expected to outlive the installed pipe and fitting insulation jackets. The baseline is the preexisting steam system with bare pipes and fittings, supplying steam at 100 psi.

Evaluation Calculation Method

The evaluator modeled energy savings using 3EPlus simulations to determine bare and insulated heat loss values for each unique application using the input parameters confirmed on-site. These parameters include pipe size, insulation thickness, as well as operating and ambient temperatures.

In 3EPlus the default calculation type of “heat loss per hour” was used for all applications. Under the system application drop down, “Pipe – Horizontal” was used for straight pipe applications while “tank shell – horizontal” was used for blanket applications. For material selection, “850F Mineral Fiber PIPE, Type I” was used for straight pipe applications while “850F MF Blanket, Type IV” was used for blanket applications. An example of a 3EPlus output is shown below in and Figure 6-3. 3EPlus: Blanket Insulation

Figure 6-19. 3EPlus: Blanket Insulation



Heat Loss Per Hour Report

System Application:	Tank Shell - Horizontal	
Dimensional Standard:	ASTM C 585 Rigid	
Calculation Type:	Heat Loss Per Hour	
Process Temp:	224.4	°F
Ambient Temp:	89	°F
Wind Speed:	0.0	mph
Jacket Material:	All Service Jacket	
Jacket Emittance:	0.9	
Insulation Layer 1:	850F MF BLANKET, Type IV, C553-13	Varied

Variable Insulation Thickness	Surface Temp (°F)	Heat Loss (BTU/hr/ft^2)	Efficiency (%)
Bare	224.2	299.80	
0.5	125.0	63.18	78.92
1.0	110.9	35.54	88.14
1.5	104.9	24.78	91.73
2.0	101.6	19.04	93.65
2.5	99.4	15.46	94.84
3.0	97.9	13.02	95.66

The evaluated savings for the insulation measure were calculated for each unique insulated application using the following formula:

$$Svgs = \frac{Qty \times \left(SA_{fitting}\ or\ L_{pipe}\right) \times (HLR_{\ bare} - HLR_{insulated}) \times Hours}{100{,}000 \times \eta}$$

where,

$Svgs$ = Annual energy savings per year (therm/yr)

$SA_{fitting}$ = Surface area of fitting being insulated (ft^2)

L_{pipe} = Length of the pipe (ft)

HLR_{bare} = Heat loss rate of bare pipe ($Btu/hr/ft^2$ or Btu/hr/ft), calculated using 3EPlus

$HLR_{insulated}$ = Heat loss rate of insulated pipe ($Btu/hr/ft^2$ or Btu/hr/ft), calculated using 3EPlus

$Hours$ = Annual energized hours of use

100,000 = Therms per Btu conversion

η = Boiler combustion efficiency, 83.2%

Table 6-8 compares the calculated results for the equipment bins corresponding to Table 6-4. Savings shown were determined using the heat loss bins below, as well as the building specific hours of use shown in Table 6-7. Annual Energized Operating Hours.

Table 6-46 Comparison of Applicant and Evaluation Calculated Results

			Application		Evaluation		
Bins	Count	Bare heat loss [BTU/hr/sf]	Insulated heat loss [BTU/hr/sf]	Total Savings [Therm]	Bare heat loss [BTU/hr/sf]	Insulated heat loss [BTU/hr/sf]	Total Savings [Therm]
Jacket Bin 1	828	233	17.7	37,148	225	29.5	29,257
Jacket Bin 2	117	354	24.7	8,862	299	33.7	6,171
Jacket Bin 3	345	395	28.9	20,051	343	42.3	15,703
Jacket Bin 4	183	437	32.0	8,445	377	52.3	6,649
Jacket Bin 5	8	446	43.3	595	383	44.4	370
Jacket Bin 6	26	589	31.7	3,102	432	50.0	2,350
Jacket Bin 7	110	563	39.9	5,245	488	60.7	3,252
Jacket Bin 8	94	642	45.8	6,428	529	63.9	4,635
Jacket Bin 9	13	661	26.6	1,304	572	50.4	1,178
Jacket Bin 10	12	689	31.5	672	599	55.7	530
Jacket Bin 11	267	766	34.8	49,829	915	74.0	49,040
Jacket Bin 12	34	824	42.1	1,820	742	60.4	1,367
Pipe Bin 13	84	240	16.4	485	228	30.2	83
Pipe Bin 14	73	418	38.7	65	343	44.0	24
Pipe Bin 15	6	775	54.2	138	484	52.7	31

