DNV

FINAL REPORT

Impact Evaluation of PY2021 Custom Gas Installations in Rhode Island

RI Energy

Date: November 2, 2023

Table of contents

List of figures

List of tables

List of acronyms used in this report

CDA	comprehensive design approach
C&I	commercial and industrial
CI	confidence interval
EMS	energy monitoring system
HVAC	heating, ventilation, and air-conditioning
ISP	industry standard practice
M&V	measurement and verification
MA	Massachusetts
MBSS	model-based statistical sampling
PA	program administrator
PY	program year
PY2018	program year 2018
PY2019	program year 2019
PY2020	program year 2020
PY2021	program year 2021
RI	Rhode Island
RR	realization rate
SEMP	strategic energy management partnership
TMY3	typical meteorological year 3

1 INTRODUCTION

This section presents the objective and describes the organizational format for DNV's Impact Evaluation report of Program Year (PY) 2021 custom gas Installations for RI Energy (RIE).

1.1 Study purpose, objectives, and research questions

The objective of this Impact Evaluation for Program Year 2021 (PY2021) custom gas Installations is to provide verification or re-estimation of energy (therms) savings for sampled custom gas sites through site-specific inspections, end-use monitoring, and analysis. Site-specific results were aggregated to determine realization rates (RR) for RI Energy's custom gas installations. Custom gas evaluations for RI Energy starting from PY2016 are designed to be rolling/staged evaluations. The goal of this approach is to repeat measurement and verification (M&V) annually as the previous year's tracking data became available. The current study consists of PY2019 as Year 1, PY2020 as Year 2, and PY2021 as Year 3.

This study:

- Achieved gross natural gas energy savings for RI custom gas projects, with targeted sampling precision of ±35% at 80% confidence for the current evaluation year (PY2021).

In PY2021, DNV discussed with RI Energy and the EERMC evaluation consultants (C-team) the approach to evaluating steam traps in the current year and upcoming evaluation cycles. During these discussions, the group determined that steam trap and non-steam trap sites have fundamentally different evaluation methodologies so the precision results for the two categories should not be grouped together. Non-steam trap sites are evaluated through in-depth M&V whereas the current method for evaluating steam traps is to use an ex-ante estimate that is from a calibrated model which is assumed for now to be equivalent to evaluated or ex-post. For these reasons, the group decided to exclude steam trap sites for PY2021 evaluation, and whether to continue to evaluate steam trap sites, whether to use an existing tool or develop a new one, has been deferred to the PY2022 custom gas evaluation. For this year's evaluation the group decided that PY2021 single year results will report on just the evaluated non-steam trap sites, but three-year rolling results will combine non-steam trap RR and steam trap RR (considered to be 100% RR in line with previous evaluation years) for an overall RR. The group considered this to be a reasonable step as part of a longer-term path to entirely separating evaluation and reporting on the two categories. Despite only evaluating non-steam trap sites, DNV was able to select a non-steam trap-only site sample from PY2021 that would still meet the necessary annual precision target. The following report shows the sampling and evaluation results exclusively for the non-trap sample since steam traps were not evaluated this year. The PY2021 results presented later in Section 4.1 represent only the non-steam trap population results. The methodology for calculating the combined three-year rolling results which does include the 100% RR for steam traps is discussed further in Section 4.2.

This program evaluation performed site-based M&V impact evaluations to quantify the achieved natural gas energy savings using 4 RI custom gas non-steam trap sites from projects completed in the PY2021 cycle. Since steam traps were not evaluated in this evaluation year, PY2021 results are only for non-steam trap sites and are reported in Section 4.1. For three-year rolling results, the PY2021 results were combined with those from PY2019 and PY2020 to produce an overall RR including both non-steam trap and steam trap RRs for the purpose of updating statewide realization rates.

1.2 Organization of report

The remainder of this report is organized as follows:

- Section 2: Methodology and Approach. The methods associated with sampling and the M&V tasks are described in this section.

- Section 3: Data Sources. The study used various data sources including RIE's tracking data, individual application project files etc.
- Section 4: Analysis and Results. The results associated with the program evaluation of PY2021 and the latest rolling three-year results are presented in this section.
- Section 5: Conclusions, Recommendations, and Considerations. Conclusions and recommendations from analyzing the M&V findings are presented in this section.

2 METHODOLOGY AND APPROACH

The evaluation team's approach was consistent with the COVID-19 procedures and protocols developed during the previous round of custom gas impact evaluations conducted for PY2019 and PY2020, with the change in this year to forego the evaluation of steam trap sites. The approach was changed to account for the RI Energy steam trap tool which already adjusts for operational discrepancies through its embedded calibrated billing analysis. A decision was made between DNV, RI Energy, and the C-team to forego evaluating steam traps for the current year and reassess the steam trap evaluation approach in the next program year during scoping including the option to entirely separate out steam traps and non-steam trap for the purposes of sampling, evaluating and reporting. The group determined that the two categories have inherently different evaluation approaches so the precision of the evaluated results cannot be seamlessly combined. The group will decide in the next evaluation round whether to evaluate steam trap sites as a separate sample with separate single and three-year rolling results and which approach to take, whether that includes using an existing calibrated tool with desk reviews, developing a new RI-specific calibrated tool, or using a new non-calibrated tool.

In PY2021, all sites were completed as full M&V with on-site metering and verification. As was seen in PY2021 and discussed in further sections, customers and facilities have normalized post COVID operations. Since all the sites in the sample were full M&V sites, each site has both non-operational and operational results. The differences in these results are discussed in the following sections.

2.1 Description of sampling strategy

DNV designed the PY2021 impact evaluation sample to pool annual program evaluation results with the PY2019 and PY2020 results to produce a three-year rolling result.

PY2019, PY2020, and PY2021 results will be pooled to use in PY2024 planning. 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 2-1 for the targets listed. The sample design for this study assumed the results would pool with prior (and future) custom gas results. In PY2021, the annual expected relative precision was determined to be ±40% expected relative precision with an 80% confidence interval. DNV used a Model-Based Statistical Sampling (MBSS) technique to develop the sample design. The sampling unit is the sum of all projects installed in the evaluated program year for an account or location if the account serves multiple locations.

Table 2-1. Sampling targets

Annual Sampling Target	Error Ratio

±40% expected relative precision - 80% CI	0.55 (non-stream trap)

2.1.1 PY2021 sample frame

The initial population for this program impact evaluation was the set of custom gas projects rebated in 2021. The table below separates the C&I Custom General into three categories: steam trap only accounts, non-steam trap only accounts, and accounts that had both steam trap and non-steam trap measures in this program year.

Table 2-2 shows the distribution of all tracking records and the associated savings by RI Energy. The table below separates the C&I Custom General into three categories: steam trap only accounts, non-steam trap only accounts, and accounts that had both steam trap and non-steam trap measures in this program year.

Table 2-2. PY2021 population distribution of custom gas accounts

Distribution	Number of Accounts	Gas Savings (Therms)	% Savings
Custom Design Approach (CDA)	4	55,791	4.7%
Custom-Prescriptive	4	52,579	4.4%
Less than 1,000 therms savings	18	8,540	0.7%
C&I Custom General - ST only	13	219,514	18.4%
C&I Custom General - Non-ST only	51	412,436	34.6%
C&I Custom General - Both ST and non-ST	9	443,499	37.2%
Grand Total	99	1,192,359	100%

Custom Design Approach (CDA) projects, Custom-Prescriptive projects and sites that saved less than 1,000 therms were excluded. CDA projects were removed as they were studied separately by RIE and custom prescriptive projects were removed because their evaluation is not representative of custom programs. Sites with less than 1,000 therms of savings were removed because small savers typically have less rigorous savings estimates and cover <1% of the total program savings. Accounts with only steam trap sites were also removed from the population frame. Table 2-3 shows the selected sample frame after dropping the small sites, CDA projects, prescriptive measures, and steam trap sites. The number of accounts in the table below are a combination of accounts that had only non-ST projects and the accounts that had both non-ST and ST projects. The tracking savings shown in the table below include only the non-ST tracking savings.

Table 2-3. PY2021 adjusted (final) non-ST project population frame

Accounts	Tracking Savings (Therms)
60	752,277

2.1.2 PY2021 sample design

Table 2-4 shows the selected sample for this project. DNV estimated that four sampled non-steam trap sites would result in an expected relative precision of ±40% precision at an 80% confidence interval. No steam traps were evaluated in PY2021 as discussed above.

Table 2-4. PY2021 Project sample design

Stratum	Number of Sites (n)	Sampled Sites (n)	Total Therms	Expected Relative Precision @ 80% CI
1	52	2	278,569	±40%
2	8	2	473,708	

2.1.3 Rolling sample design

The expected precision from the PY2021 sample design was combined with the achieved PY2019 and PY2020 study results to produce a combined estimated precision for the overall three-year rolling result. DNV noted that the savings for PY2021 were significantly lower than the previous two program years, which means the PY2021 portion of the three-year rolling result would carry less weight. When all three years are combined, this will result in an expected precision of ±7.8% at 80% confidence for the three-year pooled value. Although only non-steam traps were planned to be evaluated in PY2021, DNV, RI Energy, and the C-team proposed that the three-year rolling result would still combine non-trap and trap RRs into an overall RR for the purpose of reporting results which will be used to inform the PY2024 program planning. However, in PY2021, since precisions for steam trap and non-steam trap RRs were considered to not seamlessly combine, the RP for the three-year rolling is reported below as N/A. Table 2-5 provides the combined expected precision based on this sample design. This table shows the 2019, 2020, and 2021 accounts, therm savings, and design RPs for combined samples (ST and Non-STs) because the three-year rolling results are calculated from the combined RRs from each year.

Table 2-5. PY2019, PY2020, and PY2021 combined expected precision at 80% confidence interval

Program Year	Accounts (N)	Therms Savings	Error Ratio	Sample (n)		RP @80% CI
				Design	Achieved	Design
PY2019	91	1,944,204	0.55 (non-ST) 0.65 (ST)	10	2 non-OP non-ST 4 OP non-ST 3 ST 1 non-OP combined	±35.0%
PY2020	77	1,280,693	0.65 (ST) 0.55 (SS) 0.55 (non-ST)	8	3 non-OP non-ST 1 OP non-ST 4 ST	±29%
PY2021	73	1,075,449	0.55 (non-ST)	4	4 OP non-ST	±28%
PYs (2019, 2020, & 2021)	242	4,300,346	N/A	22	20	N/A

ST = Steam Trap; OP = Operational, combined = Combined steam trap and non-steam trap, N/A = Did not calculate.

2.1.4 PY2021 final sample disposition

The final (achieved) sample includes four non-steam trap sites, listed in Table 2-6. No replacements or backup sites were needed for this program year. All four sites were completed with both non-operational and operational results. The summary includes the site ID, the verified measure description, tracking savings, and site RR.

2.2 Site M&V planning

The site evaluation (M&V) plan played an important role in establishing approved field methods and ensuring that the 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 submitted full individual M&V plans for each evaluated site. These plans were reviewed by RI Energy. 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
  - Key baseline assumptions.
  - Key proposed-case assumptions.
  - Evaluator assessment of tracking savings methods or assumptions, including program-reported baseline.
- **Project (site) evaluation** – A short description of the methods to be 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 to be collected by DNV; where several similar items have been installed or are being controlled, the site 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 or to be provided by the site (e.g., EMS trends, production, pre-metering) and/or RI Energy.
  - The expected site 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 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 are determined through the site evaluation preparation to compare to those used in the original savings estimate.
- Measurement verification equipment to install on select equipment and quantity of devices intended for installation.

DNV updated the M&V plan, responding to RI Energy comments, and in most of the cases, submitted a revised M&V plan before the site visit.

2.3 Data collection

DNV performed a site contact interview and scheduled a site visit to perform the tasks described in the site M&V plan. Data collection occurred from February 2023 to June 2023.

2.3.1 Customer Outreach

Using the information provided in the project files, project engineers reached out to customer site contacts. During this initial outreach, the engineers discussed the purpose of the site evaluation, the scope of measures installed, the availability of onsite trend/EMS/production data, any other applicable parameters, the impact of a COVID-19 health emergency, and confirmed that the site would allow DNV to conduct the site visits.

All four primary sites selected for evaluation agreed to an onsite visit. No backups were selected for any sites. As Table 2-6 lists below, the site-level information of data types collected, and the type of data collected.

Table 2-6. Site-level information for the type of visit and data collected

Site ID	Type of Site Visit	Data Collected				Type of Adjustment
		Site Interview	Equipment Verification	Trend Data	M&V Data	
RIG21N078	Onsite	X	X	N/A	X	Operational
RIG21N060	Onsite	X	X	X	X	Operational
RIG21N081	Onsite	X	X	N/A	X	Operational
RIG21N080	Onsite	X	X	N/A	X	Operational

N/A = Not applicable to evaluated measures, trend data was not received

2.3.2 Site visit

Each initial site visit consisted of verification of installed equipment; a discussion with facility personnel regarding the baseline characteristics of the measure, if called for, 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. For one site, RIG21N060, billing data was requested and used for a billing analysis. A second site visit to retrieve meters was scheduled for sites where evaluators installed meters during the initial visit. In PY2021, no sites were affected by COVID-19 impacts and all sampled sites included site visits with full M&V.

2.3.3 M&V plan update

DNV submitted an updated site M&V plan to RI Energy after the completion of the initial site visit. These updated plans for each site 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.
- A summary of the data in progress of being collected, information that will not be available for analysis purposes, and lists tasks to complete on the return for meter pickup.

The update provided RI Energy current status of the site evaluation and communicate any anticipated or resulting deviations from the plan.

2.4 Site analysis

As previously shown In Table 2-6, the evaluation team evaluated all four projects with operations adjustments (traditionally called full site evaluations) from metered data or billing data. Results were normalized to typical production or weather data. For weather-dependent measures that result in savings, the site analysis involves normalizing the models to weather data using Typical Meteorological Year 3 (TMY3) data from the closest representative weather station to each site.

2.5 Site reporting

DNV submitted draft site reports to RI Energy for all four sites, after which RI provided comments or questions to the engineer who led the site analysis. The engineer responded to comments and questions 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 site 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's baseline and proposed conditions
    - Applicant savings calculation methods
    - Evaluator assessment of the applicant savings calculation methods
    - Measure verification results and methods for verifying measures
    - The data collected by DNV, summarized in graphical or tabular form for each data point
    - The data provided by the site and/or RI Energy, with key data summarized in graphical or tabular form
    - Site evaluation baseline used
    - The site evaluation analysis method used, identifying any deviations from the original savings estimation method
    - Key savings parameters determined through the site 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 site evaluation savings estimates

An internal quality assurance lead reviewed all four sites. This review determined if the reports complied with the requirements for this deliverable and if the document communicated information clearly and consistently.

2.5.1 Measure event type and baseline review

Table 2-7 shows the measure event types used in RI Energy tracking information and site evaluations. Site RIG21N060 was classified by the applicant as a new construction/replace on failure. The evaluators determined the measure to be a New Construction with the distinction that the equipment was at the end of its useful life, noting that the pre-existing had not failed but was beyond its useful life. All other projects were classified as retrofits in the application but reclassified as add-on retrofits by the evaluators.

Table 2-7. Measure event type in RI Energy tracking information and site evaluations

Site ID	Measure Type	RI Energy Application#	Tracking Event Type	Site Evaluation Event Type
RIG21N078	Destratification fans and cooler case doors	13219566	Retrofit	Add-on Retrofit
RIG21N060	Hot water heaters	11982442	New Construction / Replace on Failure	New Construction
RIG21N081	EMS fan controls	11246974	Retrofit	Add-on Retrofit
	Process controls	11246977	Retrofit	Add-on Retrofit
RIG21N080	Steam piping and equipment	11529748	Retrofit	Add-on Retrofit
	Hot oil and steam equipment	12785274	Retrofit	Add-on Retrofit

After the measure event type was selected, the evaluator selected the evaluated baseline for the event type. Measures classified as retrofit (and add-on) used pre-existing conditions as a baseline. Measures classified as new construction (and replace on failure) used ISP or code as the baseline. The evaluation team completed an independent review of the baseline for each sampled project. Using site data project documentation and interviews at the facility, DNV assessed the reasonableness of the baseline for each sampled project. The evaluators reclassified the evaluation event type as needed to be more specific but noted that they are effectively the same when considering the baseline conditions and savings.

2.6 Sample expansion

2.6.1 Site weight calculation

Weights are calculated similarly to previous rounds of custom gas program evaluations and are determined by dividing total number of observations in the stratum by the number of evaluated observations. Operational adjustments use the same weights as non-operational adjustments; however, the final realization rate and error calculations may be based on imputed values for any portion of population savings not represented by sampled sites where operational adjustments were evaluated . For PY2021, operational and non-operational adjustments (described in Section 2.6.2) were calculated and combined to arrive at an overall realization rate. . PY2021 did not require imputing any portion of the operational adjustment since all PY2021 sites had full M&V. Using PY2019 – PY2021 results, a three-year rolling realization rate can be calculated. The methodology for this rolling realization rate is summarized in the following steps:

- The non ops and ops factors for each year are multiplied together to get an overall realization rate for 2019, 2020, and 2021 respectively.
- The annual realization rates are weighted based on the proportion of first year tracked savings across the three-year evaluation period to calculate an overall three year realization rate with associated

2.6.2 Operational and non-operational sample with imputed historical adjustments

The operational and non-operational sample estimation approach accounts for the difference within program year 2021 from two results: operational and non-operational adjustment factors. In PY2021, all four sites had operational adjustments from onsite metering, therefore no historical operational (ops) adjustments were necessary. However, the three-year rolling results use historical operational adjustments developed as part of those previous evaluations, insofar as the results from PY2019 and PY2020 had those values applied to calculate their final operational adjustments. The current three-year weighted rolling average uses PY2021 operational adjustments from metering, along with PY2019 and PY2020 results which have historical ops adjustments from their respective evaluation years.

The methodology in APPENDIX B is used to calculate the realization rates for both sample components of the 2021 program year. The overall 2021 program year realization rate is shown and discussed in detail in Section 4.1.

Table 2-8 shows the adjustment factors used by evaluators to categorize discrepancies from tracking data and how those factors are categorized within PY2019, PY2020, and PY2021. Non-operational adjustment factors include factors that are obtained during a desk review, site contact interview, and primary site visit. Operational adjustments require metering or trend data collected for analysis which is obtained during logger installation or delivered after the initial site visit.

Table 2-8. Adjustment factors for site evaluation

	Adjustment Factors						
Ratio Name:	Non-Operational Adjustments					Operational Adjustments	
Obtain During:	In-depth file review			1st site visit		Logger Installation	
Factor:	Baseline	Methodology	Tracking & Admin	Technology	Quantity	Operational	HVAC Interactive

3 DATA SOURCES

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

- PY2021 tracking data provided by RI Energy
- PY2021 parent/child tracking data provided by RI Energy
- PY2019 and PY2020 tracking data
- PY2019, PY2020 and PY2021 program impact evaluation results
- Project files, which typically include one or more of the following: original applications, offer letters, BCR screenings, invoices, minimum requirements documents, technical assistance studies, applicant savings calculations that match claimed savings, and post-installation reports
- Onsite observations and data collection, including inspection and verifications of equipment, nameplate data, staff interviews, vendor interviews, spot measurements of various parameters including kW and longer-term measurements.
- Metered, billing and/or EMS trend data from operational-adjusted sites that participated in the study

4 ANALYSIS AND RESULTS

The RI PY2021 study achieved the target precisions for that individual year's projects as well as for the combination of the latest three years (PY2019, PY2020, and PY2021). PY2019 impact evaluations were finalized in December 2021, and PY2020 impact evaluations were finalized in August 2022. DNV collected operational and non-operational data for all four sites. Trend data, metered data, or a combination of both were collected for each site. Both sets of non-operational and operational adjustment factors in PY2021 were combined to calculate the overall site RR for operational adjusted sites.

The following subsections provide more details on the PY2021 results.

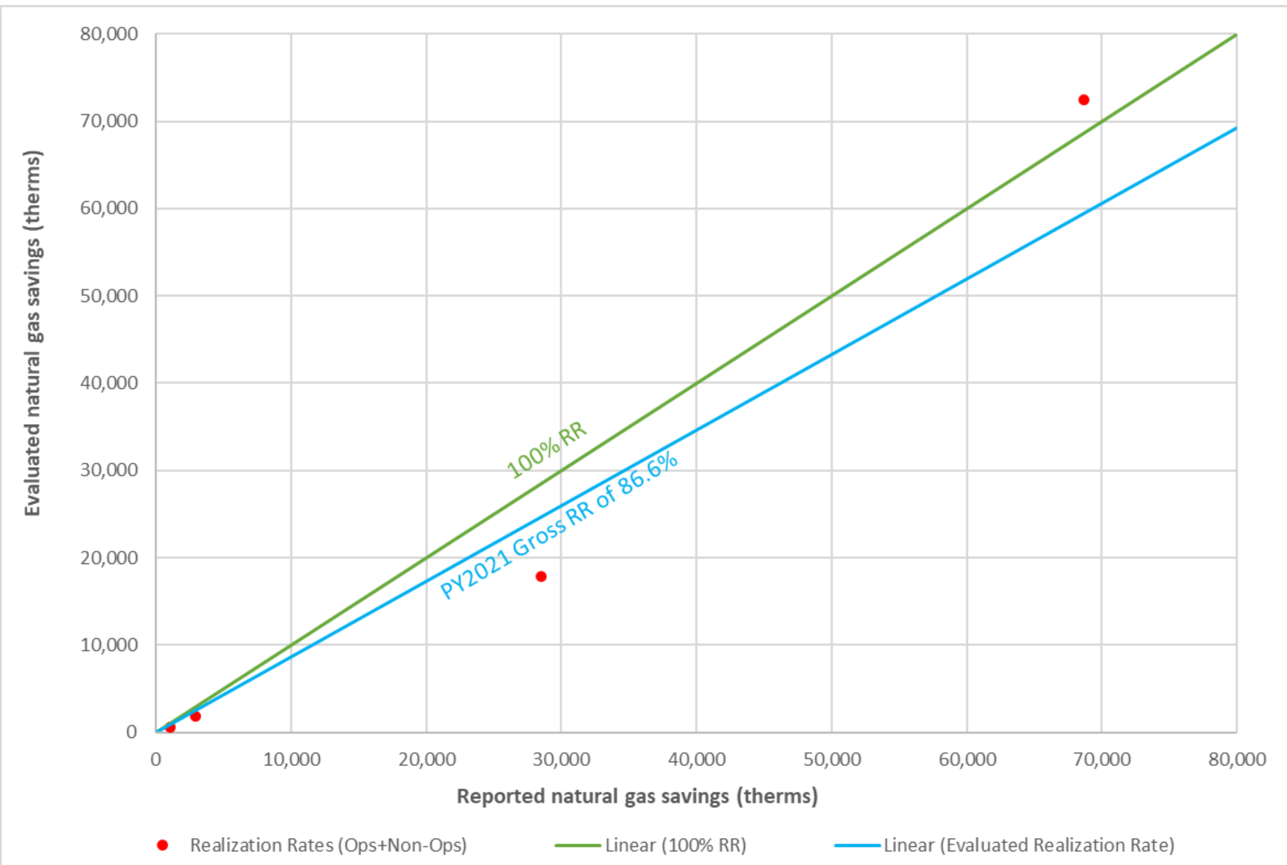
4.1 PY2021 results

This section provides an overview of the results from comparing PY2021 tracking and evaluated results.

4.1.1 Site-level results

Figure 4-1 illustrates the comparison of reported (x-axis) and evaluated (y-axis) annual natural gas savings for each of the four sites included in the program evaluation sample for PY2021. APPENDIX A summarizes the four sites for which M&V activities were completed, with statistics such as the site ID, the verified measure description, tracking savings, and RR.

Figure 4-1. PY2021 reported and evaluated annual natural gas savings



For program years where historical operational adjustments are needed, the historical operational adjustment is calculated after operational/non-operational realization rates and standard errors are calculated in a program year. The historical adjustment extrapolates results from the operational adjustment factors from the most recent three years available at the time of the evaluation (inclusive of the current evaluation year) to calculate a combined operational realization rate. The historical operational adjustment is calculated from the most recent three years available at the time of the evaluation. The expansion methodology is discussed further in APPENDIX B. It is important to note that in PY2021, all 4 sites had full M&V and did not have historical operational adjustments applied to the results.

Table 4-1 presents the discrepancy change percentage of non-operational and operational adjustment factors from tracking and the resulting weighted therms totals for the two adjustment classifications (non-operational and operational). The non-operational realization rate is calculated with weighted tracking savings as the denominator. This realization rate is used to calculate the non-operational realization rate and precisions. In this table, the operational realization rate contains all operational adjustment factors for the sites where operational adjustments were collected. In PY2021, all four sites had ops adjustments collected from full M&V, so no historical ops adjustments were needed. See Section 4.1.2 for specific non-operational and operational discrepancy percentages when compared with tracking individually that combine to achieve the site level realization rate in Table 4-4.

Table 4-1. PY2021 Non-Trap Realization Rate

		After Non-Operational Adjustments		After Site Specific Operational Adjustments		
Site ID	Weighted Tracking Savings (therms)	Weighted Evaluated Savings (therms)	Site Level Realization Rate from Non-Operational (%)	Weighted Evaluated Savings (therms)	Site Level Realization Rate from Operational (%)	PY2021 Custom Gas RR
RIG21N078	75,842	76,596	101%	48,568	64%	N/A
RIG21N060	27,586	30,082	109%	16,224	59%	
RIG21N081	274,780	274,780	100%	289,944	106%	
RIG21N080	113,860	74,920	66%	71,264	63%	
Non-Trap Total	**492,068**	**456,378**	**90%**	**426,000**	**92%**	**86.6%**

N/A = Not applicable

The single-year realization rate for PY2021 RI custom gas non-steam trap installations is 86.6% with an achieved relative precision of 21.9% which is within the single-year target precision of ±40% at 80% confidence for only non-ST sites. The approach for calculating the current year realization rate is outlined in APPENDIX B.

4.1.2 Discrepancy results

For each of the four sites included in the PY2021 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 seven categories: baseline, methodology, tracking/administrative, technology, quantity, HVAC interaction, and operational. A more discrete breakdown of possible differences and how they are categorized is presented below in Table 4-2.

Table 4-2. Possible discrepancy factors and their mapping to major categories

Major Discrepancy Category	Discrepancy Definition or Examples
Baseline	Change in the baseline of the post-retrofit condition
Methodology	Accuracy/appropriateness of Analysis Methodology Calculation changes Non-metered data input updates
Tracking/Admin	Accuracy of Tracking Savings Errors during claimed savings input Savings changed but not changed in tracking savings
Technology	Differences in proposed vs. installed technology or measure type
Quantity	Quantity of installed equipment is different
Operational	Boiler combustion efficiency Difference in equipment hours of operation Different equipment load profile Inaccurate pre-project characterization Steam operating pressure difference System optimization or programming not implemented Faulty or improperly installed equipment Operating temperature differences
HVAC Interaction	Interactive effects

The evaluation team used the site-specific, non-operational sampling weights and the sum of site-specific impacts of each discrepancy category to calculate the impact of adjustment factors for differences between the program tracking and evaluated results at the population level. Table 4-3 below presents the discrepancy factors and their impacts. There were no tracking/admin, quantity, or interactive adjustments discrepancies found in the PY2021 sample. All sites had operational discrepancies with site-specific comparisons found in Table 4-4. In PY 2021, baseline discrepancies had the largest impact on overall RR. The evaluators found baseline discrepancies in 2 of the 4 sites in which the applicant used wrong inputs for the baseline assumptions such as size, capacity, or baseline temperatures.

Table 4-3. PY2021 weighted discrepancy factors between tracking and evaluated results

Adjustment Factor	Site Counts	Impact on RR	Impact (%)
Baseline	2		-22.4%
Methodology	2		1.8%
Tracking/Admin	0		0.0%
Technology	0		0.0%
Quantity	0		0.0%
Operational*	4		3.2%
Interactive*	0		0.0%
Historical Operations Adjustment			4.0%
Total			-13.4%

Adjustment percentages found in Table 4-4 are the magnitude of changes from tracking for each site and are reported at the site level. The combination of non-operational and operational discrepancies sums to the change from tracking to evaluated (realization rate). The percentages are the total adjustments for operational and non-operational adjustments when compared to site-level savings.

Table 4-4. Non-operational and operational weighted discrepancies – PY2021

Site ID	Tracking Savings (therms)	Evaluated Savings (therms)	Site Level Discrepancies		Combined Ops/Non-Ops Realization Rate (%)
			Non-Operational	Operational	
RIG21N078	2,917	1,868	1.0%	-37.0%	64.0%
RIG21N060	1,061	624	9.1%	-50.3%	58.8%
RIG21N081	68,695	72,486	0.0%	5.5%	105.5%
RIG21N080	28,465	17,816	-34.2%	-3.2%	62.6%

Section 3 of each site report presents detailed information on site-specific differences, which is included in APPENDIX C.

