DNV

Impact Evaluation of PY2023 Custom Electric Installations

Rhode Island Energy

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Table of contents

List of tables

List of acronyms and abbreviations used in this report

BMS   building management system

CDA   comprehensive design assistance

C&I   commercial and industrial

EERMC   Energy Efficiency Resource Management Council

EMS   energy monitoring system

ESPO   energy system performance optimization

ERV   energy recovery ventilator

EUL   effective useful life

FCM   forward capacity market

HVAC   heating, ventilating, and air-conditioning

ISP   industry standard practice

LSAF   lifetime saving adjustment factor

M&V   measurement and verification

MBSS   model-based statistical sampling

ML   measure life

MRD   minimum requirements document

Non-ops non-operational parameters

PY   program year

PYR   plan year report

RR   realization rate

SEMP   Strategic Energy Management Plan

SCADA   supervisory control and data acquisition

TMY3   typical meteorological year 3

TA study technical assistance study

VRF   variable refrigerant flow system

skW   summer kW

wkW   winter kW

%on-pk energy   percent on-peak kWh

1 INTRODUCTION

1.1 Study purpose and objectives

This document is the final report for DNV's Impact Evaluation of Program Year (PY) 2023 Custom Electric Installations, conducted for RI Energy, carried out from August 2024 to August 2025. The DNV team includes expertise from our partner firm DMI.

The primary objective of the impact evaluation was to provide verification and re-estimation of energy and demand savings for a sample of statistically selected custom electric projects through site-specific verification, monitoring, and analysis. The results of this study, combined with those from previous years[1](PY2021 and PY2022), were used to determine the gross realization rates to be used for custom electric energy efficiency projects implemented in 2026 and will be updated annually as subsequent impact evaluations are completed.

The key objectives of this evaluation were as follows:

1. **Evaluate savings impacts of PY2023 custom electric projects** to be pooled with the results of the PY2021 and PY2022 studies. This study aimed to quantify:
    a. Achieved electric energy savings for custom non-lighting projects,[2] with a targeted combined sampling precision of ±15% at 90% confidence when pooled with the results from the PY2021 and PY2022 studies.
    b. Summer and winter on-peak demand realization rates calculated with a precision target of ±20% at 80% confidence for custom non-lighting when pooled with the results from the PY2021 and PY2022 studies.
    c. Percent on-peak realization rates calculated with a precision target of ±20% at 80% confidence for custom non-lighting for the three-year rolling average.

2. **Evaluate lifetime savings adjustment factors (LSAF)** for PY2023 using the results for the sites included in the study and the sampling weights calculated for Objective 1 above. LSAF was not calculated until PY2020. Therefore, PY2023 (considered Year 4) was the second year that a three-year (rolling/staged; PY2021+PY2022+PY2023) LSAF was calculated. Although RIE does not use LSAF for tracking savings, DNV calculated it for future program planning purposes should it be needed.

1.2 Organization of report

The rest of the report is organized as follows:

*   Section 2: Methodology and Approach
*   Section 3: Data Sources
*   Section 4: Analysis and Results
*   Section 5: Conclusions and Recommendations
*   Appendices

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[1]Starting from PY2018, a three-year pooling evaluation framework was adopted by RIE and approved by the RI Consultant Team. This decision was made to be cost effective, reduce sample size, and meet statistical precisions.

[2] Projects where lighting is used in industrial process measures, such as for agricultural production in greenhouses, e.g., growing cannabis, are considered "custom process" in RIE tracking.

2 METHODOLOGY AND APPROACH

This section provides details on the PY2023 impact evaluation, summarizing both methodology and approach.

This study is the seventh annual C&I custom electric impact evaluation in Rhode Island using the rolling average approach. Like last year's study, this year's study calculated savings and realization rates for non-lighting projects only due to the stability of lighting RRs within the state over the last several years. All 10 sites in the PY2023 sample received full M&V, with loggers installed or data collected on-site.

Custom non-lighting projects include HVAC systems, controls, and other non-lighting energy-using equipment. The study also included custom industrial process measures, which include process lighting projects for greenhouse operations, which are reported as process and not lighting measures in RIE tracking.

2.1 Sample development

The basis for sample development is that the results from this evaluation achieve the targeted statistical estimates mentioned in Section 1.1. The sample was developed through a tracking data review and a stratified sampling plan as described in the following sections and outlined in the sample design memo produced in advance of the evaluation.

2.1.1 Tracking data review

As part of the data tracking review, DNV reviewed project parameters in the raw tracking data files received from Rhode Island Energy. Measures were classified as "IN" or "OUT" based on their project type to prepare the data for the sample design process. Projects excluded from the population included lighting, comprehensive design (CDA) projects, and parent/child applications[3] where the child applications were not closed in PY2023.

The tracking data included a total of 199 unique applications and 27 child applications. Of these applications, 27 were ambient lighting and two were CDA projects, which were removed from the population. An additional 18 parent/child applications were removed because the child was not closed in PY2023, leaving the population with 152 applications and seven child applications. These 159 total applications were aggregated at the site level based on billing account to ensure all applications were evaluated at a selected site. The total population represents 135 different sites.

Out of the 135 sites, DNV removed another 19 that claimed less than 2,000 kWh in energy savings through the program to be cost-effective,[4] resulting in 116 sites in the population. The 19 small savings sites removed constituted 0.2% (<1%) of the total program savings.

PY2023 claimed 9.3 million annual energy (kWh) savings, 33% less than the previous year. The reduction in savings can be attributed to many HVAC operation and maintenance (O&M) coil cleaning measures in the population that typically result in lower per-application savings. These projects are typically tracked as Energy System Performance Optimization (ESPO) measures. In PY2023, there were 66 coil cleaning projects representing a little over 10% of the total population savings, or 975,443 kWh. Additionally, there was one large non-coil cleaning ESPO project that claimed 1,363,103 kWh of savings.

Table 2-1. PY2023 gross annual energy and peak demand savings with ESPO

Total unique accounts (sampling unit)	Total energy savings (kWh)	Total peak summer savings (kW)	Total peak winter savings (kW)
116	9,300,701	1,046	876

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[3] Parent/child applications are RIE defined and typically refer to applications that are paid in multiple installments. A child application often involves using post-installation data to confirm installation or commissioning has been completed.

[4] Removing small savings projects before developing the sample is industry standard practice for program evaluation. This step ensures evaluation budgets remain commensurate with program savings by reducing the quantity of sampled sites needed to meet the statistical targets.

After the sample design population was finalized and sites were selected for evaluation, DNV and RI Energy decided to remove ESPO measures from the 2023 sample design. This decision was made because RIE plans to remove ESPO projects from the custom electric program starting in PY2026 and since the realization rate resulting from this study will be prospectively applied starting in 2026, removing the ESPO projects is justified. Project measures implemented through ESPO that were in the PY2023 population included AHU/RTU programming upgrades and coil cleaning. Table 2-2 presents the updated gross annual energy and demand savings with ESPO projects removed from the population and sample design.

Table 2-2. PY2023 gross annual energy and peak demand savings without ESPO – Final Design

Total unique accounts (sampling unit)	Total energy savings (kWh)	Total peak summer savings (kW)	Total peak winter savings (kW)
64	6,091,338.00	823	752

2.1.2   Sampling plan

As indicated earlier, the DNV team will pool the annual evaluation results from this study with the prior years' results to maintain a rolling updated result[5] so that the sampling precision will meet the targets in Table 2-3 below.

Based on the energy (kWh) realization results achieved in the previous studies, this sample design assumed error ratios[6] (ER) as shown in Table 2-3 which is an average of the ERs from the last three completed years (PY2020, PY2021, PY2022). The sample design for this round of the study was developed assuming the results would be pooled with prior (and future) custom electric results. The basis for this design is that each year's results would need to achieve ±26% precision at the 90% confidence interval to maintain a three-year pooled result of ±15% precision at 90% confidence for non-lighting gross energy realization rates. It should be noted that the sampling plan was developed for energy confidence levels and precision targets, as shown in Table 2-4.

Precision for summer and winter peak kW savings realization rates was also developed for each of these saving's parameters at the 80% confidence interval with a precision target of ±20% for the three-year rolling average. DNV used model-based statistical sampling (MBSS) techniques to develop the sample design.

Table 2-3. Sampling targets without ESPO

Annual sampling target	3-year pooled sampling target	Error ratio
±26% on non-lighting energy (kWh) at the 90% confidence interval	±15% on non-lighting energy (kWh) at the 90% confidence interval	PY2023 = 0. 45

Table 2-4 presents the sample design for PY2023 and samples from the previous evaluations of PY2021 and PY2022 that are used in support of the three-year combined design. The targeted PY2023 relative precision (RP) was proposed to be 24.0%. The combined precision was proposed to be 10.0% @ 90% confidence for non-lighting: within the goal of ±15% RP and the one-year goals of ±26% @ 90% confidence. Table 2-4 details the total savings for each year, their sample size, and RP based on each program year of the three-year pooled result.

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[5]This study is the sixth custom electric study. The intention is to maintain a rolling three-year pooling of results, so when this year is completed, the first and second year (PY2019 and PY2020) will be removed.

[6] Error ratio is a measure of the population variability between the x (known for population) and y (known only for the sample) variables. The error ratio is defined as the ratio between (a) the sum or average of the residual standard deviations of all customers, and (b) the sum or average of the expected values of y.

Table 2-4. 2023 project sample design and estimated relative precisions without ESPO

End-use	Program year	Energy savings (kWh)	Sample size	RP @90% CI
Non-lighting	2021	26,073,183	10	±15.8% (actual)
	2022	13,916,893	10	±13.0% (actual)
	2023	6,091,338	10	23.0% (proposed)
Non-lighting (3-year rolling)	**2021+2022+2023**		**30**	**10.0% (proposed)**

2.1.2.1   Sample stratification and site weights

Measures in the program population were aggregated to sites on a "single organization at a single location" basis. The PY2023 sample was not stratified based on Strategic Energy Management Plan[7] (SEMP)/Non-SEMP project types as the population did not include large energy-saving SEMP non-lighting sites like in previous years. The sample design used the stratification shown in Table 2-5 to achieve the study's objectives. Please note that the sample design uses model assisted survey sampling methods to establish stratum boundaries, which assign the boundaries such that there is an equal amount of expected uncertainty around tracked energy savings within each stratum, but not necessarily an equal amount of tracked energy savings.[8] Also note that while we estimate realization rates for tracked demand savings during our final analysis, demand savings is not considered when setting stratum boundaries.

Case weights have been created for each of the 10 sites by determining the total number of sites in the stratum and dividing by the number of evaluated sites.

Table 2-5. Stratification and weighting

Strata#	Population (N)	Sample (n)	Maximum (kWh)	Weight
1	54	5	929,866	10.8
2	10	5	3,512	2.0

For the PY2023 annual evaluation, each site has a single case weight based on the stratum they were assigned to.

2.2   Sample draw and data request

After defining the sample stratification based on tracked energy savings and the target number of completes for each stratum, DNV randomly selects a set of "primary" sites from the population sufficient to meet the targets, along with an equal number of "backup" sites available to replace the primary sites in the event they are non-responsive for recruitment. The process for moving from a primary to a backup site is discussed in Section 2.4. After the primary sites have been assigned, DNV requests all project files associated with the evaluated project which typically include site docs, savings, and email transcripts.

2.3   Analysis methodology

Section 4.2.2 and Section 4.3.1 explain the process for calculating the current and three-year realization rates.

DNV has updated the yearly realization rates as part of this custom electric evaluation framework. The evaluation also generated lifetime savings adjustment factors (LSAFs) in this round. See APPENDIX C for more information on LSAF.

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[7] The SEMP program allows customers to plan for and implement projects over a 3-4 year period. These projects often involve multiple measures across different buildings.

[8] Chapter 13 of the 2004 California Evaluation Framework describes the application of this sampling methodology to impact evaluation in detail: FINAL California Evaluation Framework

2.4 Customer outreach

Project engineers reached out to customer site contacts using an RI Energy–approved communication protocol and the information provided in the project files. During this initial outreach, the engineers discussed the purpose of the outreach, facility operation and usage, the scope of measures installed, the availability of on-site trend/SCADA/production data, and any other applicable parameters relevant to the evaluation, and confirmed the site's ability and willingness to participate in the evaluation. Efforts were made to minimize pre-recruitment evaluation activities until the customer site contact indicated they would accommodate the evaluation process.

A backup site was selected if the site contact was unresponsive or refused to participate in the evaluation through multiple email and phone call attempts. If a site refused or was unresponsive, DNV staff attempted assistance through RIE account managers and technical representatives who may have a closer relationship with a given site. If a backup was needed, DNV selected the next highest priority site that was randomly assigned in the stratum that the primary site was in.

Two backup sites were selected to replace sites in the primary sample. DNV Site IDs RICE23N086 and RICE23N120 were each unresponsive and were replaced with sites RICE23N091 and RICE23N077 respectively.

With RI Energy's input on the site evaluation plan, the DNV team contacted each customer to schedule an on-site visit at a day and time convenient for the customer site contact.

The DNV team conducted site visits to collect the data listed in the site evaluation plan for each site. In general, each data collection visit consisted of verifying the installed technology, quantities, a discussion with facility personnel regarding installed measure(s) and the baseline conditions that existed before the measure(s) installation.

2.4.1 On-site M&V

On-site M&V data collection included physical inspection, an interview with facility personnel, observation of site operating conditions and equipment, metering of equipment usage, and collection of facility-provided data. The physical inspection focused on verifying measure installation and expected operation. In some cases, multiple facility interviews and/or equipment vendor interviews were completed to ensure an accurate understanding of the operating practice.

For all sites, instrumentation and metering equipment such as power recorders, time-of-use (TOU) current loggers, plug load monitors, and temperature loggers were installed to monitor the usage of operating equipment and conditions of the impacted systems. Production data and EMS trends were also collected when available. Each site report includes a full description of the data collected and received, and, where applicable, data from installed meters.

A unique savings analysis was created for each sampled project. When required, a typical meteorological year (TMY3) dataset of ambient temperatures was used for temperature-sensitive calculations. Energy savings were either calculated by the hour in an 8,760-hour spreadsheet or allocated to each hour in the year to estimate on-peak kW and kWh savings impacts. Each analysis provided estimates for annual kWh savings, on-peak kWh savings, and on-peak demand (kW) savings at the times of the winter and summer peaks, as defined by the ISO New England Forward Capacity Market (FCM). All coincident summer and winter peak reductions were calculated using the following FCM definitions:

- *Coincident summer on-peak kW reduction* is the average demand reduction that occurs overall hours between 1 PM and 5 PM on non-holiday weekdays in June, July, and August.
- *Coincident winter on-peak kW reduction* is the average demand reduction that occurs overall hours between 5 PM and 7 PM on non-holiday weekdays in December and January.

Each site report details the specific analysis methods used for each project, including baseline and evaluation algorithms, assumptions, and calibration methods where applicable.

Engineers submitted draft site reports to RI Energy upon completion of each site evaluation. The DNV team responded to the comments received and submitted revised reports for additional comment. A sample of reports was also submitted to the EERMC consultant team for review. The final site reports are included in APPENDIX D. The body of this report provides an overview of the evaluation methods and findings only.

3 DATA SOURCES

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

- PY2023 tracking data provided by RI Energy
- PY2021 and PY2022 impact evaluation results and historical operation adjustment factors
- Project files, which typically include the following: applications, BCR screenings, invoices, technical assistance studies, applicant savings calculations, and post-installation reports.
- On-site audit observations and data collection, including inspection and verifications of equipment, nameplate data, staff interviews, logged data and vendor interviews
- Customer- or vendor-supplied operational data (metered or trended data).

4 ANALYSIS AND RESULTS

4.1 Introduction

Ten sites were evaluated within the PY2023 population for an on-site visit with full M&V. Full M&V is considered a traditional measurement and verification (M&V) that involves on-site measurements using power, time-of-use meters, or validated trend data and measure verification. A summary of sampled projects is listed in APPENDIX A.

Table 4-1 presents the adjustment factors used in the evaluation.

Table 4-1. Adjustment factors for site evaluation

	Adjustment factors						
Ratio name:	Non-operational adjustments					Operational adjustments	
Obtain during:	In-depth file review			First site visit		Logger installation	
Factor:	Baseline	Methodology	Tracking & admin	Technology	Quantity	Operation	HVAC interactive

The results from this study were calculated in the following steps:

- The evaluated non-operational adjustments and operational adjustments for PY2023 were multiplied together to arrive at an overall realization rate (RR) for PY2023 (kWh, skW, wkW, % on-peak, LSAF).
- The realization rate for PY2023 was combined with the overall RRs from PY2021 and PY2022 in proportion to their respective first-year savings relative to the total savings for the three program years to provide an estimate of the overall three-year RR (kWh, skW, wkW, % on-peak, LSAF).

4.2 PY2023 results

4.2.1 PY2023 site-level discrepancies and RR

This section provides an overview of the top five discrepancies from PY2023 that had the biggest difference in site-level tracking and evaluated results. For each of the 10 sites in the PY2023 study, 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 occurrence of each discrepancy factor at all sites and how they are categorized is presented in Table 4-2.

In PY2023, six out of 10 sites reported savings below 100% of ex-ante estimates with major discrepancies in operation. The highest RR was 120% at DNV site ID RICE23N004. The lowest RR was 46% at DNV site ID RICE23S088. More details on each site and their discrepancies can be found in the individual site reports in APPENDIX D.

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

Major discrepancy category	Discrepancy definition or examples	PY2023 projects
Baseline	Change in the baseline of the post-retrofit condition	No discrepancies
Methodology	Accuracy/appropriateness of analysis methodology Calculation changes Non-metered data input updates	No discrepancies
Tracking/Admin	Accuracy of tracking savings Errors during claimed savings input Savings changed but not changed in tracking savings	No discrepancies
Technology	Differences in proposed vs. installed technology or measure type	No discrepancies
Quantity	The quantity of installed equipment is different	No discrepancies
Operational	Inaccurate pre-project characterization Steam operating pressure difference System optimization or programming not implemented Faulty or improperly installed equipment Operating temperature differences Boiler combustion efficiency Difference in equipment hours of operation Different equipment load profile	RICE23S100, RICE23S088, RICE23N059, RICE23N096, RICE23N082, RICE23N062, RICE23N004, RICE23N091, RICE23N077
HVAC Interaction	Interactive effects	RICE23N096, RICE23N077

Whether the site had an efficiency, load, hours, or HVAC interaction discrepancy, the major source of each site's discrepancy greater than 100% RR or less, was an operational load adjustment. The following five sites had the largest discrepancies with respect to savings, in order from largest to smallest discrepancy based on overall RR. Further details with regard to site specific discrepancies and adjustments can be found in the site reports APPENDIX D.

RICE23S088: Operational – The primary measures on this project were VRF and ERV units. The impacted VRF heating and cooling loads were evaluated to be less than the tracking estimate, which reduced savings by -47%. There was also an hour of operation adjustment on the VRF cooling hours that reduced savings by -2% but a VRF heating hours adjustment that increased savings by 1%. The effectiveness of the impacted ERV was evaluated to be less than the tracking assumption, which reduced savings by -6%. The site had an evaluated energy realization rate of 46%.

RICE23N077: Operational – The primary measures on this project were VRF and ERV units. The multi-measure project had several loads (-20%) and efficiency (-12%) adjustments. Load adjustments made up six of the nine total project discrepancies. The single biggest discrepancy was the impacted VRF heating and cooling load which reduced savings by -24%. The site had an evaluated energy realization rate of 68%.

RICE23N059: Operational – The primary measure on this project was an air compressor. The evaluator found the installed average CFM and baseline operating load to be less than tracking, which reduced savings by a total of -36%. An hour of operation adjustment increased savings by 5%. The site had an evaluated realization rate of 69%.

RICE23N091: Operational – The primary measure on this project was refrigeration equipment. The evaluator made three operating profile adjustments to one of the two project measures based on onsite metering data. The largest profile

discrepancy was on the load of the impacted refrigeration racks, which reduced savings by -29%. The other two operating profile adjustments increased savings by 4% and reduced savings by -3% respectively, for a total adjustment of -28% for one of the two measures. The other measure had no discrepancies, which increased the project realization rate by 3%. The site had an overall evaluated energy realization rate of 75%.

RICE23S100: Operational – The primary measure on this project was a heat pump water heater. Three operating load (-21%, -9%, and +56%) and two operating efficiency (-49% and +1%) adjustments were found by the evaluator. The largest positive adjustment was +56% on the recirculation loop distribution losses that were not accounted for by the applicant. This adjustment was almost entirely offset by a single -49% operating efficiency adjustment. The site had an evaluated energy realization rate of 78%.

4.2.2 PY2023 RR calculation methodology

This section discusses the methodology to calculate the PY2023 realization rates. Individual site RRs are shown in APPENDIX B.

RR_3 for PY2023 was calculated using the same methodology as prior years, where the overall realization rate is the product of operational and non-operational adjustments. Since the full sample of sites this year received an operational evaluation, no imputation to operational adjustments were needed.

Both the non-operational and 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 respectively for the sample via the usual formulas.

The overall RR is the product of the operational and non-operational RR:

$$RR_3 = RR_{O3}\, RR_{N3}$$

The constituent parts of the overall RRs for PY2023 are shown in Table 4-3**Error! Reference source not found.**.

Table 4-3. Non-lighting prospective realization rates for PY2023

Statewide results (n=10)	Annual MWh	Summer on-peak kW	Winter on-peak kW	% on-peak energy MWh
Total tracking savings	6,091	823	752	6,091
Total evaluated savings	5,454	502	503	5,073
Realization rate	**89.6%**	**67.2%**	**65.7%**	**81.2%**
Confidence level	90%	80%	80%	80%
Relative precision	±9.2%	±18.6%	±13.0%	±9.7%
Operational results	89.8%	67.4%	66.0%	81.4%
Non-operational results	99.8%	99.7%	99.5%	99.8%

4.3 Combined program-level results

This section presents rolled-up/program-level realization rates by combining PY2021, PY2022, and PY2023 evaluated sample results as described in Section 4.2.2.

The site-level evaluation results were aggregated using the final case weights for each respective year. The realization rates for each year were calculated by taking a product of operational and non-operational adjustment factors and then applying them to total tracking savings (Table 2-2) to determine their total evaluated savings for that year. As discussed above, these one-year RRs were then used to calculate the three-year rolling RR.

Table 4-4 presents the non-lighting realization rates for each year and the combined prospective realization rate for the custom electric program in RI to be used to estimate 2026 savings. The combined RR for non-lighting meets the targeted relative precision (RP) of ±15% at a 90% confidence interval (CI) with a value of ±9.8% for the three-year rolling RR of 85.5%.

Table 4-4. Combined non-lighting realization rates (kWh)

| Non-lighting | RI | | | Combined results |
	PY 2021	PY 2022	PY 2023	PY2021-+ PY2022+PY2023
Tracking energy savings (kWh)	26,073,183.00	13,916,893.00	6,091,338.00	46,081,414
Sample size (n)	10	10	10	30
RR (Ops x Non-ops)	88.4%	78.3%	89.6%	85.5%
Relative precision @ 90% CI	±15.8%	±12.8%	±9.2%	±9.8%
Operational results	86.8%	78.5%	89.8%	
Non-operational results[9]	101.8%	99.8%	99.8%	

Table 4-5 and Table 4-6 present prospective realization rates for summer and winter peak demand (kW) savings, and Table 4-7 presents prospective realization rates for percent on-peak energy savings. Summer kW, winter kW, and % energy savings RRs decreased compared to PY2022. The three-year rolling/combined results for both summer and winter peak demands met the target precision of ±20% at 80% CI.

Table 4-5. Prospective realization rates from evaluated summer peak demand (kW) savings for non-lighting measures

| Non-lighting | RI | | | Combined results |
	PY2021	PY2022	PY2023	PY2021+ PY2022+PY2023
Tracking summer demand (kW)	3,099	1,864	823	5,787
Sample size (n)	10	10	10	30
RR	83.3%	74.3%	67.2%	78.1%
Relative precision @ 80% CI	±15.6%	±32.7%	±18.6%	±13.7%
Operational results	80.2%	72.0%	67.4%	
Non-operational results	103.9	103.1	99.7%	

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[9]Starting in 2020, the non-operational results (non-ops) ratio was calculated using two factors: non-ops 1 and non-ops 2. Non-ops 1 includes discrepancies from Baseline, Methodology and Administrative adjustment factors, while non-ops 2 includes Technology and Quantity adjustment factors.

Table 4-6. Prospective realization rates from evaluated winter peak demand (kW) savings for non-lighting measures

| Non-lighting | RI | | | Combined results |
	PY2021	PY2022	PY2023	PY2021+ PY2022+PY2023
Tracking winter demand (kW)	3,685	2,091	752	6,528
Sample size (n)	10	10	10	30
RR	120.6%	75.7%	65.7%	99.9%
Relative precision @ 80% CI	±23.7%	±22.6%	±13.0%	±15.2%
Operational results	115.5%	76.9%	66.0%	
Non-operational Results[10]	104.4%	98.4%	99.5%	

Table 4-7. Prospective realization rates from evaluated % on-peak energy savings for non-lighting measures

| Non-lighting | RI | | | Combined results |
	PY 2021	PY 2022	PY 2023	PY2021+ PY2022+PY2023
% on peak energy	26,073,183	13,916,893	6,091,338	46,081,414
Sample size (n)	10	10	10	30
RR	74.7%	100.4%	81.2%	83.3%
Relative precision @ 80% CI	±7.1%	±14.4%	±9.7%	±5.8%
Operational results	70.7%	99.9%	81.4%	
Non-operational results	105.6%	100.5%	99.8%	

4.3.1 Combined program RR calculation methodology

This section discusses the methodology to calculate the combined program-level realization rates. PY2021, PY2022, and PY2023 each had site-specific operational adjustments for all of their 10 sampled sites. Individual site RRs are shown in APPENDIX B.

Calculation of Combined Program RR:

$$RR_{1-3} = (S_1 RR_1 + S_2 RR_2 + S_3 RR_3)/S_T = q_1 RR_1 + q_2 RR_2 + q_3 RR_3$$

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

Where,

1- represents PY2021, 2 is PY2022, 3 is PY2023 and T is total (2021+2022+2023)

S_y - Population tracked savings of PY-y

S_T- population tracked savings for all three PYs combined ($S_T = S_1 + S_2 + S_3$)

q_T- percentage of three-year population tracked savings represented by each program year

RR_3 = Realization rate calculated for this program year

RR_1 and RR_2 were calculated in previous studies and have not been readjusted as part of this study.

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[10]Starting in 2020, the non-operational results (non-ops) ratio is calculated using two factors: non-ops 1 and non-ops 2. Non-ops 1 includes discrepancies from Baseline, Methodology and Administrative adjustment factors, while non-ops 2 includes Technology and Quantity adjustment factors.

Combined Program Variance Estimation

The standard error for the three-year rolling period is calculated as:

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

4.3.2   Lifetime savings adjustment factors (LSAFs)

Lifetime savings adjustment factors were developed for the third time in this study using the weighted tracking and evaluated lifetime savings. DNV also calculated the first three-year pooled LSAF in this study. The LSAFs for non-lighting are provided in Table 4-8. As shown, the lifetime savings adjustment factor RR for PY2023 is 92.2% and the three-year pooled RR is 101.5%. The methodology for these calculations can be found in APPENDIX C.

Table 4-8. Custom non-lighting LSAFs

| Non-lighting | RI | | | Combined results |
	PY2021	PY2022	PY2023	PY2021+ PY2022+PY2023
LSAF	104.9%	99.0%	92.2%	101.5%
Relative precision @ 90% CI	±22.2%	±19.1%	±14.4%	±13.8%

Table 4-9. Custom non-lighting lifetime savings (kWh)

| Non-lighting | RI | | | Combined results |
	PY2021	PY2022	PY2023	PY2021+PY2022+PY2023
Lifetime kWh (annual weighted)	26,073,183	13,916,893	6,091,338	46,081,414
Sample size (n)	10	10	10	30
RR	92.7%	77.5%	82.5%	86.8%
Relative precision @ 90% CI	±15.6%	±14.2%	±11.1%	±9.797%

Six out of 10 sites in PY2023 had tracking measure lives that were equal to their evaluated measure life. The remaining four sites had evaluated measure lives that were updated based on site findings.

5 CONCLUSIONS, RECOMMENDATIONS, AND CONSIDERATIONS

5.1 Conclusions

This study's scope and approach were like the last round of evaluations (PY2021 and PY2022) in handling operational factors. There were no historical adjustments[11] made for PY2023 since all sites in the three-year period received full M&V.

For custom non-lighting, the gross annual energy savings RR saw a net increase from 78.3% in PY2022 to 89.6% in PY2023. The RR for PY2023 was also slightly better than the PY2021 RR of 88.4%. Overall, the combined three-year rolling value increased from 81.4% (PY2020, PY2021, PY2022) to 85.5% (PY2021, PY2022, PY2023). The increase in this RR is attributable to the PY2020 RR of 68.7% dropping from the combined results, but also because of programmatic changes and improvements made by RIE during this three-year cycle.

The RRs for summer and winter on-peak demand showed a decrease in non-lighting peak demand RRs from PY2022 to PY2023 due to operational adjustments, consistently evaluated loads that differed from tracking. The RR for % on-peak energy decreased from PY2022 to PY2023. The increase in PY2023 energy RRs was due to sites having high RRs in non-operational results. All discrepancies occurred in on-site operational parameters. Overall, four sites had RRs greater than or equal to 100%, but three of those four sites had smaller weights (2). Of the six sites with RRs less than 100%, four had larger weights (10.8).

5.2 Recommendations

The RI Energy implementation team and vendors were extremely helpful in addressing questions and concerns during the evaluation. As a result of this assistance, DNV was able to perform a robust evaluation and collect additional research in support of RI Energy.

The DNV team makes the following recommendations based on the data collected, conclusions, results, and process of this impact evaluation. Many of these recommendations could immediately improve operational savings estimates with regards to load, hours of use, etc.

Recommendation 1: This study's RI three-year rolling non-lighting (85.5%) realization rate results shall replace the previous realization rates used by RI Energy beginning in PY2026. RI Energy should continue using 95.4% (from the previous evaluation) RR for lighting. The results from this study should be combined with the next round of custom electric impact evaluation, which will evaluate PY2024 applications and is expected to be applied to the PY2027 tracking savings.

Recommendation 2: DNV recommends that regressive baselines[12] are well documented in applicant documentation including in measure life determination and documents when exceptions are made, such as with previous program participation..

For example, in PY2023, at least three sites (RICE23N059, RICE23N082, RICE23N004) employed a regressive air compressor baseline. Project information did not document the reason for the selected baseline, and evaluators had to rely on information from air compressor vendors, notes from older emails and TA vendors. There is often staff turnover at sites between the implementation and evaluation of projects, which limits the available knowledge on pre-existing equipment or older projects. Requiring the applicant to document the use of the regressive baseline would result in a streamlined evaluation of the project without the reliance on the program administrator or previous site knowledge.

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[11] Results from the PY2019, PY2020, and PY2021 evaluations needed an imputed operational adjustment due to COVID effects at facilities that did not allow on-site metering.

[12] A regressive baseline is a baseline that uses a less efficient piece of equipment in the system it replaces to estimate savings.

Per RI policy that is adopted from the MA baseline framework, a regressive baseline is not allowed unless at least one of the following conditions are met:

1. If equipment is replaced as part of a gut rehabilitation, the pre-existing equipment efficiency need not be considered the minimum standard.
2. If a VFD replaces a failed VFD but the prior drive is documented to have failed more than two years prior to replacement and the system is documented not to have been controlled via speed modulation, then the non-VFD baseline is allowed.
3. The pre-existing condition (equipment) was program funded.

Other exceptions may be allowed, but for each of these sites the regressive baseline was permitted because the pre-existing VFD air compressor was determined to be program funded.

Recommendation 3: DNV recommends that all submittals and final as-built plans for building envelope measures (wall insulation, roof insulation, windows, doors) are included in project closeouts.

For example, for RICE23N077 evaluators could not completely verify the installed insulation type and U or R-values due to the absence of exposed sections and no documentation provided in project files or on-site. Collecting this information as part of the application process—such as in progress photographs of installation before walls are closed, and window labels with make and model numbers—help ensure legitimacy regarding what was installed and will support future M&V efforts.

Recommendation 4: DNV recommends that the implementer should verify the rated heating and cooling capacities of installed equipment and ensure that accurate equipment capacity values are utilized or adjusted in savings estimation tools. Additionally, implementers should perform a post installation site-specific adjustment on calculation models with metered data as appropriate, which would consider the impact of backup heating, heat pump tank water temperature, and standby losses when modeling heat pump and heat pump water heater performance.

For RICE23S100, RICE23N091 and RICE23S088 equipment capacities, operating loads, or efficiencies at specific loads were not calculated accurately. For RICE23S100, the use of backup electric heating was not accounted for which reduced the load on the installed heat pump and impacted overall efficiency. For RICE23N091, one of two measures used a spreadsheet model with assumed/estimated values which shown not to be reflect actual operation. Lastly, for RICE23S088, the savings model assumed year-round heating and cooling loads even though the facility had significantly reduced capacity half of the year. For each of these sites, there was no pre-metering or post-metering performed which would have better informed load estimates and improved overall RRs.

Recommendation 5: DNV recommends RI Energy continue evaluating lifetime savings and reporting them at the site level in all future custom electric evaluations. A standard three-year rolling LSAF was calculated for the second time in this study (Year 4).

Recommendation 6: DNV recommends that project implementers include a list in all savings analysis spreadsheets detailing the key assumptions and inputs used for the project savings analysis. Implementers should link the inputs to the place in the analysis they are being used, and state where each assumption is being sourced from. DNV also recommends that program implementers regularly review and update all baseline assumptions to reflect current Rhode Island Building Code and ASHRAE standards, especially for new construction projects or projects that use a standard calculator with code values ingrained in the calculator.

For RICE23N077, hard coded RI Building Code values were not documented to indicate what code and year were being referenced. For RICE23S088, equipment heating and cooling loads were hard coded based on nameplate information but not documented as such.

5.3   Considerations

The DNV team makes the following considerations based on the data collected, conclusions, results, as part of this impact evaluation. These considerations are drawn from site findings but may require more conversation or thought to implement.

Consideration 1: RIE should consider building modeling, billing, or load analysis for new construction additions to existing buildings.

For RICE23N077, the evaluation included a new wing addition of a school that operated on the same schedule and usage patterns as the existing school. RIE should consider having program implementers use the existing schedules and loads to inform the savings analysis for proposed measures if part of an existing structure. Additionally, this modeling would capture interactive effects between measures.

Consideration 2: RIE should consider having projects provide an estimate of loading when estimating transformer savings to understand load loss savings.

For RICE23N080, transformer savings were estimated based off their load and no-load losses. No-load losses happen whenever the transformer is powered on, even if it isn't supplying electricity to any of the equipment at the facility. These losses are caused by the magnetic field in the transformer's core and stay relatively constant as long as the transformers are energized. For this site, the applicant did not account for load losses—only the no-load losses in the transformers—but the evaluator concluded that load loss savings are not significant unless the transformers are loaded above 25%. Since transformers are typically oversized, having documentation of their expected load would improve M&V.

Consideration 3: RIE should consider that future refrigerant leak consultant reports provide more detailed findings, including the specific causes of leaks (e.g., gasket failures, cracks in welds, gaps between fittings) and an assessment of contributing factors such as excessive vibration, along with potential corrective actions like the use of vibration mounts.

As part of the project for RICE23N091, a refrigerator leak measure was evaluated. DNV anticipates that these types of measures will be more frequent in the future, therefore specific documentation with regards to the leaks will be important for evaluators and customers to understand.

Consideration 4: Based on the outcome of the final report of the MA/RI CAIR ISP Study, RIE may consider removing the third clause of the regressive baseline exception for air compressors, that states a regressive baseline is allowed if the pre-existing condition (equipment) was program funded.

As a result of the MA/RI CAIR ISP Study that is currently with stakeholder review for comment, research concluded that many customers would still install VFD air compressors absent of any program funding.

Consideration 5: RIE may consider program close-out meetings with evaluators and implementers to review findings, recommendations, considerations, and lessons learned from the evaluated program year.

Consideration 6: RIE may consider removing ESPO projects from previous annual RRs that contribute to the next combined three-year RR.

This year's three-year combined RR includes PY2021, PY2022, and PY2023 RRs. Starting in PY2023, ESPO projects were excluded from the evaluation population because RIE is removing such projects from the custom electric program in 2026. Inclusion of ESPO projects in the PY2021 and PY2022 result that make up the first two years of the three-year rolling average may be unrepresentative of the target population forecast of realization rates when applied to a population that no longer contains ESPO projects. DNV believes the risk to the program from using the current combined result is small and

suggests Rhode Island Energy consider removing ESPOs in the next three-year rolling average (PY2022, PY2023, PY2024).

APPENDIX A. SUMMARY OF PY2023 SAMPLED PROJECTS

The following table summarizes the tracking and evaluation savings estimates, site weights by site, measure, and evaluation type.

Site ID	App	Tracking kWh	Weight	Measure	Market event
RICE23S100	14322896	19,644.0	10.8	DHW	NC
RICE23S088	13005334, 13005336	9,459.0	10.8	HVAC	Retrofit
RICE23N080	13992198	28,935.0	10.8	Transformer	Retrofit
RICE23N059	13457744	290,749.0	2	CAIR	NC
RICE23N096	13806092, 14151552	293,934.0	2	Process lighting	NC
RICE23N082	13134292, 14044447	210,273.0	2	CAIR	NC
RICE23N062	13922447, 14572978	517,520.0	2	CAIR	Retrofit/NC
RICE23N004	2117379	144,527.0	2	CAIR	Retrofit
RICE23N091	13977788, 14078553	71,596.0	10.8	Refrigeration, process equipment and controls	Retrofit
RICE23N077	13005576	24,947.0	10.8	HVAC, building shell	NC

APPENDIX B. PY2023 SITE SAVINGS SUMMARY

Site ID	RI Energy application #	TRACKING DATA				EVALUATED RESULTS				Energy realization rate
		Annual energy savings (kWh)	% on-peak savings	Summer on-peak demand savings (kW)	Winter on-peak demand savings (kW)	Annual energy savings (kWh)	% on-peak savings	Summer on-peak demand savings (kW)	Winter on-peak demand savings (kW)	
RICE23S100	14322896	19,644.0	0.83	0.00	0.70	15,386	0.58	2.30	2.50	78%
RICE23S088	13005334, 13005336	9,459.0	0.00	3.48	0.42	4,355	0.65	0.31	2.25	46%
RICE23N080	13992198	28,935.0	0.33	3.30	3.30	28,935	0.46	3.30	3.30	100%
RICE23N059	13457744	290,749.0	0.53	40.90	36.10	201,717	0.39	17.9	21.00	69%
RICE23N096	13806092, 14151552	293,934.0	0.62	58.38	47.74	266,832	0.57	55.85	15.13	91%
RICE23N082	13134292, 14044447	210,273.0	0.67	42.10	38.10	217,417	0.53	27.6	23.1	103%
RICE23N062	13922447, 14572978	517,520.0	0.37	56.69	58.90	549,551	0.18	23.1	19.4	106%
RICE23N004	2117379	144,527.0	0.57	19.70	19.00	173,653	0.41	17.24	19.31	120%
RICE23N091	13977788, 14078553	71,596.0	0.45	4.49	9.95	53,450	0.45	2.62	7.71	75%
RICE23N077	13005576	24,947.0	0.66	3.92	7.82	16,967	0.62	2.56	5.00	68%

APPENDIX C. LIFETIME SAVINGS ADJUSTMENT FACTORS (LSAFs) METHODOLOGY

Evaluation lifetime savings findings should be captured in a lifetime savings adjustment factor (LSAF), which is applied to the tracking **measure life** in the BC Tool used to report PA evaluated savings in the Annual Report. The LSAF is intended to account for the following evaluation findings:

1. Incorrect applicant effective useful life (EUL) measure life assumptions
2. Change in measure application type impacting dual versus single baseline status[13]
3. Incorrect applicant outyear factor (OYF) assumption

First-year saving realization rate. As a starting point, the annual savings realization rate is calculated as the weighted sample verified annual savings divided by the weighted sample tracked savings.

$$RR\% = \frac{\sum w_i \times FYS_i^{Evaluated}}{\sum w_i \times FYS_i^{Tracking}}$$

where:

$RR\%$ = first-year savings realization rate

w_i = site weight

$FYS_i^{Evaluated}$ = site evaluated first-year savings (kWh)

$FYS_i^{Tracking}$ = site tracking first-year savings (kWh)

Measure-level lifetime savings. For each evaluated measure, the evaluators calculated an evaluated lifetime savings using the following formula:

$$LS_{Savings} = FYS_{Evaluated} \times [\ RUL_{Evaluated} + \text{OYF} \times (EUL_{Evaluated} - RUL_{Evaluated})]$$

where:

$LS_{Savings}$ = evaluated lifetime savings (kWh)

$FYS_{Evaluated}$ = evaluated first year savings (kWh)

$EUL_{Evaluated}$ = evaluated measure life (years in decimal form) Reflects revisions to measure life due to alignments with eTRM measure lives or other adjustments or to account for equipment removal after one year.

$RUL_{Evaluated}$ = 1/3 of $EUL_{Evaluated}$ (years)

OYF = 100% for single-baseline measures. 90% for non-lighting dual-baseline measures.

Program lifetime savings realization rate (LSRR%). The LSRR is calculated in similar fashion to the annual savings RR. To calculate LSRR, the weighted evaluated lifetime savings is divided by the weighted tracked lifetime savings. The team calculated LSRR using the following formula:

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[13] For non-lighting measures only. The LSAF published for lighting measures does not incorporate the impacts of dual baseline as RIE at the time did not have the ability in their BCR models to track dual baseline. These dual baseline impacts are covered when applying AMLs published through the LMC study for RIE that have been able to adjust tracking measure lives to use the AMLs, and through the LMC adjustment factor discussed later in this section for RIE that have not been able to make that adjustment, or only partially did.

$$LSRR\% = \frac{\sum w_i \times LS_i^{Evaluated}}{\sum w_i \times FYS_i^{Tracking} \times EUL_i^{Tracking}}$$

where:

$LSRR\%$	= program lifetime savings realization rate
w_i	= site weight
$LS_i^{Evaluated}$	= site evaluated lifetime savings (kWh)
$FYS_i^{Tracking}$	= site tracking first-year savings (kWh)
$EUL_i^{Tracking}$	= tracking measure life

Program LSAF. The LSAF accounts for differences noted in items 1 to 5 above and the different distribution of savings for both first-year and lifetime savings at sites included in the sample. To avoid double counting the impacts of both the FYS RR and the LS RR, we need to calculate both RRs. The LSAF can now be backed out by calculating the ratio of the lifetime savings RR over the first-year savings RR.

$$LSAF = \frac{LSRR\%}{RR\%}$$

where:

$LSAF$	= lifetime savings adjustment factor
$RR\%$	= program first-year savings realization rate
$LSRR\%$	= program lifetime savings realization rate

The program-level LSAF can be used by PAs for reporting lifetime savings and will incrementally impact the lifetime savings after the annual savings realization rate (RR) is applied. To calculate lifetime adjusted gross savings (LAGI), PAs will use the following formula:

$$LAGI = \left(Annual\ Gross\ Savings_{Tracking} \times Annual\ RR\%\right) \times \left(Measure\ life_{Tracking} \times LSAF\right)$$

where:

$LAGI$	= lifetime adjusted gross impact savings (kWh)
$Annual\ gross\ savings_{Tracking}$	= tracking annual gross savings (kWh)
$Measure\ life_{Tracking}$	= tracking measure life (years)
$RR\%$	= program realization rate
$LSAF$	= lifetime savings adjustment factor

The BC Model requires as input PA gross annual tracking savings and tracking measure life and does not accept as input tracking lifetime savings. The tracking measure life reflects project level applicant effective useful measure life selections and in the future dual baseline effects. The BC Model specifies evaluation factors that are required to report evaluated savings. Due to the calculation methods employed by the BC Model, the LSAF will be applied to tracking measure life.

APPENDIX D. PY2023 SITE REPORTS

RHODE ISLAND CUSTOM ELECTRIC SITE-SPECIFIC REPORT
SITE ID: RICE23N062

Report Date: May 27, 2025

Program Administrator	Rhode Island Energy
Application ID(s)	13922447,14572978
Project Type	C&I New Construction, Existing Building Retrofit
Evaluation Type	Full M&V
Program Year	PY2023
Evaluation Firm	DNV
Evaluation Engineer	Dan Barbieri
Senior Engineer	Rick Boswell

1   EVALUATED SITE SUMMARY AND RESULTS

The evaluated project consists of two applications at an existing light industrial facility: one new construction project for the installation of two new variable speed drive (VSD) air compressors and one cycling refrigerated compressed air dryer (Measure M1); and one retrofit project for compressed air leak repairs (Measure M2). The installed VSD air compressors save energy due to their lower electricity usage compared to the baseline fixed-speed air compressors. The installed cycling refrigerated dryer saves energy due to its lower electricity usage compared to the baseline non-cycling refrigerated compressed air dryer. The leak reduction measure saves energy due to the reduction of air flow load on the air compressors. The impacted facility is described as operating 24 hours per day for seven days per week, with one day of shutdown every other Sunday. There are approximately two weeks of shutdown per year.

According to the project documents, the facility had three existing compressors in place:

- One Ingersoll Rand EP-200 200HP fixed-speed compressor installed circa 1989. The unit failed in 2021 and was taken offline.
- One Ingersoll Rand R160ie 200HP fixed-speed compressor circa 2016. This unit recently failed in 2022 and had temporarily been replaced with a rental compressor of the same size and model.
- One Ingersoll Rand R160ne 200HP VSD backup compressor circa 2011 currently running (presumably in addition to the rental) to satisfy the required compressed air load. Given its age and high run hours, the unit is expected to become a backup if/when the two fixed-speed machines are replaced.

After reviewing the tracking files and information gathered during the site visit, the evaluator classified Measure M1 as a new construction measure with a single baseline and Measure M2 as a retrofit. The evaluator calculated the project savings using an 8,760 spreadsheet analysis using evaluation data collected between February 18, 2025 and April 11, 2025. The evaluation results are presented in Table 1-1.

Table 1-1. Evaluation results summary

PA application ID	Measure name		Annual electric energy (kWh)	% of energy savings on-peak	Summer on-peak demand (kW)	Winter on-peak demand (kW)
13922447	M1: Air Compressor Replacement	Tracked	135,552	30%	0.7	2.9
		Evaluated	40,718	-381%	-39.6	-39.6
		Realization Rate	30%	-1268%	-5651%	-1365%
14572978	M2: Compressed Air Leak Reduction	Tracked	381,968	40%	56.0	56.0
		Evaluated	508,833	50%	62.7	59.0
		Realization Rate	133%	126%	112%	105%
Total		Tracked	517,520	37%	56.7	58.9
		Evaluated	549,551	18%	23.1	19.4
		Realization Rate	106%	49%	41%	33%

1.1   Explanation of deviations from tracking

Overall, the evaluated savings for this project are 6% greater than the tracking values predominantly because of operational discrepancies related to compressor performance and operating hours. For Measure M1, the evaluated savings are 70% less than the tracking values due primarily to the average kW/CFM of the installed compressors being greater (less efficient) than the baseline compressors. For Measure M2, the evaluated savings are 33% more than the tracking values due

primarily to increased operating hours and improved delta kW/CFM between the installed compressor's loading before and after the leaks were repaired. Further details regarding deviations from the tracked savings are presented in Section 3.1.

1.2   Recommendations for program designers and implementers

The evaluator recommends that an updated industry standard practice (ISP) baseline study be performed on common compressed air measures such as VSD air compressors. The most recent compressed air ISP study was completed in 2018,[1] and recommends a load/no-load baseline. However, this measure has been available for many years now, and the evaluator believes that the industry standard practice may be moving away from load/no-load compressors and instead may be shifting toward VSD-driven air compressors as standard practice.

The evaluator recommends that multi-measure projects within the same end-use should use the same applicant analysis methodology whenever possible, or otherwise account for interaction between measures.

1.3   Customer alerts

There are no relevant customer alerts.

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[1] https://ma-eeac.org/wp-content/uploads/AirCompressors_ISP_Memo_final.pdf

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 with the information available.

The evaluated measures for this site are summarized in Table 2-1.

Table 2-1. Evaluated measures

Measure	Project ID	Measure description
M1	13922447	Install two Ingersoll Rand R160ne 200 HP VSD air compressors each capable of providing up to 1,060 cfm at 100 psi. The pre-existing equipment consists of 1) a failed EP-200 200 HP fixed speed compressor circa 1989, 2) a failed R160ie 200 HP fixed speed compressor circa 2016 temporarily replaced with the same size/model rental compressor, and 3) a R160ne 200 HP VSD backup compressor circa 2011 currently running to satisfy the required compressed air load. The applicant baseline was (2) R160ie fixed speed air compressors operating load/no-load, with the existing VSD compressor relegated to backup given its age and high run hours. Install one Ingersoll Rand DA3000NVCA cycling refrigerated compressed air dryer capable of drying up to 1,800 cfm of compressed air at 100 psi. The pre-existing equipment consists of an end-of-life compressed air dryer. The applicant baseline was a non-cycling refrigerated compressed air dryer.
M2	14572978	Repair 120 compressed air leaks ranging in size from 1 CFM to 4.5 CFM totaling 271 CFM of leakage. The baseline for this measure is a two VSD compressor system operating at 1,166 CFM of total load, six days per week, 50 weeks per year. The proposed condition is removing 271 CFM of leakage load from the baseline compressed air system.

2.1   Application information and applicant savings methodology

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

2.1.1   Applicant description of baseline

According to the project files, the applicant classified measure M1 as new construction with a single baseline using industry standard practice. The applicant used two 200 HP fixed-speed air compressors and one 2,000 CFM non-cycling refrigerated dryer for the baseline. Despite the presence of an existing VSD air compressor at the facility, this did not affect the applicant baseline. It was running only because two other compressors had failed, and project documents state that the existing R160ne will become a full-time backup unit. The existing R160ne was manufactured in 2011, has high run hours, and it is unknown whether it was incentivized, so the applicability of a regressive baseline was not mentioned. In effect, the event type suggests "replace on failure" since the new compressors will physically and operationally replace the two failed fixed speed compressors. The applicant used industry standard practice baseline of fixed-speed, load/no-load compressors with 4 gallons per CFM of storage and a non-cycling refrigerated air dryer.

For the compressed air leak reduction measure M2, the applicant classified it as a retrofit and used a baseline of two VSD compressors operating at a maximum load of 1,166 CFM, six days per week, 50 weeks per year, inclusive of 271 CFM of compressed air leaks.

Table 2-2 shows the pre-existing key parameters in the savings models.

Table 2-2. Applicant baseline key parameters

Measure	Parameter name	Parameter value	Source of parameter value
M1	Control type	Load/no-load compressor with 4 gal/cfm of storage	2018 Compressed Air ISP Study[2]
M1	Compressor size	200 HP each	Project documents
M1	Total Compressor average CFM demand	1,808 CFM (both)	Flow data from 9/24/23 to 10/5/23
M1	Compressor annual runtime	7,200 hours/year	144 hours per week x 50 weeks per year
M1	Compressor average kW when running	335.7 kW (both)	Applicant calculations
MI	Compressor average kW/CFM	0.186 kW/CFM	Ratio of preceding values: 335.7 kW / 1,808 CFM
M1	Air dryer type	Non-cycling refrigerated	Project documents
M1	Dryer full flow capacity	2,000 CFM	Project documents
M1	Dryer full flow power	13.8 kW	Project documents
M1	Dryer zero flow power	10.35 kW	Project documents
M2	Number of leaks identified	120	Project documents
M2	Total leak flow identified	271 CFM	Project documents

2.1.2 Applicant description of installed equipment and operation

This project includes installing two 200 HP VSD air compressors and one 1,800 CFM cycling refrigerated air dryer. Table 2-3 presents the main parameters of the proposed case as defined by the applicant.

Table 2-3. Applicant's proposed key parameters

Measure	Parameter name	Parameter value	Source of parameter value
M1	Control type	Variable speed drive	Project documents
M1	Compressor size	200 HP each	Project documents
M1	Compressor average kW when running	315.5 kW (both)	Applicant calculations
M1	Compressor average kW/CFM	0.175 kW/CFM	Ratio of preceding values: 315.5 kW / 1,808 CFM
M1	Air dryer type	Cycling refrigerated	Project documents
M1	Dryer full flow capacity	1,800 CFM	Project documents
M1	Dryer full flow power	5.1 kW	Project documents
M1	Dryer zero flow power	0.51 kW	Project documents
M2	Number of leaks repaired	120	Project documents
M2	Total leak flow post-repair	0 CFM	Project documents

2.1.3 Applicant energy savings algorithm

Measure 1: New VSD air compressors and cycling refrigerated dryer

The tracking calculations for the VSD air compressors began with baseline flow (CFM) data that was measured between 9/24/23 and 10/5/23 on the pre-existing compressors. The measurements were taken at 1-minute intervals. This CFM data

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[2] https://ma-eeac.org/wp-content/uploads/AirCompressors_ISP_Memo_final.pdf

was converted to ISP baseline kW data using the formula below. This formula references the Compressed Air Challenge kW vs. CFM curves, and from those curves, the tracking calculations compute the coefficients using the "Linest()" function in Excel, which also adjusts for rated full load and zero flow kW from CAGI data. No adjustments for operating pressure were necessary.

$$Compressor\ kW_{Baseline} = A \times CFM^3 + B \times CFM^2 + C \times CFM + D$$

Where the baseline constants are:

Variable	Value
A	-0.0177
B	-0.3783
C	0.9971
D	0.3997

The proposed case compressor kW for this measurement period was calculated using the formula below. The coefficients are based on plotting the kW vs. CFM points from the CAGI sheet and then using the "Linest()" function in excel. No adjustments for operating pressure were necessary.

$$Compressor\ kW_{Proposed} = A \times CFM^3 + B \times CFM^2 + C \times CFM + D$$

Where the proposed case constants are:

Variable	Value
A	0
B	0.0000
C	0.1259
D	11.3153

For the compressed air dryer component of this project, tracking savings were modeled in a similar manner, building upon the same baseline flow (CFM) data that was measured between 9/24/23 and 10/5/23 on the pre-existing compressors. This CFM data was converted to ISP baseline kW data using the linear relationship below and Excel's "Slope()" and "Intercept()" functions. The non-cycling refrigerated dryer used to model the baseline was an Ingersoll Rand D3400INA.

$$Dryer\ kW_{Baseline} = m \times CFM + b$$

Where the baseline constants are:

Variable	Value
m	0.0017
b	10.35
kW_{min}	10.35
kW_{max}	13.8
CFM_{min}	0
CFM_{max}	2,000

Similarly, the proposed cycling refrigerated dryer was modeled as an Ingersoll Rand DA3000NVCA using the linear relationship below and Excel's "Slope()" and "Intercept()" functions.

$$Dryer\ kW_{Proposed} = m \times CFM + b$$

Where the proposed constants are:

Variable	Value
m	0.0026
b	0.51
kW_{min}	0.51
kW_{max}	5.1
CFM_{min}	0
CFM_{max}	1,800

Finally, building upon the average measured CFM data, a weekly by hourly matrix was developed, as shown in Figure 2-1. The quantities Base ("baseline") kW and Prop ("proposed") kW are computed as follows:

$$Base\ kW = Compressor\ kW_{Baseline} + Dryer\ kW_{Baseline}$$

$$Prop\ kW = Compressor\ kW_{Proposed} + Dryer\ kW_{Proposed}$$

Figure 2-1. CFM and kW for baseline and proposed compressor by hour and day of week

	Average Hourly Data (CFM, Base/Existing Demand, Proposed Demand)																					
	Mon			Tue			Wed			Thu			Fri			Sat			Sun		
Hour	CFM	Base kW	Prop kW	CFM	Base kW	Prop kW	CFM	Base kW	Prop kW	CFM	Base kW	Prop kW	CFM	Base kW	Prop kW	CFM	Base kW	Prop kW	CFM	Base kW	Prop kW
0	688	147.8	117.0	1831	341.5	318.4	1844	342.1	321.0	1996	351.7	350.9	2007	352.8	353.1	1943	349.2	340.2	0	0.0	0.0
1	705	149.9	120.0	1747	334.5	302.3	1841	341.5	320.6	1921	346.2	336.3	1960	350.2	343.6	1879	344.9	327.8	0	0.0	0.0
2	704	149.8	119.7	1812	340.2	314.7	1801	338.7	312.7	1964	349.6	344.7	1933	348.6	338.2	1880	345.3	327.9	0	0.0	0.0
3	1235	262.3	213.8	1667	327.7	287.1	1686	329.3	290.7	1746	334.0	302.2	1793	338.6	311.1	1754	335.6	303.5	0	0.0	0.0
4	1377	295.7	234.0	1824	340.8	317.0	1814	339.8	315.1	1866	343.9	325.2	1876	344.6	327.1	1714	332.2	295.9	0	0.0	0.0
5	1385	296.7	235.4	1814	340.0	315.2	1766	336.2	305.8	1827	340.4	317.8	1772	336.9	307.0	1682	329.0	289.9	0	0.0	0.0
6	1383	296.5	235.1	1774	336.2	307.6	1805	339.5	313.4	1838	341.2	320.0	1822	340.6	316.6	1396	295.6	243.7	0	0.0	0.0
7	1347	287.4	229.3	1751	334.2	303.3	1817	339.9	315.7	1829	339.9	318.3	1746	334.8	302.1	1144	262.8	205.5	0	0.0	0.0
8	1353	258.1	237.2	1981	351.0	347.8	2001	352.1	351.9	2084	356.6	368.5	1989	351.6	349.3	1141	262.4	204.9	0	0.0	0.0
9	1422	274.3	246.6	1947	349.2	341.2	1912	347.1	334.2	1876	344.4	327.1	1945	349.1	340.6	1140	262.2	204.6	0	0.0	0.0
10	1933	343.4	339.9	2025	353.7	356.6	1990	351.4	349.7	2069	355.8	365.4	2028	354.0	357.1	1139	262.0	204.4	0	0.0	0.0
11	2083	356.5	368.3	1996	351.8	350.9	2041	354.0	359.9	2077	355.9	367.2	2035	354.3	358.6	1138	261.8	204.2	0	0.0	0.0
12	1962	350.1	344.1	1849	342.1	322.1	1893	345.8	330.4	1896	345.2	331.2	1789	338.2	310.3	1137	261.7	204.0	0	0.0	0.0
13	1942	348.4	340.2	1893	344.6	330.8	2027	353.6	357.1	2008	352.6	353.3	2029	353.6	357.5	1135	261.4	203.6	0	0.0	0.0
14	1904	345.4	333.0	1846	342.2	321.4	2021	353.1	356.0	2118	357.9	375.3	2003	352.5	352.2	910	216.0	165.3	0	0.0	0.0
15	1861	342.7	324.5	1801	338.2	312.9	1958	349.6	343.4	2053	354.6	362.3	2079	356.0	367.7	0	0.0	0.0	0	0.0	0.0
16	2073	355.9	366.3	1970	349.3	346.0	2005	352.2	352.7	2115	357.9	374.7	2133	358.5	378.4	0	0.0	0.0	0	0.0	0.0
17	1969	350.2	345.6	1934	348.0	338.6	1938	347.6	339.5	2029	353.6	357.5	1973	351.0	346.2	0	0.0	0.0	0	0.0	0.0
18	2033	353.8	358.2	1959	349.4	343.7	1789	337.2	310.6	2095	357.0	370.7	2061	355.6	363.7	0	0.0	0.0	0	0.0	0.0
19	1833	341.0	318.9	1751	334.8	303.2	1594	320.2	273.6	1904	346.8	332.5	1944	349.2	340.5	0	0.0	0.0	597	126.5	101.9
20	1850	342.8	322.1	1872	343.8	326.6	1722	332.3	297.6	1945	349.4	340.7	1974	351.0	346.4	0	0.0	0.0	664	144.6	112.7
21	1869	344.1	325.7	1740	333.8	301.0	1812	340.0	314.8	1857	343.5	323.4	1813	340.0	314.9	0	0.0	0.0	657	143.7	111.5
22	1735	333.4	300.0	1815	340.1	315.2	1779	336.8	308.6	1782	337.4	309.0	1764	336.1	305.4	0	0.0	0.0	657	143.7	111.4
23	1736	333.5	300.3	1739	333.8	300.8	1746	333.7	302.2	1851	343.0	322.2	1753	334.6	303.5	0	0.0	0.0	662	144.3	112.3

The baseline and proposed kW data was then summed by day-of-week and hour-of-day times 50 weeks to estimate the total annual energy usage.

$$Baseline\ kWh = \sum_{DOW=1}^{7} \sum_{Hour=0}^{23} Base\ kW \times 50 \frac{weeks}{year}$$

$$Proposed\ kWh = \sum_{DOW=1}^{7} \sum_{Hour=0}^{23} Prop\ kW \times 50 \frac{weeks}{year}$$

Using the preceding formulas, the applicant computed baseline compressor and dryer energy use as 2,272,529 kWh. The corresponding proposed energy use was computed to be 2,136,977 kWh, so the annual energy savings attributable to the installation of the new VSD air compressors and cycling dryer is 135,552 kWh.

Measure 2: Compressed air leak reduction

Unlike the preceding compressed air analysis, the associated energy analysis for the compressed air leak reduction measure is done in a more simplified manner that incorporates some broad assumptions and does not build upon any known operational data. Instead of leveraging the same analysis model as Measure 1, the tracking analysis used the assumed capacity of the proposed VSD compressors (1,060 CFM), the tallied existing leaks and proposed leak repairs from a survey, and the loading percentages presented in Figure 2-2 below to develop an hourly analysis for a typical weekday, Saturday, and Sunday by shift. The model assumes three shifts on weekdays, two shifts on Saturday, and no operation on Sunday. It should be noted that the assumed flow rate of 1,060 CFM is considerably less than the 1,808 CFM used in the calculations for Measure 1.

Figure 2-2. Compressor loading assumptions

Compressor weekly loading	Shift #	Weekday	Saturday	Sunday	Overall
Compressor #1 Percent Load - First Shift (%)	1	95%	95%	0%	95.0%
Compressor #1 Percent Load - Second Shift (%)	2	95%	95%	0%	95.0%
Compressor #1 Percent Load - Third Shift (%)	3	95%	0%	0%	95.0%
Average (%)	avg	95%	95%	0%	95.0%
Compressor #2 Percent Load - First Shift (%)	1	15%	15%	0%	15.0%
Compressor #2 Percent Load - Second Shift (%)	2	15%	15%	0%	15.0%
Compressor #2 Percent Load - Third Shift (%)	3	15%	0%	0%	15.0%
Average (%)	avg	15%	15%	0%	15.0%

The applicant used kW/CFM values from the Compressed Air Challenge as depicted in Figure 2-3 for compressor Type 8 (Rotary Screw, Multi-Stage, VSD). The applicant modeled the CFM by hour in three separate analysis grids: Weekday (Figure 2-4), Saturday (Figure 2-5), and Sunday (Figure 2-6). To convert from CFM to kW, This contrasts with the analysis for Measure 1 in which the applicant used polynomial curve coefficients to develop kW estimates.

Figure 2-3. Compressor performance data used in calculations (Type 8)

Compressor Performance Data												
Percent Load	Type 1 kW/CFM	Type 2 kW/CFM	Type 3 kW/CFM	Type 4 kW/CFM	Type 5 kW/CFM	Type 6 kW/CFM	Type 7 kW/CFM	Type 8 kW/CFM	Type 9 kW/CFM	Type 10 kW/CFM	Type 11 kW/CFM	Type 12 kW/CFM
0%	0.0000	0.0000	0.0000	0.0000	0.2122	0.0000	0.0000	0.2016	0.0000	0.2016	0.0000	0.2730
1%	0.0000	0.0000	0.5000	2.0000	0.2122	2.0000	2.0000	0.2016	0.7120	0.2016	0.0300	0.2730
10%	0.3452	0.3452	0.4892	1.4038	0.2122	0.6510	1.4038	0.2016	0.6440	0.2016	0.0500	0.2730
20%	0.2440	0.2440	0.3204	0.7369	0.2122	0.3883	0.7369	0.2016	0.3864	0.1868	0.0741	0.2730
30%	0.2099	0.2099	0.2637	0.5151	0.2122	0.3138	0.5151	0.2016	0.3189	0.1859	0.1456	0.2049
40%	0.1926	0.1926	0.2352	0.4041	0.2122	0.2794	0.4041	0.2016	0.2760	0.1845	0.1714	0.1886
50%	0.1820	0.1820	0.2178	0.3379	0.1923	0.2608	0.3379	0.1827	0.2355	0.1838	0.1874	0.1930
60%	0.1747	0.1747	0.2060	0.2934	0.1877	0.2492	0.2934	0.1784	0.2146	0.1826	0.1936	0.1932
70%	0.1694	0.1694	0.1975	0.2619	0.1855	0.2212	0.2619	0.1762	0.2024	0.1813	0.2011	0.1945
80%	0.1653	0.1653	0.1909	0.2380	0.1849	0.2000	0.2380	0.1757	0.1955	0.1794	0.2099	0.1972
90%	0.1620	0.1620	0.1857	0.2196	0.1852	0.1837	0.2196	0.1759	0.1922	0.1773	0.2176	0.2000
100%	0.1593	0.1593	0.1804	0.2052	0.1873	0.1706	0.2052	0.1780	0.1842	0.1761	0.2437	0.2021

At the top of Figure 2-4, we see the existing and proposed leakage with resultant flow savings of 276.2 CFM. This differs from the 271 CFM listed in project documentation and the leak survey. This is one applicant discrepancy that will be annotated at the end of this site report in Section 3.1, Explanation of differences.