5.3 Final Results

The project consisted of the installation of fitted insulation jackets on various sections of straight pipe, fittings, steam sleeves, and other heating equipment. The evaluator used field parameters to calculate heat loss through 3EPlus simulations. The evaluated savings are less than the reported values. The parameters impacting the analysis are summarized below in Table 6-9. Summary of Key Parameters

Table 6-47. Summary of Key Parameters

As-Built	Applicant	Evaluator
Energized annual operating hours	Classroom: 5,040 Lab: 5,040 Residential: 5,040 Unspecified: 1,500, 5,040, 8,640	Classroom: 4,446 Lab: 4,225 Residential: 4,194 Unspecified: 1,500, 5,040, 8,640
Average combustion efficiencies	80%	83.2%
Ambient temperature	70-110°F	89°F
Operating temperature	185-350°F	200-350°F
Gas/Oil usage ratio	85%	88%
Savings		
Annual natural gas savings (therms)	144,188	120,639
Natural gas realization rate	84%	

5.3.1 Explanation of Differences

The evaluated savings are less than the tracked savings primarily due to the difference in the oil/gas usage ratio, calculated heat loss values using 3EPlus, boiler combustion efficiency, and energized operating hours. Table 6-10 provides a summary of the differences between tracking and evaluated values.

Table 6-48. Summary of Deviations

End-use	Discrepancy	Parameter	Impact of Deviation	Discussion of Deviations
Process	Other	Oil/Gas Ratio	+3%	**Increased savings** – due to the difference in usage between oil and gas.
Process	Other	Heat Loss	+1%	**Increased savings** – due to the difference in calculated heat loss values based on gathered field parameters, primarily operating and ambient temperatures.
Process	Other	Quantity adjustment	-<1%	**Decreased savings** – due to an error in documented savings where some applications were considered twice.
Process	Other	Boiler Efficiency	-4%	**Decreased savings** – due to the difference in boiler efficiency
Process	Operational	Boiler operating hours	-14%	**Decreased savings** - the evaluated operating hours of hot water heaters 3 and 4 are less than the values used by the applicant to calculate the measure savings.

5.3.2 Lifetime Savings

Because the steam distribution system will outlive the installed measure, the evaluators classified this measure as an add-on with a single baseline.

The evaluated lifetime savings are smaller than the tracking lifetime savings because the evaluated first year savings are smaller than the tracking first year savings. Table 6-11 provides a summary of key factors that influence the lifetime savings.

Table 6-49. Lifetime Savings Summary

Factor	Tracking	Applicant	Evaluator
Lifetime savings	2,162,823 therms	2,162,823 therms	1,809,582 therms
First year savings	144,188 therms	144,188 therms	120,639 therms
Measure lifetime	15 years	15 years (project BCR)	15 years (MA TRM for jacket insulation)
Baseline classification	Retrofit	Retrofit	Add-on single

Ancillary impacts

There are no ancillary impacts for this site as the space isn't cooled.

6 Site 2017RIG053

Program Administrator	National Grid	
Application ID(s)	7031387	
Project Type	Retrofit	
Program Year	2017	
Evaluation Firm	DNV GL	
Evaluation Engineer	Ryan Brown	
Senior Engineer	Srikar Kaligotla	

6.1 Evaluated Site Summary and Results

The evaluated project was implemented at a manufacturing plant and consisted of the repair of failed steam traps under this retrofit measure. The applicant calculated the measure savings due to the reduction in steam losses from the repair of failed traps.