4.2 Combined three-year rolling results (PY2019, PY2020, and PY2021)

The evaluators calculated the gross RR and precisions using the results from PY2019, PY2020, and PY2021. The results are summarized in Table 4-5. The PY2021 results did not use historical ops adjustments, but the three-year rolling results use historical ops adjustments insofar as the results from PY2019 and PY2020 had those values applied to calculate their final ops adjustments. PY2019 and PY2020 results are not recalculated with the PY2021 ops adjustment, they only have historical ops adjustments from their own respective years and the imputations are not revisited. The combined three-year rolling results include PY2019 and PY2020 which do have historical ops adjustments and are used to calculate the three-year weighted rolling average.

For the purposes of program reporting, the combined three-year rolling results combine both the PY2021 non-trap RR (86.6%) and a steam trap RR which is assumed to be 100%. Since non-steam trap sites in 2021 were evaluated as full M&V

sites and steam traps have a different evaluation methodology and have an uncertain RP, the three-year pooled results do not calculate a RP. The following Table 4-5 shows the results for both steam trap and non-steam trap populations for each year along with the three-year rolling results which consist of PY2019, PY2020, and PY2021.

Table 4-5. Three-year rolling combined steam trap and non-steam trap results and statistics

Parameter	PY2019	PY2020	PY2021	PYs 2019+2020+2021
Tracking Savings (therms)	1,944,204	1,280,693	1,075,449	4,300,346
Non-Operational Sample Size	10	8	4	22
Operational Sample Size[1]	6	6	4	16
Realization Rate (RR)	80.8%	84.5%	90.6%	84.4%
Relative Precision @ 80% CI (%)	±48.3%	±8.9%	±15.3%	N/A*

N/A = Not applicable; * = There is no associated RP for the steam traps RR and it is not appropriate to combine RPs for non-steam traps and steam traps since they are evaluated using different types of analyses

The three-year rolling combined RR was determined to be 84.4% with no calculated RP. As stated in Section 2, the PY2019 an PY2021 steam trap sites were re-evaluated under the new methodology adopted in PY2020. However, no steam trap sites were evaluated in PY2021. Table 4-5 shows the individual PY2019, PY2020, and PY2021 results along with the combined three-year rolling program evaluation for PY2019, PY2020, and PY2021. Table 4-6 shows the non-operational and operational realization rates that are used to calculate the three-year rolling realization rate.

Table 4-6. RRs used to calculate three-year rolling RR

Program Year	Tracking Savings (therms)	Non-Operational RR	Operational RR	Combined RR
PY2019 Non-Trap	1,649,362	98.3%	78.7%	77.3%
PY2020 Non-Trap	556,583	75.2%	85.7%	64.4%
PY2021 Non-Trap	752,277	96.0%	90.1%	86.6%
PY2019 ST	294,842	100%	100%	100%
PY2020 ST	724,110	100%	100%	100%
PY2021 ST	323,172	100%	100%	100%
3-Year Rolling	4,300,346	95.4%	82.9%	84.4%

Non-Trap = Non-steam trap site, ST = Steam Trap Site *PY2019 and PY2020 include imputed historical adjustments

[1] The minimum sample size of each of the inner samples (sites with operational adjustments) dictates the overall sample size of the year for combined results.

5 CONCLUSIONS, RECOMMENDATIONS, AND CONSIDERATIONS

5.1 Conclusions

5.1.1.1 PY2021 Performance

PY2021 custom gas projects, non-steam trap saved an estimated 1.19 million therms annually, with 86.6% of the program year tracking savings realized based on the program evaluation sample for RI PY2021 sites. By combining the 86.6% for non-ST and 100% for steam trap, DNV calculated the three-year rolling results and determined the realization combined three-year rolling rate is 84.4%. The results for the current year are slightly better than the prior program year. The current results are accurate within agreed upon precision standards and provide adequate planning and program reporting savings estimates.

A more detailed explanation of the PY2021 performance is found in Section 4.1. Site-specific details are shown in APPENDIX A. More details on the PY2021 results are presented in the sections below, and each site report included in APPENDIX C.

5.1.1.2 Combined three-year rolling (PY2019, PY2020, & PY2021) Performance

Combined over the three-year rolling sampling period, the program realized gross savings of 4.30 million therms, with 84.4% savings realized as shown in Table 4-6. In PY2021, the evaluation team consulted with RI Energy and decided to not evaluate steam trap sites in the current program year, restricting them from being selected for evaluation in the sample. This was done so that the decision of whether to continue evaluating steam trap sites that generally have a close to 100% realization rate would be deferred to the next program year, PY2022, impact evaluation. For purposes of reporting a combined three-year rolling result, the RRs for non-traps and steam traps (assumed to have a 100% RR) were combined to achieve the 84.4% RR result. However, RP was not calculated because the RP associated with steam traps are uncertain and it is not appropriate to combine RPs with non-steam traps since they are evaluated differently. This approach was determined to be a reasonable step if the longer-term plan is to entirely separate out steam traps and non-steam traps studies.

5.2 Recommendations

5.2.1.1 R1: Realization rate

DNV recommends RI Energy use the PY2019, PY2020, and PY2021 combined RR of 84.4% for planning and program reporting, starting with PY2024 and continuing until new program impact evaluation study results are available.

Based on the results listed for PY2021, an individual program year sampling Error Ratio Target of 0.55 for non-steam trap and SEMP projects has been recommended for the 2022 RI custom gas Impact Evaluation to maintain the next three-year rolling savings program evaluation precision targets.

5.2.1.2 R2: Separate Steam Trap and Non-Steam Trap Studies

DNV recommends that RI Energy separate out steam trap and non-steam trap studies. The evaluation group consulted with RI Energy and the C-team and determined that steam traps are evaluated in an inherently different approach than non-steam trap sites. Currently, non-steam trap sites are generally evaluated using full M&V whereas the currently established method for evaluating steam traps is to use an ex-ante estimate that is from a calibrated model which is assumed for now to be equivalent to evaluated or ex-post. Considering this, it is unclear whether it is appropriate to continue to combine their results or if reporting their results separately is preferable. Furthermore, since the methodology for evaluating the two categories are so different, it is not appropriate to combine their relative precisions. The current sample design methodology separates out steam trap and non-steam trap sites so that they are independent of each other showing that it is feasible to separate out steam traps and non-steam traps into their own independent studies.

5.2.1.3 R3: Steam Trap Tool Utilization

DNV recommends that RI Energy assess whether to implement the new MA steam trap study results or determine an alternate approach to vetting RI steam trap sites which may include developing an independent steam trap tool in RI. Whether steam traps will be separated into their own studies or not, RI Energy should assess the viability of using existing steam trap tools but consider that they are based upon billing data that has become outdated. Otherwise, RI Energy should assess whether developing a RI specific steam trap tool would be warranted given the costs of development. If costs are feasible, DNV recommends continuously expanding the tool with recent billing data for operational adjustments in order to avoid the issues present with the other steam trap tools that are available. In MA, the current recommendation is to update the steam trap tool continually every couple years. DNV recommends RI Energy to monitor the MA Steam Trap Tool development and consider modelling the RI tool in a similar approach. Alternatively, RI Energy should investigate the possibility of using the MA tool if it is too expensive for RI to develop their own tool relative to the amount of steam trap annual savings. The approach would include both implementers and evaluators using the same tool to model steam traps.

5.3 Considerations

5.3.1.1 C1: Perform more site-specific adjustments on calculation models

DNV recommends that the engineer preforming savings analyses should perform more site-specific adjustments on the calculation models they use for their energy savings calculation methodology. By conducting a site-specific adjustment, the implementer can account for factors such as building layout, usage patterns, and other site-specific variables that may impact the estimated savings. For example, for RIG21N078 the implementers used an eQuest refrigeration model to estimate energy savings for the installation of destratification fans and doors for refrigerated cooler cases. The evaluators determined that the energy model for both measures were designed using generic inputs rather than site-specific inputs. For example, factors such as impacted space square footage, case lengths, and weather data location (Massachusetts vs Rhode Island) could have been changed to match the facility and equipment specifications. The evaluator updated the models by updating some input parameters based on the on-site findings and metered data. Although DNV believes this is already occurring to some degree, DNV recommends that implementors perform site-specific adjustments to calculation models, when possible, rather than using generic non-defined inputs.

5.3.1.2 C3: Ensure baseline inputs are accurate

DNV recommends that the project implementer ensure that baseline inputs used for the savings analysis are as accurate as possible. In PY 2021, baseline discrepancies had the largest impact on the overall realization rate. The evaluators found in two sites that the wrong baseline inputs were used by the applicant in the savings calculations resulting in baseline discrepancies. Factors such as input capacity, tank size, ambient temperature, process temperature, and insulation thickness were determined to be wrong and had a large impact on realization rate. DNV recommends that project implementers ensure that pre-project factors and inputs used in savings analyses be as accurate as possible to avoid baseline errors.

APPENDIX A. SITE EVALUATION RESULTS & REALIZATION RATES

This Appendix includes the site ID, the verified measure description, tracking savings and site RR that were used to calculate over realization rates for the program. Operational realization rates include adjustments from metered data and non-metered observational data collected on-site. Non-operational realization rates include only non-metered observational data confirmed on-site or through site contact interview. The realization rates for all categories are shown in the Table 5-1 shown below.

Table 5-1. Evaluated site summary

Sample ID	Applications	Measure Description	Site Evaluation Type	Tracking Savings	Evaluated Savings	Combined Ops/Non-Ops Realization Rate
RIG21N078	13219566	Destratification fans and case doors	Operational	2,917	1,868	64%
RIG21N060	11982442	Hot water heaters	Operational	1,061	624	59%
RIG21N081	11246974, 11246977	EMS fan controls Process controls	Operational	68,695	72,486	106%
RIG21N080	11529748, 12785274	Steam piping and equipment Hot oil and steam equipment	Operational	28,465	17,816	63%

APPENDIX B. ADJUSTING GROSS REALIZATION RATE STANDARD ERRORS FOR IMPUTED OPERATING ADJUSTMENT

This appendix explains the process for calculating the current and three-year realization rates. The calculation of the current year realization rate is different from years 1 and 2 as an imputed operational adjustment was not necessary. This section describes the calculation of the current year realization rate, as well as the operational adjustments used for years 1 and 2, which are included in the 3-year rolling result.

Basic structure

We have samples for three successive periods: 1, 2, and 3. In this evaluation these samples are 1) PY2019, 2) PY2020, and 3) PY2021. Sample 3 is a full sample with operational adjustments for all sampled sites. Sample 1 and Sample 2 had non-operational results for all sites and operational results for only a subset of sites. The three-year realization rate has imputed operational adjustments for PY2019 and PY2020 results.

For PY2021 sampled customers used in the third year of the rolling three-year sample, the operational RR formula was adjusted to make each year in the imputation weighted according to the sample weighted savings of sites with operational adjustments rather the previous formula that used population tracking savings to weight historical years operational adjustments. The new weighting for 2021 takes into account that historical evaluations also imputed portions of the operational adjustment. By using sample weighted savings, the historical data is more balanced in its representation.

Notation

w_j = full-sample weight for sample site j in the period-3 sample

S_y = population tracked savings of period y

S_T = population tracked savings for all 3 periods combined

$= S_1 + S_2 + S_3$

q_y = period-y savings as a fraction of the 3-period total

$= S_y/S_T$

SW_y = full sample weighted savings represented by “good” sites, i.e. those with operational data for period y

SW_T = full sample weighted savings represented by “good” sites, i.e. those with operational data for all 3 periods combined

$= SW_1 + SW_2 + SW_3$

f_{g1} = fraction of Period-1 savings represented by “good” sites, ie those with operational data

= (full-sample-weighted savings of Period 1 sample sites with operational data)/(total full-sample weighted savings for Period 1)

f_{g2} = fraction of Period-2 savings represented by “good” sites, ie those with operational data

= (full-sample-weighted savings of Period 2 sample sites with operational data)/(total full-sample weighted savings for Period 2)

S_{Tg} = total savings for population represented by sites with operational data, across all samples

$= f_{g1}S_1 + f_{g2}S_2 + S_3$

RR_{oy} = operational-only realization rate for the period-y sample

RR_{Ny} = non-operational-only realization rate for the period-y sample

RR_{og1} = operational-only realization rate for the population represented by good sites in the period-1 sample, those with operational data

RR_{og2} = operational-only realization rate for the population represented by good sites in the period-2 sample, those with operational data

RR_{ob1} = imputed operational-only realization rate for the population represented by bad sites in the period-1 sample, those without operational data

RR_{ob2} = imputed operational-only realization rate for the population represented by bad sites in the period-2 sample, those without operational data

SE(X) = standard error of estimate X

RSE(X) = relative standard error of estimate X

=SE(X)/X

Period 1 and 2 operational realization rates: RR_{o1} and RR_{o2}

- For the portion of the population represented by sampled sites with operational adjustments ("good" sites g), RR_{og1} and RR_{og2} are directly calculated from the sample, using the full sample weights w_j. That is, RR_{og1} and RR_{og2} are the weighted sum of verified gross savings, divided by the weighted sum of tracked gross savings for each year respectively.
- For sampled sites without operational adjustment ("bad" sites b), RR_{ob1} and RR_{ob2} are imputed as

$$RR_{ob1} = (f_{g-2}S_{-2}RR_{o-2} + f_{g-1}S_{-1}RR_{o-1} + f_{g1}S_1RR_{og1})/S_{(-2,-1,1)g}$$ [2]

$$RR_{ob2} = (f_{g-1}S_{-1}RR_{o-1} + f_{g1}S_1RR_{og1} + f_{g2}S_2RR_{og2})/S_{(-1,1,2)g}$$

That is, all available sites with operational data from a particular year, along with two earlier years, are used to impute the RR for the uncovered portion of the period-1 and period-2 populations, with the RR from different periods weighted by the savings it represented. The specific years used to impute ops adjustments where needed for any particular year in the analysis are show in Table 5-2 below, with the year of the annual result shown horizontally, and the years used to inform the ops adjustments shown vertically. Years marked as "full sample" indicate that no ops adjustments were imputed for that particular year, while years marked as "partial sample" indicate that ops adjustment imputations were needed for some sites. For example, the imputed ops adjustment for 2019 is based on ops adjustments from sites evaluated in 2017, 2018, and those sites with ops adjustments available in 2019.

[2] RR_{-2} and RR_{-1} denote two earlier years prior to the current 3-year rolling period which were used as part of the operational adjustments for RR_1 and RR_2. The specific years used in the calculations are shown in Table 5-2.

Table 5-2. Ops adjustment imputation sources for each annual result

		Annual RR Results					
		2016	2017	2018	2019	2020	2021
Ops Adjustment sources	2016	Full Sample					
	2017		Full Sample		-2) Full Sample		
	2018			Full Sample*	-1) Full Sample*	-1) Full Sample*	
	2019				1) Partial Sample	1) Partial Sample	
	2020					2) Partial Sample	
	2021						Full Sample

*No imputation was done for this year. This sample was reweighted due to lack of ops adjustment for two sites, but treated as a full sample because the reweighting allowed us to consider the operational adjustment valid for all sites.

- Overall Operational Adjustment for Periods 1 and 2 are calculated as

$RR_{o1} = f_{g1}\, RR_{og1} + (1\text{-}f_{g1})RR_{ob1}$.

$RR_{o2} = f_{g2}\, RR_{og2} + (1\text{-}f_{g2})RR_{ob2}$.

That is, the operational adjustment for the directly represented portions of the population and the remainder are combined in proportion to their shares of period-1 and period-2 tracked savings respectively. This formulae can be expanded as

$RR_{o1} = f_{g1}\, RR_{og1} + (1\text{-}f_{g1})\, (f_{g\text{-}2}S_{\text{-}2}RR_{o\text{-}2} + f_{g\text{-}1}S_{\text{-}1}RR_{o\text{-}1} + f_{g1}S_1RR_{og1})/S_{(-2,-1,1)g}$
$= (1 + (1\text{-}f_{g1})\, S_1/S_{(-2,-1,1g)}f_{g1}RR_{og1} + (1\text{-}f_{g1})(S_{\text{-}2}/S_{(-2,-1,1g)})RR_{o\text{-}2} + (1\text{-}f_{g1})(S_{\text{-}1}/S_{(-2,-1,1g)})RR_{o\text{-}1})$
$= a_{og1}\, RR_{og1} + a_{\text{-}2}RR_{o\text{-}2} + a_{\text{-}1}RR_{o\text{-}1}$,

Where

$a_{og1} = (1 + (1\text{-}f_{g1})\, S_1/S_{(-2,-1,1)g})f_{g1}$
$a_{\text{-}2} = (1\text{-}f_{g1})(S_{\text{-}2}/S_{(-2,-1,1)g})$
$a_{\text{-}1} = (1\text{-}f_{g1})(S_{\text{-}1}/S_{(-2,-1,1)g})$

$RR_{o2} = f_{g2}\, RR_{og2} + (1\text{-}f_{g2})\, (f_{g\text{-}1}S_{\text{-}1}RR_{o\text{-}1} + f_{g1}S_1RR_{o1} + f_{g2}S_2RR_{og2})/S_{(-1,1,2)g}$
$= (1 + (1\text{-}f_{g2})\, S_2/S_{(-1,1,2)g})f_{g2}RR_{og2} + (1\text{-}f_{g2})(S_{\text{-}1}/S_{(-1,1,2)g})RR_{o\text{-}1} + (1\text{-}f_{g2})(S_1/S_{(-1,1,2)g})RR_{o1})$
$= a_{og2}\, RR_{og2} + a_{\text{-}1}RR_{o\text{-}1} + a_1RR_{o1}$,

Where

$a_{og2} = (1 + (1\text{-}f_{g2})\, S_2/S_{(-1,1,2)g})f_{g2}$
$a_{\text{-}1} = (1\text{-}f_{g2})(S_{\text{-}1}/S_{(-1,1,2)g})$
$a_1 = (1\text{-}f_{g2})(S_1/S_{(-1,1,2)g})$

This expansion expresses the overall Period 3 operational realization rate as a weighted average of three independently estimated terms, the directly observed operational realization rate from each period. The factors multiplying the three realization rates have the property that:

$a_{og1} + a_{-2} + a_{-1} = 1$ for period 1

and

$a_{og2} + a_{-1} + a_{1} = 1$ for period 2

- Standard error of Period 1 and Period 2 realization rates: The standard error is calculated from the individual standard errors as

  $SE(RR_{o1}) = sqrt[a_{og1}^2\ SE^2(RR_{og1}) + a_{-2}^2\ SE^2(RR_{o-2}) + a_{-1}^2\ SE^2(RR_{o-1})]$

  $SE(RR_{o1}) = sqrt[a_{og2}^2\ SE^2(RR_{og2}) + a_{-1}^2\ SE^2(RR_{o-1}) + a_{1}^2\ SE^2(RR_{o1})]$

  This is true because the three RRs at step 3 are from independent samples.

Period 3 combined RR

- **The operation and non-operational realization rates** RR_{N3} and RR_{O3} are calculated from the full sample using the full sample weights and the non-operational and operational adjusted savings for the sample, via the usual formulas.

- **The Overall RR** is the product of the operational and non-operational RR

  $RR_3 = RR_{o3}\ RR_{N3}$

- **Standard error:** First calculate the relative standard error
  a. $RSE(RR_3) = sqrt[RSE^2(RR_{o3}) + RSE^2(RR_{N3})]$

  This formula is approximately correct, assuming that even though RR_{o3} and RR_{N3} are from a common sample, they are essentially unrelated so can be treated as independent.

  The standard error is then calculated from the RSE.

  $SE(RR_3) = RR_3\ RSE(RR_3)$

3-year combined RR

Preferred calculation

$RR_{1\text{-}3} = (S_1RR_1 + S_2RR_2 + S_3RR_3)/S_T$
$= q_1RR_1 + q_2RR_2 + q_3RR_3$

That is, the three-year RR is the savings-weighted average of the three separately estimated RRs.

This calculation produces an overall realization rate for each period, then combines these across periods. This approach is the natural one, combining the historical overall results with the most recent, consistent with our general method for three-year rolling realization rate calculation, and is therefore the preferred way to produce the three-year value.

However, because the first and second terms, RR_1 and RR_2, are determined in part from the operational portions of other years, the three are not independent estimates. Moreover, there's no obvious way to express the calculation as the sum of independent estimates, as would be needed to produce the standard error. We therefore look at an alternative calculation for purposes of standard error calculation only.

SE calculation

We use the standard error of an alternative calculation as an approximate to the standard error of the preferred calculation. The alternative calculation would be to calculate separate operational and non-operational realization rates for the three-year period and multiply them. We calculate this SE. We can check how different the results are, but the SEs or inflation of SE ought to be ballpark the same.

Alternative RR calculation for SE calculation only

- 3-year operational realization rate
  $RR_{o1\text{-}3} = q_1RR_{o1} + q_2RR_{o2} + q_3RR_{o3}$
- 3-year non-operational realization rate
  $RR_{N1\text{-}3} = q_1RR_{N1} + q_2RR_{N2} + q_3RR_{N3}$
- Combined 3-year realization rate
  $RR_{1\text{-}3} = RR_{o1\text{-}3}\ \ RR_{N1\text{-}3}$

Standard error calculations for the alternative RR calculation

Non-operational three-period realization rate SE

The non-operational three-period realization rate is the savings-weighted average of the separate period realization rates. Since these are all independent, we can use the formula for combinations of independent estimates to produce the standard error.

$SE(RR_{N1\text{-}3}) = \text{sqrt}[q_1^2\, SE^2(RR_{N1}) + q_2^2\, SE^2(RR_{N2}) + q_3^2\, SE^2(RR_{N3})]$

Operational three-period realization rate SE

The operational realization rate is also the savings-weighted average of the three periods' operational realization rates, but these aren't all independent. We rearrange the formula to express the operational realization rate as a combination of independent estimates.

$RR_{o1\text{-}3} = q_1\, RR_{o1} + q_2\, RR_{o2} + q_3RR_{o3}$
$\quad = ((a_{-2}\, q_1)\, RR_{o\text{-}2} + (a_{-1}\, q_1)\, RR_{o\text{-}1} + q_1a_{og1}RR_{og1}) + ((a_{-1}\, q_2)\, RR_{o\text{-}1} + (a_1\, q_2)\, RR_{o1} + q_2a_{og2}RR_{og2}) + q_3RR_{o3}$

where the factors a_x are as defined above. With this expression of the three-period operational realization rate as a combination of independent estimates, is standard error is calculated as

$SE(RR_{o1\text{-}3}) = \text{sqrt}[((a_{-2}\, q_1)\, RR_{o\text{-}2} + (a_{-1}\, q_1)\, RR_{o\text{-}1} + q_1a_{og1})^2\, SE^2(RR_{O1}) + ((a_{-1}\, q_2)\, RR_{o\text{-}1} + (a_1\, q_2)\, RR_{o1} + q_2a_{og2})^2\, SE^2(RR_{O2}) + (q_3)^2\, SE^2(RR_{O3})]$.

Relative standard error of overall three-period realization rate

By the same argument as above, the relative standard errors of the two realization rate factors are combined as if they were independent estimates. This is approximately correct, assuming that even though RR_o and RR_N are from a common sample, they are essentially unrelated so can be treated as independent.

$RSE(RR_{1\text{-}3}) = \text{sqrt}[RSE^2(RR_{o1\text{-}3}) + RSE^2(RR_{N1\text{-}3})]$

Standard error of the three-year realization rate

$SE(RR_{1-3}) = RR_3 \, RSE(RR_{1-3})$

Level of aggregation for applying the formulas

Calculating Period 3 and three-period realization rates

The formulas for calculating the Period 3 operational realization rate RR_{o3}, the Period 3 overall realization rate RR_o, and the preferred three-period overall realization rate RR_{1-3} are applied separately for each reporting category of realization rate. Typically, each reporting category includes sample points from multiple sampling cells.

APPENDIX C. SITE REPORTS

Individual site reports are shown below.

RI CUSTOM GAS EVALUATION SITE SPECIFIC MEASUREMENT AND VERIFICATION REPORT

Site ID: RIG21N060

Report Date: 6/07/2023

Program Administrator	Rhode Island Energy	
Application ID(s)	11982442	
Project Type	Base and Add-On #3	
Program Year	2021	
Evaluation Firm	DMI	
Evaluation Engineer	Brian Paonessa	
Senior Engineer	Mickey Bush	

1 EVALUATED SITE SUMMARY AND RESULTS

The evaluated new construction project was installed at a manufacturing plant with lab and office support spaces. The application considered the installation of two new tankless domestic hot water heaters to serve non-process domestic hot water loads. The site indicated that the water heaters serve two infrequent showers, a dining area with dishwashers and sinks, and bathroom faucets.

The evaluation approach is Base + Add-On #3 (on-site M&V) because COVID is not currently impacting the site. The site indicated that a number of jobs shifted to hybrid/remote during the pandemic, but that this was expected to remain the case indefinitely.

The application contains a single measure. The applicant classified the measure as new construction end of life. Based on the information gathered during the site visit, the evaluator agreed with the classification of the measure as a new construction.

The evaluator identified deviations in methodology, ambient temperatures, and the thermal load on the water heaters that resulted in a decrease in savings compared to the tracking estimate. The evaluation results are presented in Table 1-1.

Table 1-1. Evaluation Results Summary

PA Application ID	Measure Name		Annual Savings (therms)
11982442	Hot Water heaters	Tracked	1,061
		Evaluated	624
		Realization Rate	58.8%

1.1 Explanation of Deviations from Tracking

The evaluated savings are 58.8% of the applicant-reported savings. The savings were decreased primarily from a lower than predicted thermal load handled by the domestic hot water heaters. The reduction in savings from the lower hot water load was partially offset by an adjustment to the standby loss baseline, whereby the evaluators adjusted the baseline to consider the storage and input capacity of the baseline domestic hot water heater.

1.2 Recommendations for Program Designers & Implementers

There are no recommendations at this time.

1.3 Customer Alert

There is no relevant customer alert.

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 two natural gas tankless domestic sized hot water heaters.

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.

2.2 Applicant Description of Baseline

The applicant classified the measure as a new construction/replace on failure. The applicant described the baseline as two natural gas storage-type domestic hot water heaters with an efficiency of 80%, per IECC Table C404.2.

The baseline operation is identical to that of the installed case. The applicant assumed the baseline water heaters had an input capacity of 751,000 btu/h and a rated volume of 4 gallons, based on the properties of the installed tankless heaters. The 4 gallons represents the capacity of the tankless water heater, which the applicant incorrectly used as the storage volume of the baseline storage water heater. The water temperature setpoint was modelled as 120°F, the incoming supply water temperature was modelled as 55.8°F, and the ambient temperature was indicated to be 70°F, as summarized in Table 2-1.

Table 2-1. Base case summary

Description	Value
Water Heater Type	Natural Gas Storage
Thermal Efficiency	80%
Rated Volume	4 Gallons
Input Capacity	751,000 Btu/h
Water Temperature Setpoint	120°F
Incoming Supply Water Temperature	55.8°F
Ambient Temperature	70°F

2.2.1 Applicant Description of Installed Equipment and Operation

The applicant described the installed equipment as two Intellihot Hot Water Heaters with model number iQ750. The applicant indicated that the water heaters had a thermal efficiency of 94%, an input capacity of 751,000 Btu/h, and a rated volume of 4 gallons.

The installed equipment was modelled by the applicant to operate with a water temperature setpoint of 120°F and an incoming supply water temperature of 55.8°F. The applicant also indicated that the ambient temperature of the space is a constant 70°F. A summary of the installed equipment and operation is presented in Table 2-2.

Table 2-2. Installed case summary

Description	Value
Water Heater Type	Natural Gas Tankless
Thermal Efficiency	94%
Rated Volume	4 Gallons
Input Capacity	751,000 Btu/h
Water Temperature Setpoint	120°F
Incoming Supply Water Temperature	55.8°F
Ambient Temperature	70°F

2.2.2 Applicant Energy Savings Algorithm

The applicant considered savings from two sources: an improved thermal efficiency in the installed case, and a reduction in standby losses as a result of removing the storage tank associated with the baseline.

The applicant's analysis included a one-formula calculation that considered both affects, which is separated below for clarity:

$$\text{Total Savings} = \text{Savings}_{\text{Eff}} + \text{Savings}_{\text{Standby Losses}}$$

where,

Total Savings = The total savings of the evaluated measure as a result of installing the specified tankless domestic hot water heaters as opposed to a baseline storage unit, in therms

$\text{Savings}_{\text{Eff}}$= The savings of the evaluated measure as a result of installing water heaters with a thermal efficiency of 94%, in therms.

$\text{Savings}_{\text{Standby Losses}}$ = The savings of the evaluated measure as a result of installing a tankless water heater without standby losses, in therms.

