Rhode Island Commercial and Industrial Impact Evaluation of 2016 Custom Electric Installations

National Grid

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1 EXECUTIVE SUMMARY

This Executive Summary provides a high-level review of the results for the Rhode Island (RI) Commercial and Industrial (C&I) Impact Evaluation of 2016 Custom Electric Installations. In this section, we state the study objectives, summarize the evaluation approach, and present key findings, conclusions, and recommendations.

The scope of work of this impact evaluation covered the 2016 Custom Electric impact category, which included lighting, HVAC, process, refrigeration, motors, compressed air, and others. The measures installed include new construction, major renovation, and retrofit projects.

The project was completed between 2018 and 2019. This is the first custom evaluation to combine the broad category of custom electric installations into one evaluation[1] to be done annually. RI National Grid has historically rotated impact evaluations of different custom electric end uses on an approximate three to five-year cycle by piggybacking with National Grid's sampled sites in Massachusetts (MA[2]).

1.1 Overview of objectives and approach

The objective of this impact evaluation is to provide verification or re-estimation of electric energy and demand savings estimates for a sample of custom lighting and non-lighting electric projects through site-specific inspection, monitoring, and analysis.

The results of this study will be used to determine the gross realization rates for custom electric energy efficiency projects implemented in 2020 and beyond. These results are scheduled to be updated annually as subsequent impact evaluations of 2018 and 2019 program years are completed. This aligns with the new impact evaluation paradigm of studying the Custom installations on a staged basis annually. DNV GL and National Grid have decided to skip PY2017 due to the availability of more recent (2018) population data.

For this year the RI site-specific results were aggregated with evaluation results of a similar study in Massachusetts to determine realization rates for National Grid's custom electric installations in RI. RI site results will be reviewed on their own but for this year "piggybacking" on top of MA[2] results is still necessary to achieve required precisions. It is envisioned that over the three years RI will evaluate enough sites to develop independent RI only results.

A synopsis of the research approach is as follows:

The DNV GL team developed a stratified sampling design from program participation data provided by National Grid based on agreed assumptions. The study was designed to quantify (a) achieved electric energy savings for custom electric projects, with a targeted sampling precision of ±10% at 90% confidence overall MA[2] and RI combined; (b) achieved electric energy savings for custom lighting and custom non-lighting projects, with a targeted sampling precision of ±15% at 90% confidence overall MA[2] and RI combined; and (c) achieved electric demand savings for custom electric projects, with a targeted sampling precision of ±10% at 80% confidence overall MA[2] and RI combined.

Site-specific measurement and verification (M&V) plans were created for each sampled site. These plans were reviewed and approved by National Grid before data collection was initiated.

[1] Broken down into two measures groups; lighting and non-lighting. CHP and CDA were also not included

[2] National Grid territory of MA

The evaluation collected and reviewed all the provided program documentation and collected data associated with each sampled project. Data collection methods included interviews of facility personnel, interviews of equipment vendors, on-site monitoring of operating equipment, receipt of data collected by the customer, and receipt of utility meter consumption data. The data used in the estimation of evaluated savings were collected by the team according to each approved M&V plan.

The evaluation created a custom measure specific analysis for each sampled project. Included in this analysis was an assessment of the baseline condition for each project sampled. When the need for a revised baseline was determined, the evaluators worked with National Grid to develop one that was appropriate for the measure. Evaluated savings estimates were then calculated using this revised baseline.

The evaluation created unique site reports for each sampled project. Each report includes a project description, a description of the tracking savings assumption and methodology, a baseline review, a description of the data collected by the evaluation, a description of the evaluation analysis completed, and a discussion of the evaluation results and reasons for the variance between tracking and evaluation estimates of savings. These reports are available in APPENDIX B.

1.2 Key findings and conclusions

The site-level evaluation results were aggregated using the final adjusted case weights. The realization rates were calculated and then applied to total tracking savings to determine their total evaluated savings. The overall (MA+RI) realization rate is the ratio of the total evaluated savings to the total tracking savings, each of which is calculated by summing across National Grid (MA+RI). Table 1-1 and Table 1-2 summarize the lighting and non-lighting results of this analysis. The results presented include realization rates (and associated precision levels) for annual kWh savings, and on-peak demand (kW) savings at the times of 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:

1. 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.
2. 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.

The electric lighting annual energy savings realization rate was 99.8% overall (MA+RI) with a relative precision (RP) of ±7.6% at 90% confidence interval. Summer Peak demand achieved 104% RR with an RP of ±12.8% at 80% confidence interval and 85% RR with ±9.9% at 80% confidence interval (CI) for winter peak demand savings.

The error ratio for lighting savings in MA+RI was calculated to be 0.23 compared to the design estimate of 0.40 for energy. Summer and winter peak demand error ratios were 0.46 and 0.36 compared to 0.5 and 0.8 design estimates, respectively.

For RI, the lighting realization rate is 99.9% with RP of ±5.0% at 90% confidence interval. Summer and winter peak demands are at 104% and 85% with RP of ±11.9% and ±7.5% at 80% confidence interval, respectively. These RI-only lighting results have achieved really good precisions in 2016 but it is important to note that the study had only 3 sampled sites with one really large street lighting site. The large street[3] lighting site makes nearly 50% of the entire custom lighting program savings, therefore the evaluation

[3] The large street lighting achieved a realization rate of nearly 99% for energy and 96% for winter peak demand kW savings and no summer demand savings. A small change in the site savings would change the overall RR significantly.

result has a big impact on the overall program. More sample points (observations) are needed in the RI population to use RI-standalone results.

Table 1-1. 2016 custom lighting results by state

Savings	Energy MWh (@90%CI)			Summer On-Peak kW (@80%CI)			Winter		
Territory	MA	RI	MA+RI	MA	RI	MA+RI	MA	RI	MA+RI
Total Tracking Savings	61,381	19,143	80,524	936	8,299	7,363	4,021	13,647	9,626
Realization Rate	99.8%	99.9%	99.8%	107.4%	104.3%	104.0%	85.3%	85.2%	85.2%
Error Ratio	0.26	0.05	0.23	0.11	0.46	0.46	0.06	0.29	0.36
Relative Precision	±9.2%	±5.0%	±7.6%	±8.2%	±11.9%	±12.8%	±4.3%	±7.5%	±9.9%

The electric non-lighting annual energy savings realization rate was 65.5% overall (MA+RI) with a relative precision (RP) of ±12.3% at 90% confidence interval. Summer and Winter Peak demands were 69.9% and 68.7% RR with ±12.4% and ±10.6% RP at 80% confidence interval respectively.

The error ratio for non-lighting savings in MA+RI was calculated to be 0.51 compared to the design estimate of 0.60 for energy. Summer and winter peak demand error ratios were 0.65 and 0.56 compared to 0.8 and 0.8 design estimates, respectively.