The evaluators modeled savings based on temperature spot measurements using an infrared temperature gun, logged temperature data, logged boiler run-time hours, and information gathered from on-site interviews. A boiler combustion efficiency test was not performed by the evaluator. Gas savings were calculated using site data to determine the impact on associated steam losses. The evaluators determined the measure is a retrofit with a single baseline. The evaluated baseline is pre-existing conditions as identified when the vendor conducted a steam trap survey, which is the same as the applicant baseline. The evaluator calculated the project savings using the newly revised 2018 Custom Express steam trap tool with input parameters observed on site. The older tool was used for the tracking estimate. The evaluated savings were less than the tracking values using the older tool and less than the savings that would have been reported by the program if they would have been calculated using the revised 2018 Custom Express tool.

The evaluation results are presented in Table 6-3.

Table 6-50. Evaluation Results Summary

PA Application ID	Measure Name		Savings (Therms/yr)	Measure Life (years)	Lifetime Savings (Therms)
7031387	Steam traps	Tracked	2,081	6	12,487
		Tracking savings calculated with the new tool[1]	2,415	6	14,490
		Evaluated	1,442	6	8,652
		Realization rate[2]	60%	N/A	N/A
Totals		**Tracked**	**2,081**	**6**	**12,487**
		Tracking savings calculated with the new tool[1]	**2,415**	**6**	**14,490**
		Evaluated	**1,442**	**6**	**8,652**
		Realization rate[2]	**60%**	**N/A**	**N/A**

N/A = Not applicable

[1]Program savings calculated using the new tool are calculated using the applicant inputs applied to the 2018 Custom Express Tool

[2]The realization rate is the ratio of evaluated savings to program savings calculated using the new tool

6.1.1 Explanation of Deviations from Tracking

The evaluated savings are 40% less than the savings the program would have been reported if the savings would have been calculated using the new 2018 Custom Express tool primarily due to the difference in operating pressure, energized hours, and boiler efficiency. Further details regarding deviations from the tracked savings are presented in Section 3-4.

6.1.2 Recommendations for Program Designers & Implementers

The evaluator recommends that savings for all steam trap projects going forward, be calculated using the newly revised 2018 Custom Express tool.

6.1.3 Customer Alert

There are no customer alerts for this project.

6.2 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 the repair or replacement of 7 failed steam traps identified in the vendor scoping audit.

6.2.1 Application Information and Applicant Savings Methodology

This section describes the application information, savings methodology provided by the applicant, and the evaluation assessment of the savings calculation algorithm used by the applicant. Both applicant and evaluated approaches calculated system steam losses based on steam properties calculated via on-site findings and assumptions. Project savings were primarily based upon the reduction in steam losses.

6.2.2 Applicant Description of Baseline

The applicant classified the measure as a retrofit with a single baseline. According to the savings analysis file provided by the applicant, the baseline is the pre-existing steam system identified through a third-party scoping audit. In the survey, each trap was classified as working, plugged, leaking, or blowing through. The vendor performed temperature and ultrasonic testing to determine the working status of the steam traps. Per the project documents, the vendor identified 23 steam traps where 7 were found to need repairs. The results of the survey can be seen in Table 6-13. Steam Trap Survey Results with the corresponding loss factors associated with each classification. The applicant used a boiler combustion efficiency of 80%.