The thermal efficiency savings were calculated by the applicant as:

$$\text{Savings}_{\text{Eff}} = \text{Qty} \times \left(\frac{\text{GPD} \times 365 \times 8.33 \times (\text{Temp Setpoint} - \text{Temp supply})}{100000}\right) \times \left(\frac{1}{\text{Base}_{\text{eff}}} - \frac{1}{\text{Install}_{\text{Eff}}}\right)$$

Where:

Qty= 2, The quantity of newly installed and simultaneously running water heaters

GPD= 1,210 gallons per day of DHW per water heater. It is not clear to the evaluators how this value was derived.

365 = conversion factor from days to year

8.33= conversion factor from gallons to pound of water

Temp setpoint = 120°F, the temperature setpoint of the domestic hot water heaters

Temp supply = 55.8°F, the entering water temperature to the DHW heaters

100,000 = conversion factor from BTU to therms

Base_{eff} = 80%, the baseline efficiency of the water heaters

$\text{Install}_{\text{eff}}$ = 94%, the efficiency of the installed water heaters

The applicant calculated 879.4 therms for the thermal efficiency portion of the analysis. This constitutes ~83% of the total savings calculated by the applicant.

The standby loss savings were calculated as:

$$\text{Savings}_{\text{Standby Losses}} = \text{Qty} \times \text{HLC} \times (\text{Temp Setpoint} - \text{Ambient Temp}) \times 8760 \big/ \text{Base}_{\text{Eff}} \times 100{,}000$$

Where:

Ambient Temp = 70°F, the average ambient temperature impacting the DHW heaters

8760 = hours/year

HLC= the heat loss coefficient of the baseline hot water heaters, calculated as:

$$\text{HLC} = \left(\frac{\text{Input Cap}}{800} + 110 \times \sqrt{\text{Vol}}\right) \Big/ 70$$

Where:

Input cap = 751,000 BTU/h, the input capacity of a DHW heater

Vol = 4 gallons, the internal water volume of one installed DHW heater

The heat loss coefficient formula is based on IECC Table C404.2, which provides the following:

$$\text{Standby Loss} = \frac{\text{Input Cap}}{800} + 110 \times \sqrt{\text{Vol}}$$

The formula provided by IECC is based on a nominal 70°F temperature difference between the stored water and ambient temperature. Therefore, the applicant divided by the 70°F temperature delta in order to substitute the actual water temperature and ambient temperature delta in the $\text{Savings}_{\text{Standby Losses}}$ formula shown above.

The applicant calculated 181.3 therms for the standby loss savings portion of the application. This constitutes ~17% of the total savings calculated by the applicant.

2.2.3 Evaluation Assessment of Applicant Methodology

The evaluator generally agrees with the overall methodology used by the applicant. The evaluators agree that savings are a result of an improved thermal efficiency as well as reduced standby losses. The evaluators also agree that standby losses are not present in the installed case, since tankless water heaters only operate when there is a demand for hot water and there is no associated storage tank. However, the applicant used a volume of 4 gallons, which represents the capacity of the coil in the installed tankless water heaters instead of the storage tank volume of the baseline water heaters. Additionally, the applicant found that the ambient temperature would vary with outside air temperature, which was not considered by the applicant.

2.3 On-Site Inspection and Metering

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

2.3.1 Summary of On-site Findings

The evaluators conducted a site-visit on April 21, 2023. During the site visit, the evaluators interviewed the site contact and verified the installation of the water heaters. A summary of the on-site verification is provided in Table 2-3.

Table 2-3. Measure verification

Measure Name	Verification Method	Verification Result
Tankless Domestic Hot Water Heaters	On-site visual inspection	Tankless Domestic Hot Water Heaters installed as specified and with the indicated efficiency confirmed via cut-sheet. Water temperature setpoint observed to be 120°F.

2.3.2 Measured and Logged Data

The evaluators collected billing data for this application in order to determine the load on the water heaters. The site contact indicated that the water heaters shared a meter with boilers that served space heating loads and shut down during the cooling season. During the cooling season, the only indicated load on the meter was to be the water heaters. The site has seven different billing accounts. The correct billing account was determined based on a combination of on-site findings, the description from the customer, and an analysis of all available billing accounts at the site. The chosen billing account was the only account that showed seasonal heating boiler use, summer domestic hot water use, and usage that continued into 2023. The monthly average therms used for the billing account serving the evaluated water heaters is shown below in Figure 2-1 for the past five years.

Figure 2-1. Average therms per month

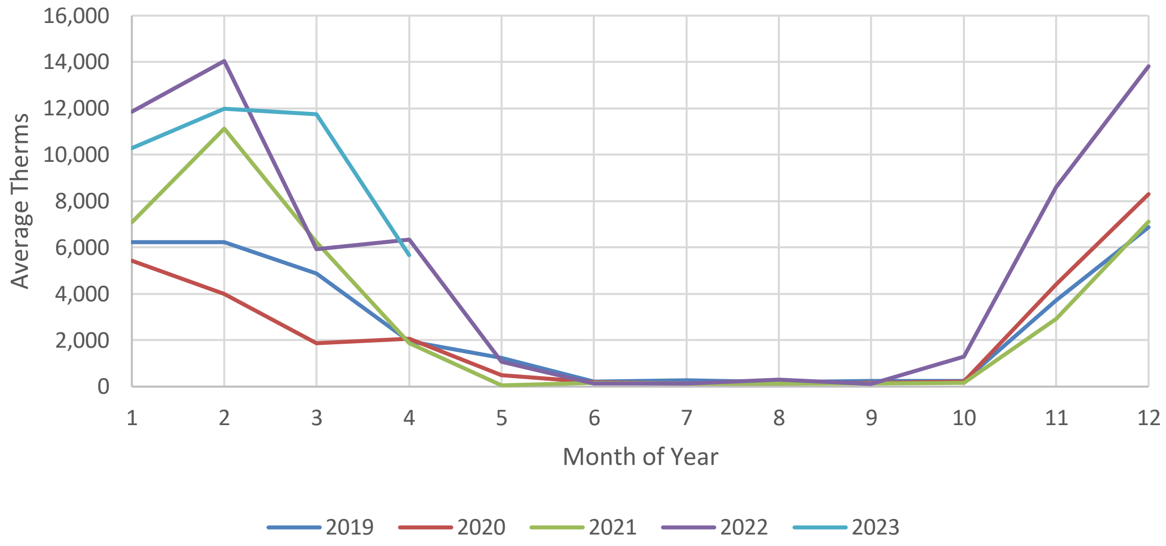
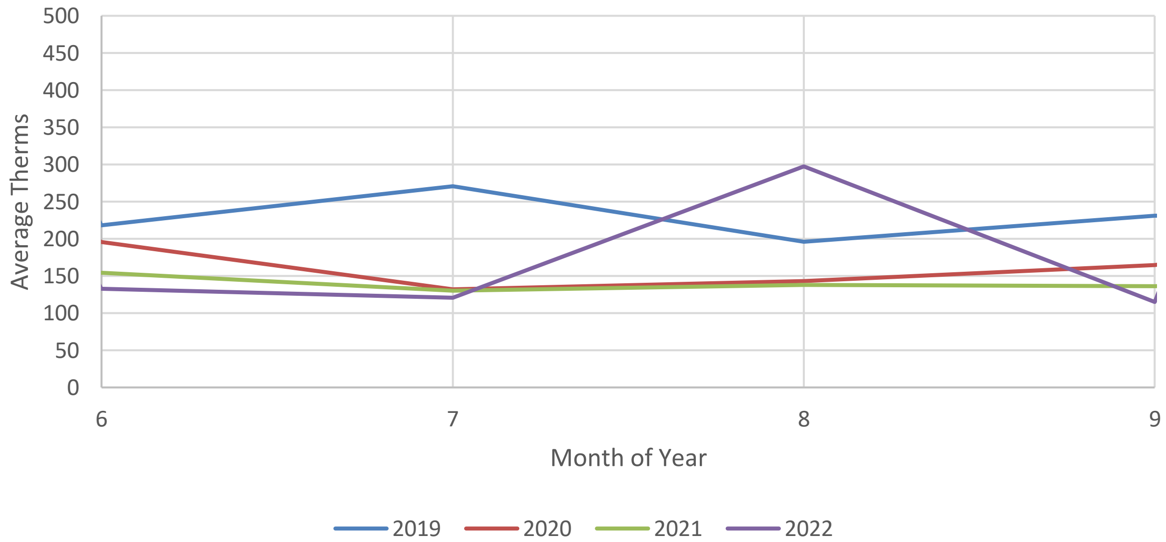


Figure 2-2 shows the average therms per month between June and September to highlight the domestic hot water use.

Figure 2-2. June through September average therms



The evaluator also took spot readings of the ambient temperature in the mechanical room that houses the domestic water heaters. The evaluators found that the mechanical room was ~80°F when it was ~60°F outside. The evaluators also confirmed that the domestic hot water heaters were set to 120°F, and the site contact confirmed that this value does not change.

2.4 Evaluation Methods and Findings

This section describes the evaluator methods and findings.

2.4.1 Evaluation Description of Baseline

The evaluators classify the baseline as a new construction end of useful life. The site contact indicated that the pre-existing water heaters were 23 years old and beginning to break down. The new construction baseline for domestic hot water heaters is pursuant to IECC Table C404.2, which requires gas water heaters with a 751,000 BTU/h capacity to have a thermal efficiency great than or equal to 80%.

IECC Table C404.2 also provides the following formula for determining the maximum allowable standby losses of a storage water heater:

$$SL = \frac{\text{Input Cap}}{800} + 110 \times \sqrt{\text{Vol}}$$

Where,

SL = maximum allowable output standby losses in BTU/h at a nominal temperature difference of 70°F between the stored water and ambient temperatures

Input Cap = The input capacity in BTU/h of the water heaters

Vol = The volume in gallons of the storage capacity of the water heaters

The evaluators determined that the standby losses in the baseline would be that of two storage water heaters. IECC does not mandate storage tank size, so the size of the existing water heater at the site before the project was installed were used. The site contact confirmed that the project did not take place due to changing capacity requirements, and also indicated that existing storage tank size was 70-gallons for each water heater. In order to find the baseline input capacity, the evaluators opted to hold the output capacity of the water heaters constant in the base and installed case since the load requirements are expected to be similar in both the base and installed case. The applicant installed water heaters with an input capacity of 751,000 Btu/h, which is a 705,940-output capacity when considering a 94% efficiency. The baseline input capacity is therefore 882,425 Btu/h when considering an 80% efficiency, shown in the formula below:

$$\text{Baseline Input Capacity} = \text{Installed Input Capacity} \times {}^{\text{Installed Efficiency}}/_{\text{Baseline Efficiency}}$$

The methodology and results of the standby losses formula is discussed in Section 2.4.2.

2.4.2 Evaluation Calculation Method

The evaluators determined that the average domestic hot water use from 2021-2022 was 5.01 therms per day, as shown in Table 2-4. The average use from 2021 and 2022 was used because it represents the available post-installation time period. This average daily use equates to 1,718 therms per year, which is lower than the system load of 4,724 therms predicted by the applicant. Since the applicant load calculation overestimated the therms usage, the source of that difference is likely the gallons per day of water use. A source of the average daily water use was not provided by the applicant. The evaluators theorize that the 1,210 gallons per day assumed by the applicant should have been the total system gallons per day, but instead was calculated to represent the load on each individual water heater.

Table 2-4. Average domestic hot water therms per month

Year	Month	Therms/Day
2021	June	4.5
	July	3.8
	August	4.9
	September	4.7
2022	June	4.4
	July	4.3
	August	9.3
	September	4.0
Average Therms/Day Usage		5.01
Average Annual Therms/Year Usage		1,827

There are no expected standby losses in the installed case, so the entire domestic hot water load can be attributed to the thermal load of bringing the water from the incoming temperature to the 120°F setpoint. The installed domestic hot water load is assumed by the evaluators to be constant each month since the end uses are not seasonally dependent. Therefore, the annual thermal load and savings can be calculated as:

$$\text{Average Annual DHW Load} = \text{Aveage DHW Annual Therms Usage} * \text{Install}_{\text{Eff}}$$

$$\text{Annual Therms Saving} = (\text{Average Annual DHW Load})\text{x}\frac{1}{\text{base}_{\text{eff}}} - \text{Average DHW Annual Therms Usage}$$

Where,

Average DHW Annual Therms Usage from Table 2-4 = 365 Days/year * 5.01 Therms/Days=1,827 Therms/year

Average Annual DHW Thermal Load = therms of heating energy that goes into bringing the incoming water temperature to the water heater setpoint

Annual Therms Saving = Savings in gas usage as a result of an improved efficiency bringing the incoming water temperature to the water heater setpoint.

Base_{eff} = The baseline thermal efficiency of a code-compliant storage hot water heater, 80%

$\text{Install}_{\text{Eff}}$ = The thermal efficiency of the installed tankless water heaters, 94%.

The evaluators calculated a total thermal load savings of 320 therms per year.

In order to calculate standby losses, the standby loss formula provided by IECC (shown in Section 2.4.1) was modified. The given formula assumes a 70°F difference between the stored water and ambient temperatures. In order to find the allowable standby losses at the actual temperatures, the 70°F temperature difference was divided out of the result of the formula and replaced with the actual temperature difference between the water setpoint and the ambient temperature. The quantity and baseline efficiency were also considered, shown below. This formula is identical to the one used by the applicant.

$$SL = \frac{(\frac{\text{Input Cap}}{800} + 110 \times \sqrt{\text{Vol}}) \times \text{Quantity} \times (\text{Water Temperature} - \text{Ambient Temperaure})}{70 \times \text{Base}_{\text{eff}}}$$

Where,

Input Cap = 882,425 Btu/h, determined by holding the output of the installed case constant and accounting for an adjustment in efficiency

Vol = 70 gallons, matching the pre-existing equipment

Quantity = 2 units. The evaluators expect that both storage tanks of the existing water heaters were filled at any given time.

Water Temperature = The holding temperature of the storage tank, discussed further in Section 2.4.2

Ambient Temperature = The ambient temperature in the mechanical room, discussed further in Section 2.4.2

Base_{eff} = 80% per IECC

The evaluators determined that the mechanical room housing the water heaters was approximately 20°F warmer than the outside air temperature. Additionally, the mechanical room had unit heaters that were indicated to run in the winter. The mechanical room was not mechanically cooled. The evaluators determined an approximate monthly ambient temperature profile by considering the temperature to be 20°F higher than the outside air temperature, with a minimum ambient temperature of 55°F. The outside air temperature is based on TMY3 weather data from Providence, RI.

Table 2-5. Ambient temperature profile

Month	Average Outside Air Drybulb, °F	Estimated Average Ambient Temperature, °F
January	29.1	55.0
February	32.3	55.0
March	38.8	58.8
April	47.2	67.2
May	59.2	79.2
June	66.6	86.6
July	73.9	93.9
August	70.8	90.8
September	64.9	84.9
October	53.4	73.4
November	42.5	62.5
December	31.1	55.0
Average	50.8	71.9

The average ambient temperature each month was used in the standby loss formula to determine the standby loss savings for each month. The sum of all the months in the year represents the total standby loss savings, determined to be 304 therms.

The total savings for the project was determined by the evaluators to be 624 therms. The average therm use from June-September before and after the hot water heater installation is shown in **Error! Not a valid bookmark self-reference.** below indicates that the site used approximately 2.5 less therms per day for domestic hot water use after the install. Extrapolated out to a full year this equals 918 therms, or 147% of the evaluated savings. One possible reason this value is greater than the evaluated savings is that the site contact indicated a number of jobs went permanently remote since the start of COVID. With less people coming into the office, the domestic hot water loads would also likely decrease, contributing to some of the reduction seen in the billing data. For this reason, a simple pre versus post billing analysis was not used.

Table 2-6, below.

Error! Not a valid bookmark self-reference. below indicates that the site used approximately 2.5 less therms per day for domestic hot water use after the install. Extrapolated out to a full year this equals 918 therms, or 147% of the evaluated savings. One possible reason this value is greater than the evaluated savings is that the site contact indicated a number of jobs went permanently remote since the start of COVID. With less people coming into the office, the domestic hot water loads would also likely decrease, contributing to some of the reduction seen in the billing data. For this reason, a simple pre versus post billing analysis was not used.

Table 2-6. Post and pre install therm use comparison

Month	Pre-Install (2019) Therms/Day	Post-Install (Average of 2021-2022) Therms/Day
June	7.0	4.5
July	9.0	4.1
August	6.5	7.1
September	7.5	4.3
Average Therms/Day	**7.5**	**5.0**
Average Therms/Year	**2,742**	**1,824**

3 FINAL RESULTS

The project consisted of the installation of two tankless domestic hot water heaters at a manufacturing site, which serve showers, faucets, and dishwasher loads. The calculated savings are less than the tracked values due to a decrease in the water heating load served by the water heaters as compared to the applicant. Table 3-1 summarizes the key parameters used to calculate the energy savings for the measure contained in Application 11982442.

Table 3-1. 11982442 Summary of Key Parameters

Parameter	Applicant	Evaluator
Baseline	2x storage water heaters with an 80% thermal efficiency.	2x storage water heaters with an 80% thermal efficiency.
Baseline Input Capacity	751,000 Btu/h	882,425 Btu/h
Baseline Storage Capacity	2x 4-gallon tanks	2x 70-gallon tanks
Installed Case	2x tankless water heaters with no tank, 751,000 Btu/h input capacity, and a 94% thermal efficiency.	2x tankless water heaters with no tank, 751,000 Btu/h input capacity, and a 94% thermal efficiency.
Average Total Yearly Thermal Load Output	4,724 Therms	1,718 Therms
Ambient Temperature	Constant 72°F	Varies 55-94°F. Average of 71.9°F.
Water Heater Setpoint	120°F	120°F
Savings		
Annual natural gas savings (therms)	1,061	624
Natural gas realization rate (%)	58.8%	

3.1 Explanation of Differences

The evaluated savings are less than the applicant savings. The reduction in savings comes primarily from the reduction in thermal load served by the domestic water heaters. The evaluators also adjusted the ambient temperature to vary each month instead of being constant. This had a small, negative affect on the savings. Finally, the standby losses were adjusted to consider the existing 70-gallon tanks in the base case as opposed to the proposed water heater capacity of 4-gallons and an input capacity of 882,425 Btu/h as opposed to 751,000 Btu/h. This change partially offset the losses. Table 3-2 provides a summary of the differences between tracking and evaluated values.

Table 3-2. Summary of Deviations

End-use	Discrepancy	Parameter	Impact of Deviation	Discussion of Deviations
HVAC	Operating Load	Thermal load on domestic hot water system	-50.3%	**Decreased Savings:** The evaluators found from a billing analysis that the load on the domestic hot water system was 1,718therms/year as opposed to the applicant's 2,362 therms/year/heater (4,724 therms total)
HVAC	Baseline	Baseline storage tank size and input capacity	9.8%	**Increased Savings:** The evaluators considered the storage tank size of the existing equipment in the baseline as opposed to the applicant considering the installed case capacity. The evaluators also adjusted the baseline input capacity to be 882,425 Btu/h instead of 751,000 Btu/h as a result of holding the output capacity of the installed water heaters constant instead of the input as was done by the applicant.
HVAC	Pre-project errors (inputs of calculations)	Ambient temperature	-0.73%	**Decreased Savings:** The evaluator considered an ambient temperature varying between 55°F and 94°F with an average of 71.8°F, as opposed to a constant 72°F assumed by the applicant.
Total			**-41.2%**	**Decreased savings by 41.2%**

3.2 Lifetime Savings

Because the steam boilers will outlive the installed measures, the evaluators classified this measure as an add-on with a single baseline. The evaluators calculated applicant and evaluated lifetime savings values using the following formula:

$$\mathrm{LAGI} = FYS \times \mathrm{EUL}$$

where:

LAGI = lifetime adjusted gross impact (therm)

FYS = first year savings (kWh)

EUL = measure life (years)

The evaluated lifetime savings are less than the tracking lifetime savings. Table 3-3 provides a summary of key factors that influence the lifetime savings. The evaluation uses the same 15-year measure life as the applicant.

Table 3-3. Measure 11529748 - Lifetime Savings Summary

Factor	Tracking	Evaluator
Lifetime savings (therms)	13,528	9,357
First year savings (therms)	1,061	624
Measure lifetime (years)	15	15
Measure life reference	Tracking	MA TRM
Measure event type	New Construction	New Construction
Baseline classification	End of Life	End of Life
Measure status (operational or removed)	N/A	Operational

N/A = Not Applicable

3.2.1 Ancillary impacts

There were no ancillary impacts associated with the evaluated measure.

RI CUSTOM GAS EVALUATION SITE SPECIFIC MEASUREMENT AND VERIFICATION REPORT

Site ID: RIG21N078

Report Date: 5/23/2023

Program	RI Custom Gas | PY2021
Program Administrator	National Grid
Application ID(s)	13219566
Project Type	C&I Existing Building Retrofit
Adjustment Method	Ops
Evaluation Method	Base + Add on #3
Program Year	PY2021
Evaluation Firm	DNV
Evaluation Engineer	Shaobo Feng
QA/QC Engineer	Max Ma

1 EVALUATED SITE SUMMARY AND RESULTS

The project was implemented at a supermarket as part of the National Grid GrocerSmart initiative. Two measures were implemented:

- ECM-1: Install 18 destratification fans throughout the sales floor. This measure saves energy because the installed fans prevent stratification of indoor air, thereby allowing a lower heating setpoint for an equivalent level of occupant comfort, and thus leading to a lower space heating load. The tracking savings for ECM-1 is 2,128 therms per year.
- ECM-2: Install doors onto refrigerated cooler cases. The baseline pre-existing cases were open. The impacted cases had 10 doors, and 2 ft wide each. The measure saves energy because less heated store ambient air infiltrates into the cases, resulting in a space heating load reduction. The tracking savings for ECM-2 is 789 therms per year.

The total tracking annual savings for these measures are 2,917 therms.

During the initial interview with the site contact, the evaluator learned the following:

- The store operation was not impacted by COVID-19.
- The site contact is on-site and willing to accommodate an on-site evaluation.

Based on the information gathered during the initial interview with the site contact, the evaluator proposed this site be evaluated using Schedule 3: Base + Add-on #3 – on-site verification with full M&V where an on-site audit was used to verify measure installation and operation, and installation of logger data to capture the key parameters and conduct the operational adjustments.

The applicant classified both measures as a retrofit with pre-existing conditions as the baseline. After reviewing the tracking files and conducting the on-site visit with collection of metered data, the evaluator classified this measure as an add-on with single baseline. The evaluation results are presented Table 1-1.

Table 1-1. Evaluation results summary

PA Application IDs	Measure Name	Parameter	Annual Natural Gas Savings (therms/yr)
13219566	M1: Destratification fans	Tracked	2,128
		Evaluated	1,037
		Realization Rate	49%
13219566	M2: Case doors	Tracked	789
		Evaluated	831
		Realization Rate	105%
13219566	Total	Tracked	2,917
		Evaluated	1,868
		Realization Rate	64%

1.1 Explanations of deviations from tracking

The evaluated savings are 36% lower than the applicant-reported savings primarily due to the operational adjustment. The applicant relied on a general calculation model at the program level instead of using a site-specific model to estimate the savings. Additionally, the applicant overestimated the area affected by destratification fans. Further details regarding deviations from the tracked savings are presented in Section 3.1.

1.2 Recommendations for program designers and implementers

The evaluator suggests that the implementer should perform a more site-specific adjustment on the calculation model. By conducting a site-specific adjustment, the implementer can account for factors such as building layout, usage patterns, and other site-specific variables that may impact the estimated savings.

1.3 Customer alert

There are no customer alerts for this project.

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 evaluated measure for this site is summarized in Table 2-1.

Table 2-1. Evaluated measures

Measure	Project ID	Parameter
M1	13219566	Install 18 destratification fans throughout the sales floor.
M2	13219566	Install doors onto refrigerated dairy cases. The impacted cases had 10 doors, and 2 ft wide each.

2.1 Application information and applicant savings methodology

This section describes the application information, the savings methodology provided by the applicant, and the evaluation assessment of the savings calculation algorithm used by the applicant.

2.2 Applicant description of baseline

According to the project files, the applicant classified both measures as a retrofit with pre-existing conditions as the baseline. Table 2-2 shows the pre-existing key parameters in the model.

Table 2-2. Applicant's baseline key parameters

APPLICANT BASELINE	
Measure ID	**Operation Description**
M1: Destratification fans	The sales floor was conditioned without destratification fans. The applicant modeled the baseline indoor air temperature to be 70°F from 6am to 12am, and 65°F from 12am to 6am.
M2: Case doors	There were ten 2-ft wide pre-existing open refrigerated cases without doors. All cases were medium temperature.

2.2.1 Applicant description of installed equipment and operation

This project includes installing 18 destratification fans throughout the sales floor and installing doors onto 10 refrigerated medium-temperature cases. Table 2-3 presents the main parameters of the proposed case as defined by the applicant.

Table 2-3. Applicant's proposed key parameters

APPLICANT PROPOSED	
Measure ID	**Operation Description**
M1: Destratification fans	The sales floor was conditioned with destratification fans. The applicant modeled the baseline indoor air temperature to be 67.4°F from 6am to 11am, 67.3°F from 11am to 11pm, and 65°F from 11pm to 6am.
M2: Case doors	There were ten 2-ft wide refrigerated cases with doors. All cases were medium temperature.

2.2.2 Applicant energy savings algorithm

The applicant used eQUEST modeling to quantify each measure's savings, with the on-site audit findings for key input parameters, and GrocerSmart guidelines to determine a variety of building inputs including refrigeration system, complex building geometry, lighting systems, and HVAC systems to estimate the energy savings from these two measures.

Figure 2-1 and Figure 2-2 are examples of baseline and as-built model heating temperature schedule for ECM-1.

Figure 2-1 Model input schedule for ECM-1 – baseline

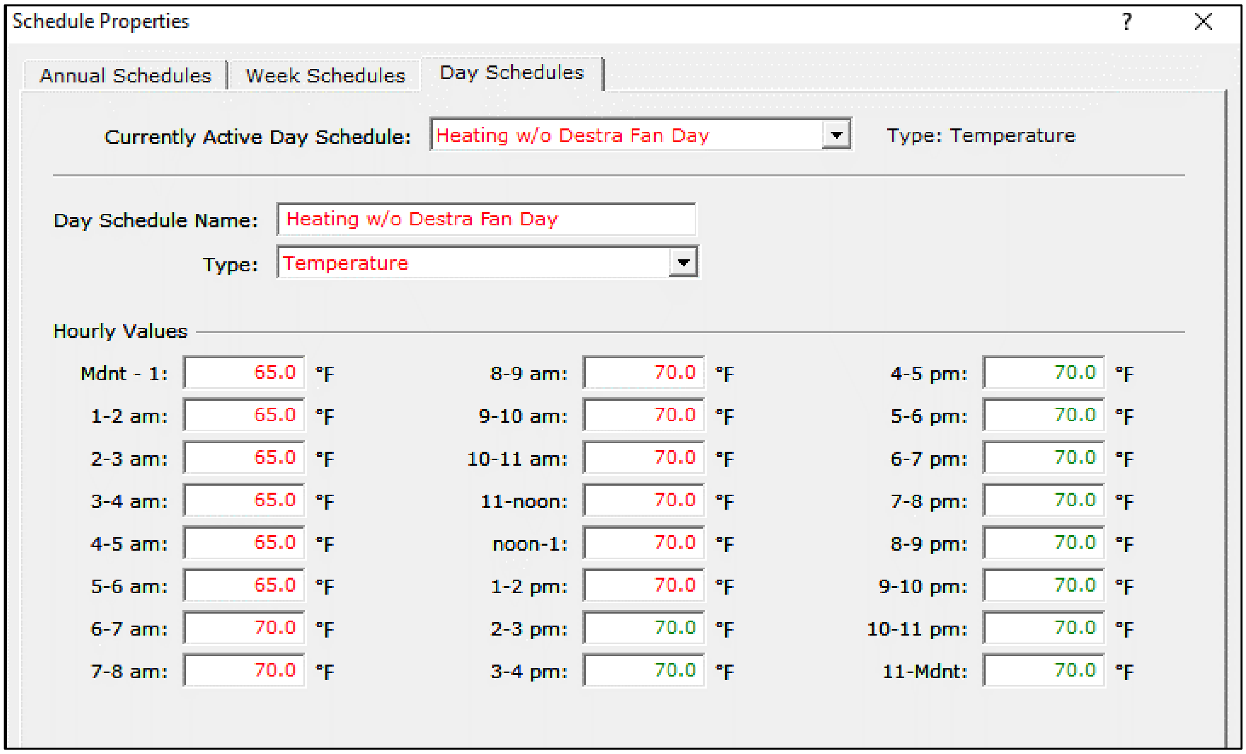
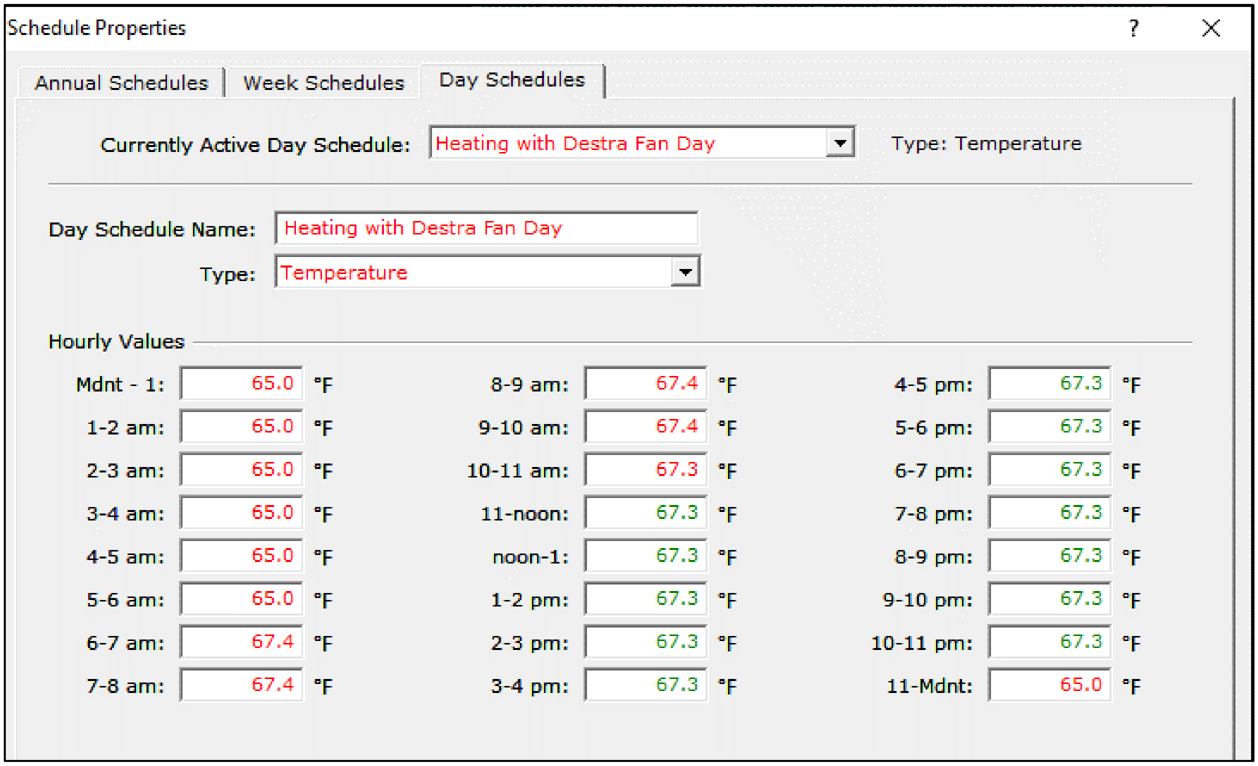


Figure 2-2 Model input schedule for ECM-1 – as-built



This schedule was assigned specifically to the sales area heating temperature. The lower temperature is the as-built case is because with less air stratification, an equivalent level of occupant comfort can be achieved with a lower average indoor air temperature. In particular, the lower air temperature near the ceiling results in a lower average indoor air temperature.