For RI, the non-lighting realization rate is 69.3% with RP of ±23.0% at 90% confidence interval. Summer and winter peak demands are at 70.9% and 77.1% with RP of ±17.8% and ±17.3% at 80% confidence interval, respectively. This RI-only energy savings (kWh) realization rate is higher than MA due to less variance in MA-only site level results. Therefore, DNV GL and National Grid are planning a larger sample for year-2 and year-3 of this rolling-based evaluation to achieve the targeted combined RP by the end of year-3.

Table 1-2. 2016 custom non-lighting statewide results

Savings	Energy MWh (@90%CI)			Summer On-Peak kW (@80%CI)			Winter		
Territory	MA	RI	MA+RI	MA	RI	MA+RI	MA	RI	MA+RI
Total Tracking Savings	53,184	21,045	74,229	5,538	3,799	9,337	6,250	2,390	8,640
Realization Rate	64.2%	69.3%	65.5%	69.5%	70.9%	69.9%	66.0%	77.1%	68.7%
Error Ratio	0.54	0.39	0.51	0.77	0.39	0.65	0.62	0.38	0.56
Relative Precision	±14.5%	±23.0%	±12.3%	±15.9%	±17.8%	±12.4%	±13.0%	±17.3%	±10.6%

Recommendations

The DNV GL team makes the following recommendations based on the data collected, conclusions, results, and process of this impact evaluation.

Recommendation 1: The MA+RI lighting and non-lighting realization rate results from this study shall replace the previous realization rates used by National Grid beginning in PY2020.

Recommendation 2: The evaluator recommends National Grid to continue the rolling impact evaluation approach for custom electric installations. These results will be updated annually as subsequent impact evaluations of 2018 and 2019 program years are completed. Following the third year of evaluation, National Grid will have enough RI only sample to support a RI only result so that piggybacking with MA will no longer be necessary. National Grid could also use RI only aggregated results from 2 years if required precision targets are met.

Recommendation 3: For street lighting projects, DNV GL recommends National Grid to use actual hours of operation and % dimming (if any) instead of billing or tariff hours to calculate the overall project savings.

- Currently, there are 4 different categories of tariff hours estimates that are being used by National Grid: Continuous (8,760 hours), Dusk-to-Dawn (4,175 hours), Dimming (@ 70%, 3,737 hours) and Part-night (4 hr, 2,715 hours); the option that is used to bill the customer is often used for savings calculations.
- The street lighting site in RI used the Dusk-to-Dawn assumption of 4,175 hours in tracking calculation while the actual hours estimated by evaluation were 4,322 hours. This increase in hours has increased the total project savings by 4%. And, 4% of such large street lighting sites may impact[4] the overall program savings significantly.

Recommendation 4: Future custom electric projects should standardize how baseline conditions and operation are documented in applications. These recommendations below are essentially coming from the MA study but are included in RI as they are also considered relevant in RI.

1. For all custom lighting applications, the source used to estimate pre-retrofit annual operating hours should be clearly stated.
2. Retrofit Custom lighting applications that exceed 500,000 kWh in annual claimed energy savings should require photographs and detailed descriptions regarding dominant existing lighting system types, quantities, and conditions.
3. Custom non-lighting applications should clearly document the source of their baseline operating condition and control strategy and use actual trend data whenever possible. The application should seek to understand and account for any planned operational strategy changes after the measure installation is complete.

1.3 Considerations

The following considerations for National Grid are for the future custom electric program.

1. For some complex control-based and/or large savings measures National Grid currently withholds part of the incentive until the measure is visually verified. Consider adding another level of verification such as verifying the trend data showing that the control is operating as designed or capturing screenshots of the new control software interface that shows the actual setpoints, or some other meaningful form of documentation to ensure control based claimed savings are operational.
2. Consider including photographs of the repaired air leak repair tags and results from the pre- and post-retrofit air leakage test as a part of tracking documentation. Measure life for air leak repairs is only 2 years and evaluating these measures will most likely be after the measure life expires.

[4] 4% of this site savings (9,183 MWh) is nearly 367 MWh.

2 INTRODUCTION

This document presents the final report for DNV GL's Impact Evaluation of 2016 Custom Electric Installations, conducted for National Grid in Rhode Island (RI).

Traditionally, the custom electric segment has been evaluated at the individual end-use level on a rotating 3- to 5-year cycle. The custom electric end-uses include lighting, HVAC, process, refrigeration, motors, compressed air, custom design approach (CDA), Combined Heat and Power (CHP) and others. The most recent custom impact evaluations include Custom HVAC completed in July 2016, Custom Process, completed in October of 2017, and Custom Design Approach, completed in January 2019.

2.1 Study objectives

This custom electric impact evaluation's population included most of the custom electric end-uses including lighting, HVAC, process, refrigeration, motors, compressed air and others except CDA and CHP. CDA and CHP are excluded from the study and are typically studied separately due to the complexity of the projects. The primary objective of this Impact Evaluation of 2016 Custom Electric Installations was to provide verification and re-estimation of energy and demand savings for a sample of statistically selected from the above-mentioned custom electric population through site-specific inspection, monitoring, and analysis. The results of this study will be used to determine the gross realization rates for custom electric energy efficiency projects implemented in 2020 and beyond. These results will be updated annually as subsequent impact evaluations of 2018 and 2019 program years are completed. This aligns with the new impact evaluation paradigm of studying the Custom installations on a staged basis annually. DNV GL and National Grid have decided to skip PY2017 due to the availability of more recent (2018) population data.

For this year the RI site-specific results will be aggregated with evaluation results of a similar study in Massachusetts to determine realization rates for National Grid's custom electric installations in RI. RI site results will be reviewed on their own but for this year "piggybacking" on top of MA results is still necessary to achieve required precisions.

The key objectives of this evaluation are as follows:

1. Evaluate savings impacts of 2016 Custom Electric projects. The study will aim to quantify (a) achieved electric energy savings for custom electric projects, with a targeted sampling precision of ±10% at 90% confidence overall for MA[5] and RI combined; (b) achieved electric energy savings for custom lighting and custom non-lighting projects, with a targeted sampling precision of ±15% at 90% confidence overall MA and RI combined; and (c) achieved electric demand savings for custom electric projects, with a targeted sampling precision of ±10% at 80% confidence overall MA and RI combined.
2. Establish a rolling M&V Approach for evaluating custom electric installations on an annual basis. The goal of this approach is to perform site visits and data monitoring on a smaller sample of projects each year rather than complete larger samples of individual Custom end-uses on a rotating basis. This will allow for a rolling M&V approach that will be repeated annually as the previous year's tracking data become available.