Table 6-51. Steam Trap Survey Results

Trap Status	Loss Factor	Quantity Surveyed	Gas Savings (Therms)	% of Gas Savings
Fully operational	0%	16	0	0%
Partial leak	25%	7	2,081	100%
Grand total		**23**	**2,081**	**100%**

Applicant Description of Installed Equipment and Operation

The vendor replaced the 7 steam traps that were leaking

Table 6-52. Measure Level Details

Location	Trap Quantity	Gas Savings (Therms)	Average Operating Hours	Average Steam Pressure at Trap (psig)
Dryer room	7	2,081	2,000	40
Grand Total	**7**	**2,081**	**2,000**	**40**

Applicant Energy Savings Algorithm

he applicant calculated the savings using a custom analysis spreadsheet provided by the Program Administrators using the findings from the steam trap survey as inputs. 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 the 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 the latent heat of trap steam not serving boiler loads (Btu/hr) see below

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

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

A 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 the latent heat of steam not being used to serve boiler loads throughout the 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 the 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%)

Evaluation Assessment of Applicant Methodology

The applicant correctly used the 2010 Custom Express tool, and the evaluator determined the application calculation methodology reasonable.

6.2.3 On-Site Inspection and Metering

This section provides details on the tasks performed during the site visit and the gathered data.

Summary of On-site Findings

The evaluators conducted a site visit on February 19, 2019. During the site visit, the evaluators interviewed the facility maintenance manager and verified the applicant inputs by taking spot temperature measurements using an infrared gun, performing ultrasonic testing, and installing some temperature and motor loggers for long term metering. A summary of the on-site spot verification and metered data compared with the inputs used by the applicant in the tracking savings calculations is provided in Table 6-15. Note that in addition to the seven replaced traps, the evaluator also verified three other traps to confirm they are not leaking. The evaluator steam pressure was extrapolated from the steam tables based on measured temperature data.

Table 6-53. Summary of Applicant's and Verified Parameters

	Applicant		Evaluator				
Tag #	Annual Hours of Operation	Steam Pressure at Trap (psig)	Ultrasonic Readings (dB) In	Ultrasonic Readings (dB) Out	Ultrasonic Readings (dB) Orifice	Temp (°F)	Steam Pressure at Trap (psig)
290	2,000	40	16	28	11	263	22.6
291	2,000	40	19	20	22	253	16.7
292	2,000	40	16	17	17	255	17.8
293	2,000	40	16	17	17	264	23.2
294	2,000	40	22	21	23	255	17.8
295	2,000	40	32	34	30	254	17.3
962	2,000	40	22	26	21	253	16.7
963	2,000	40	23	16	15	254	17.3
969	2,000	40	14	24	16	254	17.3
Unknown	2,000	40				252	16.2
Unknown	2,000	40				273	29.3

Steam traps listed as "unknown" were monitored long term for temperature. The evaluator did not note the trap tags. An ultrasonic leak detector with dB level measurements was used to listen to the steam trap operation to determine if steam was leaking. Ultrasonic dB measurements were taken within 6 in. of the inlet and outlet of the steam trap for baseline operation. If the ultrasonic dB measurements at the orifice were equal to or lower than the baseline, then the trap was fully operational. If not, the steam trap was leaking within 10% of the baseline dB level and blowing by if greater than 10%. Based on the on-site results, the steam traps measured were found to be on the border of fully operational.

The site is equipped with one natural gas-fired boiler estimated to operate at 40 psi and maintain energized steam to the traps for 2,000 annual hours. Two high-temperature HOBO loggers with thermocouples were installed to bare trap surfaces to capture temperature fluctuations over a period of four months. One DENT motor logger was installed to the boiler motor to capture and estimate annual run-time hours. The evaluator was not able to perform a boiler combustion efficiency test due to safety constraints on-site. Historic efficiency tests were not provided either. Instead, the evaluator used a boiler efficiency of 83.2% for the boilers with linkage control, which is a value derived from the MA baseline advisory group for this specific boiler configuration.