It's important to note that this heating temperature schedule was implemented throughout the entire sales area. To determine the coverage area for the destratification fans, the applicant utilized information from the fan specification sheets. They performed a quadratic regression analysis to establish a relationship between the fan's cubic feet per minute (cfm) and the area it could effectively cover. The regression results were then applied using the actual installed fan cfm, multiplied by a factor of 18 (total number of fans), to calculate the normalized sales area that could be covered by ECM-2. Then the saving was calculated as:

$$Gas\ Savings = (Baseline\ Heating\ Consumption - Proposed\ Heating\ Consumption) \times \frac{Total\ Covered\ Area}{Total\ Salesfloor\ Area}$$

Where,

- Baseline and proposed heating consumption was based on the eQUEST simulation.
- Total covered area is 24,569 ft^2, based on the regression between cfm and cover area.
- Total salesfloor area is 72,000 ft^2, based on the site specs.

For ECM-2, the refrigeration specs in the eQUEST model were generated from a proprietary audit tool that maps an on-site data collection to a proprietary database. The database is a collection of refrigeration equipment data and specification sheets that have been modified such that the database outputs are compatible with eQUEST parameter keywords. The database outputs shape the eQUEST model to match observed equipment specifications (e.g., number of refrigeration fixtures, case heat conduction rate, case lighting power, suction groups, etc.) that were collected through the on-site audit. The evaluator compared the input files of the base case and proposed case eQUEST Refrigeration models to determine what input keywords are the drivers for savings. The comparison is shown in Figure 2-3. below:

Figure 2-3. Difference between the base and proposed case eQUEST models for ECM-2

Component	Reference(s)	Keyword	Array Idx	Baseline	Run #2
Refrigeration Fixture	CD5829D6562AD(1 of 9)	SST-SUPPLY-TD	N/A	7.000	4.000
Refrigeration Fixture	CD5829D6562AD(1 of 9)	INF-SCH	N/A	Night Cover_Sch	Inf_Sched
Refrigeration Fixture	CD5829D6562AD(1 of 9)	INF-LOAD/LEN	N/A	1,209.530	302.380
Refrigeration Fixture	CD5829D6562AD(1 of 9)	CONDUCTION/LEN	N/A	134.392	60.480
Refrigeration Fixture	CD5829D6562AD(1 of 9)	CANOPY-KW/LEN	N/A	0.022	0.018
Refrigeration Fixture	CF2829D6562AD	SST-SUPPLY-TD	N/A	8.000	4.000
Refrigeration Fixture	CF2829D6562AD	INF-SCH	N/A	Inf_Sched	Inf_Sched
Refrigeration Fixture	CF2829D6562AD	INF-LOAD/LEN	N/A	1,128.580	282.150
Refrigeration Fixture	CF2829D6562AD	CONDUCTION/LEN	N/A	125.398	56.430
Refrigeration Fixture	CF2829D6562AD	CANOPY-KW/LEN	N/A	0.020	0.018

Where,

- SST-SUPPLY-TD: defines the design temperature differential between the wet-bulb temperature leaving the evaporator (supply to the fixture) and the saturated-suction temperature.
- INF-SCH: if infiltration changes over the store schedule (i.e., if the display case has a night cover), this keyword defines a scheduling factor (0 to 1) that modifies INF-LOAD/LEN. In this situation, the proposed case "Inf_Sched" schedule is a typical flat 1.0 profile (has no effect on INF-LOAD/LEN because the proposed case now has a door), while the base case "Night Cover_Sch" reduces INFLOAD/LEN by 0.8 from 11p-6a to simulate the night covers that used to be draped over the display cases during store closures.
- CONDUCTION/LEN: a per length conduction value for the refrigeration fixture (i.e., display case). It defines the design heat gain due to conduction through the fixture surfaces.
- INF-LOAD/LEN: a per length infiltration value for the refrigeration fixture. It defines the design infiltration heat gain due to infiltration i.e., air exchange between the fixture and the surrounding zone.
- CANOPY-KW/LEN: a per length lighting power of the refrigeration fixture.

The affected eQUEST keyword values in the proposed case model were adjusted from the base case values according to a case door measure apparently from the ESG program. While baseline key input values are based on the proprietary database and the refrigeration audit, the proposed values are based on the measure assumptions in Table 2-4.

Table 2-4 ECM-2 Input assumptions

OE2R/eQUEST	Proposed value	Source
SST-SUPPLY-TD	4	Faramarzi, Ramin T., B.A. Coburn, and R. Sarhadian, 2002. Performance and Energy Impact of Installing Glass Doors on an Open Vertical Deli/Dairy Display Case. ASHRAE Transactions, AC-02-7-2, pp. 673-679
INF-LOAD/LEN	Baseline INFLOAD/LEN * 0.25	Faramarzi, Ramin T., B.A. Coburn, and R. Sarhadian, 2002. Performance and Energy Impact of Installing Glass Doors on an Open Vertical Deli/Dairy Display Case. ASHRAE Transactions, AC-02-7-2, pp. 673-679
CONDUCTION/LEN	Baseline CONDUCTION/LEN * 0.45	Faramarzi, Ramin T., B.A. Coburn, and R. Sarhadian, 2002. Performance and Energy Impact of Installing Glass Doors on an Open Vertical Deli/Dairy Display Case. ASHRAE Transactions, AC-02-7-2, pp. 673-679
CANOPY-KW/LEN	0.018	Research of LEDs installed in PECI programs, summary found in WP for Reach-in Case Lighting, Fluorescent to LED, with and without motion sensors, Figure 1.

In addition, “LINE-UP_LENGTH” (i.e., refrigeration fixture/case length in feet) in the eQUEST models are as Table 2-5:

Table 2-5 Affected fixture case lengths in ECM-2

Refrigeration System	Refrigeration Fixture	LINE-UP_LENGTH
SG-67DA4	CD5829D6562AD	32
SG-03EBC	CD6829D6562AD	24
SG-03EBC	CD8829D6562AD	20
SG-03EBC	CD9829D6562AD	72
SG-67DA4	CDF829D6562AD	35
SG-67DA4	CE0829D6562AD	40
SG-67DA4	CE8829D6562AD	12
SG-03EBC	CE9829D6562AD	4
SG-67DA4	CEA829D6562AD	16
SG-67DA4	CF2829D6562AD	8
Total		263

The applicant conducted the simulation to get the annual gas reduction and divided by the total 263 feet of refrigeration cases to get the therms savings per feet. The saving for ECM-2 was calculated as:

$$Gas\ Savings = {}^{Therms\ Savings}/_{ft} \times Total\ Length\ of\ Impacted\ Cases$$

Where,

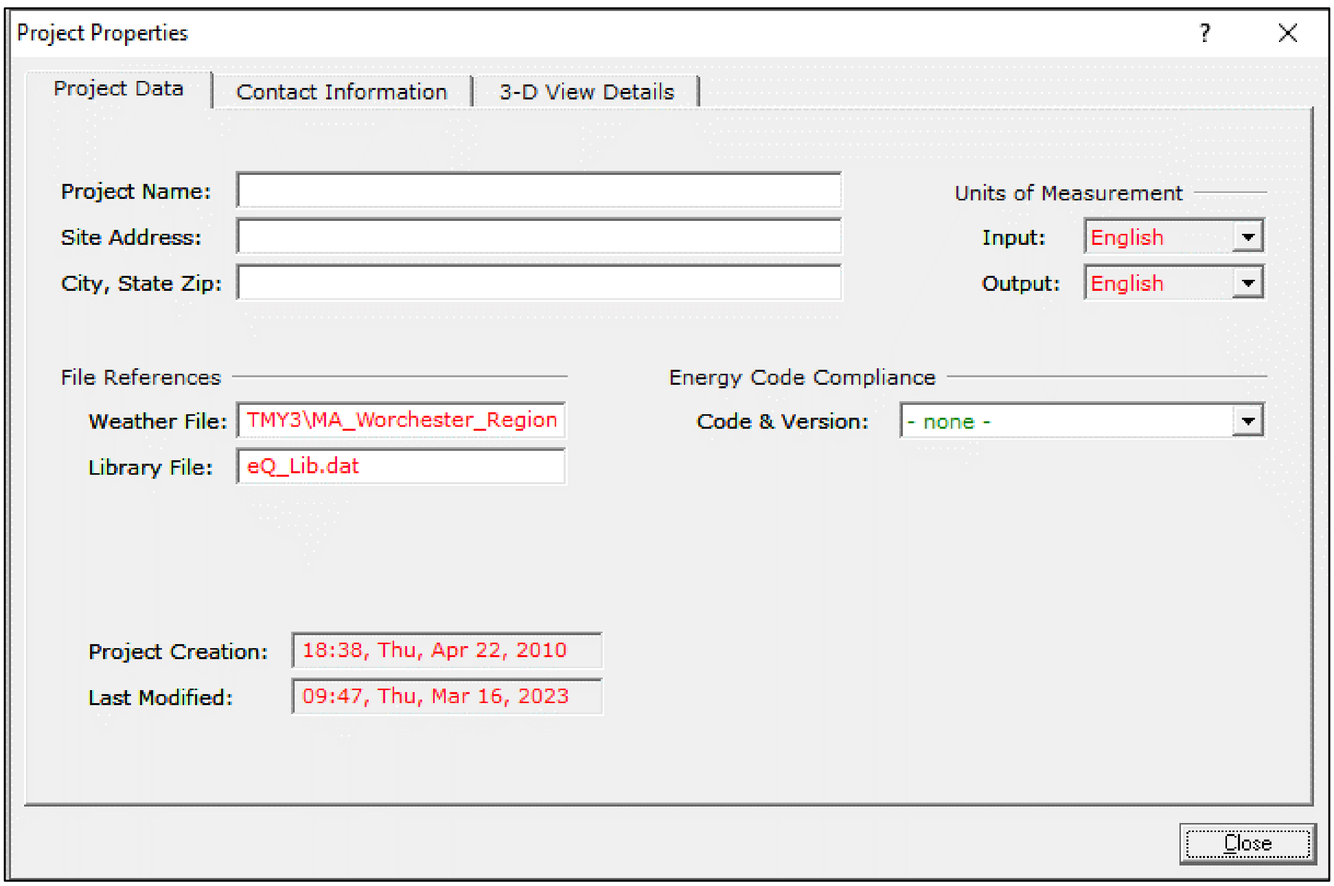
- Therms savings/ft was based on the simulation result.
- Total length of impacted cases is 20 feet.

2.2.3 Evaluation assessment of applicant methodology

Overall, the evaluator found that the applicant's use of eQUEST to estimate energy savings was appropriate. And the evaluator was able to get the eQUEST input files from the implementation vendor and replicate the same baseline and proposed consumption as the vendor reported. However, the energy model for both measures were designed in a generic level rather than using many site-specific inputs. The evaluator updated the models by updating some input parameters based on the on-site findings and metered data in Section 2.4.2. below.

Instead of using TMY3 weather file in RI, the applicant used MA weather file for the ECM-1 energy model as Figure 2-4 shows. The evaluator corrected this error in the section below.

Figure 2-4 Weather file for ECM-1



2.3 On-site inspection and metering

This section provides details on the tasks performed during the site visit and on the gathered data. Because the operation of the facility and the installed measures were not impacted by the pandemic, the evaluator conducted a site inspection to verify the installation of the installed measures and installed temperature sensors to capture the temperature of the sales floor that covered by the destratification fans. This section provides details on the tasks performed during the site visit and on the gathered data.

2.3.1 Summary of site visit findings

The site contact indicated that it was safe to visit the site and preferred an on-site verification with logger installation of the evaluated measures. The evaluator conducted the site visit with meter deployment on March 1, 2023, and retrieved the meters on May 3, 2023, with the help of the store manager.

During the site visit, the following relevant information was gathered:

- The evaluator visually verified there were 18 destratification fans were installed and all of them were operational.
- The evaluator verified the total sales area was approximately 72,000 ft^2, which is same as applicant estimated. Table below shows the spaces covered by destratification fans. The evaluator updated the cover ft^2 in the following section based on this finding.

Table 2-6 Spaces covered by destratification fan

Aisle	Fan quantity
21	5
22	6
23	7
Total	**18**

- The evaluator verified the total of 10 doors installed on two cases. Evaluators measured each case door as 24" wide, 66" tall. Both cases have temperature gauge readings of 36°F - 37.6°F. Both cases are remote condensing.
- During the site visit, the site contact confirmed there was no temperature setback during the unoccupied periods. The metered data also supported this indication. The evaluator updated the model schedule for both baseline and as-built cases in the section below.
- The evaluator was unable to get access to the roof to get the nameplate information of the HVAC system.

Table 2-7 summarizes the findings from the installed measure verification.

Table 2-7. Measure verification – M1 and M2

Measure name	Verification method	Verification result
M1	Full M&V	Visually verified the installed of destratification fans and their quantity. Deployed temperature sensors inside the store, to quantify the average indoor air temperature.
M2	Full M&V	Visually verified the installed of doors on two refrigeration cases.

Error! Not a valid bookmark self-reference. and Figure 2-6 Figure 2-3. below are the pictures of the installed equipment for both measures.

Figure 2-5. Installed destratification fan

Figure 2-6 Installed case doors

2.3.2 Measured and logged data

During the site visit the evaluator deployed temperature loggers to characterize the space temperature, from March 1, 2023, to May 3, 2023, in a representative sample of orientations, locations and heights in the section of the sales floor where the destratification fans were installed, to quantify the average indoor air temperature. The evaluator deployed six temperature sensors across the building and was able to retrieve all of them. Table 2-8 presents the logger deployment details.

Table 2-8 Data Logger Deployment Details

Logger Number	Logger ID	Aisle	Location Description	Approx. Height (ft)	Time Interval	Duration
1	4228	21	Above bread freezer, under destratification fan	7	15 mins	8.5 weeks
2	4197	21	Behind 1st pillar closest to milk cases, under 4th lowest shelf	4		
3	3780	21	Behind 1st pillar closest to milk cases, under lowest shelf	1		
4	2780	23	Closest shelf near end cap by bakery, under 5th lowest shelf	5		
5	2298	23	Closest shelf near end cap by bakery, under 2nd lowest shelf	2		
6	3762	23	Closest shelf near end cap by bakery	7		

2.4 Evaluation methods and findings

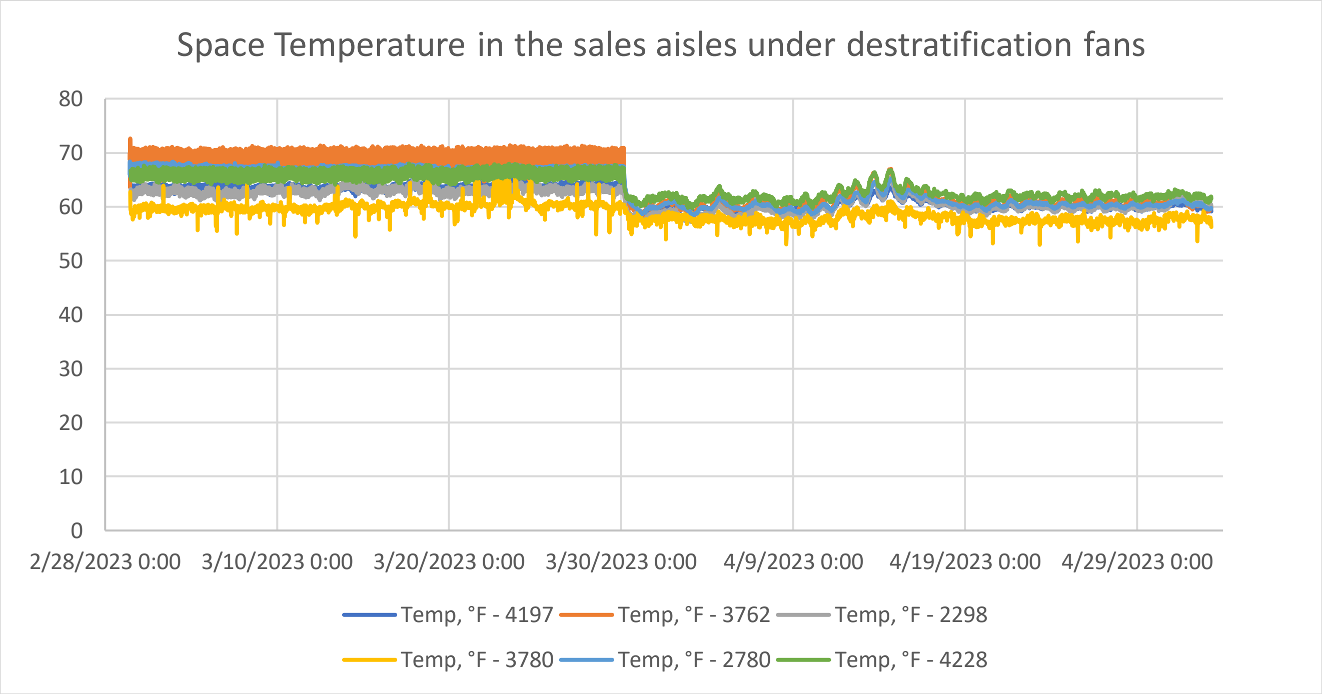
This section describes the evaluator methods and findings.

2.4.1 Evaluation description of baseline

The evaluator reviewed the project files and interviewed the site contact to gather information on the baseline. Based on that information, the evaluator determined both measures are an add-on with single baseline. The baseline is single because the measure lives (10 years for destratification fans, 12 years for case doors) are less than 2/3 of the measure life of the underlying heating system (20 years for RTUs). The baseline is the pre-existing condition.

For ECM-1, Figure 2-7 shows the metered temperature for all six locations that covered by the destratification fans.

Figure 2-7 Metered space temperature



Based on the metered data above and the interview on site contact, the evaluator updated the heating schedule by removing the temperature setback during the nighttime.

Table 2-9. Evaluated baseline key parameters

EVALUATED BASELINE	
Measure ID	**Operation Description**
M1: Destratification fans	The sales floor was conditioned without destratification fans. The evaluated modeled the baseline indoor air temperature to be 70°F for 24 hours a day, and 7 days a week.
M2: Case doors	There were ten 2-ft wide pre-existing open refrigerated cases without doors. All cases were medium temperature.

2.4.2 Evaluation calculation method

The evaluator calculated the project impacts using a similar methodology as applicant, by using eQUEST refrigeration version 3.61 but updated some key input parameters to make the model more site-specific instead of representing a general program-level approach.

Based on Figure 2-7, while some loggers indicate a slight temperature drop on March 30, the overall space temperature remained stable in each specific location (the overall average temperature before March 30 was 64°F, and 60°F after March 30). Table 2-10 Metered space temperatureprovides a comparison of temperature differences among different locations. As observed, the air temperature was higher near the ceiling, and the overall temperature was lower than the baseline temperature.

Table 2-10 Metered space temperature

Logger Number	Logger ID	Aisle	Location Description	Approx. Height (ft)	Average Temperature
1	4228	21	Above bread freezer, under destratification fan	7	63.89
2	4197	21	Behind 1st pillar closest to milk cases, under 4th lowest shelf	4	61.67
3	3780	21	Behind 1st pillar closest to milk cases, under lowest shelf	1	58.82
4	2780	23	Closest shelf near end cap by bakery, under 5th lowest shelf	5	63.44
5	2298	23	Closest shelf near end cap by bakery, under 2nd lowest shelf	2	61.24
6	3762	23	Closest shelf near end cap by bakery	7	64.17

Therefore, the evaluator updated the as-built model based on the information above, to use the average of all metered temperature during the whole metered period as the as-built heating temperature, which is 5.1°F lower than the tracked heating temperature in as-built situation. This shows that destratification fans can help to maintain a lower heating temperature throughout the impacted space by pushing the warm air from the ceiling down to the occupied zone. Then the saving was calculated as:

$$Gas\ Savings = (Baseline\ Heating\ Consumption - Proposed\ Heating\ Consumption) \times \frac{Total\ Covered\ Area}{Total\ Salesfloor\ Area}$$

Where,

- Baseline and proposed heating consumption was based on the eQUEST simulation with updated temperature.
- Total covered area is 9,391 ft^2, based on 3 out of 23 aisles were covered by the destratification fans.
- Total salesfloor area is 72,000 ft^2, based on the site specs and same as applicant used.

For ECM-2, the evaluator confirmed there were total of 20 feet of cases installed with doors. However, instead of incorporating the measure impact for all 10 refrigeration fixtures as the applicant did in their model, the evaluator only considered a 12-feet case and an 8-feet case during the parametric run, as indicated in Table 2-11 below.

Table 2-11 Affected fixture case lengths in ECM-2

Refrigeration System	Refrigeration Fixture	LINE-UP_LENGTH
SG-67DA4	CE8829D6562AD	12
SG-67DA4	CF2829D6562AD	8
Total		20

The evaluator also removed the door heater setting in the energy model, because the evaluators verified that the impacted cases were not equipped with any anti-sweat door heaters. Figure 2-8 provides a case nameplate showing the case was not designed with anti-condensate heaters. The evaluators also verified that the added case doors did not have anti-sweat circuits.

Figure 2-8. Verified case nameplate – no anti-condensate heaters on door, also verified no heater circuit on door

Table 2-12 shows the evaluated as-built model input values.

Table 2-12. Evaluator's as-built key parameters

EVALUATOR AS-BUILT	
Measure ID	**Operation Description**
M1: Destratification fans	The sales floor was conditioned with destratification fans. The evaluated modeled the baseline indoor air temperature to be 62.2°F for 24 hours a day, 7 days a week.
M2: Case doors	There are ten 2-ft wide refrigerated cases with doors. All cases were medium temperature. No door heaters.

3 FINAL RESULTS

The evaluated project consisted of installing 18 destratification fans throughout the sales floor and installing doors onto 10 refrigerated dairy cases. The evaluated savings are less than the tracking values, primary due to an operational adjustment on the load shape. The parameters impacting the analysis are summarized in Table 3-1 below.

Table 3-1. Summary of key parameters

Parameter	BASELINE Model		PROPOSED Model	
	Applicant	Evaluated	Applicant	Evaluated
Heating temperature schedule	Occupied: 70°F Unoccupied: 65°F	24/7: 70°F	Occupied: 67.4°F Unoccupied: 65°F	24/7: 62.2°F
Impacted sales area	24,569 ft^2	9,391 ft^2	24,569 ft^2	9,391 ft^2
Modeled cases length	263 ft (to get therms/ft)	20 ft	263 ft (to get therms/ft)	20 ft
Door heater	Yes	No	Yes	No
Weather profile	Worchester, MA	Providence, RI	Worchester, MA	Providence, RI
ECM-1 model annual gas consumption	64,499 therms	60,425 therms	58,262 therms	52,472 therms
ECM-2 model annual gas consumption	50,738 therms	50,690 therms	40,235 therms	49,859 therms

3.1 Explanation of differences

The evaluated savings are 36 % less the tracking values. Table 3-2 provides a summary of the differences between tracking and evaluated values.

Table 3-2. Summary of deviations

Measure	Discrepancy	Parameter	Impact of Deviation	Discussion of Deviations
M1	Operational	Operating load	20%	**Increased Savings:** Evaluator updated the as-built space temperature, which is lower than the applicant estimated. This increased the savings due to less as-built heating load. The evaluator also updated the weather profile from MA to RI.
M1	Operational	Load Shape	-57%	**Decreased Savings:** Evaluator updated the impacted space square feet, which is lower than applicant estimated.
M2	Non-operational	Analysis methodology	1%	**Increased Savings:** The applicant used 263 ft in the model to simulate the savings, then adjusted the savings by applying a linear ratio to estimate the savings for 20 feet. Evaluator used the actual length (20 ft) of cases impacted by this measure in the model.

3.2 Lifetime savings

The evaluator classified measure both evaluated measures as an add-on with single baseline. The evaluator calculated applicant and evaluated lifetime savings values using the following formula:

$$\text{LAGI} = \text{FYS} \times [\text{RUL} + \text{outyear}\,\% \times (\text{EUL} - \text{RUL})]$$

where:

LAGI =	lifetime adjusted gross impact (therms)
FYS =	first year savings (therms)
EUL =	measure life (years)
RUL =	1/3 of EUL (years)
outyear % =	100% for this single baseline measure

The evaluated lifetime savings are lower than the tracking lifetime savings because the evaluated first year savings are lower than the tracking first year savings. Table 3-3 to Table 3-5 provides a summary of key factors that influence the lifetime savings.

Table 3-3. Measure M1 - Application ID: 13219566 - Lifetime savings summary

Factor	Tracking	Evaluator
Lifetime savings (therms)	21,280	10,373
First year savings (therms)	2,128	1,037
Measure lifetime (years)	10	10
Baseline classification	Retrofit with single baseline	Add-on with single baseline

Table 3-4. Measure M2 - Application ID: 13219566 - Lifetime savings summary

Factor	Tracking	Evaluator
Lifetime savings (therms)	9,468	9,972
First year savings (therms)	789	831
Measure lifetime (years)	12	12
Baseline classification	Retrofit with single baseline	Add-on with single baseline

Table 3-5. Measure Total - Application ID: 13219566 - Lifetime savings summary

Factor	Tracking	Evaluator
Lifetime savings (therms)	30,478	20,345
First year savings (therms)	2,917	1,868
Measure lifetime (years)	10.5 (weighted)	10.9 (weighted)
Baseline classification	Retrofit with single baseline	Add-on with single baseline

3.2.1 Ancillary impacts

There are total of 4,560 kWh savings as the ancillary impacts of these two measures.

RI CUSTOM GAS EVALUATION SITE SPECIFIC MEASUREMENT AND VERIFICATION REPORT

Site ID: RIG21N081

Report Date: 6/5/2023

Program Administrator	RI Energy
Application ID(s)	11246974, 11246977
Project Type	Retrofit
Program Year	2021
Evaluation Firm	DNV
Evaluation Engineer	Matthew Piana
Senior Engineer	Rick Boswell

1 EVALUATED SITE SUMMARY AND RESULTS

This project consisted of two retrofit applications at an industrial facility with a warehouse. The applications are comprised of two unique measures identified through a vendor scoping audit.