[5] National Grid territory in MA.

2.2 Methods

The DNV GL team’s approach used the following steps to achieve the research objectives and ensure the study goals of National Grid are met.

1. Examine the 2016 large C&I population to improve understanding of the relative impact of this category
2. Design an efficient sampling plan for selecting custom electric projects for on-site visits to achieve the relative precision targets determined by National Grid
3. Develop a project work plan outlining the sample design, scope of work, timeline, and budget for this evaluation
4. Review the formulas, calculations, and factors used in the development of the tracking savings for each sampled participant, to develop site-specific M&V plans
5. Perform comprehensive data collection at each sample site to support an independent analysis of achieved gross energy and demand savings realization rates
6. Produce comprehensive reporting of results, including analysis methods, findings and trends, final sample plans, and data collection instruments.

3 METHODOLOGY

3.1 Sample development

The DNV GL team developed a sampling population from 2016 program participation data provided by National Grid. National Grid determined relative precision and confidence interval targets using this sampling population along with information provided by the DNV GL team. This information included characteristics of the sampling population, the relative impact of the sampling population to National Grid's electric portfolio, and historic evaluation targets and results.

Once National Grid set the sampling targets, the DNV GL team selected a primary and back-up sample for the evaluation that minimized the number of sample points required to meet the targets and provided these samples to National Grid for review. Sampling targets consisted of single applications or groups of similar custom lighting or non-lighting applications completed at a single service address during the 2016 calendar year. A single service address is considered a sampling unit or "site" in the study. For some large applications, National Grid releases incentives in two phases namely parent and child and these applications sometimes go into multiple program years. This study included 11 such parent-child applications that were completed in 2016. Parent-child applications are included in the population based on the year of completion of the child application.

In previous studies, applications completed at the same service address sometimes were not bundled into one single site however this evaluation sought to group these applications together to minimize the sample size required to achieve precision targets. This strategy proved successful with the exception of a few larger sites that became overly burdensome to customers and difficult to completely evaluate. For future studies, this can be handled by selecting a sample of applications at the site based on the amount of savings (preferably largest savings applications) and/or uncommon or unique measures (if any).

National Grid provided the DNV GL team with documentation supporting the tracked savings for each primary sample point.

3.1.1 Population review

The number of sample points required to achieve a desired level of precision depends upon the expected variability of the observed realization rates; DNV GL used the same error ratio that was used in the MA custom electric evaluation (P80) sample design as shown in Table 3-1 below.

Table 3-1 Sampling Targets at the end of rolling 3-year study and Error ratios for year-1

<table>
<tr><th>Sampling Target</th><th>Error Ratio</th></tr>
<tr><td>±10% on Overall Energy (kWh) at the 90% confidence interval</td><td rowspan="3">0.4 Lighting
0.6 Non-lighting</td></tr>
<tr><td>±15% on Lighting Energy (kWh) at the 90% confidence interval</td></tr>
<tr><td>±15% on Non-Lighting Energy (kWh) at the 90% confidence interval</td></tr>
<tr><td>±10% on overall demand (kW) at the 80% confidence interval</td><td>Summer: 0.5 Lighting
Summer: 0.8 Non-lighting
Winter: 0.6 Lighting
Winter: 0.8 Non-lighting</td></tr>
</table>

Table 3-2 presents the Electric savings for the 2016 Custom Electric installations in the National Grid territory for both MA and RI. A total of 686 accounts participated in the program in 2016 across both territories, producing an estimated 154,753 MWh of annual energy savings. RI projects account for 35% of the total Custom electric energy savings of the combined total. The overall savings are split nearly evenly between lighting (52%) and non-lighting (48%). Note that neither population (MA or RI) includes CDA and combined heat and power (CHP) projects completed in 2016. PY2016 included some street lighting projects with very large energy savings, and National Grid expects more street lighting measures completed across other towns/cities in RI in the following years.

Table 3-2: PY2016 Custom Electric Population Summary

State	Lighting/ Non-lighting	Accounts	Energy Savings	Summer Demand	Winter Demand
		N	kWh	kW	kW
MA Only	Lighting	287	61,381,204	9,565	6,940
	Non-lighting	267	53,183,876	3,247	4,424
MA Overall	Both	554	114,565,080	12,812	11,363
RI Only	Lighting	49	19,142,741	936	4,021
	Non-lighting	83	21,044,847	3,799	2,390
RI Overall	Both	132	40,187,588	4,736	6,411
MA +RI	Lighting	336	80,523,945	10,501	10,961
	Non-lighting	350	74,228,723	7,046	6,814
MA[5] +RI Overall	Both	686	154,752,668	17,547	17,774

3.1.2 Rolling based sampling plan

In MA, National Grid's primary 2016 sample was 61 sites that targeted 90/10 overall (Lighting + Non-lighting energy) and 90/15 for Lighting and Non-lighting measure individually. Considering limited budgets for evaluation in RI, DNV GL developed a RI sampling strategy that piggybacks on the MA[5] study in the short term with a long-term plan to follow MA's staged[6] M&V approach to target a ±10 relative precision (RP) with 90% confidence for energy (kWh) as part of a 3-year rolling/staged evaluation for RI (stand-alone) as shown in Table 3-3.

The planned RI sample of 2016 sites included 4 lighting and 8 non-lighting sites. A larger sample size was planned for years-2 and 3 to achieve a precision target of ±15% @ 90% CI for lighting and non-lighting individually and an RP of ±10% @ 90% CI for a combined lighting and non-lighting measures completed at the end of year 3 as shown in Table 3-3.

[6] The goal of this approach is to perform site visits and data monitoring during seasonally optimal times based on measure and end-use equipment. This will also allow for a staged M&V approach that will be repeated annually as the previous year's tracking data becomes available.

Table 3-3: RP estimates for the first 3-years (RI only) in a rolling-based evaluation

Measure	Program Years[7]	Accounts (N)	Energy Savings (kWh)	Error Ratio	Sample (n)	RP @90% CI
RI only Lighting	PY2016	49	19,142,741	0.40	4	±30.7%
	PY2016 + PY2018	98	38,285,482	0.40	10	±21.0%
	PY2016 + PY2018 + PY2019	147	57,428,223	0.40	16	±14.5%
RI only Non-lighting	PY2016	83	21,044,847	0.60	8	±33.6%
	PY2016 + PY2018	166	42,089,694	0.60	21	±22.0%
	PY2016 + PY2018 + PY2019	249	63,134,541	0.60	34	±15.3%
Custom Electric - 3 years combined		396	120,562,764		50	±10.5%

3.1.2.1 PY2016 sampling plan

Table 3-4, Table 3-5 and Table 3-6 below show the designed relative precisions for each state individually and combined together (piggybacking) for the PY2016 year for kWh, summer kW, and winter kW. Overall (MA+RI), the precisions were estimated to be better than ±10% for energy at 90% confidence and both summer and winter demand at 80% confidence interval.