Measured and Logged Data

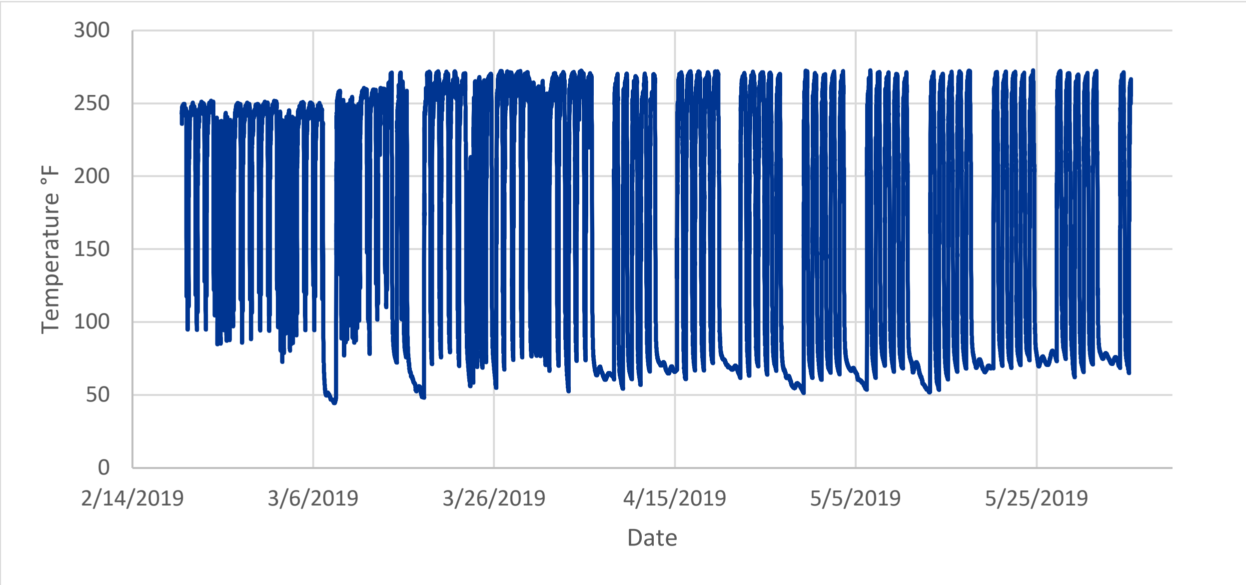
The evaluator deployed data loggers to characterize the temperature profiles for a couple of steam traps from February 19, 2019, through June 4, 2019. Table 6-16 presents the logger deployment details.

Table 6-54. Data Logger Deployment Details

Data Logger Type	Parameter	Time Interval	Duration	Quantity
HOBO high-temperature logger with thermocouple	Temperature	5 minute	17 weeks	2
DENT motor logger	Annual Operating Hours	15 minutes	17 weeks	1

An example of logged temperature data is shown below in Figure 6-4. Logged Temperature Data.

Figure 6-20. Logged Temperature Data – Other



The evaluator did not note the boiler operating discharge pressure or the observed pressure readings at the pressure-reducing valves (if applicable). Instead, long term temperature samples were used to extrapolate pressure from the steam tables by using the max observed value. The evaluator decided not to include spot measurements taken from IR gun samples as those could be inconsistent. The average calculated pressure from the two traps that were metered long term was used as a proxy for the remaining sample of traps, as all were shown to operate on the same pressure.

Temperature loggers were deployed on two traps to determine annual energized hours of use. Logger data from one of the traps is shown in Figure 2-1, depicting temperature fluctuations during the metered period. The evaluator used the metered temperature data to calculate an operating profile to show when steam was supplied to the as-built steam traps during the metered period. Metered hourly data was expanded to fit a weekly profile. The profiles depict an hourly percent on value that shows the supplied steam operation over baseline (212°F) compared to the max temperature value seen in the data. The max value shown in the metered data correlates to a pressure less than the estimated operating pressure shown in the application. It is possible that the application over estimated trap operating pressure for this steam system. Table 6-17. Steam Supplied to Process Trap - % On presents the weekly operating profile for the sampled trap.