EEM1 consisted of exhaust fan controls for four exhaust fans added to a pre-existing energy management system (EMS). Gas savings result from the reduced run time of the exhaust fans compared to their baseline operation, which reduces the heating load during the winter. The exhaust fans are meant to cool the warehouse space during the summer, but in the baseline case they were operating year-round. The application consisted of installing automatic controls to operate the exhaust fans based on outside air temperature (OAT).

EEM2 consisted of process controls meant to turn off the supply of steam to eight unit heaters located within the warehouse space. The site uses a large boiler to supply steam to process end uses and the eight steam-driven unit heaters in the warehouse. In the baseline, each unit heater's steam piping was energized all year round regardless of fan operation. Though the unit heater blowers were not on, the hot steam piped within the unit heaters caused an increase in the boiler's load. The application consisted of installing automated steam valves to eliminate the flow of steam to certain parts of the warehouse during summer months which only needed steam for heating end uses. Savings result from the reduced boiler load during summer and shoulder months when no heating is necessary.

The tracking savings for this project are 68,695 therms. The total evaluated savings for this project are 72,486 therms. The tracking and evaluated savings are presented in Table 1-1. In addition to the gas savings, there were 18,483 kWh claimed as part of this project. The evaluation calculated electric savings, at 18,294 kWh.

Table 1-1. Evaluation results summary

PA Application ID	Measure Name		Annual Savings (therms)
11246974	EEM 1: EMS fan controls	Tracked	61,284
		Evaluated	63,793
		Realization rate	104%
11246977	EEM2: Process controls	Tracked	7,411
		Evaluated	8,693
		Realization rate	117%
Total	EEM1 and EEM2	Tracked	68,695
		Evaluated	72,486
		Total project realization rate	106%

1.1 Explanation of Deviations from Tracking

The evaluated savings are 6% greater than the applicant-reported savings, primarily due to differences in the heating setpoints used by the applicant and evaluators. Further details regarding deviations from the tracked savings are presented in Section 3.1.

1.2 Recommendations for Program Designers & Implementers

There are no recommendations from evaluators for program designers & implementers.

1.3 Customer Alert

There are no customer alerts.

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.

This project involved two applications. Application 11246974 consisted of EMS exhaust fan controls for four exhaust fans and application 11246977 consisted of process controls meant to turn off the supply of steam to eight unit heaters located within the warehouse space.

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.

2.2 Applicant Description of Baseline

The applicant classified the installed measures as retrofits and characterized the baseline as the pre-existing conditions. Table 2-1 summarizes the critical applicant baseline parameters for each application.

Table 2-1. Applicant baseline key parameters

		BASELINE		
Measure	**Parameter**	**Value(s)**	**Source of Parameter Value**	**Note**
EEM1: EMS fan controls	Number of fans	4	Applicant calcs.	-
EEM1: EMS fan controls	Number of hours 1 fan operating	0	Applicant calcs.	-
EEM1: EMS fan controls	Number of hours 2 fans operating	0	Applicant calcs.	-
EEM1: EMS fan controls	Number of hours 3 fans operating	0	Applicant calcs.	-
EEM1: EMS fan controls	Number of hours 4 fans operating	8,760	Applicant calcs.	-
EEM1: EMS fan controls	Airflow per fan (cfm)	10,000	Applicant calcs.	-
EEM1: EMS fan controls	Baseline heating setpoint (°F)	68	Applicant calcs.	-
EEM1: EMS fan controls	Heating system balance point (°F)	50	Applicant calcs.	-
EEM2: Process controls	Annual hours of operation of unit heaters	8,760	Applicant calcs.	-
EEM2: Process controls	Boiler burner efficiency	80%	Applicant calcs.	-

2.2.1 Applicant Description of Installed Equipment and Operation

The applicant described the installed equipment and its operation as follows:

- EEM1: EMS fan controls. Automated controller to operate warehouse exhaust fans based on OAT.
- EEM2: Process controls. Automated valves and controller on steam distribution system to control flow of steam and eliminate flow to unit heaters and legs of steam system that never require steam during summer months.

Table 2-2 summarizes the key proposed applicant parameters.

Table 2-2: Application proposed key parameters

		Proposed		
Measure	**Parameter**	**Value(s)**	**Source of Parameter Value**	**Note**
EEM1: EMS fan controls	Number of fans	4	Applicant calcs.	-
EEM1: EMS fan controls	Number of hours 1 fan operating	4,189	Applicant calcs.	-
EEM1: EMS fan controls	Number of hours 2 fans operating	3,122	Applicant calcs.	-

EEM1: EMS fan controls	Number of hours 3 fans operating	1,031	Applicant calcs.	-
EEM1: EMS fan controls	Number of hours 4 fans operating	418	Applicant calcs.	-
EEM1: EMS fan controls	Airflow per fan (cfm)	10,000	Applicant calcs.	-
EEM1: EMS fan controls	Proposed heating setpoint (°F)	67	Applicant calcs.	-
EEM1: EMS fan controls	Heating system balance point (°F)	50	Applicant calcs.	-
EEM2: Process controls	Annual hours of operation of unit heaters	5,568	Applicant calcs.	-
EEM2: Process controls	Demand reduction achieved by controls (BTU/h)	232,185	Applicant calcs.	-
EEM2: Process controls	Boiler burner efficiency	80%	Applicant calcs.	-

2.2.2 Applicant Energy Savings Algorithm

The applicant used custom savings spreadsheets to calculate the savings for both EEM1 and EEM2. For EEM1 the applicant used the following algorithms and assumptions:

- EEM1: The exhaust fan controls follow the following sequence based on OAT: >80 °F-4 Fans; >70 °F-3 Fans; >50 °F-2 Fans; <50 °F-1 fan. It is important to note that in this control sequence, one fan always operates regardless of OAT. When the OAT is greater than 50 °F, a second fan will energize in addition to the first, and so on until all four fans are operating when OAT is greater than 80 °F. The applicant used a weather bin-based analysis to determine savings using the following algorithms:

$$\Delta Svgs = \sum \frac{\dot{m}_{air} \times c_{p_{air}} \times \Delta T \times Hours}{100{,}000 \times Eff_{burner}}$$

where,

$Svgs$	=	Annual energy savings per year (therms)
$\dot{m}_{air}$	=	Mass flow of air (lbs/h)
$c_{p_{air}}$	=	Specific heat of air (0.240 BTU/lb-°F)
ΔT	=	Difference in OAT and heating setpoint (68 °F baseline, 67 °F proposed)
$Hours$	=	Annual hours in each bin
$100{,}000$	=	BTU to Therm conversion rate
Eff_{burner}	=	Boiler burner efficiency (80%)

$$\dot{m}_{air} = Quantity \times \rho_{air} \times cfm_{rated} \times 60$$

where,

$\dot{m}_{air}$	=	Mass flow of air (lbs/h)
$Quanitity$	=	Quantity fans operating (based on control sequence and OAT)
ρ_{air}	=	Density of air (lb/ft^3)
cfm_{rated}	=	Flow of air per fan (10,000 cfm)
60	=	Min to hour conversion rate

Figure 2-1 shows a screenshot from the applicant savings spreadsheet for EEM1.

Figure 2-1. Screenshot from applicant savings spreadsheet EEM1

Assumptions	Value:	Units:	Notes:
Flow of Air (per fan)	10,000	cfm	per fan
Heating Setpoint	68	DegF	
Heating setpoint (proposed)	67		
Heating System Balance Point	50	DegF	
Heating System Efficiency	80%	%	*estimated
Conversion	100,000	BTU/therm	
Conversion	60	minutes/hour	
Specific Heat of Air	0.240	BTU/lb-F	
Fan Power Draw	0.93	kW	

> 80 deg; 4 fans running
> 70 deg; 3 fans running
> 50 deg; 2 fans running
< 50 deg; 1 fan running

Weather Bin Data		Warehouse Fan - Current Operation						Warehouse Fan Proposed Operation						Savings Summary		
OAT Mid Point	Hours	Number of Fans Operating	Density of Air (lb/ft3)	Mass Flow of Air (lbs/hr)	Fan Power (kW)	Fan Energy (kWh)	Estimated heating Energy (therms)	Number of Fans Operating	Density of Air (lb/ft3)	Mass Flow of Air (lbs/hr)	Fan Power (kW)	Fan (kWh)	Estimated heating Energy (therms)	Fan (kW)	Fan (kWh)	Therms
97.5	3	4.0	0.071	171,108	3.7	11	-	4.0	0.071	171,108	3.7	11	-	-	-	-
92.5	41	4.0	0.072	172,659	3.7	153	-	4.0	0.072	172,659	3.7	153	-	-	-	-
87.5	76	4.0	0.073	174,238	3.7	283	-	4.0	0.073	174,238	3.7	283	-	-	-	-
82.5	298	4.0	0.073	175,846	3.7	1,110	-	4.0	0.073	175,846	3.7	1,110	-	-	-	-
77.5	475	4.0	0.074	177,485	3.7	1,770	-	3.0	0.074	133,113	2.8	1,327	-	1	442	-
72.5	556	4.0	0.075	179,154	3.7	2,072	-	3.0	0.075	134,365	2.8	1,554	-	1	518	-
67.5	813	4.0	0.075	180,854	3.7	3,029	-	2.0	0.075	90,427	1.9	1,515	-	2	1,515	-
62.5	904	4.0	0.076	182,588	3.7	3,368	-	2.0	0.076	91,294	1.9	1,684	-	2	1,684	-
57.5	647	4.0	0.077	184,355	3.7	2,411	-	2.0	0.077	92,177	1.9	1,205	-	2	1,205	-
52.5	758	4.0	0.078	186,156	3.7	2,824	-	2.0	0.078	93,078	1.9	1,412	-	2	1,412	-
47.5	616	4.0	0.078	187,993	3.7	2,295	7,122	1.0	0.078	46,998	0.9	574	1,694	3	1,721	5,428
42.5	740	4.0	0.079	189,866	3.7	2,757	10,748	1.0	0.079	47,467	0.9	689	2,582	3	2,068	8,167
37.5	921	4.0	0.080	191,778	3.7	3,432	16,161	1.0	0.080	47,944	0.9	858	3,908	3	2,574	12,254
32.5	805	4.0	0.081	193,728	3.7	2,999	16,609	1.0	0.081	48,432	0.9	750	4,035	3	2,250	12,574
27.5	387	4.0	0.082	195,718	3.7	1,442	9,203	1.0	0.082	48,930	0.9	360	2,244	3	1,081	6,959
22.5	375	4.0	0.082	197,750	3.7	1,397	10,122	1.0	0.082	49,437	0.9	349	2,475	3	1,048	7,647
17.5	224	4.0	0.083	199,824	3.7	835	6,781	1.0	0.083	49,956	0.9	209	1,662	3	626	5,119
12.5	96	4.0	0.084	201,942	3.7	358	3,228	1.0	0.084	50,485	0.9	89	792	3	268	2,435
7.5	24	4.0	0.085	204,105	3.7	89	889	1.0	0.085	51,026	0.9	22	219	3	67	670
2.5	1	4.0	0.086	206,316	3.7	4	41	1.0	0.086	51,579	0.9	1	10	3	3	31
-	-	4.0	0.086	207,213	3.7	-	-	1.0	0.086	51,803	0.9	-	-	3	-	-
	8,760					32,640	80,904					14,157	19,620		18,483	61,284

For EEM2 the applicant used the following algorithms and assumptions:

- EEM2: The vendor calculated energy savings by quantifying steam consumption (lbs/hr) used by various loads from historical gas usage data. The vendor calculated the hourly steam demand of the two process loads (batcher machine and calender machine), the hourly steam demand of the piping losses and attributed the rest of the hourly steam demand to the remaining energized unit heaters. The baseline was built using daily gas usage for one month, and assuming consistent use through the summer when usage was the same as winter. The formulas for calculating savings are identified below:

$$Therm_{prop} = \frac{Quantity \times Avoided\ losses \times Enthalpy \times Hours}{100{,}000 \times Eff_{system}}$$

where,

$Therm_{prop}$	= Proposed consumption (therms)
Quantity	= Quantity of unit heaters
$Avoided\ losses$	= Steam loads and losses (lbs)
$Enthalpy$	= Saturated steam enthalpy (950 BTU/lb)
$Hours$	= 3,192 (assumes 7 days/week, 19 weeks/year)
100,000	= BTU to therm conversion rate
Eff_{system}	= Assumed system efficiency (80%)

$$Avoided\ losses = Demand - Loads$$

$$Demand = \frac{Steam\ use_{hourly}}{Enthalpy / Eff_{system}}$$

where,

$Steam\ use_{hourly}$	= Based on billing data (BTU/h)

$$Loads = Piping\ losses + Batcher\ use + Calender\ use + Unit\ heater\ losses$$

$$Piping\ losses = \frac{\left(\frac{(SA_{fitting}) \times (HLR_{bare}\ \text{OR}\ HLR_{insulated})}{Eff_{burner}}\right)}{(Enthalpy)}$$

where,

$Piping\ losses$	= Steam load from live pipes (lb/h)
$SA_{fitting}$	= Surface area of insulated or bare fitting (ft^2)
HLR_{bare}	= Heat loss rate of bare pipe or fitting (BTU/h/ft^2) calculated using 3EPlus
$HLR_{insulated}$	= Heat loss rate of insulated pipe or fitting (BTU/h/ft^2), calculated using 3EPlus
Eff_{burner}	= Boiler burner efficiency (80%)
$Enthalpy$	= Saturated steam enthalpy (950 BTU/lb)

$$\text{Batcher use} = \frac{8.3 \times Time_{operation} \times Flow}{24 \times (1 - \%Loss_{steambacther})}$$

where,

$Batcher\ use$	= Batcher steam process load (lb/h)
8.3	= Gallon to lb conversion rate
$Time_{operation}$	= Metered operation of the pump (min/day)
$Flow$	= 9 gpm
24	= Hour per day conversion rate
$\%Loss_{steambacther}$	= Estimated steam percent loss, 10%

$$Calendar\ use = \frac{8.3 \times Time_{operation} \times Flow}{24 \times (1 - \%Loss_{steamcalendar})}$$

where,

$Calender\ use$	= Calender steam process load (lb/h)
8.3	= Gallon to lb conversion rate
$Time_{operation}$	= Metered operation of the pump (min/day)
$Flow$	= 9 gpm
24	= Hour per day conversion rate
$\%Loss_{steamcalendar}$	= Estimated steam percent loss, 66%

$$Unit\ heater\ losses = Total\ avg.steam\ load - (Piping\ losses + Batcher\ use + Calender\ use)$$

where,

$Unit\ heater\ losses$	= Unit heater steam losses (lb/h)
$Total\ avg.steam\ load$	= Average hourly steam demand (lb/h)
$Piping\ losses$	= Steam load from live pipes (lb/h)
$Batcher\ use$	= Batcher steam process load (lb/h)
$Calender\ use$	= Calender steam process load (lb/h)

Figure 2-2 shows a screenshot from the applicant savings spreadsheet for EEM1.

Figure 2-2: Tracking analysis savings calculations

Description	Value	Unit	Note
Avg use per day (workday)	42.0	MMBtu/day	from daily gas billing info
Avg use per day (workday)	420.3	therms/day	
Avg use per day (workday)	42,026,014	BTUs/day	
hours of workday boiler operation	24	hrs	
hourly avg use	1,751,083.94	BTU/hr	
boiler hp conversion	33500	BTU/hr/HP	
Estimated Boiler Demand	52.3	hp	
Estimated Boiler Load	35%	%	150 hp boiler
Annual Hours of Reduction	3,192	hrs annually	site estimates 7 days/week, 19 weeks/year (~4.5 months)
Estimated Current Energy Use (Summer)	**55,895**	**Therms**	
Boilers - Steam Production			
Energy to make 1 lb of steam	950	BTU/lb	assumed
Efficiency of Boiler	80%	%	assumed
Actual energy to make steam	1,188	BTU/lb	
Avg. Steam generation at current demand	1,475	lbs/hr	
Boiler System Losses			
Total Avg. Summer Steam Flow/Load Site	**1,475**	**lbs/hr**	total avg. demand
Piping Losses	113	lbs/hr	measured/calculated
Process (batcher) Usage	13	lb/hr	measured/calculated
Process (calander) Usage	102	lb/hr	measured/calculated
Total Accounted for Loads	**228**	**lbs/hr**	
Calculated Losses	1,246	lbs/hr	unit heaters losses
Assumed Losses to "live" unit heaters	**1,246**	**lbs/hr**	
Unit Heater Operations			
Number of Steam Unit Heaters On	51	qty	
Assumed losses per unit heater	24.4	lbs/hr	reasonable assumption based on unit heater specs
Estimated Potential Savings			
Number of heaters to be shut off	8	qty	#4 warehouse, Bldg #1, #5, #3
Avoided losses per heater (plus piping)	24.4	lbs/hr	piping losses included to be conservative
Total Steam Losses to be removed	196	lb/hr	
Energy to make steam	950	btu/lb	
Assumed system efficiency	80%	%	
Loss Demand to be removed	232,185	BTU/hr	
Annual Hours of Reduction	3,192	hrs annually	site estimates 7 days/week, 19 weeks/year (~4.5 months)
Estimated Future Demand	1,518,899	BTU/hr	
Future Boiler Hp Demand	45.34	hp	20% loaded - unit has 10:1 turndown
Proposed Energy Use	**48,483**	**Therms**	
Total Savings	**741,133,210**	**BTU**	
Total Savings	**7,411**	**Therms**	

2.2.3 Evaluation Assessment of Applicant Methodology

Given the available information the applicant had access to such as gas usage data, evaluators consider the savings methodology used by the applicant to be appropriate. However, evaluators decided to use an approach based on direct metered data.

2.3 On-Site Inspection and Metering

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

2.3.1 Summary of On-site Findings

Evaluators conducted a site visit to the facility on February 9, 2023. During the site visit, evaluators met with the site contact, interviewed the site contact about the nature of the project, and installed metering equipment to monitor the operation of the exhaust fans from EEM1 and the unit heaters from EEM2. Evaluators installed amp loggers on two exhaust fans to verify their operation according to outside air temperature. Evaluators originally thought that the amp loggers were installed to the first two exhaust fans in the control sequence, however upon review of the recorded data, evaluators concluded that amp loggers were installed to fans #1 and #3. Further explanation of the logged fan data is presented in Section 2.4.2.1. Evaluators also installed two high-temperature thermocouples to verify the operating temperature of the steam system and the ambient temperature of the warehouse space. Evaluators gathered the following information during the site visit and during conversations with the site contact:

- EEM1: in the base case all four exhaust fans were operating 24/7/365
- EEM1: nameplate information of the exhaust fans (Figure 2-3)
- EEM1: the warehouse as-built space heating setpoint is 64°F
- EEM2: in the base case the unit heaters were energized 24/7/365
- EEM2: nameplate information of the unit heaters (Figure 2-4)

Figure 2-3: Nameplate exhaust fan

Figure 2-4: Nameplate unit heater

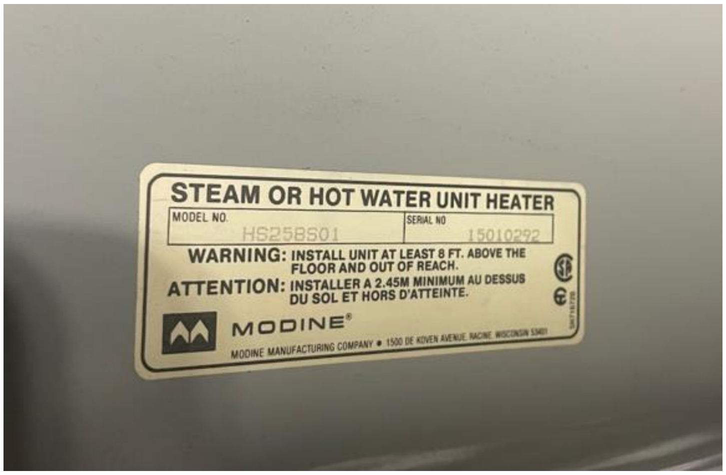


Table 2-3: Measure verification

Measure Name	Verification Method	Verification Result
EEM1: EMS fan controls	Visual verification, amp loggers	The fans operate with OAT as described in the project documents.
EEM2: Process controls	Visual verification, high-temperature thermocouples	Metering confirmed that unit heaters are valved off during summer and shoulder months.

2.3.2 Measured and Logged Data

During the initial site visit, the evaluators verified that the two EEMs had been installed. The evaluators deployed amp loggers to verify the operation of the exhaust fans and high-temperature thermocouples to verify the operation of the unit heaters. This is summarized in Table 2-4.

Table 2-4: Evaluation data collection – data received

Source	Parameter	Interval	Duration
Amp logger	Exhaust fans #1 and #3 operating amperage	5-minute	12 weeks
Thermocouple	Unit heater operating temperature	10-minute	12 weeks

Figure 2-5 shows a sample of the metered amperage data for fan #1 in the control sequence of EEM1. Figure 2-6 shows a sample of the metered amperage data vs. OAT for fan #3 in the control sequence of EEM1. Figure 2-7 shows a sample of metered data for EEM2.

Figure 2-5. Fan 1 logged amperage data

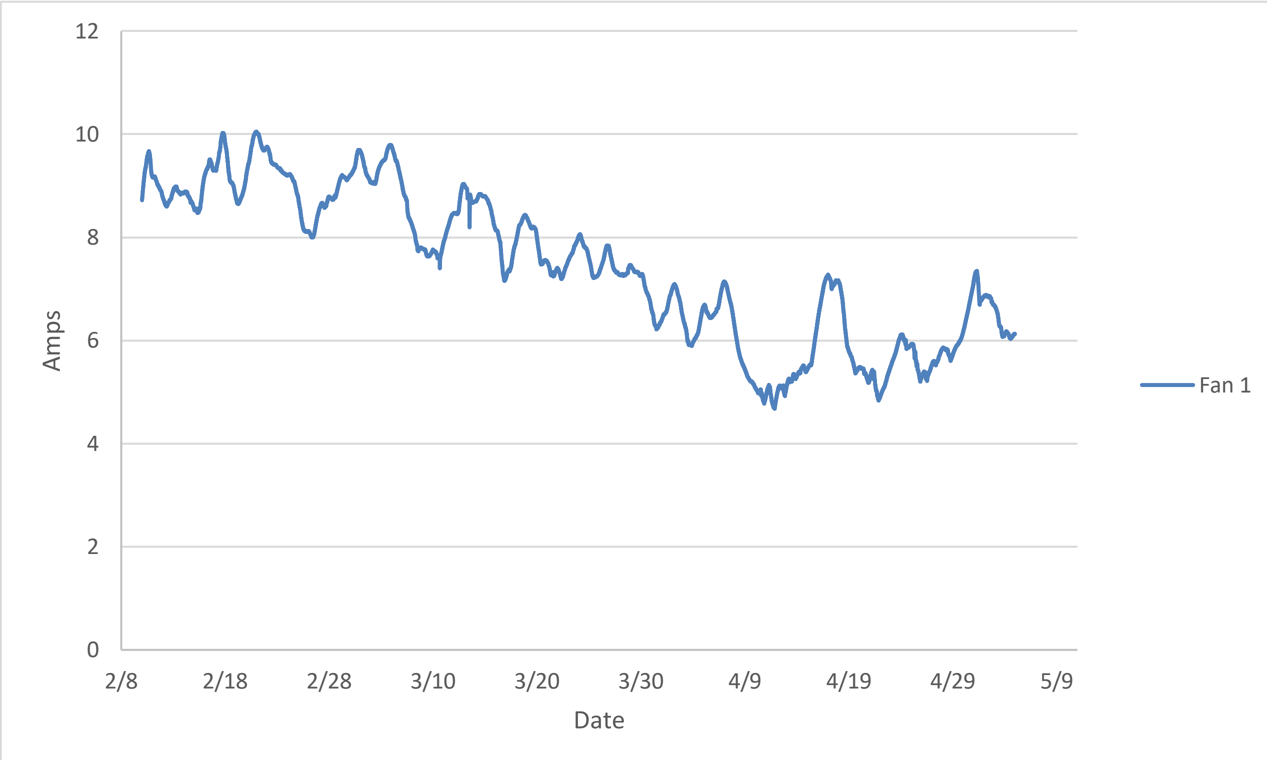


Figure 2-6. Fan 3 logged amperage data vs. OAT

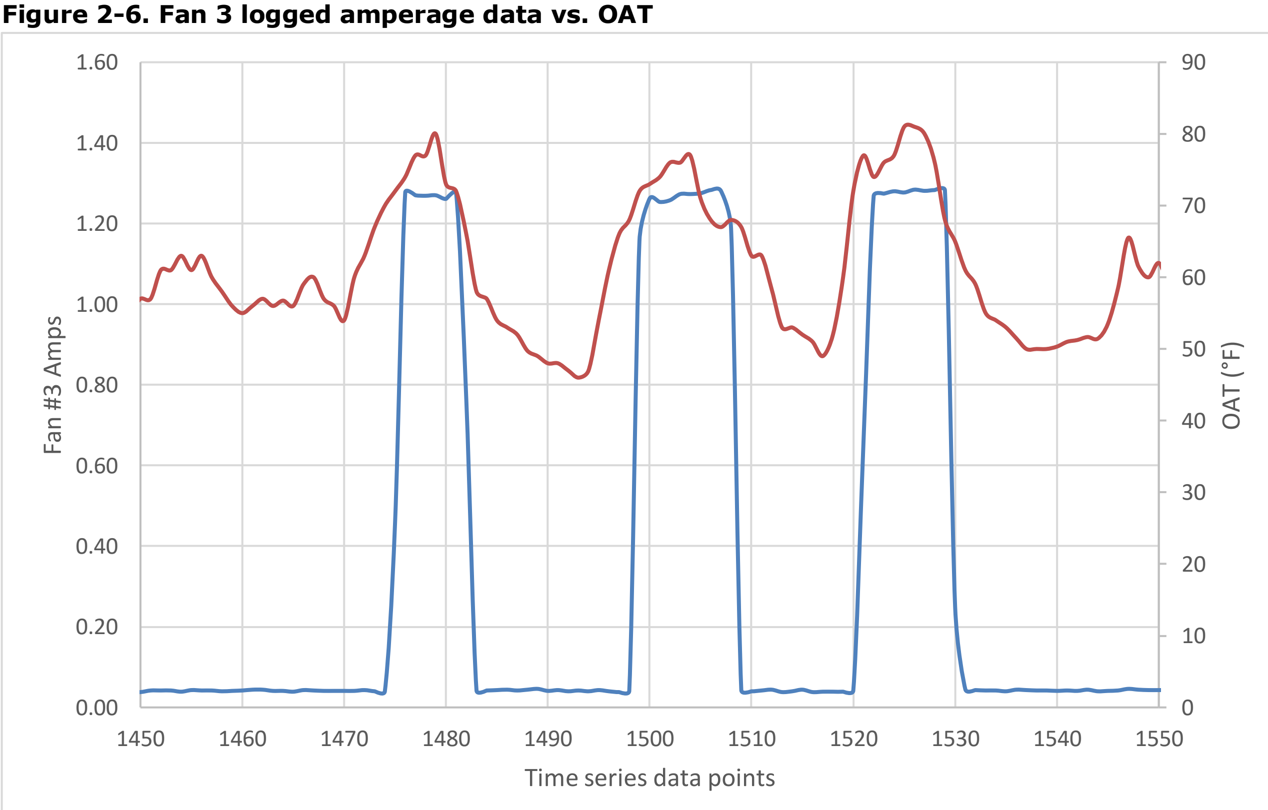
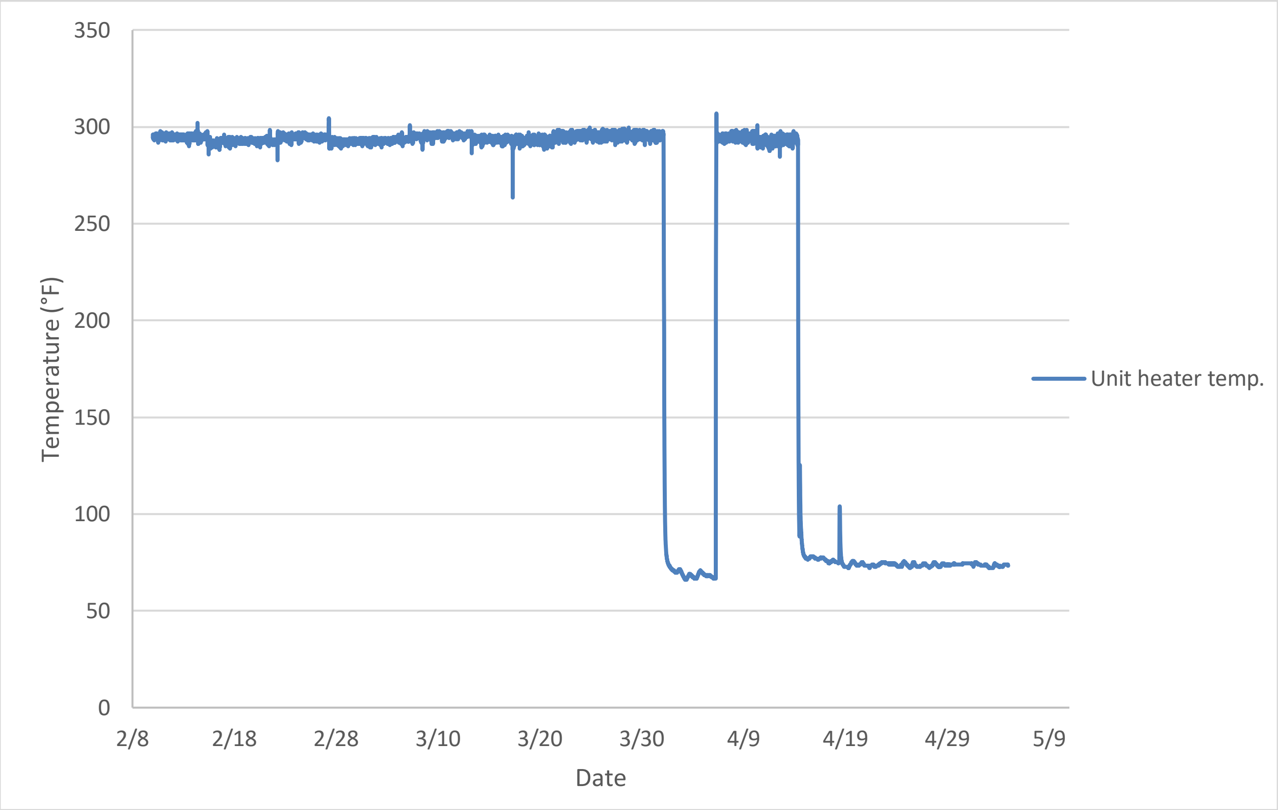


Figure 2-7. Unit heater operating temperature



2.4 Evaluation Methods and Findings

This section describes the evaluator methods and findings.