Figure 2-4. Leak reduction analysis: Weekday

		#1	#2	#3	#4
Existing leaks total	819.0				
Proposed leaks total	542.8				
CFM savings	276.2				
User input kW/cfm correc	1.00	1.00	1.00	1.00	
Dryer kW/cfm factor	0.008				

Weekday Compressed Air Leak Analysis

Hour	Existing Total CFM	Existing Total kW	CFM Output #1	#2	#3	#4	Power kW #1	#2	#3	#4	Post-Repair Total CFM	Total kW	CFM Output #1	#2	#3	#4	Power kW #1	#2	#3	#4	Total Savings kW=kWh
1	1,166	220.8	1,007	159	0	0	188.7	32.1	0.0	0.0	890	164.6	890	0	0	0	164.6	0.0	0.0	0.0	56.2
2	1,166	220.8	1,007	159	0	0	188.7	32.1	0.0	0.0	890	164.6	890	0	0	0	164.6	0.0	0.0	0.0	56.2
3	1,166	220.8	1,007	159	0	0	188.7	32.1	0.0	0.0	890	164.6	890	0	0	0	164.6	0.0	0.0	0.0	56.2
4	1,166	220.8	1,007	159	0	0	188.7	32.1	0.0	0.0	890	164.6	890	0	0	0	164.6	0.0	0.0	0.0	56.2
5	1,166	220.8	1,007	159	0	0	188.7	32.1	0.0	0.0	890	164.6	890	0	0	0	164.6	0.0	0.0	0.0	56.2
6	1,166	220.8	1,007	159	0	0	188.7	32.1	0.0	0.0	890	164.6	890	0	0	0	164.6	0.0	0.0	0.0	56.2
7	1,166	220.8	1,007	159	0	0	188.7	32.1	0.0	0.0	890	164.6	890	0	0	0	164.6	0.0	0.0	0.0	56.2
8	1,166	220.8	1,007	159	0	0	188.7	32.1	0.0	0.0	890	164.6	890	0	0	0	164.6	0.0	0.0	0.0	56.2
9	1,166	220.8	1,007	159	0	0	188.7	32.1	0.0	0.0	890	164.6	890	0	0	0	164.6	0.0	0.0	0.0	56.2
10	1,166	220.8	1,007	159	0	0	188.7	32.1	0.0	0.0	890	164.6	890	0	0	0	164.6	0.0	0.0	0.0	56.2
11	1,166	220.8	1,007	159	0	0	188.7	32.1	0.0	0.0	890	164.6	890	0	0	0	164.6	0.0	0.0	0.0	56.2
12	1,166	220.8	1,007	159	0	0	188.7	32.1	0.0	0.0	890	164.6	890	0	0	0	164.6	0.0	0.0	0.0	56.2
13	1,166	220.8	1,007	159	0	0	188.7	32.1	0.0	0.0	890	164.6	890	0	0	0	164.6	0.0	0.0	0.0	56.2
14	1,166	220.8	1,007	159	0	0	188.7	32.1	0.0	0.0	890	164.6	890	0	0	0	164.6	0.0	0.0	0.0	56.2
15	1,166	220.8	1,007	159	0	0	188.7	32.1	0.0	0.0	890	164.6	890	0	0	0	164.6	0.0	0.0	0.0	56.2
16	1,166	220.8	1,007	159	0	0	188.7	32.1	0.0	0.0	890	164.6	890	0	0	0	164.6	0.0	0.0	0.0	56.2
17	1,166	220.8	1,007	159	0	0	188.7	32.1	0.0	0.0	890	164.6	890	0	0	0	164.6	0.0	0.0	0.0	56.2
18	1,166	220.8	1,007	159	0	0	188.7	32.1	0.0	0.0	890	164.6	890	0	0	0	164.6	0.0	0.0	0.0	56.2
19	1,166	220.8	1,007	159	0	0	188.7	32.1	0.0	0.0	890	164.6	890	0	0	0	164.6	0.0	0.0	0.0	56.2
20	1,166	220.8	1,007	159	0	0	188.7	32.1	0.0	0.0	890	164.6	890	0	0	0	164.6	0.0	0.0	0.0	56.2
21	1,166	220.8	1,007	159	0	0	188.7	32.1	0.0	0.0	890	164.6	890	0	0	0	164.6	0.0	0.0	0.0	56.2
22	1,166	220.8	1,007	159	0	0	188.7	32.1	0.0	0.0	890	164.6	890	0	0	0	164.6	0.0	0.0	0.0	56.2
23	1,166	220.8	1,007	159	0	0	188.7	32.1	0.0	0.0	890	164.6	890	0	0	0	164.6	0.0	0.0	0.0	56.2
24	1,166	220.8	1,007	159	0	0	188.7	32.1	0.0	0.0	890	164.6	890	0	0	0	164.6	0.0	0.0	0.0	56.2
																					1,348.1

Within each calculation grid, the total CFM in column two is distributed across each of the two existing compressors using the factors presented in Figure 2-2. Note that the spreadsheet has room for four compressors but only two are utilized in this analysis. Above in Figure 2-4 we see that 1,166 CFM is distributed as 1,007 CFM to compressor #1 and 159 CFM to compressor #2. The 1,007 CFM is the CAGI rated full load capacity (1,060 CFM) times an assumed 95% load factor. The balance of 159 CFM went to the second compressor, simulating a lead/lag control method. Then the "Power Consumed by Compressors (kW)" columns are computed using the kW/CFM values from Figure 2-3. Next, the analysis subtracts the leak reduction CFM savings of 276.2 CFM from the total 1,166 CFM to yield the Post-Repair flow of 890 CFM. That flow is distributed across the compressors and converted to kW using the same method for the existing system. Finally, the last column subtracts the post-repair total kW from the existing total kW to yield total kW savings. The total at the bottom of the last column in Figure 2-4 is the 1,348.1 kWh consumption across all 24 hours for an average weekday. This modelling approach is repeated in the next two figures for Saturday and Sunday operation.

Figure 2-5. Leak reduction analysis: Saturday

Saturday Compressed Air Leak Analysis

Hour	Existing Total CFM	Existing Total kW	CFM Output #1	#2	#3	#4	Power kW #1	#2	#3	#4	Post-Repair Total CFM	Total kW	CFM Output #1	#2	#3	#4	Power kW #1	#2	#3	#4	Total Savings kW=kWh
1	0	0.0	0	0	0	0	0.0	0.0	0.0	0.0	0	0.0	0	0	0	0	0.0	0.0	0.0	0.0	0.0
2	0	0.0	0	0	0	0	0.0	0.0	0.0	0.0	0	0.0	0	0	0	0	0.0	0.0	0.0	0.0	0.0
3	0	0.0	0	0	0	0	0.0	0.0	0.0	0.0	0	0.0	0	0	0	0	0.0	0.0	0.0	0.0	0.0
4	0	0.0	0	0	0	0	0.0	0.0	0.0	0.0	0	0.0	0	0	0	0	0.0	0.0	0.0	0.0	0.0
5	0	0.0	0	0	0	0	0.0	0.0	0.0	0.0	0	0.0	0	0	0	0	0.0	0.0	0.0	0.0	0.0
6	0	0.0	0	0	0	0	0.0	0.0	0.0	0.0	0	0.0	0	0	0	0	0.0	0.0	0.0	0.0	0.0
7	1,166	220.8	1,007	159	0	0	188.7	32.1	0.0	0.0	890	164.6	890	0	0	0	164.6	0.0	0.0	0.0	56.2
8	1,166	220.8	1,007	159	0	0	188.7	32.1	0.0	0.0	890	164.6	890	0	0	0	164.6	0.0	0.0	0.0	56.2
9	1,166	220.8	1,007	159	0	0	188.7	32.1	0.0	0.0	890	164.6	890	0	0	0	164.6	0.0	0.0	0.0	56.2
10	1,166	220.8	1,007	159	0	0	188.7	32.1	0.0	0.0	890	164.6	890	0	0	0	164.6	0.0	0.0	0.0	56.2
11	1,166	220.8	1,007	159	0	0	188.7	32.1	0.0	0.0	890	164.6	890	0	0	0	164.6	0.0	0.0	0.0	56.2
12	1,166	220.8	1,007	159	0	0	188.7	32.1	0.0	0.0	890	164.6	890	0	0	0	164.6	0.0	0.0	0.0	56.2
13	1,166	220.8	1,007	159	0	0	188.7	32.1	0.0	0.0	890	164.6	890	0	0	0	164.6	0.0	0.0	0.0	56.2
14	1,166	220.8	1,007	159	0	0	188.7	32.1	0.0	0.0	890	164.6	890	0	0	0	164.6	0.0	0.0	0.0	56.2
15	1,166	220.8	1,007	159	0	0	188.7	32.1	0.0	0.0	890	164.6	890	0	0	0	164.6	0.0	0.0	0.0	56.2
16	1,166	220.8	1,007	159	0	0	188.7	32.1	0.0	0.0	890	164.6	890	0	0	0	164.6	0.0	0.0	0.0	56.2
17	1,166	220.8	1,007	159	0	0	188.7	32.1	0.0	0.0	890	164.6	890	0	0	0	164.6	0.0	0.0	0.0	56.2
18	1,166	220.8	1,007	159	0	0	188.7	32.1	0.0	0.0	890	164.6	890	0	0	0	164.6	0.0	0.0	0.0	56.2
19	1,166	220.8	1,007	159	0	0	188.7	32.1	0.0	0.0	890	164.6	890	0	0	0	164.6	0.0	0.0	0.0	56.2
20	1,166	220.8	1,007	159	0	0	188.7	32.1	0.0	0.0	890	164.6	890	0	0	0	164.6	0.0	0.0	0.0	56.2
21	1,166	220.8	1,007	159	0	0	188.7	32.1	0.0	0.0	890	164.6	890	0	0	0	164.6	0.0	0.0	0.0	56.2
22	1,166	220.8	1,007	159	0	0	188.7	32.1	0.0	0.0	890	164.6	890	0	0	0	164.6	0.0	0.0	0.0	56.2
23	0	0.0	0	0	0	0	0.0	0.0	0.0	0.0	0	0.0	0	0	0	0	0.0	0.0	0.0	0.0	0.0
24	0	0.0	0	0	0	0	0.0	0.0	0.0	0.0	0	0.0	0	0	0	0	0.0	0.0	0.0	0.0	0.0
																					898.7

Figure 2-6. Leak reduction analysis: Sunday

Sunday Compressed Air Leak Analysis																					
	Existing										Post-Repair										Total Savings
	Total		CFM Output of Compressors (CFM)				Power Consumed by Compressors (kW)				Total		CFM Output of Compressors (CFM)				Power Consumed by Compressors (kW)				
Hour	CFM	kW	#1	#2	#3	#4	#1	#2	#3	#4	CFM	kW	#1	#2	#3	#4	#1	#2	#3	#4	kW=kWh
1	0	0.0	0	0	0	0	0.0	0.0	0.0	0.0	0	0.0	0	0	0	0	0.0	0.0	0.0	0.0	0.0
2	0	0.0	0	0	0	0	0.0	0.0	0.0	0.0	0	0.0	0	0	0	0	0.0	0.0	0.0	0.0	0.0
3	0	0.0	0	0	0	0	0.0	0.0	0.0	0.0	0	0.0	0	0	0	0	0.0	0.0	0.0	0.0	0.0
4	0	0.0	0	0	0	0	0.0	0.0	0.0	0.0	0	0.0	0	0	0	0	0.0	0.0	0.0	0.0	0.0
5	0	0.0	0	0	0	0	0.0	0.0	0.0	0.0	0	0.0	0	0	0	0	0.0	0.0	0.0	0.0	0.0
6	0	0.0	0	0	0	0	0.0	0.0	0.0	0.0	0	0.0	0	0	0	0	0.0	0.0	0.0	0.0	0.0
7	0	0.0	0	0	0	0	0.0	0.0	0.0	0.0	0	0.0	0	0	0	0	0.0	0.0	0.0	0.0	0.0
8	0	0.0	0	0	0	0	0.0	0.0	0.0	0.0	0	0.0	0	0	0	0	0.0	0.0	0.0	0.0	0.0
9	0	0.0	0	0	0	0	0.0	0.0	0.0	0.0	0	0.0	0	0	0	0	0.0	0.0	0.0	0.0	0.0
10	0	0.0	0	0	0	0	0.0	0.0	0.0	0.0	0	0.0	0	0	0	0	0.0	0.0	0.0	0.0	0.0
11	0	0.0	0	0	0	0	0.0	0.0	0.0	0.0	0	0.0	0	0	0	0	0.0	0.0	0.0	0.0	0.0
12	0	0.0	0	0	0	0	0.0	0.0	0.0	0.0	0	0.0	0	0	0	0	0.0	0.0	0.0	0.0	0.0
13	0	0.0	0	0	0	0	0.0	0.0	0.0	0.0	0	0.0	0	0	0	0	0.0	0.0	0.0	0.0	0.0
14	0	0.0	0	0	0	0	0.0	0.0	0.0	0.0	0	0.0	0	0	0	0	0.0	0.0	0.0	0.0	0.0
15	0	0.0	0	0	0	0	0.0	0.0	0.0	0.0	0	0.0	0	0	0	0	0.0	0.0	0.0	0.0	0.0
16	0	0.0	0	0	0	0	0.0	0.0	0.0	0.0	0	0.0	0	0	0	0	0.0	0.0	0.0	0.0	0.0
17	0	0.0	0	0	0	0	0.0	0.0	0.0	0.0	0	0.0	0	0	0	0	0.0	0.0	0.0	0.0	0.0
18	0	0.0	0	0	0	0	0.0	0.0	0.0	0.0	0	0.0	0	0	0	0	0.0	0.0	0.0	0.0	0.0
19	0	0.0	0	0	0	0	0.0	0.0	0.0	0.0	0	0.0	0	0	0	0	0.0	0.0	0.0	0.0	0.0
20	0	0.0	0	0	0	0	0.0	0.0	0.0	0.0	0	0.0	0	0	0	0	0.0	0.0	0.0	0.0	0.0
21	0	0.0	0	0	0	0	0.0	0.0	0.0	0.0	0	0.0	0	0	0	0	0.0	0.0	0.0	0.0	0.0
22	0	0.0	0	0	0	0	0.0	0.0	0.0	0.0	0	0.0	0	0	0	0	0.0	0.0	0.0	0.0	0.0
23	0	0.0	0	0	0	0	0.0	0.0	0.0	0.0	0	0.0	0	0	0	0	0.0	0.0	0.0	0.0	0.0
24	0	0.0	0	0	0	0	0.0	0.0	0.0	0.0	0	0.0	0	0	0	0	0.0	0.0	0.0	0.0	0.0
																					0.0

30,028	Existing Weekly Energy Consumption
1,501,415	Existing Annual Energy Consumption
220.8	Existing Compressor Demand

22,389	Proposed Weekly Energy Consumption
1,119,447	Proposed Annual Energy Consumption
164.6	Proposed Compressor Demand

Weekly kWh savings	7,639
Annual kWh savings	381,968
Monthly kW savings	56.2

$$Weekly\ kWh\ savings = \sum_{Hour=1}^{24} Weekday\ kW\ Savings \times 5\frac{days}{week} + \sum_{Hour=1}^{24} Saturday\ kW\ Savings + \sum_{Hour=1}^{24} Sunday\ kW\ Savings$$

$$Annual\ kWh\ savings = Weekly\ kWh\ savings \times 50\frac{weeks}{year}$$

At the bottom right of Figure 2-6, we see that the applicant totaled the weekly kWh savings as 7,639 and multiplied by 50 weeks per year to yield the total measure savings of 381,968 kWh.

2.1.4   Evaluation assessment of applicant methodology

The evaluator determined that the applicant's use of a spreadsheet analysis to estimate energy savings was appropriate, although inconsistent between Measures 1 and 2. However, to compute peak demand impacts, the evaluator used an 8,760 spreadsheet analysis. The evaluator updated the analysis by incorporating data from the evaluation measurement period based on data described in Section 2.2.2.

2.2   On-site inspection and metering

The evaluator conducted the initial site visit on November 21, 2024, and was assisted by the site contact. Meters were retrieved on January 21, 2025, but one of the air compressor meters was found to have failed in the field. Due to the importance of the missing data, a second meter install was performed from February 18, 2025, to April 11, 2025. Table 2-4 summarizes the findings from the installed measure verification.

Table 2-4. Measure verification

Measure name	Verification method	Verification result
M1: New VSD air compressors and cycling refrigerated dryer	On-site inspection	The evaluator verified the installation of the two newly installed 200 HP VSD air compressors, as well as the cycling refrigerated air dryer. Photographs were taken of the new equipment, nameplates, and display panels showing operational data. All equipment models and locations were as described in project documentation. The display panels confirmed that both compressors were set at 100 psi as expected.
M1: New VSD air compressors and cycling refrigerated dryer	Evaluation kW measurements	The evaluator installed kW loggers on both compressors and the cycling refrigerated air dryer. The loggers were installed to record at 1-minute intervals between 11/21/24 and 1/21/25. Unfortunately, one of the kW loggers on an air compressor failed to capture data, so kW loggers and backup amp loggers were redeployed for the period 2/18/25 to 4/11/25. The metered data from the first period was useful in confirming that the holiday schedule correlated with compressor off-time, since the first period spanned Thanksgiving and Christmas. See Section 2.2.2 for details and charts of the metered data.
M1: New VSD air compressors and cycling refrigerated dryer	Interview the site contact and collect information about the project	The following information was gathered from the site contact about this project: • At the November site visit, the site contact was somewhat new to the facility and had been there for about six months. Production averages about 2,200 tons per month and the last three months varied between 1,900 to 2,200 tons. Evaluators requested historical production data, but it was unavailable. • The compressed air system generally runs 24 hours per day, seven days per week, with a one-day shutdown every other Sunday. There is also a one-week shutdown in July and a week or two in December depending on when the holidays land on the calendar. In total there are approximately 2-4 weeks of shutdown per year during which maintenance performs repairs. Holidays include typical federal holidays and ones in the union contract. Evaluators obtained a list of official company holidays for 2024. • With the new equipment, one old VSD compressor and the old non-cycling dryer remain as backups. Given their old age, they would only be used in an emergency should primary equipment fail. • Both compressors run simultaneously and serve different parts of the facility on different floors. There is a two-story compressed air storage tank on the system, but its volume was unknown to the site contact. Each compressor has its own refrigerated dryer. • It is reasonable to assume that the observed metering period will be typical of an average year.
M2: Compressed air leak reduction	On-site inspection	Referencing a list of compressed air leaks, the evaluator verified a random sample of approximately 25% of the CFM leaks which had been tagged as part of the project. Using visible, physical, and auditory cues, evaluators assessed whether the leaks had been repaired and were still intact. An ultrasonic leak detection device was used to point at the locations and listen for leaks.

2.2.1   Summary of site visit findings

Evaluators physically verified all equipment associated with this project and took photographs to document the installations. Figure 2-7 shows the second floor cycling refrigerated dryer (left) and 200 HP VSD air compressor (right). Evaluators failed to obtain an overview photo of the first-floor air compressor, but it was verified and its nameplate was photographed in Figure 2-8. Based upon the model number of the outdoor storage receiver, its volume is 2,560 gallons which translates to

about 1.2 gallons per CFM based on total compressor capacity, less than the industry standard practice baseline of 4 gallons per CFM for this new construction project.

Figure 2-7. Second floor dryer and air compressor

Figure 2-8 shows the nameplates of both new 200 HP VSD air compressors, and Figure 2-9 shows the nameplate of the new cycling refrigerated dryer.

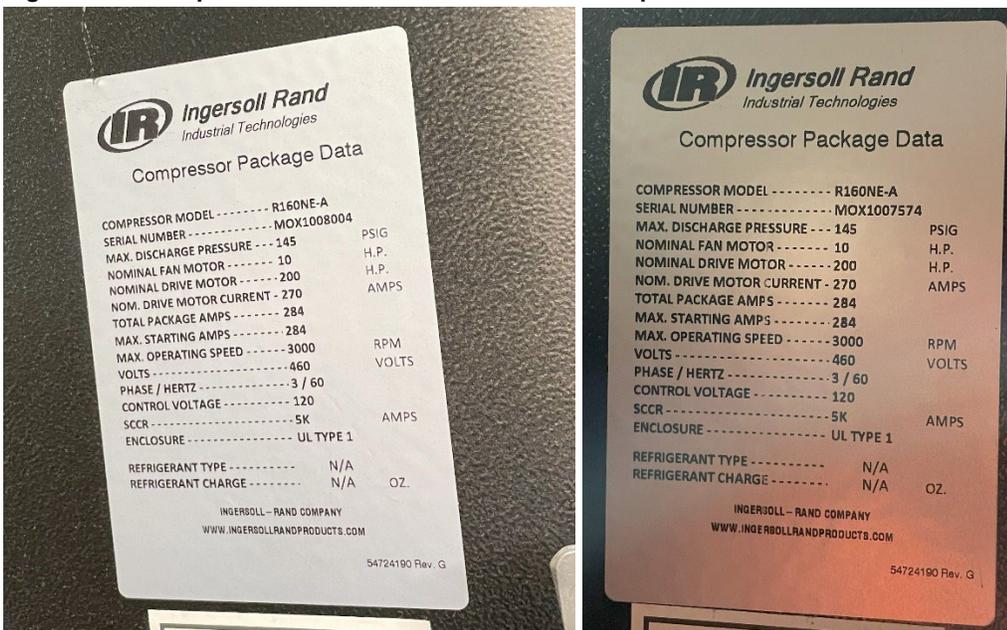**Figure 2-8. Nameplates of both new 200 HP VSD air compressors**
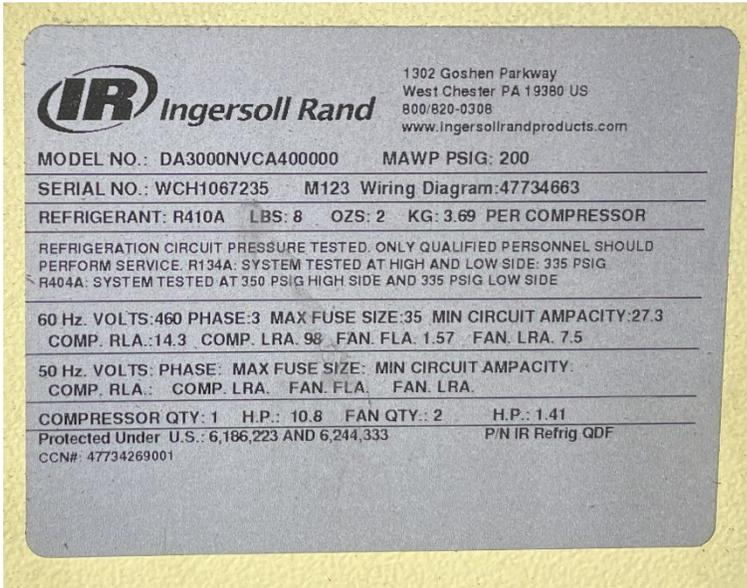
Figure 2-9. Nameplate of new cycling refrigerated dryer

Ingersoll Rand
1302 Goshen Parkway
West Chester PA 19380 US
800/820-0308
www.ingersollrandproducts.com

MODEL NO.: DA3000NVCA400000   MAWP PSIG: 200

SERIAL NO.: WCH1067235   M123 Wiring Diagram:47734663

REFRIGERANT: R410A   LBS: 8   OZS: 2   KG: 3.69 PER COMPRESSOR

REFRIGERATION CIRCUIT PRESSURE TESTED. ONLY QUALIFIED PERSONNEL SHOULD
PERFORM SERVICE. R134A: SYSTEM TESTED AT HIGH AND LOW SIDE: 335 PSIG
R404A: SYSTEM TESTED AT 350 PSIG HIGH SIDE AND 335 PSIG LOW SIDE

60 Hz. VOLTS:460 PHASE:3 MAX FUSE SIZE:35 MIN CIRCUIT AMPACITY:27.3
   COMP. RLA.:14.3 COMP. LRA. 98 FAN. FLA. 1.57 FAN. LRA. 7.5

50 Hz. VOLTS: PHASE: MAX FUSE SIZE: MIN CIRCUIT AMPACITY:
   COMP. RLA.: COMP. LRA. FAN. FLA. FAN. LRA.

COMPRESSOR QTY: 1   H.P.: 10.8   FAN QTY.: 2   H.P.: 1.41
Protected Under U.S.: 6,186,223 AND 6,244,333   P/N IR Refrig QDF
CCN#: 47734269001

Figure 2-10 shows the user interface screen for both of the installed 200 HP VSD air compressors showing that the discharge pressures are set to 100 psi.

Figure 2-10. Observed discharge pressures for first (left) and second (right) floor VSD compressors

Figure 2-11. Control panel for cycling refrigerated air dryer

For the compressed air leak reduction Measure M2, evaluators spot checked 28% of the number of tagged leaks and tested the location for leakage with an ultrasonic leak detection device. Figure 2-12 shows the inspection and testing of two compressed air leaks.

Figure 2-12. Inspection of leak #104 and testing of leak #143

2.2.2   Metered and logged data

Measure 1: New VSD air compressors

Figure 2-13 shows the evaluator kW measurements of the first and second floor 200 HP VSD air compressors. In general, both compressors operated concurrently without any apparent lead/lag sequencing. Note that there was a gap in the operation of the second-floor compressor. At the time of meter installation, evaluators were told that it was going to be down for maintenance for a short time, but it turned out to be down from February 21, 2025, to March 13, 2025, during which time the backup compressor served its load.

Figure 2-13. Evaluator kW measurements of newly installed 200 HP VSD air compressors
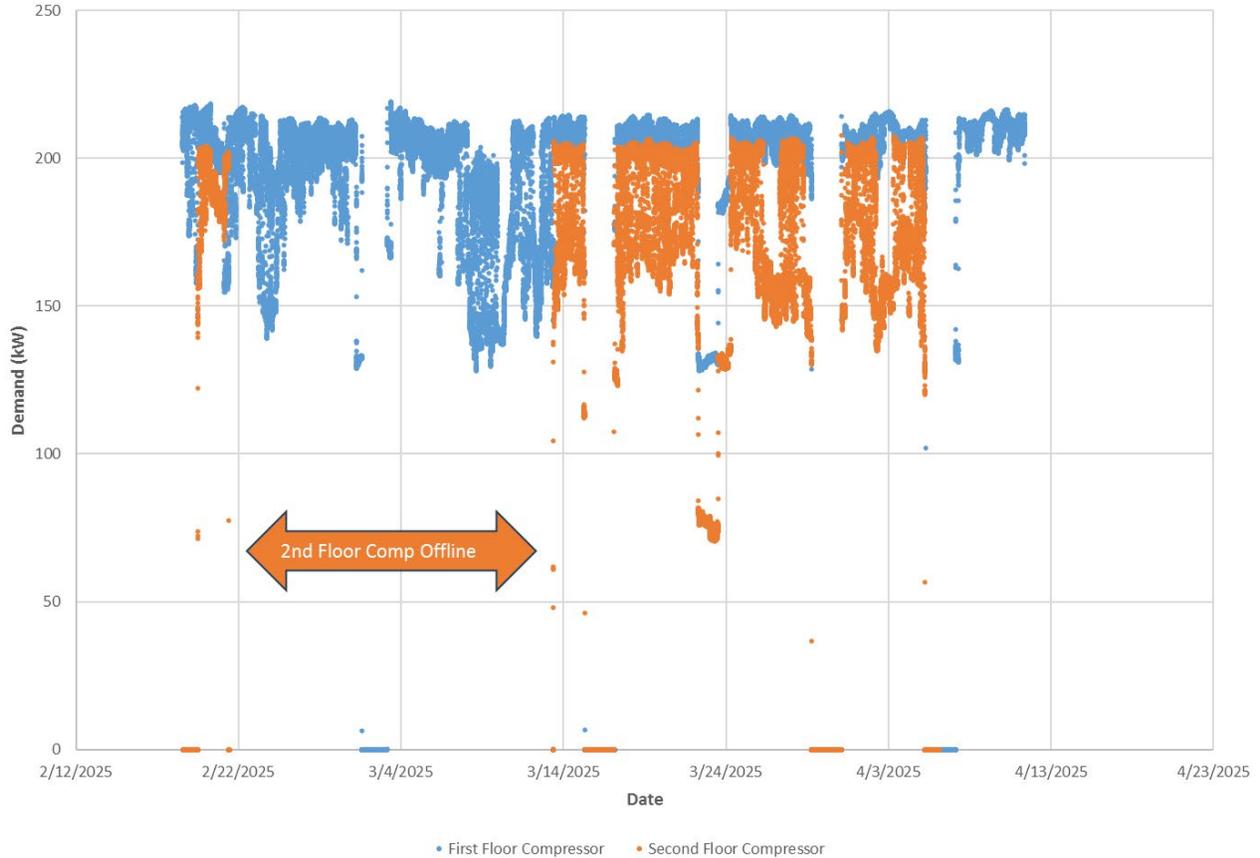
Figure 2-14 and Figure 2-15 show heatmaps of the evaluator kW measurements of both the first floor and second floor 200 HP VSD air compressors, by weekday and hour.

Figure 2-14. Heatmap of compressor kW measurements, by weekday and hour (First floor)

Average of Comp1	Hour																							
Weekday	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
Sunday	25	25	25	25	25	24	24	24	24	24	25	25	28	44	44	44	44	44	44	44	44	44	44	44
Monday	44	43	45	142	137	137	136	161	184	182	184	186	184	195	180	182	199	191	198	185	191	189	194	190
Tuesday	200	194	199	181	197	201	197	189	201	197	201	200	180	193	195	192	200	196	199	179	195	191	197	182
Wednesday	197	194	200	165	190	189	166	165	166	166	167	168	163	170	171	165	168	168	169	160	170	169	168	163
Thursday	168	167	165	159	170	169	165	179	198	186	185	194	166	190	198	185	192	190	201	175	200	189	192	175
Friday	191	178	193	174	187	180	174	176	192	193	199	195	173	195	199	192	197	195	191	171	190	179	184	168
Saturday	182	178	186	169	178	153	73	22	19	19	19	19	19	20	19	19	19	19	19	19	19	19	19	19
Holiday	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Figure 2-15. Heatmap of compressor kW measurements, by weekday and hour (Second floor)

Average of Comp2	Hour																							
Weekday	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
Sunday	75	70	53	71	67	68	65	67	74	71	72	75	64	79	77	76	80	77	81	69	79	77	76	72
Monday	73	70	75	159	166	166	165	179	189	199	199	198	199	201	199	199	200	202	198	202	204	204	205	204
Tuesday	204	206	205	207	206	206	205	206	204	204	203	204	203	202	203	199	203	204	203	207	202	207	206	206
Wednesday	209	207	208	203	204	203	201	200	200	196	201	198	200	201	201	202	204	205	205	205	205	207	204	205
Thursday	206	207	206	207	207	206	202	202	200	203	207	207	206	205	204	204	202	205	203	207	203	204	205	207
Friday	205	205	204	200	202	205	204	205	202	199	204	204	199	202	201	203	203	204	205	202	206	207	206	203
Saturday	203	208	204	200	202	195	162	108	91	92	92	93	87	94	80	69	75	72	73	69	76	73	74	71
Holiday	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Note that in Figure 2-15, the average hourly kW peaks at 209 kW for the installed, metered VSD compressor. This is notably higher than the max input power of 185.3 kW depicted on the corresponding CAGI sheet. Evaluators had multiple email exchanges with technical representatives at Ingersoll-Rand regarding how to explain the difference between operating and rated peak kW. While the reps were unable to definitively explain the difference and instruct evaluators on the exact implications for the kW/CFM performance curve, evaluators were told that the measured kW is nonetheless within operating tolerances for the machine. After conversing with the technical representatives, evaluators decided to assume that the metered kW values were valid and represented increased power at the machine's rated peak flow. See their quote on unit performance below:

> "The fact that this unit is showing higher power consumption without an increase in pressure and speed indicates to me that there is some degradation in performance. Performance is defined by the following terms: Flow rate, full load operating pressure, power consumption, specific energy consumption and isentropic efficiency. If a compressor was meeting performance and is now failing performance that indicates something has changed with the unit. For example, a significant pressure drop, an air leak in the system, high viscosity oil, poor AE sealing (usually only on oil free when the rotor coating is failing) etc. etc. All of these can cause higher than normal power consumption/less performance."

Based upon the manufacturer's statement above about performance degradation, evaluators concluded that it would be appropriate to proportionally adjust the performance curves of these machines to reflect higher kW power at the same CFM rating points, resulting in higher specific power values of kW/CFM. The CAGI rated and evaluator-adjusted performance parameters are presented in Table 2-5.

Table 2-5. CAGI kW/CFM and adjusted performance to metered kW

From CAGI sheet R160NE-A145			Adjusted CAGI to metered kW		
kW	aCFM	kW/100CFM	kW	aCFM	kW/100CFM
185.3	1060.0	17.48	208.9	1060.0	19.71
160.0	935.5	17.10	180.4	935.5	19.28
136.5	811.3	16.82	153.9	811.3	18.97
114.6	686.7	16.69	129.2	686.7	18.81
93.8	562.0	16.69	105.7	562.0	18.82
73.6	437.2	16.83	83.0	437.2	18.98
53.8	313.0	17.19	60.7	313.0	19.38

Figure 2-16 shows the CFM vs. kW curves for the newly installed VSD air compressors for a CAGI-rated Ingersoll Rand R160NE-A145 200 HP compressor, as well as the adjusted curve that reflects the heightened metered kW and relationship modeled in Table 2-5 for both machines. Both curves are shown for the rated pressure of 100 psi. The installed compressors

are operating at 100 psi based upon the photographs in Figure 2-10, so no pressure adjustments were necessary. To reflect the performance observed over nearly two months of metering, a period that the site contact stated would be representative of a typical year, evaluators decided that there was sufficient evidence to use the adjusted performance profile in the hourly savings analysis for this measure.

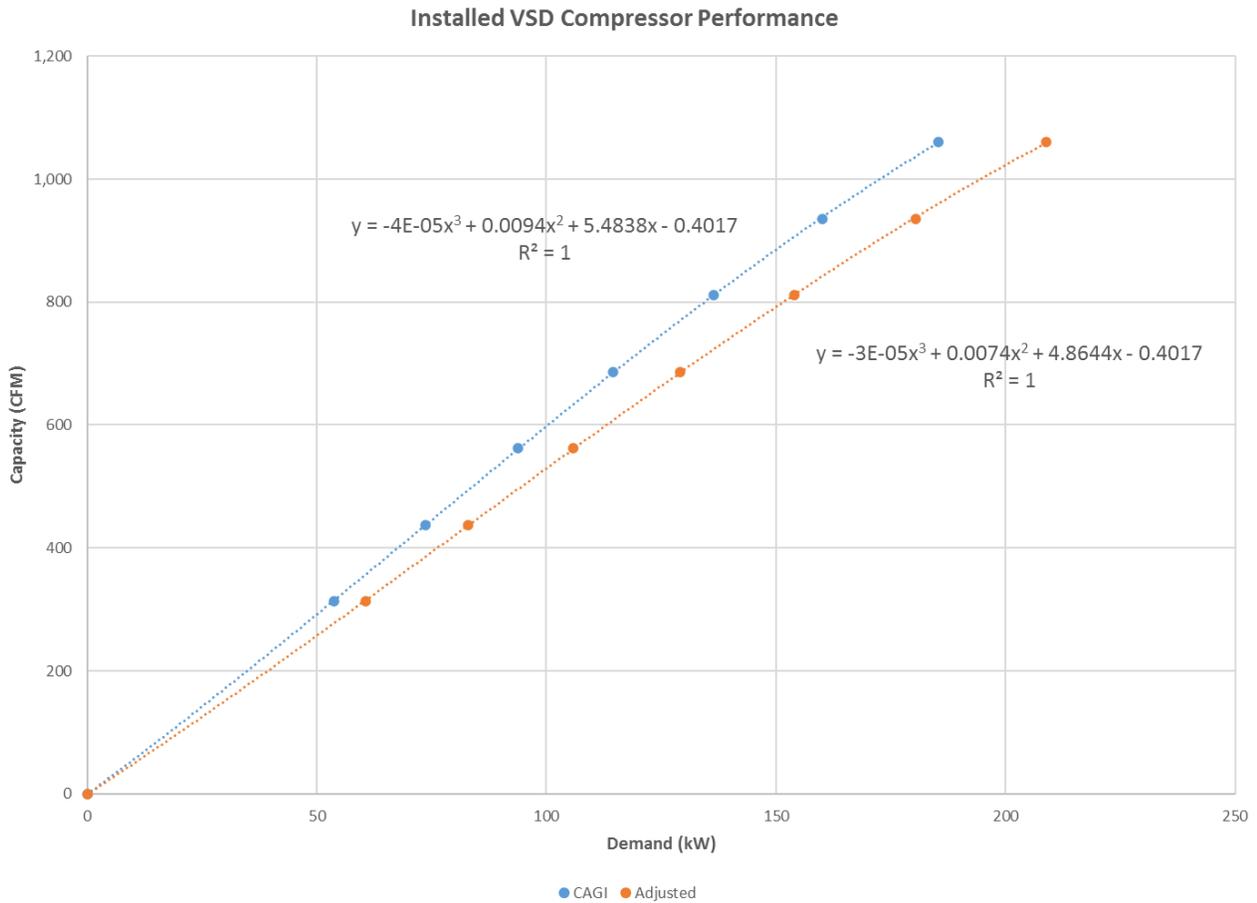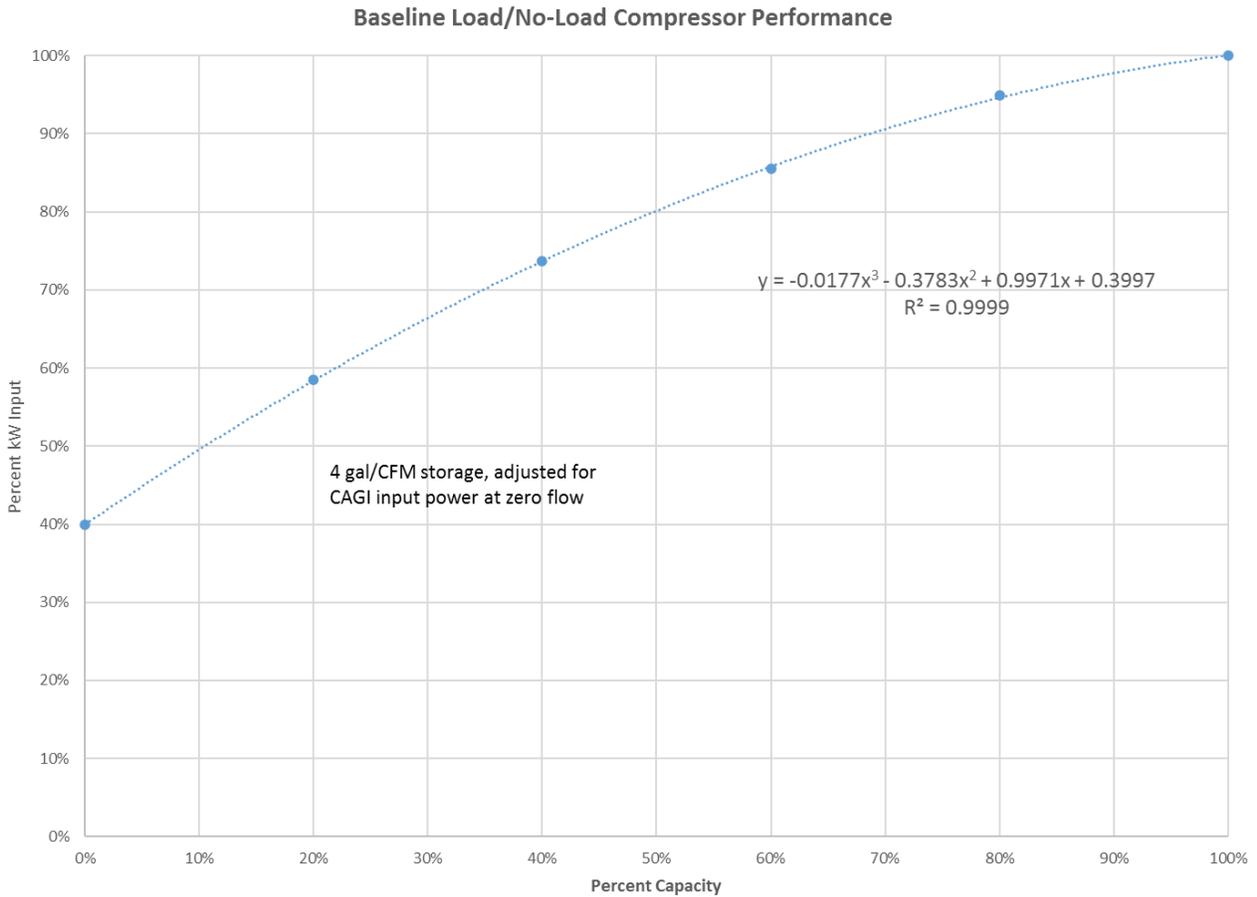**Figure 2-16. CFM vs. kW for newly installed VSD air compressors, CAGI rated and Adjusted**

Installed VSD Compressor Performance

$y = -4E-05x^3 + 0.0094x^2 + 5.4838x - 0.4017$
$R^2 = 1$

$y = -3E-05x^3 + 0.0074x^2 + 4.8644x - 0.4017$
$R^2 = 1$

Figure 2-17 shows the % kW vs % CFM capacity for the industry standard practice load/no-load compressor operating at 100 psi, with 4 gal/cfm storage that was used in the evaluator calculations. This curve is from the Compressed Air Challenge textbook, adjusted for the CAGI sheet for an Ingersoll Rand RS160ie-A110 200 HP load/no-load screw air compressor.

Evaluators considered but ultimately decided that there is no systematic rationale for transferring the aforementioned performance degradation of the installed variable-speed machines to their corresponding constant-speed baseline compressors.

Figure 2-17. % kW vs. % CFM capacity for ISP baseline air compressor

Baseline Load/No-Load Compressor Performance

$y = -0.0177x^3 - 0.3783x^2 + 0.9971x + 0.3997$
$R^2 = 0.9999$

4 gal/CFM storage, adjusted for
CAGI input power at zero flow

The site contact indicated that both compressors run simultaneously and serve different parts of the facility. The evaluator's metered data confirmed that the two compressors—while piped into a common compressed air system—operate independently and do not show indications of intelligent lead/lag sequencing. In contrast with the tracking calculations in which the two baseline compressors operated lead/lag, evaluators modeled the baseline compressors as serving the same CFM load as the corresponding installed compressor.

In Figure 2-18, we see how the installed first-floor compressor performs relative to its modeled baseline under the same CFM conditions. Notice how the performance curves cross at around 850 CFM above which the VSD compressor uses more power than the constant-speed baseline. The installed VSD compressor is more efficient (uses less kW per CFM) below 850 CFM. While running, this compressor averages 725 CFM, putting it into the region where the installed compressor is more efficient than the baseline. The first-floor compressor operates 5,568 hours above 850 CFM, and 3,192 hours below 850 CFM. The baseline compressor averages 20.19 kW per 100 CFM while the installed compressor averages 19.32 kW per 100 CFM, so overall the first-floor compressor is generating positive savings.

Figure 2-18. First floor compressor operating profile, modelled 8,760 hours

First Floor Compressor
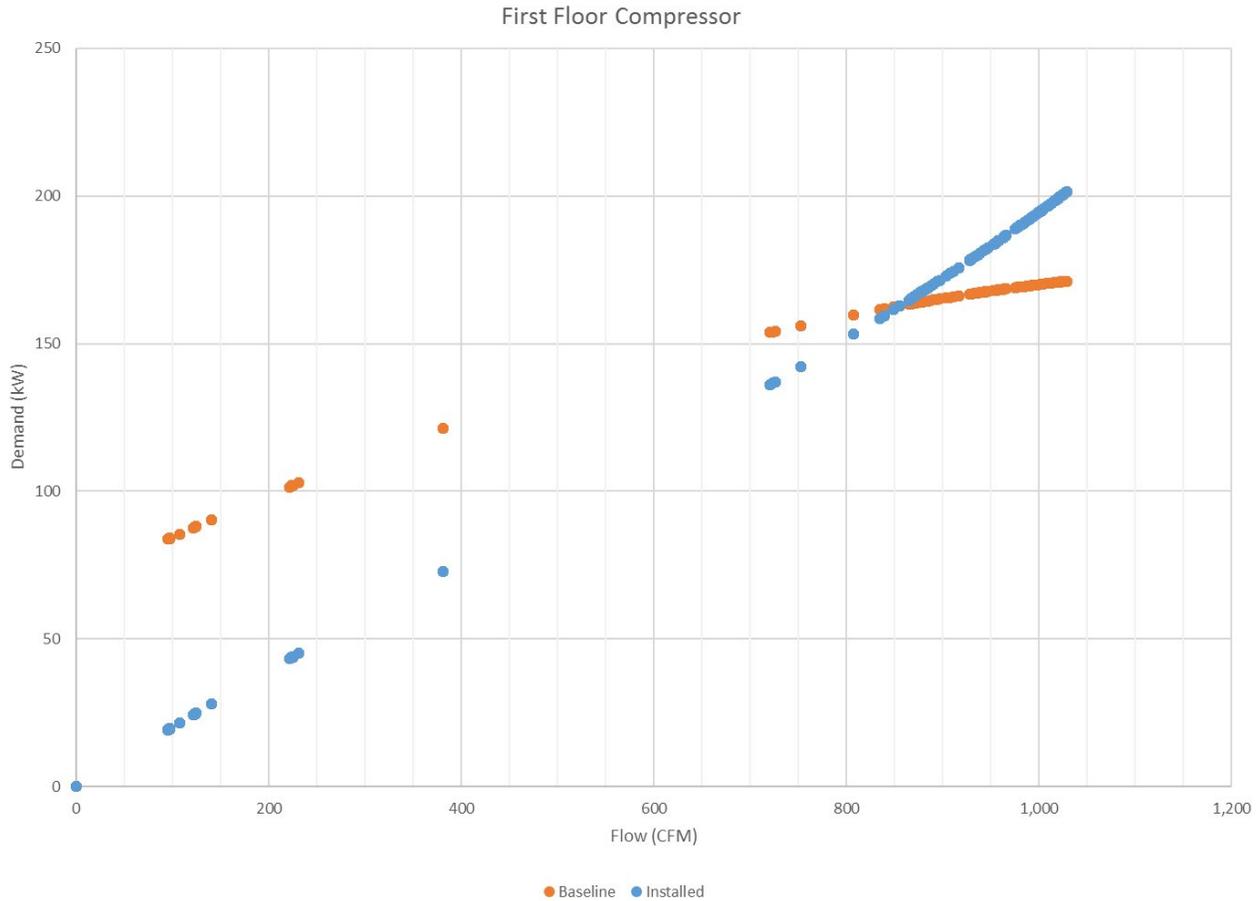
Likewise, in Figure 2-19, we see how the installed second-floor compressor performs relative to its modeled baseline under the same CFM conditions. These performance curves also cross at around 850 CFM, but this second-floor compressor operates more evenly across the CFM range. The second-floor compressor annually operates for 5,900 hours above 850 CFM, and 2,860 hours below 850 CFM. While running, this compressor averages 859 CFM, putting it into the region where the installed compressor is less efficient than the baseline. The baseline compressor averages 18.41 kW per 100 CFM while the installed compressor averages 19.53 kW per 100 CFM. Overall, the second-floor compressor is generating negative savings.

Figure 2-19. Second floor compressor operating profile, modelled 8,760 hours

Second Floor Compressor
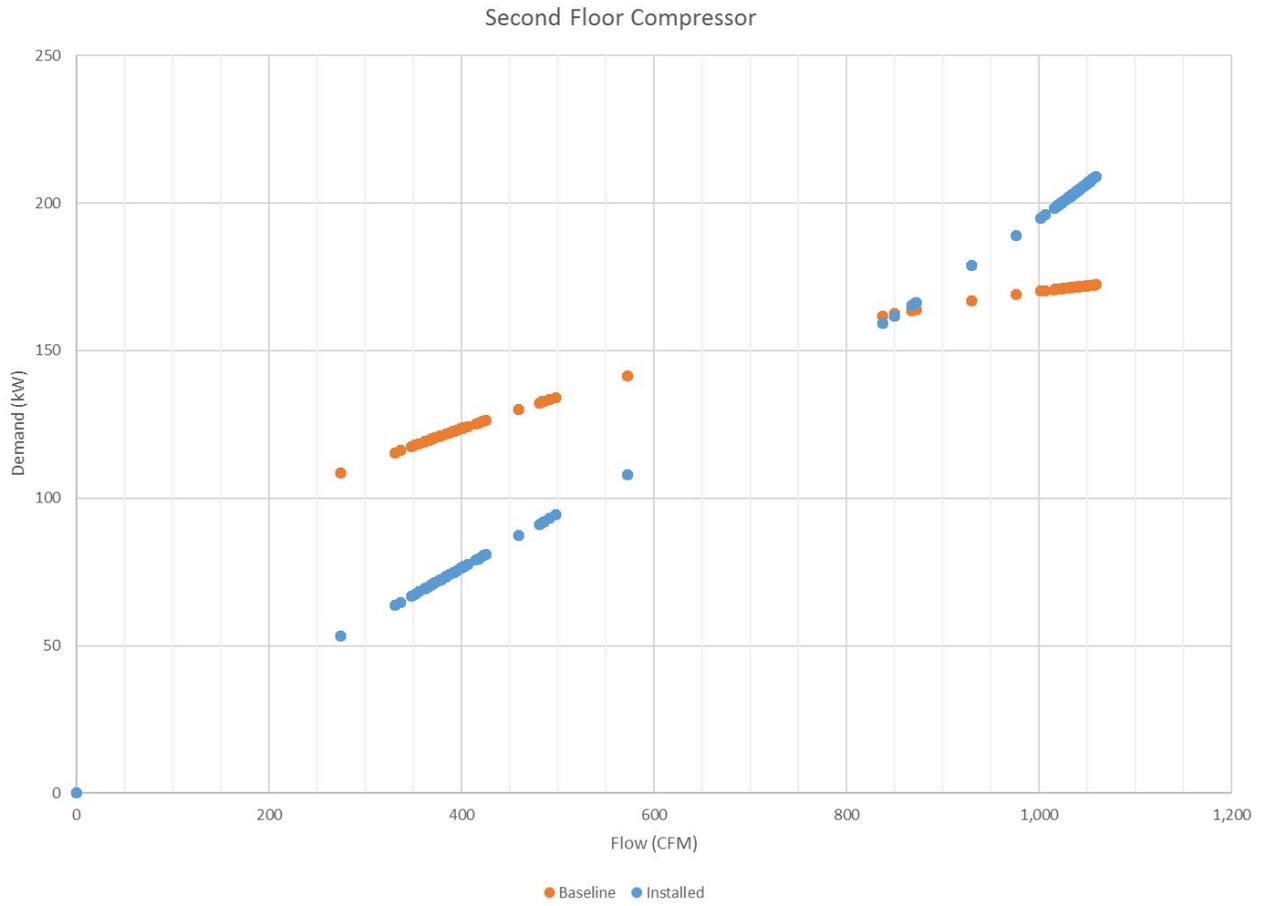
Measure 1: New cycling refrigerated dryer

Figure 2-20 shows the evaluator kW measurements of the new cycling refrigerated air dryer located adjacent to the second-floor compressor.

Figure 2-20. Evaluator kW measurements of cycling refrigerated air dryer
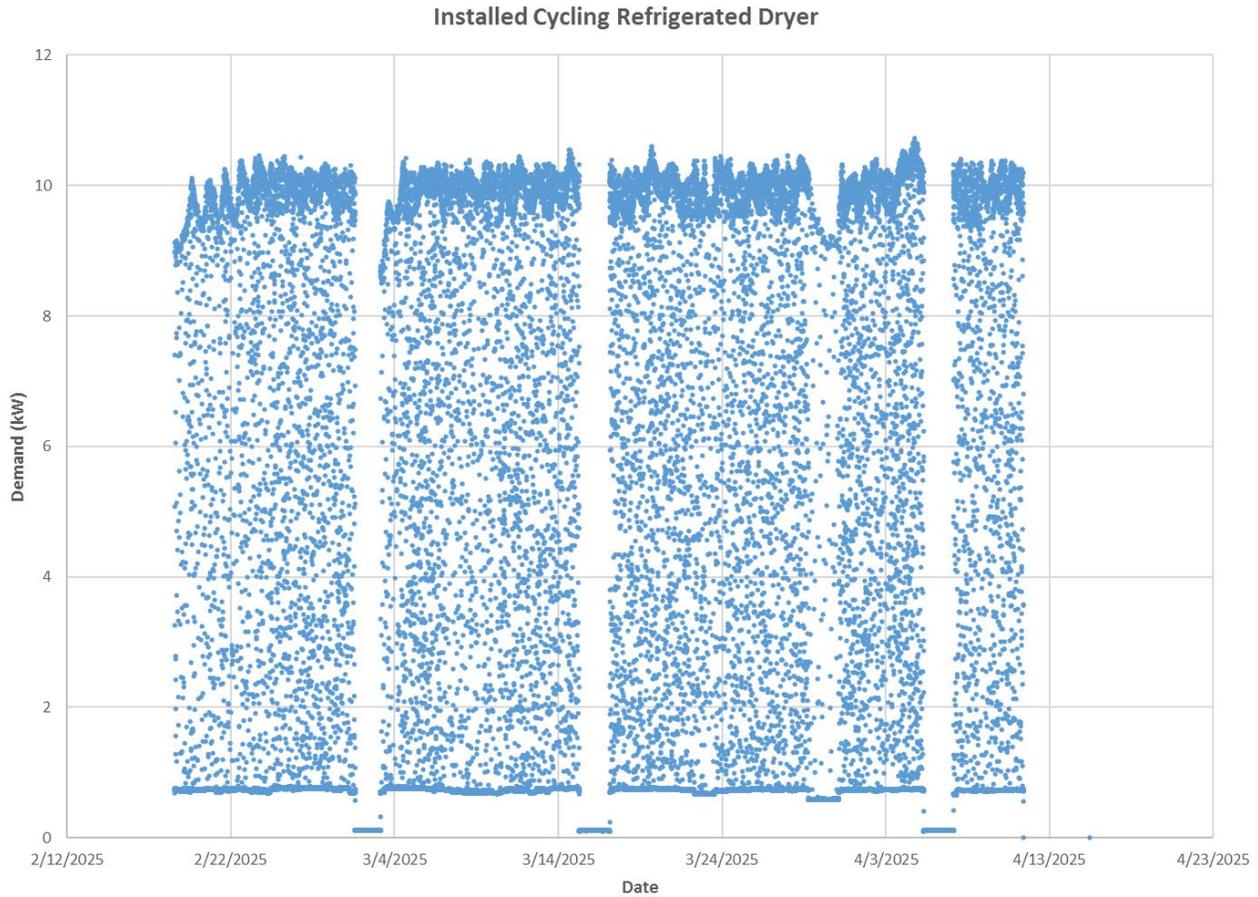
Figure 2-21 shows a heatmap of the evaluator kW measurements of the cycling refrigerated air dryer, by weekday and hour.

Figure 2-21. Heatmap of dryer kW measurements, by weekday and hour

Average of Dryer Weekday	Hour 0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
Sunday	1.0	1.0	0.8	0.9	0.9	1.0	0.8	1.0	1.0	1.0	1.0	1.1	1.2	1.3	1.3	1.3	1.3	1.3	1.2	1.1	1.2	1.1	1.1	1.0
Monday	1.0	1.0	1.1	2.5	2.0	2.1	2.1	2.3	2.6	2.6	2.7	2.7	2.8	2.9	2.9	2.9	3.0	3.0	2.9	2.8	2.8	2.7	2.7	2.7
Tuesday	2.6	2.6	2.6	2.7	2.5	2.6	2.5	2.6	2.6	2.7	2.9	3.1	3.2	3.4	3.3	3.3	3.4	3.3	3.2	3.1	2.8	2.9	2.8	2.7
Wednesday	2.6	2.4	2.5	2.4	2.3	2.3	2.3	2.4	2.5	2.5	2.8	2.9	2.9	3.2	3.2	3.2	3.3	3.1	3.1	2.8	2.8	2.7	2.6	2.5
Thursday	2.6	2.5	2.5	2.4	2.5	2.5	2.5	2.5	2.6	2.6	2.8	3.0	2.9	3.2	3.2	3.4	3.3	3.3	3.1	3.0	3.0	2.9	2.9	2.8
Friday	2.8	2.8	2.7	2.7	2.7	2.7	2.6	2.6	2.7	2.8	2.8	3.1	3.0	3.2	3.4	3.3	3.3	3.2	3.3	2.9	3.0	2.9	2.9	2.6
Saturday	2.6	2.7	2.6	2.5	2.5	2.4	2.1	1.6	1.3	1.4	1.5	1.5	1.5	1.6	1.4	1.2	1.3	1.2	1.2	1.1	1.1	1.1	1.1	1.0
Holiday	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Note that in the one-minute interval data scatterplot of Figure 2-20 the peaks are just above 10 kW. This is notably higher than the installed package power of 5.1 kW published in product specifications and used in the tracking analysis for the

installed Ingersoll-Rand dryer model DA3000NVCA. Reflecting on the installed dryer nameplate in Figure 2-9, we can compute the maximum kW of the package from the amperage of the refrigeration compressor and fans along with assumptions for voltage and power factor. Using reasonable assumptions for volts and power factor we can compute a more realistic full flow power kW as follows:

$$Dryer\ kW_{Max} = \sqrt{3} \times 480 \text{ volts } \times 17.44 \text{ amps} \times 0.85 \div 1,000 = 12.3 \text{ kW}$$

Evaluators also observed that the data bottoms out at 0.79 kW which is indicative of the zero flow power of the cycling refrigerated dryer. As a reminder, the applicant values for this refrigerated dryer were 5.1 kW full flow power and 0.51 kW zero flow power.

Figure 2-22 shows the CFM vs. kW relationship for the installed cycling refrigerated air dryer, based on both product specifications (tracking calculations) and nameplate data (evaluation calculations) for the Ingersoll Rand DA3000NVCA dryer. Evaluators used the "nameplate" regression equation to compute the CFM for the installed dryer from the measured kW.

Figure 2-22. CFM vs. kW for installed cycling refrigerated air dryer, per specifications and nameplate
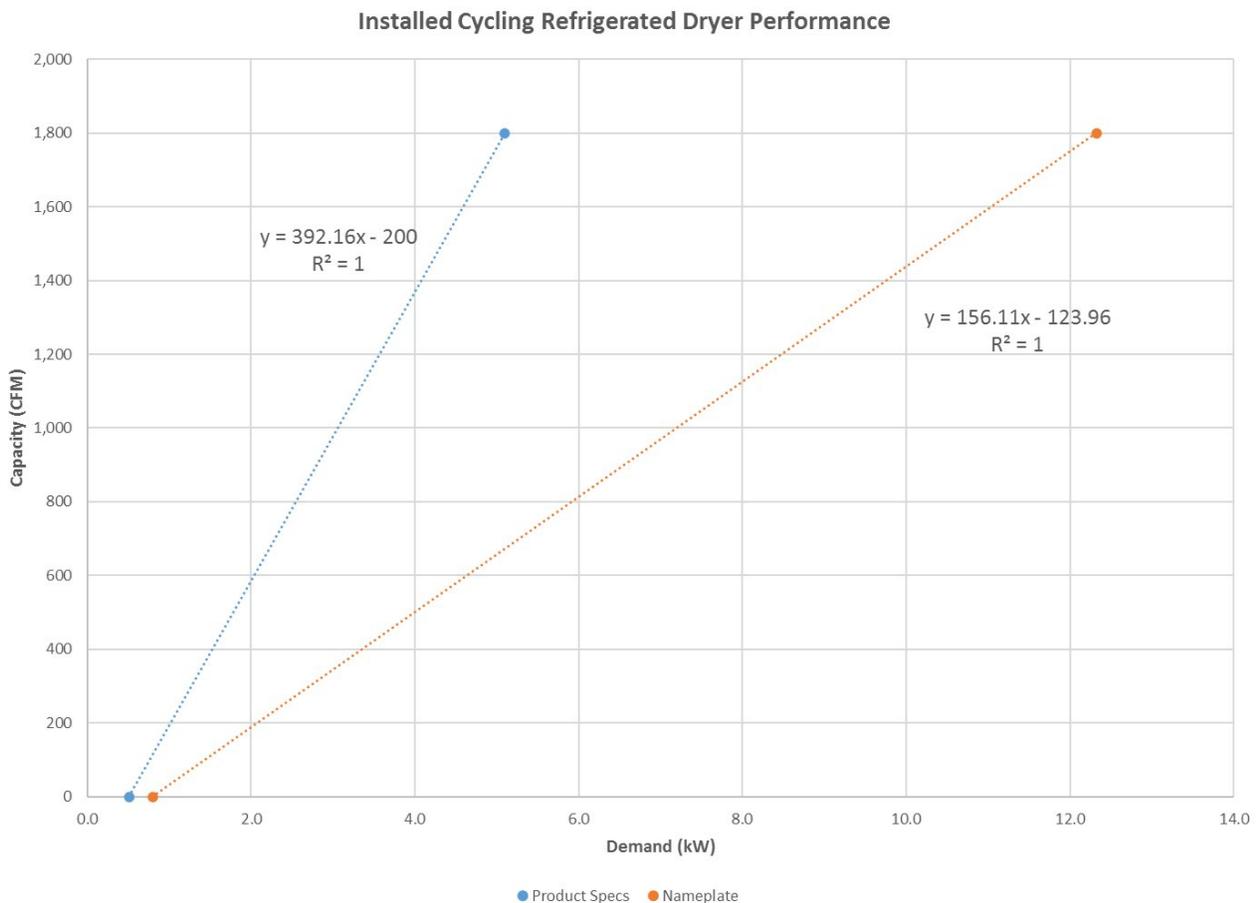
Figure 2-23 shows the kW vs CFM capacity for the industry standard practice baseline non-cycling refrigerated air dryer that was used in the evaluator calculations. This curve is from manufacturer specifications for an Ingersoll Rand D3400INA non-cycling refrigerated air dryer. These data points are presented earlier in Section 2.1.3, Applicant energy savings algorithm, but in this plot the x and y variables have been flipped to compute dryer baseline kW in terms of CFM.

Figure 2-23. kW vs. CFM capacity for ISP baseline non-cycling refrigerated air dryer

Baseline Non-Cycling Refrigerated Dryer Performance

$y = 0.0017x + 10.35$
$R^2 = 1$
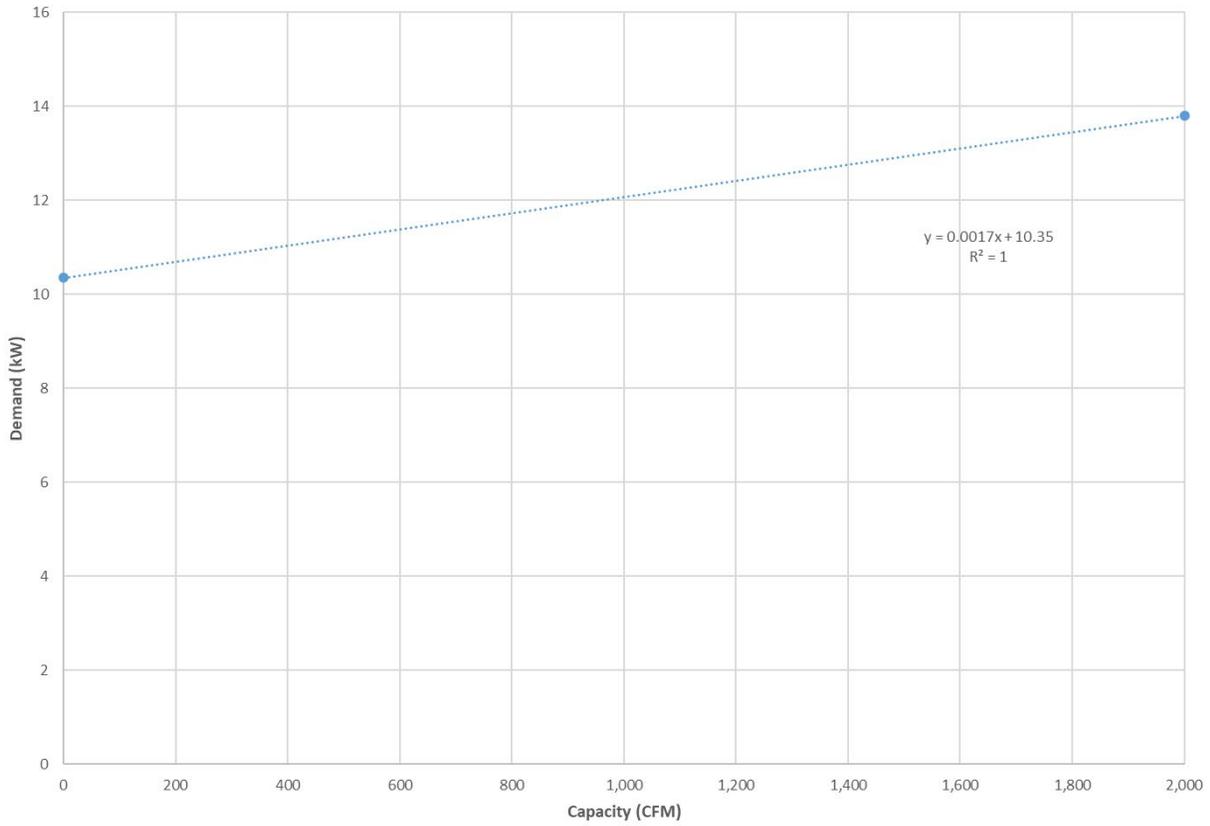
Measure 2: Compressed air leak reduction

While on site, evaluators inspected a sample of the documented compressed air leak repairs. In total, 33 out of 120 (28%) documented leak repairs were inspected. These 33 locations represent 69 CFM of repaired leakage or 25% of the total 271 CFM of documented compressed air leak repairs. Documented leaks range in size from 1 CFM to 4.5 CFM. One of the 33 evaluator inspected leaks was found to be leaking 1 CFM.

Figure 2-24. Summary of compressed air leaks and evaluator inspections

Total number of leaks in project files	120
Total number of leaks inspected	33
Percentage of leaks inspected	28%
Total CFM leakage in project files	271
Total CFM leakage locations inspected	69
Percentage of CFM leakage inspected	25%
Total CFM leakage reduction verified	68
Weighted CFM of leakage reduction achieved	268.3
Percentage of CFM leakage reduction achieved	99.0%

Evaluators employed a basic sample design stratified by the leakage size in CFM to assign case weights to the inspected leakage and develop an estimate of the weighted total leakage. This sample design and estimation is depicted in Figure 2-25. In total, this statistical approach concludes that 268.3 CFM of leaks were repaired, 99% of the original estimate of 271 CFM. At the 90% confidence interval, this estimate achieves 1.3% relative precision.

Figure 2-25. Compressed air leak reduction sample design

Leakage CFM	Population N	Population CFM	Sample n	Sample CFM	Weight (N/n)	Weighted CFM
1	38	38	14	13.0	2.71	35.3
2	23	46	6	12.0	3.83	46.0
2.5	24	60	5	12.5	4.80	60.0
3	11	33	1	3.0	11.00	33.0
3.5	10	35	2	7.0	5.00	35.0
4	8	32	4	16.0	2.00	32.0
4.5	6	27	1	4.5	6.00	27.0
Grand Total	**120**	**271**	**33**	**68.0**		**268.3**

In order to estimate the M2 baseline energy usage for the leak reduction measure, evaluators "reversed" some of the equations shown earlier in this report to compute the kW of the VSD compressors and cycling air dryer from an adjusted flow that reflects the increased CFM before the leaks were repaired. Specifically, evaluators had to flip the x and y variables in Figure 2-16 and Figure 2-22 to compute kW as a function of flow.

The equations and revised coefficients are shown below:

$$M2\ Compressor\ kW_{Baseline} = A \times CFM^3 + B \times CFM^2 + C \times CFM + D$$

Where the revised M2 baseline constants are:

Variable	Value
A	0.0000
B	-0.0001
C	0.1845
D	0.0267

$$M2\ Dryer\ kW_{Baseline} = m \times CFM + b$$

Where the revised M2 baseline constants are:

Variable	Value
m	0.0026
b	0.5100

Using these equations, evaluators were able to compute the M2 baseline kW for each compressor and the air dryer that pertain to the leak reduction measure.

2.3   Evaluation methods and findings

This section describes the evaluator methods and findings.

2.3.1   Evaluation description of baseline

Based on information provided in the project files and gathered during the site visit, the evaluator determined that Measure 1: New VSD air compressors and cycling refrigerated dryer is a lost-opportunity measure with a single baseline. Despite the presence of an existing VSD air compressor at the facility, this did not affect the evaluator baseline for the following reasons:

- The existing VSD compressor was running only because the two fixed speed compressors had failed, and project documents state that the existing VSD R160ne will become a full-time backup unit.
- The existing VSD R160ne was manufactured in 2011 and has over 80,000 run hours. It is unknown whether it was incentivized in 2011, so the applicability of a regressive baseline is unclear. In effect, the event type is "replace on failure" since the new compressors will physically and operationally replace the two failed fixed speed compressors. Evaluators will use an industry standard practice baseline of fixed-speed, load/no-load compressors with 4 gallons per CFM of storage and a non-cycling refrigerated air dryer.