Table 3-4: RP for Energy (kWh) @ 90% CI

State	Lighting/ Non-lighting	Accounts (N)	Sample (n)	Energy (kWh)		
				Savings (kWh)	Error Ratio	Expected RP @90% CI
MA	Lighting	287	22	61,381,204	0.40	±13.5%
	Non-lighting	267	39	53,183,876	0.60	±13.6%
MA Overall	Both	554	61	114,565,080	N.A.	±9.6%
RI	Lighting	49	4	19,142,741	0.40	±30.7%
	Non-lighting	83	8	21,044,847	0.60	±33.6%
RI Overall	Both	132	12	40,187,588	N.A.	±22.9%
MA+RI	Lighting	336	26	80,523,945	0.40	±11.9%
	Non-lighting	350	47	74,228,723	0.60	±12.4%
MA+RI Overall only	Both	686	73	154,752,668	N.A.	±8.6%

[7] The savings for the future years (2018, 2019) were assumed to be the same as 2016 for estimation purposes only.

Table 3-5: RP for Summer Demand (kW) @ 80% CI

State	Lighting/ Non-lighting	Accounts (N)	Sample (n)	Summer Demand kW		
				Summer Demand (kW)	Error Ratio	Expected RP @80% CI
MA	Lighting	287	22	9,565	0.50	±13.2%
	Non-lighting	267	39	3,247	0.80	±14.1%
MA Overall	Both	554	61	12,812	N.A.	±10.5%
RI	Lighting	49	4	936	0.50	±29.9%
	Non-lighting	83	8	3,799	0.80	±34.9%
RI Overall	Both	132	12	4,736	N.A.	±28.6%
MA+RI	Lighting	336	26	10,501	0.50	±11.5%
	Non-lighting	350	47	7,046	0.80	±12.9%
MA+RI Overall only	Both	686	73	17,547	N.A.	±8.6%

Table 3-6: RP for Winter Demand (kW) @ 80% CI

State	Lighting/ Non-lighting	Accounts (N)	Sample (n)	Winter Demand kW		
				Winter Demand (kW)	Error Ratio	Expected RP @80% CI
MA	Lighting	287	22	6,940	0.60	±15.8%
	Non-lighting	267	39	4,424	0.80	±14.1%
MA Overall	Both	554	61	11,363	N.A.	±11.1%
RI	Lighting	49	4	4,021	0.60	±35.9%
	Non-lighting	83	8	2,390	0.80	±34.9%
RI Overall	Both	132	12	6,411	N.A.	±26.0%
MA+RI	Lighting	336	26	10,961	0.60	±13.9%
	Non-lighting	350	47	6,814	0.80	±12.9%
MA+RI Overall only	Both	686	73	17,774	N.A.	±9.9%

3.1.2.2 Final Sample

This section shows the final evaluation sample and the population change in the project.

Site 2016RIN041 site was replaced with a backup site 2016RIN038 and a street lighting site 2016RIL001 was removed from the sample but included in the population. The site was removed due to potential safety concerns at the site.

During the first visit for site 2016RIN023, DNV GL learned that the sampled account has applications completed at multiple locations across the state (same account number). To be cost-efficient and to keep with the sample design intent of sampling all applications at a given site, only one location was chosen for the evaluation purposes and the population was adjusted accordingly during expansion analysis. The site has been split into two with application 4728393 as site 2016RIN023a and the remaining four applications as site 2016RIN023b. Note that only 2016RIN023a was evaluated. The replacement site (2016RIN038) was sourced in order of priority within the same stratum.

Table 3-7. Final Evaluation Sample:

DNV GL ID	National Grid App#	Measure Type	Measure Installed	Tracking savings (kWh)	Case-weight	Evaluated
2016RIL079	5774109	Lighting	LED Lighting - Indoor	54,322	24.0	Yes
2016RIL006	4361977	Lighting	Lighting Systems	58,062	24.0	Yes
2016RIL001	6476763	Lighting	Street Lighting	2,843,297	N/A	No
2016RIL043	6279032	Lighting	Street Lighting	9,183,114	1.0	Yes
2016RIN008	5648427	Non-Lighting	Compressed Air	45,902	21.3	Yes
	6299117	Non-Lighting	Process	40,385	21.3	Yes
2016RIN125	6594244	Non-Lighting	HVAC	46,647	21.3	Yes
2016RIN118	6316395	Non-Lighting	Refrigeration Equipment	42,610	21.3	Yes
	6421680	Non-Lighting	Refrigeration Equipment	69,735	21.3	Yes
2016RIN094	5389177	Non-Lighting	Compressed Air	494,168	5.0	Yes
2016RIN093	5384747	Non-Lighting	Compressed Air	283,325	5.0	Yes
	5648426	Non-Lighting	Compressed Air	163,286	5.0	Yes
	5853340	Non-Lighting	Process	29,423	5.0	Yes
	6299115	Non-Lighting	HVAC	21,826	5.0	Yes
2016RIN038*	3855780	Non-Lighting	Compressed Air	283,049	5.0	Yes
2016RIN023a†	4728393	Non-Lighting	Comprehensive Retrofit	932,006	2.5	Yes
2016RIN023b†	5172277	Non-Lighting	EMSB-EMS / HVAC	316,089	2.5	No
2016RIN023b†	5685728	Non-Lighting	Operation / Maintenance	86,386	2.5	No
2016RIN023b†	5685728	Non-Lighting	EMSB-EMS / HVAC	286,660	2.5	No
2016RIN023b†	5685728	Non-Lighting	VSDH-Drives on HVAC	287,822	2.5	No
2016RIN028	5631781	Non-Lighting	EMSB-EMS / HVAC	1,182,614	2.5	Yes

**backup site;*
†Split-site

Updated case weights and population summaries are shown in Table 3-8. Note the increase in non-lighting accounts from 83 (in Table 3-2) to 84 from the splitting of the site 2016RIN023.

Table 3-8: Updated Population and post-stratified sample

Measure Type	Stratum	Total Savings (kWh)	Accounts (N)	Achieved Sample (n)	Case Weight
Lighting	1	9,959,627	48	2	24.0
	2	9,183,114	1	1	1.0
	Total	19,142,741	49	3	N.A.
Non-lighting	1	4,865,253	64	3	21.3
	2	6,537,458	15	3	5.0
	3	9,642,136	5	2	2.5
	Total	21,044,847	84	8	N.A.
Grand Total		40,187,588	133	11	N.A.