2.4.1 Evaluation Description of Baseline

The evaluator reviewed the project files and interviewed the site contact to gather information on the baseline. The baseline is the pre-existing conditions. For EEM1, the baseline is four exhaust fans running continuously throughout the year. For EEM2, the baseline is eight unit heaters energized with steam continuously throughout the year. Evaluators classified both measures as add-ons with the pre-existing conditions as the single baseline for each measure.

2.4.2 Evaluation Calculation Method

The evaluators calculated measure savings for EEM1 and EEM2 using an 8,760 spreadsheet-based analysis.

2.4.2.1 EEM1- EMS Fan Controls

For EEM1, evaluators used metered fan amperage data to determine operation and the savings associated with the EMS fan controls. Based on metered data and illustrated in Figure 2-5, evaluators determined that fan #1 is always operational. Evaluators also confirmed through metered data that fan #3 turns on when the outside air temperature reaches 70°F as illustrated in Figure 2-6. These observations are aligned with the fan control sequence detailed by the applicant (>80 °F-4 Fans; >70 °F-3 Fans; >50 °F-2 Fans; <50 °F-1 fan). Evaluators calculated savings using the following algorithms:

$$\Delta Svgs = \sum \frac{\dot{m}_{air} \times c_{p_{air}} \times \Delta T \times Hours}{100{,}000 \times Eff_{burner}}$$

where,

$\Delta Svgs$	= Annual energy savings per year (therms)
$\dot{m}_{air}$	= Mass flow of air (lbs/h)
$c_{p_{air}}$	= Specific heat of air (0.240 BTU/lb-°F)
ΔT	= Difference in OAT and heating setpoint (68 °F baseline, 64 °F as-built)
$Hours$	= Annual hours in each bin
$100{,}000$	= BTU to Therm conversion rate
Eff_{burner}	= Boiler burner efficiency (80%)

$$\dot{m}_{air} = \text{Quantity} \times \rho_{air} \times cfm_{rated} \times 60$$

where,

$\dot{m}_{air}$	= Mass flow of air (lbs/h)
$Quanitity$	= Quantity of fans operating (based on control sequence and OAT)
ρ_{air}	= Density of air (lb/ft^3)
cfm_{rated}	= Flow of air (10,000 cfm per fan)
60	= Minute to hour conversion rate

During the metering period, evaluators observed OAT values up to 81 °F. Using an 8760 format with Providence TMY3 data, evaluators determined the quantity of exhaust fans operating according to the OAT-based control sequence. The number of fans in operation, according to OAT were used to calculate the corresponding mass flow and gas savings in the equations above. Figure 2-8 is an example screenshot from the evaluator analysis that shows fan #2 activating as OAT crosses the 50 °F threshold, resulting in an increase in the lb/min of air mass flow.

Figure 2-8. As-built mass flow of air analysis

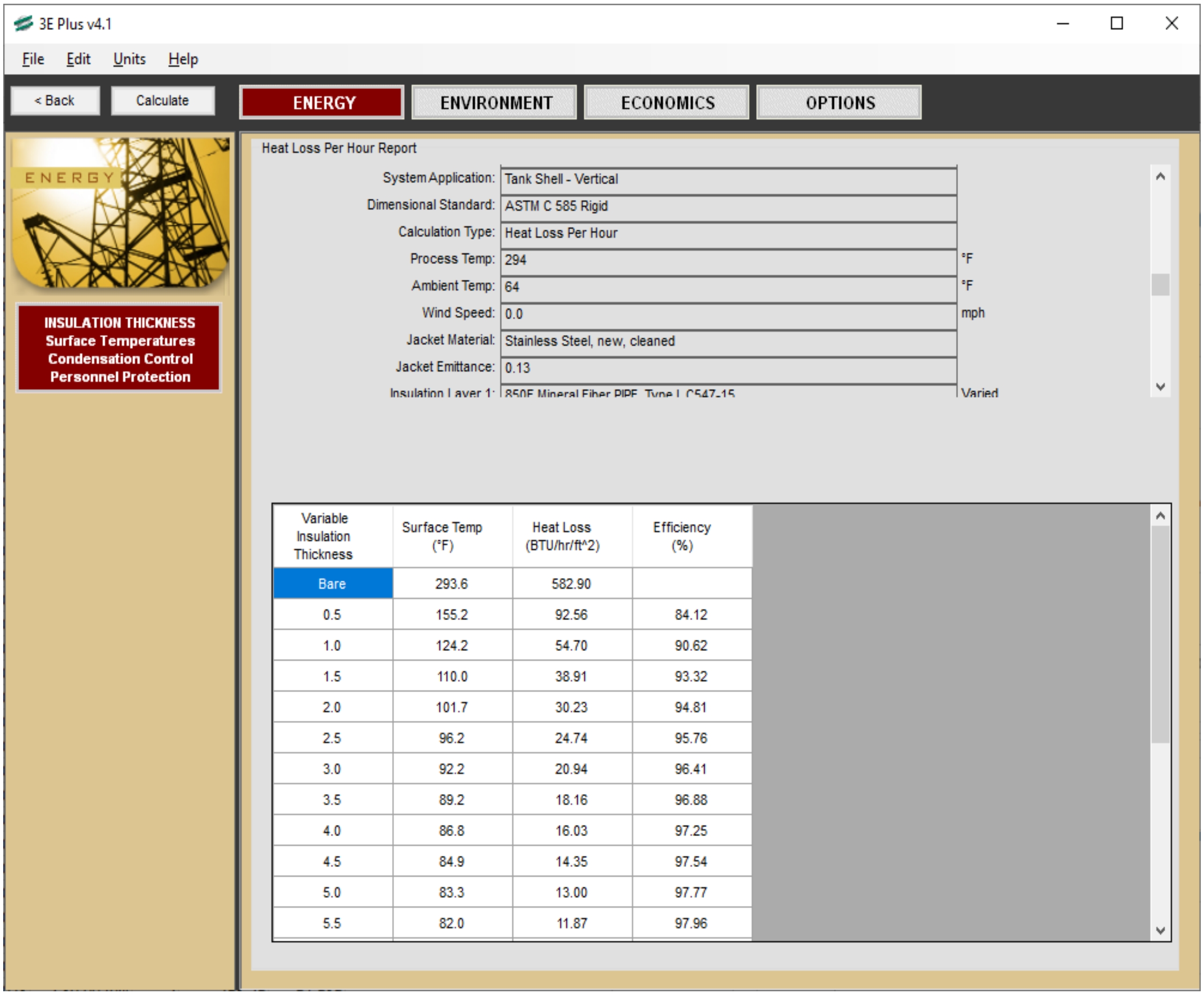
Date	Hour	TMY3 Temp (F)	Number of fans operating	Density of air (lb/ft3)	As-built lb/min
3/2/2021	17	56	2	0.0770	1539
3/2/2021	18	55	2	0.0771	1542
3/2/2021	19	54	2	0.0773	1545
3/2/2021	20	52	2	0.0776	1551
3/2/2021	21	51	2	0.0777	1554
3/2/2021	22	50	2	0.0779	1557
3/2/2021	23	50	2	0.0779	1557
3/3/2021	0	50	2	0.0779	1557
3/3/2021	1	49	1	0.0780	780
3/3/2021	2	47	1	0.0783	783
3/3/2021	3	45	1	0.0786	786
3/3/2021	4	44	1	0.0788	788
3/3/2021	5	43	1	0.0790	790
3/3/2021	6	42	1	0.0791	791
3/3/2021	7	46	1	0.0785	785
3/3/2021	8	48	1	0.0782	782
3/3/2021	9	50	2	0.0779	1557
3/3/2021	10	52	2	0.0776	1551
3/3/2021	11	55	2	0.0771	1542
3/3/2021	12	55	2	0.0771	1542
3/3/2021	13	56	2	0.0770	1539
3/3/2021	14	55	2	0.0771	1542
3/3/2021	15	53	2	0.0774	1548
3/3/2021	16	51	2	0.0777	1554
3/3/2021	17	50	2	0.0779	1557
3/3/2021	18	48	1	0.0782	782
3/3/2021	19	46	1	0.0785	785
3/3/2021	20	44	1	0.0788	788

EEM2- Process Controls

For EEM2, evaluators used metered temperature data to determine the savings associated with the process controls. Based on metered data, evaluators confirmed that the hot steam supply to the unit heaters is valved off in April as the site contact described during the initial interview. Based on this confirmation, evaluators calculated the unit heater savings according to the unit heaters being valved off in April and valved on in October as described by the site contact, resulting in the unit heaters being energized 4,368 hours annually.

Evaluators calculated the heat transfer rate from the unit heaters using 3EPlus according to the recorded temperature data. Evaluators modelled the unit heaters as vertical stainless steel tank shells with an internal process temperature of 294 °F and an ambient temperature of 64 °F. According to the results of the 3EPlus simulation, evaluators estimate that while energized, each unit heater loses heat at a rate of 582.90 BTU/h/ft^2. Figure 2-9 shows a screenshot from the 3EPlus unit heater simulation.

Figure 2-9. 3EPlus simulation of unit heater



Using this calculated heat loss rate from 3EPlus, evaluators calculated savings using an 8,760 spreadsheet-based approach using the following algorithm:

$$Savings = \frac{SA_{UH}}{100{,}000 \times Eff_{burner}} \times \sum_{1}^{8760} (HLR_{\,baseline} - HLR_{\,as-built})$$

where,

$Savings$	= Annual energy savings per year (therms)
SA_{UH}	= Surface area of all eight unit heaters, (3.2 ft x 3.2 ft x 1 ft) x 8 unit heaters (ft^2)
$HLR_{baseline}$	= Baseline heat loss rate of unit heater (BTU/h/ft^2) calculated using 3EPlus
$HLR_{as-built}$	= As-built heat loss rate of unit heater (BTU/h/ft^2) calculated using 3EPlus
$100{,}000$	= BTU to therm conversion rate
Eff_{burner}	= Boiler burner efficiency (80%)

3 FINAL RESULTS

This project consisted of two measures: EMS exhaust fan controls for four exhaust fans and process controls for eight unit heaters. The applicant used a custom spreadsheet-based analysis to calculate the project savings. The evaluators used an 8,760 spreadsheet-based analysis to calculate savings, utilizing metered data. The evaluated savings are more than the reported savings. Table 3-1 summarizes the key tracking and evaluated parameters.

Table 3-1. Summary of key parameters

	BASELINE		PROPOSED / INSTALLED	
Parameter	Tracking Value(s)	Evaluation Value(s)	Tracking Value(s)	Evaluation Value(s)
EEM1: Hours of operation of only 1 fan	0	0	4,189	4,185
EEM1: Hours of operation of only 2 fans	0	0	3,122	2,959
EEM1: Hours of operation of only 3 fans	0	0	1,031	1,198
EEM1: Hours of operation of all 4 fans	8,760	8,760	418	418
EEM1: Airflow per fan (cfm)	10,000	10,000	10,000	10,000
EEM1: Heating setpoint (°F)	68	68	67	64
EEM1: Heating system balance point (°F)	50	50	50	50
EEM2: Annual hours of operation of unit heaters	8,760	8,760	5,568	4,368
EEM2: Demand reduction achieved by controls (BTU/h)	0	0	232,185	158,338
EEM2: Boiler burner efficiency	80%	80%	80%	80%

3.1 Explanation of Differences

This section describes the key drivers behind any difference in the application and evaluation estimates of therm savings. Table 3-2 provides a summary of the differences between tracking and evaluated values.

Table 3-2. Summary of deviations

End-use	Discrepancy	Parameter	Impact of Deviation	Discussion of Deviations
Space heating	Operational	EEM1: As-built heating setpoint	+4%	Small increase in savings – lower as-built heating setpoint results in more savings.
Space heating	Operational	EEM2: Heat flux of unit heaters	-6%	Decrease in savings – the heat flux of the unit heaters calculated by evaluators based on metered data was less than the value used by the applicant.
Space heating	Operational	EEM2: Unit heater operation hours	+8%	Increase in savings - the unit heater operational hours observed by evaluators based on metered data were less than the operational hours value used by the applicant.
		Total	+6%	

3.2 Lifetime Savings

Both measures installed were deemed by evaluators to be add-on measures with single baselines. Evaluators calculated applicant and evaluated lifetime savings values using the following formula:

$$LAGI = FYS \times EUL$$

where,

$LAGI =$	lifetime adjusted gross impact (therm)
$FYS =$	first year savings (kWh)
$EUL =$	measure life (years)

The evaluated lifetime savings are greater than the tracking lifetime savings because the evaluated first year savings are greater than the tracking first year savings. Table 3-3 provides a summary of the savings values for EEM1, the EMS fan control measure. Table 3-4 provides a summary of the savings values for EEM2, the process controls measure. Table 3-5 provides a summary of the savings value for the whole project.

Table 3-3. Measure 11246974- lifetime savings summary

Factor	Tracking	Application	Evaluator
Lifetime savings	612,840 therms	612,840 therms	637,930 therms
First year savings	61,284 therms	61,284 therms	63,793 therms
Measure lifetime	10 years	10 years	10 years
Baseline classification	Retrofit	Retrofit	Add-on

Table 3-4. Measure 11246977- lifetime savings summary

Factor	Tracking	Application	Evaluator
Lifetime savings	74,110 therms	74,110 therms	86,930 therms
First year savings	7,411 therms	7,411 therms	8,693 therms
Measure lifetime	10 years	10 years	10 years
Baseline classification	Retrofit	Retrofit	Add-on

Table 3-5. Project lifetime savings summary

Factor	Tracking	Application	Evaluator
Lifetime savings	686,950 therms	686,950 therms	724,860 therms
First year savings	68,695 therms	68,695 therms	72,486 therms
Measure lifetime	10 years	10 years	10 years
Baseline classification	Retrofit	Retrofit	Add-on

3.2.1 Ancillary Impacts

This section explains the ancillary impacts associated with the electric savings. The reduction in the run time of the exhaust fans results in reduced fan electricity usage. The original tracking analysis calculated annual electric savings of 18,483 kWh. Evaluators calculated the annual electric savings due to the reduction in fan run times to be 18,294 kWh. The evaluated electric savings are slightly less than what was reported.

RI CUSTOM GAS EVALUATION SITE SPECIFIC MEASUREMENT AND VERIFICATION REPORT

Site ID: RIG21N080

Report Date: 6/07/2023

Program Administrator	Rhode Island Energy	
Application ID(s)	11529748, 12785274	
Project Type	Base and Add-On #3	
Program Year	2021	
Evaluation Firm	DMI	
Evaluation Engineer	Brian Paonessa	
Senior Engineer	Mickey Bush	

1 EVALUATED SITE SUMMARY AND RESULTS

The evaluated retrofit project was installed at a thermoplastics manufacturing site with industrial process spaces. Application 11529748 installed thermal insulation jackets on 1,608 ft of steam pipes and 145 ft^2 of equipment, while Application 12785274 installed thermal insulation jackets on 324 ft^2 of hot oil tanks and associated steam and condensate equipment. The piping and equipment associated with application 11529748 is located in open manufacturing space.

The site is comprised of 12 different buildings, of which 4 are included in the scope of this evaluation. The site uses steam boilers to generate 115 psig steam for process applications. The steam is reduced to 60 psig for space heating and to ~3.5 psig for operation with a hot water heat exchanger. Hot oil is also used for certain manufacturing processes. The scope of both applications includes process and space heating steam, associated condensate lines, low pressure steam lines, and hot oil tanks. The majority of the site is heated to maintain a space temperature setpoint in the winter; however, Application 12785274 is wholly located in a rooftop mezzanine equipment room that is unconditioned. Piping and equipment in spaces that are controlled to a heating setpoint yield limited savings for insulation measures due to the increased uninsulated heat loss being used to meet the space setpoint.

The evaluation approach is Base + Add-On #3 (on-site M&V) because COVID did not have a large impact on the industrial processes and the site was able to accommodate a in-person visit. The site indicated that during the pandemic the company worked in reduced personnel shifts, but that production continued and is now back to full output.

Each application contains a single measure type. The applicant classified both measures as a retrofit with single baseline. Based on the information gathered during the site visit, the evaluator classified the measures as add-ons with a single baseline. The measure has a single baseline because the measure life of the installed insulation (15 years) is less than 2/3 of the life of the steam distribution system.

The evaluator identified deviations in methodology, run-hours, boiler efficiency, ambient temperatures, and process temperatures that resulted in a decrease in savings compared to the tracking estimate. The evaluation results are presented in Table 1-1.

Table 1-1. Evaluation Results Summary

PA Application ID	Measure Name		Annual Savings (therms)
11529748	Steam Piping and Equipment Insulation	Tracked	18,453
		Evaluated	14,189
		Realization Rate	76.9%
12785274	Hot Oil and Steam Equipment Insulation	Tracked	10,012
		Evaluated	3,628
		Realization Rate	36.2%
Total	-	Tracked	28,465
		Evaluated	17,816
		Realization Rate	62.6%

1.1 Explanation of Deviations from Tracking

The evaluated savings are 62.6% of the combined applicant-reported savings. The savings were decreased primarily due to a decrease in savings hours on Application 11529748 and a process temperature adjustment on Application 12785274. On Application 11529748, the evaluators only considered savings hours when the spaces containing the piping and equipment was not conditioned. On Application 12785274, the evaluators determined a portion of the insulated equipment was carrying condensate, and adjusted surface temperatures based on metered data.

Adjustments to the methodology, as well as the ambient and process temperatures furthered lowered the savings on Application 11529748, while an adjustment to the boiler efficiency partially offset some of the savings decreases. Savings on Application 12785274 were further decreased as a result of an adjustment to the run hours and a methodology change, while an adjustment to the ambient temperature partially offset losses.

1.2 Recommendations for Program Designers & Implementers

There are no recommendations at this time.

1.3 Customer Alert

There is no relevant customer alert.

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 insulation on thermal piping and equipment, shown below in Table 2-1.

Table 2-1. Application Scope Summary

PA Application ID	Measure Description	Parameter	Value
11529748	Steam Piping and Equipment	Piping (ft)	1,608
		Equipment (ft^2)	145
12785274	Hot Oil and Steam Equipment	Piping (ft)	0
		Equipment (ft^2)	324

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.

2.2 Applicant Description of Baseline

Application 11529748 (Steam Piping and Equipment)

The applicant classified the measure contained in Application 11529748 as a retrofit with a single baseline. The applicant described the baseline as steam piping and equipment with no insulation. The applicant did not explicitly separate the application into piping and other equipment. However, certain line items in the analysis included a calculation for the area in ft^2, generalized as:

$$A = 2 \times \pi \times \frac{D}{2} / 12 \times L$$

where,

D = The diameter of the pipe in inches

L = The length of the pipe in feet

The evaluators extracted the diameter and length from these calculations in order to separate the line items into pipes and equipment.

The applicant indicated that one line item representing 72 ft of piping was at an ambient temperature of 80°F, while the remaining pipes and equipment were at an ambient temperature of 70°F. Process temperatures ranged from 188°F to 308°F, and 24 different process temperatures were used. Table 2-2 presents the main parameters of the baseline for Application 11529748 as defined by the applicant and described above.

Table 2-2. Application 11529748 baseline summary

Operation Description	Value
Average operating hours	4,000
Linear feet of bare piping	1,608
Square feet of steam equipment	145
Range of piping or equipment surface temperatures (°F)	188-308
Range of ambient temperatures (°F)	70-80*
Baseline heat loss (kBTU)	2,004,599
Boiler efficiency	100%

*72 ft of piping is calculated with an 80°F ambient temperature, the remaining is calculated at 70°F.

Application 12785274 (Hot Oil and Steam Equipment)

The measure contained in Application 12785274 is also defined by the applicant as a retrofit with a single baseline. The applicant described the baseline as 11 hot oil tanks supplied with steam with varying levels of existing insulation. The applicant indicated that the oil tanks were held between 240°F and 250°F, while 5 tanks were supplied with 60 psig steam and the remaining 6 tanks were supplied with 115 psig steam. The applicant also indicated that the tanks shut off over the weekend, yielding an annual run time of 6,137 hours.

The applicant indicated that the steam fittings had existing insulation that no longer provided the full benefit. The fittings had an existing coverage ranging from 0% to 80%, while the tanks themselves were uninsulated. The baseline for Application 12785274 is summarized in Table 2-3.

Table 2-3. Application 12785274 baseline summary

Operation Description	Value
Average operating hours	6,137
Square feet of steam equipment	255
Square feet of hot oil tanks	69
Steam equipment surface temperature (°F)	325
Hot oil tank surface temperature (°F)	245
Average existing insulation coverage of steam equipment	25.3%
Baseline heat loss (kBTU)	1,072,873
Boiler efficiency	82%

2.2.1 Applicant Description of Installed Equipment and Operation

The applicant considered the installed case as the baseline heating system with added jacket insulation in both applications.

Application 11529748 (Steam Piping and Equipment)

The jacket and insulation material in Application 11529748 was not indicated by the applicant. The process and ambient temperature, as well as pipe diameter, varied by component. Piping included in this application was indicated to have an insulation thickness of 2”, while other equipment was indicated to have 1.5”.

Application 12785274 (Hot Oil and Steam Equipment)

The applicant indicated that the insulation material was a standard NAIMA fiberglass insulation, 850F Mineral Fiber PIPE, Type I, C547-15. The applicant also used an “All Purpose Jacket” input that has an emittance of 0.90. The installed insulation thickness was indicated to be 1” on the steam equipment and 0.5” on the hot oil tank.

2.2.2 Applicant Energy Savings Algorithm

Application 11529748 (Steam Piping and Equipment)

The applicant used a one-line calculation to find the existing and installed case heat flows, shown below.

$$\text{Heat Loss}\left(\frac{\text{BTU}}{\text{h}}\right) = \text{K} \times \frac{\text{dT}}{\text{L} + \text{K}/\text{H}_t} \times \text{A} \times \text{Qty}$$

where,

K = The thermal conductivity of the pipe or equipment, $\frac{\text{BTU}}{\text{h}\times\text{ft}\times°\text{F}}$

dT = the temperature differential between the ambient and process temperature, °F

L = Insulation thickness, inches

H_T = Combined heat transfer coefficients

A = Surface area of the pipe of equipment, ft²

Qty = Quantity of the pipe or equipment section

The applicant used a value of 26.9 $\frac{BTU}{h \times ft \times °F}$ for the thermal conductivity in the existing case and a value of 0.525 $\frac{BTU}{h \times ft \times °F}$ in the installed case. The evaluators found that steel has a thermal conductivity generally in the range of 26.0-37.5 $\frac{BTU}{h \times ft \times °F}$, however it is not clear what the thermal conductivity value of 0.525 $\frac{BTU}{h \times ft \times °F}$ in the installed case corresponds with. An H_t value of 3.2 was used in both the existing and installed case by the applicant, however the evaluators were unable to determine how this value was calculated or which heat transfer coefficients were included.

After the existing and installed heat flows were calculated, the final savings were calculated with the following equation:

$$\text{Savings (Therms)} = \sum \frac{\text{Bare Heat Loss } \times \text{Operating Hours}}{100{,}000} - \sum \frac{\text{Insulated Heat Loss } \times \text{Operating Hours}}{100{,}000}$$

Where,

Operating Hours = Hours the pipes or equipment are energized. Applicant used 4,000 in all cases.

Bare Heat Loss = The heat loss of the bare piping and equipment in the existing case, in BTU/h

Insulated Heat Loss = The heat loss of the insulated piping and equipment in the installed case, in BTU/h

100,000 = Conversion factor from btu to therms

Application 12785274 (Hot Oil and Steam Equipment)

The applicant used one-line calculations to find the existing and installed heat flows. The applicant used 3E Plus to determine the heat flow of each tank of equipment section. The 3E Plus inputs used by the applicant are summarized below in Table 2-4.

Table 2-4. Application 12785274 3E Plus inputs

Operation Description	Value
System Application	Tank Shell - Horizontal
Calculation Type	Heat Loss Per Hour
Base Metal	Steel
Insulation Material	850F Mineral Fiber PIPE, Type I, C547-15
Insulation Thickness (Inches)	Varies
Jacket Material	All Service Jacket (0.9 Emittance)
Ambient Temperature (°F)	Varies
Process Temperature (°F)	Varies
Wind Speed (mph)	0

The heat loss in the existing case was calculated for both the bare sections and the sections with existing insulation. The applicant used an insulation thickness of 0.5" for the existing insulation. The heat flow, in BTU, for the bare, existing insulation, and installed insulation cases were determined using the following formulas:

$$\text{Bare Heat Flow (BTU)} = \frac{(1 - \text{IC}) \times (\text{Qty} \times \text{A} \times \text{Hours} \times \text{Bare Heat Flow})}{\text{Boiler Efficiency}}$$

$$\text{Existing Insulated Heat Flow (BTU)} = \frac{\text{IC} \times (\text{Qty} \times \text{A} \times \text{Hours} \times \text{Existing Insulated Heat Flow})}{\text{Boiler Efficiency}}$$

$$\text{Installed Heat Flow (BTU)} = \frac{(1 - \text{IC}) \times (\text{Qty} \times \text{A} \times \text{Hours} \times \text{Installed Heat Flow})}{\text{Boiler Efficiency}}$$

Where,

IC = The existing insulation coverage, ranging from 0-80% on each line. It is not clear why the applicant included this value in the installed heat flow equation.

Qty = The quantity of identical tanks or equipment, 11 in all cases

A = The area of the equipment in ft^2

Boiler Efficiency = The efficiency of the steam boiler, 82% in all cases

With the separate heat flows determined, the final savings were calculated as:

$$\text{Savings (Therms)} = (\text{Bare Heat Loss} + \text{Existing Insulated Heat Flow}) - \text{Installed Heat Flow}$$

2.2.3 Evaluation Assessment of Applicant Methodology

The evaluator disagrees with the methodology used by the applicant in Application 11529748, since 3E Plus is the currently accepted standard methodology for pipe and equipment heat transfer calculations. Additionally, the applicant did not account for boiler efficiency in this application.

The evaluator generally agrees with the applicant's use of 3E Plus in Application 12785274, but disagrees with the inclusion of the insulation coverage term in the installed case heat flow formula. In both applications, the applicant additionally did not consider the effects of outside air temperature on the ambient temperature.

2.3 On-Site Inspection and Metering

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

2.3.1 Summary of On-site Findings

The evaluators conducted a site-visit on February 2, 2023. During the site visit, the evaluators interviewed the site contact and verified the insulation on the piping and equipment. A summary of the on-site verification is provided in Table 2-5.

Table 2-5. Measure verification

Measure Name	Verification Method	Verification Result
1129748 – Steam Piping and Equipment	On-site visual inspection	Both insulation type and thickness matched project description
12785274 – Hot Oil and Steam Equipment	On-site visual inspection	Both insulation type and thickness matched project description

2.3.2 Measured and Logged Data

The evaluators determined from interviewing the site contact that throughout the main factory (Application 1129748), steam was either low pressure to serve a hot water heat exchanger, 60 psig for space heating, or 115 psig for process purposes. The evaluators also determined that Application 12785274 was comprised of the hot oil tank itself as well as a steam line and condensate line for each tank. The evaluators therefore opted to meter one of each pressure and corresponding temperature that was present in the facility. The different equipment and pipe sections were metered underneath the insulation to determine the surface temperature. Ambient temperatures were also metered for representative spaces. The process and ambient temperatures were metered for approximately two months, from 2/23/2023 through 4/22/2023. The full metering parameters are shown in Table 2-6.