The evaluator determined that Measure 2: Compressed air leak reduction is a retrofit maintenance measure with a single baseline. Like the applicant, evaluators used the new VSD compressors and cycling dryer as the baseline equipment to make the two measures interactive. However, it is noteworthy that the applicant baseline CFM load and calculation method for M2 differs significantly from M1. For Measure M1, an engineering implementation firm utilized a robust and detailed calculation approach with a lot of documentation of their assumptions. The M1 analysis leveraged one-minute interval CFM metering and annualized energy usage from hour of day and day of week averages. In contrast, Measure M2 utilized an RIE Custom Express calculator with considerably less documentation and very different (lower) CFM loading assumptions. The M2 analysis performed three 24-hour analyses: one each for weekdays, Saturdays, and Sundays. The evaluator used the M1 compressor model to compute the impacts of the M2 leak reductions and more accurately capture the interaction between the two measures.

2.3.2   Evaluation calculation method

The evaluator calculated the project impacts for Measure 1: New VSD air compressors and cycling refrigerated dryer in a manner consistent with the application but updating the analysis to an 8760 hourly format. For Measure 2: Compressed air leak reduction, the evaluator used the 8760 model from Measure 1 to estimate the M2 baseline energy usage inclusive of the pre-repair leaks.

The evaluator calculations for both measures followed the following steps:

1. The installed case air compressor kW data, which was collected over the 52 days of the evaluation's second[3] monitoring period, was applied to an 8,760-hour analysis by mapping a matrix of average demand by hour-of-day and day-of-week (with an additional day type for holidays) onto each hour of a typical operating year for each new VSD compressor independently. These average measured values that feed the 8,760 model are depicted in Figure 2-14 and Figure 2-15.

2. The installed case kW data in the 8,760 model was then converted to installed case CFM data using the VSD compressor CAGI sheets, plus an additional adjusted curve to reflect the degraded kW performance observed in the monitored data for both compressors The kW vs. CFM curves are shown in Figure 2-16. The baseline CFM data was then set equal to the installed case CFM data.

3. The baseline kW data was calculated from the baseline CFM data using industry standard compressor curves from the Compressed Air Challenge as shown in Figure 2-17.

4. The same approach was employed to model the installed cycling refrigerated air dryer from the metered data shown in Figure 2-20 and Figure 2-21. The installed case dryer CFM was developed using Figure 2-22, and the baseline dryer kW was developed from the CFM using the relationship in Figure 2-23. It is noteworthy that while the tracking calculations reflect the one installed dryer carrying the total CFM load of both VSD compressors, the site contact and metered data both indicate that the new dryer only serves its adjacent second floor VSD compressor.

5. The installed total kW was based on adding the installed air compressor kW (from step 1) and the installed dryer kW (from step 4) for each hour of the year.

6. The baseline total kW was based on adding the baseline air compressor kW (from step 3) and the baseline dryer kW (from step 4) for each hour of the year.

7. For Measure 1: New VSD air compressors and cycling refrigerated dryer, the demand savings for each hour of the year was calculated from the difference between the total baseline and installed kW. The annual energy savings is the sum of all demand savings across all 8,760 hours in the analysis.

8. For Measure 2: Compressed air leak reduction, the impacts of the Measure 2 leak reduction are computed relative to the installed condition from Measure 1 in order to correctly account for measure interaction. Evaluators added the total achieved leakage reduction of 268.3 CFM to the operating CFM of the air compressors and dryer to represent the higher M2 baseline air flow before the leaks were fixed. Evaluators refer to this as the "M2 baseline" to differentiate from the Measure 1 baseline earlier in this report. This additional CFM was distributed evenly across both new air compressors since they operate in unison, and half of the CFM was assigned to the second-floor new air dryer assuming that the other half of the leaks are downstream of the first-floor dryer.

9. Evaluators then computed the M2 baseline compressor and dryer kW from the Measure 2 baseline CFM using the equations and coefficients presented after Figure 2-25.

10. For Measure 2: Compressed air leak reduction, the demand savings for each hour of the year was calculated from the difference between the total M2 baseline and installed kW. The annual energy savings is the sum of all demand savings across all 8,760 hours in the analysis.

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[3] The first monitoring period spanned 11/21/24 to 1/21/25, but the kW logger on the first-floor air compressor failed to capture data. This was problematic because evaluators needed to understand how the two compressors operate in relation to one another. KW loggers and backup amp loggers were redeployed for a second monitoring period from 2/18/25 to 4/11/25. The first period metering spanned some major holidays so was useful to inform annual operating patterns. The final analysis for this project relied predominantly on the second monitoring period because it showed how the first-floor compressor, second-floor compressor, and air dryer all operate in concert.

3   FINAL RESULTS

The evaluated project consisted of installing two new 200 HP VSD air compressors, one cycling refrigerated air dryer, and repairing 120 compressed air leaks. In sum, all measure savings are about 6% greater than the tracking values. Measure 1 underperformed significantly with an evaluated realization rate of 30% due to one of the VSD compressors operating less efficiently than its corresponding baseline compressor. In contrast, Measure 2 overperformed with an evaluated realization rate of 133%. The parameters impacting the analysis are summarized in Table 3-1 for Measure 1 and Table 3-2 for Measure 2.

Table 3-1. Summary of key parameters (Measure 1)

Parameter	BASELINE		PROPOSED / INSTALLED	
	Tracking Value(s)	Evaluation Value(s)	Tracking Value(s)	Evaluation Value(s)
Compressor average CFM demand	1,808	1,584	1,808	1,584
Compressor average kW/CFM	0.168	0.192	0.162	0.194
Compressor kW/CFM improvement			0.006	-0.002
Compressor annual operating hours	7,200	8,208	7,200	8,208
Compressor kWh	2,181,201	2,499,440	2,102,322	2,526,783
Compressor kWh savings			78,878	-27,343
Dryer kW	12.68	10.64	4.81	2.35
Dryer annual operating hours	7,200	8,208	7,200	8,208
Dryer kWh	91,329	87,331	34,655	19,270
Dryer kWh savings			56,674	68,061
Total Measure 1 savings			135,552	40,718

Table 3-2. Summary of key parameters (Measure 2)

Parameter	BASELINE		PROPOSED / INSTALLED	
	Tracking Value(s)	Evaluation Value(s)	Tracking Value(s)	Evaluation Value(s)
Compressor average CFM demand	1,166	1,852	890	1,584
Compressor average kW/CFM	0.189	0.199	0.185	0.194
Compressor kW/CFM improvement			0.004	0.005
Compressor annual operating hours	6,800	8,208	6,800	8,208
Compressor kWh	1,501,415	3,028,124	1,119,447	2,526,783
Dryer kWh	0	27,236	0	19,270
Total Measure 2 savings			381,968	508,833
Total Site savings (Measure 1 + Measure 2)			517,520	549,551

3.1 Explanation of differences

Overall, the evaluated savings for this project are 6% greater than the tracking values predominantly because of operational discrepancies related to compressor performance and operating hours.

For Measure M1, the evaluated savings are 70% less than the tracking values due primarily to the average kW/CFM of the installed compressors being greater (less efficient) than the baseline compressors. The evaluator found the kW metering to indicate that the installed compressors used more energy than their CAGI ratings. Email exchanges with the manufacturer indicated that the high compressor kW readings were "within spec," but also that the data was reflective of a "performance degradation." So, the negative kW/CFM improvement dominates the discrepancies for this measure. There was also a reduction in savings due to less CFM flow than represented by the tracking estimate. These decreases were countered by a modest increase in annual operating hours.

For Measure M2, the evaluated savings are 33% more than the tracking values due primarily to increased operating hours and improved kW/CFM between the installed compressors post leak reduction loading and baseline compressors pre leak reduction loading There was a small negative discrepancy for lower CFM leak reduction which is partially a tracking documentation/calculation error and partially due to evaluators identifying one unfixed or recurring leak while on site. Otherwise, the evaluated savings are higher because a) the modeled kW/CFM improved and b) the tracking estimate of savings underestimated the annual operating hours considerably.

Table 3-3 provides a summary of the differences between tracking and evaluated values for both measures.

Table 3-3. Summary of deviations

Measure	Discrepancy	Parameter	Impact of deviation	Discussion of deviations
M1	Operation (Compressors)	CFM Demand	-8%	Decreased savings – Evaluator value = 1,584 CFM Tracking value = 1,808 CFM
M1	Operation (Compressors)	kW/CFM Improvement	-82%	Decreased savings – Evaluator value = -0.002 kW/CFM Tracking value = 0.006 kW/CFM
M1	Operation (Compressors)	Annual Operating Hours	+10%	Increased savings – Evaluator value = 8,208 hours Tracking value = 7,200 hours
M1	Operation (Dryer)	kW Savings	+3%	Increased savings – Evaluator value = 8.426 kW Tracking value = 7.871 kW
	Operation (Dryer)	Annual Operating Hours	+7%	Increased savings – Evaluator value = 8,208 hours Tracking value = 7,200 hours
		M1 Total	**-70%**	
M2	Application Review	CFM Leak Reduction	-3%	Decreased savings – Evaluator value = 268.3 CFM Tracking value = 276.2 CFM
M2	Operation	kW/CFM Improvement	+13%	Increased savings – Evaluator value = 0.005 kW/CFM Tracking value = 0.004 kW/CFM

Measure	Discrepancy	Parameter	Impact of deviation	Discussion of deviations
M2	Operation	Annual Operating Hours	+24%	Increased savings – Evaluator value = 8,208 hours Tracking value = 6,800 hours
		M2 Total	**+33%**	
TOTAL			**+6%**	

3.2 Lifetime savings

The evaluator classified Measure 1: New VSD air compressors and cycling refrigerated as lost opportunity with a single baseline. The evaluator classified Measure 2: Compressed air leak reduction as a retrofit with a single baseline. The evaluator calculated applicant and evaluated lifetime savings values using the following formula:

$$\text{LAGI} = \text{FYS} \times [\text{ EUL}]$$

where:

LAGI = lifetime adjusted gross impact (therms)

FYS = first year savings (therms)

EUL = measure life (years)

For Measure M1, 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. For Measure M2, the evaluated lifetime savings are higher than the tracking lifetime savings because the evaluated first year savings are higher than the tracking first year savings.

Table 3-4 and Table 3-5 provide summaries of key factors that influence the lifetime savings for each measure.

Table 3-4. Measure M1 – Application ID: 13922447– Lifetime savings summary

Factor	Tracking	Application	Evaluator
Lifetime savings (kWh)	2,033,280	2,033,280	610,777
First-year savings (kWh)	135,552	135,552	40,718
Measure lifetime (years)	15	15	15
Baseline classification	Lost Opportunity	Lost Opportunity	Lost Opportunity

Table 3-5. Measure M2 – Application ID: 14572978– Lifetime savings summary

Factor	Tracking	Application	Evaluator
Lifetime savings (kWh)	763,936	763,936	1,017,666
First-year savings (kWh)	381,968	381,968	508,833
Measure lifetime (years)	2	2	2
Baseline classification	Retrofit	Retrofit	Retrofit

Table 3-6. Site-level total – Lifetime savings summary

Factor	Tracking	Application	Evaluator
Lifetime savings (kWh)	2,797,216	2,797,216	1,628,443
First-year savings (kWh)	517,520	517,520	549,551

3.3 Ancillary impacts

There are no ancillary impacts associated with this project.

RHODE ISLAND CUSTOM ELECTRIC SITE-SPECIFIC REPORT
SITE ID: RICE23N077

Report Date: August 6, 2025

Program Administrator	Rhode Island Energy	
Application ID(s)	13005576	
Project Type	C&I New Construction	
Evaluation Type	Full M&V	
Program Year	PY2023	
Evaluation Firm	DNV	
Evaluation Engineer	Laengheng Khoun	
Senior Engineer	Koushik Mandlem	

1 EVALUATED SITE SUMMARY AND RESULTS

The evaluated project was implemented as part of a new construction expansion to an existing school. The school is approximately 64,000 sq. ft in area after the expansion. The new construction project added a new two-floor wing to the school which included classrooms, bathrooms, and hallway spaces comprising approximately 6,061 sq. ft. in area for each floor (12,122 sq. ft. total). All measures in the application serve the new wing exclusively and no existing HVAC or DHW systems serve the new wing. The project includes four measures installed through a single application and classified as a new construction project. The evaluators note that for new construction measures, the baseline efficiency case assumes compliance with RI building codes or industry standard practice. For these measures where the RI does not specify specific efficiency or performance values, the evaluators use the applicable values from ISP for each measure which may also vary depending on the specificity provided by each standard. The measures and baseline values are described below.:

- M1 – Low-flow Domestic Hot Water (DHW) fixtures: The new construction addition added 14 classroom sink faucets rated at 1.5 gallons per minute (GPM) and eight bathroom sink faucets rated at 0.35 GPM. The baseline for classroom sink faucets are 2.2 GPM and 0.5 GPM for bathroom sink faucets according to the LEED v4 baseline fixture flow ratings. The electric hot water heater serves all faucets included in this application and does not have any other sources of water load. The energy savings comes from reduced DHW heating demand and water usage from installing low-flow fixtures.
- M2 – Variable refrigerant flow (VRF) heat pumps: The measure installed two VRF heat pumps that serve the classrooms and hallways in the new wing of the school. Baseline ratings for VRF heat pumps are a cooling efficiency of 10.4 EER and 13.7 IEER, with heating efficiencies of 3.2 COP at 47°F and 2.1 COP at 17°F, based on IECC 2021. The measure saves energy through higher efficiency of the proposed equipment compared to the efficiency of the baseline equipment. The applicant assumes load profiles are identical in the base and proposed case.
- M3 – Building envelope insulation: Installation of building envelope insulation including wall, roof, and windows. The baseline building envelope values are a wall U-value of 0.064 Btu/hr·ft²·°F, a roof U-value of 0.032 Btu/hr·ft²·°F, and a window U-value of 0.398 Btu/hr·ft²·°F, consistent with prescriptive requirements from IECC 2021 for new construction. The energy savings result from the improved thermal performance of building envelope assemblies beyond requirements of the energy code.
- M4 – Energy recovery ventilator (ERV): This measure saves energy by installing an ERV that reclaims heat from the new addition exhaust air to precondition incoming air, thus reducing HVAC heating and cooling loads. The evaluator noted that the applicant only claims savings for when the building is in heating mode. The baseline for ERVs assumes a 50% sensible effectiveness, as required by IECC 2021 C403.2.7 for energy recovery ventilators.

After reviewing the tracking files and information gathered during the site visit, the evaluator classified all measures as new construction with a single baseline. The applicant calculated savings using the small buildings new construction savings calculator which uses a temperature bin analysis approach for each measure. The evaluator used data collected between February 26, 2025, and June 30, 2025, to update the applicant analysis or calculate project savings using an 8,760 spreadsheet approach. The evaluation results are presented in Table 1-1.

Table 1-1. Evaluation results summary

PA application ID	Measure name		Annual electric energy (kWh)	% of energy savings on-peak	Summer on-peak demand (kW)	Winter on-peak demand (kW)
13005576	M1: Low flow DHW fixtures	Tracked	2,566	76%	0.45	0.37
		Evaluated	2,676	45%	0.33	0.25
		Realization Rate	104%	59.6%	73%	67%

PA application ID	Measure name		Annual electric energy (kWh)	% of energy savings on-peak	Summer on-peak demand (kW)	Winter on-peak demand (kW)
13005576	M2: VRF heat pumps	Tracked	14,502	63%	3.34	2.60
		Evaluated	6,375	61%	2.00	0.92
		Realization Rate	44%	96%	60%	35%
13005576	M3: Building envelope insulation	Tracked	3,077	46%	0.05	0.72
		Evaluated	2,780	47%	0.07	0.65
		Realization Rate	90.3%	102%	131%	90%
13005576	M4: Energy recovery ventilator	Tracked	4,802	85%	0.08	4.13
		Evaluated	5,131	81%	0.16	3.18
		Realization Rate	107%	95%	196%	77%
Total		Tracked	24,947	66%	3.92	7.82
		Evaluated	16,967	62%	2.56	5.00
		Realization Rate	68.0%	93%	65%	64%

1.1   Explanation of deviations from tracking

Overall, the evaluated savings for this project are 32.0% less than the tracking values predominantly because of the lower performance of Measure 2 stemming from lower heating and cooling loads and lower as-built efficiencies for the heat pumps. Further details regarding deviations from the tracked savings are presented in Section 3.1.

1.2   Recommendations for program designers and implementers

The evaluator recommends that implementers request submittals of as-built plans for building envelope measures as part of the project closeout process. The evaluator could not completely verify the installed insulation type and U or R-values, due to the absence of exposed sections and lack of documentation provided by the site. The personnel at this site indicated that they did not have any documentation explicitly showing the building insulation materials. Collecting this type of information as part of the application process, such as in-progress photographs of installation before walls are closed, and window labels with make and model numbers, helps ensure legitimacy regarding what was installed and will support future evaluations and verification efforts. Furthermore, since the new wing of the school operates on the same schedule and has the same usage patterns as the rest of the school, the evaluators recommend in cases like this to use the existing schedules and loads to inform the savings analysis for proposed measures.

The evaluators also recommend that the implementers consider interactive effects when calculating energy savings for multiple measures. For example, considering improved insulation values when estimating HVAC loads.

1.3   Customer alerts

There are no relevant 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 with the information available.

The evaluated measures for this site are summarized in Table 2-1.

Table 2-1. Evaluated measures

Measure	Project ID	Measure description
M1	13005576	Install 14 classroom faucets (1.5 GPM) and eight bathroom faucets (0.35 GPM).
M2	13005576	Install two VRF heat pump units rated at the following specification: HP-1: 184,000 Btu/h cooling, 206,000 Btu/h heating, 10.6 EER / 20.0 IEER, COP 3.3 @ 47°F, COP 2.5 @ 17°F HP-2: 206,000 Btu/h cooling, 230,000 Btu/h heating, 10.7 EER / 22.3 IEER, COP 3.6 @ 47°F, COP 2.6 @ 17°F
M3	13005576	Install building envelope insulation including walls, roofs, and windows. Each component has proposed insulation with the following U-values: - Walls: 0.052 (8,484 sq. ft.) - Roof: 0.032 (6,061 sq. ft.) - Windows: 0.346 (1,390 sq. ft.)
M4	13005576	Install an ERV to recover heat from conditioned air. The applicant only claimed savings for heating but the evaluator accounts for heating and cooling savings. The proposed ERV will have a sensible effectiveness of 72 and total effectiveness of 55%.

2.1 Application information and applicant savings methodology

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

2.1.1 Applicant description of baseline

According to the project files, the applicant classified all four measures as new construction with a single baseline using industry standard practice (ISP). Since there are multiple measures, the sources for ISP for each measure vary depending availability of efficiency specifications provided by each standard. For example, in the case of DHW fixtures, LEED v4 specifies the GPM rating for standard flow bathroom faucets, whereas IECC does not. For the DHW fixtures (M1), the baseline was defined as standard-flow faucets rated at 2.2 GPM for classrooms and 0.5 GPM for bathrooms, representative of typical existing installations in schools according to the LEED v4 baseline for low flow fixtures.

For the VRF systems (M2), the baseline efficiency was based on ISP assumptions of conventional heat pumps with 10.4 EER, 13.7 IEER, and COPs of 3.2 at 47°F and 2.1 at 17°F according to IECC 2021.

For the building envelope insulation (M3), the baseline U-values were derived from code minimums for opaque walls, roofs, and windows (U-values are 0.064, 0.032, and 0.398, respectively) which are based on IECC 2021.

For the ERV system (M4), the applicant used a baseline of 50% heat recovery effectiveness as required by IECC 2021 C403.2.7.

Table 2-2 shows the baseline key parameters in the application calculator savings models.

Table 2-2. Applicant baseline key parameters

Measure	Parameter name	Parameter value	Source of parameter value
M1: Low-flow DHW fixtures	Faucet flow rate	2.2 GPM (classroom), 0.5 GPM (bathroom)	LEED v4
M1: Low-flow DHW fixtures	Faucet quantity	8 (classroom), 14 (bathroom)	Applicant calculator
M2: VRF heat pumps	Capacity	HP-1: 184,000 Btu/h cooling, 206,000 Btu/h heating (Qty 1) HP-2: 206,000 Btu/h cooling, 230,000 Btu/h heating (Qty 1)	Applicant calculator
M2: VRF heat pumps	Cooling efficiency	10.4 EER / 13.7 IEER	IECC 2021
M2: VRF heat pumps	Heating efficiency	COP 3.2 @ 47°F, COP 2.1 @ 17°F	IECC 2021
M3: Building envelope	Wall area	8,484 sq. ft.	Applicant calculator
M3: Building envelope	Roof area	6,061 sq. ft.	Applicant calculator
M3: Building envelope	Window area	1,390 sq. ft	Applicant calculator
M3: Building envelope	Wall U-value	0.064 Btu/hr·ft²·°F	IECC 2021
M3: Building envelope	Roof U-value	0.032 Btu/hr·ft²·°F	IECC 2021
M3: Building envelope	Window U-value	0.398 Btu/hr·ft²·°F	IECC 2021
M4: ERV	Max CFM	3900	Applicant calculator
M4: ERV	ERV effectiveness	50% sensible effectiveness	IECC 2021

2.1.2 Applicant description of installed equipment and operation

This project includes installing M1: low flow DHW fixtures with lower GPM ratings, M2: higher efficiency VRF heat pumps, M3: lower U-value building envelope insulation and M4: ERV with higher sensible effectiveness than those claimed in the baseline case. Table 2-3 presents the main parameters of the proposed case as defined by the applicant.

Table 2-3. Applicant's proposed key parameters

Measure	Parameter name	Parameter value	Source of parameter value
M1: Low-flow DHW fixtures	Faucet flow rate	1.5 GPM (classroom), 0.35 GPM (bathroom)	Applicant calculator
M1: Low-flow DHW fixtures	Faucet quantity	8 (classroom), 14 (bathroom)	Applicant calculator
M2: VRF heat pumps	Capacity	HP-1: 184,000 Btu/h cooling, 206,000 Btu/h heating HP-2: 206,000 Btu/h cooling, 230,000 Btu/h heating	Equipment cut sheets
M2: VRF heat pumps	Cooling efficiency	10.6 EER / 20.0 IEER (HP-1), 10.7 EER / 22.3 IEER (HP-2)	Equipment cut sheets
M2: VRF heat pumps	Heating efficiency	COP 3.3 @ 47°F, COP 2.5 @ 17°F (HP-1)	Equipment cut sheets

Measure	Parameter name	Parameter value	Source of parameter value
		COP 3.6 @ 47°F, COP 2.6 @ 17°F (HP-2)	
M3: Building envelope	Wall area	8,484 sq. ft.	Applicant calculator
M3: Building envelope	Roof area	6,061 sq. ft.	Applicant calculator
M3: Building envelope	Window area	1,390 sq. ft	Applicant calculator
M3: Building envelope	Wall U-value	0.052 Btu/hr·ft²·°F	Applicant calculator
M3: Building envelope	Roof U-value	0.032 Btu/hr·ft²·°F	Applicant calculator
M3: Building insulation	Window U-value	0.346 Btu/hr·ft²·°F	Applicant calculator
M4: ERV	Max CFM	3900	Applicant calculator
M4: ERV	ERV effectiveness	72% sensible effectiveness	Applicant calculator

2.1.3   Applicant energy savings algorithm

The applicant used an in-house calculator, the small buildings new construction savings calculator for all measures. The evaluator reviewed the calculator and found that the calculation methodology in the calculator is reasonable for all measures and recognizes it as standard for new construction projects for small buildings. However, the evaluator noted that the calculator does not consider interactive effects from installing multiple measures which results in an overestimation of savings. For example, both the envelope and ERV measures include parameters for the HVAC system efficiencies. In the applicant's analysis, the baseline HVAC efficiency is used in both cases which is not appropriate. The applicant approach for each measure is discussed in further detail and the savings algorithms are presented in the following:

Measure 1: Low Flow DHW Fixtures

The tracking calculations for the low-flow DHW fixtures were calculated by estimating the reduction in annual hot water usage compared to baseline fixtures (based on LEED v4 baseline GPM ratings) and converting the resulting reduction in water heating load into electric energy savings. The calculation used assumed daily usage volume based on building type and square footage. The applicant assumed a 75°F temperature rise. The applicant calculates energy savings for each temperature bin based on the demand savings for a certain bin and the associated hours for that bin based on OAT. The following formula represents the methodology:

$$Annual\ Energy\ Savings = \sum_{i=1} Bin\ Hours_i \times Demand\ Savings\ (kW)$$

The applicant calculates demand savings is calculated with the following formula:

$$Demand\ Energy\ Savings = \frac{Baseline\ Average\ Load - Proposed\ Average\ Load}{Eff\ \times 3412}$$

Where,

$$Baseline\ Average\ Load\ (MBH) = \frac{8.33 \times Area\ \times Usage\ Rate \times \Delta T}{Daily\ Occ\ Hours \times 1000}$$

Where,

$DHW\ Daily\ Usage\ Rate$ = Daily area based usage rate, 0.010 gal/day for a K-12 school

$Area$ = Area, 12,122 sq. ft.

8.33 = density of water in lb/gal

ΔT	= Temperature rise, 75 ℉
$Daily\ Occ\ Hours$	= Daily occupied hours, 9 hours based on applicant informed schedule
Eff	= Electric Resistance Water Heater Efficiency, 0.95
3,412	= Btu per kWh conversion
1000	= Btu to kBtu conversion

The proposed average load is calculated using a 32% DHW flow reduction factor based on the ratio of average GPM ratings of the baseline and proposed faucets assuming the restroom faucets account for 24% of the DHW use and classroom faucets account for 76% of the DHW use. The following formula shows the formula for proposed average load:

$$Proposed\ Average\ Load\ (MBH) = Baseline\ Average\ Load\ (MBH) \times \frac{Average\ GPM_p}{Average\ GPM_b}$$

Where,

$Baseline\ Average\ Load\ (MBH) \times$ = Baseline average load in MBH, as calculated above

$Average\ GPM_p$ = Proposed average GPM, calculated as the product of restroom faucets rated at 0.35 GPM accounting for 24% of the DHW usage and classroom faucets rated at 1.5 GPM accounting for 76% usage

$Average\ GPM_b$ = Baseline average GPM, calculated as the product of restroom faucets rated at 0.5 GPM accounting for 24% of the DHW usage and classroom faucets rated at 2.2 GPM accounting for 76% usage

Measure 2: VRF heat pumps

The applicant calculated the cooling and heating energy consumption of the baseline and proposed HVAC equipment utilizing a bin model. Savings are calculated by estimating the annual cooling and heating loads, then applying equipment efficiencies from baseline and proposed cases to determine energy use. The annual cooling and heating loads are determined from annual temperature bins for New Bedford, MA using a bin analysis approach. The following formulas represent the applicant's calculations:

$$Annual\ Energy\ Savings\ (kWh) = Annual\ Cooling\ Savings + Annual\ Heating\ Savings$$

$$Annual\ Cooling\ Savings = \sum_{i=1}^{8760} \left(\frac{Cooling\ Load_{b,i} \times Hours}{EER_{b,i}} - \frac{Cooling\ Load_{p,i} \times Hours}{EER_{p,i}} \right) \div 1,000$$

Where,

$Cooling\ Load$	= Annual cooling load per bin, Btu
$Hours$	= Hours per temperature bin
EER	= Rated EER efficiency at each temperature bin based on performance table
1,000	= Watts per kW conversion

Similarly, heating savings are calculated with the following formula:

$$Annual\ Heating\ Savings = \sum_{i=1}^{8760} \left(\frac{Heating\ Load_b \times Hours}{COP_b} - \frac{Heating\ Load_p \times Hours}{COP_p} \right) \div 3,412$$

Where,

Heating Load	= Heating load per bin, Btu
Hours	= Hours per temperature bin
COP_b	= Baseline rated COP efficiency at each temperature bin based on performance table
COP_p	= Proposed rated COP efficiency at each temperature bin based on performance table
3,412	= Btu per kWh conversion

The applicant calculates load for heating and cooling based on the rated capacity (MBH) for each unit and the percentage cooling or heating load for each temperature bin based on an occupied or unoccupied load profile. The following formula represents applicant's approach for determining heating or cooling load.

$$Load = Capacity \times \% \, Load \times 1000$$

Where,

Load	= Heating or cooling load, based on regressions described below, Btu
1000	= MBH to Btu conversion
% Load	= Percentage heating or cooling load for each temperature bin based trends

The applicant calculates percentage load for heating and cooling based on performance tables relating OAT to percent load for unoccupied and occupied times. The applicant uses the performance data shown in Figure 2-1 and Figure 2-2 to calculate percent load using regressions based on OAT for each temperature bin. The evaluator notes that this method is not appropriate and overestimate savings due to overestimating the load and operation of the heat pumps. For example, for cooling, the applicant estimates 10% load at 50 °F. The evaluators observed from the operating data that the cooling system does not operate when OAT is as low as 50 °F. The evaluators do not consider these temperature ranges and estimated load profiles to be accurate.

Figure 2-1. Cooling Load Profile

Occupied Profile				Unocc Profile			
Max OAT °F	Min OAT °F	%Load @ Max OAT	%Load @ Min OAT	Max OAT °F	Min OAT °F	%Load @ Max OAT	%Load @ Min OAT
95	50	100%	10%	95	70	40%	5%

Figure 2-2. Heating Load Profile

Occupied Profile				Unocc Profile			
Max OAT °F	Min OAT °F	%Load @ Max OAT	%Load @ Min OAT	Max OAT °F	Min OAT °F	%Load @ Max OAT	%Load @ Min OAT
60	0	10%	100%	60	0	0%	50%

Measure 3: Building Insulation

The applicant used a temperature bin analysis to estimate annual heating and cooling loads based on hours in which the outdoor air temperature is within a temperature bin range. For each temperature bin, the spreadsheet calculates the heat transfer through each building envelope component using the formula:

$$Q \, (Btu/year) = U \times A \times \Delta T \times Hours$$

Where,

Q	=Annual heat loss/gain, Btu/year
U	= U-value, thermal resistance for each component, Btu/hr·ft²·°F
A	= Surface area for each component, ft²
ΔT	= Average temperature difference for each bin
$Hours$	= Number of occupied or unoccupied hours for each bin

The heat losses or gains are summed across all bins to determine annual energy use for both baseline and proposed U-values. The applicant calculates energy savings as the difference between the baseline and proposed case using the following equations for either heating or cooling savings:

$$Annual\ Savings\ (heating) = \frac{Q_{baseline} - Q_{proposed}}{Eff \times 3{,}412}$$

$$Annual\ Savings\ (Cooling) = \frac{Q_{baseline} - Q_{proposed}}{Eff}$$

Where,

$Q_{baseline}$	=Baseline annual heat loss/gain, Btu/year
$Q_{proposed}$	=Proposed annual heat loss/gain, Btu/year
Eff	=HVAC system efficiency, 2.7 COP for heating, 11.4 IEER for cooling 3,412
	= Btu per kWh conversion

Measure 4: Energy recovery ventilator

The applicant determined energy savings by calculating the amount of thermal energy recovered from exhaust air and subtracting that from the HVAC load required to condition outdoor air. The evaluators note that the applicant used the small buildings new construction calculator and set the "cooling included" parameter to "No" which eliminates the cooling hours from the analysis and thus does not consider savings for the cooling mode. It is not clear why the applicant does not include the savings for cooling mode operation. For heating savings, the applicant uses a binned approach which calculates heat recovered for each temperature bin using the following formula:

$$Q\ (Btu) = CFM \times 60 \times \rho \times cp \times Effectiveness \times \Delta T \times Hours$$

Where,

CFM	= Air flow rate, ft³/min
60	= minutes per hour to convert CFM to ft³/hr
ρ	= Air density, 0.075 lb/ ft³
c_p	= Specific heat of air, 0.24 Btu/lb ̄F
$Effectiveness$	= Sensible heat recovery effectiveness, 0.50 in the baseline and 0.72 in the proposed case
ΔT	= Temperature difference between indoor return air and outdoor air
$Hours$	= Number of occupied hours for each bin

The applicant calculates the energy recovered for each bin in both the proposed and baseline cases to determine the annual Btu savings. Annual electric savings for ERV are calculated as the difference between baseline and proposed annual energy recovery shown in the formula below:

$$Annual\ Savings = \frac{(Q_{baseline} - Q_{proposed})}{(Eff \times 3,412)}$$

Where,

$Q_{baseline}$	=Baseline annual heat gain, Btu/year
$Q_{proposed}$	=Proposed annual heat gain, Btu/year
Eff	=Baseline HVAC system efficiency, 2.63 COP for heating
3,412	=Btu per kWh conversion

As summarized in Section 2.3.2, the evaluators did not update the sensible heat recovery effectiveness proposed in tracking.

2.1.4　Evaluation assessment of applicant methodology

The evaluator determined that the applicant's use of the small buildings new construction savings calculator to estimate energy savings was appropriate. Each measure is calculated using a temperature bin approach and is reasonable. However, the evaluator notes that the applicant set the "cooling included" parameter in the ERV analysis to "No" which eliminates the cooling hours from the savings algorithm and thus does not consider savings for the cooling mode. It is not clear why the applicant does not include the savings for cooling mode operation. The evaluators determined that the ERV still operates in the cooling season and thus cooling mode operation should be included in the ERV savings analysis. The evaluator updated the analysis by incorporating metered data from the evaluation monitoring period based on data described in Section 2.2.2. The applicant could also have considered logging existing school HVAC system loads before finalizing the ex-ante calculations and modifying the calculator load assumptions based on existing school loads and schedules. Additionally, it is recommended that the applicant double check for all inputs in the calculator that may be left over from a prior project, such as the assumed COPs for the building shell and ERV calculations.

2.2　On-site inspection and metering

The evaluator conducted the initial site visit on February 26, 2025, and was assisted by maintenance personnel. The evaluator installed data logging equipment for the M1, M2, and M4. During the metering period, the evaluator inquired with the site contact on whether the building had any need for cooling. In late May, the site contact indicated that due to cold weather, the HVAC systems still did not enter cooling mode. In an effort to collect data inclusive of cooling mode operation, the evaluator returned to the site on June 4, 2025, to download interim data and relaunch the data loggers to collect more data. The evaluator returned to the site and retrieved meters on June 30, 2025. Table 2-4 summarizes the findings from the installed measure verification.

Table 2-4. Measure verification

Measure name	Verification method	Verification result
M1: Low-flow DHW fixtures	Evaluation kW measurements	• Inspected the sink aerators and confirmed the quantity and rated GPM for the aerators matched the applicant values • Installed a power logger on the electric DHW heater to meter kW • Confirmed that the only load on the DHW heater is for the faucets claimed in this application. There are no other DHW outlets and the DHW heater serves the new wing exclusively
M2: VRF heat pumps	Evaluation kW measurements	• Installed power loggers on each heat pump to meter kW of the entire circuit including the outside units and inside heads • Confirmed the installation of the VRF heat pumps • Inspected and confirmed the installation of outside units • Inspected and confirmed the installation of inside heads connected to each VRF heat pump • Confirmed that HP1 serves the first-floor classroom and hallways, and HP2 serves the second-floor classroom and hallways
M3: Building envelope	Interview the site contact, collect information about the project, verify setpoints and measurements	• Inquired with the site contact and school board for documentation for as-built specifications for wall, roof, and windows • Site contact and school board staff reported they do not have documentation showing the as-built specifications • Collected information on the setpoint temperatures and approximate areas for the wall, roof, and windows
M4: ERV	Evaluation kW measurements	• Confirmed the installation of the ERV • Installed a power logger on the ERV disconnect to measure total ERV power usage • Installed an amp logger on the ERV supply fan motor • Installed four temperature loggers in each corner of the ERV to measure the exhaust air, outdoor air intake, supply air, and return air temperatures • Took photos of the VFD displays serving the ERV fans and observed no significant change across multiple visits (readings taken several minutes apart and across a month between the interim and final visit)

2.2.1 Summary of site visit findings

The evaluator physically verified all equipment associated with this project and took photographs to document the installations. Findings from the site visits are summarized below:

- On February 26, 2025, the evaluator conducted a site tour of the school and confirmed that all energy measures were installed as part of a new construction project for a building expansion, specifically a newly added wing.
- Verified the installation of the low-flow water fixtures, VRF heat pumps, building envelope insulation, and ERV.
- Noted that maintenance personnel did not possess as-built documentation to verify insulation U-values or the square footage of the building envelope measure.
- Requested that site contacts search for any documentation that confirms as-built U-values for the building envelope and inquired with the school board for any relevant documentation on their servers.

- The maintenance personnel reported that they could not find any documentation, and the school board staff reported they do not have documentation on the as-built insulation.

- Inquired about trend data with maintenance staff, who stated that the energy management system (EMS) is not configured to record trends and that trending functionality is locked out by a third-party firm, not accessible by onsite staff. The on-site staff did not know which vendor to reach out to for setting up trends.
- Requested information on building schedules and setpoint temperatures across all modes:

  - Occupied: The maintenance personnel indicated that the occupied setpoint is 72°F year-round.
  - Unoccupied: Unoccupied setback is 79°F in cooling mode and 65°F in heating mode.
  - School season: The maintenance personnel indicated that the school is occupied year-round even through typical summer vacation months.
  - Summer vacation: During the summer, the school hosts summer programs and has occupancy that is similar to occupancy during the school season.

- Installed power loggers on:

  - VRF heat pumps
  - Electric DHW heater
  - ERV system

- Installed temperature loggers in the ERV to record:

  - Exhaust air temperature
  - Outdoor air (OA) intake temperature
  - Supply air temperature
  - Return air temperature

- Installed HOBO amp loggers on the ERV supply fan to monitor electrical current
- Upon returning on June 4, 2025, the maintenance personnel informed the evaluator that there was no call for cooling until that date. They estimated that June 4 was the first day they noticed a call for cooling.
- Evaluator downloaded data on June 4 for all loggers and relaunched them to collect more warm weather data.
- On June 4, the evaluator took photos of the VFD displays serving the ERV outdoor air intake motor and the exhaust air motor.
- Evaluator returned on June 30 to collect the loggers and retrieve data. During this time, the evaluator took photos of the VFD displays serving the ERV outdoor air intake motor and the exhaust air motor and noted no significant change from one month ago and over a period of 10 minutes, indicating the VFDs are set to a constant speed.

Figure 2-3 shows a bathroom faucet (GPM rating not shown) and Figure 2-4 shows a classroom faucet with a 1.5 GPM rating. The evaluator found product photos from online vendors matching the applicant-claimed model numbers for the bathroom and classroom faucets and the photos appeared to be the same as the faucets observed on-site.

Figure 2-3. Low flow DHW fixture – bathroom

Figure 2-4. Low flow DHW fixture – classroom

Figure 2-5 shows the outside units for heat pumps 1 and 2 which are part of the VRF heat pump system. Figure 2-6 and Figure 2-7 shows the nameplates for heat pump 1 and heat pump 2 respectively.

Figure 2-5. VRF heat pumps – outside units

Figure 2-6. VRF heat pump 1 nameplate

Figure 2-7. VRF heat pump 2 nameplate

Figure 2-8 shows the energy recovery ventilator, which was confirmed to be installed on the roof. Figure 2-9 shows a photo of the VFD displays serving the outside air intake and exhaust air motor, taken on June 4, 2025. Figure 2-10 shows a photo of the same VFD displays approximately one month later, taken on June 30, 2025, which shows both VFDs running at the same speed as the previous visit. The evaluator monitored the VFD over a course of 10 minutes and observed no significant difference in VFD speed during that time interval.

Figure 2-8. ERV

Figure 2-9. ERV VFD displays taken on June 4, 2025

Figure 2-10. ERV VFD displays taken on June 30, 2025

Figure 2-11 shows the energy recovery ventilator nameplate which matches the applicant description.

Figure 2-11. ERV nameplate

2.2.2 Metered and logged data

DNV installed loggers on M1: Low flow DHW fixtures, M2: VRF heat pumps, and M4: ERV. No loggers were installed for M3: Building envelope. Loggers were installed on February 26, 2025. DNV returned on June 4 to collect interim data and relaunch loggers to record more cooling season data since the maintenance personnel reported that they did not observe a call for cooling yet in the season. DNV returned on June 30 to retrieve loggers. Loggers and data for each measure are discussed in the sections below:

Measure 1: Low flow DHW fixtures

DNV installed a logger to record power (kW) on the electric resistance water heater serving the low flow fixtures. The evaluator logged data for approximately four months at 5-minute intervals.

Measure 2: VRF heat pumps

DNV installed a logger to record power (kW) on each of the heat pumps serving the new wing of the school. The maintenance technician assisted in locating the heat pumps in the electrical panels and indicated that the circuits metered include the power for the outside units and inside heads serving all spaces. The evaluator logged data for approximately four months at 5-minute intervals. The evaluator examined the data and determined that the heat pumps switch from heating to cooling mode at 60 $^{\circ}$F which is discussed further in Section 2.3.2.

Measure 4: ERV

DNV installed a logger to record power (kW) at the ERV disconnect on the roof of the building. The power logger was installed to record total ERV power usage including both VFD-controlled fan motors. The power logger recorded data at 5-minute intervals for four months. As a backup, evaluators also installed an amp logger on the supply fan motor inclusive of the VFD controlling it which logged data at a 5-minute interval. For ERV temperatures, the evaluator installed thermocouple temperature loggers at each of the four compartments of the ERV to record temperatures for exhaust air, outdoor air intake, supply air, and return air. All loggers on the ERV collected data for approximately four months.

The evaluator noted that the temperature logger for the outside air intake occasionally recorded temperature readings that were significantly different than the Newport, RI weather station OAT data for the same time period. The evaluator also noted the OA intake logger recorded negative temperatures and temperatures above 100°F despite weather station data showing the temperatures did not escalate as high. Due to these observations, the evaluator has low confidence in the logger and suspect there were issues with its operation. These issues are discussed in further detail in Section 2.3.2 which described the evaluation calculation method for the ERV measure.

2.3   Evaluation methods and findings

This section describes the evaluator methods and findings.

2.3.1   Evaluation description of baseline

The evaluator reviewed the baseline for each measure as described in Section 2.1.1 and determined the baseline inputs to be reasonable. The evaluator classified all measures as new construction with a single baseline and agreed with the baselines as described by the applicant, which are based on code requirements for new construction buildings.

2.3.2   Evaluation calculation method

The evaluators reviewed the savings calculations for each measure as described in Section 2.1.1 and agree with the use of the methodology given the lack of information on actual building loads. The evaluators note however, the applicant approach does not consider interactivity of the measures. The evaluator's approach addresses interactivity by calculating energy savings sequentially starting with the building envelope measure, then VRF heat pumps, then ERV. First, the building envelope measure is evaluated, with cooling load reduction determined from the difference between baseline and installed envelope performance, and electric savings calculated using the baseline HVAC efficiency. Next, HVAC measures are analyzed using cooling loads based on the installed envelope performance, with savings calculated from the difference between baseline and installed HVAC performance. Finally, the ERV measure is assessed, with cooling load savings based on ERV operation and electric savings calculated using the installed HVAC efficiency to avoid double counting savings.

The evaluators agreed with the approach of using the small buildings new construction savings calculator and used the same methodology as the applicant for M3: Building envelope and M4: ERV after adjusting some parameters determined through on-site data collection and including interactive effects. For M1: Low flow DHW fixtures and M2: VRF heat pumps, the evaluators used the metered data to generate regressions or hourly operating profiles for use in an 8,760 analysis. Details on the evaluation approach for each measure are described in the sections below:

Measure 1: Low-flow DHW fixtures

DNV used the 5-minute power data from the DHW heater to generate hourly operating profiles for use in an 8,760 analysis. The following steps were taken for the analysis:

1. Averaged kW power data from 5 minutes to hourly intervals to acquire average kW input for each hour during the metered period.
2. Calculated hourly average BTU input from the hourly average kW input.
3. Calculated hourly average BTU output from the hourly average BTU input using the rated as-built DHW efficiency.
4. Calculated hourly average water usage rate (GPM) based on the average hourly BTU output, considering a temperature rise from 55°F ground water temperature to 135°F hot water setpoint temperature.
5. Determined the average run time for each hour based on the average water usage rate.
6. Assumed the same hourly average run time in the baseline case and calculated the baseline water usage rate based on the ratio between total baseline aerator GPM rating (55 GPM) and total as-built aerator GPM rating (24.6).

7. Calculated hourly average BTU output energy considering baseline water usage rate.

8. Calculated hourly average BTU input energy using the rated baseline DHW efficiency.

9. Calculated average kW power usage in the baseline case from the BTU input energy.

10. Calculated energy savings for every hour as the difference between baseline and as-built energy usage.

11. Generated an hourly savings profile for a typical week. The savings profile is shown in Figure 2-12 where 1 is Monday, 2 is Tuesday, and so on.

Figure 2-12. Hourly savings profile for a typical week for the DHW heater, kWh

	1	2	3	4	5	6	7
Non - Holiday							
0	0.16	0.30	0.35	0.30	0.34	0.39	0.42
1	0.55	0.30	0.23	0.25	0.19	0.27	0.26
2	0.09	0.37	0.28	0.31	0.40	0.28	0.36
3	0.44	0.31	0.35	0.33	0.25	0.37	0.30
4	0.23	0.19	0.28	0.28	0.39	0.20	0.36
5	0.41	0.39	0.34	0.40	0.22	0.30	0.25
6	0.27	0.26	0.24	0.21	0.43	0.30	0.31
7	0.34	0.25	0.38	0.33	0.20	0.36	0.31
8	0.41	0.34	0.23	0.33	0.34	0.30	0.27
9	0.25	0.38	0.49	0.32	0.40	0.29	0.33
10	0.54	0.44	0.31	0.48	0.28	0.28	0.24
11	0.35	0.39	0.47	0.39	0.62	0.31	0.39
12	0.52	0.57	0.38	0.52	0.26	0.35	0.27
13	0.34	0.32	0.40	0.32	0.56	0.30	0.34
14	0.52	0.50	0.46	0.53	0.27	0.33	0.34
15	0.27	0.31	0.34	0.33	0.59	0.29	0.31
16	0.47	0.38	0.36	0.37	0.28	0.20	0.30
17	0.21	0.27	0.22	0.30	0.40	0.43	0.36
18	0.41	0.41	0.37	0.34	0.30	0.22	0.27
19	0.20	0.20	0.24	0.29	0.20	0.35	0.39
20	0.44	0.40	0.39	0.25	0.49	0.33	0.24
21	0.23	0.25	0.24	0.42	0.13	0.35	0.40
22	0.27	0.36	0.34	0.24	0.44	0.24	0.22
23	0.35	0.30	0.32	0.29	0.20	0.21	0.42
Holiday							
0	0.06	0.00	0.23	0.00	0.68	0.19	0.19
1	0.53	0.01	0.46	0.51	0.00	0.30	0.30
2	0.16	0.66	0.00	0.18	0.63	0.33	0.33
3	0.42	0.00	0.70	0.34	0.00	0.29	0.29
4	0.26	0.68	0.00	0.35	0.65	0.39	0.39
5	0.34	0.00	0.70	0.00	0.00	0.21	0.21
6	0.34	0.72	0.00	0.68	0.00	0.35	0.35
7	0.32	0.00	0.68	0.00	0.66	0.33	0.33
8	0.35	0.71	0.00	0.71	0.00	0.35	0.35
9	0.00	0.00	0.00	0.00	0.73	0.15	0.15
10	0.67	0.00	0.74	0.67	0.00	0.42	0.42
11	0.00	0.68	0.00	0.04	0.69	0.28	0.28
12	0.55	0.00	0.68	0.20	0.00	0.29	0.29
13	0.16	0.73	0.00	0.47	0.64	0.40	0.40
14	0.37	0.00	0.68	0.00	0.07	0.22	0.22
15	0.35	0.71	0.00	0.73	0.00	0.36	0.36
16	0.30	0.00	0.62	0.00	0.72	0.33	0.33
17	0.41	0.00	0.00	0.68	0.00	0.22	0.22
18	0.00	0.70	0.00	0.00	0.68	0.28	0.28
19	0.65	0.00	0.71	0.34	0.00	0.34	0.34
20	0.00	0.69	0.00	0.35	0.72	0.35	0.35
21	0.36	0.00	0.69	0.00	0.00	0.21	0.21
22	0.34	0.71	0.00	0.68	0.19	0.38	0.38
23	0.35	0.00	0.72	0.00	0.50	0.32	0.32

The following formula represents the approach for calculating kWh savings for each hour in the weekly profile shown in Figure 2-12:

$$Baseline\ Energy\ Usage = \frac{500\ \times\ \Delta T\ \times Usage\ Rate_{as\ built}}{Eff_{baseline}} \times \frac{Total\ rated\ GPM_{as\ built}}{Total\ rated\ GPM_{baseline}}$$

And,

$$Usage\ Rate_{as\ built} = \frac{Input\ Power\ (kW) \times Eff_{as\ built}}{500 \times \Delta T}$$

Where:

Hourly Energy Savings	= Energy savings, kW/hr
Baseline Energy Usage	=Energy usage in the baseline case, Btu/hr
	= Conversion factor which represents the product of water density of 8.33 lb/gal, specific heat capacity of water, 1 Btu/lb℉ and 60 min/hour
ΔT	= Temperature rise, 65℉
$Eff_{baseline}$	= Baseline heater efficiency, 0.95
$Eff_{as\ built}$	= Proposed heater efficiency, 0.95
$Usage\ Rate_{as\ built}$	= As-built case usage rate base on metered power data, GPM
$\frac{Total\ rated\ GPM_{as\ built}}{Total\ rated\ GPM_{baseline}}$	= Ratio of the total rated GPM for all faucets in the as-built case (16.9 GPM) and total

rated GPM for all faucets in the baseline case (24.6 GPM) to convert as built usage rate to baseline case usage rate

The evaluator calculated as built energy use using the metered power data which is shown in the following formula:

$$As\ built\ Energy\ Usage = Input\ Power\ (kW) \times 3412$$

As built Energy Usage	=Energy usage in the as built case, Btu/hr
Input Power (kW)	= Average hourly input power, from metered data, kW/hr
3,412	= Btu per kWh conversion

Lastly, the evaluator extrapolated the hourly savings profile to an 8760 table based on a lookup of day type and hour of day. The formula below shows the methodology for calculating the annual energy savings given the parameters above:

$$Annual\ Energy\ Savings = \sum_{i=1}^{8760} \frac{Baseline\ Energy\ Usage - As\ built\ Energy\ Usage}{3412}$$

Measure 2: VRF heat pumps

The evaluator analyzed 5-minute power data from the VRF heat pumps to develop kW usage temperature bins for each unit, categorized by heating mode, cooling mode, and by occupancy status (occupied and unoccupied). The evaluator used those temperature bins to generate kW vs. OAT regressions for each heat pump. The evaluator used the regressions in an 8,760 table that looked up occupied vs. unoccupied status, heating vs. cooling mode , and TMY3 OAT temperature to determine the as-built kW usage for each hour. Heating and cooling modes were determined by observed switch over points in the operating data. The evaluators observed a switch over point of 60℉ between heating and cooling modes. The evaluator

assumed the same load in the baseline case and calculated the baseline kW usage for each hour. The evaluator calculated the energy savings as the difference between baseline and as-built case energy usage for each hour in the 8760 analysis. The following steps show the methodology for M2:

1. Averaged kW power data from 5 minutes to hourly intervals to acquire average kW input for each hour during the metered period.
2. The evaluator created an hourly operating schedule for a typical week and observed that the typical operating schedule is 5 AM to 10 PM on Mondays to Thursday, 5 AM to 4 PM on Fridays. The evaluators defined those hours as occupied and all other hours as unoccupied.
3. Created 2-degree temperature bins relating the OAT and average heat pump power usage (kW) for each temperature bin. The evaluator created four bin tables: HP1 occupied kW usage, HP2 occupied kW usage, HP1 unoccupied kW usage, and HP2 unoccupied kW usage.
4. The evaluator created regressions based on each bin table relating kW to the outdoor air temperature and occupancy mode.
5. In an 8,760 table, the evaluator calculated as-built consumption (kW) for both HP1 and HP2 based on the regressions. The evaluator created a flag for unoccupied vs occupied periods based on the observed schedule from metered data and a flag for heating vs cooling based on a 60°F switch over point. Using those flags, the evaluator calculated as-built consumption (kW) based on the relevant regression for each operating mode.
6. The evaluator determined HP1 and HP2 heating and cooling loads based on the rated as-built efficiencies for each heat pump.
7. The evaluator assumed the same load in the baseline case and calculated baseline consumption for HP1 and HP2 based on the baseline efficiencies for each heat pump.
8. The evaluator calculated kW savings for each hour in an 8760 table as the difference between baseline and as-built energy usage.

The following formulas represent the evaluator's energy savings approach:

$$Baseline\ Energy\ Use = \frac{Load}{Eff_b} \div 3{,}412$$

And

$$As\ Built\ Energy\ Use = \frac{Load}{Eff_{as\ built}} \div 3{,}412$$

Where,

$Load$ = Heating or cooling load as determined by regressions of OAT vs metered kW and converted to Btu/hr, assuming the same load in baseline and as-built cases

Eff_b = Rated baseline heating or cooling efficiency of HP-1 or HP-2, as described in Table 2-2

$Eff_{as\ built}$ = Rated as-built heating or cooling efficiency of HP-1 or HP-2, as described in Table 2-3

The evaluator calculates energy savings as the difference between baseline and as built energy use for each hour in the 8760 analysis. The formula for annual energy savings is presented below:

$$Annual\ Energy\ Savings = \sum_{i=1}^{8760} Baseline\ Energy\ Use - As\ Built\ Energy\ Use$$

Measure 3: Building envelope

The evaluator used the same methodology as the applicant to calculate energy savings for the building envelope measure. The applicant approach is described in Section 2.1.3 for M3. Since the evaluator could not acquire documentation on the rated specifications for wall, roof, and window materials, the evaluator defaulted to the applicant U-values for each component. The evaluator performed measurements of the wall, window, and roof area using available online map data and found the areas as claimed by the applicant to be reasonable. The evaluator updated the applicant calculator with the set-points communicated by the maintenance personnel. The maintenance personnel indicated that the occupied setpoint is 72°F year-round. Unoccupied setback is 79°F in cooling mode and 65°F in heating mode. The applicant claimed that in cooling mode, the occupied set-point is 75°F in and the unoccupied set-point is 80°F. The applicant also claimed that in heating mode, the occupied set-point is 72°F and the unoccupied set-point is 65°F. Table 2-5 summarizes the applicant and evaluated setpoint temperatures.

Table 2-5. Heating and cooling mode setpoints based on occupancy

Mode	Condition	Applicant Setpoint (°F)	Evaluated Setpoint (°F)
Heating	Occupied	72°F	72°F
Heating	Unoccupied	65°F	65°F
Cooling	Occupied	75°F	72°F
Cooling	Unoccupied	80°F	79°F

Since the evaluator uses the same approach as the applicant, the formulas for the savings approach are also the same. For each temperature bin, the spreadsheet calculates the heat transfer through each building envelope component using the formula:

$$Q\ (Btu/year) = U \times A \times \Delta T \times Hours$$

Where,

Q =Annual heat loss/gain, Btu/year

U = U-value, thermal resistance for each component, Btu/hr·ft²·°F

A = Surface area for each component, ft²

ΔT = Average temperature difference for each bin

$Hours$ = Number of occupied hours for each bin

The heat losses or gains are summed across all bins to determine annual energy use for both baseline and proposed U-values. The applicant calculates energy savings as the difference between the baseline and proposed case using the following equation:

$$Annual\ Savings = \frac{Q_{baseline} - Q_{proposed}}{Eff \times 3,412}$$

Where,

$Q_{baseline}$ =Baseline annual heat loss/gain, Btu/year

$Q_{proposed}$ =Proposed annual heat loss/gain, Btu/year

Eff =HVAC system efficiency, 2.95 COP for heating, 11.4 IEER for cooling

3,412   = Btu per kWh conversion

The evaluator updated the HVAC system efficiency based on baseline values of COP 3.2 @ 47°F, COP 2.1 @ 17°F according to IECC 2021. The evaluators calculated a weighted average COP using weather data for New Bedford, MA. No other discrepancies for M3 were found as part of the evaluation. Results are discussed in further detail in Section 3.

Measure 4: ERV

The evaluator attempted to calculate the effectiveness of the ERV using the temperature metered for exhaust air, outdoor air intake, supply air, and return air. However, the evaluator had low confidence in the data due to logger issues, as described in Section 2.2.2. Furthermore, when the evaluator calculated the heat exchanger effectiveness using the metered temperature data, they determined an average effectiveness over 100% across the metered time period. The evaluator hypothesizes that the observed HX effectiveness of greater than 100% is possibly because the temperature logger recording the leaving air temperature, i.e., the supply air temperature before the heating coil, may have been picking up some radiant heat from the heating coils themselves. The evaluator considers another hypothesis: that the temperature loggers may have been picking up readings from stagnant air rather being in the direct air steam. The ERV is installed on a white cool roof, which may reflect radiant heat off the surface of the roof and influence the temperature of the pockets of air within the ERV, which are not directly in the airstream. Due to ductwork access limitations, the evaluators could not place the temperature loggers in the ideal locations, which would have been within the ductwork and in the direct air stream.

During the site visit, the evaluators installed loggers to monitor the entire unit power usage, inclusive of VFDs for the outside air and exhaust fans. Based on the recorded operation, the evaluators noted that the fans were running a constant speed despite the VFDs. Given the operating profile of the fans, the evaluator deemed the fans were running at a fixed speed and determined the fans were operating at 88% speed (53 hz) while on. The evaluator examined the metered kW data and observed that the power did not vary significantly other than being on or off. This is corroborated by the observations shown in Figure 2-9 and Figure 2-10, where the VFD displays showed that there was no change in VFD speed a month apart. The evaluator determined that the ERV was operating at 88% capacity (3445 CFM out of a design rated 3900) while it was running. Based on this observation and issues with the temperature data, the evaluator opted to update the applicant analysis based on the finding that the ERV operates at a maximum of 3445 CFM. The evaluator used the same analysis as the applicant which is described in 2.1.3 for M4: ERV. The evaluator updated the design max capacity from 3900 CFM to 3445 CFM.

The evaluator also noted that the applicant set the "cooling included" parameter in the ERV analysis to "No" which eliminates the cooling hours from the savings algorithm and thus does not consider cooling load savings for the cooling mode. It is not clear why the applicant does not include the savings for cooling mode operation. The evaluators determined that the ERV still operates in the cooling season and thus cooling mode operation should be included in the ERV savings analysis. The evaluator included the cooling mode savings which increased the cooling load.

The evaluators noted that the applicant used a COP of 2.63 for heating and it is not clear where this rating comes from. The evaluators replaced the heating system COP with the COP of the heat pumps. The as-built heat pump 1 is rated at a COP of 3.3 at 47°F and COP of 2.5 at 17°F. The as-built heat pump 2 is rated at a COP of 3.6 at 47°F and COP of 2.6 at 17°F. The evaluators calculated average of both HP-1 and HP-2 efficiencies and weighted by number of hours spent at each

temperature bin. The evaluators calculated an average COP of 3.05 for the heating system and updated the applicant analysis with that value. Evaluators did not update the sensible heat recovery effectiveness proposed in tracking.

Since the evaluator uses the same approach as the applicant, the formulas for the savings approach are also the same. The applicant uses a binned approach which calculates heat recovered for each temperature bin using the following formula:

$$Q\ (Btu) = CFM \times 60 \times \rho \times cp \times Effectiveness \times \Delta T \times Hours$$

Where,

CFM	= Air flow rate, ft³/min
60	= minutes per hour to convert CFM to ft³/hr
ρ	= Air density, 0.075 lb/ ft³
c_p	= Specific heat of air, 0.24 Btu/lb ℉
$Effectiveness$	= Sensible heat recovery effectiveness, 0.50 in the baseline and 0.72 in the proposed case
ΔT	= Temperature difference between indoor return air and outdoor air
$Hours$	= Number of occupied hours for each bin

The applicant calculates the energy recovered for each bin in both the proposed and baseline cases to determine the annual Btu savings. Annual electric savings for ERV are calculated as the difference between baseline and proposed annual energy recovery shown in the formula below:

$$Annual\ Savings = \frac{(Q_{baseline} - Q_{proposed})}{(Eff \times 3,412)}$$

Where,

$Q_{baseline}$	=Baseline annual heat gain, Btu/year
$Q_{proposed}$	=Proposed annual heat gain, Btu/year
Eff	=Baseline HVAC system efficiency, 3.05 COP for heating or 10.6 EER for cooling
3,412	=Btu per kWh conversion

No other discrepancies for M4 were determined. Results are discussed in further detail in Section 3.

3 FINAL RESULTS

The evaluated project consisted of four measures at an elementary school. The measures comprised of M1: Low flow DHW fixtures, M2: VRF heat pumps, M3: Building envelope insulation and M4: ERV. In sum, all measure savings are about 32% less than the tracking values. Measure 1 performed slightly better with an evaluated realization rate of 104% due to the difference in evaluated average hot water usage rate (GPM) between the baseline and as-built cases being higher than the applicant estimates. The evaluators note that the evaluator's baseline usage is higher than the applicant's baseline usage. Similarly, the evaluator's installed case usage is higher than the applicant's proposed usage. Overall, the evaluated difference in hot water usage rate between installed and baseline cases is higher than the applicant's difference in usage resulting in more savings. Measure 2 performed significantly worse with an evaluated realization rate of 44% due to having a lower heating and cooling load and lower as-built heat pump efficiencies in the evaluated case resulting in lower savings. Measure 3 performed worse in the evaluated case with an evaluated realization rate of 90.3% due to a slightly higher evaluated case baseline average heating system efficiency. The applicant's average heating system efficiency was weighted by different weather data. The evaluators calculated average heating system efficiency for HP1 and HP2 and weighted based on local weather data resulting in a slightly higher baseline COP. The higher baseline COP resulted in lower savings for this measure. Lastly, Measure 4 performed better with an evaluated realization rate of 107% primarily due to the inclusion of cooling ERV savings which were not claimed by the applicant. Only heating ERV savings were claimed in the applicant's analysis. The parameters impacting the analysis are summarized in Table 3-1 for Measure 1, Table 3-2 for Measure 2, Table 3-3 for Measure 3, and Table 3-4 for Measure 4.

Table 3-1. Summary of key parameters (Measure 1- DHW)

Parameter	BASELINE		PROPOSED / INSTALLED	
	Tracking	Evaluation	Tracking	Evaluation
	Value(s)	Value(s)	Value(s)	Value(s)
Faucet flow rate (rated)	1.5 GPM (classroom), 0.35 GPM (bathroom)	1.5 GPM (classroom), 0.35 GPM (bathroom)	1.5 GPM (classroom), 0.35 GPM (bathroom)	1.5 GPM (classroom), 0.35 GPM (bathroom)
Faucet quantity	8 (classroom), 14 (bathroom)	8 (classroom), 14 (bathroom)	8 (classroom), 14 (bathroom)	8 (classroom), 14 (bathroom)
Temperature rise	75℉	80℉	75℉	80℉
Building area	12,122 sq. ft.	12,122 sq. ft.	12,122 sq. ft.	12,122 sq. ft.
Heater efficiency	0.95	0.95	0.95	0.95
Usage rate	0.084 GPM	0.09 GPM	0.0575 GPM	0.0585 GPM

Table 3-2. Summary of key parameters (Measure 2- ERV)

Parameter	BASELINE		PROPOSED / INSTALLED	
	Tracking	Evaluation	Tracking	Evaluation
	Value(s)	Value(s)	Value(s)	Value(s)
Capacity	HP-1: 184,000 Btu/h cooling, 206,000 Btu/h heating HP-2: 206,000 Btu/h cooling, 230,000 Btu/h heating	HP-1: 184,000 Btu/h cooling, 206,000 Btu/h heating HP-2: 206,000 Btu/h cooling, 230,000 Btu/h heating	HP-1: 184,000 Btu/h cooling, 206,000 Btu/h heating HP-2: 206,000 Btu/h cooling, 230,000 Btu/h heating	HP-1: 184,000 Btu/h cooling, 206,000 Btu/h heating HP-2: 206,000 Btu/h cooling, 230,000 Btu/h heating
Cooling efficiency	10.4 EER / 13.7 IEER	10.4 EER / 13.7 IEER)	10.6 EER / 20.0 IEER (HP-1), 10.7 EER / 22.3 IEER (HP-2)	10.5 EER / 19.9 IEER (HP-1), 10.7 EER / 22.4 IEER (HP-2)

	BASELINE		PROPOSED / INSTALLED	
Heating efficiency	COP 3.2 @ 47°F, COP 2.1 @ 17°F	COP 3.2 @ 47°F, COP 2.1 @ 17°F	COP 3.3 @ 47°F, COP 2.5 @ 17°F (HP-1) COP 3.6 @ 47°F, COP 2.6 @ 17°F (HP-2)	COP 3.3 @ 47°F, COP 2.41 @ 17°F (HP-1) COP 3.2 @ 47°F, COP 2.34 @ 17°F (HP-2)
Annual heating load	541,575MBH	302,458 MBH	541,575MBH	302,458 MBH
Annual cooling load	255,367 MBH	238,668 MBH	255,367 MBH	238,668 MBH

Table 3-3. Summary of key parameters (Measure 3- BUILDINGSHELL)

	BASELINE		PROPOSED / INSTALLED	
Parameter	**Tracking**	**Evaluation**	**Tracking**	**Evaluation**
	Value(s)	Value(s)	Value(s)	Value(s)
Wall area	8,484 sq. ft.	8,484 sq. ft.	8,484 sq. ft.	8,484 sq. ft.
Roof area	6,061 sq. ft.	6,061 sq. ft.	6,061 sq. ft.	6,061 sq. ft.
Window area	1,390 sq. ft	1,390 sq. ft	1,390 sq. ft	1,390 sq. ft
Wall U-value	0.064 Btu/hr·ft²·°F	0.064 Btu/hr·ft²·°F	0.052 Btu/hr·ft²·°F	0.052 Btu/hr·ft²·°F
Roof U-value	0.032 Btu/hr·ft²·°F	0.032 Btu/hr·ft²·°F	0.032 Btu/hr·ft²·°F	0.032 Btu/hr·ft²·°F
Window U-value	0.398 Btu/hr·ft²·°F	0.398 Btu/hr·ft²·°F	0.346 Btu/hr·ft²·°F	0.346 Btu/hr·ft²·°F
Heating system efficiency	2.7 COP	2.95 COP	2.7 COP	2.95 COP
Cooling system efficiency	11.4 EER	11.4 EER	11.4 EER	11.4 EER
Occupied heating setpoint	72°F	72°F	72°F	72°F
Unoccupied heating setpoint	65°F	65°F	65°F	65°F
Occupied cooling setpoint	75°F	72°F	75°F	72°F
Unoccupied cooling setpoint	80°F	79°F	80°F	79°F
Cooling Load Reduction	165 MBH	165 MBH	398 MBH	538 MBH

Table 3-4. Summary of key parameters (Measure 4 - ERV)

	BASELINE		PROPOSED / INSTALLED	
Parameter	**Tracking**	**Evaluation**	**Tracking**	**Evaluation**
	Value(s)	Value(s)	Value(s)	Value(s)
Max CFM	3900 CFM	3445 CFM	3900 CFM	3445 CFM
Winter ERV effectiveness	50% sensible effectiveness	50% sensible effectiveness	72% sensible effectiveness	72% sensible effectiveness
Summer ERV effectiveness	50% effectiveness	50% effectiveness	55% effectiveness	55% effectiveness
Heating system efficiency	2.63 COP	3.05 COP	2.63 COP	3.05 COP
Cooling system efficiency	Not applicable	10.6 EER	Not applicable	10.6 EER

	BASELINE		PROPOSED / INSTALLED	
Cooling load	0 MBH	1,491 MBH	0 MBH	1,491 MBH
Heating load	43,093 MBH	52,693 MBH	43,093 MBH	52,693 MBH

3.1   Explanation of differences

Overall, the evaluated savings for this project are 32% less than the tracking values predominantly because of the lower performance of Measure 2 stemming from lower heating and cooling loads and lower as-built efficiencies.