3.2 Description of methodology

This section describes the general methodology used for both the development of site evaluation plans, the execution of the plans, and the final process for producing program results. Each site report in (APPENDIX B) describes the site-specific methodology in detail.

3.2.1 Measurement and Verification Plans

Following sample selection and prior to beginning any site visits, the evaluation team developed detailed measurement and verification plans for each sampled project. If multiple similar measures were to be evaluated at the same site, one plan was created. The plans included a description of the project, a description of the tracking assumptions and methodology, expected verification method, expected data collection methods, and strategies and the anticipated analysis methodology. National Grid provided comments and edits to clarify and improve the plans prior to the plans being finalized.

Evaluators used the savings analysis methodologies from the Technical Assistance (TA) Study whenever possible. However, in a small number of cases, the TA methodology was unavailable or found to be incorrect or inappropriate. In those cases, the evaluators planned an appropriate analysis for the measure being evaluated and data to be collected. In most cases, adjustments to savings methodologies were presented and agreed to in the measurement and evaluation plans.

3.2.1.1 Site recruitment/interviews

National Grid provided a list of contacts to the evaluation team along with approval to contact the customer. In some cases, National Grid approved the evaluation team to proceed directly with recruitment using the information available in the project file.

The evaluation team called each site contact to discuss the site details and schedule a site visit. This discussion was used to improve our understanding of the site, the project, and data available for the evaluation. Any new information received at this time was integrated into each site’s M&V plan.

3.2.2 Data Collection for Verification, Analysis, and Reporting

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. In some cases, multiple facility interviews and/or equipment vendor interviews were completed to ensure an accurate understanding of the operating practice.

The physical inspection focused on verifying measure installation and expected operation. For all but a handful of sites, equipment was found to be installed and operating as expected. Each site report includes the result of measure verification.

Instrumentation such as power recorders, TOU current loggers, TOU lighting loggers, lumen loggers, plug load monitors, and temperature loggers was installed to monitor the usage of operating equipment and conditions of the associated affected spaces. Production data and EMS trends were also collected, when available. Each site report includes a full description of the data collected and received.

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 spreadsheet or allocated to each hour in the year in order to estimate on-peak 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:

1. 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.

2. 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 algorithms, assumptions and calibration methods where applicable. Engineers submitted draft site reports to National Grid upon completion of each site evaluation. The evaluation team responded to the comments received and submitted revised reports for comment. The final site reports are included in APPENDIX B. This report provides a concise overview of the evaluation methods and findings.

3.2.2.1 M&V plan update

The DNV GL team submitted an updated site M&V plan to National Grid for every site after the completion of the primary site visit for most projects. The intention of the update was to keep National Grid current on the status of the site evaluation and communicate any anticipated or resultant deviations from the plan.

This updated plan included the following information based on the site visit:

- Any deviations to the plan that occurred during the visit or were expected to occur
- All the measurement equipment installed, and parameters measured
- All data provided by the site at the time of the visit
- All data expected to be provided by the site and the agreed deadline for receipt of that data
- Site conditions observed during the visit and any potential issues identified with the measures being evaluated, including changes at the facility since installation that may impact project savings

3.2.2.2 Measure Event Type and Baseline review

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

The DNV GL team selected a measure baseline event type based on a preponderance of the evidence presented in the project file and the data gathered during the interview with the site contact. National Grid classified measures into two event types: new construction measures and retrofit measures; Evaluation used 4 measure event types: new construction, retrofit with single baseline, retrofit with dual baseline, add-on with a single baseline.

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

Table 3-9: Measure event type in tracking and evaluation

SITE ID	NATIONAL GRID APPLICATION#	TRACKING EVENT TYPE	EVALUATION EVENT TYPE
2016RIN008	5648427	Retrofit	Retrofit with a single baseline
2016RIN008	6299117	New Construction	New Construction
2016RIN023	4728393	Retrofit	Retrofit with a single baseline
2016RIN023	5172277	Retrofit	Retrofit with a single baseline
2016RIN023	5685728	Retrofit	Retrofit with a single baseline
2016RIN023	5685728	Retrofit	Retrofit with a single baseline
2016RIN023	5685728	Retrofit	Retrofit with a single baseline
2016RIN028	5631781	Retrofit	Retrofit with a single baseline
2016RIN038	3855780	Retrofit	Retrofit with a single baseline
2016RIN093	5384747	Retrofit	Retrofit with a single baseline
2016RIN093	5648426	Retrofit	Retrofit with a single baseline
2016RIN093	5853340	Retrofit	Retrofit with a single baseline
2016RIN093	6299115	New Construction	New construction
2016RIN094	5389177	New Construction	New Construction
2016RIN118	6316395	Retrofit	Addon with a single baseline
2016RIN118	6421680	Retrofit	Retrofit with a single baseline
2016RIN125	6594244	Retrofit	Retrofit with a single baseline
2016RIL006	4361977	Retrofit	Retrofit with dual baseline
2016RIL043	6279032	Retrofit	Retrofit with a single baseline
2016RIL079	5774109	Retrofit	Retrofit with a single baseline

After the measure event type was selected, the evaluator selected the evaluated baseline for the event type. Measures classified as retrofit or add-ons used pre-existing conditions as a baseline. Industry-standard practice or code was used for new construction event types. The evaluation team completed an independent review of the baseline for each sampled project. And, using site data project documentation, and interviews at the facility, DNV GL assessed the reasonableness of the baseline for each sampled project and updated the baselines as shown in the examples below.

For example:
Site 2016RIN028: The evaluator adjusted the model's design cooling setpoints so the base case design setpoints matched the proposed case design setpoints. The tracking savings project's modeler had mistakenly adjusted the design setpoints instead of adjusting the thermostat schedule.

Site 2016RIN038: For air dryer measure at this site, the tracking savings included a hypothetical "standard" dryer for the baseline but also included compressed air losses associated with purging condensate as a method for drying. This baseline scenario was considered inappropriate because the standard dryer could have performed all the drying and condensate draining functions.