Table 6-55. Steam Supplied to Process Trap - % On

Hour	Sun	Mon	Tue	Wed	Thu	Fri	Sat
1	3%	4%	5%	6%	7%	2%	5%
2	5%	3%	3%	5%	4%	3%	5%
3	3%	1%	1%	1%	2%	0%	0%
4	3%	2%	2%	1%	2%	2%	2%
5	10%	8%	7%	9%	13%	11%	4%
6	8%	13%	10%	14%	17%	15%	3%
7	11%	27%	35%	37%	38%	40%	8%
8	17%	51%	55%	58%	57%	53%	16%
9	11%	68%	68%	67%	67%	66%	9%
10	9%	72%	72%	68%	70%	69%	4%
11	4%	75%	73%	72%	71%	70%	1%
12	5%	75%	76%	75%	73%	71%	5%
13	0%	78%	76%	75%	74%	72%	1%
14	1%	78%	77%	76%	73%	73%	0%
15	3%	81%	79%	79%	76%	78%	1%
16	4%	71%	69%	70%	66%	70%	6%
17	0%	50%	53%	56%	47%	52%	1%
18	2%	37%	45%	51%	36%	41%	1%
19	9%	35%	44%	50%	36%	41%	8%
20	6%	32%	38%	44%	30%	36%	10%
21	3%	26%	29%	35%	25%	26%	4%
22	11%	24%	28%	33%	25%	24%	9%
23	7%	12%	16%	18%	13%	16%	9%
24	2%	4%	5%	5%	2%	3%	2%

The operating profile from the logged temperature data depicts average operation weekdays between 8 AM and 4 PM. Morning, evening, and weekends seem to be shut down. The logged boiler runtime data corroborate these findings as the boiler seems to mainly operate between 8 AM and starts to ramp down after 4 PM. The boiler looks to be typically off during early mornings and weekends.

From the expanded temperature data set, the evaluator was able to determine an estimated annual operation for the as-built steam traps. Table 6-56 below depicts the estimated annual operation for both metered traps compared to the applicant assumed operating hours.

Table 6-57 Evaluated Steam Trap Operating Hours by Application

Steam Trap	Applicant Annual Hours	Evaluation Annual Hours
Other – Logger 20550129	2,000	936
Other – Logger 20550137	2,000	2,611
Average	2,000	1,774

6.2.4 Evaluation Methods and Findings

This section describes the evaluator methods and findings.

Evaluation Description of Baseline

The evaluator reviewed the project files and interviewed the site contact to gather information on the baseline. The evaluator determined the measure is a retrofit with a single baseline measure, where the baseline would be the pre-existing traps as identified in the steam trap survey.

Evaluation Calculation Method

The evaluator calculated the savings using a revised version of the Custom Express tool that was adopted by the National Grid subsequent to the program year of this application. The 2018 revised Custom Express tool includes a different leak factor and no longer applies the repair/replace factor to the trap savings calculation. 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 also compare the evaluated steam trap savings with the savings calculated using the 2018 Custom Express methodology updated with the original applicant inputs.

Evaluated savings. A revised version of the custom express tool was adopted by National Grid following the completion of the Phase 2 Steam Trap Evaluation[20] 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)

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

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)

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 by the applicant as they were verified on-site using spot checks and site contact interviews. The evaluator corrected the pre-retrofit operating status to reflect the updated inputs. Specifically, "partially leaking" and "partially blowing-by" was updated to "leaking" and "blowing-by" respectively, based on guidance from the Phase 2 study results. With these updated statuses, the evaluators were able to apply the revised leak factors to the custom savings equation.

Program savings calculated using the new tool. The evaluator calculated the program savings that would have been reported if the 2018 Custom Express tool had been used to model the measure savings. The savings calculated using the ex-ante assumptions resulted in savings of 2,415 therms per year. Table 2-7 compares the reported tracking estimates, program savings calculated using ex-ante assumptions and the 2018 Custom Express tool, and the evaluated savings.