Measure 1 performed slightly better with an evaluated realization rate of 104% due to the difference in evaluated average usage rate (GPM) between the baseline and as-built cases being higher than the applicant estimates. The slightly higher difference in usage rate resulted in higher savings. The evaluators note that the evaluator's baseline usage is higher than the applicant's baseline usage. Similarly, the evaluator's installed case usage is higher than the applicant's proposed usage. Overall, the evaluated difference in hot water usage rate between installed and baseline cases is higher than the applicant's difference in usage resulting in more savings

Measure 2 performed significantly worse with an evaluated realization rate of 44% due to having a lower heating and cooling load in the evaluated case. The evaluators determined that the heating and cooling load on the heat pumps are significantly lower than the applicant estimated. The evaluator observed in the metered data that the recorded operating power was low, with an average of 2.0 kW for HP-1 and 1.84 kW for HP-2 during the metered period. The evaluators hypothesized that good insulation resulted in less infiltration and less load on the heating system. The evaluators noted that the operating profile for the heating system showed that there was high power usage each morning (around 6 AM) and usage was comparatively low for the rest of the day indicating the system was able to get up to setpoint temperatures and the building was able to maintain that temperature either through good insulation or heat recovery. Furthermore, the evaluators determined that the as-built case heat pumps had lower heating and cooling efficiencies than the applicant's proposed heat pumps. The lower efficiencies of the as-built heat pumps result in lower savings.

Measure 3 performed worse in the evaluated case with an evaluated realization rate of 90.3% primarily due to a higher baseline heating system efficiency. The applicant calculated average baseline efficiency for HP1 and HP2 and weighted based on weather data from a different location. The evaluators used weather data from New Bedford, MA which closely matches the climate in Newport, RI to weight the average COP. The evaluator's average baseline COP of 2.95 is slightly higher than the applicant's average baseline COP of 2.7 which resulted in less savings. The evaluator also determined that the setpoint temperatures for the cooling mode are slightly different than the applicant estimated. For cooling, the applicant estimated an occupied setpoint temperature of 75 ℉ and unoccupied setpoint temperature of 80 ℉ whereas the evaluator determined an occupied setpoint temperature of 72 ℉ and unoccupied setpoint temperature of 79 ℉. This resulted in less cooling energy and therefore increased savings. However, this increase is offset by the baseline efficiency discrepancy which results in this measure saving less overall.

Measure 4 performed better with an evaluated realization rate of 107% primarily due to the inclusion of savings from cooling mode which increased the cooling load. The evaluators also noted that the lower maximum airflow rate of 3445 resulted in lower maximum load and overall lower savings than the applicant estimate. The evaluator also calculated a heating system efficiency for the baseline and proposed cases. The higher system efficiency in the baseline results in lower savings. The airflow and efficiency discrepancies are offset by the overall higher savings stemming from increased cooling load including cooling mode savings. Table 3-5 provides a summary of the differences between tracking and evaluated values for both measures.

Table 3-5. Summary of deviations

Measure	Discrepancy	Parameter	Impact of deviation	Discussion of deviations
M1	Load (Low flow DHW fixtures)	Water usage rate (GPM)	0.3%	Increased savings – Evaluator value = Baseline 0.09 GPM to as built 0.058 GPM Tracking value = Baseline 0.08 GPM to proposed 0.057 GPM
M1	Load (Low flow DHW fixtures)	Temperature Rise	0.1%	Increased savings – Evaluator value = 85℉ Temperature rise Tracking value = 75℉ Temperature rise
		M1 Total	**+0.4%**	
M2	Load (VRF heat pumps)	Heating and cooling load	-24.1%	Decreased savings – Evaluator value = 302,458 MBH Heating load 238,668 MBH Cooling load Tracking value = 541,575 MBH Heating load 255,367 MBH Cooling load
M2	Efficiency (VRF heat pumps)	As-built efficiency	-8.5%	Decreased savings – Evaluator value = Cooling: 10.5 EER / 19.9 IEER (HP-1), 10.7 EER / 22.4 IEER (HP-2) Heating: COP 3.3 @ 47°F, COP 2.41 @ 17°F (HP-1) COP 3.2 @ 47°F, COP 2.34 @ 17°F (HP-2) Tracking value = Cooling: 10.6 EER / 20.0 IEER (HP-1), 10.7 EER / 22.3 IEER (HP-2) Heating: COP 3.3 @ 47°F, COP 2.5 @ 17°F (HP-1) COP 3.6 @ 47°F, COP 2.6 @ 17°F (HP-2)
		M2 Total	**-32.6%**	
M3	Load (Building envelope insulation)	Proposed case cooling load reduction	+0.05%	Increased savings – Evaluator value = 538 MBH Tracking value = 398 MBH
M3	Efficiency (HVAC System efficiency)	Interactive HVAC system efficiency	-1.24%	Increased savings – Evaluator value = 2.95 COP Tracking value = 2.7 COP
		M3 Total	**-1.2%**	
M4	Load (ERV)	Max CFM	-2.2%	Decreased savings – Evaluator value = 3,445 CFM Tracking value = 3,900 CFM
M4	Load(ERV)	Cooling load	+6.2%	Increased savings – Evaluator value = 1,491 MBH Tracking value = 0 MBH
M4	Efficiency (ERV)	Interactive heating system efficiency	-2.6%	Decreased savings – Evaluator value = 3.05 COP

Measure	Discrepancy	Parameter	Impact of deviation	Discussion of deviations
				Tracking value = 2.63 COP
		M4 Total	**+1.3%**	
TOTAL			**-32.0%**	

3.2 Lifetime savings

The evaluator classified all measures as new construction with a single baseline. The evaluator calculated applicant and evaluated lifetime savings values using the following formula:

$$\text{LAGI} = \text{FYS} \times [\text{EUL}]$$

where:

LAGI = lifetime adjusted gross impact (therms)

FYS = first year savings (therms)

EUL = measure life (years)

For Measure M1, the evaluated lifetime savings are higher than the tracking lifetime savings because the evaluated first year savings are lower than the tracking first year savings. For Measure M2, the evaluated lifetime savings are lower than the tracking lifetime savings because the evaluated first year savings are higher than the tracking first year savings. For Measure M3, the evaluated lifetime savings are higher than the tracking lifetime savings because the evaluated first year savings are higher than the tracking first year savings. For Measure M4, the evaluated lifetime savings are higher than the tracking lifetime savings because the evaluated first year savings are higher than the tracking first year savings

Table 3-6 through Table 3-7 provide summaries of key factors that influence the lifetime savings for each measure.

Table 3-6. Measure M1 – Application ID: 13005576 – Lifetime savings summary

Factor	Tracking	Application	Evaluator
Lifetime savings (kWh)	25,660	25,660	26,761
First-year savings (kWh)	2,566	2,566	2,676
Measure lifetime (years)	10	10	10
Baseline classification	Lost Opportunity	Lost Opportunity	Lost Opportunity

Table 3-7. Measure M2 – Application ID: 13005576– Lifetime savings summary

Factor	Tracking	Application	Evaluator
Lifetime savings (kWh)	217,530	217,530	95,628
First-year savings (kWh)	14,502	14,502	6,375
Measure lifetime (years)	15	15	15
Baseline classification	Lost Opportunity	Lost Opportunity	Lost Opportunity

Table 3-8. Measure M3 – Application ID: 13005576– Lifetime savings summary

Factor	Tracking	Application	Evaluator
Lifetime savings (kWh)	76,925	76,925	59,495
First-year savings (kWh)	3,077	3,077	2,780

Factor	Tracking	Application	Evaluator
Measure lifetime (years)	25	25	25
Baseline classification	Lost Opportunity	Lost Opportunity	Lost Opportunity

Table 3-9. Measure M4– Application ID: 13005576 – Lifetime savings summary

Factor	Tracking	Application	Evaluator
Lifetime savings (kWh)	72,030	72,030	76,968
First-year savings (kWh)	4,802	4,802	5,131
Measure lifetime (years)	15	15	15
Baseline classification	Lost Opportunity	Lost Opportunity	Lost Opportunity

Table 3-10. Site-level total – Lifetime savings summary

Factor	Tracking	Application	Evaluator
Lifetime savings (kWh)	392,145	392,145	268,852
First-year savings (kWh)	24,947	24,947	16,962
Combined measure lifetime (years)	15.7	15.7	15.8

3.3   Ancillary impacts

There are no ancillary impacts associated with this project.

RHODE ISLAND CUSTOM ELECTRIC SITE-SPECIFIC REPORT
SITE ID: RICE23N004

Report Date: March 7, 2025

Program Administrator	Rhode Island Energy	
Application ID(s)	2117379	
Project Type	C&I Existing Building Retrofit	
Evaluation Type	Ops	
Program Year	PY2023	
Evaluation Firm	DNV	
Evaluation Engineer	Joe St. John	
Senior Engineer	Dan Barbieri	

1 EVALUATED SITE SUMMARY AND RESULTS

The evaluated project involves the installation of a 125 HP VFD air-compressor at a manufacturing facility. The project was completed in 2023. The pre-existing equipment consists of a 9-year-old VFD air compressor, which was incentivized when it was installed in 2014, according to email documentation from a Rhode Island Energy representative dated 2/14/23. A regressive, load/no-load baseline—i.e. a baseline that is less efficient than the pre-existing in-situ equipment—was chosen because the pre-existing VFD air compressor was incentivized by the program. One of the exceptions to the rule prohibiting the use of a regressive baseline is if the in-situ baseline was incentivized by the program. The reasoning for this exception is that the program influenced the installation of the VFD compressor in 2014, so program influence would carry over to the installation of the second air compressor in 2023.

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

- The site contact was present on-site and agreed to accommodate an on-site evaluation.
- It was safe to visit the facility and inspect the measure.

After reviewing the tracking files and information gathered during the site visit, the evaluator classified this measure as a lost-opportunity measure with a single baseline and calculated the project savings using an 8,760 spreadsheet analysis using evaluation data collected between 1/7/25 and 2/11/25. The evaluation results are presented in Table 1-1.

Table 1-1. Evaluation results summary

PA application ID	Measure name		Annual electric energy (kWh)	% of energy savings on-peak	Summer on-peak demand (kW)	Winter on-peak demand (kW)
2117379	VFD air compressor	Tracked	144,527	57.0%	19.70	19.0
		Evaluated	173,653	40.9%	17.24	19.31
		Realization rate	120.2%	71.7%	87.5%	101.6%

1.1 Explanation of deviations from tracking

The evaluated savings are 20.2% greater than the tracked savings, primarily due to updates of operational parameters from on-site measurements. The tracking calculations estimated an average CFM demand of 148 CFM, whereas the evaluators estimated an average CFM demand of 245 CFM. Additionally, the tracking calculations estimated that the kW/CFM would improve by 0.112 kW/CFM, whereas the evaluator calculations estimated that the kW/CFM would improve by 0.081kW/CFM because of this project. Further details regarding deviations from the tracked savings are presented in Section 3.1.

1.2 Recommendations for program designers and implementers

The evaluator recommends that an updated industry standard practice (ISP) baseline study be performed on common compressed air measures such as VFD air compressors. The most recent compressed air ISP study was completed in 2018,[1] and recommends a load/no-load baseline. However, this measure has been available for many years now, and the evaluator believes that the industry standard practice may be moving away from or has already moved away from load/no-load compressors as standard practice and instead may have shifted to VFD-driven air compressors as standard practice.

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[1] https://ma-eeac.org/wp-content/uploads/AirCompressors_ISP_Memo_final.pdf

1.3 Customer alert

There are no relevant customer alerts.

2 EVALUATED MEASURE

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 the information available.

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

Table 2-1. Evaluated measure

Measure	Project ID	Measure description
M1	2117379	Installation of a 125 HP VFD air-compressor (Atlas Copco GA90VSD+). The pre-existing equipment consists of a 9-year-old VFD air-compressor (also an Atlas Copco GA90VSD), as well as a back-up single speed 100 HP air-compressor (Sullair) that rarely ran. The project involved scrapping the 100 HP back-up single-speed Sullair compressor, using the 9-year-old VFD air-compressor as backup, and using the new 125 HP VFD air-compressor as the primary compressor. The customer stated that there was no change in CFM demand that prompted this project. The customer indicated that both compressors never run simultaneously. A regressive baseline was permitted for this project because the baseline VFD compressor installed in 2014 was also incentivized by the program. This exception to the non-regressive baseline rule results in an inherent claim within the tracking calculations that absent the program, the facility would have installed an industry standard practice load/no-load compressor during both the initial 2014 installation as well as the more recent 2023 installation.

2.1 Application information and applicant savings methodology

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

2.1.1 Applicant description of baseline

According to the project files, the applicant classified this measure as a replacement with industry standard practice conditions as the baseline. A regressive baseline was permitted because the VFD air compressor that was installed in 2014 was also incentivized by the program, so the applicant is claiming that absent the program, the facility would have installed an industry standard practice load/no-load compressor during the initial 2014 installation, as well as for the subsequent 2023 installation. Table 2-2 shows the pre-existing key parameters in the model.

Table 2-2. Applicant baseline key parameters

Measure	Parameter name	Parameter value	Source of parameter value
M1	Control type	Load/no-load compressor with 4 gal/cfm of storage	2018 Compressed Air ISP Study[2]
M1	Compressor size	125 HP	Project documents
M1	Compressor average CFM demand	148 CFM	kW data collected on baseline VFD compressor between 1/26/23 and 2/9/23
M1	Compressor annual runtime	8,736 hours/year	52 weeks/year x 7 days/week x 24 hours/day
M1	Compressor average kW/CFM	0.307	kW data collected on baseline VFD compressor between 1/26/23 and 2/9/23

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[2] https://ma-eeac.org/wp-content/uploads/AirCompressors_ISP_Memo_final.pdf

Measure	Parameter name	Parameter value	Source of parameter value
			combined with CAGI data sheet for load/no-load compressor

2.1.2 Applicant description of installed equipment and operation

This project includes installing a 125 HP VFD air compressor. Table 2-3 presents the main parameters of the proposed case as defined by the applicant.

Table 2-3. Applicant's proposed key parameters

Measure	Parameter	Operation description	Source of parameter value
M1	Control type	VFD	Project documents
M1	Compressor average kW/CFM	0.195	kW data collected on baseline VFD compressor between 1/26/23 and 2/9/23 combined with CAGI data sheet for VFD air compressor

2.1.3 Applicant energy savings algorithm

The tracking calculations began with baseline kW data that was measured between 1/26/23 and 2/9/23 on the pre-existing primary compressor, which is the same model as the post-case installed primary compressor. The measurements were taken at 1-minute intervals. This kW data was converted to CFM data, although that calculation was not provided in the information included in the back-up documentation to the evaluator. This CFM data was then converted to ISP baseline kW data using the formula below after converting the CFM data to % CFM data using the rated CFM capacity of 631 CFM. The formula to convert %CFM data to % kW data references the Compressed Air Challenge kW vs. CFM curves, and from those curves, the tracking calculations compute the coefficients using the "Linest()" function in Excel, which also adjusts for operating pressure and rated nominal CFM.

$$\%kW_{Baseline} = Min(Max((A \times \%CFM^3 + B \times \%CFM^2 + C \times \%CFM + D),0),100\%)$$

Where the baseline constants are:

Variable	Value
A	-0.0177
B	-0.3783
C	1.1540
D	0.2427
$\%CFM_{min}$	0
$\%CFM_{max}$	100%

$$kW_{Baseline} = \%kW\ Baseline \times kW_{baseline-full\ load\ operational}$$

$$kW_{baseline-full\ load\ operational} = kW_{baseline-full\ load\ rated} \times (Rated\ Pressure - Operational\ Pressure)^{0.995}$$

The post-case compressor %kW for this measurement period was calculated using the formula below. The coefficients are based on plotting the kW vs. CFM points from the CAGI sheet, adjusting from nominal pressure to operating pressure, and then using the "Linest()" function in excel.

$$\%kW_{Post} = Min(Max((A \times \%CFM^3 + B \times \%CFM^2 + C \times \%CFM + D),0), 100\%)$$

Where the post-case constants are:

Variable	Value
A	0
B	0.0001
C	0.1222
D	7.5681
%CFM$_{min}$	0
%CFM$_{max}$	100%

$$kW_{Post} = \%kW\ Post \times kW_{Post-full\ load\ operational}$$

$$kW_{Post-full\ load\ operational} = kW_{Post-full\ load\ rated} \times (Rated\ Pressure - Operational\ Pressure)^{0.995}$$

From this period where the ISP baseline and post-case kW was calculated from the measured in-situ baseline kW data converted to CFM, a weekly heatmap was developed, as shown in Figure 2-1.

Figure 2-1. CFM and baseline and proposed compressor kW by hour and day of week

	Mon			Tue			Wed			Thu			Fri			Sat			Sun		
Average Hourly Data (CFM, Base/Existing Demand, Proposed Demand)																					
Hour	CFM	Base kW	Prop kW	CFM	Base kW	Prop kW	CFM	Base kW	Prop kW	CFM	Base kW	Prop kW	CFM	Base kW	Prop kW	CFM	Base kW	Prop kW	CFM	Base kW	Prop kW
0	49	26	15	111	40	24	108	37	23	97	38	22	91	37	23	55	31	18	51	27	16
1	61	30	18	84	36	21	65	32	19	64	31	18	67	33	19	62	34	19	63	30	18
2	52	26	15	71	32	18	57	28	17	58	29	17	68	33	20	57	32	18	53	27	16
3	62	30	18	81	35	20	68	32	19	61	30	18	67	33	20	64	34	20	63	31	18
4	49	26	15	72	32	19	57	28	17	56	28	16	67	33	19	61	33	19	50	26	15
5	126	44	25	127	44	26	131	45	25	139	46	26	66	33	19	68	35	20	63	31	18
6	258	64	43	243	61	41	273	66	45	275	66	45	121	44	26	64	33	19	51	27	16
7	275	66	45	276	66	45	277	66	46	312	71	51	140	47	28	72	36	21	62	30	18
8	294	68	48	309	70	50	267	65	44	316	71	51	142	47	29	67	34	20	52	26	16
9	252	63	42	279	67	46	264	65	44	270	65	44	151	48	30	73	36	21	62	31	18
10	276	66	45	308	70	50	296	69	48	318	71	52	166	50	32	69	34	20	52	27	16
11	221	59	37	255	63	42	233	61	39	188	54	33	142	47	29	75	36	21	62	31	18
12	285	67	47	303	69	49	298	69	49	225	59	38	159	49	31	70	34	20	51	27	16
13	255	63	42	272	66	45	282	67	46	199	55	34	138	46	28	77	36	21	62	30	18
14	234	61	39	281	67	46	278	66	46	207	56	36	134	45	28	57	29	17	52	27	16
15	248	62	41	293	68	48	278	66	46	204	56	35	54	31	18	63	31	18	61	31	18
16	248	63	41	274	66	45	265	65	44	189	54	33	49	30	17	52	27	16	51	26	15
17	228	60	38	218	58	37	237	61	40	171	51	33	55	31	18	64	31	18	62	31	18
18	271	66	45	252	63	42	233	61	39	188	53	35	50	30	17	52	26	16	51	27	16
19	195	55	34	196	55	34	194	55	33	146	48	29	57	32	18	63	31	18	62	30	18
20	271	66	45	273	66	45	261	64	43	170	51	33	53	31	17	53	27	16	52	27	16
21	274	66	45	260	64	43	275	66	45	173	51	33	59	33	19	63	31	18	61	30	18
22	237	61	40	223	59	38	234	60	39	155	49	31	54	31	18	52	27	16	50	26	15
23	251	63	42	260	64	43	258	64	43	172	51	33	54	31	18	52	26	16	49	26	15

The baseline and post-case kW data was then summed over 52 weeks to estimate the total baseline energy use as 397,555 kWh. The post energy use was computed to be 253,027 kWh, with the annual energy savings the difference of 144,527 kWh.

2.1.4   Evaluation assessment of applicant methodology

The evaluator determined that the applicant's use of a spreadsheet analysis to estimate energy savings was appropriate. However, to compute peak impacts, the evaluator used an 8,760 spreadsheet analysis. The evaluator updated the analysis by incorporating data from the evaluation measurement period based on data described in Section 2.2.

2.2   On-site inspection and metering

The site contact indicated that it was safe to visit the site and permitted an on-site visit with kW measurements of the air compressor measure. The evaluator conducted the site visit on January 7, 2025, and was assisted by the site contact. Table 2-5 summarizes the findings from the installed measure verification.

Table 2-4. Measure verification

Measure name	Verification method	Verification result
VFD air compressor	On-site inspection	The evaluator verified the installation of the newly installed 125 HP VFD air compressor, as well as the VFD air compressor which was installed in 2014. See Figure 2-2 and Figure 2-3.
VFD air compressor	Evaluation kW measurements	The evaluator installed kW loggers and back-up amp loggers on both compressors, the 125 HP VFD air compressor installed in 2014 (which is currently operating as the back-up compressor), as well as the 125 HP VFD air compressor installed in 2023, which is currently operating as the primary compressor. The loggers recorded at 1-minute intervals between 1/7/25 and 2/11/25. The observed pressure reading was 104 psi (see Figure 2-4). See Figure 2-5 for the charts of the kW measurements of the 125 HP VFD air compressor installed in 2023, as well as the 125 HP VFD air compressor installed in 2014 which is currently used as backup.
VFD Air Compressor	Interview the site contact and collect information about the project	The following information was gathered from the site contact, as well as a RIE representative about this project: • Compressed air system runs 365 days per year, 24 hours a day, unless there is a fault and it is being serviced • The primary motivation for this project was to increase efficiency and reliability, since every part of the manufacturing process requires clean, dry, compressed air. • The back-up compressor that was in place prior to 2023 was a 100 HP load/unload Sullair 24KT unit, which was scrapped as part of this project. The 125 HP VFD air compressor installed in 2014 now serves as the back-up machine. • Both compressors never run simultaneously. • There have been no changes in CFM demand since the new compressor was installed in October 2023. • A utility representative confirmed that the 125 HP VFD air compressor installed in 2014 received an incentive from the utility.

Figure 2-2 shows the 125 HP VFD air compressor installed in 2023 (right), as well as the 125 HP VFD air compressor installed in 2014 which is currently used as backup (left).

Figure 2-2. 125 HP VFD air compressor installed in 2014 and 2023

Figure 2-3 shows the nameplates of the 125 HP VFD air compressor installed in 2023 (left), as well as the 125 HP VFD air compressor installed in 2014 which is currently used as backup (right).

Figure 2-3. Nameplates of 125 HP VFD air compressor installed in 2014 and 2023

Figure 2-4 shows the user interface screen for the newly installed 125 HP VFD air compressor installed in 2023 and shows that the discharge pressure is 104 psi.

Figure 2-4. Observed discharge pressure

Figure 2-5 shows the evaluator kW measurements of the of the 125 HP VFD air compressor installed in 2023, as well as the 125 HP VFD air compressor installed in 2014, which is currently used as backup. The backup compressor came on for 2.4 hours during the evaluation monitoring period, which represented 0.24% of the evaluation monitoring period.

Figure 2-5. Evaluator kW measurements of newly installed 125 HP VFD air compressor, and backup compressor
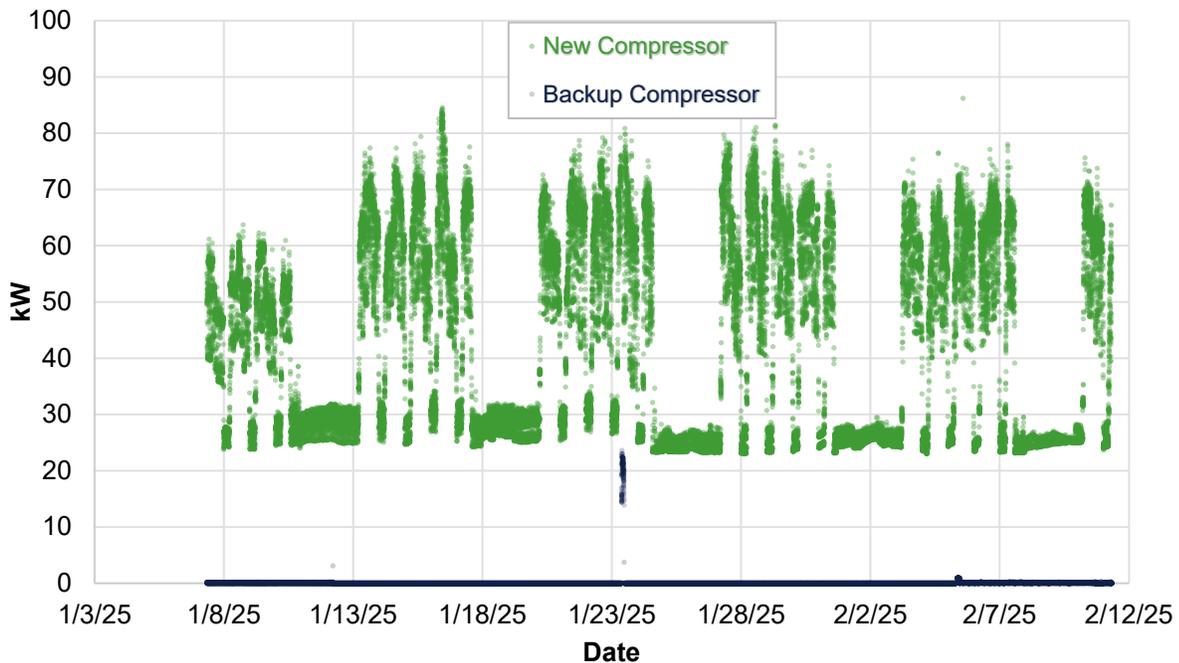
Figure 2-6 shows a heatmap of the evaluator kW measurements of the newly installed 125 HP VFD air compressor, and the backup compressor by date, week number, weekday, and hour. The heatmap is the sum of the primary and backup compressor. The backup compressor only came on for 2 hours during the monitoring period, when the primary compressor was temporarily down.

Figure 2-6. Heatmap of evaluator kW measurements of newly installed 125 HP VFD air compressor, and backup compressor by date, week number, weekday, and hour

Date	Weeknum - Weekday	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
1/7/25	2-Tue	59	27	26	27	27	28	48	53	58	53	57	54	51	52	52	52	39	38	48	36	47	48	36	46
1/8/25	2-Wed	26	27	28	25	27	24	53	53	59	44	53	51	54	55	59	58	54	43	63	38	49	44	40	46
1/9/25	2-Thu	39	28	27	28	27	28	43	53	57	57	47	59	60	60	49	56	52	44	41	39	48	48	39	47
1/10/25	2-Fri	28	27	27	26	28	26	46	55	55	54	53	54	53	52	30	29	25	28	28	28	28	30	28	27
1/11/25	2-Sat	28	29	29	29	29	30	29	27	29	28	30	30	28	30	28	30	29	29	30	30	30	30	30	29
1/12/25	3-Sun	30	31	29	31	29	31	29	28	28	28	30	30	30	28	30	30	30	30	30	31	30	28	27	27
1/13/25	3-Mon	29	30	30	31	30	31	60	63	66	51	58	69	69	68	65	67	62	55	68	53	68	64	45	64
1/14/25	3-Tue	37	31	30	31	31	28	54	59	62	59	63	62	62	68	66	66	70	53	67	49	69	66	48	62
1/15/25	3-Wed	43	25	25	26	25	26	58	62	65	61	67	70	74	69	67	69	61	53	56	48	59	58	48	58
1/16/25	3-Thu	39	31	30	31	30	31	60	64	62	68	69	82	80	69	73	64	55	49	58	44	56	59	42	54
1/17/25	3-Fri	45	30	31	28	31	33	68	68	59	65	66	73	69	67	40	28	28	28	28	28	28	28	28	29
1/18/25	3-Sat	29	29	29	29	26	29	27	30	29	29	30	30	29	31	26	30	29	30	26	30	27	29	31	27
1/19/25	4-Sun	29	30	29	31	29	29	29	29	28	28	29	26	25	25	29	28	30	28	30	28	30	25	31	28
1/20/25	4-Mon	28	28	31	26	26	29	63	68	60	64	63	56	60	57	57	58	57	46	59	53	58	56	48	48
1/21/25	4-Tue	44	30	30	28	29	28	52	50	67	65	62	70	60	66	70	63	61	46	71	42	62	64	43	64
1/22/25	4-Wed	41	30	28	31	29	29	50	58	62	57	62	68	56	74	68	74	65	46	73	47	59	66	45	65
1/23/25	4-Thu	41	29	30	31	30	31	69	66	72	66	63	63	60	75	62	66	62	39	58	37	61	67	38	61
1/24/25	4-Fri	42	26	26	26	26	26	67	70	71	67	64	69	47	62	44	24	27	23	23	23	24	25	26	24
1/25/25	4-Sat	24	26	25	26	25	25	24	25	24	25	25	25	24	25	24	25	24	25	25	25	24	25	24	24
1/26/25	5-Sun	24	26	25	27	25	26	25	26	24	26	24	26	24	25	24	26	24	25	24	26	24	25	24	23
1/27/25	5-Mon	23	25	24	25	24	26	70	66	61	75	73	76	75	73	59	62	66	50	58	46	47	49	42	54
1/28/25	5-Tue	41	24	23	24	24	24	67	73	68	66	70	75	72	76	71	67	64	46	54	45	57	55	45	63
1/29/25	5-Wed	40	24	23	24	23	24	59	72	76	62	72	68	69	55	74	65	65	49	62	46	48	64	44	55
1/30/25	5-Thu	37	24	24	24	24	24	57	64	58	59	61	55	66	59	59	66	58	50	71	51	61	62	54	67
1/31/25	5-Fri	49	27	26	26	27	27	61	60	65	58	68	68	67	66	64	23	24	25	24	25	25	25	25	25
2/1/25	5-Sat	25	25	25	25	25	25	25	25	25	25	24	25	24	25	25	25	25	25	25	26	25	26	25	25
2/2/25	6-Sun	25	26	26	27	26	27	26	28	27	26	25	26	26	26	26	26	26	26	26	26	26	26	26	26
2/3/25	6-Mon	26	26	26	26	26	28	55	67	71	63	63	64	64	68	65	68	67	49	60	49	51	60	49	60
2/4/25	6-Tue	43	25	24	26	24	24	43	51	58	57	66	66	65	62	63	65	67	53	62	46	63	64	57	59
2/5/25	6-Wed	49	25	25	25	25	26	42	56	62	70	71	68	69	58	65	56	57	47	66	48	55	66	46	62
2/6/25	6-Thu	55	24	24	25	25	25	62	64	60	54	64	65	55	56	68	70	70	51	65	51	71	66	54	66
2/7/25	6-Fri	32	24	23	24	24	24	42	52	66	65	67	65	53	64	49	23	23	23	23	23	23	23	23	23
2/8/25	6-Sat	24	25	26	26	26	26	26	26	26	26	25	25	25	26	25	25	26	26	26	25	26	26	26	26
2/9/25	7-Sun	26	26	26	26	26	26	26	26	26	26	26	26	26	25	25	25	25	26	25	26	25	25	25	28
2/10/25	7-Mon	25	26	25	25	25	26	54	64	67	66	67	66	69	68	63	62	59	45	64	48	62	63	43	59

Figure 2-7 shows a heatmap of the evaluator kW measurements of the newly installed 125 HP VFD air compressor and the backup compressor, averaged by weekday and hour. Note that the row labelled "Hol" is for holiday, and is set equal to the values for "Sun" since there were no holidays captured during the evaluation monitoring period.

Figure 2-7. Heatmap of evaluator kW measurements of newly installed 125 HP VFD air compressor and backup compressor, by weekday and hour

Weekday													Hour											
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
Hol	27	28	27	28	27	28	27	28	27	27	27	27	26	26	27	27	27	27	27	27	27	26	27	26
Sun	27	28	27	28	27	28	27	28	27	27	27	27	26	26	27	27	27	27	27	27	27	26	27	26
Mon	26	27	27	27	26	28	60	66	65	64	65	66	68	67	62	63	62	49	62	50	57	58	46	57
Tue	45	27	27	27	27	26	53	57	62	60	64	65	62	65	64	63	60	47	60	44	60	59	46	59
Wed	40	26	26	26	26	26	53	60	65	59	65	65	64	62	67	64	61	48	64	45	54	60	45	57
Thu	42	27	27	28	27	28	58	62	62	60	60	65	64	64	62	64	59	47	59	45	59	60	45	59
Fri	39	27	27	26	27	27	57	61	63	62	64	66	58	62	45	25	26	25	25	25	26	26	26	26
Sat	26	27	27	27	26	27	26	27	27	27	27	27	26	27	26	27	27	27	26	27	26	27	27	26

Figure 2-8 shows the CFM vs. kW curves for the newly installed VFD air compressor, based on the CAGI sheet for the installed compressor. The CFM vs. kW curves are shown for the rated pressure at 102 psi and the operating pressure of 104 psi.

The operating kW at 104 psi was obtained using equation (4) from Chapter 22 of the Uniform Methods Project, which is the compressed air evaluation protocol.[3] That equation is shown below and indicates that for every 2 psi increase in operational discharge pressure, energy consumption will increase by approximately 1%.

$$kW_{Operational} = Full\ Load\ kW_{Rated} \times [1 - \left(\left(\frac{P_{Rated} - P_{Operational}}{2} \right) \times 0.01 \right)]$$

Figure 2-8. CFM vs. kW for newly installed VFD air compressor, at CAGI rated 102 psi and operating pressure of 104 psi

[3] https://www.energy.gov/sites/prod/files/2015/01/f19/UMPChapter22-compressed-air-evaluation.pdf
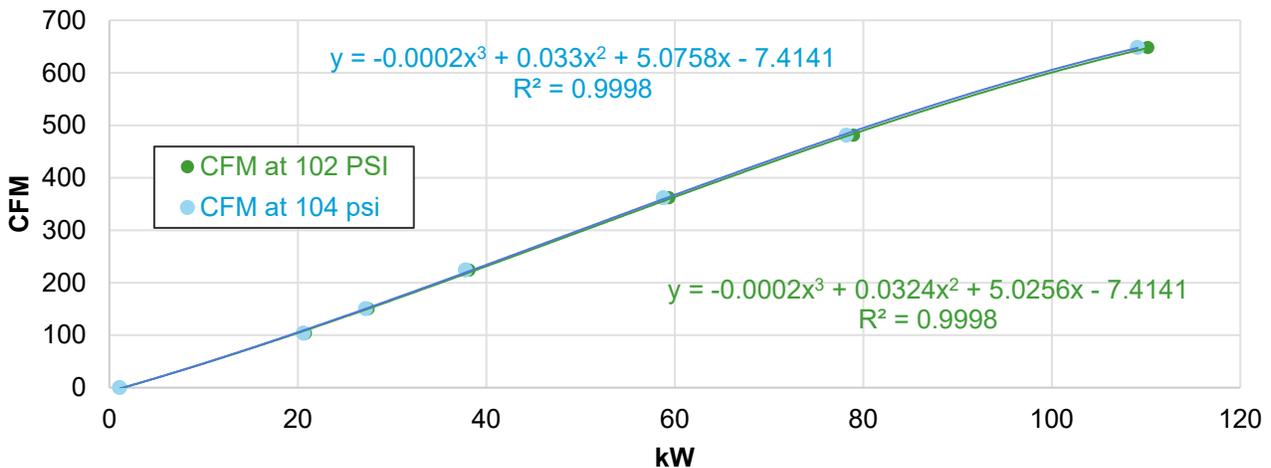
Figure 2-9 shows the % kW vs % CFM capacity for the industry standard practice load/no-load compressor operating at 104 psi, with 4 gal/cfm storage that was used in the evaluator calculations. This curve is from the Compressed Air Challenge textbook, adjusted to 104 psi, and the CAGI sheet for a 120.7 HP load/no-load screw air compressor. Also shown is the %kW vs. %CFM line for 105 psi, which is the rated pressure, whereas 104 psi is the operational pressure.

Figure 2-9. % kW vs. % CFM capacity for baseline air compressor operating at 104 psi, with 4 gal/CFM of storage, based on Compressed Air Challenge Data
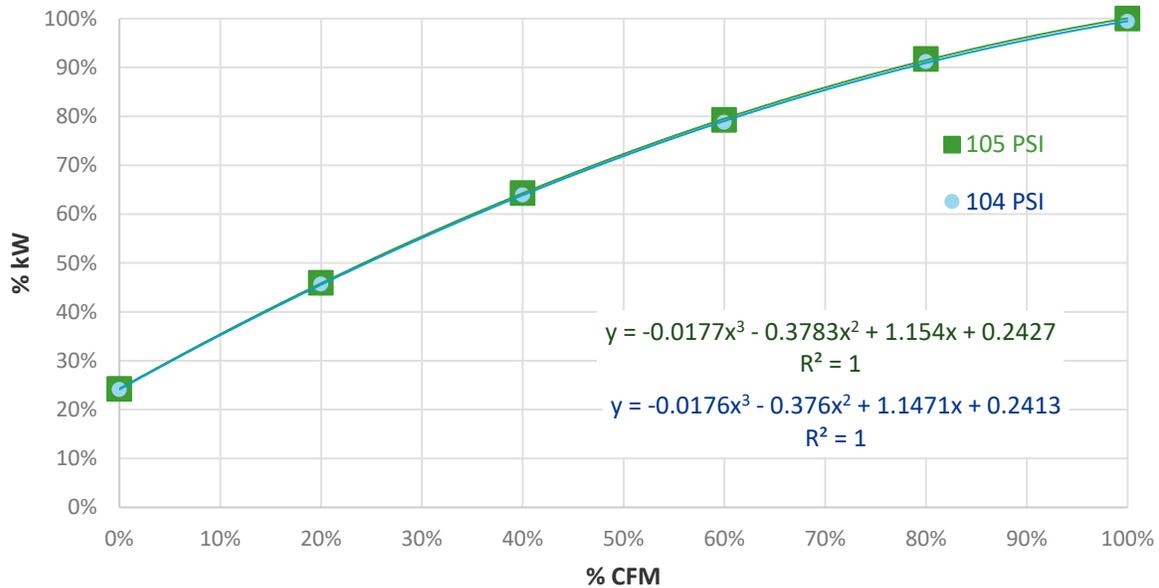
The chart shows:
$$y = -0.0177x^3 - 0.3783x^2 + 1.154x + 0.2427$$
$$R^2 = 1$$
$$y = -0.0176x^3 - 0.376x^2 + 1.1471x + 0.2413$$
$$R^2 = 1$$

2.3   Evaluation methods and findings

This section describes the evaluator methods and findings.

2.3.1   Evaluation description of baseline

Based on information provided in the project files and gathered during the site visit, the evaluator determined this measure is a lost-opportunity measure with a single baseline. A regressive, load/no-load baseline—i.e., a baseline that is less efficient than the pre-existing in-situ equipment (a VFD air compressor)—was chosen because the pre-existing VFD air compressor was incentivized by the program. One of the exceptions to the rule that prohibits the use of a regressive baseline is if the in-situ baseline was incentivized by the program. The reasoning for this exception is that the program influenced the installation of the VFD compressor in 2014, so program influence would carry over to the installation of the second air compressor in 2023, provided that industry standard practice has not changed between when the initial air compressor was installed in 2014, and when the new compressor was installed in 2023. The industry standard practice used has not changed.

2.3.2   Evaluation calculation method

The evaluator calculations for the compressed air measure followed the following steps:

1. The post-case air compressor kW data, which was collected over the 35 days of the evaluation monitoring period, was applied to an 8,760-hour analysis using data from Figure 2-7. The site contact stated that the compressed air system runs 365 days/year, 24 hours/day, indicating no holiday shutdown, so the evaluator applied Sunday operation, when usage is significantly lower, but not fully off, to holidays.

2. The post-case kW data in the 8,760 file was then converted to post-case CFM data using the compressor's CAGI sheets, adjusted to 104 psi, which is the psi observed during the site visit. The kW vs. CFM curve is shown in Figure 2-8. The baseline CFM data was then set equal to the post-case CFM data.

3. The baseline kW data was calculated from the baseline CFM data using the air compressor curve from the compressed air challenge, adjusted to 104 psi, based on the curve shown in Figure 2-9.

4. The post case total kWh was based on adding the post-case air compressor kW (from step 1) for each hour of the year.

5. The baseline total kWh was based on adding the baseline air compressor kW (from step 3) for each hour of the year.

6. The energy savings for each hour of the year was calculated from the difference in the total baseline and post-case kWh.

3   FINAL RESULTS

The evaluated project consisted of installing a new 125 HP VFD air compressor. The evaluated savings are greater than the tracking values primarily because the observed CFM demand was higher in the data collected during the evaluation monitoring period than what was used in the tracking calculations. The parameters impacting the analysis are summarized in Table 3-1.

Table 3-1. Summary of key parameters

Parameter	BASELINE		PROPOSED / INSTALLED	
	Tracking Value(s)	Evaluation Value(s)	Tracking Value(s)	Evaluation Value(s)
Compressor average CFM demand	148	248	148	248
Compressor average kW/CFM	0.307	0.252	0.195	0.171
Compressor kW/CFM improvement			0.112	0.081
Compressor annual operating hours	8,736	8,760	8,736	8,760
Compressor kWh	397,555	540,679	253,027	367,026
Compressor kWh savings			144,527	173,653

3.1   Explanation of differences

The evaluated savings are 19% greater than the tracking values predominantly because of operational discrepancies. The evaluator found the CFM demand observed during the evaluation monitoring period was higher than the CFM demand used in the tracking calculations. This increase was countered by a reduction in the average kW/CFM improvement between the tracking analysis and the evaluator analysis. Finally, the evaluator operating hours were slightly higher than the annual operating hours used in the tracking calculations. 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	Operation	CFM Demand	+35%	Increased savings – Evaluator value = 245 CFM Tracking value = 148 CFM
M1	Operation	kW/CFM Improvement	-15%	Decreased savings – Evaluator value = 0.081 kW/CFM Tracking value = 0.112 kW/CFM
M1	Operation	Annual Operating Hours	+0.15%	Increased savings – Evaluator value = 8,760 hours Tracking value = 8,736 hours
		Total	**+20.2%**	

3.2 Lifetime savings

The evaluator classified measure both evaluated measures as lost opportunity with a single baseline. The evaluator calculated applicant and evaluated lifetime savings values using the following formula:

$$LAGI = FYS \times [EUL]$$

where:

LAGI =   lifetime adjusted gross impact (therms)

FYS =   first year savings (therms)

EUL =   measure life (years)

The evaluated lifetime savings are higher than the tracking lifetime savings because the evaluated first year savings are higher than the tracking first year savings. The tracking calculations claimed a 9-year measure life because the original VFD air-compressor that was installed in 2014, was made the backup compressor in 2023, meaning that it had nine years of measure life as the primary unit. The evaluator agrees with this approach. Table 3-3 provides a summary of key factors that influence the lifetime savings.

Table 3-3. Measure M1 – Application ID: 13815325 – Lifetime savings summary

Factor	Tracking	Application	Evaluator
Lifetime savings (kWh)	1,300,743	1,300,743	1,562,874
First-year savings (kWh)	144,527	144,527	173,653
Measure lifetime (years)	9	9	9
Baseline classification	Lost-opportunity	Lost-opportunity	Lost-opportunity

3.3 Ancillary impacts

There are no ancillary impacts associated with this project.

RHODE ISLAND CUSTOM ELECTRIC SITE-SPECIFIC REPORT
SITE ID: RICE23N091

Report Date: April 19, 2025

Program Administrator	Rhode Island Energy	
Application ID(s)	13977788, 14078553	
Project Type	C&I Existing Building Retrofit	
Evaluation Type	Ops	
Program Year	PY2023	
Evaluation Firm	DNV	
Evaluation Engineer	Shaobo Feng	
Senior Engineer	Dan Barbieri	

1   EVALUATED SITE SUMMARY AND RESULTS

The project was implemented at a supermarket as part of the GrocerSmart initiative. The facility has two multiplex refrigeration rack systems. Rack A has two low temperature (LT) groups and Rack B has one MT group medium temperature (MT) suction group. There are two measures installed through separated applications, and below is the detail description for each measure:

- 13977788 Refrigerant Leak Repair: A contractor conducted a refrigerant leak study and repaired all leaks, to ensure the refrigeration system operate at the proper refrigerant levels over an extended period of time. This measure was installed in 2022 and the reported tracking annual savings for this measure is 5,785 kWh.

- 14078553 Monitoring based commissioning (MBCx) measure including:

    o   For rack A:

        i.   Lower the minimum condensing temperature setpoint from 81.9°F (185 PSI) to 70°F.

        ii. Set the maximum condensing temperature setpoint to 90°F.

        iii. Adjust condenser control from a fixed pressure control strategy to a temperature differential (TD) control strategy.

        iv. Change the condensing temperature control from pressure-based to temperature-based, and set condensing temperature differential setpoint to 12°F above ambient dry bulb temperature.

        v.   Lower the split condenser initiation point from 55°F to 50°F. Half of the condenser fans operate below this setpoint to maintain the condensing temperature setpoint.

        vi. Adjust the modulating defrost pressure regulator (MDPR) from its current mechanical setting of 38 PSI to 30 PSI.

    o   For rack B:

        i.   Increase suction group 1 suction pressure setpoint from 53 PSI to 55.5 PSI.

        ii. Lower the minimum condensing temperature setpoint from 71°F to 70°F.

        iii. Increase the maximum condensing temperature setpoint from 90°F to 100°F.

        iv. Adjust condensing temperature differential setpoint from 10°F above ambient dry bulb temperature to 12°F above ambient dry bulb temperature.

    This measure was installed in 2023 and the reported tracking annual savings for this measure is 65,811 kWh. The total reported tracking annual savings for this project is 71,596 kWh.

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

- The project contact is not on-site but he agreed to accommodate an on-site evaluation with the store manager.
- It is safe to visit the facility and inspect the measure.

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 use metered data to conduct the load adjustments.

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

Table 1-1. Evaluation results summary

PA application ID	Measure name		Annual electric energy (kWh)	% of energy savings on-peak	Summer on-peak demand (kW)	Winter on-peak demand (kW)
13977788	Refrigerant leakage repair	Tracked	5,785	50%	0	0
		Evaluated	5,785	50%	0	0
		Realization Rate	100%	100%	N/A	N/A
14078553	MBCx on refrigeration system	Tracked	65,811	45%	4.49	9.95
		Evaluated	47,665	44%	2.62	7.71
		Realization Rate	72%	99%	58%	77%
	Total	Tracked	71,596	45%	4.49	9.95
		Evaluated	53,450	45%	2.62	7.71
		Realization Rate	75%	99%	58%	77%

1.1   Explanation of deviations from tracking

The evaluated savings are 25% lower than the applicant-reported savings primarily due to the load adjustment. The evaluator conducted power metering on both refrigeration racks' main power circuit to capture the actual kW readings. The metered load is 24%[1] lower than the applicant estimated in the model, which reduced the savings for the second measure. Further details regarding deviations from the tracked savings are presented in Section 3.1.

1.2   Recommendations for program designers and implementers

The evaluator recommends that the implementer should perform a post installation site-specific adjustment on the calculation model. By conducting a site-specific adjustment, the implementer can account for factors that may impact the estimated savings. Some of the evaluation's refrigeration control parameter findings for the second measure may have been identified in a QC site visit. In addition, the evaluator recommends the future leak consultant reports provide more detailed findings, including the specific causes of leaks (e.g., gasket failures, cracks in welds, gaps between fittings) and an assessment of contributing factors such as excessive vibration, along with potential corrective actions like the use of vibration mounts.

1.3   Customer alerts

There are no relevant customer alerts.

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[1] Based on the OAT bin average

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 the information available.

The evaluated measure(s) for this site is/are summarized in Table 2-1.

Table 2-1. Evaluated measure(s)

Measure	Project ID	Parameter
M1	13977788	Refrigerant leakage repair
M2	14078553	MBCx on refrigeration system

2.1 Application information and applicant savings methodology

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

2.1.1 Applicant description of baseline

According to the project files, the applicant classified both measures as retrofit with the pre-existing situation as the baseline.

For 13977788 Refrigerant Leak Repair, the baseline is the pre-existing refrigeration rack, with the identified leakage through the contractor's leak survey. The applicant did not provide details on the amount or locations of leaks.

For 14078553 Monitoring based commissioning (MBCx), the pre-existing input key parameters are shown as Table 2-2 below.

Table 2-2. Applicant baseline key parameters – M2 (14078553)

Variables	Unit	Category	Rack A	Rack B
Suction StPt (SG1)	PSI	Setpoint	17	53
Suction StPt (SG2)	PSI	Setpoint	19	-
Suction StPt (SG3)	PSI	Setpoint	53	-
Minimum Cond StPt	degF	Setpoint	81.9	71
Maximum Cond StPt	degF	Setpoint	-	90
Condenser Control	-	Type	Pressure	TD
Condenser TD StPt	degF	Setpoint	-	10
Cond Split	degF	Setpoint	55	50
MDPR Adjustment	PSI Difference	Setpoint	38	-
Subcooler Correction	-	Status	Not Operational	-

2.1.2 Applicant description of installed equipment and operation

This project includes fixing the identified leaks in the refrigeration systems and upgrading control settings through an MBCx measure.

For 13977788 Refrigerant Leak Repair, the installed case is fixing all identified leaks in the refrigeration system.

For 14078553 Monitoring based commissioning (MBCx), Table 2-3 presents the main parameters of the proposed case as defined by the applicant.

Table 2-3. Applicant's proposed key parameters – M2 (14078553) main inputs

Variables	Unit	Category	Rack A	Rack B
Suction StPt (SG1)	PSI	Setpoint	17	55.5
Suction StPt (SG2)	PSI	Setpoint	19	-
Suction StPt (SG3)	PSI	Setpoint	53	-
Minimum Cond StPt	degF	Setpoint	70	70
Maximum Cond StPt	degF	Setpoint	90	100
Condenser Control	-	Type	TD	TD
Condenser TD StPt	degF	Setpoint	12	12
Cond Split	degF	Setpoint	50	50
MDPR Adjustment	PSI Difference	Setpoint	30	-
Subcooler Correction	-	Status	Operational	-

2.1.3 Applicant energy savings algorithm

The applicant developed two separated customized Excel spreadsheet to estimate the savings for each measure.

13977788 Refrigerant Leak Repair:

The applicant conducted a full M&V for this measure, with metering the kW on the compressor for rack A and rack B individually. The pre metering period is 9/3/2022 – 10/15/2022, and the post metering period is 10/27/2022 – 11/17/2022.

Based on the collected data, the applicant observed that the compressor exhibited distinct operating patterns depending on the outside air temperature (OAT) being above or below 50°F. Additionally, the applicant identified a noticeable step-up and step-down different pattern in power consumption (kW) during specific periods: between 12 a.m. and 6 a.m., and between 8 p.m. and 12 a.m. for the rest of the period, the power consumption was relative stable.

Considering these two independent variables, the applicant developed separate linear regression models to analyze the relationship between OAT (using local TMY3 weather data) and compressor power under two scenarios:

- When OAT is ≤ 50° F, and the hour is between 12 a.m. and 6 a.m. or 8 p.m. and 12 a.m.

- When OAT is > 50°F, and the hour is between 12 a.m. and 6 a.m. or 8 p.m. and 12 a.m.

Using 8,760 hourly bin data from the local TMY3 weather profile, the applicant applied the regression results for both scenarios to estimate annual compressor energy consumption for the baseline (pre-repair) and installed (post-repair) conditions. The difference between these two estimates represents the savings achieved from this leakage repair measure.

Finally, the applicant applied 75% to the savings as an adjustment factor for a conservative approach.

14078553 MBCx:

The applicant developed a Macro-enabled spreadsheet to estimate the savings for all MBCx sub-measures. It is using 5-degree OAT as the bin profile, with the consideration of each compressor group and condenser.

Most equations are built inside the Macro, with VBA coding. The applicant's methodology calculates energy savings by determining the difference in energy consumption between the existing and installed refrigeration systems. Both pre-existing and installed energy consumption is calculated based on the power demand during normal and defrost cycles across various operating conditions (bin profiles), multiplied by the hours spent in each mode.

The power demand for each cycle combines condenser and compressor power. Condenser power is derived from the fan's full power, scaled based on system capacity utilization and the cycling factor. Compressor power is derived from the estimated load and efficiency based on each outside air temperature bin, expressed as the energy efficiency ratio (EER). EER is calculated using a cycle analysis function, which incorporates thermodynamic properties determined by a software named REFPROP[2], developed by NIST. REFPROP is incorporated into the complex spreadsheet model using a Microsoft Excel Add-in.

Compressor load is based on a linear relationship with the OAT. Below is the linear relationship between compressor load and the temperature:

$$Compressor\ Load\ =\ c_0\ +\ c_1 \times Temp$$

This linear regression and the coefficients are estimated based on designed summer and winter load, which assumed summer load is 85% of the design load at 95°F, and winter load is 70% of the design load at 0°F. Therefore, this compressor load is the weather normalized result based on the design capacity, with the consideration of load factor.

Key inputs include electrical specifications from nameplate data, such as current and voltage, as well as site survey data for refrigerant type, pressures, and temperature changes. Some variables, like fan cycling factors and utility factors, are contractor assumptions. Compressor capacity is modeled as a function of outdoor air temperature, based on design conditions.

Operation hours are allocated between normal and defrost modes using bin profile data, with defrost frequency and duration determining the percentage of defrost time. Combined, these calculations result in the energy use for both pre- and post-installation scenarios, to get the final savings estimation.

Below is the methodology and inputs that applicant used:

$$Savings = Existing\ Refrigeration\ System\ Consumption - Installed\ Refrigeration\ System\ Consumption$$

$$Refrigeration\ System\ Consumption = \sum_{all\ bin\ profile} Normal\ kW \times Normal\ Hours + Defrost\ kW \times Defrost\ Hours$$

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[2] https://www.nist.gov/srd/refprop

For Normal or Defrost cycle:

$$kW = Condenser\ kW + \sum All\ Compressor\ Group\ kW$$

$$Condenser\ kW = FullFanPower \times ((Load\% - 0.1^3)\ /\ 0.9)\ \char94\ FanCycle\_N$$

$$Compressor\ Group\ kW = Compressor\ Load \times EER$$

Where,

$$FullFanPower = \sqrt{3} \times Current \times Voltage \times Load\ Factor \times Power\ Factor$$

$$Load\% = \frac{Total\ Heat\ Rejection}{Unit\ Load \times (Condenser\ Temperature - OAT)}$$

$$Condenser\ Temperature = Max(OAT + TD\ Setpoint, \qquad Minimum\ Condensing\ Temp)$$

$$Total\ Heat\ Rejection = \sum_{all\ groups} Compressor\ Load + Compressor\ kW \times 3412$$

Table 2-4 shows the rest of variables inputs.

Table 2-4 Applicant's key parameters – M2 (14078553) other inputs

Variable	Input Value	Unit	Reference
Summer Load	85%	-	Contractor assumption
Winter Load	70%	-	Contractor assumption
FanCycle_N	2.5	-	Contractor assumption
Current	34.8	A	Condenser spec sheet
Voltage	460	V	Condenser spec sheet
Utility Factor	0.75	-	Contractor assumption
Power Factor	0.85	-	Contractor assumption
Unit Capacity	Rack A baseline: 86,310, if OAT > 55°F 43,155, if OAT <= 55°F Rack A installed:	Btu/hr-F	Site survey

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[3] The subtraction of 0.1 reflects a 10% minimum threshold below which fans are assumed not to run. Dividing by 0.9 normalizes the range from 10% to 100%, so the scaling starts only after the minimum threshold is reached.

Variable	Input Value	Unit	Reference
	86,310, if OAT > 50°F 43,155, if OAT <= 50°F Rack B: 86,310, if OAT > 50°F 43,155, if OAT <= 50°F		
TD Setpoint	Rack B baseline: 10 Rack A and B installed: 12	°F	Site survey
Minimum Condensing Temp	Rack A baseline: 81.9 Rack B baseline: 71 Rack A and B installed: 70	°F	Site survey

EER calculation is built through an individual function named "Cycle Analysis". This function is used for multiple different dependent variables. In the evaluated case, it is used to calculate the cooling COP as the EER with the following equation:

$$EER = (Enthalpy\_LP3 - Enthalpy\_LP1) / (Enthalpy\_HP2 - Enthalpy\_LP4)$$

Enthalpy_LP3, Enthalpy_LP1, Enthalpy_HP2, and Enthalpy_LP4 are all calculated by another function REFPROP, which estimates the specs for different refrigerant type, based on the cycle mode (normal or defrost). REFPROP is a software program for the prediction of thermophysical properties of fluids, developed by the National Institute of Standards and Technology (NIST).

Table 2-11 shows all the inputs for this Cycle Analysis function.

Table 2-5 Applicant's inputs for Cycle Analysis function.

Variable	Input Value	Unit	Reference
Refrigerant type	R507A	-	Site survey
Condensing pressure	Varies, based on REFPROP function	psia	Site survey
MDPR Adjustment	Rack A normal cycle: N/A Rack A defrost cycle baseline: 38 Rack A defrost cycle installed: 30 Rack B normal cycle both cases: N/A	psi	Site survey
Evaporator pressure	Rack A baseline: 33.7 Rack B baseline: 67.7	psia	Site survey
Suction gas PD	0	psi	Site survey
Subcooling TD leaving condenser	5	°F	Site survey
Subcooling TD for mechanical subcooler	Varies, based on REFPROP function	°F	Site survey
Evaporator superheat	7	°F	Site survey
Temperature rise in suction line	Rack A Group 1: 46.9 Rack A Group 2: 44.5 Rack A Group 3: 29	°F	Site survey

Variable	Input Value	Unit	Reference
	Rack B Group 1: 33		
Isentropic efficiency	68%	-	Site survey

For the operation hours in each bin profile:

$$\% \, Time \, Spent \, in \, Defrost \, Mode = \frac{Number \, of \, Defrost \, per \, Day \times Defrost \, Time}{24 \, hours}$$

Where,

Number of Defrost per Day = 30

Defrost time   = 0.25 hours for rack A and 0 hours for rack B

2.1.4   Evaluation assessment of applicant methodology

Overall, the evaluator found that the applicant's use of the spreadsheets to estimate energy savings was robust and appropriate. The evaluator updated the model for M2 by updating some input parameters based on the metered kW data and screenshots including refrigeration system control sequence in section 2.2 below.

2.2   On-site inspection and metering

This section provides details on the tasks performed during the on-site inspection, the date it was conducted, and how it was conducted.

2.2.1   Summary of site visit findings

The site contact indicated that it was safe to visit the site and preferred an on-site verification with meter deployment of the evaluated measures. The evaluator conducted the site visit on February 5, 2025, and retrieved the loggers on March 14, 2025, with the help of the store manager.

Table 2-6 summarizes the findings from the installed measure verification.

Table 2-6 Data collection findings

Measure Name	Verification Method	Verification Result
M1 – Leakage repair	On-site inspection and customer interview	The evaluator obtained access to the compressor room and visually verified the impacted refrigeration system and did not observe any leaks. The store manager confirmed that the pre-identified leaks were fixed through this project. And they did not have any further leak survey activity on the refrigeration system.
M2 – MBCx	Inspect installed controls	The evaluator visually checked the control system in the compressor room and collected some control strategy parameters for the refrigeration racks with suction, saturation and evaporator temperature. And the evaluators collected the refrigeration equipment layout and schedule to verify the refrigerant type, compressor capacity and condenser fan size for the impacted refrigerated racks.

Measure Name	Verification Method	Verification Result
M2 – MBCx	Deploy meters	The evaluator deployed kW metering on the impacted refrigeration racks. Please see section 2.2.2 for more details.
M2 – MBCx	Control system screenshots	Due to controller communication issues, the control system did not store any historical operation data. However, the evaluator collected screenshots of the control system including all the control settings.

Figure 2-1 and Figure 2-2 shows an example of the refrigeration racks and the schedule including the specs for compressor and case. Figure 2-3 shows the control settings for rack A suction group A. The evaluator collected screenshots for the condenser fan and each suction group on both racks. Figure 2-4 is the defrost setting for rack A. It lists the frequency of defrost cycle and the time slots for each cycle.

Figure 2-1 Refrigeration rack A (right) and B (left)

Figure 2-2 Refrigeration schedule for rack B

Figure 2-3 Refrigeration control setting for Rack A group A
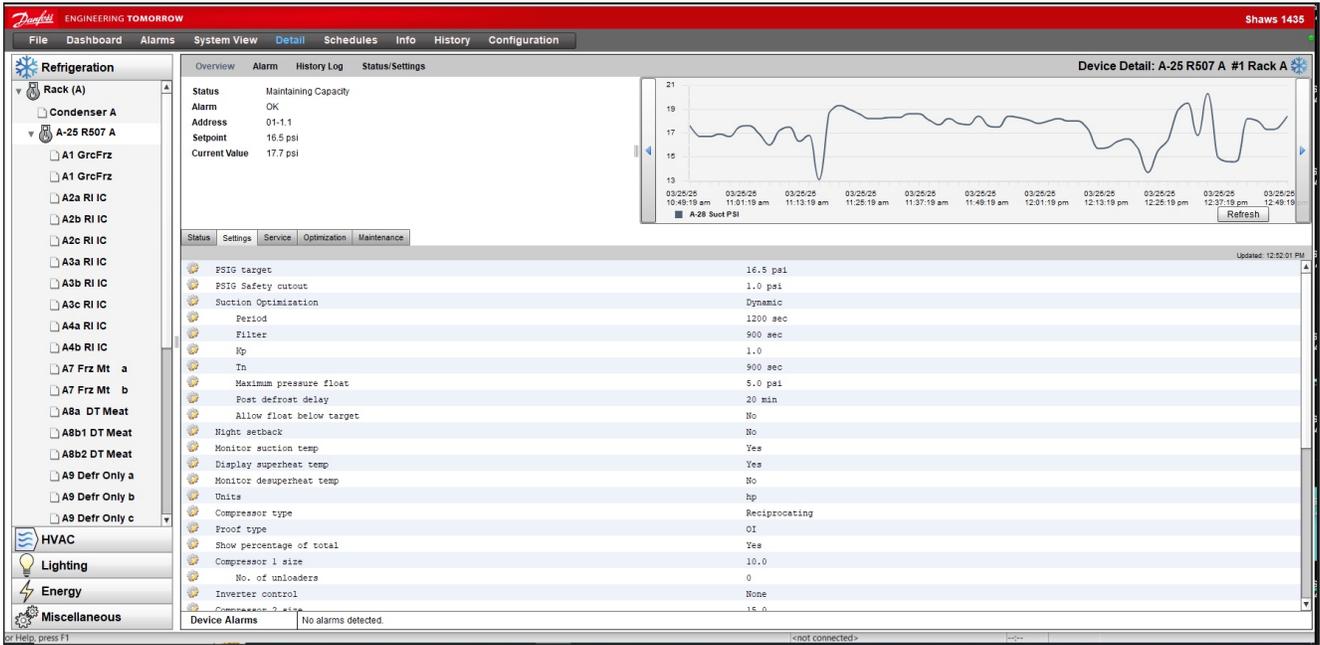
Figure 2-4 Defrost setting for rack A

```
Defrost:
Name                 Duration Time
A1 GrcFrz            15 min   12:00AM 06:00AM 12:00PM 06:00PM
A2a RI IC            35 min   12:15AM
A3a RI IC            35 min   12:50AM
A4a RI IC            35 min   01:25AM
A7 Frz Mt      a     20 min   02:00AM
A8a  DT Meat         35 min   02:30AM 06:30AM 10:30AM 02:30PM 06:30PM 10:30PM
A8b1 DT Meat         35 min   02:30AM 06:30AM 10:30AM 02:30PM 06:30PM 10:30PM
A9 Defr Only a       20 min   02:20AM 02:20PM
A10 RI F/Cake        25 min   02:40AM
A5 RI IC             30 min   03:05AM 03:05PM
A8c DT Meat          35 min   02:30AM 06:30AM 10:30AM 02:30PM 06:30PM 10:30PM
A9a Dual MT          20 min   03:35AM 03:35PM
A9b Dual MT          20 min   03:55AM 03:55PM
A9c Dual MT          30 min   04:15AM 04:15PM
A9d Dual MT          30 min   04:45AM 04:45PM
A13 Bakery Frez      25 min   04:30AM 10:30AM 04:30PM 10:30PM
A14.1 R/I F/F        35 min   10:00PM 10:00AM
A15.1 R/I F/F        30 min   09:00PM
A16.1 R/I F/F        30 min   08:00PM
A17.1 R/I F/F        30 min   09:35AM
A18.1 R/I F/F        25 min   11:00PM
A19.1 R/I F/F        25 min   12:45AM
A21 RI Fish          30 min   05:00AM
A23 Deli Frzr        20 min   01:10AM 09:10AM 05:10PM
A28 MD Meat          60 min   01:50AM 05:50AM 09:50AM 01:50PM 05:50PM 09:50PM
A29.1 M/D Meat       60 min   02:00AM 06:00AM 10:00AM 02:00PM 06:00PM 10:00PM
A30.1 M/D Meat       60 min   02:10AM 06:10AM 10:10AM 02:10PM 06:10PM 10:10PM
A31 Srv Meat         120 min  12:00AM 02:00AM
A32 SvFsh            60 min   10:30AM 02:00AM 04:00AM 06:00PM
A33b Sushi           40 min   05:30AM 09:30AM 01:30PM 05:30PM 09:30PM 01:30AM
A33c Fish            30 min   03:30AM 07:30AM 11:30AM 03:30PM 07:30PM 11:30PM
A36 Back Bar         30 min   01:30AM 05:30AM 09:30AM 01:30PM 05:30PM 09:30PM
A37 Deli Drs a       50 min   12:30AM 06:30AM 12:30PM 06:30PM
A39 Cheese    a      45 min   04:30AM 10:30AM 04:30PM 10:30PM 12:00AM 12:00AM
A40 Isla      a      35 min   02:30AM 06:30AM 10:30AM 02:30PM 06:30PM 10:30PM
A41 SandWch   a      45 min   12:30AM 05:18AM 12:00AM 02:54PM 07:42PM
A42 Prod             45 min   01:00AM 07:00AM 01:00PM 07:00PM
A43 Cheese    a      45 min   02:15AM 08:15AM 02:15PM 08:15PM
A11 Saled Bar        120 min  08:00PM 10:00PM 12:00AM 02:00AM 04:00AM 05:00AM
```

2.2.2   Metered and logged data

With the help of store manager, the evaluator obtained access to the electric panel in the compressor room and identified that each rack had a master circuit breaker, with individual circuit breakers for each compressor downstream of the main breaker. And each condenser fan group had its own circuit breaker in the same electrical panel. Table 2-7 shows the detail of evaluator installed logger information.