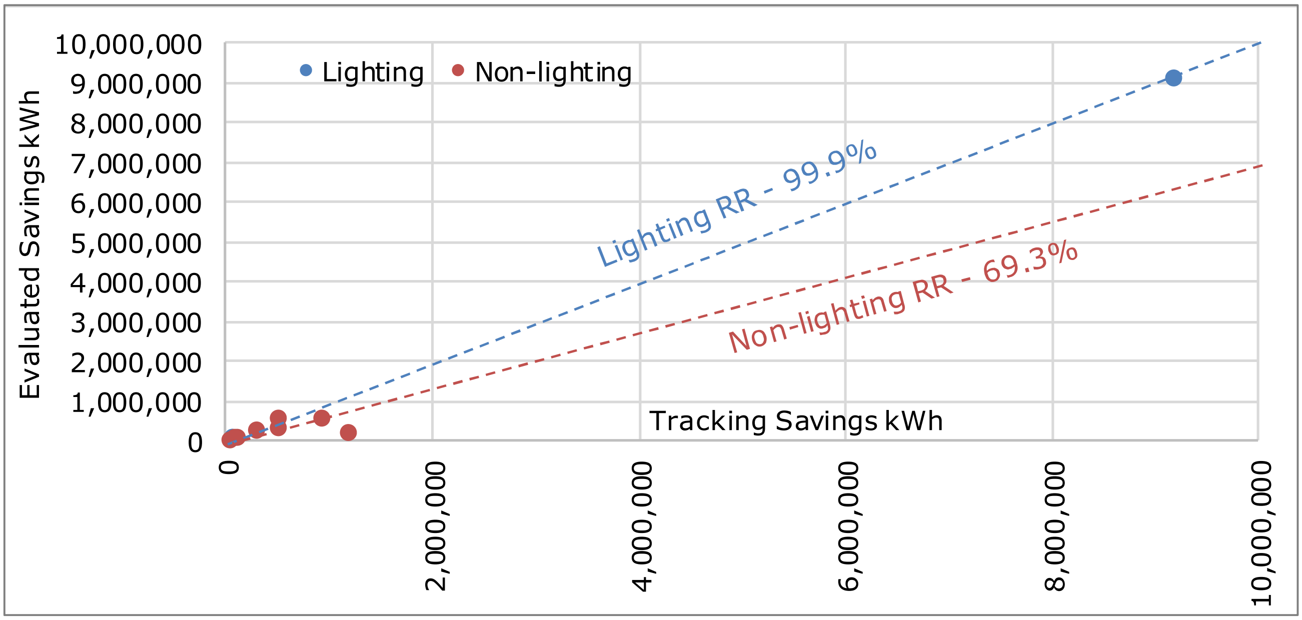
Site 2016RIN093: Double counting of baseline low-pressure compressor usage was removed.

4 RI-SPECIFIC FINDINGS

4.1 Site-level findings

Figure 4-1 presents a scatter plot of evaluated annual energy (MWh) savings plotted against National Grid tracking savings for all 11 sites in RI. The data points shown are the actual unweighted values. The slope of the dashed blue line is the RI lighting realization rate (99.9%) and the slope of the dashed red line is the RI non-lighting realization rate (69.3%). Every site that has been evaluated carried a case weight as shown in Table 3-8. The weighted expansion of these site-level results is used to calculate the overall program level realization rates for Lighting and Non-lighting projects. The scatter of the data around the dashed line indicates the variation of savings between the tracking estimates and evaluated savings. Individual site results are shown in APPENDIX B.

Figure 4-1. Annual energy (kWh), evaluated savings vs. tracking savings (RI only)



4.1.1 Lighting realization rates

Table 4-1. RI statewide lighting realization rates

Savings	Annual	Summer	Winter
	MWh	On-Peak kW	On-Peak kW
	90% Confidence	80% Confidence	80% Confidence
Total Tracking Savings	19,143	936	4,021
Total Evaluated Savings	19,121	1,006	3,429
Realization Rate	99.9%	107.4%	85.3%
Error Ratio	0.05	0.11	0.06
Relative Precision	±5.0%	±8.2%	±4.3%

4.1.2 Non-lighting realization rates

Table 4-2. RI statewide non-lighting realization rates

Savings	Annual	Summer	Winter
	MWh	On-Peak kW	On-Peak kW
	90% Confidence	80% Confidence	80% Confidence
Total Tracking Savings	21,045	3,799	2,390
Total Evaluated Savings	14,592	2,695	1,842
Realization Rate	69.3%	70.9%	77.1%
Error Ratio	0.39	0.39	0.38
Relative Precision	±23.0%	±17.8%	±17.3%

4.2 Discrepancy analysis

There are many reasons for the differences between evaluated and tracking savings on every site. The discrepancies shown below are presented with a +/- value, which is the isolated impact of that specific adjustment on the overall savings realization rate in RI (weighted). Additionally, these site-specific discrepancy values have been multiplied by the site case weights (Table 3-8) to demonstrate the impact each discrepancy has on the overall RI results (weighted). The individual site reports provide a detailed discussion of the savings variance and the discrepancies that drove the results at each site. The following describes the discrepancy categories used to characterize the changes in savings between the tracking and evaluated estimates:

- Methodology: Differences attributed to changes in calculation methodology between the tracking analysis and the evaluation analysis. The evaluation only changed methodology when determined to be necessary to accurately calculate savings.
- Tracking/Admin: Differences that are attributed to incorrect adjustments to savings that occurred between completion of the analysis as documented by the supporting material and entry into the National Grid tracking system.
- Quantity: Differences that are attributed to differences between the number of units expected or assumed in the project calculations and the number of units operating at the time of evaluation or in the baseline.
- HVAC Interaction: Differences due to the assumptions used to estimate how the change in consumption by the primary equipment impacts the consumption of the site's HVAC system.
- Technology: Differences between the as-found and baseline equipment system type, size, and/or efficiency as compared to the equipment assumed in the tracking analysis.
- Baseline: Savings variance is due to changes to the assumed baseline condition by the evaluation.
- Operation: Differences between how the primary equipment is being "operated" or used by the facility now compared to the final assumptions used to estimate tracking savings. This category includes differences in the as-found hours of operation compared to those assumed in the tracking analysis and changes in baseline hours. This category also includes differences in the annual production volume or facility production strategy.

4.2.1 Discrepancy factors

A summary of the discrepancies on the electric lighting and non-lighting savings estimates are presented in Table 4-3. As shown, operational change discrepancy was the primary driver of savings variance for both lighting and non-lighting sites in this study. For lighting, -3.9% in the technology difference and for non-lighting, about -13.4% in operational change were other main drivers of the discrepancy in the overall savings in this study.

The figure is followed by a list of a few sites and the drivers of those discrepancies by weighted savings.

Table 4-3: Weighted Energy Savings Discrepancy Analysis (RI sites only)

Measure	Discrepancy Factor	%discrepancy
Lighting	Operation	2.7%
	Quantity	0.1%
	HVAC interaction	0.9%
	Technology	-3.9%
	Total	**-0.1%**
Non-lighting	Operation	-13.4%
	Technology	-5.8%
	Methodology	-3.3%
	Tracking/Admin	-0.2%
	Baseline	-3.8%
	Quantity	-4.1%
	Total	-30.6%

The top five savings discrepancy changes in the RI sample include the following. More details on each site can be found in the individual site writeups.