Table 2-6. Data logger deployment details

Application Number	Data Logger Type	Parameter	Time Interval	Duration	Installed Logger Quantity
1129748	HOBO UX100-014M thermocouple	Input to condensate tank	15 minutes	8 weeks	1
	HOBO UX100-014M thermocouple	Low pressure steam leading to HW heat exchanger	15 minutes	8 weeks	1
	HOBO UX100-014M thermocouple	115 psig process steam	15 minutes	8 weeks	1
	HOBO UX100-014M thermocouple	60 psig heating steam	15 minutes	8 weeks	1
	HOBO U12 Temperature/RH with 2 external channels	HW heat exchanger room ambient temperature	15 minutes	8 weeks	1
	HOBO U12 Temperature/RH with 2 external channels	Typical factory ambient temperature	15 minutes	8 weeks	1
12785274	HOBO UX120-014M thermocouple	Hot oil tank, steam line, and condensate line	15 minutes	8 weeks	1 (3 inputs)
	HOBO UX100-014M thermocouple	Additional hot oil tank steam line	15 minutes	8 weeks	1
	HOBO U12 Temperature/RH with 2 external channels	Hot oil tank room ambient temperature	15 minutes	8 weeks	1

A spot temperature reading on the majority of the metered pieces of piping/equipment was also taken at the time of the site visit and meter pickups using a FLIR thermal imaging camera. These results were used to confirm the accuracy of the metered data, but were not separately recorded.

Application 1129748 (Steam Piping and Equipment)

It was found that the majority of the equipment operated on a schedule such that the temperatures were periodically setback on some weekends. Table 2-7 summarizes the results of the metered data.

Table 2-7. 1129748 Metered data results

Equipment Section	Weekday Temperature (°F)	Weekend Temperature (°F)
Condensate	210.9	175.6
Low Pressure Steam	212.7	171.7
Heating Steam	249.0	196.1
Process Steam	331.5	249.6
Ambient Temperature – HW HX Room*	84.0	84.0
Ambient Temperature – Main Factory Floor**	72.9	72.9

* Ambient temperature varies with outside air temperature

** Ambient temperature varies with outside air temperature above 55°F

Plots of the process temperatures over time for the aforementioned equipment sections, as well as the ambient temperature, are shown below.

Figure 2-1. Condensate temperature over time

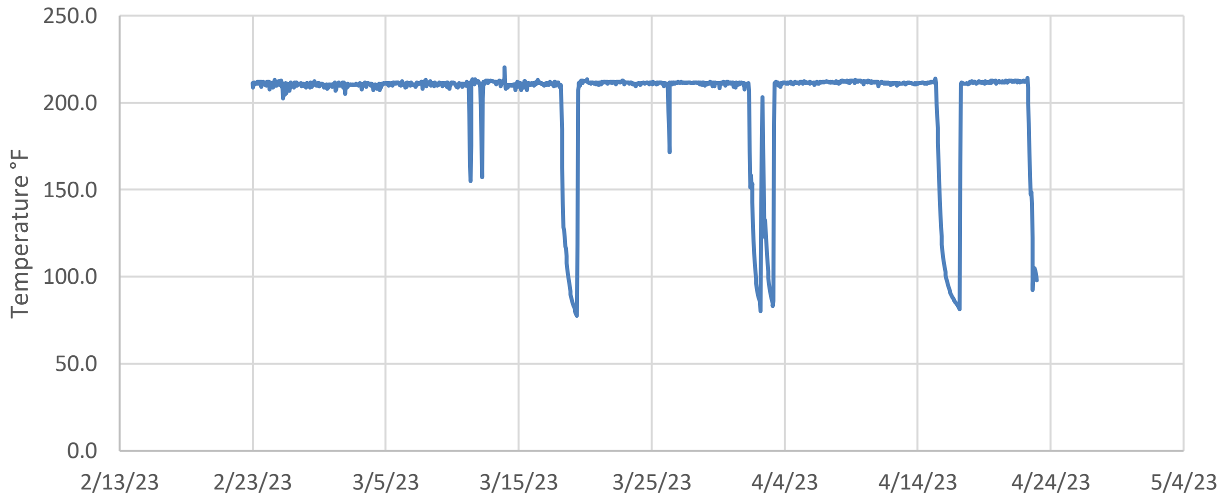


Figure 2-2. Low pressure steam temperature over time

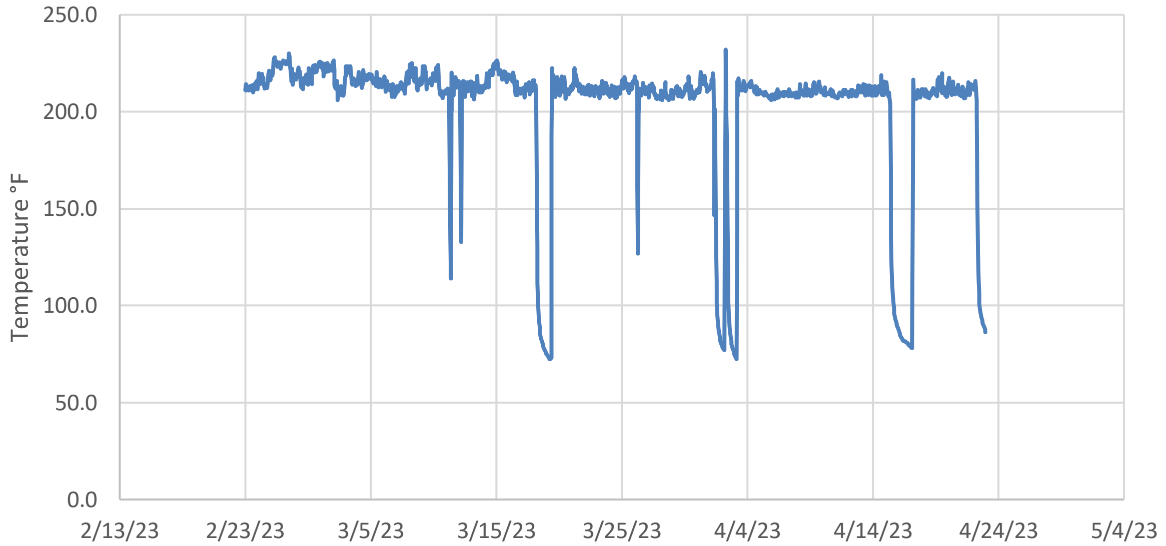


Figure 2-3. Heating steam temperature over time

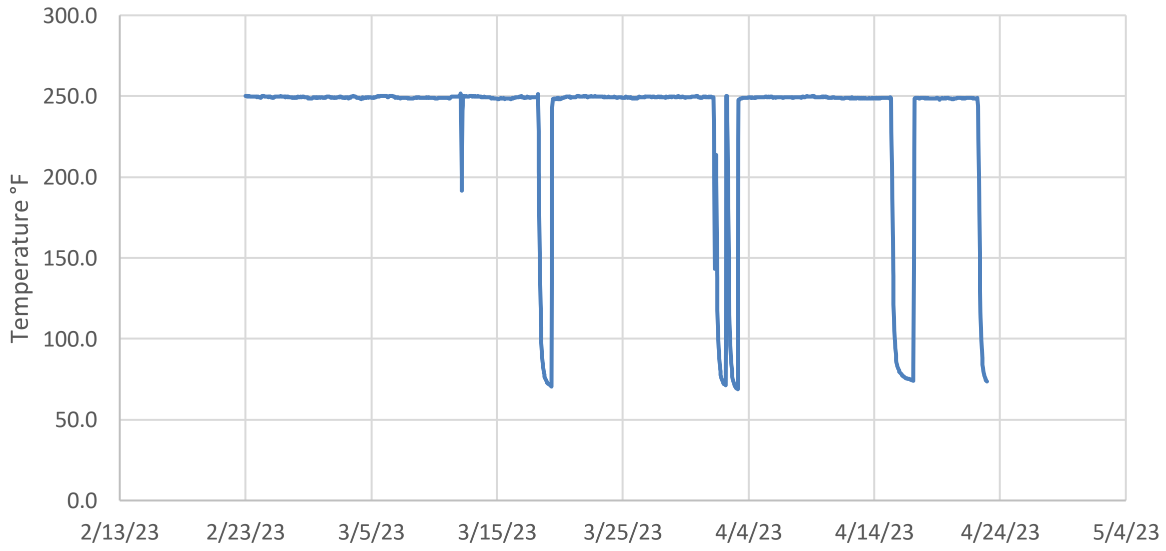


Figure 2-4. Process steam temperature over time

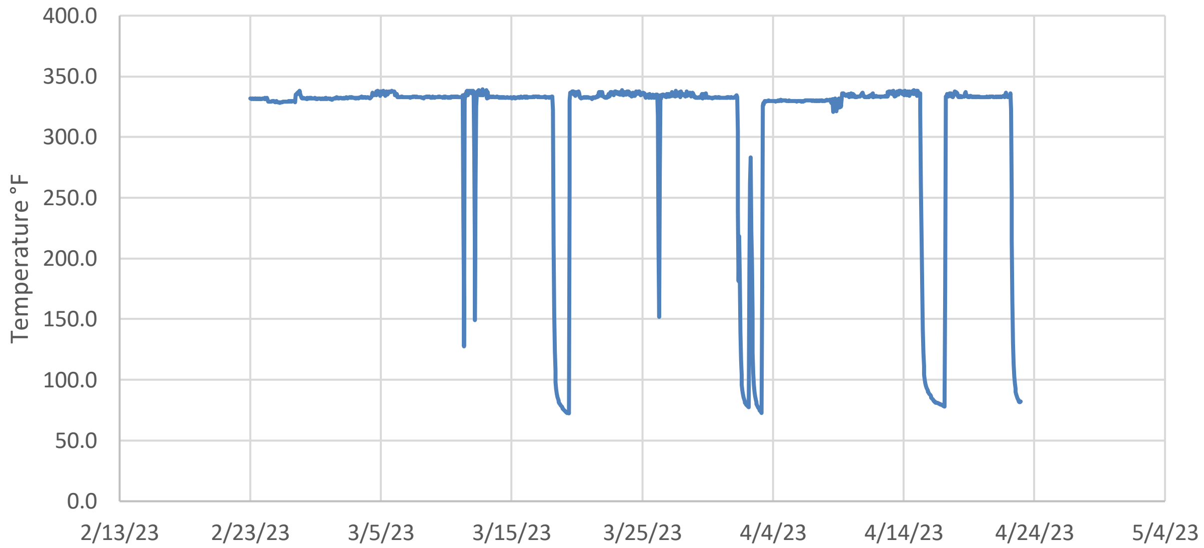
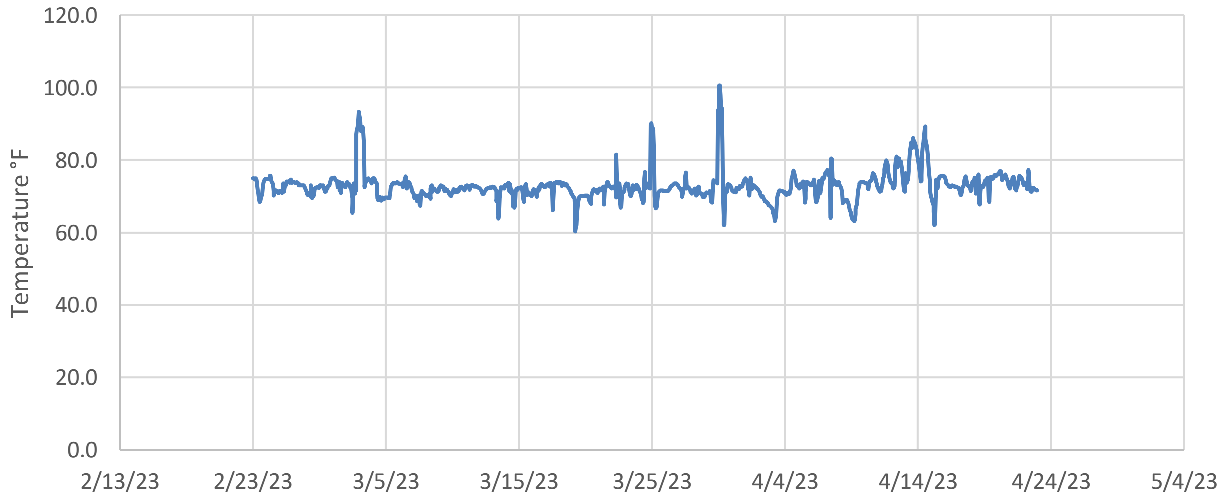


Figure 2-5. HW Heat exchanger room ambient temperature over time

Figure 2-6. Main factory floor ambient temperature over time



Application 12785274 (Hot Oil and Steam Equipment)

The evaluators determined that the steam and condensate lines serving the hot oil tanks followed a similar pattern to the temperatures recorded in Application 1129748 wherein the temperature drops over the weekends. The data is summarized in Table 2-8.

Table 2-8. 12785274 metered data results

Equipment Section	Weekday Temperature (°F)	Weekend Temperature (°F)
Condensate	145.8	113.4
Steam 1	214.7	171.4
Steam 2	218.5	156.8
Hot Oil Tank	128.8	101.0
Ambient Temperature*	76.5	76.5

*Ambient temperature varies with outside air temperature

Plots of the process temperatures over time for the aforementioned equipment sections, as well as the ambient temperature, are shown below.

Figure 2-7. Condensate temperature over time

Figure 2-8. Steam line 1 temperature over time

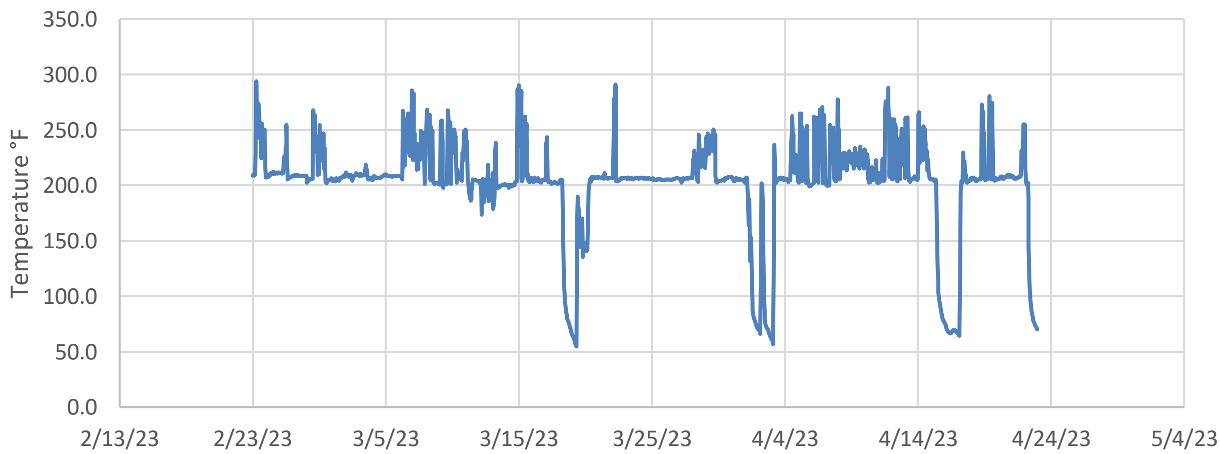


Figure 2-9. Steam line 2 temperature over time

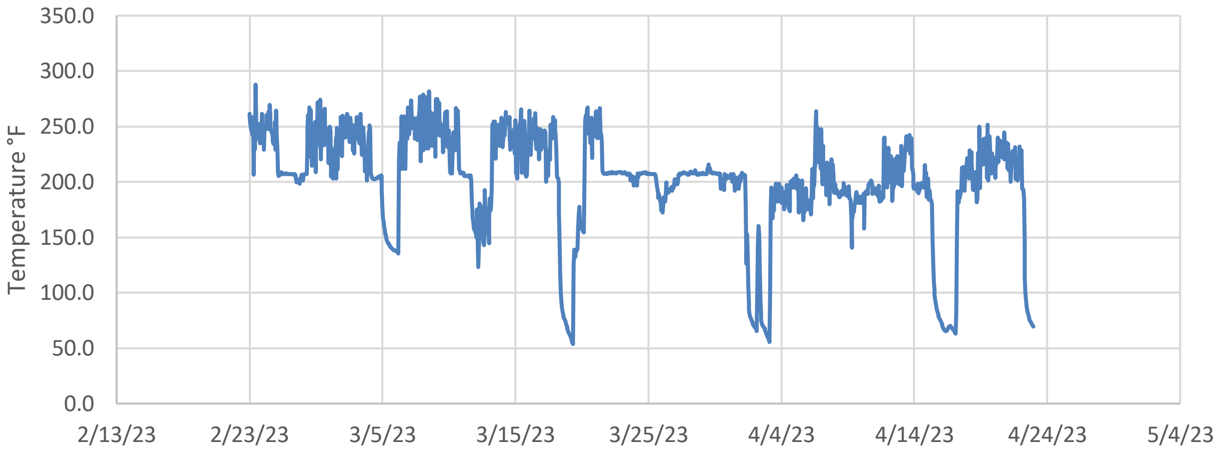


Figure 2-10. Hot oil tank temperature over time

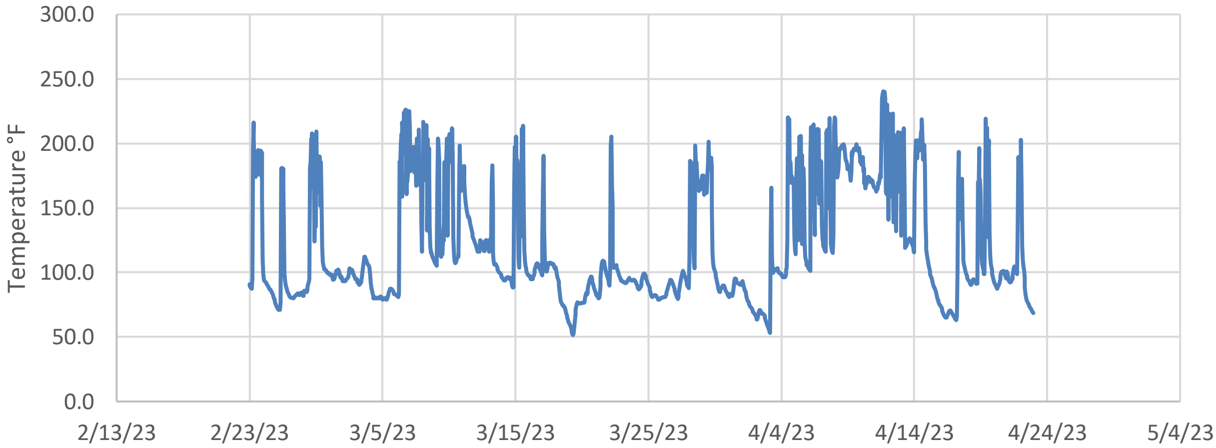
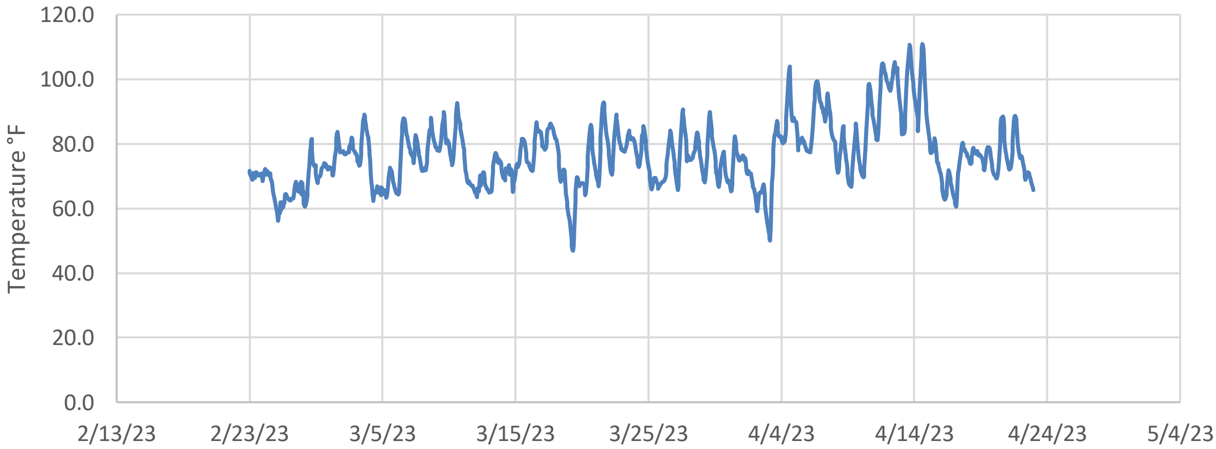


Figure 2-11. Ambient temperature over time



2.4 Evaluation Methods and Findings

This section describes the evaluator methods and findings.

2.4.1 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 insulation measures to be an add-on with a single baseline as the installed measure life is less than 2/3 of the life of the underlying steam distribution system. The evaluator determined that the baseline of bare piping and equipment was reasonable based on conversations with the site contact for Application 11529748.

In Application 12785274, the applicant indicated that the tanks and steam and condensate lines had varying amounts of prior insulation. However, the insulation that was used at the time was unsuitable for the situation, and led to the insulation becoming oil-soaked and broken down. The evaluators consider this situation as having 0.25" of effective insulation, per a research paper that studied the impact of moisture accumulation on chilled water pipe insulation[1]. This research paper, which has been previously vetted by the baseline advisory group in Massachusetts, indicates that heat loss increased by about 3 times when the insulation was wet, which corresponds to the difference in heat loss between a 0.25" insulation baseline and the proposed insulation at around 1".

The applicant provided a number of photos of the pre-existing insulation at the site. Figure 2-12 shows a photo of the steam or condensate line insulation. However, these photos were not all-encompassing, and the evaluators were unable to determine exactly which components had prior insulation and what percent of insulation coverage those components had. Therefore, the evaluators opted to defer to the applicant's analysis for determining the existing insulation coverage.

Figure 2-12. Steam or condensate line existing insulation

[1] Cai, S., Cremaschi, L. and Ghajar, A., 2021. *Moisture Accumulation and Its Impact on the Thermal Performance of Pipe Insulation for Chilled Water Pipes in High Performance Buildings*. Purdue University.

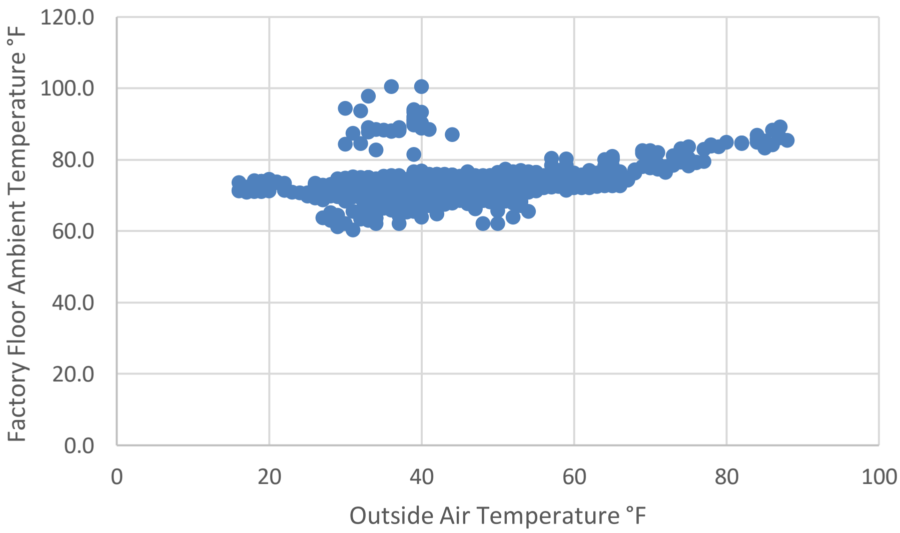
2.4.2 Evaluation Calculation Method

The evaluator used 3E Plus to find the heat loss for different pipe and equipment sections in both the baseline and proposed case. The parameters of the 3E Plus runs are based on the metered data and information acquired on the site visit. A deemed boiler efficiency of 82% was used based on the MA21CO2 "Steam Traps and Boiler Efficiency Research – Phase II" report.

Application 11529748 (Steam Piping and Equipment)

The ambient temperature in Figure 2-6 is representative of the main factory floor and includes 100% of the piping length and ~85% of the equipment surface area. Figure 2-13 shows the ambient temperature plotted against the outdoor dry bulb temperature.

Figure 2-13. Factory floor ambient vs outdoor air temperature



Hours

The site contact indicated that the factory is heated in the winter. When the spaces are controlled to a heating setpoint, any heat lost to the space from uninsulated pipes or equipment would contribute to meeting that setpoint. Therefore, insulating pipes and equipment does not represent a savings opportunity during hours where space heating is active, because the load on the boiler is the same in either case. The contact also described that heating would primarily operate on the weekends because there are less space loads as a result of a reduction in manufacturing equipment use. Figure 2-14 and Figure 2-15 show the ambient factory floor temperature on weekdays vs weekends.

Figure 2-14. Ambient factory floor weekday temperature

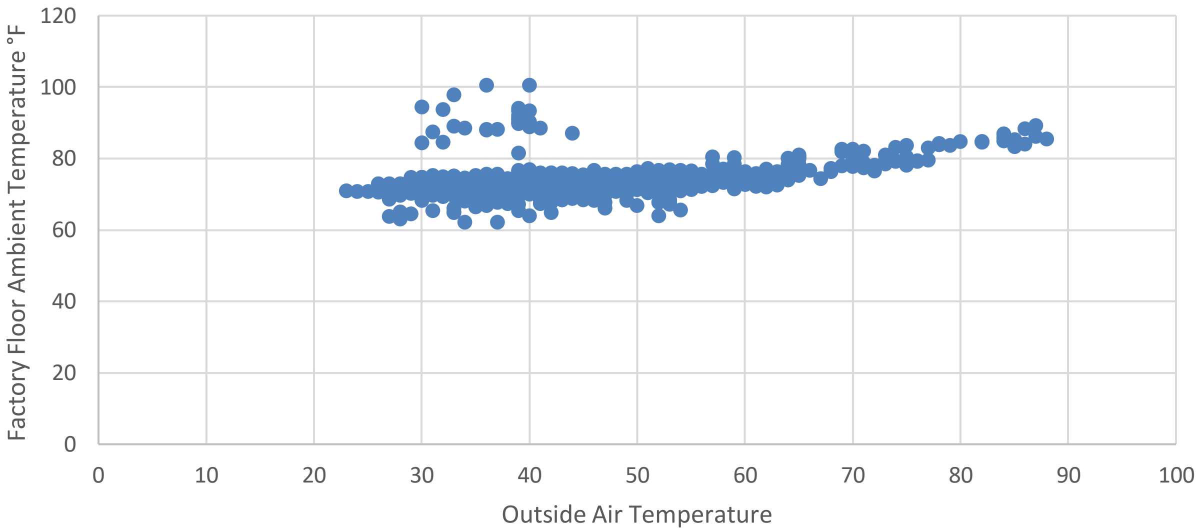
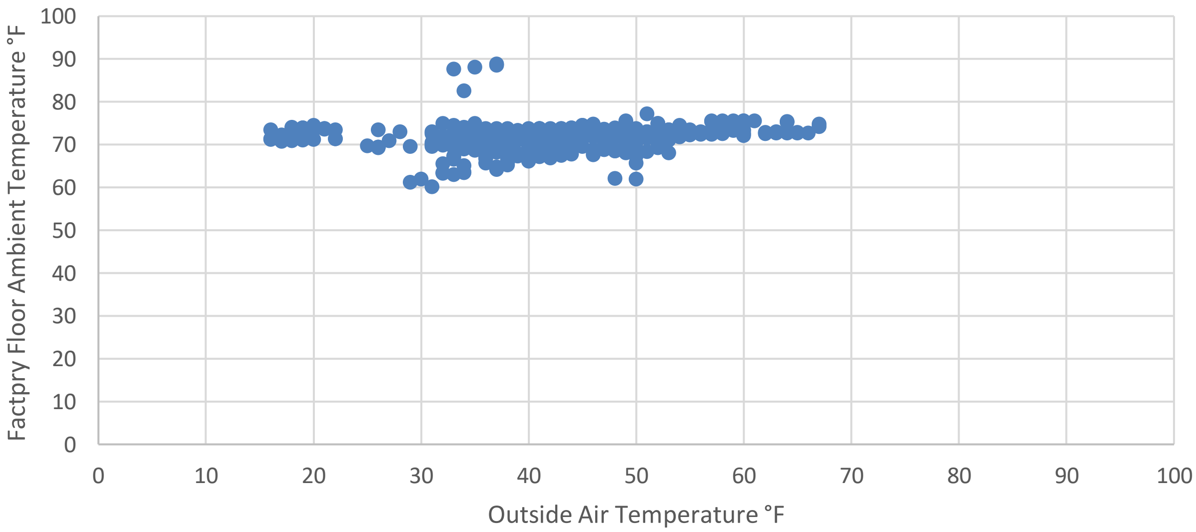


Figure 2-15. Ambient factory floor weekend temperature



The evaluators determined based on Figure 2-14 and Figure 2-15 as well as the insight from the site contact that the heating controlled the ambient temperature to approximately 72°F when the outside air temperature was less than 55°F on the weekdays. The weekend ambient temperature was consistently controlled by the heating for the duration of the metered period, to a maximum outside air temperature of 67°F. Therefore, the evaluators only considered weekday hours above 55°F and weekend hours above 72°F (the apparent heating control setpoint) for savings. This is summarized in Table 2-9.