Table 2-7. Installed loggers with metered variables

Data Logger Type	Description	Time Interval	Duration	Quantity
DENT kW meter	On the main circuit breaker, capturing total load of rack A.	5-min	2/5/2025 – 3/14/2025	1
HOBO amperage meter	On the main circuit breaker, capturing total load of rack B.	5-min	2/5/2025 – 3/14/2025	1

Data Logger Type	Description	Time Interval	Duration	Quantity
DENT kW meter	Rack A condenser fans.	5-min	2/5/2025 – 3/14/2025	1
DENT kW meter	Rack B condenser fans.	5-min	2/5/2025 – 3/14/2025	1
HOBO amperage meter	Rack A compressors #1, 2, 4, and 7 (total of 10 compressors for Rack A).	5-min	2/5/2025 – 3/14/2025	1
HOBO amperage meter	Rack B compressors #2, 3, 4, and 5 (total of 7 compressors for Rack B).	5-min	2/5/2025 – 3/14/2025	1
HOBO amperage meter	Rack A and B condenser fans.	5-min	2/5/2025 – 3/14/2025	1

During the site visit, the evaluator noted that for rack B, compressor 1 was disconnected, and compressors 6 and 7 were turned off. Therefore, we did not put loggers on those compressors. The HOBO amperage meters on individual compressors and rack A and B condenser fans are used as backup.

The evaluator also gathered the local weather data during the metered period, from NOAA website, and compared with the metered kW data for both racks. Figure 2-5, Figure 2-6, Figure 2-7, and Figure 2-8 show the relationship between metered kW and OAT, on the whole refrigeration system kW and condenser fan kW for rack A and B, respectively.

Figure 2-5 Rack A total kW with the outside air temperature (OAT)

$$y = 0.0002x^2 + 0.1072x + 35.708$$
$$R^2 = 0.1241$$
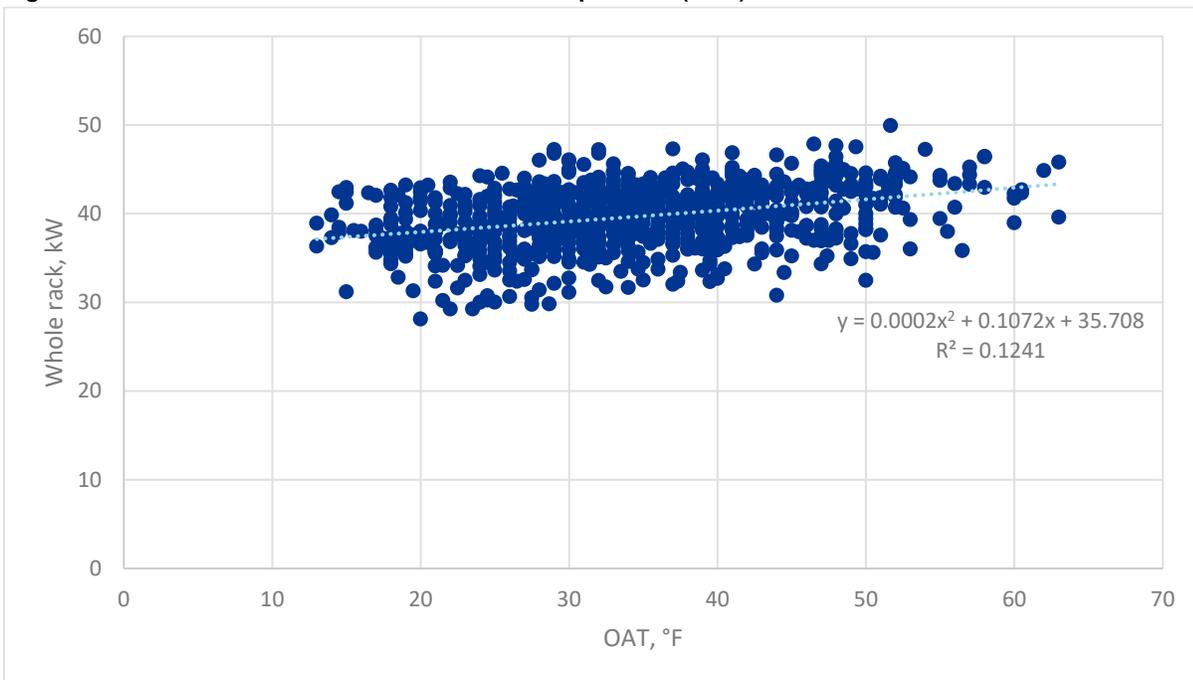
Figure 2-6 Rack B total kW with OAT
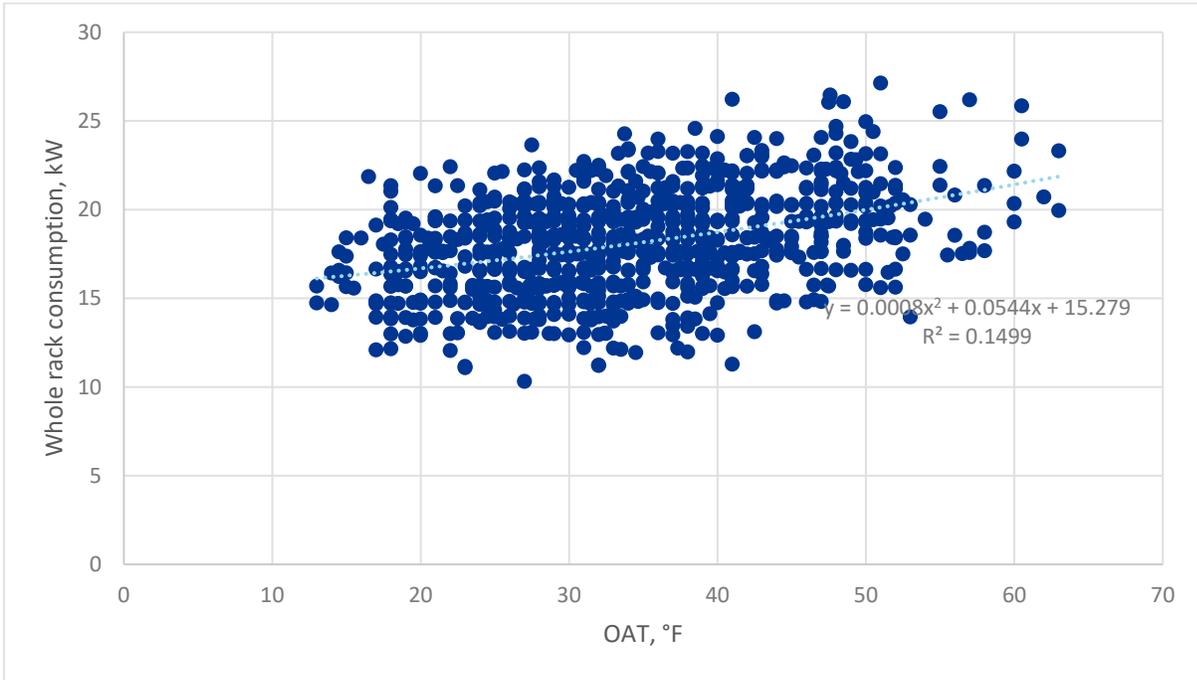
Figure 2-7 Rack A condenser fans kW with OAT

$y = 0.0008x^2 + 0.0544x + 15.279$
$R^2 = 0.1499$
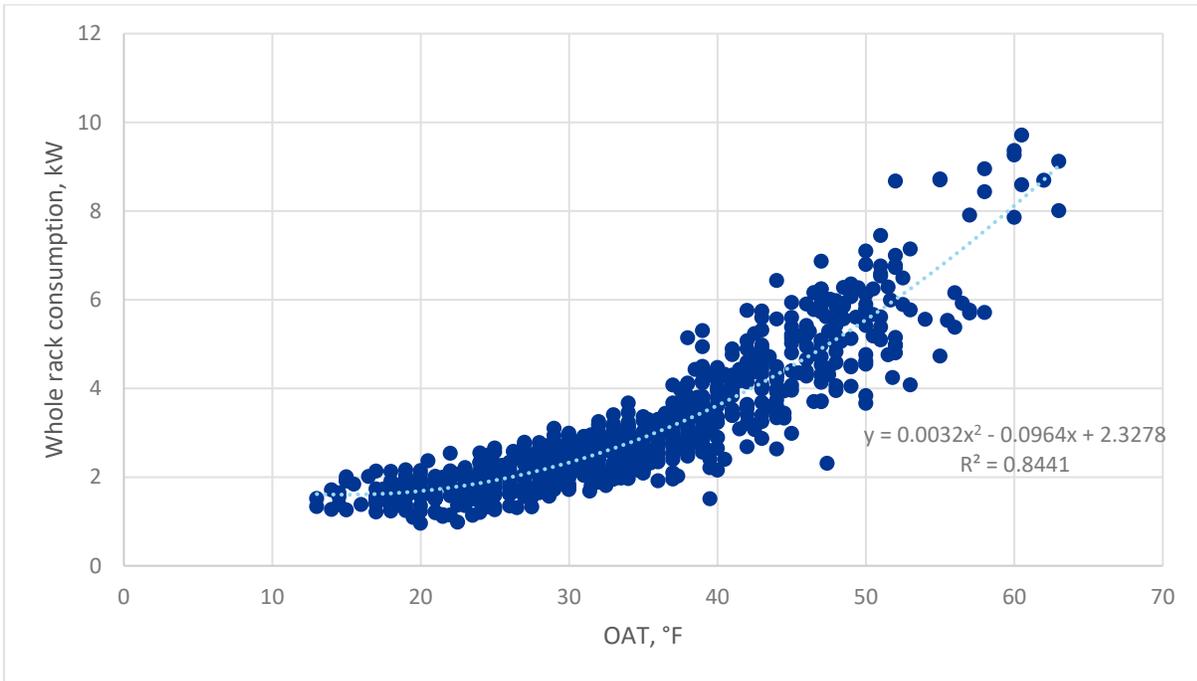
Figure 2-8 Rack B condenser fans kW with OAT

$y = 0.0032x^2 - 0.0964x + 2.3278$
$R^2 = 0.8441$
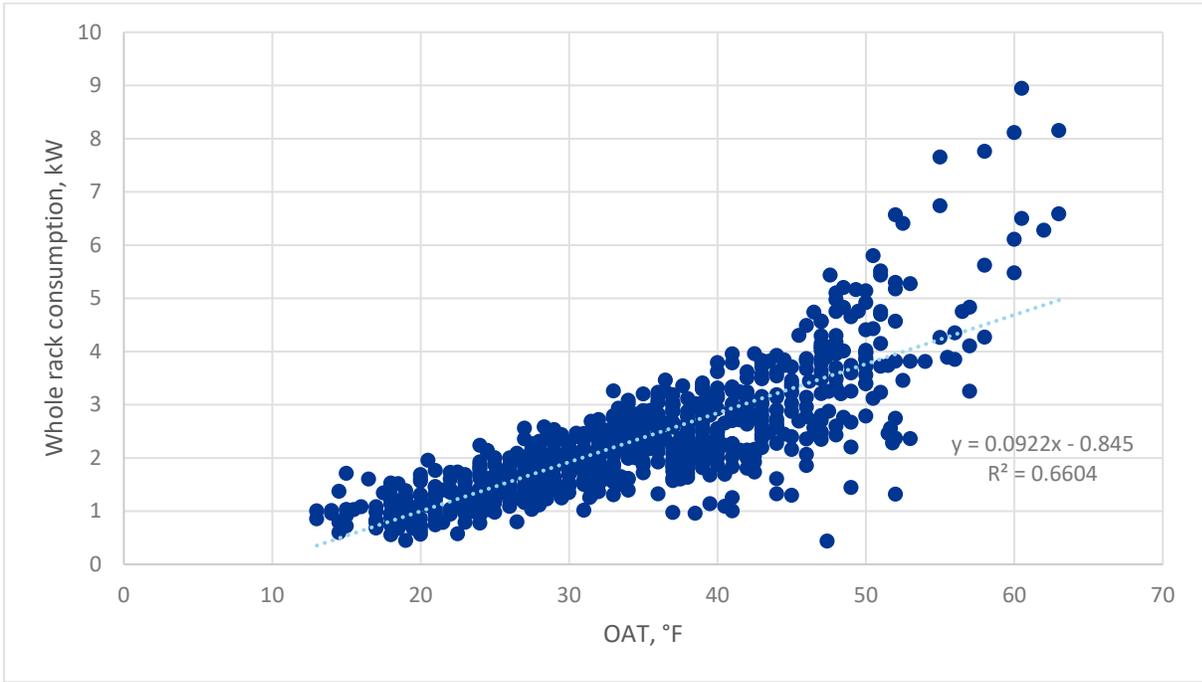
As we can see from the charts, the condenser fan energy consumption is highly correlated with the OAT. In contrast, the overall refrigeration system consumption exhibits a weaker dependency on weather conditions than applicant assumed.

In addition, the evaluator worked with vendor to go through their refrigeration management system and requested screenshots including the variables listed in Table 2-8 below.

Table 2-8. Collected variables from the control system

System	Variables	Unit	Baseline (Applicant and Evaluated)	Applicant Installed	Evaluated Installed
Rack A	Suction StPt (SG1)	PSI	17.0	17.0	16.5
	Suction StPt (SG2)	PSI	19.0	19.0	19.0
	Suction StPt (SG3)	PSI	53.0	53.0	55.0
	Minimum Cond StPt	degF	81.9	70	70
	Maximum Cond StPt	degF	-	90	100
	Condenser Control	-	Pressure	TD	TD
	Condenser TD StPt	degF	-	12	12
	Cond Split	degF	55	50	50
Rack B	Suction StPt (SG1)	PSI	53	55.5	55.5
	Minimum Cond StPt	degF	71	70	70
	Maximum Cond StPt	degF	90	90	100

System	Variables	Unit	Baseline (Applicant and Evaluated)	Applicant Installed	Evaluated Installed
	Condenser Control	-	TD	TD	TD
	Condenser TD StPt	degF	10	12	12
	Cond Split	degF	50	50	50

2.3 Evaluation methods and findings

This section describes the evaluator methods and findings.

2.3.1 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 for this project are an add-on with single baseline. The baseline is single since the measure life of the refrigeration leakage repair and retro-commissioning (2 years and 10 years, respectively) are both less than or equal to 2/3 the measure life of the underlying system (commercial refrigeration is 15 years, so 2/3 x 15 years = 10 years).

For 13977788 Refrigerant Leak Repair, the baseline is the pre-existing refrigeration rack, with the identified leaks through the contractor's leak survey.

For 14078553 Monitoring based commissioning (MBCx), the pre-existing input key parameters are shown as Table 2-9 below. This is the same as what the applicant used in their calculation.

Table 2-9. Applicant baseline key parameters – M2 (14078553)

Variables	Unit	Category	Rack A	Rack B
Suction StPt (SG1)	PSI	Setpoint	17	55.5
Suction StPt (SG2)	PSI	Setpoint	19	-
Suction StPt (SG3)	PSI	Setpoint	53	-
Minimum Cond StPt	degF	Setpoint	81.9	71
Maximum Cond StPt	degF	Setpoint	-	90
Condenser Control	-	Type	Pressure	TD
Condenser TD StPt	degF	Setpoint	-	10
Cond Split	degF	Setpoint	55	50
MDPR Adjustment	PSI Difference	Setpoint	38	-
Subcooler Correction	-	Status	Not Operational	-

2.3.2   Evaluation calculation method

13977788 Refrigerant Leak Repair:

Since this measure was installed and completed before the MBCx measure began, the applicant was able to perform pre- and post-kW metering prior to the MBCx installation to quantify the savings impact of this measure. However, the evaluator cannot apply the same approach, as both measures have already been implemented, making it impossible to isolate their individual savings impacts. Given the following considerations:

- this is a two-year lifetime measure.

- The measure accounts for only 8% of the total savings and

- This measure was verified to be installed through the evaluator's inspection, and the site contact interview during the site visit and the savings was based on metered results,

the evaluator conducted a thorough desk review of the customer's self-report analysis and did basic measure verification, and accepted their approach and maintained all original inputs and savings results without modifications including using a 25% reduction in savings as a conservative safety factor..

14078553 MBCx:

Based on the on-site findings, the evaluator confirmed that most of the proposed control setting upgrades had been implemented as planned. However, there are still some discrepancies between the applicant's estimated settings and the actual control settings observed through the control screenshots, which mainly happens on the suction setpoints for rack A group 1 and 3, and the maximum condenser fan setpoints for rack A. No discrepancy found for rack B. Table 2-10 lists the details of the evaluator's installed case inputs for this measure.

Table 2-10. Evaluator's proposed key parameters – M2 (14078553) main inputs

Variables	Unit	Category	Rack A - Applicant	Rack A – Evaluator	Rack B - Applicant	Rack B – Evaluator
Suction StPt (SG1)	PSI	Setpoint	17.0	16.5	55.5	55.5
Suction StPt (SG2)	PSI	Setpoint	19.0	19.0	-	-
Suction StPt (SG3)	PSI	Setpoint	53.0	55.0	-	-
Minimum Cond StPt	degF	Setpoint	70	70	70	70
Maximum Cond StPt	degF	Setpoint	90	100	100	100
Condenser Control	-	Type	TD	TD	TD	TD
Condenser TD StPt	degF	Setpoint	12	12	12	12
Cond Split	degF	Setpoint	50	50	50	50
MDPR Adjustment	PSI Difference	Setpoint	30	30	-	-
Subcooler Correction	-	Status	Operational	Operational	-	-

In addition, instead of assuming 25% and 0% defrost time for racks A and B, the evaluator calculated the actual defrost time by using the collected defrost setting from Figure 2-3. Considering a weighted average approach without detailed capacity

value for each case could introduce more uncertainties, the evaluator used a simple average for all cases, by using the following formula:

$$Defrost\ Time\ \% = \sum_{All\ Cases} \frac{Defrost\ Duration\ Minutes \times Defrost\ Frequency\ per\ Day}{24\frac{Hours}{Day} \times 60 Minutes/Hour} \div \#\ of\ Cases$$

The evaluator calculated the actual defrost time for rack A and B are 10% and 12% respectively. This indicates that the loads slightly decrease for rack A and increase a bit for rack B.

In the next step, the evaluator converted the metered kW data into a bin profile, using the same 5-degree OAT as the interval and compared with the applicant estimated kW. Table 2-11 shows the comparison between these two approaches. Noted this table only shows the bin profile during the metered period, and the evaluator metered kW cannot distinguish the system performance between normal and hot gas (HG) defrost mode, due to the defrost could happen at any time during a single day.

Table 2-11. Comparison between the applicant estimated rack consumption and actual metered kW – installed case

OAT DB (°F)	Mode	Applicant Estimated kW	Evaluator Metered kW
62.5	Normal	57.92	42.28
	HG defrost	63.18	
57.5	Normal	52.95	42.63
	HG defrost	58.37	
52.5	Normal	49.30	41.66
	HG defrost	54.73	
47.5	Normal	53.05	41.40
	HG defrost	58.34	
42.5	Normal	50.34	40.50
	HG defrost	55.62	
37.5	Normal	48.33	39.64
	HG defrost	53.58	
32.5	Normal	46.74	39.90
	HG defrost	51.96	
27.5	Normal	45.42	38.91
	HG defrost	50.60	
22.5	Normal	44.29	37.60
	HG defrost	49.42	
17.5	Normal	43.29	37.86
	HG defrost	48.38	
12.5	Normal	42.38	37.74

OAT DB (°F)	Mode	Applicant Estimated kW	Evaluator Metered kW
	HG defrost	47.43	

In order to have a direct comparison between applicant estimated loads and the actual metered loads, the evaluator revised applicant's model by using a blended kW for each temperature bin, using the following formula:

$$Blended\ kW = Defrost\ Time\% \times Defrost\ kW + (1 - Defrost\ Time\%) \times Normal\ kW$$

The table above shows that the applicant assumed refrigeration system consumption was strongly weather-dependent, estimating a summer load factor of 85% and a winter load factor of 70%. However, the kW data collected by the evaluator does not indicate such a strong correlation, though weather still plays a role, primarily due to the impact of the condenser fans. To improve accuracy, the evaluator calibrated the model by testing various summer and winter load factor alternatives, ensuring the model's estimated blended kW closely aligned with the metered kW. By adjusting the summer load factor from 85% for both racks to 63% for Rack A and 61% for Rack B, and the winter load factor from 70% for both racks to 62% for Rack A and 60% for Rack B, the evaluator improved the model's alignment with the metered data. As shown in Table 2-12 below, these revised factors resulted in a more accurate calibration of the model's estimated kW consumption:

Table 2-12 Calibrated model estimation – blended kW in the installed case

OAT DB (°F)	Calibrated Model Estimation – Rack A	Actual Metered kW – Rack A	Comparison Ratio – Rack A	Calibrated Model Estimation – Rack B	Actual Metered kW – Rack B	Comparison Ratio – Rack B
62.5	48.82	42.71	0.87	21.95	21.95	1.00
57.5	45.15	42.28	0.94	19.85	20.23	1.02
52.5	41.67	42.63	1.02	18.19	19.78	1.09
47.5	39.17	41.66	1.06	20.45	19.94	0.98
42.5	42.56	41.40	0.97	19.27	19.26	1.00
37.5	40.78	40.50	0.99	18.45	18.31	0.99
32.5	39.54	39.90	1.01	17.85	17.67	0.99
27.5	38.62	39.64	1.03	17.38	17.49	1.01
22.5	37.91	38.91	1.03	17.01	16.83	0.99
17.5	37.35	37.60	1.01	16.71	16.64	1.00
12.5	36.89	37.86	1.03	16.46	15.99	0.97
Overall			1.0016			1.0025

The evaluator also revised the baseline model by updating the defrost time and the summer/winter load factor for rack A and B, to keep the load consistent between baseline and installed case. In the end, this evaluation approach preserved the high rigor of the applicant refrigeration model and REFPROP calculations, while a) adjusting the model with revised control parameters and b) calibrating the model to actual metered kW data across a wide range of observed temperatures. Figure 2-9 and Figure 2-10 are input variable definitions and descriptions of the thermodynamic properties calculations in the Cycle Analysis function developed by NIST, which evaluator pulled from the tracking spreadsheet. Figure 2-11 shows as an example, for the input variable values. Figure 2-12 and Figure 2-13 are the screenshots of the bin hour analysis and the evaluator estimated blended kW for each bin hour, with the consideration of defrost model.

Figure 2-9 Cycle Analysis function – inputs definition

```
General)                                                    ∨ | Describe_Cycle_Analysis_Function                                                    ∨

Option Explicit

Private Sub Workbook_Open()
    Call Describe_Cycle_Analysis_Function
    Call Describe_Refrigeration_Piping_Design
    Call Describe_PipeInsideDiameter
    Call Describe_MinRiserVelocity
 End Sub


'insert function dialog box for Cycle Analysis
Sub Describe_Cycle_Analysis_Function()
    Dim FuncName, FuncDesc, Arg1Desc, Arg2Desc, Arg3Desc, Arg4Desc, Arg5Desc, Arg6Desc, Arg7Desc, Arg8Desc, Arg9Desc, Arg10Desc, Arg11Desc As String
    Dim FuncCat As Long

    FuncName = "Cycle_Analysis"
    FuncDesc = "Calculates state points and principle parameters for refrigeration cycle"
    FuncCat = 14 'User defined
    Arg1Desc = "Refrigerant (see REFPROP options)"
    Arg2Desc = "Condensing Pressure (psia)"
    Arg3Desc = "Discharge Gas PD (psi)"
    Arg4Desc = "Evap Pressure (psia)"
    Arg5Desc = "Suction gas PD (psi)"
    Arg6Desc = "Subcooling TD leaving condenser (F)"
    Arg7Desc = "Subcooling TD for mechanical subcooler (F)"
    Arg8Desc = "Evaporator superheat (F) (useful cooling)"
    Arg9Desc = "Temperature rise in suction line (F) (non-useful cooling)"
    Arg10Desc = "Isentropic Efficiency"
    Arg11Desc = "1:Btu/lb_c, 2:Btu/lb_h, 3:Btu/lb_SC 4:Btu/lb_comp, 5: COP_c, 6:COP_h, 7:Disch_T(F), 8:Mean CondT(F), 9:Mean EvapT(F), 10:D lb/ft^3_su
```

Figure 2-10 Cycle Analysis Function – variable calculation

```vba
(General)                                              ∨ | Cycle_Analysis

        'Thermodynamic properties are calculated at each state point

        'Low pressure #2 (Evaporator-outlet (saturated)
        Pressure_LP2 = Evap_Pressure_psia
        Temperature_LP2 = REFPROP("T", Refrigerant, "Pvap", "E", Pressure_LP2)
        Density_LP2 = REFPROP("D", Refrigerant, "Pvap", "E", Pressure_LP2)
        Enthalpy_LP2 = REFPROP("H", Refrigerant, "Pvap", "E", Pressure_LP2)

        'Low pressure #3 (Evaporator-outlet (superheated)
        Pressure_LP3 = Evap_Pressure_psia - Suction_Pressure_PD_psi
        Temperature_LP3 = Temperature_LP2 + Evaporator_Superheat_F
        If (Evaporator_Superheat_F = 0) Then
            Density_LP3 = REFPROP("D", Refrigerant, "Pvap", "E", Pressure_LP3)
            Enthalpy_LP3 = REFPROP("H", Refrigerant, "Pvap", "E", Pressure_LP3)
            Viscosity_LP3 = REFPROP("KV", Refrigerant, "Pvap", "E", Pressure_LP3)
        Else
            Density_LP3 = REFPROP("D", Refrigerant, "TP&", "E", Temperature_LP3, Pressure_LP3)
            Enthalpy_LP3 = REFPROP("H", Refrigerant, "TD&", "E", Temperature_LP3, Density_LP3)
            Viscosity_LP3 = REFPROP("KV", Refrigerant, "TD&", "E", Temperature_LP3, Density_LP3)
        End If


        'Low pressure #4 (Compressor inlet (superheated))
        Pressure_LP4 = Evap_Pressure_psia - Suction_Pressure_PD_psi
        Temperature_LP4 = Temperature_LP3 + Return_Pipe_Superheat_F
        If (Evaporator_Superheat_F + Return_Pipe_Superheat_F = 0) Then
            Density_LP4 = REFPROP("D", Refrigerant, "Pvap&", "E", Pressure_LP4)
            Enthalpy_LP4 = REFPROP("H", Refrigerant, "Pvap", "E", Pressure_LP4)
            Entropy_LP4 = REFPROP("S", Refrigerant, "Pvap", "E", Pressure_LP4)
            Viscosity_LP4 = REFPROP("KV", Refrigerant, "Pvap", "E", Pressure_LP4)
        Else
            Density_LP4 = REFPROP("D", Refrigerant, "TP&", "E", Temperature_LP4, Pressure_LP4)
            Enthalpy_LP4 = REFPROP("H", Refrigerant, "TD&", "E", Temperature_LP4, Density_LP4)
            Entropy_LP4 = REFPROP("S", Refrigerant, "TD&", "E", Temperature_LP4, Density_LP4)
            Viscosity_LP4 = REFPROP("KV", Refrigerant, "TD&", "E", Temperature_LP4, Density_LP4)
        End If


        'High pressure #1 (Compressor discharge (isentropic))
        Pressure_HP1 = Condensing_Pressure_psia + Discharge_Gas_PD_psi
        Entropy_HP1 = Entropy_LP4
        Temperature_HP1 = REFPROP("T", Refrigerant, "PS&", "E", Pressure_HP1, Entropy_HP1)
        Density_HP1 = REFPROP("D", Refrigerant, "TP&", "E", Temperature_HP1, Pressure_HP1)
        Enthalpy_HP1 = REFPROP("H", Refrigerant, "TD&", "E", Temperature_HP1, Density_HP1)

        'High pressure #2 (Compressor discharge (actual))
        Pressure_HP2 = Condensing_Pressure_psia + Discharge_Gas_PD_psi
        Enthalpy_HP2 = Enthalpy_LP4 + (Enthalpy_HP1 - Enthalpy_LP4) / Isentropic_Efficiency
        Temperature_HP2 = REFPROP("T", Refrigerant, "PH&", "E", Pressure_HP2, Enthalpy_HP2)
        Density_HP2 = REFPROP("D", Refrigerant, "TP&", "E", Temperature_HP2, Pressure_HP2)
```

Figure 2-11 Rack A inputs

Figure 2-12 Rack A bin profile with blended kW estimation

Figure 2-13 Rack A bin hour analysis

3 FINAL RESULTS

The evaluated project includes fixing the identified leakages in the refrigeration systems and upgrading control settings through an MBCx measure. The evaluated savings are lower than the tracking values, primary due to an operational adjustment to the load which resulted from the lower kW measurement for the refrigeration equipment translating into lower loads.. The parameters impacting the analysis are summarized in Table 3-1.

Table 3-1. Summary of key parameters

Parameter	BASELINE		PROPOSED / INSTALLED	
	Tracking Value(s)	Evaluation Value(s)	Tracking Value(s)	Evaluation Value(s)
Rack A group A suction pressure setpoint, PSI	17.0	16.5	17.0	16.5
Rack A group B suction pressure setpoint, PSI	19.0	19.0	19.0	19.0
Rack A group C suction pressure setpoint, PSI	53.0	55.0	53.0	55.0
Rack B group A suction pressure setpoint, PSI	53.0	53.0	55.5	55.5
Rack A minimum condensing fan temperature setpoint, °F	81.9	81.9	70	70
Rack A maximum condensing fan temperature setpoint, °F	N/A	N/A	90	100
Rack B minimum condensing fan temperature setpoint, °F	71	71	70	70
Rack B maximum condensing fan temperature setpoint, °F	71	71	100	100
Rack A condenser control	Pressure	Pressure	TD	TD
Rack B condenser control	TD	TD	TD	TD
Rack A Condenser Split Temperature, °F	55	55	50	50
Rack B Condenser Split Temperature, °F	50	50	50	50
Rack A MDPR Adjustment, PSI	38	38	30	30
Rack A subcooler correction	Not operational	Not operational	Operational	Operational
Rack A defrost time, %	25%	10%	25%	10%
Rack B defrost time, %	0%	12%	0%	12%
Rack A summer load factor, %	85%	63%	85%	63%
Rack A winter load factor, %	70%	62%	70%	62%
Rack B summer load factor, %	85%	61%	85%	61%
Rack B winter load factor, %	70%	60%	70%	60%

3.1 Explanation of differences

The evaluated savings are 25% lower than the tracking values predominantly because of discrepancies in operations. The evaluator found the actual summer and winter load factor for both racks were lower than the applicant estimated. This would decrease the refrigeration load and lead the measure to save less energy. 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
M2	Operation	Operating profile	4.1%	**Increased savings** – the evaluated findings indicate the actual suction pressure setpoints for one out of three groups from rack A are higher than the applicant estimated. This increases the load and leads to higher savings.
M2	Operation	Operating profile	-2.9%	**Decreased savings** – the evaluated findings indicate the actual defrost time is lower than applicant assumed on rack A and higher on rack B. Since rack A has larger capacity and defrost mode consumes more energy, this discrepancy leads to lower savings.
M2	Operation	Operating profile	-28.8%	**Decreased savings** – the evaluated findings indicate actual summer and winter loading as indicated in the new calibrated load factors, for both racks are lower than applicant assumed. This reduces the load and leads to lower savings

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:

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

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, Table 3-4 and Table 3-5 provide a summary of key factors that influence the lifetime savings.

Table 3-3. Measure M1 – Application ID: 13977788 – Lifetime savings summary

Factor	Tracking	Application	Evaluator
Lifetime savings (kWh)	11,570	11,570	11,570

Factor	Tracking	Application	Evaluator
First-year savings (kWh)	5,785	5,785	5,785[4]
Measure lifetime (years)	2	2	2
Baseline classification	Retrofit	Add-on	Add-on

Table 3-4. Measure M2 – Application ID: 14078553 – Lifetime savings summary

Factor	Tracking	Application	Evaluator
Lifetime savings (kWh)	658,110	658,110	476,649
First-year savings (kWh)	65,811	65,811	47,665
Measure lifetime (years)	10	10	10
Baseline classification	Retrofit	Add-on	Add-on

Table 3-5. Project level – Lifetime savings summary

Factor	Tracking	Application	Evaluator
Lifetime savings (kWh)	669,680	669,680	488,219
First-year savings (kWh)	71,596	71,596	53,450
Measure lifetime (years)	9.35	9.35	9.13
Baseline classification	Retrofit	Add-on	Add-on

3.3   Ancillary impacts

There are no ancillary impacts from installing the evaluated measures.

---

[4] The evaluator maintained the 75% adjustment factor as applicant did as a conservative approach, this is due to limited detail on the exact leak locations and quantities. In the absence of more specific data to support a refined estimate, the evaluator judged the applicant's conservative factor to be reasonable and appropriate for this evaluation.

RHODE ISLAND CUSTOM ELECTRIC SITE-SPECIFIC REPORT
SITE ID: RICE23N096

Report Date: July 4, 2025

Program Administrator	Rhode Island Energy
Application ID(s)	13806092, 14151552
Project Type	C&I Existing Building Retrofit
Evaluation Type	Full M&V
Program Year	PY2023
Evaluation Firm	DNV
Evaluation Engineer	Shravan Iyer
Senior Engineer	Nathan Throop

1 EVALUATED SITE SUMMARY AND RESULTS

The evaluated cannabis grow facility consists of two buildings, North and South respectively, with a total of ten grow rooms across the two buildings. The facility operates 24/7 throughout the year. The measure that was evaluated as part of this project was installed in Building North only and included the installation of 478 792W LED fixtures in the grow rooms in Building North, operating between 12 hours per day and 18 hours per day during the different stages of the grow cycle. The total canopy area of the six rooms in the North building is 18,210 ft². The lights are mostly turned off during the harvesting period. The baseline fixtures consist of high-pressure sodium (HPS) fixtures with rated inputs of 1,050W each.

The energy savings for this measure come from the reduced lighting fixture wattage as well as interactive cooling savings that result from the various HVAC equipment in the grow rooms such as RTUs, ductless mini-splits and dehumidifier units. The evaluators observed an average on-site dimming percentage of 37% overall as compared to 44% in the tracking estimate. The applicant classified this measure as a retrofit with the pre-existing condition as the baseline. After reviewing the tracking documentation and conducting the site visit, the evaluators classified the measure as a retrofit with a single baseline with the pre-existing condition being the baseline.

The evaluation results are presented in Table 1-1.

Table 1-1. Evaluation results summary

PA application ID	Measure name		Annual electric energy (kWh)	% of energy savings on-peak	Summer on-peak demand (kW)	Winter on-peak demand (kW)
13806092, 14151552	**Cannabis Grow Light Replacement**	Tracked	293,934	62%	58.38	47.74
		Evaluated	266,832	57%	55.85	15.13
		Realization Rate	91%	92%	96%	32%

1.1 Explanation of deviations from tracking

The evaluated savings are 9% lower than the tracking savings primarily because of slightly lower dimming levels of the lights observed by the evaluator. Additionally, the evaluator also observed lower space temperature and relative humidity (RH) levels in the grow rooms as determined during the site visit. These findings impacted the interactive space conditioning savings. Further details regarding deviations from the tracked savings are presented in Section 3.1.

1.2 Recommendations for program designers and implementers

The evaluators recommend considering shell losses in the building as part of the tracking savings calculation.

1.3 Customer alerts

There are no relevant customer alerts.

2 EVALUATED MEASURES

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

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

Table 2-1. Evaluated measure(s)

Measure	Project ID	Parameter
M1	13806092, 14151552	Cannabis LED Grow Light Replacement

2.1 Application information and applicant savings methodology

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

2.1.1 Applicant description of baseline

The applicant classified this project as a retrofit, with the pre-existing condition as the baseline. The applicant's baseline consists of HPS fixtures with a rated input of 1,050W each. The applicant's baseline consists of 478 fixtures at an equivalent dimming output as the installed fixtures, and identical operating hours as the installed fixtures. The baseline fixtures and their respective wattage are listed in Table 2-2 below:

Table 2-2 Baseline fixture wattages and quantities

Room	Fixture Type	Fixtures Watts	Fixtures Quantity
N1	HPS	1,050	66
N2	HPS	1,050	112
N3	HPS	1,050	112
N4	HPS	1,050	48
N5	HPS	1,050	70
N6	HPS	1,050	70
Total			**478**

The base case flower cycle was estimated to be 9-weeks and the room dimming schedule was determined using utility billing data analysis and the average dimming output was found to be 44%.

The base case dimming schedule and grow hours are listed in the Table 2-3 below:

Table 2-3 Base case dimming and grow hours

Week	Grow Hour From	Grow Hour To	Lights On per Day	Output %
1	0	168	18	44%
2	168	336	18	44%
3	336	504	12	44%
4	504	672	12	44%
5	672	840	12	44%
6	840	1,008	12	44%
7	1,008	1,176	12	44%
8	1,176	1,344	12	44%
9	1,344	1,512	12	44%
Off	1,512	1,632	0	44%

The average expected space dry bulb setpoint does not change over the course of the grow cycle, but the RH setpoint is lowered after two weeks. There are no space condition setbacks during the lights off period. The average dry bulb and relative humidity setpoints are listed in Table 2-4 below:

Table 2-4 Temp/RH conditions

Week	Dry bulb (F)	RH (%)
1	79	58%
2	79	58%
3	79	53%
4	79	53%
5	79	53%
6	79	53%
7	79	53%
8	79	53%
9	79	53%

The building's HVAC system is listed below in Figure 2-1 for each room and space type:

Figure 2-1 HVAC system inventory by space

North

Room 1	Model #	Serial #
RTU 20 Ton	ZS-20N40AWAAA3	N1D5674241
RTU 15 Ton	ZS-15N30AWAAA3	
Excel Air 5 ton FR	AHR60D3XH21B	W1A5421046
Excel Air 5 ton BR	AHR60D3XH21B	W1A5421050
Excel Air 5 ton BL	AHR60D3XH21B	W1A4325870
Excel Air 5 ton FL	AHR60D3XH21B	W1A5421039
Ideal Air 180 Pint	701600	201712090
Ideal Air 180 Pint	701600	201710220
Ideal Air 180 Pint	700897	20160314130

Room 2	Model #	Serial #
RTU 25 Ton	ZF300N40P4B1AAA1A2	N2L0271556
RTU 20 Ton	ZF240N40R4B2AAA1A1	N2F0931069
Excel Air 5 ton FR	AHR60D3XH21B	W1M432588R
Excel Air 5 ton BR	AHR60D3XH21B	W1A5421045
Excel Air 5 ton BL	AHR60D3XH21B	W1M4325589
Excel Air 5 ton FL	AHR60D3XH21B	W1A5377918
Ideal Air 180 Pint	701600	201712125
Ideal Air 180 Pint	701600	201712140
Ideal Air 180 Pint	701600	201710096
Ideal Air 180 Pint	701600	201710233
Ideal Air 180 Pint	700897	2016011003
Ideal Air 180 Pint	700897	20140710A073
Ideal Air 180 Pint	700897	20160415135
Active Air	AADHC180P	3.41E+13
3 Ton LG Mini split	LSN363HLV	701KAGS01M55
3 Ton LG Mini split	LSN363HLV	701KAGS01M55

Room 3	Model #	Serial #
RTU 20 Ton	ZS-20N40AWAAA3	N1D5674242
RTU 15 Ton	ZS-15N30AWAAA3	N1D5674240
Excel Air 5 ton FL	AHR60D3XH21B	W1M4325869
Excel Air 5 ton BL	AHR60D3XH21B	W1A5421037
Excel Air 5 ton FR	AHR60D3XH21B	W1M4325881
Excel Air 5 ton BR	AHR60D3XH21B	W1A5377899
Ideal Air 180 Pint	701600	201712099
Ideal Air 180 Pint	701600	201710224
Ideal Air 180 Pint	701600	201710286
Ideal Air 180 Pint	701600	201710222
Ideal Air 180 Pint	701600	201710176
Ideal Air 190 Pint	DS190-700837	HT17100327
Ideal Air 190 Pint	DS190-700837	HT17081602
Ideal Air 190 Pint	DS190-700837	HT17050230
Ideal Air 190 Pint	DS190-700837	HT17050342
3 Ton LG Mini split	LSN363HLV	701KAGS01M55
3 Ton LG Mini split	LSN363HLV	701KAGS01M55
Quest 506	506-230V	E2106683

Room 4	Model #	Serial #
Liebert 15 ton	VH199AUAAEO	733086-004
Liebert 20 ton	VH245AUAAEO	417995-006
Ideal Air 180 Pint	700897	20160415042
Ideal Air 180 Pint	700897	20140710A001
Ideal Air 180 Pint	700897	20160415086
Ideal Air 180 Pint	700897	20160111083
Ideal Air 190 Pint	DS190-700837	HT17021998
Ideal Air 190 Pint	DS190-700838	HT17021997
Ideal Air CG2	700899	1608124
Quest 506	506-230V	E2106683

Room 5	Model #	Serial #
Liebert 20 Ton	VH245AUAAEO	417995-004
Liebert 20 Ton	VH245AUAAEO	710645-001
Ideal Air 180 Pint	700897	20160405071
Ideal Air 180 Pint	700897	20160314130
Ideal Air 180 Pint	700897	20160405090
Ideal Air 180 Pint	700897	20160405076
Ideal Air 170 Pint	700899	1549181
Ideal Air 170 Pint	700899	1608125
Ideal Air 170 Pint	700899	1549183
Ieal Air 190 Pint	DS190-700837	HT17021997
Ieal Air 190 Pint	DS190-700838	HT17021998
Quest 506	506-230V	E2106683

Room 6	Model #	Serial #
Liebert 20 Ton	VH245AUAAEO	414818-003
Liebert 20 Ton	VH245AUAAEO	388180-002
Ideal Air 190 Pint	DS190-700837	HT16091270
Ideal Air 190 Pint	DS190-700838	HT17050004
Ideal Air 190 Pint	DS190-700839	HT16091210
Ideal Air 190 Pint	DS190-700840	HT16091271
Ideal Air 190 Pint	DS190-700841	HT17050259
Ideal Air 190 Pint	DS190-700842	HT17050040
Ideal Air 190 Pint	DS190-700843	HT16091270
Ideal Air 190 Pint	DS190-700844	HT17050006
Active Air	AADHC180P	3.41E+13
Active Air	AADHC180P	3.41E+13
Active Air	AADHC180P	3.41E+13
Quest 506	506-230V	E2106683

Veg	Model #	Serial #
Mini Split 3 ton	GGHH36(10.6)LSK4DH	GHJ220106824
Mini Split 3 ton	LSN360HV3	512KAAE04Y68
Mini Split 3 ton	GGHH36(10.6)LSK4DH	GHJ220106824
Ideal Air 180 Pint	700897	20150915031
Ideal Air 170 Pint	700899	1549184
Quest 506	506-230V	E2106683

The applicant key baseline parameters are listed in Table 2-5 below:

Table 2-5. Applicant baseline key parameters

Measure	Parameter	Operation description	Source of parameter value
M1	Baseline fixture type	High pressure sodium	TA study report
M1	Baseline fixture wattage	1,050 W	TA study report
M1	Baseline fixture quantity	478	TA study report
M1	Baseline dimming (%)	44%	Applicant calculation
M1	Baseline Photosynthetic Photon Flux Density (PPFD)	1901μmol/s	Lighting Spec sheets
M1	Baseline grow room temperature setpoint	79°F	TA study report

2.1.2   Applicant description of installed equipment and operation

This project involved installing 478 792 W LED lights in the grow rooms. The list of fixtures and their quantities are listed in Table 2-6 below:

Table 2-6 Installed case fixture wattages and quantities

Room	Fixture Type	Fixtures	
		Watts	Quantity
N1	LED	792	66
N2	LED	792	112
N3	LED	792	112
N4	LED	792	48
N5	LED	792	70
N6	LED	792	70
	Total		**478**

Table 2-7 presents the main parameters of the proposed case as defined by the applicant.

Table 2-7. Applicant's proposed key parameters

Measure	Parameter	Operation description	Source of parameter value
M1	As-built fixture type	LED	TA study report
M1	As-built fixture wattage	792.9 W	TA study report
M1	As-built fixture quantity	478	TA study report
M1	As-built dimming (%)	44%	Applicant calculation
M1	Baseline Photosynthetic Photon Flux Density (PPFD)	1901μmol/s	Lighting Spec sheets
M1	As-built grow room temperature setpoint	79°F	TA study report

2.1.3   Applicant energy savings algorithm

The applicant calculations used an 8,760 model to estimate the savings. The latent and sensible heat loads in the rooms were calculated for each hour of the day. The loads in the spaces include lighting heat gain, plug loads, heat from supply fans, evaporative cooling as a result of transpiration and conditioning of fresh outdoor air brought in from the ERVs.

The applicant used the following formulas to quantify the energy savings from the light fixtures for this measure:

Fixture Savings:

$$kW_{Ltg-F} = (kW_{Base} - kW_{Installed}) \times Dim_F \times Qty_F$$

where,

kW $Ltg-F$	= Fixture wattage savings	
kW_{Base}	= baseline HPS fixture input power, 1.070 kW/fixture	
$kW_{Installed}$	= Installed LED fixture input power, 0.636 kW/fixture	
Dim_F	= average dimming factor in the grow rooms, 44%	
Qty_F	= fixture quantity in the grow rooms	

Interactive Savings (HVAC):

The interactive savings come from the HVAC interactive effects, i.e. from the change in heating and cooling loads, which are described below:

The total latent heat load is calculated using the formula:

$$Total\ Latent\ Heat\ load\ \left(\frac{Btu}{h}\right) = Transpiration\ \left(\frac{gal}{h}\right) \times 8.345\ \left(\frac{lb}{gal}\right) \times 970.4\ \left(\frac{Btu}{lb}\right) + (TF) \times ERV\ Load\ \left(\frac{Btu}{h}\right)$$

Where:
TF= Transpiration Factor, 10% when lights are off, 90% when lights are on.

The total sensible heat is calculated using the formula:

$$Total\ Sensible\ Load\ \left(\frac{Btu}{h}\right)$$
$$= (Lighting\ kW + Plug\ Load\ kW + Supply\ Fan\ kW) \times 3{,}412\ \left(\frac{Btu}{kWh}\right) + ERV\ Load\ \left(\frac{Btu}{h}\right)$$
$$- Total\ Latent\ Load\ \left(\frac{Btu}{h}\right) + Standalone\ Dehumidifier\ (Btu/h)$$

$$Cooling\ system\ latent\ load = Sensible\ heat\ ratio\ (SHR) \times Total\ Sensible\ load$$

$$Standalone\ Latent\ Load = Total\ Latent\ Load - Cooling\ system\ latent\ load)$$

$$HVAC\ Usage\ (kWh)$$
$$= (Total\ Sensible\ Load + Cooling\ system\ latent\ load) \times Eff\ cooling\ system\ \left(\frac{kW}{Ton}\right)$$
$$+ Standalone\ dehumidifier\ load \times Eff\ standalone\ dehumidifier\ \left(\frac{kW}{Ton}\right)$$

$$HVAC\ Interactive\ Savings = HVAC\ Usage\ (Base\ case) - HVAC\ Usage\ (Post\ case)$$

Total Energy Savings:

$$Total\ Energy\ Savings = \sum_{Hour=1}^{8760} (Lighting\ Fixture\ Savings + HVAC\ interactive\ Savings)$$

Here, the ERV loads are the portion of the total latent and sensible loads that are dependent on outdoor air conditions. Therefore, the rooms that have ERVs (i.e. N4, N5 and N6) are modeled separately from the other rooms in the spreadsheet calculation. Additionally, the Liebert dehumidification units in Rooms N4, N5 and N6 that have a dehumidification mechanism consisting of built-in electric re-heats. The electric re-heats heat the air based on room setpoint temperature that

has been overcooled during the dehumidification that takes place on the cooling coil. The primary dehumidification requirements are served by the standalone dehumidifiers. For rooms N1, N2 and N3 the heating, cooling and dehumidification requirements are served by the four RTUs and standalone dehumidification systems respectively. The individual dehumidifiers in these rooms were modeled collectively as one large dehumidifier serving each room.

2.1.4   Evaluation assessment of applicant methodology

The evaluator determined the applicant savings calculation methodology to be reasonable. The applicant savings calculation methodology calculated both fixture and HVAC interactive savings. The evaluators agree with this methodology.

2.2   On-site inspection and metering

This section provides details of the tasks performed during the on-site inspection, the date it was conducted, and how it was conducted.

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

- The site contact is present on-site and agreed to accommodate an on-site evaluation.
- It is safe to visit the facility and inspect the measure.

2.2.1   Summary of site visit findings

The evaluators conducted a site visit on December 19th, 2024, to verify the installation of the LED fixtures. The site is a cannabis cultivation facility. The impacted north building consists of a total of six grow rooms in the building. During the site visit, the evaluators interviewed the site contact who was the Cultivation Manager of the site. The site contact informed the evaluators that the veg and flower processes happen in the same rooms and that there are no separate rooms for each of them. The site contact mentioned that the veg phase is 2-3 weeks long and during the veg phase approximately half of the lights are on 18 hours per day and off six hours per day. The vegetative phase is followed by a flowering phase during which the lights are on for 12 hours per day for 9-10 weeks, completing the grow cycle. Also, after each grow cycle is completed, there is a 3–4-day cleaning cycle, and then the site starts another crop cycle at the veg phase. This cycle keeps repeating throughout the year for multiple cycles. There are no seasonal variations in the lighting schedules, and the operation is 24/7 throughout a given grow cycle.

The evaluators confirmed the installation of the new LED fixtures and verified the quantities of the fixtures installed in each of the spaces, by verifying a sample of the fixture quantities in a sample of the rooms. The quantities matched the number of fixtures claimed in the application.

Additionally, the evaluators also verified the HVAC and dehumidification systems that served the various spaces at the site. The following Figure 2-2 shows a sample of the dehumidification units that served some of the spaces at the site:

Figure 2-2 Dehumidification units observed onsite

The evaluators inquired about the baseline condition and the type of light fixtures that existed in the pre-install case. The site contact mentioned that the pre-install case fixtures consisted of 478 1,050 W HPS fixtures. The pre-existing fixtures were dimmable at specific intervals and the dimming could not be fine-tuned to the requirements of the crop during the various stages of growth. Additionally, the higher lighting wattage and the long hours of use resulted in higher electricity costs. Therefore, the site replaced the lights with LEDs that provide more granularity in terms of dimming and would also reduce utility costs. The evaluators also verified onsite that the lights are manually controlled and that there was not a building energy management system (BMS/EMS) that allowed for the automation of the lighting control.

The evaluators verified that most of the HVAC units in the applicant documentation are in place as noted. The evaluators found some units were different and gathered information about those units that were changed such as:

- Room N3- A 15 Ton RTU replaced with 20 Ton RTU unit.

- Room N3- The site replaced three Excel Air 5 Ton units that failed with one Quest 335 High efficiency unit.

- There were no electric re-heats installed onsite since the site decided that they were not needed.

- The ERVs are not functioning and have not been replaced.

A summary of the onsite verification is provided in the Table 2-8 below:

Table 2-8 Measure verification

Measure	Verification method	Verification result
M1	Onsite inspection and metering	Verified the installation of the LED grow lights and HVAC equipment.

The evaluators installed data loggers on multiple lighting circuits and HVAC units to model the operation of the lights and the HVAC units during the metering period. The following section provides additional information about the metered data that was collected.

2.2.2   Metered and logged data

The evaluators installed data loggers on the following equipment listed below in Table 2-9:

Table 2-9 Data loggers installed at the site

	Room Number	Logger ID	Logger Type	Equipment Metered
1	N6	XC1612137	ElitePRO	4 lights Row 1F
2	N6	6022	HOBO Plug load	dehumidifier
3	N6	5902	HOBO Plug load	dehumidifier
4	N3	10374702	Temp/RH logger	Space Temp/RH
5	N3	10374737	Temp/RH logger	Space Temp/RH
6	N3	5733	HOBO 4 channel Amp logger	Quest dehumidifier
7	N3	10786131	HOBO 4 channel Amp logger	RTU-7
8	N3	XC1906032	ElitePRO	RTU-8
9	N3	XC1808018	ElitePRO	4 lights (Row 2F)
10	N1	10667670	HOBO 4 channel Amp logger	4 lights (Row 5)

The evaluators were informed that during the logging period that the compressor on one of the Liebert units in room N6 failed. This resulted in the site turning off some of the lights and shutting off the dehumidifiers, otherwise the heat emanating from the lights would have raised the space temperature to levels that would have adversely affected the crop. Therefore, the data obtained from the loggers installed in room N6 are not representative of typical operations at the site. However, the evaluators obtained typical operational data from the other loggers installed in rooms N3 and N1. The raw data obtained from the lighting loggers is shown in the following figures, Figure 2-3, Figure 2-4 and Figure 2-5 below:

Figure 2-3 Room N3 lighting raw kW data
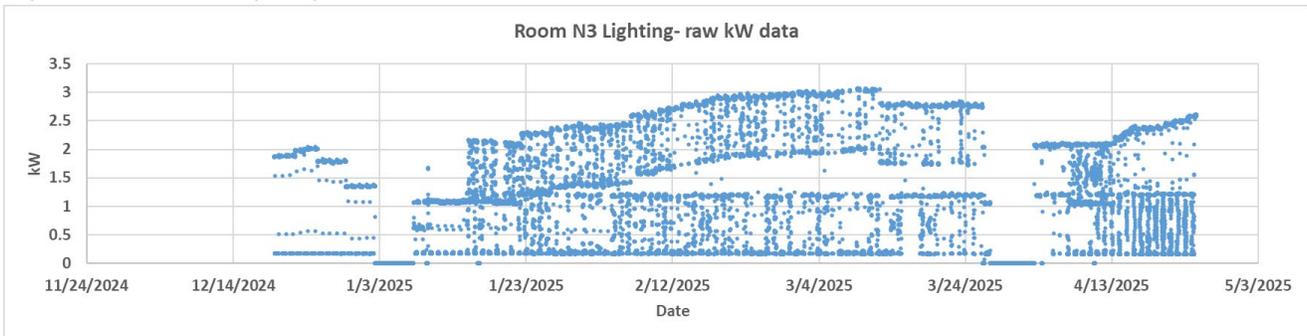
The metered data in Figure 2-3 included lights and a dehumidifier load that needed to be removed to isolate the lighting load and determine the operating profile of the lights during the grow season. It is clear from the figure that there is a static load that is ON/OFF based on consistent operation, as well as a dynamic load that varies. The evaluators identified the dynamic load to represent the dehumidifier and removed it from the static load which is approximately between zero and one kW. Therefore, using the data from the logger, the evaluators created a daily 24-hour profile of the logger during the metering period and calculated the minimum kW during the grow hours to extract the lighting load.

Figure 2-4 Room N1 lighting raw amp data
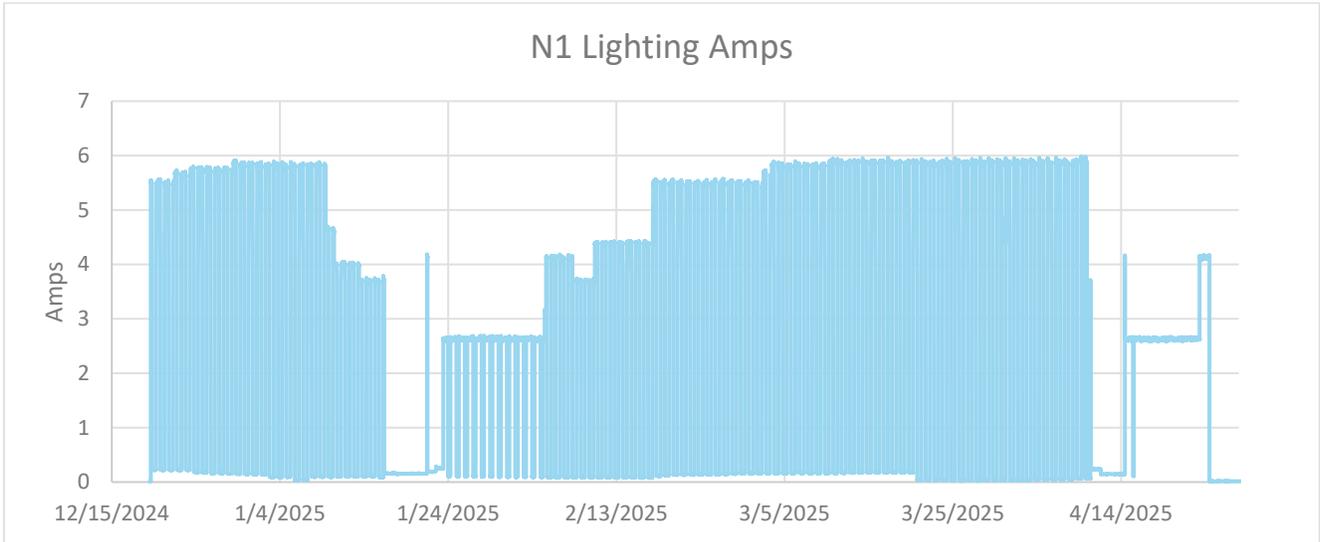
Figure 2-5 Room N6 lighting raw kW data
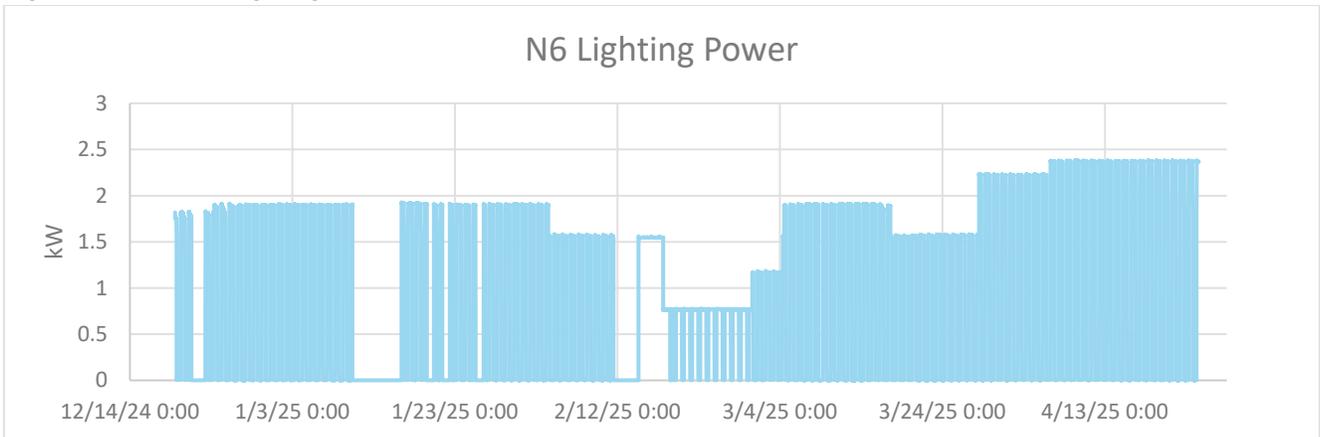
Figure 2-6 below shows a sample of the hourly operating data of the lights during the veg phase of the grow cycle. The lights operate for 18 hours per day during this phase as can be observed below.

Figure 2-6. Logger data for lighting- typical weekly profile during vegetative phase of the grow cycle

Row Labe ▼	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
1/8/2025	0.17	0.17	0.17	0.17	1.07	1.06	1.06	1.06	1.06	0.68	0.61	0.61	0.61	0.61	0.61	0.61	0.61	0.61	0.61	0.61	0.62	0.62	0.17	0.17
1/9/2025	0.17	0.17	0.17	0.17	1.06	1.06	1.06	1.06	1.06	1.06	0.00	0.00	0.00	0.00	0.00	0.61	1.07	1.07	1.07	1.07	1.08	1.08	0.17	0.17
1/10/2025	0.17	0.17	0.17	0.17	1.08	1.07	1.07	1.07	1.08	1.08	1.08	1.08	1.08	1.08	1.08	1.07	1.07	1.08	1.08	1.08	1.08	1.08	0.17	0.17
1/11/2025	0.17	0.17	0.17	0.17	1.07	1.06	1.06	1.05	1.06	1.06	1.06	1.06	1.06	1.06	1.06	1.05	1.05	1.05	1.05	1.05	1.06	1.05	0.17	0.17
1/12/2025	0.17	0.17	0.17	0.17	1.07	1.07	1.06	1.06	1.07	1.06	1.06	1.06	1.06	1.06	1.06	1.06	1.06	1.06	1.06	1.06	1.06	1.06	0.17	0.17
1/13/2025	0.17	0.17	0.17	0.17	1.07	1.07	1.06	1.07	1.06	1.05	1.05	1.05	1.05	1.06	1.06	1.06	1.06	1.06	1.06	1.06	1.06	1.06	0.17	0.17
1/14/2025	0.17	0.17	0.17	0.17	1.07	1.07	1.06	1.07	1.08	1.08	1.09	1.08	1.08	0.76	1.08	1.07	1.07	1.07	1.07	1.08	1.08	1.08	0.17	0.17

The evaluators used RTU kW data to create daily 24-hour operating profiles for the RTUs during the grow season. The raw data for room N3 RTU-8 is shown in Figure 2-7. Similar profiles were created from the raw temp/RH data shown in Figure 2-8 to create the average temperature and RH profile during the grow season. Figure 2-9 and Figure 2-10 show a sample of the weekly profile of space temperature and relative humidity (RH%) during the veg phase of the grow cycle.

Figure 2-7. Room N3 RTU-8 raw kW data

Room N3 RTU 8- raw kW data
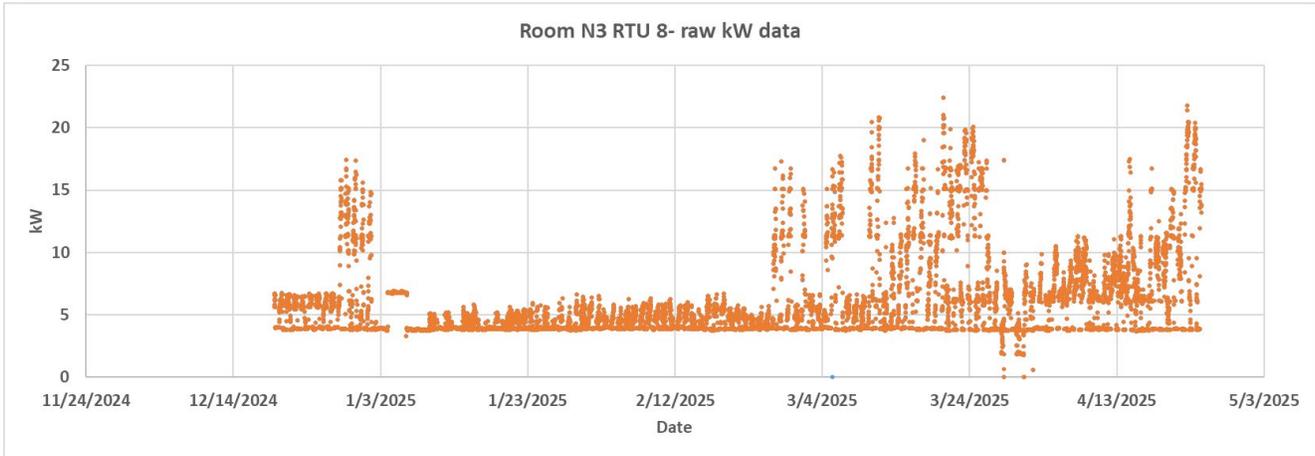
Figure 2-8. Room N3 Temp/RH raw data

Room N3 Temp/RH- raw kW data
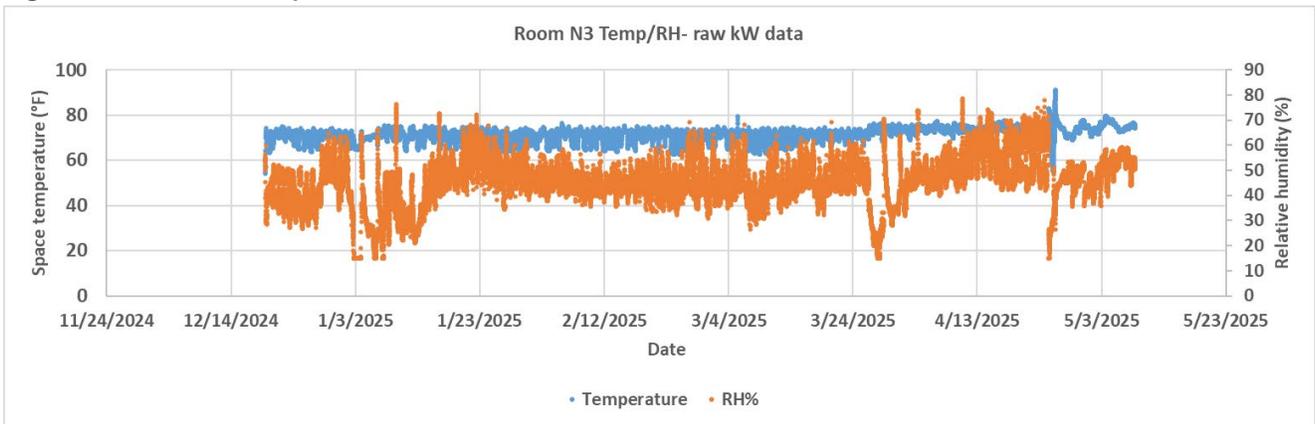
Figure 2-9. Logger data for space temperature - typical weekly profile during grow cycle

Row Labels	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
1/8/2025	70.2	70.2	69.8	68.8	71.8	73.6	73.7	73.9	73.6	73.4	73.3	72.3	72.5	72.5	72.3	72.2	72.5	73.0	73.0	73.7	73.5	73.6	73.8	72.1
1/9/2025	70.4	69.9	69.8	69.3	71.9	74.0	74.4	74.5	74.6	74.6	74.5	72.5	69.9	69.5	69.2	70.7	72.3	72.7	72.6	72.6	72.8	72.8	72.8	72.0
1/10/2025	70.1	69.8	69.5	69.7	72.2	73.2	73.2	73.2	72.8	72.1	73.0	73.1	73.0	73.0	73.1	73.3	73.3	73.4	73.2	73.2	73.2	73.3	73.3	69.8
1/11/2025	68.3	68.3	68.2	68.0	69.4	70.2	70.4	70.4	70.6	71.0	71.4	71.8	72.2	72.5	72.7	72.7	72.8	73.5	73.3	73.1	73.0	73.7	74.7	73.3
1/12/2025	71.7	70.7	70.5	69.8	72.9	74.6	74.6	74.6	73.0	73.4	73.3	72.8	72.9	72.9	72.9	73.1	73.2	73.4	73.4	73.4	73.3	73.2	73.3	70.0
1/13/2025	68.4	68.4	68.2	68.2	69.6	70.7	71.2	71.6	72.1	73.2	73.9	73.3	73.4	73.7	73.5	73.6	73.6	73.7	73.9	73.9	74.0	74.0	73.8	70.1
1/14/2025	69.2	69.9	69.5	70.8	73.3	74.5	74.5	74.6	74.3	72.7	73.0	72.7	72.7	72.7	72.7	72.7	73.1	73.7	74.1	74.0	74.2	74.1	74.2	72.4

Figure 2-10. Logger data for RH (%) - typical weekly profile during grow cycle

Row Labels	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
1/8/2025	49	48	48	48	41	35	30	28	26	24	26	35	39	39	40	42	46	46	45	46	46	46	47	49
1/9/2025	48	48	47	47	47	43	40	39	37	37	35	49	74	74	62	49	46	39	33	31	31	31	31	39
1/10/2025	48	50	48	47	46	39	36	35	33	31	29	26	25	26	29	26	25	33	35	33	30	29	28	27
1/11/2025	26	25	23	22	24	26	29	31	32	32	33	33	33	33	32	32	31	31	30	29	28	27	27	32
1/12/2025	42	46	46	48	45	35	31	30	27	26	25	25	25	24	24	24	24	25	26	26	26	26	25	25
1/13/2025	23	23	22	23	25	27	28	28	29	29	31	34	33	30	31	32	32	32	32	32	31	32	31	30
1/14/2025	30	38	38	46	46	43	40	41	40	39	40	42	41	39	39	39	42	41	42	40	41	40	42	49

The data from the loggers as shown above was used to model the evaluated savings which is described further in the section below.