Table 6-58. Steam Trap Survey Findings

Method	Savings (therms)
Tracked	2,081
Tracking savings calculated with the new tool[1]	2,415
Evaluated	1,442

[1]Program savings calculated using the new tool are calculated using the applicant inputs applied to the 2018 Custom Express tool

Cross-Check with Utility Billing Data

The evaluators conducted billing analysis to verify the evaluated savings for this site as well as analyze the pre-existing gas usage which is difficult to be accurately modeled otherwise. However, the evaluated savings is only 2.2% of the post-retrofit annual usage. Due to the embedded error in the weather normalization, DNV GL determined the billing anlaysis would not yield meaningful results given the small amount of the savings for this measure.

6.3 Final Results

The project consisted of the repair of failed steam traps discovered through a vendor study for the steam traps located in the dryer room. The applicant calculated savings for the steam trap measure using the older 2010 Custom Express tool with inputs collected from the steam trap survey conducted in 2017. The evaluator calculated savings for the steam trap measure using the 2018 revised version of the Custom Express tool with inputs collected from metered and measured data. The evaluated savings for the project were smaller than the savings the program would have been reported if the savings would have been calculated using the 2018 Custom Express tool. The parameters characterizing the analysis are depicted in Table 6-21. Summary of Key Parameters.

Table 6-59. Summary of Key Parameters

Baseline	Applicant	Evaluator
Impacted system	Existing boiler plant and steam distribution system with 7 failed steam traps	Existing boiler plant and steam distribution system with 7 failed steam traps
Boiler plant efficiency	Combustion efficiency: 80% System line losses: 0%	Combustion efficiency: 83.2 System line losses: 0%
Steam operating pressure	40 psi	22.8 psi
Steam trap operating hours	2,000	1,774
As-Built	**Applicant**	**Evaluator**
Impacted system	Existing boiler plant and steam distribution system with 7 steam traps that were repaired by this measure	Existing boiler plant and steam distribution system with 7 steam traps that were repaired by this measure
Boiler plan efficiency	Combustion efficiency: 80% System line losses: 0%	Combustion efficiency: 83.2 System line losses: 0%
Steam operating pressure	40 psi	22.8 psi
Steam trap operating hours	2,000	1,774
Savings		

Annual natural gas savings (therms)	2,415	1,442
Natural gas realization rate	60%	

6.3.1 Explanation of Differences

The evaluated savings are 40% less than the savings the program would have been reported if the savings would have been calculated using the 2018 Custom Express tool. Table 6-22. Summary of Deviations below provides a summary of the differences between tracking and evaluated values.

Table 6-60. Summary of Deviations

End-use	Discrepancy	Parameter	Impact of Deviation	Discussion of Deviations
Process	Operational	Steam operating pressure	-28%	**Decreased savings** - due to a difference in observed boiler discharge pressure.
Process	Operational	Energized steam operating hours	-8%	**Decreased savings** - due to the reduction in evaluated energized steam operating hours.
Process	Operational	Boiler efficiency	-4%	**Decreased savings** - due to a difference in boiler efficiency.

6.3.2 Lifetime Savings

The evaluator determined the measure is a retrofit with a single baseline measure, where the baseline would be the pre-existing traps as identified in the steam trap survey conducted at the facility.

The evaluated lifetime savings are smaller than the tracking lifetime savings because the evaluated first-year savings are smaller than the tracking first-year savings. Table 6-11 provides a summary of key factors that influence the lifetime savings.

Table 6-61. Lifetime Savings Summary

Factor	Tracking	Program Savings using the 2018 Custom Express Tool	Evaluator
Lifetime savings	2,081 therms	2,415 therms	1,442 therms
First year savings	12,487 therms	14,490 therms	8,652 therms
Measure lifetime	6 years	6 years (project BCR)	6 years (MA TRM for steam traps)
Baseline classification	Retrofit	Retrofit	Retrofit

The equivalent measure life for this project is 6 years.

Ancillary impacts

There are no ancillary impacts for this site as space isn’t cooled.