- 2016RIL043-Operation & Technology: This large street lighting site had a 5% decrease in savings based on the measured demand (kW) of the fixture compared to the tracking calculation's assumption that used the rated wattage of the lamp. It also had a 4% increase in tracking savings due to higher operating hours. Both these discrepancies nearly canceled out each other to give a realization rate of nearly 99% for the site. These changes resulted in a site realization rate of 99%.
- 2016RIL079-Operation & HVAC interaction: The primary reason for the higher than estimated savings at this Departmental store is due to an 11% increase in annual operating hours and an 8% increase from taking into account HVAC interactive effects. These changes resulted in a site realization rate of 118%.
- 2016RIN008-Operation: The key discrepancy reduced kWh savings by 22% because it accounts for the observed boiler's blower operation. The evaluation observed that the boilers operate in lead/lag (i.e., they do not operate simultaneously) while the tracking assumed that they operated simultaneously and under the same load. These changes resulted in a site realization rate of 78%.
- 2016RIN023-Operation, Technology & Methodology: Operational changes reduced tracking savings for this site by 28%, 19% decrease due to the technology change, and 6% change attributed to methodology. There were two primary operating factors that contributed to the reduced savings: 1)

The evaluation found that the AHUs were in dehumidifying mode longer than tracking assumptions and 2) The reduction was due to the operation of exhaust fan 2 (EF2) at nearly full speed, contrary to what was estimated in the tracking calculation.

In addition, a 19% decrease in savings was due to the change in fan demand (technology change) and a 6% increase in savings was attributed to a change in methodology. These changes resulted in a site realization rate of 59%.

- 2016RIN028-Technology, Operation & Tracking: The project included a HVAC setback optimization and DCV measures. A Trane Trace simulation model was used to calculate savings in tracking analysis and the modeler adjusted design cooling setpoints instead of adjusting the thermostat schedule. This error changed the cooling system size and capacity (technology change) in tracking model. Evaluation updated this model by adjusting the schedule and this change nearly removed all of the tracking savings (99.5%) but increased some operational savings (19%). The DCV savings were negligible (~1%). These changes resulted in a site realization rate of 19%.

5 CONCLUSIONS AND RECOMMENDATIONS

The site-level evaluation results were aggregated using the final adjusted case weights. The realization rates were calculated and then applied to total tracking savings to determine their total evaluated savings. The overall (MA+RI) realization rate is the ratio of the total evaluated savings to the total tracking savings, each of which is calculated by summing across National Grid (MA+RI). Table 1-1 and Table 1-2 summarize the lighting and non-lighting results of this analysis. The results presented include realization rates (and associated precision levels) for annual kWh savings, and on-peak demand (kW) savings at the times of 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:

1. 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.
2. 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.

The electric lighting annual energy savings realization rate was 99.8% overall (MA+RI) with a relative precision (RP) of ±7.6% at 90% confidence interval. Summer Peak demand achieved 104% RR with an RP of ±12.8% at 80% confidence interval and 85% RR with ±9.9% at 80% confidence interval (CI) for winter peak demand savings.

The error ratio for lighting savings in MA+RI was calculated to be 0.23 compared to the design estimate of 0.40 for energy. Summer and winter peak demand error ratios were 0.46 and 0.36 compared to 0.5 and 0.8 design estimates, respectively.

For RI, the lighting realization rate is 99.9% with RP of ±5.0% at 90% confidence interval. Summer and winter peak demands are at 104% and 85% with RP of ±11.9% and ±7.5% at 80% confidence interval, respectively. These RI-only lighting results have achieved really good precisions in 2016 but it is important to note that the study had only 3 sampled sites with one really large street lighting site. The large street[8] lighting site makes nearly 50% of the entire custom lighting program savings, therefore the evaluation result has a big impact on the overall program. More sample points (observations) are needed in the RI population to use RI-standalone results.

Table 5-1. 2016 custom lighting results by state

Savings	Energy			Summer			Winter		
	MWh (@90%CI)			On-Peak kW (@80%CI)					
Territory	MA	RI	MA+RI	MA	RI	MA+RI	MA	RI	MA+RI
Total Tracking Savings	61,381	19,143	80,524	936	8,299	7,363	4,021	13,647	9,626
Realization Rate	99.8%	99.9%	99.8%	107.4%	104.3%	104.0%	85.3%	85.2%	85.2%
Error Ratio	0.26	0.05	0.23	0.11	0.46	0.46	0.06	0.29	0.36
Relative Precision	±9.2%	±5.0%	±7.6%	±8.2%	±11.9%	±12.8%	±4.3%	±7.5%	±9.9%

The electric non-lighting annual energy savings realization rate was 65.5% overall (MA+RI) with a relative precision (RP) of ±12.3% at 90% confidence interval. Summer and Winter Peak demands were 69.9% and 68.7% RR with ±12.4% and ±10.6% RP at 80% confidence interval respectively.

[8] The large street lighting achieved a realization rate of nearly 99% for energy and 96% for winter peak demand kW savings and no summer demand savings. A small change in the site savings would change the overall RR significantly.

The error ratio for non-lighting savings in MA+RI was calculated to be 0.51 compared to the design estimate of 0.60 for energy. Summer and winter peak demand error ratios were 0.65 and 0.56 compared to 0.8 and 0.8 design estimates, respectively.

For RI, the non-lighting realization rate is 69.3% with RP of ±23.0% at 90% confidence interval. Summer and winter peak demands are at 70.9% and 77.1% with RP of ±17.8% and ±17.3% at 80% confidence interval, respectively. This RI-only energy savings (kWh) realization rate is higher than MA due to the variance in MA-only site level results. Therefore, DNV GL and National Grid are planning a larger sample for year-2 and year-3 of this rolling-based evaluation to achieve the targeted combined RP by the end of year-3.

Table 5-2. 2016 custom non-lighting statewide results

Savings	Energy			Summer			Winter		
	MWh (@90%CI)			On-Peak kW (@80%CI)					
Territory	MA	RI	MA+RI	MA	RI	MA+RI	MA	RI	MA+RI
Total Tracking Savings	53,184	21,045	74,229	5,538	3,799	9,337	6,250	2,390	8,640
Realization Rate	64.2%	69.3%	65.5%	69.5%	70.9%	69.9%	66.0%	77.1%	68.7%
Error Ratio	0.54	0.39	0.51	0.77	0.39	0.65	0.62	0.38	0.56
Relative Precision	±14.5%	±23.0%	±12.3%	±15.9%	±17.8%	±12.4%	±13.0%	±17.3%	±10.6%

5.1 Recommendations

The DNV GL team makes the following recommendations based on the data collected, conclusions, results, and process of this impact evaluation.

Recommendation 1: The MA+RI lighting and non-lighting realization rate results from this study shall replace the previous realization rates used by National Grid beginning in PY2020.