2.3 Evaluation methods and findings

This section describes the evaluator methods and findings.

2.3.1 Evaluation description of baseline

The evaluators agree with the applicant baseline that the measure is a retrofit with the pre-existing condition as the baseline. The pre-existing grow lights consisted of 478 1,050W HPS fixtures. The pre-existing fixtures were dimmable at specific levels and the dimming could not be fine-tuned to the requirements of the crop during the various stages of growth. Additionally, the higher wattage and the long hours of use resulted in higher electricity costs. Therefore, the site replaced the HPS lights with LEDs that provide more granularity in terms of dimming and would also reduce utility costs. The evaluator assumed the equivalent dimming levels in the baseline as found in the post case so that the base line represents same PPF as the installed case. The evaluators made a reasonable assumption that the output percent PPFD and the percent input wattage of the light fixtures are equal to establish equivalence between the two.

Even though the actual baseline equipment could not archive this dimming value. This is the accepted savings calculation methodology used for this measure.

2.3.2 Evaluation calculation method

The evaluators followed the same cultivation model that the applicant used to calculate the evaluated savings. The evaluators used metered data obtained from the loggers to determine the key inputs to update in the cultivation model to calculate the savings.

The lighting data was analyzed by categorizing each day into one of three process phases: vegetation, flower, and harvest clean. The lights "on" time hours per day and the average dimming level when on was calculated for each day using metered data. The daily operation hours and dimming levels were averaged for each room and then the rooms were averaged together for each phase. Table 2-10 below presents a summary of the logged lighting data.

Table 2-10. Summary of lighting data

Mode/ phase	N3 lights	N1 lights	N6 lights	*Average*	*Used in Calculation*
Average % lighting power					
Flower	51%	45%	57%	*51%*	***48%***
Veg	22%	21%	23%	*22%*	***22%***
Harvest clean	2%	4%	24%	*10%*	***10%***
Hr/day lights on					
Flower	11.0	12.0	12.0	*11.5*	***11.56***
Veg	17.5	20.7	18.0	*19.1*	***19.0***
Harvest clean	24.0	24.0	24.0	*24.0*	***24.0***

Duration of each phase					
Flower	1 complete cycle of 63 days	1 complete cycle of 65 days	Irregular data	*64*	**63.0**
Veg	1 complete cycle of 14 days	1 complete cycle of 10 days	Irregular data	*12*	**14.0**
Harvest	1 complete cycle of 6 days	2 complete cycles of 8 and 5 days	Irregular data	*6.3*	**7.0**

Based on the analyzed lighting data, evaluators created a 12 week operating schedule to input into the cultivation analysis model. Note that the direct average of the lighting dimming level for the 9 weeks of the flower phase was 51% compared to the 48% used in the evaluated cultivation model profile, this is to account for the dimming level changing over the flowering cycle, and there being a partial cycle that is accounted for. Since the end of the cycle has higher dimming levels compared to the start of the cycle and there being two ends of a cycle and one beginning of a cycle in the logged data, the unadjusted average is higher than the adjusted. To account for the partial cycle in the data, each week of the flower phase that was repeated in the data was averaged first and then averaged with the other weeks in the flower phase. This issue only applies to the flower cycle. Table 2-11 presents a summary of the grow cycle lighting operation used in the evaluated cultivation model for both the baseline and installed case.

Table 2-11 Evaluated lighting operating cycle

week	mode	hours/day	% power
1	veg	19	22%
2	veg	19	22%
3	flower	11	48%
4	flower	11	48%
5	flower	11	48%
6	flower	11	48%
7	flower	12	48%
8	flower	12	48%

9	flower	12	48%
10	flower	12	48%
11	flower	12	48%
12	harvest clean	24	10%
Average		13.83	36.6%

The average space temperature in the rooms during the metering period was 73°F during the lights on period and 70°F during the lights off period during the grow cycle, and the average relative humidity was 45% during the lights on period and 42% during the lights off period, during the 12-week grow cycle. This was different compared to the applicant estimate which considered the space temperature to be 79°F during both the lights on and lights off periods throughout the grow cycle and the RH to be 54% throughout the grow cycle. The evaluators adjusted the temperature and RH in the grow rooms based on the logged data and adjusted the model to represent both pre and post cases. Table 2-12 presents the grow cycle temperature and relative humidity used in the cultivation model for both baseline and installed case.

Table 2-12. Grow room temperature and RH cycle profile

week	mode	Lights-on		Lights-off	
		Temperature	RH	Temperature	RH
1	veg	73	34	70	38
2	veg	72	51	71	50
3	flower	72	53	70	49
4	flower	73	49	69	46
5	flower	74	46	71	43
6	flower	74	46	70	43
7	flower	74	46	70	41
8	flower	74	47	70	41
9	flower	74	44	69	39
10	flower	74	41	70	44
11	flower	73	46	71	45
12	harvest clean	72	31	72	31

The hours were verified from the logger data as shown in Figure 2-11 and Figure 2-12 below. The heat maps below show both the 18-hour and 12-hour operating profiles of the lights during the different stages of the grow season. The 18-hour operating profile shown in Figure 2-11 represents the veg phase and the 12-hour operating profile shown in Figure 2-12 represents the flower phase of the grow cycle. Additionally, the evaluators observed the increase in the lighting kW as the grow cycle transitioned from the veg phase to the flower phase.

Figure 2-11. 18-hour operating profile, typical for 2 weeks in vegetative phase

Date																								
1/10/2025	0.17	0.17	0.17	0.17	1.08	1.07	1.07	1.07	1.08	1.08	1.08	1.08	1.08	1.08	1.08	1.08	1.07	1.07	1.08	1.08	1.08	1.08	0.17	0.17
1/11/2025	0.17	0.17	0.17	0.17	1.07	1.06	1.06	1.05	1.06	1.06	1.06	1.06	1.06	1.06	1.06	1.05	1.05	1.05	1.05	1.05	1.06	1.05	0.17	0.17
1/12/2025	0.17	0.17	0.17	0.17	1.07	1.07	1.06	1.06	1.07	1.06	1.06	1.06	1.06	1.06	1.06	1.06	1.06	1.06	1.06	1.06	1.06	1.06	0.17	0.17
1/13/2025	0.17	0.17	0.17	0.17	1.07	1.07	1.06	1.07	1.06	1.05	1.05	1.05	1.05	1.06	1.06	1.06	1.06	1.06	1.06	1.06	1.06	1.06	0.17	0.17
1/14/2025	0.17	0.17	0.17	0.17	1.07	1.07	1.06	1.07	1.08	1.08	1.09	1.08	1.08	0.76	1.08	1.07	1.07	1.07	1.07	1.08	1.08	1.08	0.17	0.17

Figure 2-12. 12-hour operating profile, typical for 9 weeks in flowering phase

Date																									
2/14/2025	0.16	0.16	0.16	0.17	0.17	1.18	2.74	2.76	2.76	2.76	2.76	2.77	2.76	2.76	2.77	2.75	2.76	0.16	0.16	0.17	0.17	0.16	0.17	0.17
2/15/2025	0.17	0.17	0.17	0.17	0.17	1.21	2.79	2.79	1.76	1.76	2.76	2.77	2.77	2.77	2.77	1.76	1.75	0.16	0.17	0.17	0.17	0.17	0.17	0.17
2/16/2025	0.17	0.17	0.17	0.17	0.17	0.79	2.81	2.80	2.78	2.75	1.80	1.79	1.79	1.79	2.81	2.77	1.83	0.16	0.17	0.17	0.17	0.17	0.17	0.16
2/17/2025	0.16	0.17	0.17	0.16	0.17	1.18	1.81	1.83	1.85	1.85	1.84	1.85	1.85	1.79	1.88	1.88	1.87	0.16	0.16	0.17	1.19	0.57	0.17	0.17

The savings calculation algorithm used to calculate the savings is described below:

Fixture Savings:

$$kW_{Ltg-F} = (kW_{Base} - kW_{Installed}) \times Dim_F \times Qty_F$$

where,

kW_{Base} = baseline HPS fixture input power, 1.070 kW/fixture
$kW_{Installed}$ = Installed LED fixture input power, 0.792 kW/fixture
Dim_F = average dimming factor in the rooms
Qty_F = fixture quantity in the rooms

Interactive Savings (HVAC):

The interactive savings comes from the HVAC interactive effects, i.e. from the change in heating and cooling loads, which is described below:

The total latent heat load is calculated using the formula:

$$Total\ Latent\ Heat\ load \left(\frac{Btu}{h}\right) = Transpiration \left(\frac{gal}{h}\right) \times 8.345 \left(\frac{lb}{gal}\right) \times 970.4 \left(\frac{Btu}{lb}\right) \times (TF)$$

Where:
TF= Transpiration Factor, 10% when lights are off, 90% when lights are on.

The total sensible heat is calculated using the formula:

$$Total\ Sensible\ Load \left(\frac{Btu}{h}\right)$$
$$= (Lighting\ kW + Plug\ Load\ kW + Supply\ Fan\ kW) \times 3,412 \left(\frac{Btu}{kWh}\right) - Total\ Latent\ Load \left(\frac{Btu}{h}\right)$$
$$+ Standalone\ Dehumidifier\ (Btu/h)$$

$$Cooling\ system\ latent\ load = Sensible\ heat\ ratio\ (SHR) \times Total\ Sensible\ load$$

$$Standalone\ Latent\ Load = Total\ Sensible\ Load - Cooling\ system\ latent\ load$$

$HVAC\ Usage\ (kWh)$

$$= (Total\ Sensible\ Load + Cooling\ system\ latent\ load) \times Eff\ cooling\ system\ \left(\frac{kW}{Ton}\right)$$

$$+ Standalone\ dehumidifier\ load \times Eff\ standalone\ dehumidifier\ \left(\frac{kW}{Ton}\right)$$

$$HVAC\ Interactive\ Savings = HVAC\ Usage\ (Base\ case) - HVAC\ Usage\ (Post\ case)$$

Total Energy Savings:

$$Total\ Energy\ Savings = \sum_{Hour=1}^{8760} (Lighting\ Fixture\ Savings + HVAC\ interactive\ Savings)$$

3 FINAL RESULTS

The evaluated project consisted of installing 478 792 W LED lights in the grow rooms. The evaluated savings was calculated to be 266,832 kWh and is 9% lower than the tracking savings, primarily because of: the slightly reduced light dimming level observed in the post case and the lower space temperature and RH levels in the grow rooms as determined during the site visit. The parameters impacting the analysis are summarized in Table 3-1.

Table 3-1. Summary of key parameters

	BASELINE		PROPOSED / INSTALLED	
Parameter	Tracking Value(s)	Evaluation Value(s)	Tracking Value(s)	Evaluation Value(s)
Fixture wattage	1,050	1,050	792	792
Average light dimming levels during lights-on period	44%	37%	44%	37%
Average temperature of grow room during the grow cycle (Lights-on period)	79°F	79°F	73°F	73°F
Average temperature of grow room during the grow cycle (Lights-off period)	79°F	79°F	70°F	70°F
Average RH (%) of grow room during the grow cycle (Lights-on period)	54%	54%	45%	45%
Average RH (%) of grow room during the grow cycle (Lights-off period)	54%	54%	42%	42%

3.1 Explanation of differences

The evaluated savings are 9% lower than the tracking savings. The major reasons for the discrepancies are: the reduced light dimming level observed in the post case and the lower space temperature and RH levels in the grow rooms as determined during the site visit. Additionally, the ERVs were found to be not installed during the site visit since the site did not require them for their operations. 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	Operation	Light dimming (%)	-8%	The tracking value for the dimming percentage was listed to be 44%. The evaluated value was found to be 37%.
M1	Operation	HVAC interactive effects	-1%	The HVAC interactive effects were found to be lower than the tracking estimate.

3.2 Lifetime savings

The evaluator classified the measure(s) as a retrofit with the pre-existing condition as the 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 savings because the evaluated first year savings are lower than the tracking savings. Table 3-3 provides a summary of key factors that influence lifetime savings.

Table 3-3. Measure M1 – Application ID: 13815325 – Lifetime savings summary

Factor	Tracking	Application	Evaluator
Lifetime savings (kWh)	2,939,340	3,905,990	2,668,317
First-year savings (kWh)	293,934	390,599	266,832
Measure lifetime (years)	10 years	10 years	10 years
Baseline classification	Retrofit with single baseline	Retrofit with single baseline	Retrofit with single baseline

3.3   Ancillary impacts

There are no ancillary impacts.

RHODE ISLAND CUSTOM ELECTRIC SITE-SPECIFIC REPORT
SITE ID: RICE2023S088

Report Date: July 30, 2025

Program Administrator	Rhode Island Energy	
Application ID(s)	13005334, 13005336	
Project Type	C&I Retrofit	
Evaluation Type	Ops	
Program Year	PY2023	
Evaluation Firm	DNV	
Evaluation Engineer	Joshua Glick	
Senior Engineer	Sharan Suresh	

1 EVALUATED SITE SUMMARY AND RESULTS

The evaluated project involved the installation of a new variable refrigerant flow (VRF) heat pump and a new energy recovery ventilator (ERV). The project is a major renovation, with the new VRF heat pump serving three ducted indoor units and the ERV serving the bathrooms. This project was tracked as a retrofit with application documents suggesting it was a new construction project. Evaluators have classified the project as a major renovation because the existing HVAC system connected to the ERV was at the end of its useful life.

The evaluated project took place at a small training facility which includes a dormitory with sleeping quarters, a classroom, offices, bathrooms, storage, kitchen, and a few smaller spaces. The facility is occupied 24/7 from January through June every year and is then unoccupied for the remaining months, and the heating and cooling temperatures are set back (80°F for cooling and 50°F for heating) at the thermostats by the site contact, so that the units do not run often during the second half of the year.

The VRF heat pump replaced the oil heating system that was at the end of its useful life. The facility had no cooling system before the installation of this measure. The applicant classified both measures as new construction. The VRF heat pump saves energy because the Energy Efficiency Rating/Integrated Energy Efficiency Rating (EER/IEER) and Coefficient of Performance (COP) are greater than the code required minimum values.

The facility did not have any energy recovery prior to this project. The ERV serves the bathrooms and operates at 206 CFM. The measure saves energy by reducing the heating and cooling load of the space by preheating and precooling the supply air. The bathrooms are served by the installed VRF heat pump. An ERV is not required in the space under exception C403.2.7-2 of the IECC 2015/ASHRAE 90.1 2013 due to the ERV's operating hours and CFM.

After reviewing the tracking files and information gathered during the site visit, the evaluator classified this measure as a lost opportunity with a single baseline. Using evaluation data collected between February 13, 2025, and July 1, 2025, evaluated project savings were calculated using an 8,760-hour spreadsheet analysis for the VRF heat pump measure and a temperature bin analysis for the ERV measure. The evaluation results are presented in Table 1-1.

Table 1-1. Evaluation results summary

PA application ID	Measure name		Annual electric energy (kWh)	% of energy savings on-peak	Summer on-peak demand (kW)	Winter on-peak demand (kW)
13005336	Variable refrigerant flow (VRF) heat pump	Tracked	8,606	0.0%	3.45	0.42
		Evaluated	3,128	45%	0.11	0.55
		Realization rate	36%	N/A	3%	131%
13005334	Energy recovery ventilator (ERV)	Tracked	853	0.0%	0.03	0.00
		Evaluated	1,226	59%	0.20	1.70
		Realization rate	144%	N/A	679%	N/A
	Total	**Tracked**	**9,459**	**0.0%**	**3.48**	**0.42**
		Evaluated	**4,355**	**65%**	**0.31**	**2.25**
		Realization rate	**46%**	**N/A**	**9%**	**536%**

1.1 Explanation of deviations from tracking

The evaluated savings are less than the tracked savings primarily because the actual heating and cooling loads of the VRF heat pump are smaller than the applicant-estimated loads. Further details regarding deviations from the tracked savings are presented in Section 3.1.

1.2 Recommendations for program designers and implementers

The evaluator recommends that the implementer should verify the rated heating and cooling capacities of the installed equipment and ensure that accurate equipment capacity values are utilized or adjusted in the savings estimation tool.

The evaluator recommends that the implementer should verify operating hours with the site contact and the operating conditions during unoccupied hours.

1.3 Customer alerts

There are no relevant customer alerts.

2   EVALUATED MEASURES

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

The evaluated measures for this site are summarized in Table 2-1.

Table 2-1. Evaluated measure(s)

Measure	Project ID	Measure description
M1	13005336	Installation of a new variable refrigerant flow (VRF) heat pump serving three ducted indoor units
M2	13005334	Installation of an energy recovery ventilator (ERV) serving the bathrooms which are served by the new VRF heat pump to reduce the heating and cooling load of the space by preheating and precooling the supply air.

2.1   Application information and applicant savings methodology

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

2.1.1   Applicant description of baseline

According to the project files, the applicant classified both measures as new construction with applicable codes as baseline despite tracking information listing the measures as retrofit.

For 13005336 VRF heat pump measure, the applicant baseline is a code compliant electric heat pump system. According to the IECC 2015/ASHRAE 90.1 2013 selected by the applicant to be the baseline, the baseline system performance is rated at a full load Energy Efficiency Rating (EER) of 10.4, Integrated Energy Efficiency Rating (IEER/SEER) of 13.7, and heating Coefficient of Performance (COP) of 3.2 at 47°F and 2.1 at 17°F.

For 13005334 ERV measure, the applicant baseline is the underlying new VRF HVAC system with no energy recovery as the space is not required to have an ERV based on IECC 2015/ASHRAE 90.1 2013 exception C403.2.7-2. The bathrooms are served by the new VRF heat pump and the calculations use the heat pump efficiencies.

Table 2-2 shows the key baseline parameters in the model.

Table 2-2. Applicant baseline key parameters

Measure	Parameter	Value	Source of parameter value
M1	VRF cooling capacity (MBH)	206	Applicant calculator
	VRF heating capacity (MBH)	196	
	Full load EER	10.4	IECC 2015/ASHRAE 90.1 2013 code compliance
	IEER/SEER	13.7	
	COP at 47°F	3.2	
	COP at 17°F	2.1	
	Occupied hours	3,905	Applicant calculator
	Cooling equivalent full load hours (EFLH)	942	
	Heating EFLH	1,334	
M2	Airflow CFM	206	
	Full load EER	12.7	
	IEER/SEER	24.8	

Measure	Parameter	Value	Source of parameter value
	Average COP	2.89	
	ERV effectiveness	0%	IECC 2015/ASHRAE 90.1 2013 code compliance

2.1.2 Applicant description of installed equipment and operation

This project included the installation of the VRF heat pump to replace the old oil heating system that was at the end of its life, which is more efficient than required by code, and the installation of an ERV to serve the bathrooms, which is also not required by code.

Table 2-3 presents the main parameters of the proposed case as defined by the applicant.

Table 2-3. Applicant's proposed key parameters

Measure	Parameter	Value	Source of parameter value
M1	VRF cooling capacity (MBH)	206	Applicant calculator
	VRF heating capacity (MBH)	196	
	Full load EER	12.3	
	IEER/SEER	21	
	COP at 47°F	4.0	
	COP at 17°F	2.39	
	Occupied hours	3,905	
	Cooling equivalent full load hours (EFLH)	942	
	Heating EFLH	1,334	
M2	Airflow CFM	206	
	Full load EER	12.3	
	IEER/SEER	21	
	Average COP	3.2	
	ERV winter sensible effectiveness	80%	
	ERV summer total effectiveness	71%	

2.1.3 Applicant energy savings algorithm

The applicant used the Mass Save/NH Saves Small Buildings Tool to calculate savings for both measures. The Small Buildings Tool is intended to estimate energy savings and incentives for small buildings (< 100,000 sq. ft.) and is designed only to be used for New Construction/Major Renovation studies where baselines are defined by local energy codes and state-specific modifications for industry standard practice. The tool used a bin analysis with each bin spanning 5°F and pulls in the baseline efficiencies listed in Table 2-2 automatically based on the code requirements.

For the VRF measure, the tool calculated electric energy savings as the difference between baseline and proposed cooling and heating demand (kW) across each set of temperature bin hours. Load percentages for heating and cooling were estimated for each temperature bin using correlations between outdoor air temperatures and the corresponding load profiles as shown in Table 2-4 and Table 2-5. Separate load percentages were determined for occupied and unoccupied hours. These percentages were then multiplied by the VRF system's cooling and heating capacities to estimate the thermal load (Btu) at each temperature bin.

Table 2-4. Cooling load profile

Occupied Cooling Profile				Unoccupied Cooling Profile			
Max OAT °F	Min OAT °F	% load @ max OAT	% load @ min OAT	Max OAT °F	Min OAT °F	% load @ max OAT	% load @ min OAT
95	50	100%	10%	95	70	40%	5%

Table 2-5. Heating load profile

Occupied Heating Profile				Unoccupied Heating Profile			
Max OAT °F	Min OAT °F	% load @ max OAT	% load @ min OAT	Max OAT °F	Min OAT °F	% load @ max OAT	% load @ min OAT
60	0	10%	100%	60	0	0%	50%

Similarly, the tool used outdoor air temperature and equipment load percentages to estimate part-load heating and cooling efficiencies (COP and EER) for each temperature bin under both baseline and proposed scenarios. COP values for each bin were extrapolated based on rated or code-specified COPs at 47°F and 17°F. The tool also applied the following part-load efficiency coefficients to estimate cooling efficiencies (EER) at part-load conditions.

Table 2-6. Part load efficiency factors

	100% load	75% load	50% load	25% load
PL EER Factors	Rated/code EER	0.96875 * Rated/code IEER	1.049826389* Rated/code IEER	1.094184* Rated/code IEER

The overall electric energy savings follow the calculations below for each bin and then multiplied by the number of hours in each bin.

$$Cooling\ kWh\ savings = \sum \frac{cooling\ load}{baseline\ EER} - \frac{cooling\ load}{proposed\ EER}$$

$$Heating\ kWh\ savings = \sum \frac{heating\ load}{baseline\ COP} - \frac{heating\ load}{proposed\ COP}$$

$$Total\ kWh\ savings = Cooling\ kWh\ Savings + Heating\ kWh\ Savings$$

The applicant calculations resulted in annual cooling savings of 6,173 kWh and annual heating savings of 2,433 kWh, resulting in a total savings of 8,606 kWh for the VRF heat pump measure.

For the ERV measure, the tool used a bin analysis to estimate the reduction in heating and cooling loads at each outdoor air temperature bin resulting from the ERV installation. It applied the ERV's rated sensible effectiveness for winter and rated total effectiveness for summer to calculate the proposed supply air temperatures (SAT) and supply air humidities (SAH) at each bin. The differences between baseline and proposed DAT and DAH values were then used to estimate heating and cooling load reductions for each bin. These load reductions were divided by the respective heating and cooling efficiencies (COP and EER) to calculate electric energy savings at each bin. The overall electric energy savings for the ERV measure follow the calculations below:

$$ERU\ kWh\ Savings = \sum Cooling\ kWh\ Savings + Heating\ kWh\ Savings - Fan\ kWh\ consumpt$$

$$Cooling\ kWh\ Savings = \frac{Cooling\ Load\ Reduction}{EER}$$

$$Cooling\ Load\ Reduction = Cooling\ \%\ Load \times 4.45 \times CFM \times \frac{(Base\ SAH - Proposed\ SAH)}{1000}$$

$$Heating\ kWh\ Savings = \frac{Heat\ Load\ Reduction/Proposed\ COP}{3.412}$$

$$Heating\ Load\ Reduction = Heating\ \%\ Load \times 1.08 \times CFM \times \frac{Proposed\ SAT - Base\ SAT}{1000}$$

$$SAH = OA\ enthalpy - ERU\ effectiveness \times (OA\ enthalpy - return\ air\ enthalpy)$$

$$SAT = OA\ temperature - ERU\ effectiveness \times (OA\ temperature - return\ air\ temperature)$$

$$Fan\ Reductions = CFM \times (Recovery\ Static\ Pressure \times \frac{0.746}{4,131/Avg\ Motor\ Efficiency}$$

Where,

$$Recovery\ Static\ Pressure = 1.6\ wc$$
$$Avg\ Motor\ Efficiency = 92\%$$

2.1.4 Evaluation assessment of applicant methodology

The evaluator determined the applicant's use of the Small Building Tool to estimate energy savings to be appropriate for both measures. However, the applicant's savings were overestimated due to an error in equipment capacity values input to the tool. To estimate evaluated impacts, the evaluator expanded on the VRF heat pump analysis with an 8,760 approach with updated inputs and metered data and similarly refined the ERV bin analysis with revised inputs and metered information.

2.2 On-site inspection and metering

This section provides details on the tasks performed during the on-site inspection, the date it was conducted, and how it was conducted.

2.2.1 Summary of site visit findings

The evaluator performed an on-site verification with meter deployment to collect data from the evaluated measures. The evaluator conducted the site visit on February 13, 2025, and retrieved the loggers on June 30, 2025, with assistance from the site contact.

The evaluator found that the site is fully occupied from January through June and then is left unoccupied for the remainder of the year, with the HVAC setpoints set so that the units run minimally during the unoccupied months. The evaluator was on site and witnessed the site contact adjusting the heating setpoint to 50°F and the cooling setpoint to 80°F for the unoccupied months on the year. This resulted in the facility evaluated occupancy hours to be 4,344 instead of the applicant-reported value of 3,905 hours.

The evaluator found that the installed VRF heat pump had lower heating and cooling capacities than the application listed based on the VRF heat pump specification sheets. The VRF heat pump heating capacity was listed in the tracking documentation as 196 MBH but found to be 108 MBH and the cooling capacity was listed as 206 MBH but found to be 96 MBH.

The applicant-reported ERV effectiveness was 80% for the winter and 71% for the summer, but the evaluator found that the ERV rated effectiveness is 68% for the winter and 59.6% for the summer based on the ERV specification sheets.

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

Table 2-7 Data collection findings

Measure name	Verification method	Verification result
M1 – VRF heat pump	On-site inspection and customer interview	The evaluator verified the installation of the VRF as well as the typical occupancy status throughout the year. The facility is fully occupied 24/7 from January through June and then is unoccupied for the remaining months. During the unoccupied months, the heating setpoint is set at 50°F and the cooling setpoint is set to 80°F.
M2 – VRF heat pump	Deploy meters	The evaluator deployed kW metering equipment on the heat pump with backup amperage meters. The evaluator also deployed temperature/relative humidity sensors throughout the space to verify occupancy and cooling/heating trends. Please see Section 2.2.2 for more details.
M2 – ERV	On-site inspection and customer interview	The evaluator verified the installation of the ERV.
M2 – ERV	Deploy meters	The evaluator deployed kW metering on the ERV with backup amp meters. The evaluator also deployed temperature/relative humidity sensors in each chamber of the ERV. Please see section 2.2.2 for more details.

Figure 2-1 displays the installed VRF heat pump, and Figure 2-2 displays the heat pump nameplate information.

Figure 2-1. Installed VRF heat pump

Figure 2-2. VRF heat pump nameplate

Figure 2-3 shows the ERV located on the facility roof above the bathrooms it serves, and Figure 2-4 shows the interior of the unit, including the four temperature sensors deployed.

Figure 2-3. Installed ERV

Figure 2-4. ERV interior

2.2.2   Metered and logged data

Table 2-8 shows the detail of the evaluator-installed logger information.

Table 2-8. Installed loggers with metered variables

Data Logger Type	Description	Time Interval	Duration	Quantity
DENT kW meter	Metering the VRF heat pump	5-min	2/13/2025 – 6/30/2025	1
HOBO amperage meter	Backup metering on the VRF heat pump	1-min	2/13/2025 – 6/30/2025	1
DENT kW meter	Metering the ERV	5-min	2/13/2025 – 5/10/2025	1
HOBO amperage meter	Backup metering on the ERV	1-min	2/13/2025 – 6/30/2025	1
Temperature/relative humidity meters	Temp/RH sensors installed in each of the 4 sections of the ERV	5-min	2/13/2025 – 6/30/2025	4
Temperature/RH meters	Temp/RH sensors installed throughout the facility interior	5-min	2/13/2025 – 6/30/2025	4

The evaluator also used local actual meteorological year (AMY) weather data from the Rhode Island ASOS Providence station during this period to identify correlations for each dataset with outside air conditions. Figure 2-5 shows the metered VRF kW for heating operation compared to the OAT, and Figure 2-6 shows the VRF kW for cooling operations compared

with the OAT. The OAT during the metering period did not allow for a large cooling sample. However, this was insignificant in the evaluation analysis because the facility remains non-operational during major parts of the summer months.

Figure 2-5. VRF heating kW compared with OAT

$y = -0.1022x + 7.1913$
$R^2 = 0.7259$
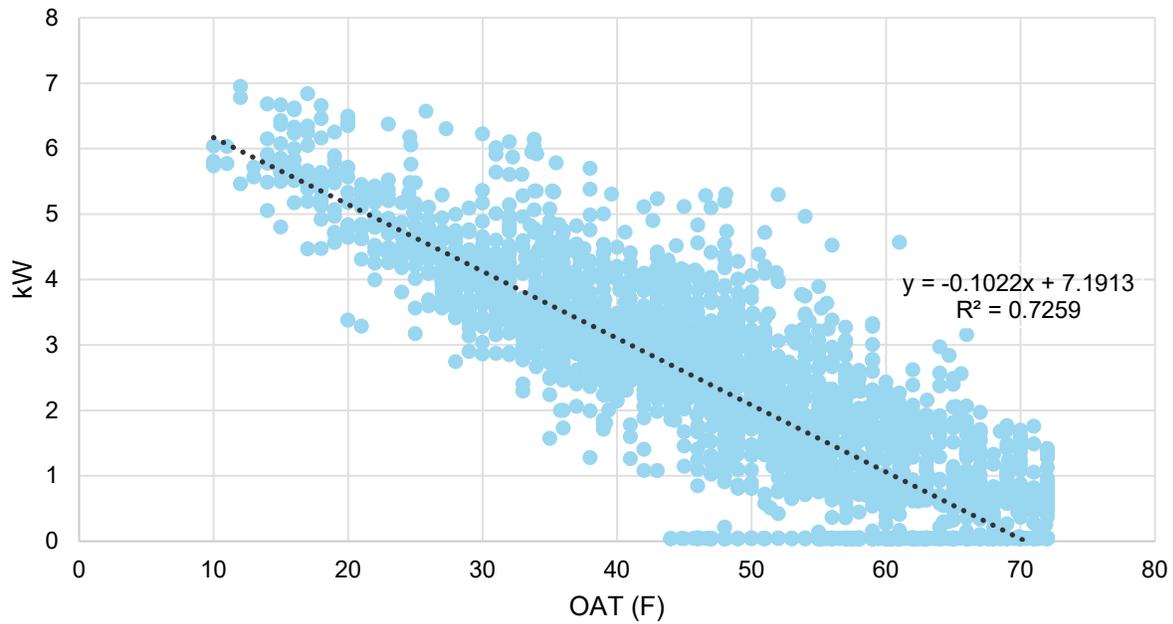
Figure 2-6. VRF cooling kW compared with OAT

$y = 0.0543x - 3.5331$
$R^2 = 0.1741$
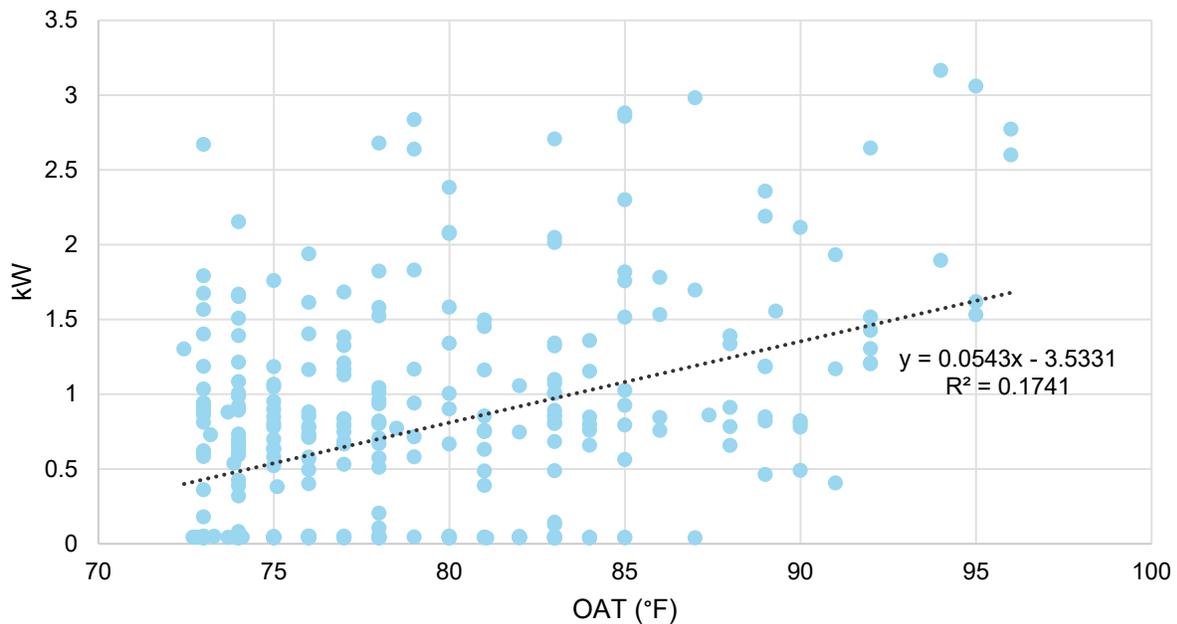
Figure 2-7, Figure 2-8, Figure 2-9, and Figure 2-10 show the ERV inlet, supply, return, and exhaust temperatures compared with the outdoor air temperatures.

Figure 2-7. ERV inlet temperature compared with OAT

$$y = 0.4463x + 34.902$$
$$R^2 = 0.3483$$
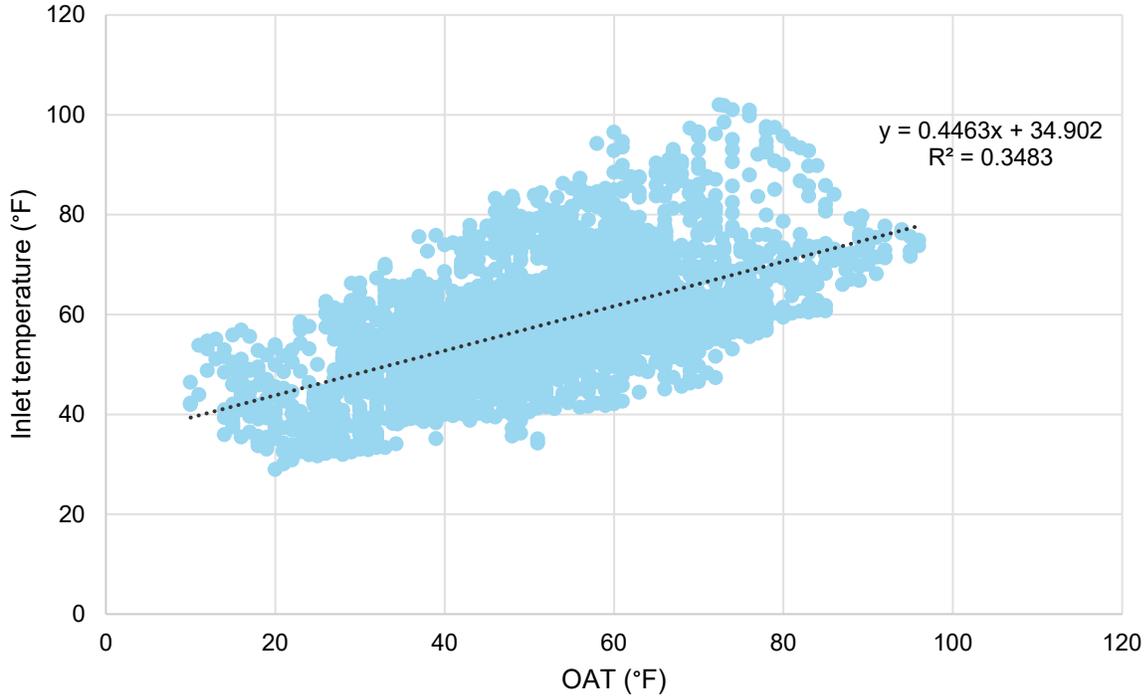
Figure 2-8. ERV supply temperature compared with OAT

$$y = 0.1168x + 60.821$$
$$R^2 = 0.261$$
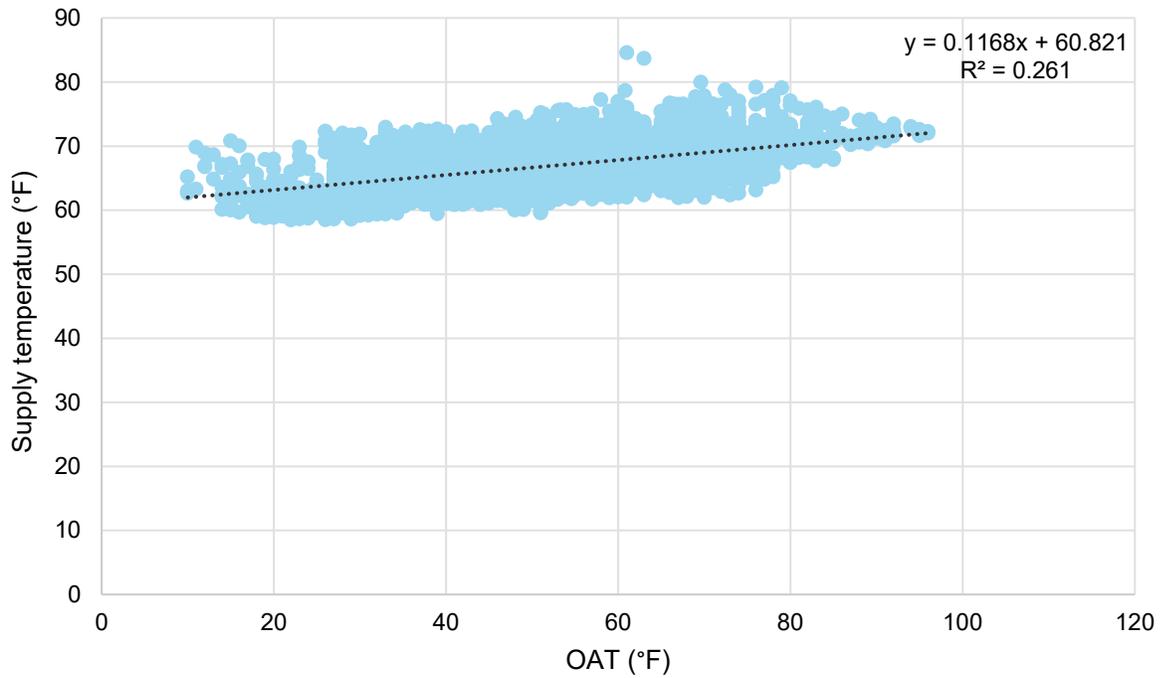
Figure 2-9. ERV return temperature compared with OAT

$$y = 0.078x + 63.643$$
$$R^2 = 0.1289$$
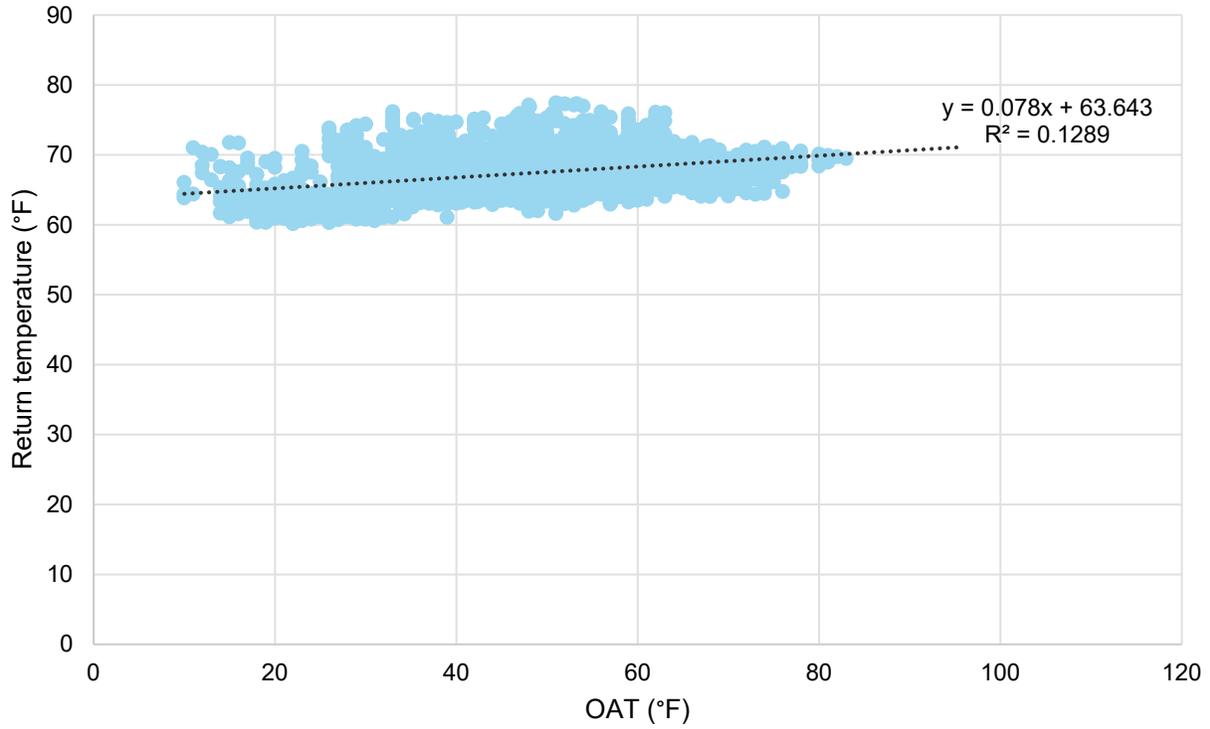
Figure 2-10. ERV exhaust temperature compared with OAT

$$y = 0.138x + 59.114$$
$$R^2 = 0.1884$$
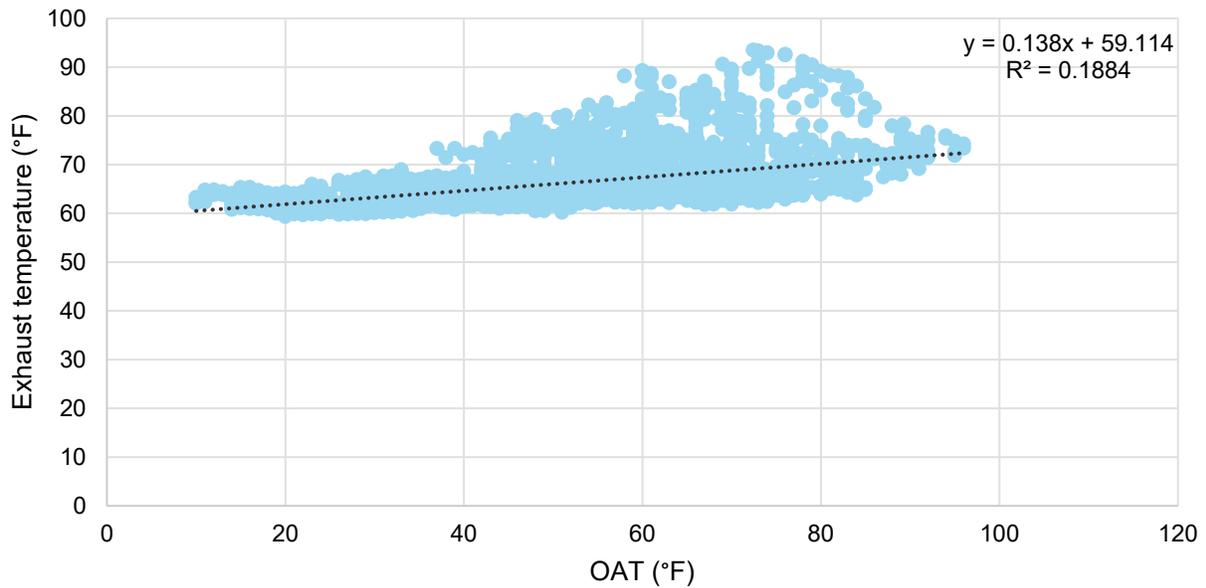
Figure 2-11 displays the bathroom space temperature compared with the outdoor air temperature.

Figure 2-11. Bathroom temperature compared with OAT
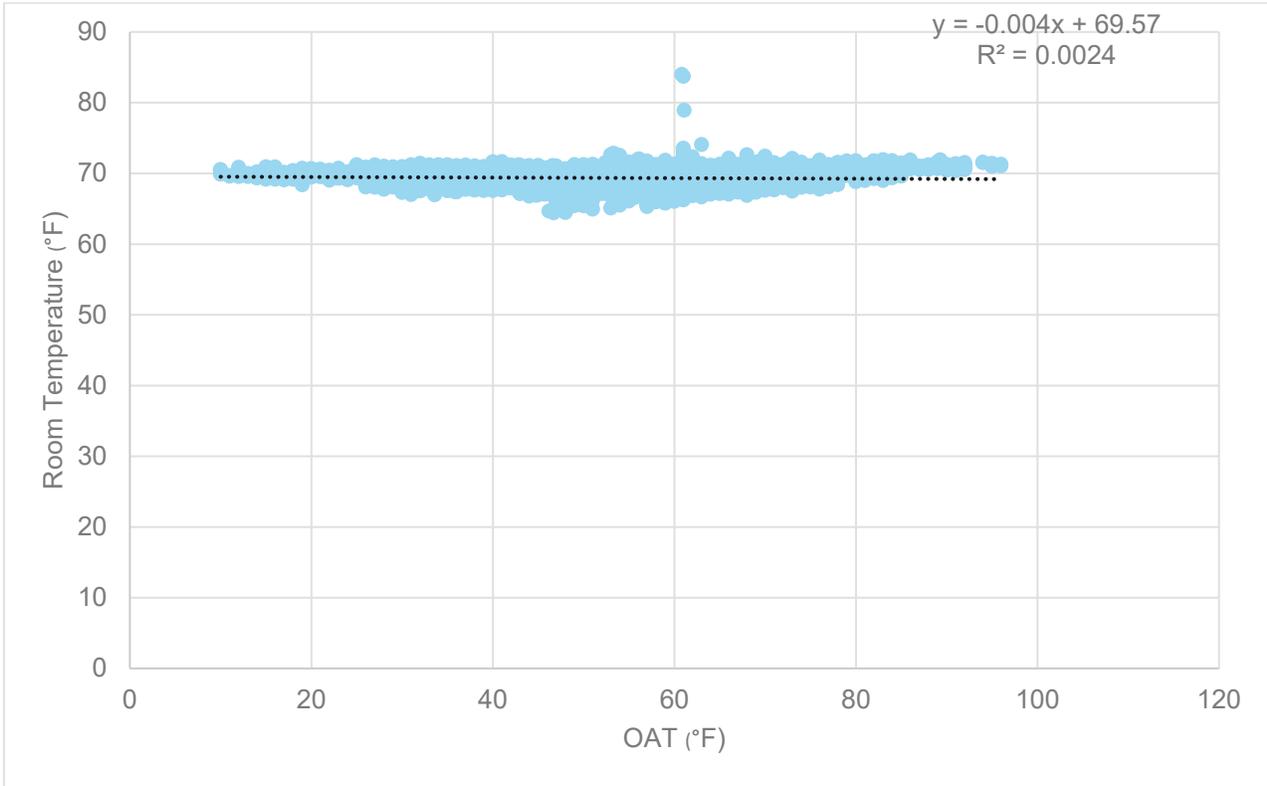
2.3 Evaluation methods and findings

This section describes the evaluator methods and findings.

2.3.1 Evaluation description of baseline

The evaluator reviewed the project files, interviewed the site contact, and reviewed the applicable codes to gather information on the baseline. Based on that information, the evaluator determined both measures are lost opportunity measures with a single baseline. The measure baseline for the VRF measure is a code compliant electric heat pump system with efficiencies of a full load EER of 10.4, IEER/SEER of 13.7, and heating COP of 3.2 at 47°F and 2.1 at 17°F.

ERVs are not required by code so the ERV measure baseline is the underlying installed VRF heat pump with no energy recovery.

Table 2-9 presents the main parameters of the baseline case as defined by the evaluator.

Table 2-9. Evaluator baseline inputs

Measure	Parameter	Operation description	Source of parameter value
M1	VRF cooling capacity (MBH)	96	VRF specifications
	VRF heating capacity (MBH)	108	
	Full load EER	10.4	IECC 2015/ASHRAE 90.1 2013 code compliance
	IEER/SEER	13.7	

Measure	Parameter	Operation description	Source of parameter value
	COP at 47°F	3.2	
	COP at 17°F	2.1	
M1+M2	Occupied heating run hours	4,010	Site contact interview + TMY3 data
	Occupied cooling run hours	334	
	Total VRF occupied run hours	4,344	
	Unoccupied heating run hours	1,046	
	Unoccupied cooling run hours	18	
	Total VRF unoccupied run hours	1,064	
	Total heating run hours	5,056	
	Total cooling run hours	352	
M2	Airflow CFM	206	New VRF heat pump specifications
	Full load EER	12.3	
	IEER/SEER	21	
	Average COP	3.2	
	ERV winter sensible effectiveness	0%	IECC 2015/ASHRAE 90.1 2013 code compliance
	ERV summer total effectiveness	0%	

2.3.2   Evaluation calculation method

13005336 VRF heat pump:

The evaluator calculated the VRF heat pump savings using an 8760 analysis. The evaluator used metered data for VRF unit power draw (kW) to develop regression equations for heating and cooling consumptions compared to OAT, as shown in Figure 2-5 and Figure 2-6 respectively. These regression equations were then utilized with TMY3 weather data to estimate the VRF heat pump consumption for all occupied hours that the equipment will be in operation. For the unoccupied hours, since the cooling space temperature set point was 80°F, the evaluator assumed that cooling would turn ON only when the OAT was above 90°F. To estimate cooling consumption during the unoccupied hours, evaluator reviewed cooling kW during occupied hours and compared it to the temperature differential between the space temperature set point and OAT as shown in Figure 2-12 below. Figure 2-13 is a simplified version of the temperature differential between the space temperature set point and OAT and average cooling kW during occupied hours that evaluators used to develop regression equations for unoccupied hours cooling operation.

Figure 2-12. Delta T (OAT – Space Temperature) vs. VRF Cooling kW during occupied hours
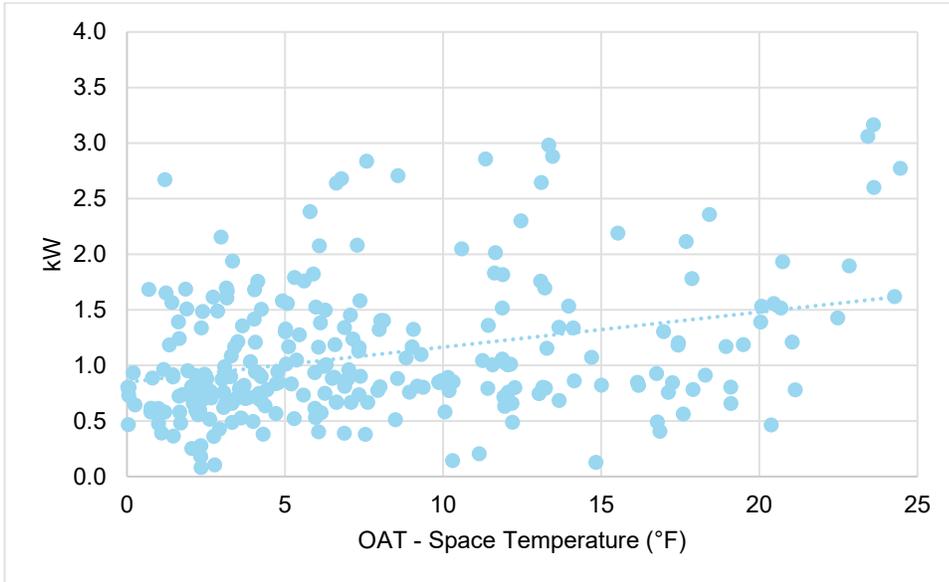
Figure 2-13. Delta T (OAT – Space Temperature) vs. VRF Cooling average kW during occupied hours
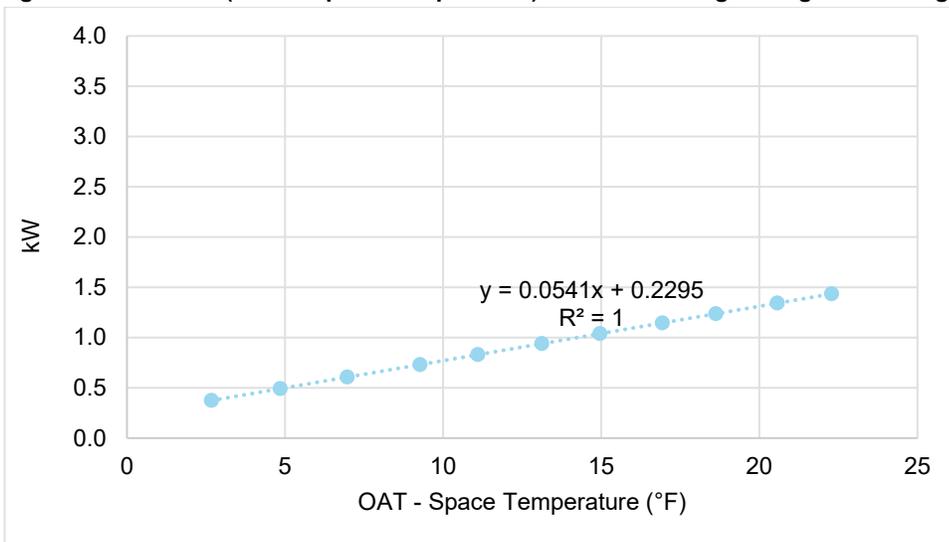
For heating during unoccupied hours, since the heating space temperature set point was 50°F, the evaluator assumed that heating would turn ON only when the OAT was below 40°F. To estimate heating consumption during the unoccupied hours, evaluator reviewed heating kW during occupied hours and compared it to the temperature differential between the space temperature set point and OAT as shown in Figure 2-14 below. Figure 2-15 is a simplified version of the temperature differential between the space temperature set point and OAT and average heating kW during occupied hours that evaluators used to develop regression equations for unoccupied hours heating operation.

Figure 2-14. Delta T (OAT – Space Temperature) vs. VRF Heating kW during occupied hours
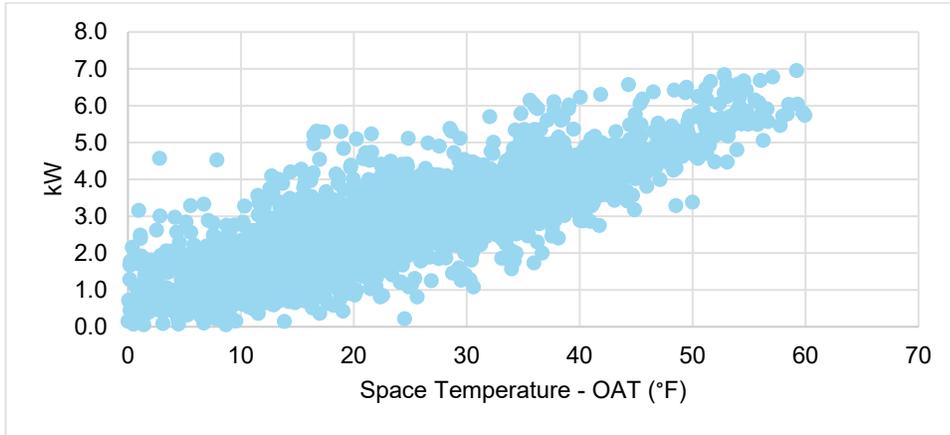
Figure 2-15. Delta T (OAT – Space Temperature) vs. VRF Heating average kW during occupied hours
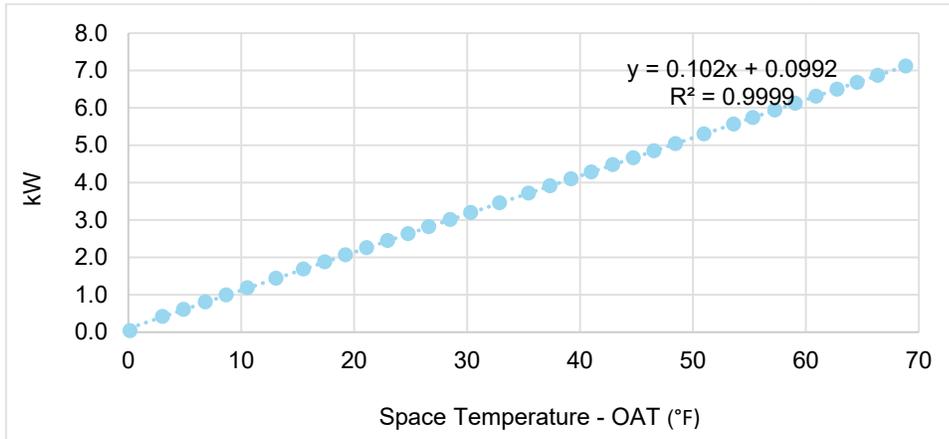
The evaluator then used the estimated kW to determine hourly cooling part load efficiencies using Table 2-10 and Table 2-11 and heating part load efficiency using Table 2-12. After identifying the cooling and heating loads, the evaluator used the baseline part load efficiencies to calculate the baseline heating and cooling consumptions (kW) for each hour. The annual energy savings were estimated as the difference between baseline VRF heat pump consumption (kWh) and the as-built VRF heat pump consumptions (kW).

The evaluator calculated the annual energy savings from the VRF measure using the following equations.

$$Cooling\ kWh\ savings = \sum \frac{cooling\ load}{baseline\ EER} - Proposed\ cooling\ kW$$

Table 2-10. Cooling load profile

Cooling Profile			
Max OAT °F	Min OAT °F	% load @ max OAT	% load @ min OAT
95	70	100%	10%

Table 2-11. Cooling part load efficiency factors per manufacturer specifications

	100% load	75% load	50% load	25% load
PL EER Factors	Rated/code EER	0.96875 * Rated/code IEER	1.049826389* Rated/code IEER	1.094184* Rated/code IEER

Table 2-12. Heating COP compared to OAT per manufacturer specifications

Heating Performance		
	OAT	
	47°F	17°F
Baseline	3.2	2.05
As-built	4.00	2.39

$$Heating\ kWh\ savings = \sum \frac{heating\ load}{baseline\ COP} - Proposed\ heating\ kW$$

$$Total\ kWh\ savings = Cooling\ kWh\ Savings + Heating\ kWh\ Savings$$

13005334 ERV:

The evaluator modified the applicant bin analyses calculations using TMY3 data to form new temperature bins, and the site verified operating hours to sort the facility operating hours into the appropriate temperature bins. In addition to updating the outdoor air temperatures, the evaluator also updated the room air temperatures within the applicant analysis based on a correlation of the metered bathroom air temperatures as a function of OAT as seen in Figure 2-11.

The evaluator also updated the rated ERV effectiveness based on the ERV specifications sheet. The evaluator attempted to use the four metered ERV temperatures to calculate the ERV effectiveness, but the calculated values were unreasonably high to use in the evaluation analysis, compared to rated effectiveness of the unit. The evaluator believes that the metered supply air temperature readings are inaccurate either because (a) the sensor could have been picking up heat from the fan motor, (b) the positioning of the sensor might have been inappropriate causing it to pick turbulent air flow, or (c) the sensor could be picking up some post conditioned air from the space resulting in unreliable temperatures to be used in the evaluation. Instead, the evaluator used the rated effectiveness of 68% in the winter and 59.6% in the summer based on ERV specification sheets.

The evaluator elected to use the bathroom space temperature metered by the temperature loggers in the analysis instead of the return air temperature because the return air temperature should be equal or close to the space temperature. The metered return air temperature most likely picked up additional heat in the ERV and the evaluator deemed it unreasonable.

Below is the methodology that the evaluator used:

$$ERV\ KWh\ Savings = \sum Cooling\ kWh\ Savings + Heating\ kWh\ Savings - Fan\ Consumpton$$

$$Cooling\ kWh\ Savings = \frac{Cooling\ Load\ Reduction}{EER}$$

$$Cooling\ Load\ Reduction = Cooling\ \%\ Load \times 4.45 \times CFM \times \frac{(Base\ Supply\ air\ humidity - Proposed\ Supply\ air\ humidity)}{1000}$$

$$Heating\ kWh\ Savings = \frac{Heat\ Load\ Reduction/Proposed\ COP}{3.412}$$

$$Heating\ Load\ Reduction$$
$$= Heating\ \%\ Load \times 1.08 \times CFM$$
$$\times \frac{Proposed\ Supply\ air\ temperature - Base\ Proposed\ Supply\ air\ temperature}{1000}$$

$$Supply\ air\ humidity = OA\ enthalpy - ERV\ effectiveness \times (OA\ enthalpy - return\ air\ enthalpy)$$

$$Supply\ air\ temperature = OA\ temperature - ERV\ effectiveness \times (OA\ temperature - return\ air\ temperature)$$

$$Fan\ Consumption = CFM \times (Recovery\ Static\ Pressure \times \frac{0.746}{4131/Avg\ Motor\ Efficiency}$$

Where,

$$Recovery\ Static\ Pressure = 1.6\ wc$$
$$Avg\ Motor\ Efficiency = 92\%$$

Table 2-13 presents the applicant and the evaluated inputs for both measures.

Table 2-13. Evaluator and applicant savings inputs

Measure	Parameter	Applicant value	Evaluator value	Justification for change
M1	VRF cooling capacity (MBH)	206	96	Rated capacity for installed heat pump
	VRF heating capacity (MBH)	196	108	
	As-built Full load EER	12.7	12.3	N/A
	As-built IEER/SEER	24.8	21	
	As-built Heating COP at 47°F	3.7	4.0	
	As-built Heating COP at 17°F	2.1	2.39	
M1+M2	Occupied heating run hours	2,220	4,010	The facility is occupied 24/7 from January through June. The heating setpoint is 50°F and the cooling setpoint is 80°F during July through December.
	Occupied cooling run hours	1,685	334	
	Total VRF occupied run hours	3,905	4,344	
	Unoccupied heating run hours	3,374	1,046	
	Unoccupied cooling run hours	1,481	18	
	Total VRF unoccupied run hours	4,855	1,064	
	Total heating run hours	5,594	5,056	
	Total cooling run hours	3,166	352	
	Average occupied heating load (MBH)	65.37	33.48	

Measure	Parameter	Applicant value	Evaluator value	Justification for change
	Average occupied cooling load (MBH)	78.84	14.78	
	Average unoccupied heating load (MBH)	34.50	21.00	
	Average unoccupied cooling load (MBH)	5.25	17.25	
M2	Airflow CFM	206	206	N/A
	Full load EER	12.7	12.3	
	IEER/SEER	24.8	21	
	Average heating COP	2.89	3.2	
	ERV winter sensible effectiveness	80%	68%	Rated ERV effectiveness for the installed ERV
	ERV summer total effectiveness	71%	59.6%	

3 FINAL RESULTS

The evaluated project involved installing a new variable refrigerant flow (VRF) heat pump to replace the old oil heating system that was at the end of its useful life and the installation of an energy recovery ventilator (ERV). The evaluated savings are less than the tracking savings, primarily due to a decrease in the VRF heating and cooling loads, a decrease in ERV effectiveness based on the ERV specification sheet, and a decrease in cooling hours despite an increase in heating hours. The parameters impacting the analysis are summarized in Table 3-1.

Table 3-1. Summary of key parameters

Parameter	BASELINE		PROPOSED / INSTALLED	
	Tracking Value(s)	Evaluation Value(s)	Tracking Value(s)	Evaluation Value(s)
VRF cooling capacity (MBH)	206	96	206	96
VRF heating capacity (MBH)	196	108	196	108
Full load EER	10.4	10.4	12.7	12.3
IEER/SEER	13.7	13.7	24.8	21
COP at 47°F	3.2	3.2	3.7	4.0
COP at 17°F	2.1	2.1	2.1	2.39
Occupied heating run hours	2,220	4,010	2,220	4,010
Occupied cooling run hours	1,685	334	1,685	334
Total VRF occupied run hours	3,905	4,344	3,905	4,344
Unoccupied heating run hours	3,374	1,046	3,374	1,046
Unoccupied cooling run hours	1,481	18	1,481	18
Total VRF unoccupied run hours	4,855	1,064	4,855	1,064
Total heating run hours	5,594	5,056	5,594	5,056
Total cooling run hours	3,166	352	3,166	352
Average occupied heating load (MBH)	65.37	33.48	65.37	33.48
Average occupied cooling load (MBH)	78.84	14.78	78.84	14.78
Average unoccupied heating load (MBH)	34.50	21.00	34.50	21.00
Average unoccupied cooling load (MBH)	5.25	17.25	5.25	17.25
Airflow CFM	206	206	206	206
Full load EER	12.7	12.7	12.7	12.3
IEER/SEER	24.8	24.8	24.8	21
Average COP	2.89	3.2	2.89	3.2
ERV winter sensible effectiveness	0%	0%	80%	68%
ERV summer total effectiveness	0%	0%	71%	59.6%

3.1 Explanation of differences

The evaluated savings are 54% lower than the tracking savings predominantly because of the decrease in the VRF heat pump cooling and heating loads. The applicant calculator tool uses the heating and cooling capacities to estimate heating and cooling loads. This methodology resulted in the applicant overestimating the heating and cooling loads. The ERV rated effectiveness is also lower than the applicant reported effectiveness causing a small decrease in savings. The evaluated savings also reflect a slight increase in savings from increased heating hours but a decrease due to fewer cooling hours. The project also has tracking errors as both measures have the savings percent on peak reported as 0% despite the

applicant calculator calculating 59% savings percent on peak. Table 3-2 summarizes the differences between tracking and evaluated values.