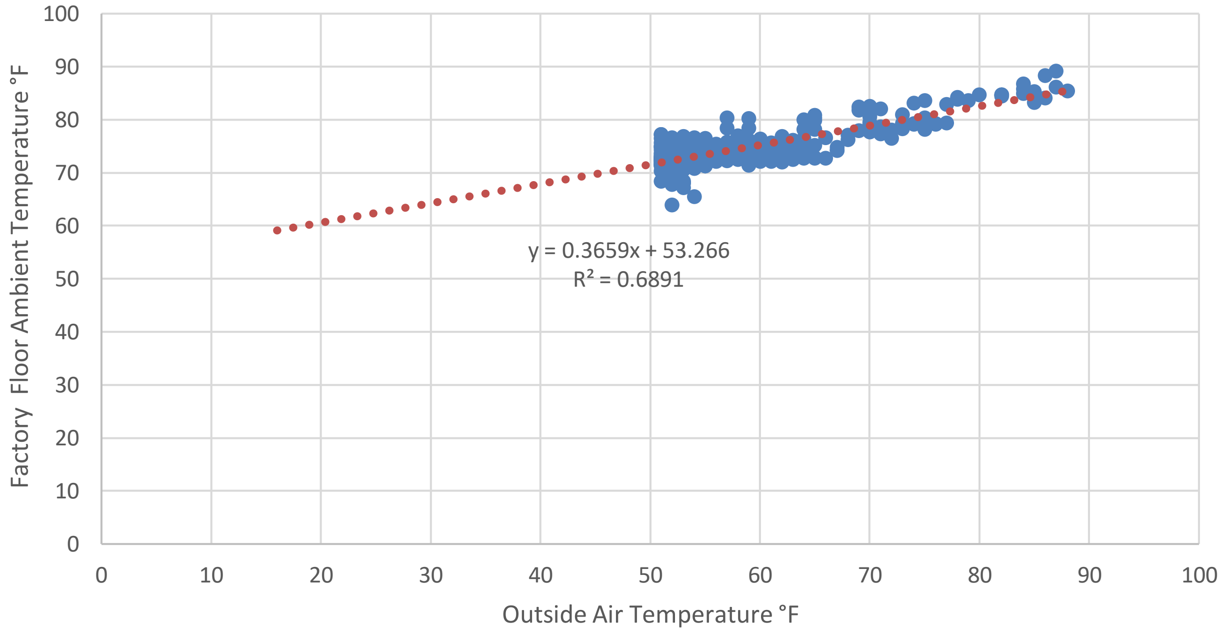
Table 2-9. Heating hour summary

Time of Week	Hours With Space Heating (No Savings)	Hours Without Space Heating (Savings)
Weekday	3,639 (<55°F OAT)	2,705
Weekend	1,991 (<67°F OAT)	425
Total	5,630	3,130

The evaluators also determined that only approximately 5 of the 9 weekends over the metered period had the steam piping and equipment energized, so only 5/9 of the applicable weekend hours were included in the analysis. The weekday factory floor temperatures when above 55°F outside air temperature appeared to correlate with the outside air temperature, as shown in Figure 2-16.

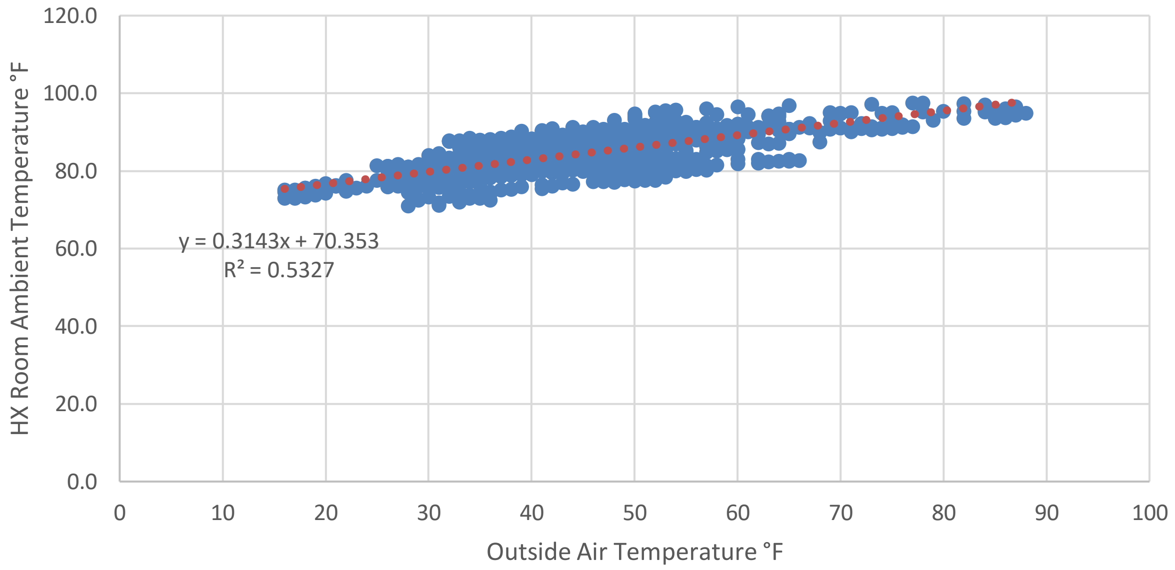
Ambient Temperatures

Figure 2-16. Factory floor ambient vs outside air greater than 55°F



A portion of the steam equipment was also located in an unconditioned room off of the main factory floor that housed a steam to hot water heat exchanger. Since the room was unconditioned, the ambient temperature corresponded closely with outside air temperature, as shown in Figure 2-17. The evaluators observed what appeared to be a levelling off in the maximum ambient temperature at around 97°F. This levelling off applies to only 120 of the 8,760 hours in the analysis.

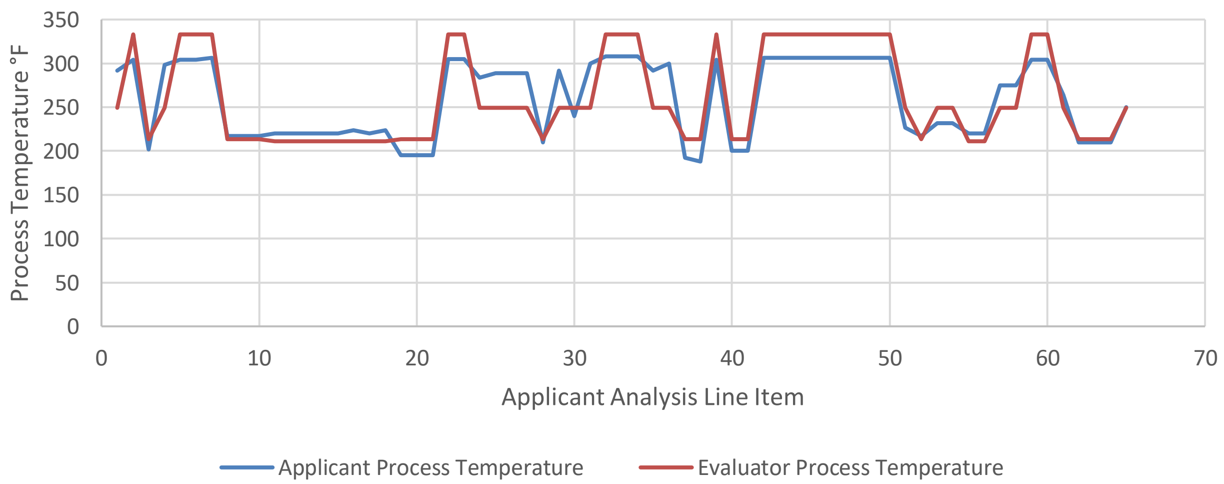
Figure 2-17. HX Room ambient temperature vs OAT



Process Temperatures

After the ambient temperatures were determined, the evaluators mapped the process temperatures supplied by the applicant to a metered temperature. The site contact indicated that the scope of the metering performed by the evaluators should be wholly representative of the pipe and equipment in the plant. The evaluators adjusted the applicant temperatures using a combination of insight from the site contact, descriptions provided by the applicant, spot metering on-site, and by comparing the applicant temperatures with the candidate metered temperatures. Figure 2-18 compares the process temperatures for each line item in the applicant's analysis. The average absolute value adjustment in process temperature was +8.0% with the evaluator values being higher. The largest adjustments from the metering are a resulting decrease in the space heating steam temperature and an increase in the process steam temperature.

Figure 2-18. Comparison of applicant and evaluator process temperatures



Savings

Due to the outside air temperature dependence of the 3E Plus parameters, an outside air temperature bin model using TMY3 weather data from Providence, RI was used to calculate the total annual heat loss. A separate bin analysis was conducted for each unique process temperature.

The analysis is structured such that each equipment designation (pipe vs equipment), pipe diameter, ambient temperature, and process temperature required its own separate bin analysis. Therefore, 20 separate bin models were analyzed, summarized below in Table 2-10. The surface temperature is different in some instances for the same process type to account for the fact that the heat exchanger room ambient location considers all hours, which includes some weekends with lower metered temperatures.

Table 2-10. Application 11529748 bin summary

Process Type	Bin #	Pipe Or Tank	Ambient Location	Surface Temperature (°F)	Pipe Diameter (Inches)	Length (ft) or Surface Area (Ft²)
Condensate	1	Pipe	Factory Floor	211	1.5	137
	2				2	47
	3				4	4
	4	Tank	Factory Floor	211	-	7
Low Pressure Steam	5	Pipe	Factory Floor	213	0.5	250
	6				0.75	250
	7				1.5	84
	8				2.0	300
	9				3.0	13
	10				4.0	59
	11	Tank	Factory Floor	213	-	43
	12		HX Room	202	-	11
Heating (60 psig) Steam	13	Pipe	Factory Floor	249	2.0	58
	14				3.0	125
	15				4.0	114
	16	Tank	Factory Floor	249	-	34
	17		HX Room	235	-	11
Process (115 psig) steam	18	Pipe	Factory Floor	331	1.5	62
	19				2.0	104
	20	Tank			-	39

Each individual bin analysis has an ambient temperature that is based on the regressions shown in Figure 2-16 and Figure 2-17. 3E Plus runs were then done to find the heat loss in each bin. The hours in each bin for equipment or pipe on the main factory floor sums to 2,941, which represents all weekday hours above 55°F and 5/9 of the weekend hours above 72°F. The bin hours for the heat exchanger room sum up to 8,760 since space heating does not affect the savings. However, the surface temperatures include lower temperatures on some weekends.

The applicant did not indicate the type of insulation or jacket emittance used in this application. The evaluators were able to determine the equipment insulation jackets were Shannon LT450TT which have an emittance of 0.95. However, the evaluators were not able to determine the pipe insulation, and the site contact was only aware that they were fiberglass. Therefore, the "850 MF Blanket, Type IV, C553-11" fiberglass insulation type was assumed on 3E Plus with an emittance of 0.90.

3E Plus calculates heat loss in BTU/hr/ft for "pipe – horizontal" and BTU/hr/ft² for "tank shell – horizontal". Figure 2-19 shows the 3E Plus report output for the NPS size 1.5" piping that is part of bin #1.

Figure 2-19. 3E Plus output report

Parameters and Assumptions

Ambient Temp: 88 (°F)
Wind Speed: 0 (mph)
Jacket Material: All Service Jacket
Dimensional Standard: ASTM C 585 Rigid
Pipe Size: 1.5

Process Temp: 211 (°F)
Base Metal: Steel
Surface Geometry: Pipe - Horizontal
Even Increment: 0

Results: Heat Loss Per Hour

Insulation Thickness (in)	Surface Temp (°F)	Heat Flow (BTU/hr/ft)	Efficiency (%)
Bare	210.9	150.48	–
Layer 1 (2.4)	93.9	14.95	90.07

The 3E Plus heat loss values were converted to annual gas savings using the following equations:

$$\text{Pipe Savings} = \frac{\text{Hours} \times \text{Length} \times [\text{HL}_{Bare\ Pipe} - \text{HL}_{Proposed\ Pipe}]}{\text{Eff}_{Boiler} \times 100{,}000}$$

where,

Pipe Savings (therms/year) = measure impacts calculated by the evaluator for piping sections

Hours = annual hours the impacted pipes and fixtures are at the analyzed conditions (hours/year)

Length = length of impacted pipe sections (ft)

$\text{HL}_{Bare\ Pipe}$ = modelled heat loss in the baseline case – bare pipes/fixtures (Btu/hr/ft)

$\text{HL}_{Proposed\ Pipe}$ $(\text{Btu/ft} \times \text{hr})$ = modelled heat loss in the proposed case – insulated pipes/fixtures

100,000 = conversion factor (Btu to therm)

Eff_{Boiler} = efficiency of steam boilers (82%)

And,

$$\text{Equipment Savings} = \frac{\text{Hours} \times \text{Surface Area} \times [\text{HL}_{Bare\ Equipment} - HL_{Proposed\ Equipment}]}{\text{Eff}_{Boiler} \times 100{,}000}$$

where,

Equipment savings = measure impacts calculated by the evaluator for the equipment jacket insulation (therms/year)

Surface Area	= surface area of impacted boilers and pumps (ft²)
$HL_{Bare\ Equipment}$	= modelled heat loss in the baseline case – bare equipment ($Btu/ft^2 \times hr$)
$HL_{Proposed\ Equipment}$	= modelled heat loss in the proposed case – insulated boilers and pumps ($Btu/ft^2 \times hr$)
$100{,}000$	= conversion factor (Btu to therm)
Eff_{Boiler}	= efficiency of steam boilers (82%)

Based on these calculations and the above equations, the evaluator found the measure to save 14,189 therms.

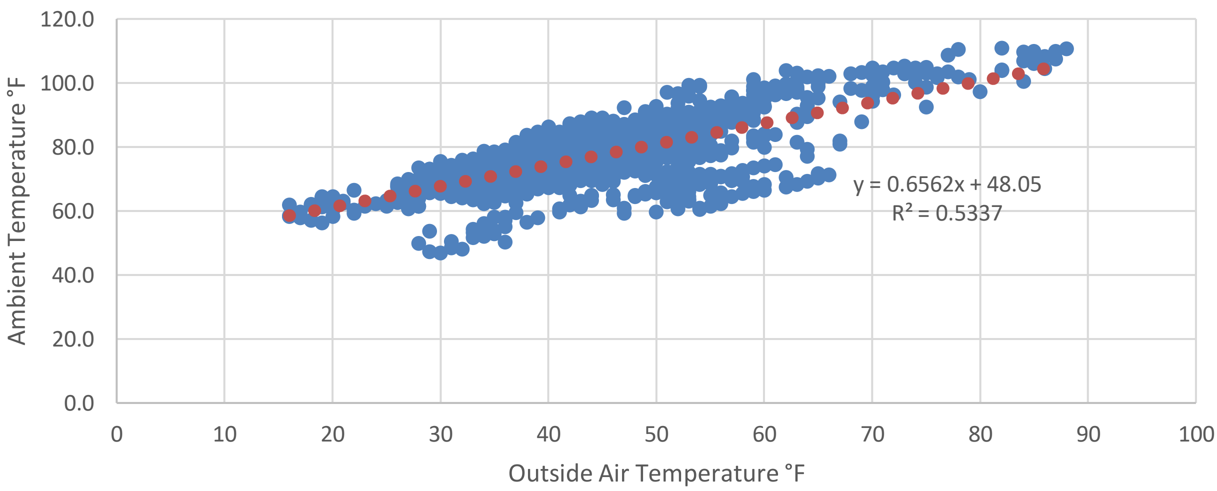
Application 12785274 (Hot Oil and Steam Equipment)

Ambient

The oil tanks and steam and condensate lines are all located in a rooftop mezzanine area that is unconditioned and largely open to the outdoors. This results in the ambient temperature shown in Figure 2-10Figure 2-11 having a strong correlation with outside air temperature, as evidenced by Figure 2-20.

Figure 2-20. Hot oil area ambient temperature vs outside air temperature

The e



Hours and Process Temperature

The evaluators determined that the scope of this application could be split into three groups: the oil tanks themselves, the steam lines feeding the tanks, and the condensate lines. The application considered 11 tank/steam/condensate systems with identical surface areas. The applicant indicated that the tanks were ~27% of the total system surface area, which the evaluators decided was a reasonable estimate based on what was observed on-site. The evaluators determined that the remaining area of each system was roughly 50% steam and 50% condensate.

From speaking to the site contact, the evaluators learned that of the 11 tanks, 7 run 5 days/week all month, while the remainder run sporadically for approximately 3 weeks per month depending on the demand. The evaluators metered the steam, condensate, and tank surface temperature for one tank that was indicated to run all month and metered the steam temperature of another hot oil system that was indicated to only operate for approximately 3 weeks of the month. The surface area of each group, the percent of time the equipment is energized during the weekdays and weekends, and the process temperature while the equipment is energized is summarized in Table 2-11 for the 11 tanks.

Table 2-11. Component summary

Component	Surface Area (ft^2)	% Of Time Energized on Weekdays	Average Energized Weekday Surface Temperature	% Of Time Energized on Weekends	Average Energized Weekend Surface Temperature
Hot Oil Tank	69.08	39%	181	18%	178
Steam Line 1	81.14	100%	217	61%	210
Steam Line 2	46.37	92%	224	31%	202
Condensate Line	127.51	89%	151	43%	146

The evaluators made bins for 3E Plus similar to in application 11529748. Table 2-12 summarizes the different bins that were analyzed for this application. The hours in each bin were found by considering the percent of time energized from Table 2-11.The existing insulation coverage used by the evaluators was identical to the applicant. The applicant and evaluator both determined that 19.9% of the total hot oil tank, steam, and condensate system had prior insulation, or 64.5 ft^2. Table 2-12 indicates that in order for the total system to have a 19.9% insulation coverage, the components that had prior insulation must have had 28% coverage.

Table 2-12. Application 12785274 bin summary

Component	Bin #	Time Period	Energized Hours	Process Temperature (°F)	Existing Insulation Thickness (Inches)	Existing Insulation Coverage (%)	Installed Insulation Thickness (Inches)
Hot Oil Tank	1	Weekdays	2,369	181	0	-	0.5
	2	Weekends	494	178	0	-	0.5
Steam Line 1	3	Weekdays	6,006	217	0.25	28%	1.0
	4				0	-	1.0
	5	Weekends	1,677	210	0.25	28%	1.0
	6				0	-	1.0
Steam Line 2	7	Weekdays	5,596	224	0.25	28%	1.0
	8				0	-	1.0
	9	Weekends	825	202	0.25	28%	1.0
	10				0	-	1.0
Condensate Line	11	Weekdays	5,382	151	0.25	28%	1.0
	12				0	-	1.0
	13	Weekends	1,150	146	0.25	28%	1.0
	14				0	-	1.0

The evaluator determined that the insulation jackets were identical to Application 11529748; Shannon LT450TT with an emittance of 0.95. The evaluators also used 3E Plus to calculate heat loss similar to Application 11529748. The 3E Plus heat loss values were converted to annual gas savings using the following equation:

$$\text{Equipment Savings} = \frac{\text{Hours } \times \text{Surface Area } \times [\text{HL}_{Existing\ Equipment} + -HL_{Proposed\ Equipment}]}{\text{Eff}_{Boiler} \times 100{,}000}$$

where,

Equipment savings = measure impacts calculated by the evaluator for the equipment jacket insulation (therms/year)

Surface Area = surface area of impacted boilers and pumps (ft²)

$\text{HL}_{Proposed\ Equipment}$ = modelled heat loss in the proposed case – insulated boilers and pumps $(\text{Btu/ft}^2 \times \text{hr})$

$100{,}000$ = conversion factor (Btu to therm)

Eff_{Boiler} = efficiency of steam boilers (82%)

$\text{HL}_{Existing\ Equipment}$ = The heat loss in $\text{Btu/ft}^2 \times \text{hr}$ of the existing equipment which is partially bare and partially insulated with 0.25” of effective insulation, calculated as:

$$\mathrm{HL}_{Existing\ Equipment} = \mathrm{HL}_{Bare\ Equipment} \times (1 - IC) + \mathrm{HL}_{Existing\ Insulated\ Equipment} \times IC$$

where,

$\mathrm{HL}_{Bare\ Equipment}$ = The heat loss in $\mathrm{Btu/ft^2} \times \mathrm{hr}$ of the portion of the existing equipment that is bare

$\mathrm{HL}_{Existing\ Insulated\ Equipment}$ = The heat loss in $\mathrm{Btu/ft^2} \times \mathrm{hr}$ of the portion of the existing equipment that had prior insulation

IC = the existing insulation coverage, as a percent, of the equipment included in the scope of the measure

Based on these calculations and the above equations, the evaluator found the measure to save 3,628 therms.

The evaluators found the combined gas savings of both applications to be 17,816 therms. The applicant indicated that the site usage was >500,000 therms, so the evaluated savings are not expected to be visible in the bill data.

3 FINAL RESULTS

The project consisted of two applications, 11529748 and 12785274. Both applications were at a plastics manufacturing site and considered the installation of new insulation on piping and other equipment. The calculated savings are less than the tracked values. Table 3-1 summarizes the key parameters used to calculate the energy savings for the measure contained in Application 11529748 and Table 3-3 summarizes the key parameters used to calculate the energy savings for the measure contained in Application 12785274.

Table 3-1. 11529748 Summary of Key Parameters

Parameter	Applicant	Evaluator
Baseline	Bare Piping/Equipment	Bare Piping/Equipment
Average Operating Hours, Piping	4,000	2,941
Average Operating Hours, Equipment	4,000	3,828
Linear Feet of Piping (ft)	1,608	1,608
Surface Area of Equipment (Ft^2)	145	145
Average Process Temperature (°F)	Varies 188-308. Average of 241.7°F	Varies 202-331. Average of 235.2°F
Average Ambient Temperature (°F)	70.8	Varies 70-97°F. Average of 72.3
Boiler Efficiency	100%	82%
Savings		
Annual natural gas savings (therms)	18,453	14,189
Natural gas realization rate (%)	76.9%	

Table 3-2. 12785274 Summary of Key Parameters

Parameter	Applicant	Evaluator
Baseline	Piping/Equipment that is partially bare and partially with 0.5" of effective insulation	Piping/Equipment that is partially bare and partially with 0.25" of effective insulation
Average percent of existing insulation coverage	19.9%	19.9%
Average Operating Hours	6,137	6,022
Surface area of tank/steam/condensate equipment (ft^2)	324.1	324.1
Average Process Temperature (°F)	Varies 245-325. Average of 308.1°F	Varies 146-224. Average of 183.1°F
Average Ambient Temperature (°F)	95	Varies 48-110°F. Average of 81.6°F
Boiler Efficiency	82%	82%
Savings		
Annual natural gas savings (therms)	10,012	3,628
Natural gas realization rate (%)	36.2%	

3.1 Explanation of Differences

The evaluated savings are less than the applicant savings for both applications. Application 11529748 has a decrease in savings due to a decrease in the savings hours, a difference in process temperatures and ambient temperatures, and a change to the analysis methodology. These adjustments are partially offset by an inclusion of the boiler efficiency. Application 12785274 has a decrease in savings primarily due to an adjustment in process and ambient temperatures. A change in analysis methodology and run hours also negatively impacts savings. These negative adjustments are partially offset by a baseline change to use 0.25" of effective insulation as opposed to 0.5". Table 3-3 provides a summary of the differences between tracking and evaluated values.

Table 3-3. Summary of Deviations

End-use	Discrepancy	Parameter	Impact of Deviation	Discussion of Deviations
Application: 11529748 (Steam Piping and Equipment)				
HVAC	Hours of operation	Energized pipe and equipment run hours	-16.8%	**Decreased Savings:** The hours for which savings were claimed (excluding non-energized and space heating hours) were decreased to 2,941 from 4,000 on the main factory floor. Equivalent run hours were increased to 6,344 in the heat exchanger room from 4,000, offsetting a portion of the savings decrease.
HVAC	Operating efficiency	Steam boiler plant efficiency	15.4%	**Increased Savings:** The evaluators adjusted the steam boiler plant efficiency to 82% based on a deemed value. The applicant did not include an efficiency (100%).
HVAC	Pre-project errors (inputs of calculations)	Ambient and Process temperatures	-8.0%	**Decreased Savings:** The evaluators adjusted the ambient temperature to vary with outside air temperature from 88°F to 74°F in the main factory floor and 97°F to 70°F in the heat exchanger room. The process temperatures were adjusted to range from 202°F to 311°F, varying with component. The applicant used a constant ambient temperature for each component with an average value of 70.8°F, and process temperatures that ranged from 188°F to 308°F for each component. Both adjustments contribute to a savings decrease.
HVAC	Analysis methodology	Heat transfer calculations/software	-2.1%	**Decreased Savings:** The evaluators used 3E Plus to calculate heat loss in the existing and installed case. The applicant used heat transfer formulas in spreadsheet form.

Application: 12785274 (Hot Oil and Steam Equipment)				
HVAC	Pre-project errors (inputs of calculations)	Ambient and Process temperatures	-25.4%	**Decreased Savings:** The evaluators adjusted the ambient temperature to vary with outside air temperature and range from 48°F to 110°F. The process temperatures were adjusted to vary with each component from 178°F to 224°F. The applicant used a constant ambient temperature of 95°F and a process temperature varying by component between 245°F and 325°F. The evaluated process temperatures include condensate, low pressure steam, and the hot oil tank, whereas the applicant calculations include the hot oil tank, 60 psig steam, and 115 psig steam. The ambient temperature adjustment partially offsets the decrease in savings from the process temperature adjustment.
HVAC	Baseline	Effective existing insulation thickness	1.8%	**Increased Savings:** The baseline effective insulation was adjusted to be 0.25" based on a research paper found by the evaluators. The applicant used 0.5".
HVAC	Analysis methodology	Formula Error	-1.7%	**Decreased Savings:** The applicant used a formula that considered only the surface area of the existing bare surface in the installed case formula. The evaluator adjusted the formula to include the surface area that also had prior insulation.
HVAC	Hours of operation	Energized equipment run hours	-0.7%	**Decreased Savings**: The evaluators used an average energized hours of 6,022 for the equipment as opposed to 6,137 by the applicant based on metered data.
Total (Both Applications)			**-37.4%**	**Decreased savings by 37.4%**

3.2 Lifetime Savings

Because the steam boilers will outlive the installed measures, the evaluators classified this measure as an add-on with a single baseline. The evaluators calculated applicant and evaluated lifetime savings values using the following formula:

$$\mathrm{LAGI} = FYS \times \mathrm{EUL}$$

where:

$LAGI$ = lifetime adjusted gross impact (therm)

FYS = first year savings (kWh)

EUL = measure life (years)

The evaluated lifetime savings are greater than the tracking lifetime savings for Application 11529748 and less than the tracking lifetime savings for Application 12785274. Table 3-4 and Table 3-5 provide a summary of key factors that influence the lifetime savings. The evaluation uses the same 15-year measure life as the applicant.

Table 3-4. Measure 11529748 - Lifetime Savings Summary

Factor	Tracking	Evaluator
Lifetime savings (therms)	209,160	212,835
First year savings (therms)	18,453	14,189
Measure lifetime (years)	15	15
Measure life reference	Tracking	MA TRM
Measure event type	Retrofit	Retrofit
Baseline classification	Single – Pre existing	Single – Pre existing
Measure status (operational or removed)	N/A	Operational

N/A = Not Applicable

Table 3-5. Measure 12785274 - Lifetime Savings Summary

Factor	Tracking	Evaluator
Lifetime savings (therms)	113,483	54,420
First year savings (therms)	10,012	3,628
Measure lifetime (years)	15	15
Measure life reference	Tracking	MA TRM
Measure event type	Retrofit	Retrofit
Baseline classification	Single – Pre existing	Single – Pre existing
Measure status (operational or removed)	N/A	Operational

N/A = Not Applicable

3.2.1 Ancillary impacts

There were no ancillary impacts associated with the evaluated measure.