Table 3-2. Summary of deviations

Measure	Discrepancy	Parameter	Impact of deviation	Discussion of deviations
M1	Load	VRF heating and cooling loads	-47%	**Decreased savings** –The applicant reported VRF heating and cooling loads were higher than the evaluated loads.
M2	Efficiency	ERV effectiveness	-6%	**Decreased savings** –The applicant reported ERV effectiveness was 80% for the winter and 71% for the summer but the ERV rated effectiveness is 68% for the winter and 59.6% for the summer.
M1+M2	Hours of operation	Cooling operating hours	-2%	**Decreased savings** –The applicant listed 2,796 cooling hours but the evaluator calculated that the site's cooling hours were 286.
M1+M2	Hours of operation	Heating operating hours	+1%	**Increased savings** –The applicant listed 4,968 heating hours but the evaluator calculated that the site's heating hours were 5,122.
Total			-54%	**Project RR = 46%**

3.2 Lifetime savings

The evaluator classified the measures as lost opportunities with single baselines. The evaluator calculated applicant and evaluated lifetime savings values using the following formula:

$$LAGI = FYS \times EUL$$

where:

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

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, Table 3-4, and Table 3-5 provide a summary of key factors that influence the lifetime savings.

Table 3-3. Measure M1 – Application ID: 13005336 – Lifetime savings summary

Factor	Tracking	Application	Evaluator
Lifetime savings (kWh)	120,484	129,090	46,927
First-year savings (kWh)	8,606	8,606	3,128
Measure lifetime (years)	14	15	15
Baseline classification	Retrofit	New Construction	Lost opportunity

Table 3-4. Measure M2 – Application ID: 13005334 – Lifetime savings summary

Factor	Tracking	Application	Evaluator
Lifetime savings (kWh)	11,942	12,795	18,396

Factor	Tracking	Application	Evaluator
First-year savings (kWh)	853	853	1,226
Measure lifetime (years)	14	15	15
Baseline classification	Retrofit	New Construction	Lost opportunity

Table 3-5. Project level – Lifetime savings summary

Factor	Tracking	Application	Evaluator
Lifetime savings (kWh)	132,426	141,885	65,323
First-year savings (kWh)	9,459	9,459	4,355
Measure lifetime (years)	14	15	15
Baseline classification	Retrofit	New Construction	Lost opportunity

3.3   Ancillary impacts

There are no ancillary impacts from installing the evaluated measures.

RHODE ISLAND CUSTOM ELECTRIC SITE-SPECIFIC REPORT
SITE ID: RICE23N080

Report Date: June 11, 2025

Program Administrator	Rhode Island Energy	
Application ID(s)	13992198	
Project Type	C&I Existing Building Retrofit	
Evaluation Type	Full M&V	
Program Year	PY2023	
Evaluation Firm	DNV	
Evaluation Engineer	Indukumar Packirisamy	
Senior Engineer	Nathan Throop	

1 EVALUATED SITE SUMMARY AND RESULTS

The evaluated project consisted of replacing nine existing transformers of various kVA ratings with nine new energy-efficient transformers of similar kVA ratings. The project was implemented at a small manufacturing facility that produces high-performance, custom-molded polyurethane components. The installed transformers operate 24 hours a day for seven days a week, regardless of load.

The installed transformers have lower no-load losses than the baseline transformers, resulting in energy savings. No-load losses happen whenever the transformer is powered on, even if it isn't supplying electricity to any of the equipment at the facility. These losses are caused by the magnetic field in the transformer's core and stay relatively constant as long as the transformers are energized.

The applicant classified the measure as a retrofit with the pre-existing transformers as the baseline and used the *Early Transformer Replacement Program's Transformer Savings Tool (TST) 2021 V1* to model the pre-existing and proposed transformers annual electric energy consumption. Further discussion of the applicant's calculations is detailed in Section 2.1.3. The applicant's tool does not account for load losses, only the no-load losses in the transformers, but the evaluator concluded that load loss savings are not significant unless the transformers are loaded above 25%. As a result, the evaluation focused on no-load losses when estimating energy savings.

Based on the information provided in the project files and information gathered during the site visit, the evaluator agrees with the applicant's measure classification and baseline.

The evaluation results are presented in Table 1-1.

Table 1-1. Evaluation results summary

PA application ID	Measure name		Annual electric energy (kWh)	% of energy savings on-peak	Summer on-peak demand (kW)	Winter on-peak demand (kW)
13992198	Transformers replacement	Tracked	28,935	33%	3.30	3.30
		Evaluated	28,935	46%	3.30	3.30
		Realization Rate	100%	139%	100%	100%

1.1 Explanation of deviations from tracking

There are no deviations from the tracked demand and kWh savings, as the evaluated savings match the tracked values. This is because the savings from load losses are not significant, and all inputs in the tracked project files aligned with what the evaluators found on site. However, the evaluator's percent of energy savings on-peak is 39% higher than the tracked value. The project files do not include the calculations for the tracked percent of energy savings on-peak, so the evaluators updated this value based on the peak periods defined by ISO New England's Forward Capacity Market (FCM). Further details regarding deviations from the tracked savings are presented in Section 3.1.

1.2 Recommendations for program designers and implementers

The evaluator recommends that project implementers provide an estimate of transformer loading when estimating savings to understand load loss savings.

1.3 Customer alerts

There are no relevant customer alerts.

2 EVALUATED MEASURES

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

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

Table 2-1. Evaluated measure

Measure	Project ID	Measure description
M1 - Transformers replacement	13992198	Replace nine transformers within their useful life with new, efficient transformers with reduced no-load losses.

2.1 Application information and applicant savings methodology

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

2.1.1 Applicant description of baseline

According to the project files, the applicant classified this measure as a retrofit with a single baseline using the pre-existing condition as the baseline. The measure was classified as a retrofit because the nine pre-existing transformers were still within their measure life and functioning properly without the need for maintenance. The baseline includes nine transformers with kVA ratings from 15-112.5, operating 24/7 for 365 days per year. The pre-existing input key parameters used in the project documents are shown in Table 2-2. Note that transformer tag numbers skip from 8 to 10.

Table 2-2. Applicant's baseline key parameters

Transformer tag no.	Location	Rated kVA	No load losses (Watts)	Source of parameter value
T1	Shipping	30	403	Project documents
T2	Priming	15	229	Project documents
T3	Molding	30	403	Project documents
T4	RIM 110	112.5	1,168	Project documents
T5	Hub area	45	566	Project documents
T6	Hub area	30	403	Project documents
T7	Kenny's area	30	403	Project documents
T8	Kenny's area	15	229	Project documents
T10	Second floor	30	403	Project documents

2.1.2 Applicant description of installed equipment and operation

The project replaced nine pre-existing transformers with new aluminum-wound transformers of similar kVA ratings but with reduced no-load losses. The new transformers also operate 24 hours a day, 7 days a week, for 365 days per year. Table 2-3 presents the main parameters of the proposed case as defined by the applicant. Note that transformer tag numbers skip from 8 to 10.

Table 2-3. Applicant's proposed key parameters

Transformer tag no.	Location	Rated kVA	No load losses (watts)	Source of parameter value
T1	Shipping	30	86	Project documents
T2	Priming	15	62	Project documents
T3	Molding	30	86	Project documents
T4	RIM 110	112.5	226	Project documents
T5	Hub area	45	120	Project documents
T6	Hub area	30	86	Project documents
T7	Kenny's area	30	86	Project documents
T8	Kenny's area	15	62	Project documents
T10	Second floor	30	86	Project documents

2.1.3 Applicant energy savings algorithm

The applicant used the *Early Transformer Replacement Program's Transformer Savings Tool 2021 V1* to calculate savings. The tool is specifically designed to estimate transformer annual kWh savings due to reduced no-load losses based on kVA rating and operating hours. The applicant used the kVA rating from each name plate and the operating hours of the transformers as inputs in the savings tool to calculate the total kWh savings. The sum of the differences between the annual no-load losses of the pre-existing and post-install systems for each transformer is the total annual kWh savings for this measure.

To calculate baseline losses (kWh), the tool uses a quadratic equation based on the transformer's kVA rating and corresponding coefficients. The resulting losses (in Watts) are multiplied by the operating hours and divided by 1,000 to convert to kWh. For post-installation losses, the tool multiplies the rated no-load losses (in Watts) by the operating hours and divides by 1,000 to calculate post-install losses in kWh. The applicant's tool used the following formula to quantify the energy savings from the transformers for this measure:

kWh Savings per transformer:

$$Annual\ Savings\ (KWh) = \sum Baseline\ Losses(kWh) - \sum Post\ Install\ Losses(kWh)$$

Where,
$$Baseline\ Losses(Kwh) = ((-0.0239 \times Rated\ kVA^2) + (12.681 \times Rated\ kVA) + 43.68)) \times (Operating\ Hrs.)/1000$$
$$Post\ Install\ Losses\ (KWh) = (No\ Load\ Losses_{Installed}) \times Operating\ Hrs./1000$$

Where,

$Rated\ kVA$	= Power rating of the transformer
$No\ Load\ losses_{Installed}$	= No Load losses of the post-install system
$Operating\ Hrs.$	= 8760, Annual operating hours of the transformer
$-0.0239, 12.681, 43.68$	= Coefficients of the quadratic equation used to estimate baseline losses (Watts) based on rated kVA
1000	= Conversion factor from W to kW

2.1.4 Evaluation assessment of applicant methodology

The evaluator determined that the applicant's use of the transformer savings tool was appropriate. The applicant included only no-load losses in their calculations, as savings from load losses are not significant unless the transformers are loaded above 25%. Generally, transformers are intentionally oversized and lightly loaded. The evaluator verified the assumptions

and input parameters, agreed with the applicant's methodology, and used the applicant's tool with the verified inputs to calculate the evaluated kWh savings.

2.2   On-site inspection and metering

This section provides details of the tasks performed during the on-site inspection, the date it was conducted, and how it was conducted.

2.2.1   Summary of site visit findings

The evaluator conducted a site visit on February 5, 2025, to verify transformer installation, install loggers, and interview the site contact about the evaluated project. Loggers were retrieved on March 14, 2025.

The evaluator did the following during the site visit:

- Visually identified eight of the nine transformers on the manufacturing floor and took photos of their nameplates. One 30 kVA transformer was initially not found. After speaking with the site contact, the missing transformer was confirmed to be installed in a second-floor office area that was not part of the site inspection. This confirmed that all nine claimed transformers were installed.
- Verified the make, model, and transformer sizes using the nameplate photos taken during the site visit and supporting documentation provided by the applicant.
- Confirmed the installation month and year of the transformers as November 2023.
- Verbally confirmed with the site contact that the transformers are energized 24 hours a day, 7 days a week, 365 days a year.
- Verified the no-load losses of the nine transformers using their model numbers and specification sheet for the manufacturer's (Hammond Power Solutions) Sentinel G3 aluminum-wound transformers.
- Was informed that the facility is expected to be sold and possibly shut down in June 2025. The site contact was not aware of the future use of the transformers or the nature of the new owner's operations.
- Installed three HOBO amperage loggers to measure the current of two transformers. Further details regarding logger installation are provided in Section 2.2.

Table 2-4 summarizes the findings from the installed measure verification.

Table 2-4. Measure verification

Measure name	Verification method	Verification result
M1 – Transformers replacement	On-site inspection and customer interview	The evaluator visited the facility and confirmed that all nine newly installed transformers are present and operational. Photographs of the equipment and nameplates were taken. While the model numbers in the project documentation do not match those on the nameplate photos, the kVA ratings, no-load losses and the quantities of each kVA-rated transformer align with the project documents. The site contact also confirmed that the transformers are energized 24 hours a day, 365 days a year.

As the 30 kVA and 15 kVA rated transformers together account for 7 of the 9 installed transformers, their nameplate photos, taken during the site visit, are shown as examples in Figure 2-1 and Figure 2-2.

Figure 2-1. Nameplate picture of the 15kVA transformer
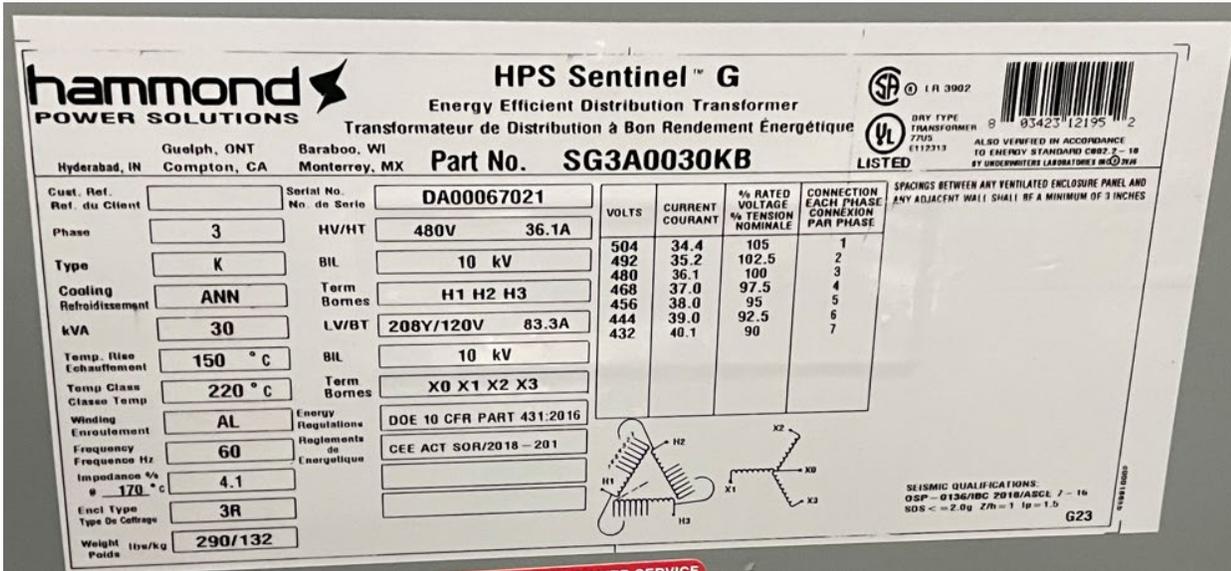
Figure 2-2. Nameplate picture of the 30kVA transformer
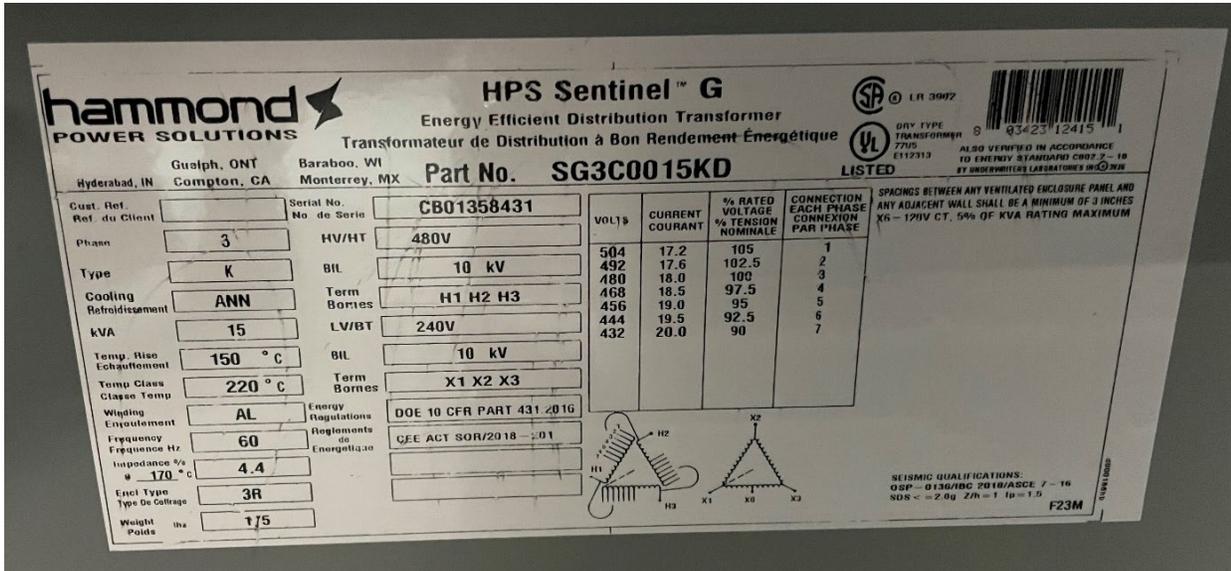
2.2.2   Metered and logged data

The evaluator installed three HOBO amperage loggers to measure the current drawn by the transformers. The maximum amperage listed on each transformer's nameplate was used to calculate the load on the transformers and ultimately estimate load losses. The metered data was also used to verify the number of hours the transformers were energized. Two loggers were installed on the input and output sides of a 30 kVA-rated transformer, and one logger was installed on the input side of a 15 kVA-rated transformer.

Table 2-5 shows the details of the evaluator installed logger information.

Table 2-5. Installed loggers with metered variables

Data logger type	Description	Time interval	Duration	Quantity
HOBO amperage meter	On the output side of the 30 kVA transformer	5-min	2/5/2025 – 3/14/2025	1
HOBO amperage meter	On the input side of the 30 kVA transformer	5-min	2/5/2025 – 3/14/2025	1
HOBO amperage meter	On the input side of the 15 kVA transformer	5-min	2/5/2025 – 3/14/2025	1

Analysis of the metered data suggests that the transformers were loaded less than 5% for 95% of the metering period. The metered data also indicated that the transformers were energized throughout the metering period. Further discussion about the analysis of metered data is explained in Section 2.3.2.

2.3   Evaluation methods and findings

This section describes the evaluator methods and findings.

2.3.1   Evaluation description of baseline

Based on the project files and information gathered during the site visit, the evaluator determined that the evaluated measure is a retrofit with a single baseline. The baseline is the existing nine transformers with kVA ratings ranging from 15 to 112.5 that operate 8,760 hours per year.

2.3.2   Evaluation calculation method

The evaluator recreated savings using the applicant transformer tool. However, the tool doesn't account for load losses, only no-load losses. The evaluator used the logged transformer amps and typical transformer performance data to assess the significance of load losses by analyzing the percent time at load and load losses at each loading. The logged data showed that the loading of the transformers had a maximum loading of 20%, with most of the time spent at less than 5% load. Analysis of the transformer performance curves shows that there is no significant load loss saving at low loadings. The evaluator determined that the impact of including load losses is insignificant based on the logged data. Details of the time at load and losses at load are explained below.

For each of the three metered transformers, the evaluator calculated the percent load at each time point by dividing the measured amperage by the maximum amperage listed on the transformer's nameplate. The evaluator grouped the load data into 0.5% intervals from 0% to 20%, which covers the typical loading range observed in the metered data. For each interval, the evaluator calculated the percentage of time the transformer operated within that load range. Then, for each interval, the percent time at percent load of all three transformers was averaged to have one representative percent time at load for each loading profile.

The percent time at each load interval was averaged, and the results showed that the transformers were operating at low load levels, below 5% for most of the time. To make the data easier to interpret, the evaluator regrouped the load data into 5% intervals (e.g., 0%–5%, 5%–10%) to summarize the percentage of time spent in each range. This analysis showed that the transformers were loaded between 0%–5% for approximately 95% of the time. Based on this, the evaluator assumed that this light loading pattern would be observed in all the transformers. Figure 2-3 shows the plot of percent load intervals versus the percentage of time the transformers operated at that load interval.

Figure 2-3. Percent load vs percent time at load

Percent load vs Percent time at load (Metered data)
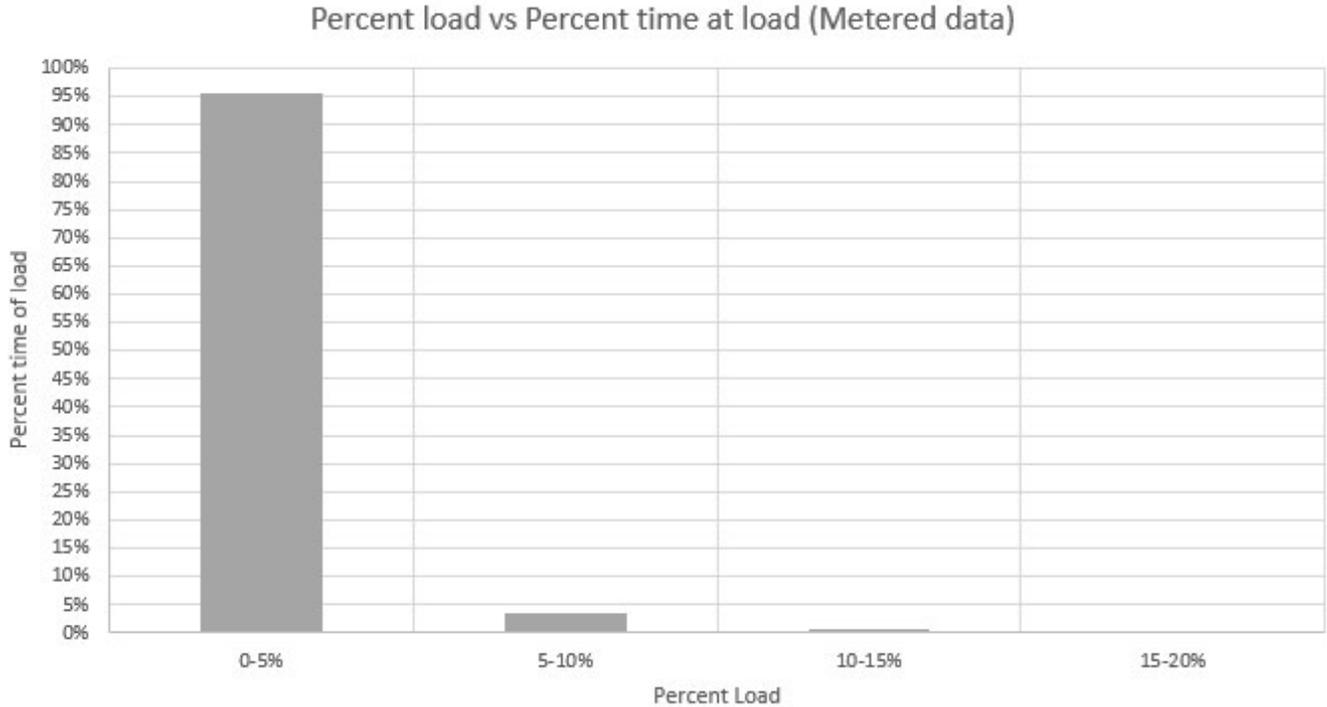
The evaluator assessed the transformer loading losses by looking at the loading curves provided in the Early Transformer Replacement Program's Transformer Savings Tool (TST) 2024 V2.3. This tool does not use the load losses curves as it was determined by the tool development team that transformer load losses are insignificant. This tool has these loading curves hidden within a sheet in the file. This sheet contains transformer loss specifications for both proposed (Powersmiths K-7) and baseline (pre-TP-1) options. The efficiencies are based on losses from Powersmith's cutsheets and logged data for varying sizes and percent load conditions.Table 2-6 and Table 2-7 show this transformer loss data for the baseline and the energy-efficient transformers.

Table 2-6. Transformers loss data for baseline transformers

Baseline transformers load losses (Watts)							
Size	Percent Load						
kVA	0%	16.70%	25%	35%	50%	75%	100%
15	297	317	348	403	522	820	1,241
30	453	484	531	615	797	1,251	1,894
45	654	698	765	886	1,148	1,803	2,730
75	857	915	1,003	1,161	1,505	2,364	3,578
112.5	1,164	1,243	1,363	1,578	2,045	3,211	4,861

Table 2-7. Transformers loss data for energy-efficient transformers

Energy efficient transformers load losses (Watts)							
Size	Percent Load						
kVA	**0%**	**16.70%**	**25%**	**35%**	**50%**	**75%**	**100%**
15	35	50	69	104	181	396	775
30	57	84	118	176	310	680	1,332
45	78	113	156	234	406	883	1,725
75	111	164	230	348	611	1,341	2,537
112.5	164	232	316	467	801	1,719	3,313

The evaluator calculated the difference in total losses (load and no load) between the baseline and the energy-efficient transformers at the percent load levels listed in Table 2-6 and Table 2-7, then divided these values by the difference at 0% load (no-load losses). This yielded a percent increase in savings due to load losses only. These percentages were averaged across different transformer sizes, and the evaluator focused specifically on the 0–50% load range, because the metered data showed that the transformers were typically loaded between 0–20%, and extending the evaluator analysis to 50% helped illustrate the trend beyond the observed range

A graph was then created plotting the percent increase in savings due to load losses against the percent load. The curve remained nearly flat up to 25% load, indicating that the incremental savings from load losses were negligible below 25% load.

Figure 2-4 shows the relationship between the percent load and the percent increase in savings for load losses.

Figure 2-4. Percent load vs percent increase in savings for load losses

Figure 2-3 shows that the transformers are loaded below 5% for 95% of the time, and Figure 2-4 indicates that savings from load losses are not significant when transformers are loaded below 25%. Based on these results, the evaluator concluded that load losses are negligible under the observed operating conditions. Therefore, the savings evaluation focused solely on no-load losses. The evaluator used the applicant's tool, along with nameplate information and metered data collected during the site visit, to calculate the final evaluated kWh savings.

The evaluator used the verified kVA rating from the name plate pictures and verified operating hours of the transformers as inputs in the transformers savings tool to calculate the evaluated savings. The sum of the differences between the annual no-load losses of the pre-existing and installed transformers is the total annual kWh savings for this measure.

The applicant's tool, which the evaluator used to calculate evaluated savings, used the following formula to quantify the energy savings from the transformers:

kWh Savings per transformer:

$$Annual\ Savings\ (KWh) = \sum Baseline\ Losses(kWh) - \sum Post\ Install\ Losses(kWh)$$

Where,

$Baseline\ Losses(Kwh) = ((-0.0239 \times Rated\ kVA^2) + (12.681 \times Rated\ kVA) + 43.68)) \times (Operating\ Hrs.)/1000$

$Post\ Install\ Losses\ (KWh) = (No\ Load\ Losses_{Installed}) \times Operating\ Hrs./1000$

where,

$Rated\ kVA$	= Power rating of the transformer
$No\ Load\ losses_{Installed}$	= No load losses of the post-install system
$Operating\ Hrs.$	= 8760, annual operating hours of the transformer
$-0.0239, 12.681, 43.68$	= Coefficients of the quadratic equation used to estimate baseline losses (Watts) based on rated kVA
1000	= Conversion factor from W to kW

3 FINAL RESULTS

The evaluated project consisted of replacing nine transformers to reduce no-load losses. There are no deviations from the tracked savings, as the evaluated savings match the tracked values. This is because the savings from load losses are not significant, and all inputs in the applicant analysis aligned with what the evaluators found on-site. Table 3-1 summarizes the parameters impacting the analysis.

Table 3-1. Summary of key parameters

Parameter	kVA rating	BASELINE		PROPOSED / INSTALLED	
		Tracking value(s)	Evaluation value(s)	Tracking value(s)	Evaluation value(s)
No-load losses (Watts)	30	403	403	86	86
	15	229	229	62	62
	30	403	403	86	86
	112.5	1,168	1,168	226	226
	45	566	566	120	120
	30	403	403	86	86
	30	403	403	86	86
	15	229	229	62	62
	30	403	403	86	86
Operating hours		8760	8760	8760	8760

3.1 Explanation of differences

The evaluated savings are the same as the tracking values because the savings from load losses are not significant, and all inputs in the applicant analysis match what the evaluator found on-site. Table 3-2 summarizes the differences between tracking and evaluated values.

Table 3-2. Summary of deviations

Measure	Discrepancy	Parameter	Impact of deviation	Discussion of deviations
M1	No discrepancy	N/A	0%	Savings from load losses are negligible, and all tracked inputs match site findings.

3.2 Lifetime savings

The evaluator classified the measure as a retrofit with a single baseline. According to the site contact, the facility has been sold and will be handed over to the new owners in June 2025. The use of the newly installed transformers will be at the discretion of the new owners.

The evaluator attempted to determine how the transformers would be used after June 2025 based on new ownership but was unable to determine future plans. After discussions with Rhode Island Energy, the evaluator assumed that the transformer would likely remain in use by the new owners and the percent load on the transformers, which was very low, would likely remain consistent throughout their measure life with the new owners and calculated the lifetime savings accordingly.

The applicants' and evaluated lifetime savings values were calculated using the following formula:

$$LAGI = [FYS \times EUL]$$

where:

       FYS =   first year savings (therms)

       EUL =   measure life (years)

The evaluated lifetime savings are the same as the applicant's savings because the evaluated first-year savings are the same as the tracking first-year savings. Table 3-3 provides a summary of key factors that influence lifetime savings.

Table 3-3. Measure M1 – Application ID: 13992198 – Lifetime savings summary

Factor	Tracking	Application	Evaluator
Lifetime savings (kWh)	868,050	868,050	868,050
First-year savings (kWh)	28,935	28,935	28,935
Measure lifetime (years)	30	30	30
Baseline classification	Retrofit	Retrofit	Retrofit

3.3 Ancillary impacts

There are no ancillary impacts from installing the evaluated measures.

RI CUSTOM ELECTRIC EVALUATION SITE-SPECIFIC REPORT

DNV SITE ID: RICE23N059

Report Date: 03/12/2025

Application ID(s)	13457744	
Project Type	C&I New Construction	
Program Year	2023	
Evaluation Firm	DMI	
Evaluation Engineer	Zac Cragan	
Senior Engineers	Alec Stevens and Mickey Bush	

1 EVALUATED SITE SUMMARY AND RESULTS

This site is an industrial plant with 24/7 operating hours with down time during typical holiday periods. The single energy savings measure installed two 100 hp variable speed drive (VSD) air compressors, one cycling refrigerated air dryer, and four zero-loss condensate drains. Due to a recent influx of business, an expansion of their existing air compressor system was needed. The applicant documented that the compressed air load at the facility was expected to increase by 250-300 CFM. The TA study, project, and post inspection were completed in 2022.

The applicant described the project as a new construction measure that replaced two pre-existing air compressors. The pre-existing air compressors included one 100 hp load/no load compressor and one 75 hp VSD compressor. The applicant used an ISP baseline that consisted of two 100 hp air compressors equipped with load / no-load controls. The applicant calculated the project savings using an hour-of-week model.

Based on the project files and information gathered from the site, the evaluator classified the measure as lost opportunity with ISP baseline and calculated the project savings using an 8,760 model with inputs based on metered data.

The evaluation results are presented in Table 1-1.

Table 1-1. Evaluation Results Summary

PA Application IDs	Measure Name		Annual Electric Energy (kWh)	% of Energy Savings On-Peak	Summer On-Peak Demand (kW)	Winter On-Peak Demand (kW)
13457744	Installation of two 100 hp VSD air compressors	Tracked	290,749	53.0%	40.9	36.1
		Evaluated	201,717	38.9%	17.9	21.0
		Realization Rate	69.4%	73.5%	43.8%	58.2%

1.1 Explanation of Deviations from Tracking

The evaluated savings are 30.6% less than the applicant-reported savings. The decrease in savings is primarily due a reduction in assumed baseline full load compressor kW. There is a further decrease in savings due to a reduced modelled CFM at the facility than assumed by the applicant. The CFM was reduced in the evaluated model due to an incorrect scaling factor with the applicant's metered CFM. The reduced CFM results in only one baseline and proposed compressor needing to run at a time. The result is a reduction in the amount of time when a second trim load/no load compressor is operating at a reduced efficiency. Further details of deviations from tracked savings are discussed in Section 3.4.

1.2 Recommendations for Program Designers & Implementers

The savings for this compressed air project rely on the use of the regressive baseline because the baseline equipment has worse performance than the pre-existing equipment. The evaluator recommends that if a regressive baseline is used, the applicant documents the rationale for the regressive baseline.

The evaluator was able to confirm that the pre-existing VSD air compressor was program funded through talking with the air compressor vendor who was involved in the previous project. Without the air compressor vendor's information, the evaluator would have had to rely on the customer to determine if the previous compressors were incentivized or not. Often times, between the implementation of the

project and the evaluation, there is staff turnover at the site which limits the available knowledge on the pre-existing equipment. Requiring the applicant to document the use of the regressive baseline would result in a streamlined evaluation of the project without the reliance on the program administrator or previous site knowledge.

The evaluator also recommends program designers complete an updated compressed air ISP study to determine if load/no load air compressors are still an appropriate baseline for new air compressor projects. Additionally, if load/no load is still the baseline, there should be a standardized baseline no load percent kW determined to standardize compressed air projects.

1.3 Customer Alert

N/A

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 the information available.

2.1 Application Information and Applicant Savings Methodology

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

2.2 Applicant Description of Baseline

The applicant classified the project as a new construction measure with an industry standard practice (ISP) baseline. The classification was made because the applicant considered the project a major renovation with an increased compressed air load. The pre-existing air compressors included one 100 hp load/no load compressor and one 75 hp VSD compressor. The applicant documented an expected plant increase of 250-300 CFM of additional load. The baseline consists of 2 x 100 hp fixed speed single stage compressors with load/no-load controls that discharge 125 psi air. The applicant assumes the performance data of the base case compressors operated at 110 psi. The applicant used a CAGI datasheet and specifications from the manufacturer's catalog to model the baseline compressor performance. The baseline also consists of one 1,000 cfm non-cycling refrigerated dryer (Gardner Denver GSRN1000).

The baseline values used in the applicant savings analysis are presented in Table 2-1.

Table 2-1. Applicant baseline key parameters

Measure	Parameter	BASELINE		
		Value(s)	Source of Parameter Value	Note
Installation of two 100 hp VSD air compressors	Size	100 hp	Applicant savings calculations	
	Compressor rated capacity	464.9 CFM		
	Rated full load kW	102.0 kW		
	Controls	Load/no load		
	Quantity	2		
	Operating pressure	125 psi		
	Performance data operating pressure	110 psi		
	Compressors operating hours	8,400 hours		

	Compressed air storage capacity	4 gal/CFM		
	Air dryer rated capacity	1,000 CFM		
	Air dryer input power at rated capacity	7.5 kW		
	Air dryer input power at zero flow	75 %		
	Average condensate drain airflow per drain	0.8 CFM		
	Demand associated with no zero-loss drains	0.738 kW		

2.2.1 Applicant Description of Installed Equipment and Operation

The installed equipment includes two 100 hp variable speed drive (VSD) air compressors. The proposed system values used in the applicant savings analysis are presented in Table 2-2.

Table 2-2: Application proposed key parameters

Measure	Parameter	PROPOSED		Note
		Value(s)	Source of Parameter Value	
Installation of two 100 hp VSD air compressors	Size	100 hp	Applicant savings calculations	
	Compressor rated capacity	436.6 CFM		
	Rated full load kW	94.2 kW		
	Controls	Variable speed		
	Quantity	2		
	Operating pressure	125 psi		
	Performance data operating pressure	125 psi		
	Compressors operating hours	8,400 hours		
	Air dryer rated capacity	1,000 CFM		
	Air dryer input power at rated capacity	5.8 kW		
	Air dryer input power at zero flow	10 %		
	Average condensate drain airflow per drain	0 CFM		
	Demand associated with no zero-loss drains	0 kW		

2.2.2 Applicant Energy Savings Algorithm

The annual savings analysis for this project is based on 13 days of compressed air flow data collected in 1-minute intervals, from a CFM logger.

The base case compressor performance is calculated based on the Compressed Air Challenge performance curve assuming a baseline storage capacity of 4 gal/CFM. The performance curve is adjusted based on the CAGI rated no load kW of the base case compressor model. The applicant assumed a no-load kW based on the CAGI data sheet for the baseline compressor rated at 125 psi.

The applicant assumes that the base case compressors must operate at an average of 5-10 psi above the setpoint to cover the pressure band of the cut-in. The applicant used performance data rated at 110 psi to determine the rated full load kW and CFM. The applicant adjusts the full load compressor demand based on the rated performance and the estimated operating compressed air pressure (125 psi) at the facility using the following equation. This same equation is used for both the base and proposed case.

$$Operating\ kW = 0.995^{Rated\ Pressure\ psi-Operating\ Pressure\ psi} * Rated\ kW$$

The performance curve is used to calculate base case compressor demand according to the metered compressed air flow data. The base compressor performance curve is as follows:

$$\%kW\ input(\%\ Load) = -0.0177x^3 - 0.3783x^2 + 1.1245x + 0.2722$$

The base case refrigerated air dryer power consumption was calculated using the manufacturer's datasheet for the baseline air dryer, which provides full-load flow and power values only. The applicant created a linear fit for dryer performance based off the assumption that the baseline dryer uses 75% of full load power at 10% air flow. The applicant's baseline dryer performance curve is shown below:

$$P_{d,n} = 0.0021 * CFM + 5.45$$

Where,

$P_{d,n}$ = dryer power for any given CFM

$P_{d,n}$ = dryer power for any given CFM *n*

The proposed case variable speed compressor performance is based on manufacturer data scaled based on the estimated CAIR pressure at the facility which was assumed to be 125 psi. The proposed case compressor performance curve is as follows:

$$kW\ input(\%\ Load) = 0.0002x^2 + 0.1165x + 11.5943$$

The proposed case cycling refrigerated air dryer power consumption was calculated using the manufacturer's datasheet for the installed air dryer, which provides full-load flow and power values only. The applicant created a linear fit for dryer performance based on the assumption that the installed dryer uses 10% of full load power at 10% air flow. The proposed case refrigerated air dryer power consumption was calculated according to:

$$P_{d,n} = 0.0058 * CFM$$

Where,

$P_{d,n}$ = dryer power for any given CFM

Zero loss drain savings are calculated by applying an average demand penalty to the base case system. Savings assume an average base case leakage rate of 0.8 CFM for four drains, and an average compressor performance of 0.2238 kW/CFM based on the proposed case variable speed compressor. The 0.2238 kW/CFM is the average of the compressor performance data points at six varying part loads, not the performance at average compressor airflow. This results in an average base case demand of 0.738 kW associated with drain leakage for 8,400 hours a year, or 6,197 kWh.

The base case and proposed case performance curves are applied to the compressed air flow trend data. The average base and proposed system demand over the trend period are projected over 168 weekly hours for 50 weeks/year (assuming 2 weeks shutdown) to calculate annual savings.

The applicant calculates peak demand savings based on the time of day, day of week averages for the base and proposed compressor. Summer peak savings compare the base and proposed average

compressor demand from 1PM-5PM Monday through Friday, and Winter Peak demand savings compare the base and proposed case demand from 5PM-7PM Monday through Friday.

2.2.3 Evaluation Assessment of Applicant Methodology

The evaluator agrees with the applicant methodology of using metered CFM data to create an hourly load profile which is then used to model baseline and proposed energy use.

The applicant used CFM data from a 4-20mA flowmeter to determine the load profile of the system. The evaluator will use metered kW of the air compressors compared with manufacturer's performance data to increase the accuracy of the CFM load profile. The applicant used a 2,000 CFM capacity on the flowmeter to convert from mA to CFM. The result is several bin hours with a CFM flow greater than the capacity of one installed air compressor (437 CFM). The site contact confirmed that the site only operates with one compressor operating at a time, so the 2,000 CFM capacity of the flowmeter assumption was deemed unreliable. Without knowing the correct capacity of the airflow meter, the evaluator will use manufacturing performance data to determine the CFM profile.

The applicant assumed performance data for the baseline compressors based on manufacturing data at an operating 110 psi and scaled the data to match the proposed case operating pressure at 125 psi. The evaluator will use CAGI data for the baseline compressor operating at 125 psi to avoid any discrepancies due to scaling.

The applicant used a 24×7 model to account for peak period reductions, and did not account for weekday holidays. The evaluator used an 8,760 model to account for holiday effects on peak period reductions.

2.3 On-site Inspection and Metering

This section provides details on the work performed during the on-site inspection.

2.3.1 Summary of Site Visit

This section summarizes the site visit.

- The evaluator visited the site on November 19, 2024.
- Nameplate information from the compressors was collected, and it was confirmed that the compressors were installed as expected.
- The pre-existing 75 horsepower VSD compressor was observed to be on site as a backup compressor. The site contact confirmed that it does not regularly operate. The pre-existing 100 hp load/no load compressor had been removed from the site.
- The pre-existing dryer remained on site but did not operate as expected.
- The cycling refrigerated dryer was installed as expected.
- The site contact indicated the following during the site interview:
    - o The compressors operate in a lead/lag system, and the load at the facility does not require both compressors to run at the same time.
    - o The lead compressor switches at midnight on Mondays and noon on Wednesdays.
    - o The facility runs 24/7 but the demand on holidays and weekends is lower.
    - o The compressed air pressure setpoint is 125 psi.
    - o The exhaust air is ducted out of the facility, so there are no ancillary impacts to the space heating or cooling load.

A photo of one of the installed air compressors is below in Figure 2-1, along with photos of the units' nameplate information in Figure 2-2.

Figure 2-1. Installed Air Compressors

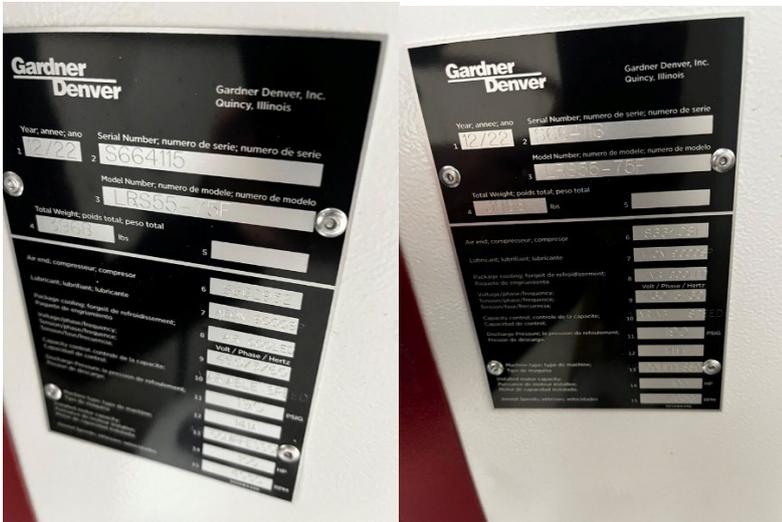
Figure 2-2. Installed unit nameplates

Table 2-4 below summarizes the verification of the installed measure.

Table 2-3. Measure verification

Measure Name	Verification Method	Verification Result
Installation of two 100 hp VSD air compressors	On-site verification with kW metering of two new air compressors, amperage metering of the refrigerated dryer	The equipment was installed as expected.

2.3.2 Measured and Logged Data

Table 2-5 summarizes the metered data collected at this site by the evaluator.

Table 2-4. Metered data summary

Equipment	Meter	Metering Period
kW power meters	WattNode WNB-3D-480-P	11/19/2024-2/4/2025
Amperage meter	Hobo UX-20	11/19/2024-2/4/2025
CFM Data	CDI 5450 Hot Tap + UX-120	12/4/2024-2/4/2024

Figure 2-3 below shows the metered kW of the two VSD air compressors over the metering period. The metering data showed that one compressor constantly ran at a lower operating kW than the other compressor. This operation is unexpected based on the collected CFM data and information from the site. The evaluator was also able to obtain spot readings on the air compressors interface, which show the instantaneous loading percent which were used to compare to the metering data. The data lined up as expected for Compressor 1, but was ~20% lower in kW for Compressor 2. It was determined that there was a faulty connection with one of the power meters installed in Compressor 2. The result is that the evaluator used the metered data from Compressor 1 to determine the weekly load profile of the system.

Figure 2-3. Metered data
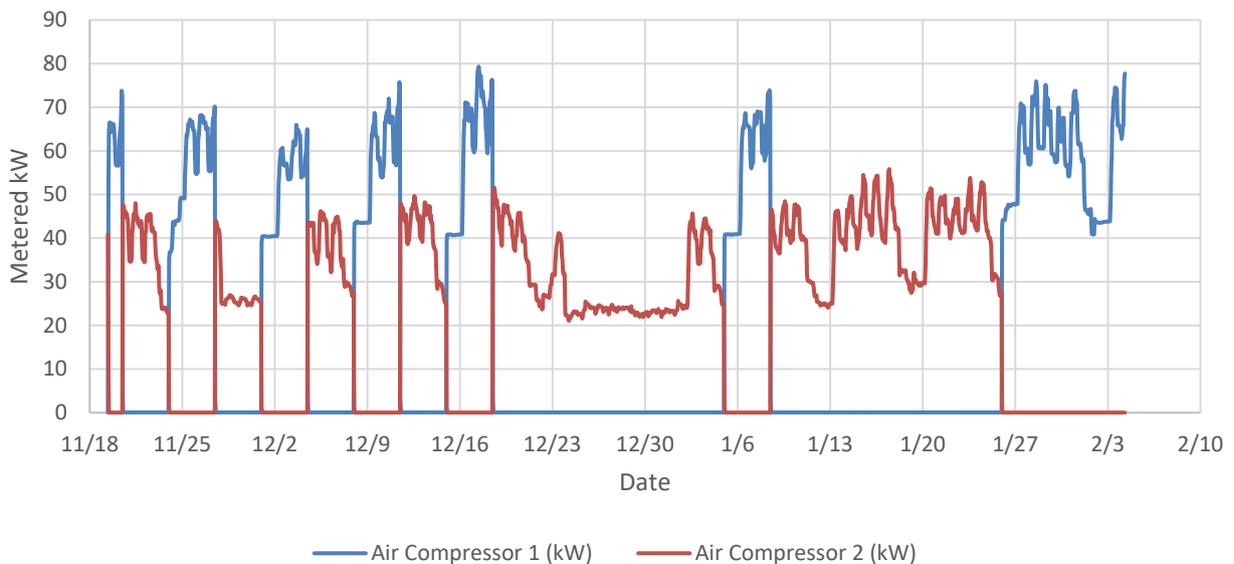
Figure 2-4 below shows eight hours of the dryer metered amperage data to show the cycling process of the dryer. The metered amperage data was not used to calculate the energy savings, but to confirm the sequencing of the system.

Figure 2-4. Cycling dryer metered amps
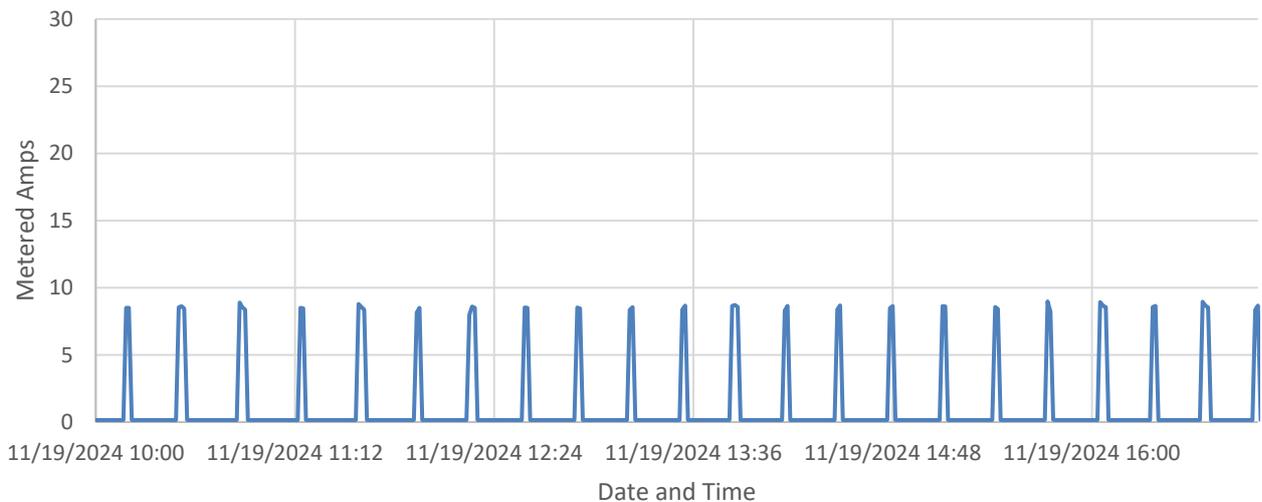
2.4 Evaluation Methods and Findings

This section describes the evaluator methods and findings.

2.4.1 Evaluation Description of Baseline

The evaluator agrees with the applicant's description of the measure as a lost opportunity measure with an ISP baseline.

The evaluator defined the baseline as two 100 hp load / no-load compressors that match the capacity of the installed equipment. The evaluator assumed a baseline storage ratio of 4 gal/CFM based on the compressed air ISP requirement for air-cooled single-staged rotary screw compressors with a new construction baseline. The evaluator agrees with the applicant's description of the baseline non-cycling dryer.

An ISP baseline of two load / no-load air compressors is a regressive baseline due to the pre-existing VSD air compressor having better performance than the baseline used. The evaluator confirmed that the regressive baseline is reasonable due to exemption three stated in the Massachusetts Commercial and Industrial Baseline Framework. The exemption states that a regressive baseline is allowed if the pre-existing condition was program-funded. The evaluator confirmed that the pre-existing VSD compressor was program funded because the air compressor vendor was able to confirm that the previous VSD machine was also installed through the program.

2.4.2 Evaluation Calculation Method

As previously discussed, the metered kW for air compressor 1 was used to determine the relationship between metered kW and site CFM. The metered kW showed a reduced load profile during weekend and holiday hours. Figure 2-4 below shows the kW profile during a typical week of operation.

Figure 2-5. Weekly kW profile
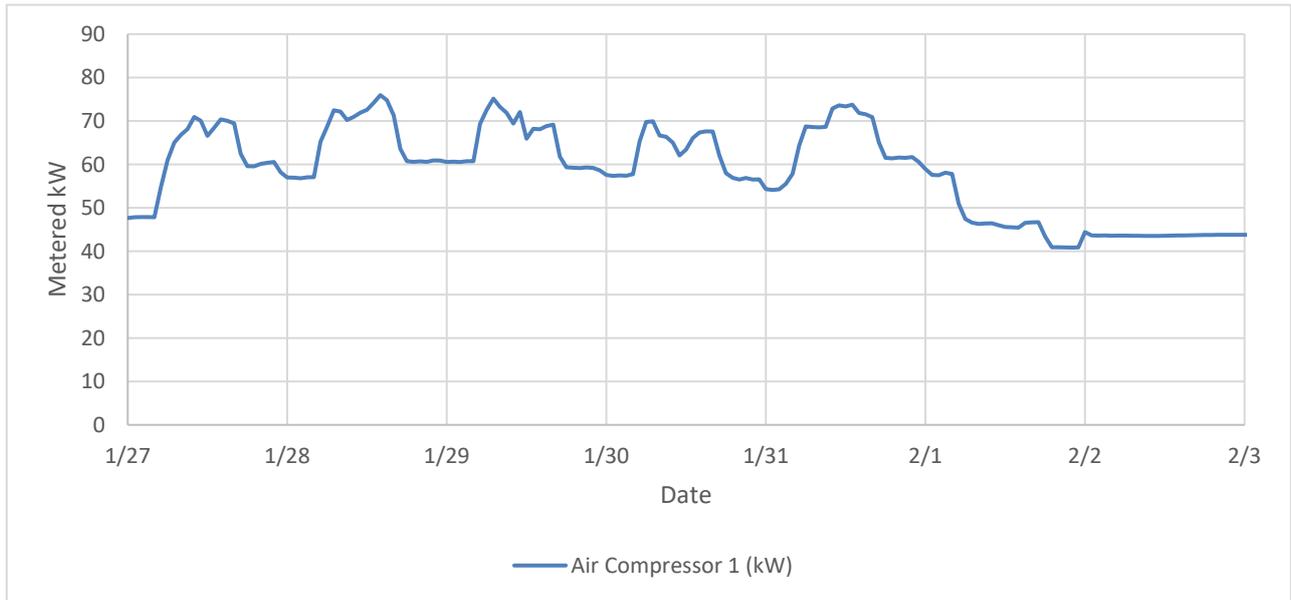
The evaluator used the manufacturer's performance data sheet for the installed compressor (L75RS) to determine a relationship between metered kW and CFM. The evaluator plotted performance data (kW/cfm) vs input power to create the third order polynomial shown in Figure 2-6. The function was used to determine the operating CFM weekly profile as a function of the metered kW.

Figure 2-6. Performance data comparing kW and kW/CFM (installed compressors)

$$y = -8E\text{-}07x^3 + 0.0002x^2 - 0.0115x + 0.4552$$
$$R^2 = 0.9891$$
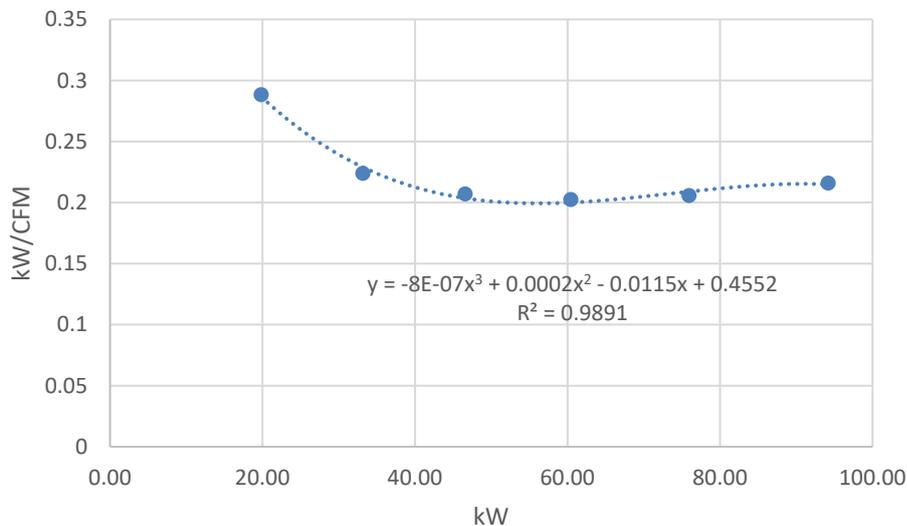
The metered power data was used in preference to the airflow data collected by the site contact because:

1. The power meters have a greater accuracy than the airflow meter.

2. The exact conversion factor to convert between the 4-20 mA airflow receiver data to CFM is unknown. The applicant used a maximum CFM of 2,000 to calibrate the data, but the result is a higher CFM profile than the maximum CFM that one compressor is rated for. The evaluator was able to confirm through the CFM metering that only one compressor runs at a time.

3. Power data was collected for the full metering period of 77 days, while the applicant was only able to collect 62 days of airflow data.

The CFM data was then plotted in a 24x8 matrix to create an hourly profile for the typical week of operation as previously described. The evaluator assumed the same profile for Holiday operation as Sunday operation based on the metered data over the Thanksgiving and Christmas holidays. Figure 2-7 below shows the CFM profile.

Figure 2-7. Compressor CFM

	CFM Typical Hours							
	1	2	3	4	5	6	7	8
Hour	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday	Holiday
0	212	287	291	289	272	295	190	190
1	212	284	290	288	271	289	197	197
2	212	286	289	288	272	288	197	197
3	212	288	290	288	279	291	197	197
4	212	288	290	290	290	290	198	198
5	239	312	312	323	319	254	198	198
6	277	322	326	341	337	234	201	201
7	301	334	335	341	336	229	206	206
8	316	335	335	329	336	227	205	205
9	320	335	339	327	336	228	205	205
10	329	327	347	322	352	228	205	205
11	330	336	347	309	355	225	206	206
12	328	336	326	315	354	223	206	206
13	332	337	335	326	356	222	206	206
14	336	340	334	331	348	222	206	206
15	329	338	337	332	347	229	207	207
16	326	334	338	332	345	229	206	206
17	319	329	308	309	322	229	207	207
18	317	328	297	291	307	210	207	207
19	313	325	297	285	307	194	208	208
20	311	321	296	283	307	194	211	211
21	313	318	297	285	307	194	211	211
22	311	321	296	284	308	193	212	212
23	294	300	294	284	303	194	212	212

To calculate the baseline energy use, the evaluator used a CAGI data sheet for the same baseline load / no-load air compressor (model L-75) that the applicant used. The evaluator used values from the Compressed Air Challenge % power curve to determine the relationship between percent kW input and percent capacity of the unit at the ISP air storage volume. The evaluator used a storage ratio of 4 gal/CFM based on the ISP for new construction measures. The relationship between percent capacity and percent kW input is shown in Figure 2-9 below.

Figure 2-8. Percent capacity vs percent kW for 4 gal/CFM per Compressed Air Evaluation Protocol

$$y = -0.0177x^3 - 0.3783x^2 + 1.107x + 0.2898$$
$$R^2 = 1$$
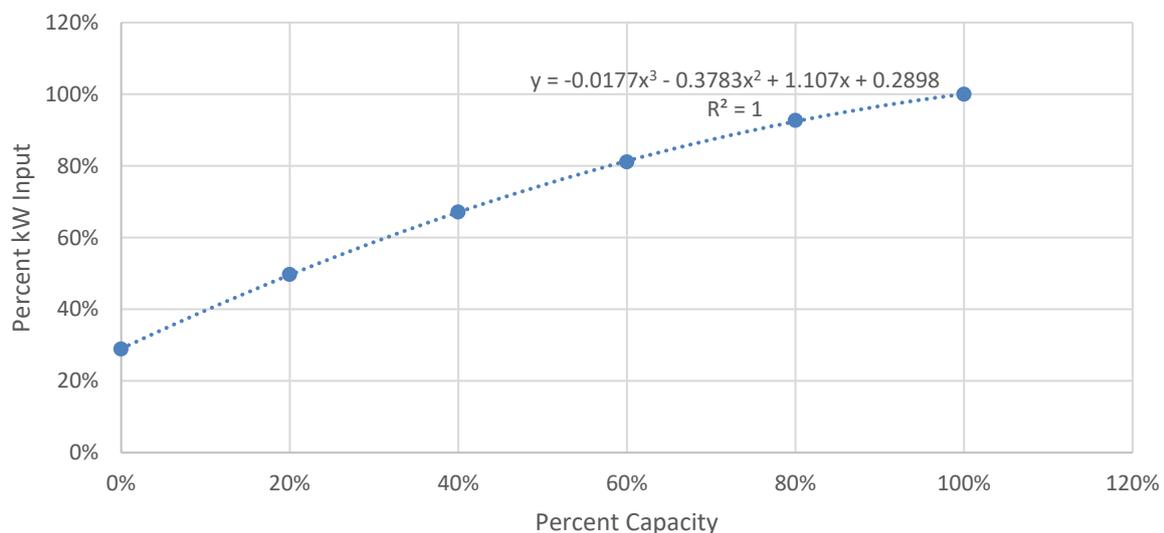
The baseline kW for each baseline air compressor per hour in the 8,760 model is calculated using the curve fits of the data in Figure 2-10. When the calculated CFM exceeds the capacity for one compressor, it is assumed that one compressor stays base loaded and the second compressor serves the remaining trim load.

$$Baseline\ kW = full\ load\ kW \times (A(\frac{x}{y})^3 + B(\frac{x}{y})^2 + C\frac{x}{y} + D)$$

Where,

Full load kW	=	Baseline compressor full load kW per CAGI datasheet (88.84 kW)
A-D	=	Polynomial fit coefficients based on an assumed 4 gal/CFM of storage. The coefficients are shown in Figure 2-9 above.
x	=	Calculated CFM
y	=	Rated flow capacity per CAGI data sheet (422.3 CFM)

The evaluator assumed the full load kW based on the CAGI data of the baseline compressor operating at 125 psi. The applicant assumed the full load kW based on the manufacturer's data of the baseline compressor operating at 110 psi and then used a scaling factor to extrapolate the data to the plant operating pressure of 125 psi. The evaluator determined the CAGI data at 125 psi to be a reliable data source and did not add in a scaling factor from a different operating pressure.

The baseline system demand includes the same assumptions for zero-loss drain savings as described in Section 2.2.2. The average compressor performance of 0.204 kW/CFM was based on the proposed case variable speed compressor average efficiency at the sites operating pressure of 125 psi. The annual compressor operating time was found to be 8,760 hours per year based on the metered data. This results in an average base case demand of 0.738 kW associated with drain leakage for 8,760 hours a year, or 5,892 kWh.

The baseline refrigerated dryer's energy impact was calculated using the same assumptions as the applicant. The evaluated created a linear fit for dryer performance based off the assumption that the baseline dryer uses 75% of full load power at 10% air flow. The evaluator's baseline dryer performance curve is shown below:

$$P_{d,n} = 0.0021 * CFM + 5.45$$

Where,

$P_{d,n}$ = dryer power for any given CFM n

The installed kW for each air compressor was calculated using a polynomial regression found to describe the relationship between CFM data and kW/CFM based on the installed compressors CAGI data. Air storage volume does not impact VSD compressor performance and no adjustments were included. Figure 2-11 shows the third order polynomial relationship generated.

Figure 2-9. CAGI data comparing CFM and kW/CFM
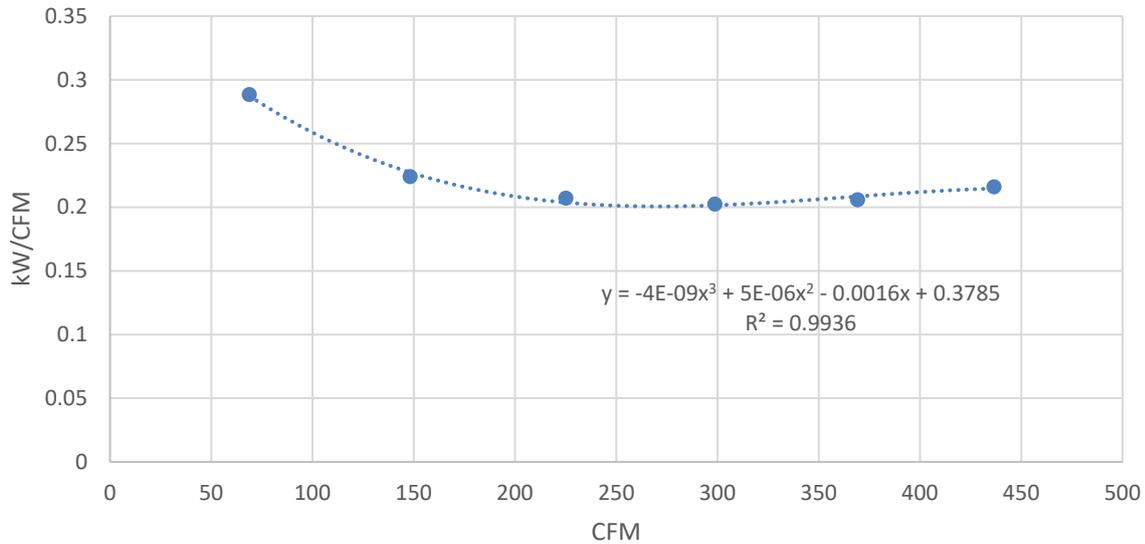
The installed kW was calculated using the following formula.

$$Installed\ kW = AX^3 + BX^2 + CX + D$$

Where,

        A-D   = Polynomial fit coefficients as shown in Figure 2-10 above.

        X   = Calculated CFM per air compressor

The evaluator used calculated kW instead of directly using metered kW to determine installed kW to remain consistent in methodology between the applicant and the modeled baseline, and to determine the impacts of each discrepancy. The evaluator confirmed that the calculated installed kWh aligned with the actual metered kWh.

The proposed case cycling refrigerated air dryer power consumption was calculated using the manufacturer's datasheet for the installed air dryer, which provides full-load flow and power values only. The evaluator created a linear fit for dryer performance based off the assumption that the installed dryer uses 10% of full load power at 10% air flow. The proposed case refrigerated air dryer power consumption was calculated according to:

$$P_{d,n} = 0.0058 * CFM$$

Where,

        $P_{d,n}$ = dryer power for any given CFM

The demand reduction for each hour of the 8,760 model are calculated using the following formula.

$$Savings\ (kW) = Base\ Comp\ kW + Drain\ Loss\ kW + Base\ Dryer\ kW - Installed\ Comp\ 1\ kW - Installed\ Comp\ 2\ KW - Installed\ Dryer\ kW$$

The evaluators used an 8,760 peak demand calculator to calculate summer and winter peak demand savings and on-peak energy savings. Figure 2-11 shows a summary of the on-peak, off-peak, and peak demand filters that were applied to the hourly savings to calculate the peak demand reductions and on-peak energy savings.

Figure 2-10. Screenshot summarizing on-peak hours, off-peak hours, and peak demand windows

Winter Peak Energy kWh savings: 7AM – 11PM, weekdays except holidays, October to May

Winter Off-Peak Energy kWh savings: 11PM – 7AM weekdays, all day weekends and holidays, October to May

Summer Peak Energy kWh savings: 7AM – 11PM, weekdays except holidays, June to September

Summer Off-Peak Energy kWh savings: 11PM – 7AM weekdays, all day weekends and holidays, June to September

Summer Average Demand kW reduction: 1PM – 5 PM, weekdays except holidays, June to August

Winter Average Demand kW reduction: 5PM – 7 PM, weekdays except holidays, December and January

3   FINAL RESULTS

The evaluated project involved the installation of two 100 hp VSD air compressors to replace pre-existing air compressors including one 100 hp load/no load compressor and one 75 hp VSD compressor in order to increase the compressed air capacity.

The applicant classified the project as a new construction project. The evaluator classified the project as a lost opportunity with an ISP baseline.

The evaluated first-year savings for the project were 30.43% less than the applicant-reported savings, primarily due to a decrease in assumed baseline compressor full load kW. These deviations are further discussed in Section 3.4. Table 3-1 presents the applicant and evaluated inputs used to model the project inputs.

Table 3-1. Summary of Key Parameters

Measure	Parameter	BASELINE		PROPOSED / INSTALLED	
		Tracking Value(s)	Evaluation Value(s)	Tracking Value(s)	Evaluation Value(s)
Installation of two 100 hp VSD air compressors	Compressors operating pressure	125 psi (110 psi)	125 psi	125 psi	125 psi
	Compressors operating hours	8,400 hours	8,760 hours	8,400 hours	8,760 hours
	Average airflow during operation	483 CFM	282 CFM	483 CFM	282 CFM
	Average performance during operation	0.271 kW/CFM	0.268 kW/CFM	0.205 kW/CFM	0.204 kW/CFM
	Compressor full load kW	102.0 kW	88.8 kW	94.2 kW	94.2 kW

3.4 Explanation of Differences

This section describes the key drivers behind any difference in the application and evaluation estimates of annual kWh savings. The following table summarizes these differences. The purpose of this table is to describe how changes to the key parameters influenced the final project savings through the end-use summary analysis. 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
Installation of two 100 HP VSD air compressors	Load Shape	Average CFM	-11.6%	**Decreased savings –** The applicant assumed an average of 483 CFM based on airflow data and the evaluator calculated an average 282 CFM. The decreased plant CFM results in a less amount of time when the baseline trim compressor operates at a minimal output with worse part load performance.
	Hours of Operation	Compressors operating hours	+4.9%	**Increased savings –** The applicant assumed the compressors would shut down for two weeks of plant shut down. The evaluator determined through metering that the compressors run to provide a base CFM throughout holiday unoccupied periods.
	Operating Load	Baseline compressor full load kW	-23.9%	**Decreased savings –** The applicant assumed a baseline full load compressor kW of 102 kW based on scaling the manufacturing performance data of 110 psi to 125 psi. The evaluator assumed a baseline full load compressor kW of 88.84 kW based on CAGI data rated at 125 psi.
Total				**-30.6%**

3.5 Lifetime Savings

Because the measure is lost opportunity with a single-baseline measure, the out-year factor is 100%. The evaluators calculated applicant and evaluated lifetime savings values using the following formula:

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

where:

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

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

Table 3-3. Measure M1 - Lifetime Savings Summary

Factor	Tracking	Application	Evaluator
Lifetime savings	4,361,235 kWh	4,361,235 kWh	3,025,750 kWh
First year savings	290,749 kWh	290,749 kWh	201,717 kWh
Measure lifetime	15 years	15 years	15 years
Baseline classification	New construction	New construction	Lost Opportunity

3.5.1 Ancillary impacts

There are no ancillary impacts because the compressed air exhaust is ducted outside of the facility.

RI CUSTOM ELECTRIC EVALUATION SITE-SPECIFIC REPORT

DNV SITE ID: RICE23N082

Report Date: 03/12/2025

Application ID(s)	13134292/14044447	
Project Type	C&I New Construction	
Program Year	2023	
Evaluation Firm	DMI	
Evaluation Engineer	Zac Cragan	
Senior Engineers	Alec Stevens and Mickey Bush	

1 EVALUATED SITE SUMMARY AND RESULTS

This site is an industrial plant with operating hours that are a function of the production demand. The single energy savings measure installed two 100 hp variable speed drive (VSD) air compressors. Due to a recent influx of business and the end of the useful life of their existing air compressors, an expansion of their existing air compressor system was needed. The TA study, project, and post inspection were completed in 2021 and 2022. The project was split into parent and child applications.

The applicant described the project as a new construction measure that replaced two pre-existing air compressors that had reached the end of their useful life. The pre-existing air compressors included a 100 hp two stage compressor and single stage 40 hp compressor. The applicant used an ISP baseline that consisted of two 100 hp air compressors equipped with load / no-load controls. The applicant calculated the project savings using an hour-of-week model.

Based on the project files and information gathered from the site, the evaluator classified the measure as lost opportunity with ISP baseline and calculated the project savings using an 8,760 model with inputs based on metered data.

The evaluation results are presented in Table 1-1.

Table 1-1. Evaluation Results Summary

PA Application IDs	Measure Name		Annual Electric Energy (kWh)	% of Energy Savings On-Peak	Summer On-Peak Demand (kW)	Winter On-Peak Demand (kW)
13134292 /14044447	Installation of two 100 hp VSD air compressors	Tracked	210,273	67.0%	42.1	38.1
		Evaluated	217,417	53.1%	27.6	23.1
		Realization Rate	103.4%	79.2%	65.6%	60.7%

1.1 Explanation of Deviations from Tracking

The evaluated savings are 3.4% greater than the applicant-reported savings. The increase in savings is primarily due a reduced plant CFM load which decreases the baseline compressor efficiency. The reduced CFM increases the quantity of hours that the trim compressors operated between 10 to 20% load which is the worst operating efficiency for a load/no load compressor. The increase in savings due a reduced plant CFM load is partially offset due to reduced run hours of the compressed air system, as well as a decrease in operating efficiency caused by the applicant manually controlling the percent load of one installed compressor. Further details of deviations from tracked savings are discussed in Section 3.4.

The reported summer and winter on-peak demand kW values are based on tracked savings values for this application. The tracked peak demand values deviate from the peak demand values calculated in the applicant's analysis which lists the summer on-peak demand kW as 42.1 kW and the winter on-peak demand kW as 38.1 kW. It is unclear why the tracked savings deviate from the applicant analysis for these values.

1.2 Recommendations for Program Designers & Implementers

The savings for this compressed air project rely heavily on the use of the regressive baseline because the baseline equipment has worse performance than the pre-existing equipment. The evaluator

recommends that if a regressive baseline is used, the applicant documents the rationale for the regressive baseline.

The evaluator confirmed that the pre-existing two-stage air compressor was program funded because the evaluator provided the TA study associated with the project in 2000 when the two-stage unit was installed through the program. Without the evaluator's history at the site, the evaluator would have to rely on the customer to determine if the previous compressors were incentivized or not. Often times between the implementation of the project and the evaluation, there is staff turnover at the site which limits the available knowledge on the pre-existing equipment. Requiring the applicant to document the use of the regressive baseline would result in a streamlined evaluation of the project without the reliance on the program administrator or previous site knowledge.

The evaluator also recommends program designers complete an updated compressed air ISP study to determine if load/no load air compressors are still an appropriate baseline for new air compressor projects. Additionally, if load/no load is still the baseline, there should be a standardized baseline no load percent kW determined to standardize compressed air projects.

1.3 Customer Alert

The customer currently manually controls the baseload on one of the two installed VSD air compressors and runs the other compressor as a trim compressor. There are additionally savings to be realized by fixing the communication problems between the two compressors. Allowing the compressors to automatically determine the shared percent load between the two compressors would improve the part load performance. This would also allow the compressors to optimize the run hours between the two machines without relying on manual changes.

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 the information available.

2.1 Application Information and Applicant Savings Methodology

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

2.2 Applicant Description of Baseline

The applicant classified the project as a new construction measure with an industry standard practice (ISP) baseline. The classification was made due to the age of the existing equipment, which was about 21 years old. The baseline consists of 2 x 100 hp fixed speed single stage compressors with load/no-load controls that discharge 95 psi air. The applicant used a CAGI datasheets to model the baseline compressor performance. The baseline oil-flooded air compressors are served by a refrigerated dryer that is to remain at the site and is not included in the project analysis.

The baseline values used in the applicant savings analysis are presented in Table 2-1.

Table 2-1. Applicant baseline key parameters

Measure	Parameter	BASELINE		
		Value(s)	Source of Parameter Value	Note
	Size	100 hp		

Installation of two 100 hp VSD air compressors	Compressor rated capacity	477.4 CFM	Applicant savings calculations	
	Rated full load kW	90.9 kW		
	Controls	Load/no load		
	Quantity	2		
	Operating pressure	95 psi		
	Compressors operating hours	8,400 hours		
	Compressed air storage capacity	1 gal/CFM		
	Average condensate drain airflow per drain(1 total drain)	3 CFM		
	Demand associated with no zero-loss drains (1 total drain)	0.563 kW		

2.2.1 Applicant Description of Installed Equipment and Operation

The installed equipment includes two 100 hp variable speed drive (VSD) air compressors. The proposed system values used in the applicant savings analysis are presented in Table 2-2.

Table 2-2: Application proposed key parameters

Measure	Parameter	PROPOSED		
		Value(s)	Source of Parameter Value	Note
Installation of two 100 hp VSD air compressors	Size	100 hp	Applicant savings calculations	
	Compressor rated capacity	499.8 CFM		
	Rated full load kW	90.6 kW		
	Controls	Variable speed		
	Quantity	2		
	Operating pressure	95 psi		
	Compressors operating hours	8,400 hours		
	Average condensate drain airflow per drain (1 total drain)	0 CFM		
	Demand associated with no zero-loss drains (1 total drain)	0 kW		

2.2.2 Applicant Energy Savings Algorithm

The annual savings analysis for this project is based on nine days of compressed air flow data collected in 1-minute intervals.

The base case compressor performance is calculated based on the Compressed Air Challenge performance curve assuming a baseline storage capacity of 1 gal/CFM. The performance curve is adjusted based on the CAGI rated no load kW of the specific base case compressor model specified.

The applicant's assumed baseline compressor model's CAGI data was only available at 125 psi. CAGI data for the proposed model was available for both 125 psi and 100 psi, which the applicant used to calculate a 9% increase in capacity when decreasing the operating pressure from 125 psi to 100 psi. The applicant assumed the same 9% increase in CFM capacity when decreasing the baseline compressor operating pressure reduces from 125 psi to 100 psi. The applicant assumes the rated full load kW of the baseline compressor at 100 psi to be the same as the CAGI rated full load kW at 125 psi.

The applicant adjusts the full load compressor demand based on the rated performance and the estimated operating compressed air pressure (95 psi) at the facility using the following equation. This same equation is used for both the base and proposed case.

$$Operating\ kW = 0.995^{Rated\ Pressure\ psi - Operating\ Pressure\ psi} * Rated\ kW$$

The performance curve is used to calculate base case compressor demand according to the metered compressed air flow data. The metered compressed air flow data is shown in Figure 2-1 below.

Figure 2-1. Applicant CFM data

Hour	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
0	444	381	399	466	454	456	449
1	442	385	399	467	463	458	448
2	443	384	408	470	463	458	447
3	453	399	415	472	461	461	449
4	455	400	461	505	522	462	447
5	580	507	657	663	651	466	448
6	768	631	720	710	656	469	451
7	802	650	738	715	655	472	452
8	815	671	790	715	657	470	456
9	816	784	786	718	661	470	457
10	816	796	788	811	662	473	458
11	795	803	792	813	663	469	459
12	791	780	789	810	660	470	457
13	788	776	786	809	659	471	456
14	787	760	780	807	654	470	454
15	780	760	764	782	648	464	450
16	751	751	759	780	651	465	447
17	749	725	749	756	626	468	448
18	729	603	627	499	462	467	450
19	454	465	590	446	455	464	449
20	381	410	578	446	455	464	449
21	380	410	480	452	461	467	448
22	377	406	466	452	460	463	450
23	378	401	464	448	456	457	448

The base compressor performance curve generated from the Compressed Air Challenge performance data adjusted for the baseline compressors operating conditions is as follows:

$$\%kW\ input(\%\ Load) = 1.0417x^3 - 2.5625x^2 + 2.1710x + 0.3548$$

The applicant did not include dryer performance in the analysis because the site was planning on leaving the existing refrigerated dryer in place.

The proposed case variable speed compressor performance is based on CAGI data scaled based on the estimated CAIR pressure at the facility which was assumed to be 95 psi. The proposed case compressor performance curve is as follows:

$$kW\ input(\%\ Load) = 0.0001x^2 + 0.1285x + 9.8961$$

Zero loss drain savings are calculated by applying an average demand penalty to the base case system. Savings assume an average base case leakage rate of 3 CFM for the one drain, and an average compressor performance of 0.1876 kW/CFM based on the proposed case variable speed compressor. The 0.1876 kW/CFM is the average of the compressor performance CAGI data points at six varying part loads, not the performance at average compressor airflow. This results in an average base case demand of 0.563 kW associated with drain leakage for 8,400 hours a year, or 4,727 kWh.

The base case and proposed case performance curves are applied to the compressed air flow trend data. The average base and proposed system demand over the trend period are projected over 168 weekly hours for 50 weeks/year (assuming 2 weeks shutdown) to calculate annual savings.

The applicant calculates peak demand savings based on the time of day, day of week averages for the base and proposed compressor. Summer peak savings compare the base and proposed average compressor demand from 1PM-5PM Monday through Friday, and Winter Peak demand savings compare the base and proposed case demand from 5PM-7PM Monday through Friday.

2.2.3 Evaluation Assessment of Applicant Methodology

The evaluator agrees with the applicant methodology of using metered CFM data to create an hourly load profile which is then used to model baseline and proposed energy use.

The applicant used a 24×7 model to account for peak period reductions, and did not account for weekday holidays. The evaluator used an 8,760 model to account for holiday effects on peak period reductions.

2.3 On-site Inspection and Metering

This section provides details on the work performed during the on-site inspection.

2.3.1 Summary of Site Visit

This section summarizes the site visit.

- The evaluator visited the site on November 19, 2024.
- Nameplate information from the compressors was collected, and it was confirmed that the compressors were installed as expected.
- One of the pre-existing air compressors was observed to be retired in place. The pre-existing retired in place unit was 125 hp. The evaluator confirmed that due to an influx in peak production demand, the pre-existing unit struggled to meet the required capacity of the facility. The pre-existing compressor had a capacity of 694 CFM while the installed compressors total a capacity of 1,000 CFM. The evaluator was unable to confirm the capacity of the pre-existing 40 hp single stage compressor.
- The existing dryer remained and was operating as expected.
- The site contact indicated the following during the site interview:
    o The compressor demand is strictly dependent on the plant's production demand which is variable.
    o The operation in the winter between the Thanksgiving and Christmas holidays is reduced compared to the remainder of the year
    o The compressed air pressure setpoint is 100 psi.
    o The two installed compressors cannot communicate between each other, so the site manually manipulates a base load between the two compressors to diversify the machine operating hours.
    o The air compressor exhaust air is ducted to the production floor during the winter months via a manual damper in the exhaust duct above the air compressor units. The exhaust air is able to provide "free" space heating to a small percentage of the production floor, but unable to entirely meet the heating demand. The damper is closed and the exhaust air is ducted outside during the summer to negate additional heat gain to the space.

A photo of the installed air compressors is below in Figure 2-2, along with photos of the units' nameplate information in Figure 2-3.

Figure 2-2. Installed Air Compressors

Figure 2-3. Installed unit nameplates

Table 2-3 below summarizes the verification of the installed measure.

Table 2-3. Measure verification

| Measure Name	Verification Method	Verification Result
Installation of two 100 hp VSD air compressors	On-site verification with kW metering of two new air compressors	The installed equipment matches the applicant analysis.

2.3.2 Measured and Logged Data

Table 2-4 summarizes the metered data collected at this site by the evaluator.

Table 2-4. Metered data summary

Equipment	Meter	Metering Period
kW meters	WattNode WNB-3D-480-P	11/19/2024-2/4/2025

Figure 2-4 below shows the metered kW of the two VSD air compressors over the metering period.

Figure 2-4. Metered data
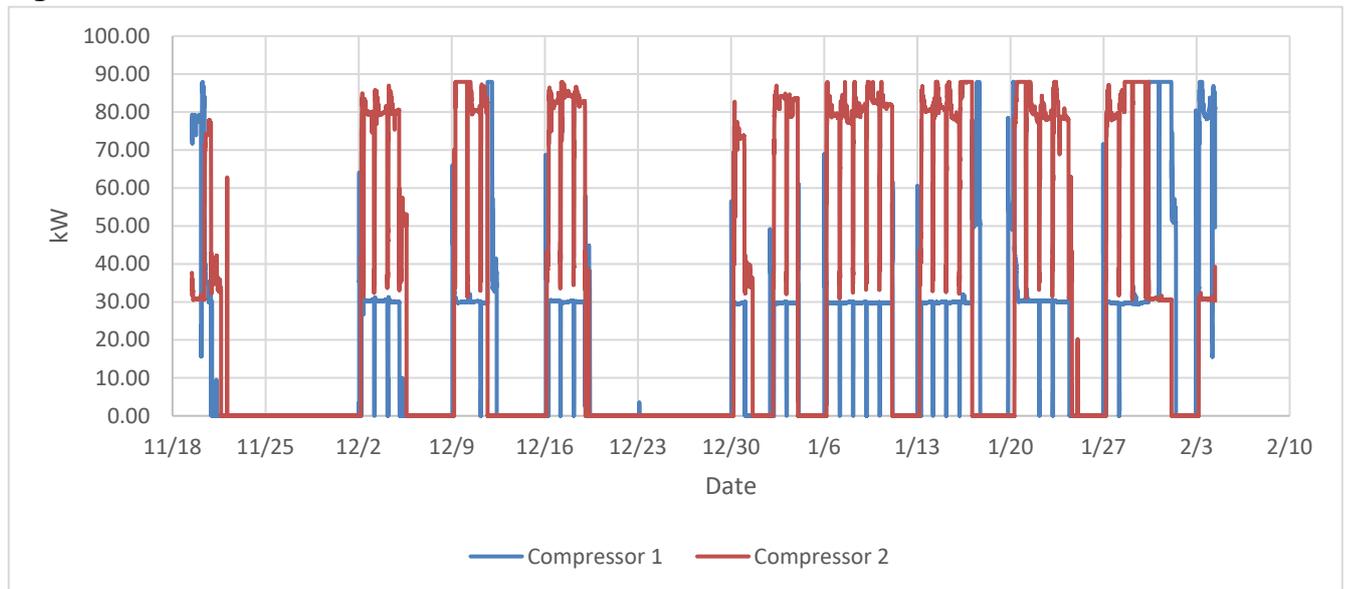
2.4 Evaluation Methods and Findings

This section describes the evaluator methods and findings.

2.4.1 Evaluation Description of Baseline

The evaluator classifies the measure as a lost opportunity with an ISP baseline. The pre-existing equipment that was reaching the end of its useful life included one two-stage 125 HP air compressor and a single speed 40 HP air compressor that was used as backup. An ISP baseline of two load / no-load air compressors is a regressive baseline due to the pre-existing two-stage air compressor having better performance than the baseline. The evaluator confirmed that the regressive baseline is reasonable due to exemption three stated in the Massachusetts Commercial and Industrial Baseline Framework. The exemption states that a regressive baseline is allowed if the pre-existing condition was program-funded. The evaluator can confirm that the pre-existing two-stage compressor was program funded because the evaluator provided the TA study associated with the project in 2000 when the two-stage unit was installed through the program.

The evaluator defined the baseline as two 100 hp load / no-load compressors that match the capacity of the installed equipment. The evaluator assumed a baseline storage ratio of 1 gal/CFM based on the compressed air ISP requirement for air-cooled single-staged rotary screw compressors with a replace on failure baseline. The site did not install additional storage as a part of this project.

2.4.2 Evaluation Calculation Method

The metered kW data showed different operating profiles between the two air compressors based on the site's control strategy. One compressor is constantly maintained at about 30% load while the other compressor serves the trim load. The metering period also revealed two different typical operating periods: one profile during the holiday season at reduced hours and the other a "typical" operation for the remaining part of the year. The difference between the two operating periods is that between Thanksgiving and Christmas, the site operates for reduced hours on Thursday, Friday, and Saturdays when compared to the "typical operation". The plant shut down periods during the week of Thanksgiving and two weeks at Christmas were also included in the evaluated model. Figure 2-5 below shows the kW profile during two weeks of the reduced operation between Thanksgiving and Christmas.

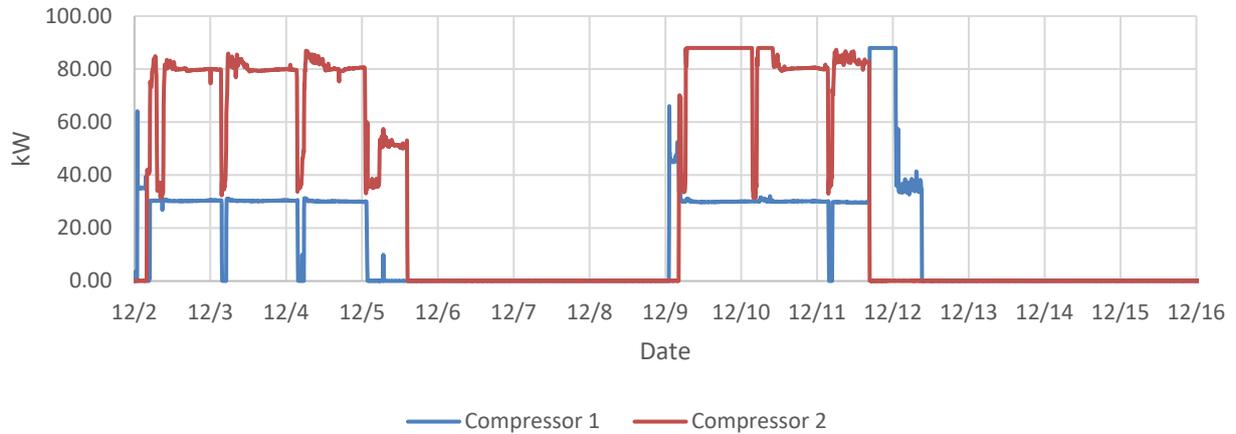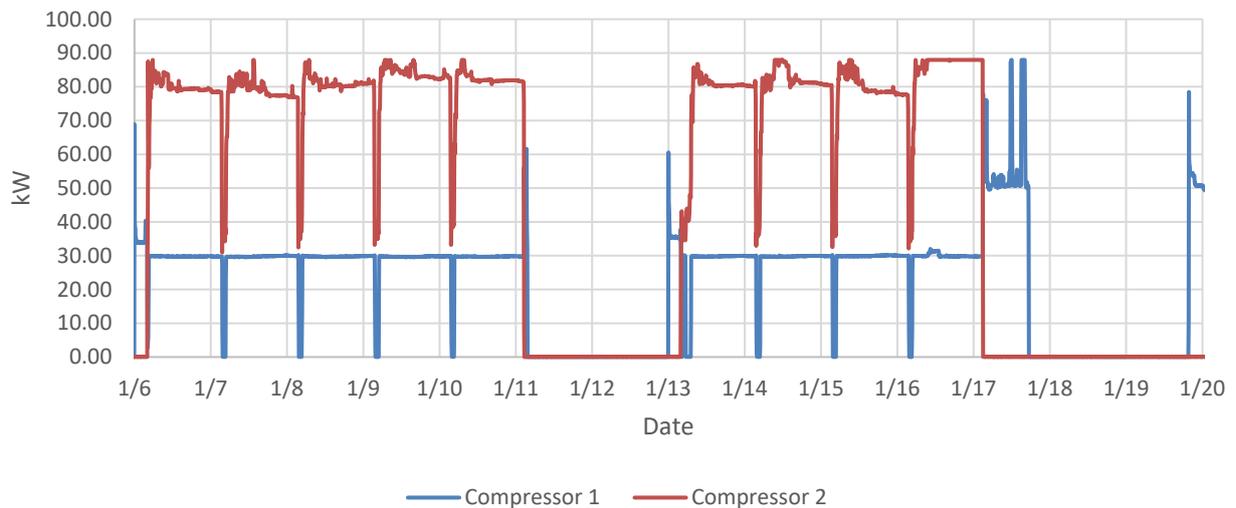**Figure 2-5. Holiday compressor kW operation**

Figure 2-6 below shows the kW profile during two weeks of the typical operation during the remaining year.

Figure 2-6. Typical compressor kW operation

Due to the differing schedules, the evaluator modeled the compressor operations in two different scenarios. The evaluator used the CAGI data sheet for the installed compressor (SN7507V) to determine a relationship between metered kW and CFM. The evaluator plotted CAGI kW vs CAGI kW/CFM to create the third order polynomial shown in Figure 2-7. The function was used to determine the operating CFM for each compressor as a function of the metered kW.

Figure 2-7. CAGI data comparing kW and kW/CFM (installed compressors)
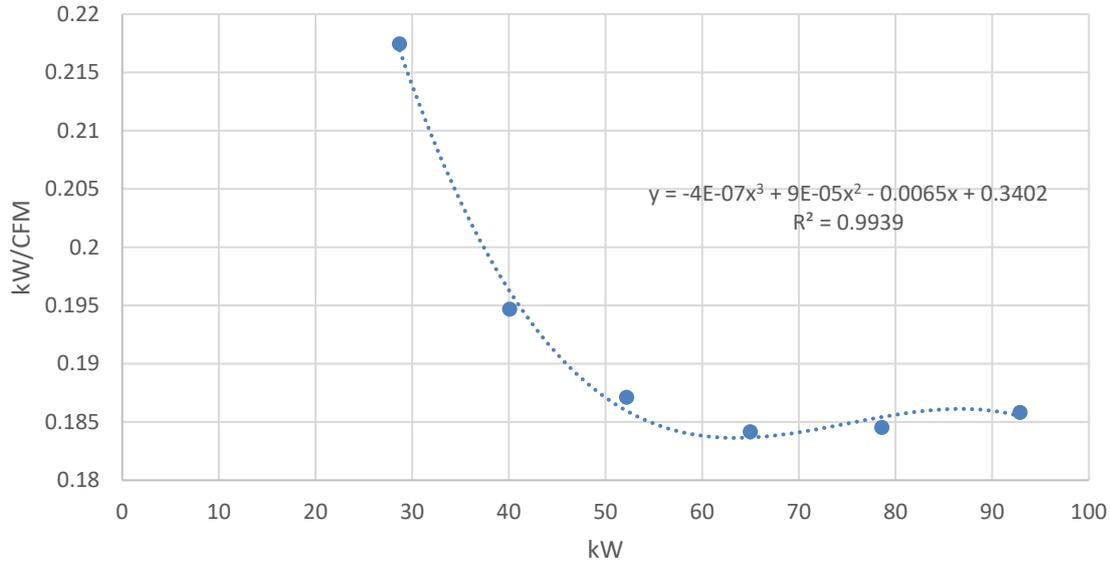
The CFM data was then plotted in 24x7 matrices to create an hourly profile for the typical and holiday weeks of operation as previously described. Figure 2-8 below shows the CFM profile during the holiday weeks between Thanksgiving and Christmas.

Figure 2-8. Compressor CFM during holiday season operation

Comp 1 CFM Between Thanksgiving and Christmas								Comp 2 CFM Between Thanksgiving and Christmas							
	1	2	3	4	5	6	7		1	2	3	4	5	6	7
Hour	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday	Hour	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
0	10	142	142	241	0	0	0	0	0	450	439	245	0	0	0
1	153	142	141	168	0	0	0	1	0	453	438	80	0	0	0
2	199	142	141	110	0	0	0	2	0	453	438	59	0	0	0
3	165	115	101	112	0	0	0	3	52	328	318	60	0	0	0
4	76	57	9	113	0	0	0	4	223	206	206	61	0	0	0
5	94	137	110	68	0	0	0	5	267	440	386	101	0	0	0
6	104	143	142	60	0	0	0	6	346	450	455	152	0	0	0
7	143	142	141	105	0	0	0	7	372	455	452	110	0	0	0
8	142	141	140	117	0	0	0	8	361	457	453	91	0	0	0
9	142	141	140	25	0	0	0	9	430	460	451	93	0	0	0
10	141	141	140	0	0	0	0	10	455	447	451	92	0	0	0
11	141	141	140	0	0	0	0	11	449	446	450	92	0	0	0
12	141	140	139	0	0	0	0	12	451	438	441	91	0	0	0
13	141	140	139	0	0	0	0	13	450	438	440	91	0	0	0
14	141	141	140	0	0	0	0	14	450	438	437	32	0	0	0
15	141	141	140	0	0	0	0	15	449	438	439	0	0	0	0
16	141	141	184	0	0	0	0	16	448	438	379	0	0	0	0
17	141	141	251	0	0	0	0	17	448	438	290	0	0	0	0
18	141	141	251	0	0	0	0	18	448	439	291	0	0	0	0
19	141	141	251	0	0	0	0	19	449	439	292	0	0	0	0
20	141	141	251	0	0	0	0	20	449	439	292	0	0	0	0
21	141	142	251	0	0	0	0	21	449	439	293	0	0	0	0
22	141	142	251	0	0	0	0	22	449	439	293	0	0	0	0
23	142	142	251	0	0	0	0	23	450	439	293	0	0	0	0

Figure 2-9 below shows the calculated CFM for each compressor during "typical" operation during the remainder of the year.

Figure 2-9. Compressor 2 CFM during typical week operation

	Comp 1 CFM Typical Hours								Comp 2 CFM Typical Hours					
	1	2	3	4	5	6	7		1	2	3	4	5	6	7
Hour	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday	Hour	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
0	213	179	112	146	206	154	0	0	0	353	349	350	387	145	0
1	207	178	112	146	206	163	0	1	0	347	349	351	389	119	0
2	204	165	112	145	209	115	0	2	0	344	348	351	385	68	0
3	209	119	87	122	203	98	0	3	5	263	252	255	243	0	0
4	158	57	45	38	139	57	0	4	173	195	174	194	206	0	0
5	236	164	114	130	230	56	0	5	249	335	340	410	283	0	0
6	227	169	114	141	234	55	0	6	273	350	362	450	290	0	0
7	220	168	113	140	233	57	0	7	342	349	360	461	293	0	0
8	207	167	113	140	234	56	0	8	381	352	361	462	288	0	0
9	206	134	112	190	233	56	0	9	386	382	361	414	241	0	0
10	201	111	112	208	213	36	0	10	386	400	357	398	239	0	0
11	193	111	111	208	219	0	0	11	386	400	356	394	238	0	0
12	190	111	111	208	211	0	0	12	384	393	355	392	237	0	0
13	188	111	111	206	213	0	0	13	384	390	352	391	244	0	0
14	187	111	111	206	205	0	0	14	383	387	351	388	242	0	0
15	187	111	111	206	244	0	0	15	383	354	351	389	208	0	0
16	187	112	112	206	215	0	0	16	383	355	350	385	206	0	0
17	187	112	112	206	172	0	0	17	383	353	350	387	206	0	0
18	187	112	112	206	150	0	0	18	383	352	350	388	206	0	0
19	187	112	112	206	150	0	18	19	383	352	350	388	207	0	0
20	187	112	112	206	150	0	59	20	383	352	350	388	207	0	0
21	187	112	112	206	150	0	57	21	383	351	351	388	207	0	0
22	187	112	146	206	150	0	87	22	384	351	351	388	207	0	0
23	189	112	148	206	150	0	145	23	384	350	350	387	207	0	0

The two weekly CFMs profiles were then extrapolated out to an 8,760-model based on the time of the year. That is, the holiday operation shown in Figure 2-8 occurs during the time between Thanksgiving and Christmas, and the typical operation in Figure 2-9 occurs during the remaining year.

To calculate the baseline energy use, the evaluator used CAGI data sheets for the same baseline load / no-load air compressor (model ST7509) that the applicant used. The evaluator used values from the Compressed Air Challenge % power curve to determine the relationship between percent kW input and percent capacity of the unit at the ISP air storage volume. The evaluator used a storage ratio of 1 gal/CFM based on the ISP for replace on failure measures. The relationship between percent capacity and percent kW input is shown in Figure 2-10 below.

Figure 2-10. Percent kW vs percent capacity for 1 gal/CFM per Compressed Air Evaluation Protocol

$$y = 1.042x^3 - 2.563x^2 + 2.171x + 0.355$$
$$R^2 = 0.998$$
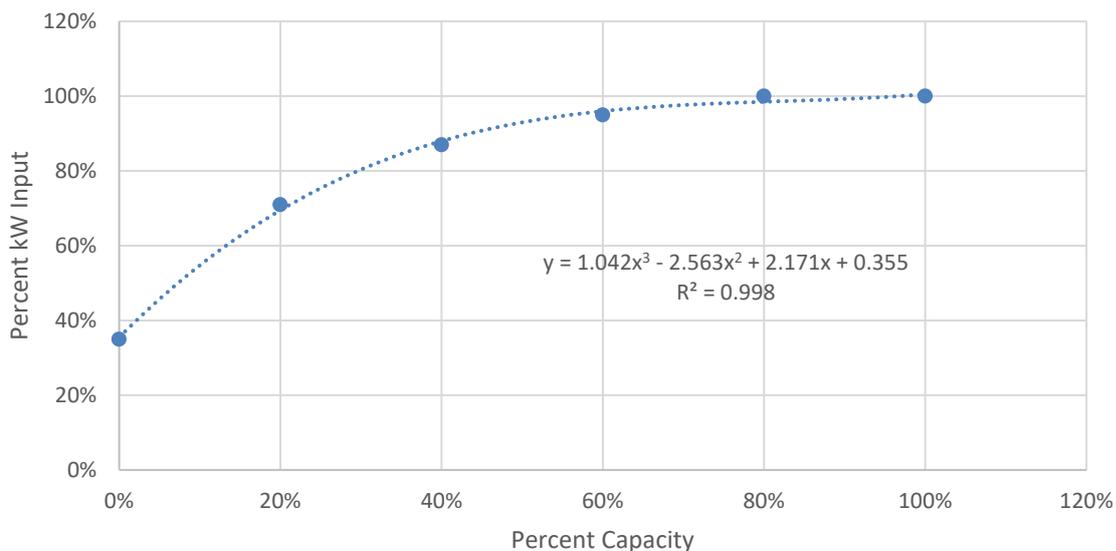
The baseline kW for each baseline air compressor in the 8,760 model is calculated using the following formula. When the calculated CFM exceeds the capacity for one compressor, it is assumed that one

compressor stays base loaded and the second compressor serves the remaining trim load. The evaluator assumed the same 9% increase in CFM capacity as the applicant as described in Section 2.2.2, when accounting for impacts from decreasing the rated CAGI data from 125 psi to 100 psi.

$$Baseline\ kW = full\ load\ kW \times (A(\frac{x}{y})^3 + B(\frac{x}{y})^2 + C\frac{x}{y} + D)$$

Where,

Full load kW	= Baseline compressor full load kW per CAGI datasheet (93.2 kW)
A-D	= Polynomial fit coefficients based on an assumed 1 gal/CFM of storage. The coefficients are shown in Figure 2-10 above.
x	= Calculated CFM. Assumed to be the sum of installed compressor 1 and compressor 2 CFM
y	= Rated flow capacity per CAGI data sheet adjusted to 100 psi operating pressure (477.42 CFM)

The baseline system demand includes the same assumptions for zero-loss drain savings as described in Section 2.2.2. The average compressor performance of 0.198 kW/CFM was based on the proposed case variable speed compressor average performance at the sites operating pressure of 100 psi. The annual compressor operating time was found to be 6,593 hours per year based on the 8,760 model. This results in an average base case demand of 0.577 kW associated with drain leakage for 6,593 hours a year, or 3,917 kWh.

The installed kW for each air compressor was calculated using a polynomial regression found to describe the relationship between CFM data and kW/CFM based on the installed compressors CAGI data. Air storage volume does not impact VSD compressor performance and no adjustments were included. Figure 2-11 shows the third order polynomial relationship generated.

Figure 2-11. CAGI data comparing CFM and kW/CFM
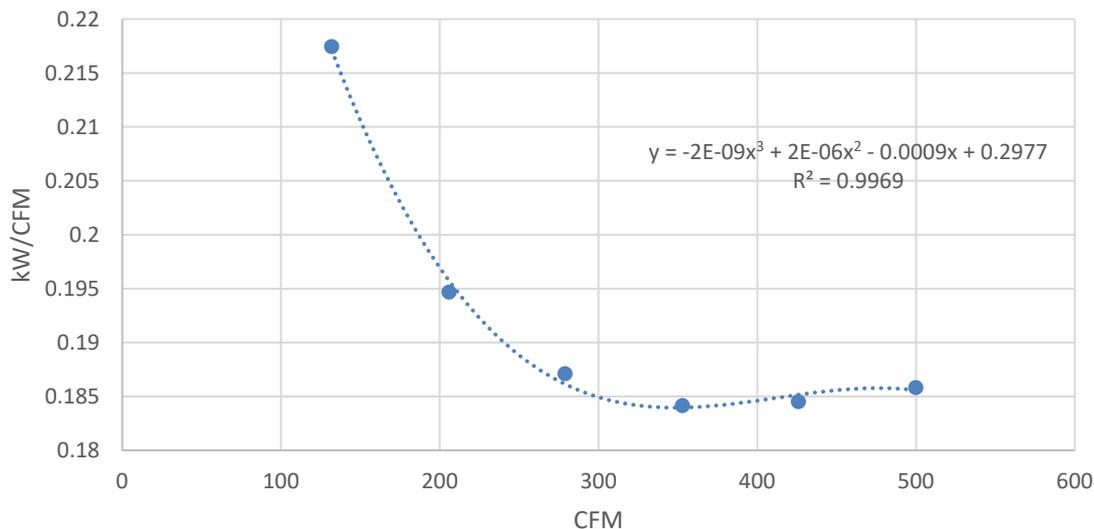
The installed kW for each compressor was calculated using the following formula.

$$Installed\ kW = AX^3 + BX^2 + CX + D$$

Where,

A-D   = Polynomial fit coefficients as shown in Figure 2-11 above.

X   = Calculated CFM per air compressor

The evaluator used calculated kW instead of directly using metered kW to determine installed kW to remain consistent in methodology between the applicant and the modeled baseline, and to determine impacts of each discrepancy. The evaluator confirmed that the calculated installed kWh for each weekly operation aligned with the actual metered kWh.

The demand reduction for each hour of the 8,760 model are calculated using the following formula.

$$Savings\ (kW) = Base\ Comp\ kW\ 1 + Base\ Comp\ kW\ 2\ + Drain\ Loss\ kW - Installed\ Comp\ 1\ kW \\ - Installed\ Comp\ 2\ KW$$

The evaluators used an 8,760 peak demand calculator to calculate summer and winter peak demand savings and on-peak energy savings. Figure 2-12 shows a summary of the on-peak, off-peak, and peak demand filters that were applied to the hourly savings to calculate the peak demand reductions and on-peak energy savings.

Figure 2-12. Screenshot summarizing on-peak hours, off-peak hours, and peak demand windows

Winter Peak Energy kWh savings: 7AM – 11PM, weekdays except holidays, October to May
Winter Off-Peak Energy kWh savings: 11PM – 7AM weekdays, all day weekends and holidays, October to May
Summer Peak Energy kWh savings: 7AM – 11PM, weekdays except holidays, June to September
Summer Off-Peak Energy kWh savings: 11PM – 7AM weekdays, all day weekends and holidays, June to September
Summer Average Demand kW reduction: 1PM – 5 PM, weekdays except holidays, June to August
Winter Average Demand kW reduction: 5PM – 7 PM, weekdays except holidays, December and January

3   FINAL RESULTS

The evaluated project involved the installation of two 100 hp VSD air compressors to replace an existing 100 hp two stage compressor and single stage 40 hp compressor that had reached the end of their useful life.

The applicant classified the project as a new construction project. The evaluator classified the project as a lost opportunity with an ISP baseline.

The evaluated first-year savings for the project were 3.4% more than the applicant-reported savings, primarily due to a decrease in plant CFM. These deviations are further discussed in Section 3.4. Table 3-1 presents the applicant and evaluated inputs used to model the project inputs.

Table 3-1. Summary of Key Parameters

Measure	Parameter	BASELINE		PROPOSED / INSTALLED	
		Tracking Value(s)	Evaluation Value(s)	Tracking Value(s)	Evaluation Value(s)
Installation of two 100 hp VSD air compressors	Compressors operating pressure	95 psi	100 psi	95 psi	100 psi
	Compressors operating hours	8,400 hours	6,593 hours	8,400 hours	6,593 hours
	Average airflow during operation	564 CFM	443 CFM	564 CFM	443 CFM
	Average performance during operation	0.223 kW/CFM	0.265 kW/CFM	0.180 kW/CFM	0.192 kW/CFM

3.4 Explanation of Differences

This section describes the key drivers behind any difference in the application and evaluation estimates of annual kWh savings. The following table summarizes these differences. The purpose of this table is to describe how changes to the key parameters influenced the final project savings through the end-use summary analysis. 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
Installation of two 100 HP VSD air compressors	Load Shape	Average CFM	+78.5%	**Increased savings –** The applicant metered an average of 564 CFM and the evaluator calculated an average 443 CFM. The decreased plant CFM results in a larger amount of time when the baseline compressor is operating at reduced output with worse part load performance.
	Hours of Operation	Compressors operating hours	-46.0%	**Decreased savings –** The applicant assumed the compressors would shut down for two weeks of plant shut down. The evaluator determined through metering that the compressors shut down for several hours every week during unoccupied hours.
	Operating efficiency	Operating sequencing	-29.1%	**Decreased savings –** The applicant assumed that the installed compressors would share the load equally when the operating CFM exceeded the capacity of one compressor. The evaluator modeled the profile based on the sites control of one manually base loaded compressor. The manual control increases run hours at a worse part-load performance which decreases savings.
Total				**+3.4%**

3.5 Lifetime Savings

Because the measure is lost opportunity with a single-baseline measure, the out-year factor is 100%. The evaluators calculated applicant and evaluated lifetime savings values using the following formula:

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

where:

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

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

Table 3-3. Measure M1 - Lifetime Savings Summary

Factor	Tracking	Application	Evaluator
Lifetime savings	3,154,095 kWh	3,154,095 kWh	3,261,262 kWh
First year savings	210,273 kWh	210,273 kWh	217,417 kWh
Measure lifetime	15 years	15 years	15 years
Baseline classification	New construction	New construction	Lost Opportunity

3.5.1 Ancillary impacts

There is ancillary gas heating impacts due to the exhaust air from the compressors being exhausted into the production space. The exhaust air is ducted to the production floor during the winter months via a manual damper in the exhaust duct above the air compressor units. The exhaust air is able to provide "free" space heating to a small percentage of the production floor, but unable to entirely meet the heating load. The higher efficiency of the installed VSD air compressors reduces the amount of heat added to the space during the winter months. The result is a loss in comfort to the occupants in the immediate area surrounding the air compressors. The space is not controlled to a tight heating setpoint, which negates any impact on the overall gas heating consumption at the facility. There are no quantifiable ancillary gas impacts from the reduction in space heat added to the space.

RI CUSTOM ELECTRIC EVALUATION SITE-SPECIFIC REPORT

DNV SITE ID: RICE23S100

Report Date: 02/10/2025

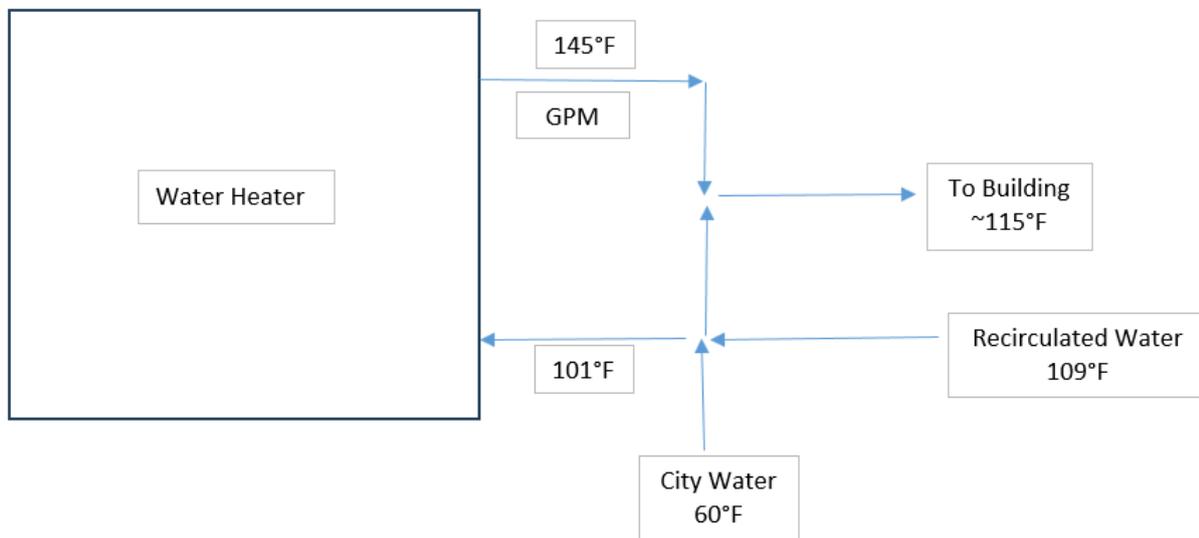| Application ID(s)	14322896	
Project Type	C&I New Construction	
Program Year	2023	
Evaluation Firm	DMI	
Evaluation Engineer	Luke Sendelbach	
Senior Engineer	Mickey Bush	

1 EVALUATED SITE SUMMARY AND RESULTS

This site is a 121,000 ft² existing office building in Providence. The single energy savings measure installed is a 34 MBH heat pump water heater (HPWH) in the basement mechanical room to serve the building's domestic hot water (DHW) loads. The domestic hot water loads are typical for an office; hand washing in restroom sinks and janitorial staff cleaning. The mechanical room is not conditioned; therefore, there are not any secondary energy impacts from the heat pump water heater.

The applicant and evaluator classify the measure as new construction measure event type because it replaces the building's existing heater that reached the end of its useful life. The baseline is an electric resistance water heater because industry standard practice in RI is a water heater with the same fuel source as the proposed water heater

A diagram of the domestic hot water system along with the average temperatures from the evaluation metering is shown in Figure 1-1.

Figure 1-1. Domestic hot water system diagram

The evaluation results are presented in Table 1-1.

Table 1-1. Evaluation Results Summary

PA Application ID	Measure Name		Annual Electric Energy (kWh)	% of Energy Savings On-Peak	Summer On-Peak Demand (kW)	Winter On-Peak Demand (kW)
14322896	M1 - Heat pump water heater	Tracked	19,644	83%	0.0	0.7
		Evaluated	15,386	58%	2.3	2.5
		Realization Rate	78%	55%	-	341%

1.1 Explanation of Deviations from Tracking

The evaluated savings are 22% less than the applicant-reported savings. The decrease in savings is primarily due to the lower average COP of the HPWH than was modelled.

1.2 Recommendations for Program Designers & Implementers

The evaluator found that the installed water heater's average COP is 1.86, which is worse the COP of 4.2 at standard rating conditions. The potential reasons that the evaluated COP is worse than the rated COP are the use of backup electric resistance heating, different hot water temperature (~140°F actual vs 120°F rated) and impact of standby losses when building loads are low. The evaluator recommends that Rhode Island Energy consider the impact of backup heating, heat pump tank water temperature, and standby losses when modelling the heat pump performance.

1.3 Customer Alert

The recirculation pump is observed to operate continuously. The customer can consider recirculation pump controls such as time of day scheduling to save pumping energy and reduce hot water system distribution losses.

Higher hot water tank temperatures can negatively impact heat pump performance; therefore, consider setting the hot water tank temperature to the minimum recommend temperature for preventing legionella.

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 the information available.

2.1 Application Information and Applicant Savings Methodology

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

2.2 Applicant Description of Baseline

The applicant measure event type is new construction. The baseline considered by the applicant is an electric resistance water heater. The new heater replaces an old heater that was at the end of its useful life. The exact age of the old heater is unknown, but it was retired in place and was clearly non-functional. A photo of that heater is shown in Figure 2-3. In Rhode Island, the appropriate baseline for a high-performance water heater is a baseline unit that uses the same fuel source (i.e. electric resistance baseline for a heat pump heater).

The baseline values used in the applicant savings analysis are presented in Table 2-1.

Table 2-1. Applicant baseline key parameters

Measure	Parameter	BASELINE		Note
		Value(s)	Source of Parameter Value	
M1	Annual DHW make-up water, gallons	173,756	Potable water bills and estimated hot/cold water split	
	Building supply temperature °F	115	Assumption	
	Makeup water temp, °F	50	Assumption	
	Baseline COP	1.0	Electric resistance	

2.2.1 Applicant Description of Installed Equipment and Operation

The applicant assumes that a new heat pump water heater would be installed to serve the building's domestic hot water loads.

The proposed system values used in the applicant savings analysis are presented in Table 2-2.

Table 2-2: Application proposed key parameters

Measure	Parameter	PROPOSED		
		Value(s)	Source of Parameter Value	Note
M1	Annual DHW make-up water, gallons	173,756	Potable water bills and estimated hot/cold water split	Same as baseline
	Building supply temperature, °F	115	Assumption	Same as baseline
	Makeup water temp, °F	50	Assumption	Same as baseline
	Installed COP	3.47	Unknown, does not match model spec sheet	

2.2.2 Applicant Energy Savings Algorithm

The applicant analyzed this measure in a monthly bin model.

The applicant first used potable water billing data over an approximately yearlong period (383 days) from July 2021 until June 2022 to estimate the DHW monthly loads. There are two water accounts associated with the evaluated building that are summed together for a total water usage (both DHW and cold water).

$$Billed\ Gallons_{month,\ total} = \sum_{account} Billed\ Gallons_{month,\ account}$$

Where,

$month$ = the monthly water bill

$account$ = each of two different billing accounts for the campus

The applicant indicates that both of these accounts also service an adjacent building. The adjacent building had its own new water heater and associated savings application, so monthly water consumption (DHW and cold) for each building was split according to an estimate of the ratio of the two buildings' floor areas (31% for the application building).

$$Billed\ Gallons_{month,\ application} = \frac{Area_{application}}{Area_{application} + Area_{adjacent}} * Billed\ Gallons_{month,\ total}$$

Where,

$Area_{applicaiton}$ = evaluated building area, 121,040 ft²

$Area_{adjacent}$ = adjacent building area not served by HPWH, 264,500 ft²

The water consuming end uses are the cold water for sinks and toilets, hot water for sinks (provided by water heater in this application) and cooling tower makeup water. The applicant divides the billed water usage into the three end uses (cold water, hot water, cooling tower water.)

In the winter months when the cooling tower is not used building water use is estimated to be split 50/50 between cold water and hot water.

The billed water usage increases significantly during the summer months due to the need for cooling tower makeup water, so the fraction of the monthly water usage that is DHW was estimated as shown in in Table 2-3. In the summer months the cooling tower is estimated to account for 30% of water consumption in October and up to 80% of consumption in August with the remaining amount being split between domestic cold and hot water.

The applicant's annual DHW usage is 173,756 gallons as shown in Table 2-3, and is calculated using the following formula:

$$DHW\ Gal_{month} = (DHW\ Fraction)_{month} * Billed\ Gallons_{month,\ application}$$

Where,

$DHW\ Fraction_{month}$ = fraction of all billed building gallons that are DHW, see Table 2-3.

Table 2-3. Applicant annual DHW loads

Bill Month	Total gallons	Tower %	Cold %	Hot %
Jan	21,372	0%	50%	50%
Feb	29,115	0%	50%	50%
Mar	23,930	0%	50%	50%
Apr	27,126	0%	50%	50%
May	52,987	0%	50%	50%
Jun	51,277	60%	20%	20%
Jul	83,392	60%	20%	20%
Aug	145,426	80%	10%	10%
Sep	54,510	40%	30%	30%
Oct	42,275	30%	35%	35%
Nov	25,726	0%	50%	50%
Dec	22,006	0%	50%	50%
Total	579,141	231,628	173,756	173,756

The heater hot water load was calculated for each month according to the following:

$$kBTU_{month} = \frac{(115°F - 50°F) * 1.0 \frac{BTU}{lb * °F} * 8.34 \frac{lb}{gal} * DHW\ Gal_{month}}{1,000 \frac{BTU}{kBTU}}$$

Where,

115°F = domestic hot water temperature supplied to the building. This is after the mixing valve. The water heater setpoint is warmer than this temperature and then the water is tempered by a mixing valve prior to going to the faucets.

50°F = city water temp

$1.0 \frac{BTU}{lb*°F}$ = specific heat of water

$8.34 \frac{lb}{gal}$ = density of water

$1,000 \frac{BTU}{kBTU}$ = conversion factor

Baseline monthly energy use is the kBTU load divided by a COP of 1.0 for electric resistance and converted to kWh:

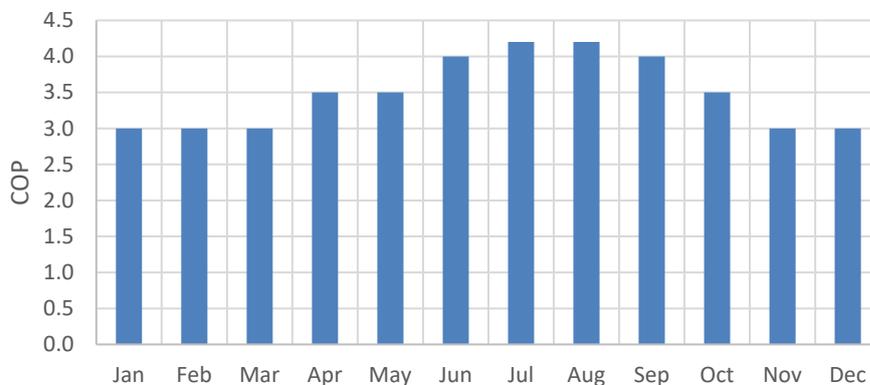$$kWh_{month,\ baseline} = \frac{kBTU_{month}}{1.0\ COP * 3.412 \frac{kBTU}{kWh}}$$

Where,

$1.0\ COP$ = electric resistance COP

$3.412 \frac{kBTU}{kWh}$ = conversion factor

The installed energy use uses the same methodology, but the COP of the HPWH changes depending on the month, as shown in Figure 2-1:

Figure 2-1. Applicant HPWH COP

The source of the changing COPs is not clear. The rated COP of the water heater is 4.2 (rating conditions are 80°F entering air temperature, inlet water at 70°F, and hot water at 120°F). It is possible that this variation is intended to capture the use of the backup resistance element that is included in the heater or the variation in ambient temperature (i.e. space is colder in the winter therefore the heat pump performance is worse).

Savings are the difference between the baseline total annual energy and the installed total annual energy. Total savings are 19,644 kWh.

2.2.3 Evaluation Assessment of Applicant Methodology

The evaluator agrees with the applicant methodology for calculating the make-up water into the hot water loop monthly and annual gallons. The monthly water use increases in May, so it appears that the cooling tower is enabled in May, but the applicant models the tower being enabled in June. If the applicant modeled cooling tower operation in May, the domestic hot water gallons would decrease along with the modelled savings.

The applicant's methodology calculates the load to heat the make-up water into the hot water system. The applicant did not consider standby losses from the storage tank or consider the DHW recirculation loop distribution losses.

It is unknown how the applicant chose the heat pump COPs for each month, or why the heat pump COP changes from month to month.

2.3 On-site Inspection and Metering

This section provides details on the work performed during the on-site inspection.

2.3.1 Summary of Site Visit

This section summarizes the site visit.

- The evaluator visited the site on October 8, 2024.
- Nameplate information from the HPWH was collected, and confirmed that the HPWH was installed as expected.
- The old heater was observed to be retired in place and disconnected from the DHW piping.
- Control screens were collected from the unit showing:
  - Water heater output temperature setpoint (140°F) (actual temperature leaving the heater is higher than the setpoint due to stratification in the tank.)
  - Current tank temperature
  - Heat pump compressor lifetime hours
  - Backup electric element lifetime hours
- The domestic hot water system includes a recirculation loop and associated pump. The recirculation loop is used to ensure that hot water is always available at the end uses. Recirculated water mixes with make-up city water before entering the water heater. Per metered data the recirculation pump runs continuously.
- The system also includes a mixing valve, which tempers the hot water from the heater before the water goes to the end uses. Hot water from the heater mixes with a portion of the combined re-circulation/city water to provide ~115-120°F to the end uses (actual temperature was not verified).
- The evaluator installed a kW meter on the heat pump water heater.
- An ultrasonic flow meter was installed to measure the flow rate leaving the DHW heater.
- A space temp/ RH sensor was installed to monitor the ambient air conditions; this HPWH uses air as a heat source, so changes in air conditions may impact unit performance.
- Thermocouple loggers were installed on the pipe surface and insulated from the air to monitor the temperatures of the following:
  - Water heater leaving water
  - Recirculation return water
  - City water temperature
  - Mixed city water & recirculation return water (entering water heater)
- A motor logger was installed on the recirculation return pump. A spot observation of the flow meter indicates that the recirculation pump is 0.5 gpm when there is no fixture DHW load.

Table 2-4 below summarizes the verification of the installed measure.

Table 2-4. Measure verification

Measure Name	Verification Method	Verification Result
M1 – HPWH	Metering and onsite verification	Evaluator confirmed that the HPWH was installed and serving DHW loads. The installed HPWH model matches the applicant analysis. The old heater was observed to be retired in place and disconnected from service.

2.3.2 Measured and Logged Data

Table 2-5 summarizes the metered data collected at this site by the evaluator.

Table 2-5. Metered data summary

Equipment	Meter	Metering Period
Ultrasonic flow meter	Fuji FSVEYY12-SYYYB-N (flow meter) Onset UX120-006M (records gpm) Onset UX90-001M (records cumulative gal)	43 Days (10/08/2024-11/20/2024)
Space temp/ RH logger	Onset U12-013	
Thermocouple logger (2 qty) & type K thermocouples	Onset UX120-014M	
kW power meter	Dent Elite Pro XC	
Motor status logger	Onset UX90-004M	

A photo of the installed HPWH and its nameplate is below in Figure 2-2, along with a photo of the retired in place unit in Figure 2-3.

Figure 2-2. New HPWH

Figure 2-3. Disconnected old water heater

Figure 2-4 shows the nameplate of the installed HPWH.

Figure 2-4. HPWH nameplate

2.4 Evaluation Methods and Findings

This section describes the evaluator methods and findings.

2.4.1 Evaluation Description of Baseline

The evaluator classifies the measure event type as lost opportunity/ replace on failure. The evaluator agrees with the applicant that an electric resistance water heater is an appropriate baseline for serving the building's DHW loads. In Rhode Island, the appropriate baseline for a high-performance water heater is a baseline unit that uses the same fuel source. The 2021 RI baseline document defines the baseline for a heat pump water heater as an electric resistance heater.

2.4.2 Evaluation Calculation Method

The evaluator calculated annual baseline and installed case energy use based on hourly profiles for a typical weekday, a typical Saturday and a typical Sunday/Holiday. The daily profiles are extrapolated to annual energy based on the number of weekdays, Saturday and Sundays/Holiday in a year.

Metered Water Heater Load

The evaluator calculated the water heater load for each 15-minute metering interval using trend data and the formula below.

$$kBTU/hr\ Load = \ gpm\ \times (HWT - MWT) \times 60 \times 8.34 \times \frac{1}{1000} \times \left(\frac{1}{4}\right)$$

Where:

|	
gpm	= metered 15-minute average hot water flow, gallon/min
HWT	= metered 15-minute average hot water temp at tank outlet, °F
MWT	= metered 15-minute average mixed water temp at tank inlet, °F
60	= minutes / hour
8.34	= lb / gallon water
1/1000	= BTU / kBTU

The mixed water or water heater inlet temperature is a mix of warm recirculation water returning to the heater and cold city water that is added to the system to replace the hot water used at the fixtures. Using this temperature accounts for the heating of make-up city water and the recirculation loop distribution losses. (The applicant only models the make-up city water heating load.) There is generally a minimum recirculation flow of 0.5 gpm that is always flowing regardless of whether there is a hot water load.

Load Profile

The water heater load was sorted into typical daily profiles in order to extrapolate the metering period to annual water heater load and energy use. Different hourly profiles were developed for weekdays, Saturdays and Sundays/holidays.

The resulting load profile is shown in Figure 2-5.

Figure 2-5. Evaluation load profile
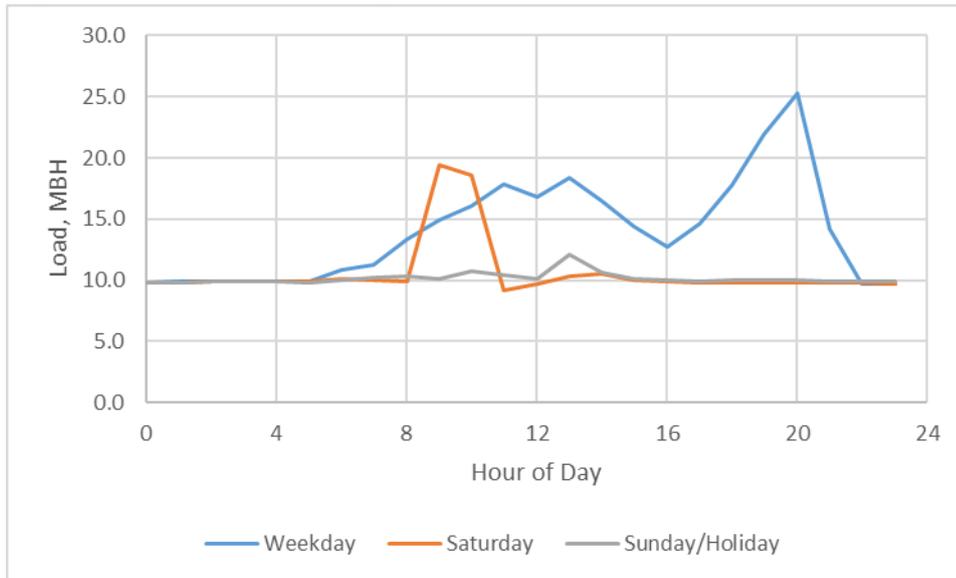
Hot water use can be seen to increase during weekdays while the building is occupied. There are also additional spikes in use after business hours. This is likely due to janitorial staff using hot water for cleaning. The Saturday profile matches the Sunday profile except for on Saturday October 26th when there was a large spike in load in the morning The reason for the spike in usage is not clear.

Baseline Equipment Performance

The baseline equipment is an electric resistance heater with a tank volume (119 gallon) and heating capacity (>12 kW) identical to that of the installed heater. IECC 2018 table C404.2 allows for the calculation of the performance of a resistance heater discounted for tank thermal losses (just as the evaluation performance is discounted for tank thermal losses). The baseline COP is calculated as:

$$COP = 1.0 - \frac{\left(0.3 + \frac{27}{119 \, gallon}\right)}{100} = 0.995$$

Baseline and Installed Demand & Savings

To calculate the baseline water heater input power daily profiles the hourly load is divided by the COP and converted to kW:

$$kW_{baseline} = \frac{MBH \, Load}{COP_{baseline \, or \, installed} \times 3.412}$$

The installed water heater hourly profiles for a typical weekday, Saturday and Sunday/Holiday are calculated based on the metered data.

Annual baseline and installed water heater energy is the sum of each day type's hourly kW, and multiplied by the number of days each type has annually:

$$Annual\ kWh_{baseline\ or\ installed}$$
$$= 251\ days \times \sum_{weekdays} kW_{baseline\ or\ installed} \times 1\ ^{hour}/_{bin}$$
$$+ 52\ days \times \sum_{Saturdays} kW_{baseline\ or\ installed} \times 1\ ^{hour}/_{bin}$$
$$+ 62\ days \times \sum_{Sundays\ \&\ Holidays} kW_{baseline\ or\ installed} \times 1\ ^{hour}/_{bin}$$

Savings are the difference between the baseline and the installed annual kWh, or 15,158 kWh.

Installed Water Heater Performance

The installed water heater performance was calculated for comparison with the applicant's calculations. The total energy use of the heater during the metering period was directly summed from the kW meter. The average COP of the HPWH was calculated as:

$$COP = \frac{(kBTU\ Load)_{trend\ period}}{HPWH\ kWh\ \times 3.412} = 1.48$$

The calculated average COP is based on the useful delivered heat and is less than the total system COP because the load due to tank thermal loss is not included—the calculated ΔT is that of the tank inlet and the outlet, not the heating coil inlet and outlet.

The COP cannot be accurately calculated on a 15-minute basis because the demand does not instantaneously meet the load—hot water demand may lower the tank temperature quickly for a brief period of time while the heat pump heats the water back up slowly for a longer duration.

The calculated COP is 1.86, which is less than the rated value of 4.2. This is due to a few reasons:

1. Periods of very high hot water loads will cause the controls logic of the heater to enable the electric resistance element to help meet demand. This element only has a COP of 1.0, and so lowers the average performance. The kW power meter data shows that the resistance element was operation for about 3% of the metering period, and so likely only contributes a small amount to the average COP.

2. The hot water heater discharge temperature is set to 140°F. Heat pump performance decreases as the hot water temperature increases. The rated COP for the installed unit is at 120°F hot water. The evaluators estimate that the 140°F setpoint decreases the rated COP by about 33%, which accounts for a large portion of the COP discrepancy. This estimate is based on data collected by a Sustainable Technologies Technical brief, which can be found in the references section of this report

3. A cooler inlet/ambient air temperature also likely reduces the performance of the heat pump. However, rating conditions at 80°F, and the boiler room the HPWH was installed in was generally between 65°F and 82°F (average of 74°F), which are not significantly different than the rating condition. As a result, the cooler air temperature likely only contributes a small amount to the metered versus rated COP discrepancy.

4. Heat pump water heaters will show lower apparent COPs during periods when there is low flow, because the standby losses make up a fixed thermal loss, regardless of what the actual DHW gpm load is. Most of the collected 15-minute increment metered data shows flows less than 1 gpm, which is low.

3 FINAL RESULTS

This section summarizes the evaluation results determined in the analysis above. This section includes a summary table of savings by major end-use and application.

Table 3-1. Summary of Key Parameters

Measure	Parameter	BASELINE		PROPOSED / INSTALLED	
		Tracking Value(s)	Evaluation Value(s)	Tracking Value(s)	Evaluation Value(s)
M1	Annual Make-up Water	173,756 gallons	162,383 gallons	173,756 gallons	162,383 gallons
	Water Heater Flow	Not provided	305,129 gallons	Not provided	305,129 gallons
	Make-up water temperature	50°F	60°F	50°F	60°F
	Return water temperature	Not calculated	109°F	Not calculated	109°F
	Entering water heater temperature	Not calculated[1]	100°F	Not calculated[1]	100°F
	Building supply temperature	115°F	Not metered[2]	115°F	Not metered[2]
	Water heater supply temperature	Not calculated[1]	144°F	Not calculated[1]	144°F
	Make-up water load	94,193 kBtu	74,514 kBtu[2]	94,193 kBtu	74,514 kBtu[2]
	Recirculation distribution losses	Not calculated	38,059 kBtu[2]	Not calculated	38,059 kBtu[2]
	Water heater load	94,193 kBtu	112,573 kBtu	94,193 kBtu	112,573 kBtu
	COP	1.0	0.99	3.47	1.86

[1] The applicant's water heater entering water temperature would be 98°F assuming the same water heater temperature of 144°F metered by the evaluator and the same recirculation loop flow rate calculated by the evaluator

[2] Evaluator assumed the building supply temperature is 115°F in order to divide the water heater load into make-up water load and recirculation loop distribution losses.

The evaluator's savings calculations are based on the water heater inlet and outlet temperatures and the flow rate through the water heater. In order to compare the evaluator's key parameters to the applicant's key parameters the evaluated water heater load is divided into the two load components; make-up water load and recirculation water distribution losses.

The applicant only models the make-up water load. The main difference between the applicant and evaluator's make-up water load is the modelled make-up (city) water temperature. The evaluator found the make-up water to be warmer (60°F vs 50°F), which reduced the make-up water load. Additionally, the evaluator found the make-up water flow rate to be lower than the applicant.

The applicant did not model the re-circulation loop distribution losses. The evaluator's modelled re-circulation loop distribution losses (building supply is 115°F and return wate temperature is 109°F) offsets the lower make-up water load resulting in a higher total water heater load than was modelled by the applicant.

3.4 Explanation of Differences

This section describes the key drivers behind any difference in the application and evaluation estimates of annual kWh savings. The following table summarizes these differences. The purpose of this table is to describe how changes to the key parameters influenced the final project savings through the end-use summary analysis. 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	Operating Load	Makeup water temperature	-21%	**Decreased savings –**The evaluated makeup water temperature is higher than the applicant resulting in a lower makeup water heating load and a reduction in energy savings.
	Operating Load	Makeup water gallons	-9%	**Decreased savings –**The evaluated makeup water use is lower than the applicant resulting in a lower makeup water heating load and a reduction in energy savings.
	Operating Load	Recirc Loop distribution losses	+56%	**Increased savings –**The evaluator included the recirculation loop distribution losses in the water heater load and the applicant did not. The higher water load increases savings.
	Operating Efficiency	Baseline COP	+1%	**Increased savings –** Adjusting the baseline efficiency to account for tank thermal losses increases savings.
	Operating Efficiency	COP	-49%	**Decreased savings –** The evaluated performance of the HPWH was worse than was modeled by the applicant, which results in a decrease in savings.
Total				**-22%**

3.5 Lifetime Savings

Because the measure is New Construction with a single-baseline measure, the out-year factor is 100%. The evaluators calculated applicant and evaluated lifetime savings values using the following formula:

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

where:

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

The evaluated lifetime savings are less than the tracking lifetime savings because the evaluated first-year savings are less than the tracking first-year savings. The source of the applicant measure life is unknown, but is consistent with the default measure life of the RI Screening Tool. Table 3-3 provides a summary of key factors that influence lifetime savings.

Table 3-3. Measure M1 - Lifetime Savings Summary

Factor	Tracking	Application	Evaluator
Lifetime savings	294,660 kWh	294,660 kWh	230,797 kWh
First year savings	19,644 kWh	19,644 kWh	15,386 kWh

Factor	Tracking	Application	Evaluator
Measure lifetime	15 years	15 years	15 years
Baseline classification	New construction	New construction	New construction

3.5.1 Ancillary impacts

There are no ancillary impacts associated with the measure.

4   REFERENCES

Gumpas, L. M., & Simons, G. (2013). Factors affecting the performance, energy consumption, and carbon footprint for ultra low temperature freezers: case study at the National Institutes of Health. *World Review of Science, Technology, and Sust. Development, 10*(1/2/3), 129-141.

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