Recommendation 2: The evaluator recommends National Grid to continue the rolling impact evaluation approach for custom electric installations. These results will be updated annually as subsequent impact evaluations of 2018 and 2019 program years are completed. Following the third year of evaluation, National Grid will have enough RI only sample to support a RI only result so that piggybacking with MA will no longer be necessary. National Grid could also use RI only aggregated results from 2 years if required precision targets are met.

Recommendation 3: For street lighting projects, DNV GL recommends National Grid to use actual hours of operation and % dimming (if any) instead of billing or tariff hours to calculate the overall project savings.

- Currently, there are 4 different categories of tariff hours estimates that are being used by National Grid: Continuous (8,760 hours), Dusk-to-Dawn (4,175 hours), Dimming (@ 70%, 3,737 hours) and Part-night (4 hr, 2,715 hours); the option that is used to bill the customer is often used for savings calculations.
- The street lighting site in RI used the Dusk-to-Dawn assumption of 4,175 hours in tracking calculation while the actual hours estimated by evaluation were 4,322 hours. This increase in hours

has increased the total project savings by 4%. And, 4% of such large street lighting sites may impact[9] the overall program savings significantly.

Recommendation 4: Future custom electric projects should standardize how baseline conditions and operation are documented in applications. These recommendations below are essentially coming from the MA study but are included in RI as they are also considered relevant in RI.

4. For all custom lighting applications, the source used to estimate pre-retrofit annual operating hours should be clearly stated.

5. Retrofit Custom lighting applications that exceed 500,000 kWh in annual claimed energy savings should require photographs and detailed descriptions regarding dominant existing lighting system types, quantities, and conditions.

6. Custom non-lighting applications should clearly document the source of their baseline operating condition and control strategy and use actual trend data whenever possible. The application should seek to understand and account for any planned operational strategy changes after the measure installation is complete.

5.2 Considerations

The following considerations for National Grid are for the future custom electric program.

1. For some complex control-based and/or large savings measures National Grid currently withholds part of the incentive until the measure is visually verified. Consider adding another level of verification such as verifying the trend data showing that the control is operating as designed or capturing screenshots of the new control software interface that shows the actual setpoints, or some other meaningful form of documentation to ensure control based claimed savings are operational.
2. Consider including photographs of the repaired air leak repair tags and results from the pre- and post-retrofit air leakage test as a part of tracking documentation. Measure life for air leak repairs is only 2 years and evaluating these measures will most likely be after the measure life expires.

[9] 4% of this site savings (9,183 MWh) is nearly 367 MWh.

APPENDIX A. RI SITE SAVINGS SUMMARY

The following table shows the tracked and evaluated savings for every site in the final sample.

DNV GL ID	National Grid App#	Measure Type	Tracking savings (kWh)	Tracking Winter On-Peak Demand Savings (kW)	Tracking Summer On-Peak Demand Savings (kW)	Evaluated Annual Energy Savings (kWh)	Evaluated Summer On-Peak Demand Savings (kW)	Evaluated Winter On-Peak Demand Savings (kW)	Realization Rate (Energy kWh)
2016RIL079	5774109	Lighting	54,322	13.90	13.9	64,302	15.81	13.13	118%
2016RIL006	4361977	Lighting	58,062	7.80	8.9	51,787	7.5	5.2	89%
2016RIL043	6279032	Lighting	9,183,114	0.00	2432.3	9,080,672	0	2101	99%
2016RIN008	5648427	Non-Lighting	45,902	5.20	5.2	46,536	5.3	5.3	101%
	6299117	Non-Lighting	40,385	2.10	2.1	20,643	2.9	2.9	51%
2016RIN125	6594244	Non-Lighting	46,647	9.50	4	15,022	6.5	-0.4	32%
2016RIN118	6316395	Non-Lighting	42,610	4.90	4.9	50,183	2.5	5.4	118%
	6421680	Non-Lighting	69,735	4.80	12.8	51,733	6.2	5.2	74%
2016RIN094	5389177	Non-Lighting	494,168	73.39	73.4	588,714	89.9	91.3	119%
2016RIN093	5384747	Non-Lighting	283,325	33.70	33.7	284,651	36.8	36.6	100%
	5648426	Non-Lighting	163,286	18.80	18.9	8,630	1	1	5%
	5853340	Non-Lighting	29,423	4.40	4.4	23,033	2.8	3.1	78%
	6299115	Non-Lighting	21,826	2.70	0	10,450	1.6	1	48%
2016RIN038	3855780	Non-Lighting	283,049	66.31	66.32	255,948	52.6	52.9	90%
2016RIN023a	4728393	Non-Lighting	932,006	130.40	57.1	546,155	74.2	38.9	59%
2016RIN028	5631781	Non-Lighting	1,182,614	236.98	96	225,463	60.7	44.4	19%

APPENDIX B. RI SITE REPORTS

Site ID: 2016RIL0006

Program Administrator	National Grid
Site ID(s)	4361977
Site Type	C&I Existing Building Retrofit
Program Year	2016
Evaluation Firm	DNV GL
Evaluation Engineer	Glenn Gavi, Ryan Brown
Senior Engineer	Jeffrey Zynda

Site Description

This site is a complete interior and exterior lighting retrofit upgrade for a 12,000 ft^2 police station, consisting of LED replacements for interior fluorescent fixtures and exterior metal halide (MH) fixtures. Pre-retrofit fixtures were noted to be between six and fifteen years of age. Different areas in the station operate on their own schedules; areas such as administration operates continuously, while areas such as offices and storage rooms followed the assumed normal business hour schedule. Savings for occupancy sensors were included in the application for a few areas where fixtures were assumed to have a 24% reduction in annual operating hours. On-site it was found that dimming controls were installed in the areas were occupancy sensors were proposed. Only a handful of fixtures were installed with occupancy control, and these were fixtures not noted in the application. Control types did not overlap in the areas where they were installed. HVAC interactive savings were not included in application estimates. The application claimed savings are derived from the reduction in wattage when replacing pre-retrofit fixtures with LEDs, as well as equivalent full load hour (EFLH) reductions from proposed controls.

The project application indicates that of the 58,063-kWh claimed annual energy savings, with 55,615 kWh (96%) the result of fixture wattage reduction and 2,448 kWh (4%) was claimed to be a result of control savings. The total evaluation savings estimate is 51,787 kWh, yielding an 89% overall realization rate. The realization rate for claimed fixture (lamps only) savings is 81% and the realization rate for the evaluated control (controls only) savings is 274%. Of the 6,708-kWh evaluation savings estimate associated with controls, 6,300 kWh were due to dimming and 408 kWh were due to occupancy control. The largest discrepancy between tracking and evaluation estimates of savings are due to hours of operation. Changes in observed operating hours compared to the application were found to decrease savings by 20%. The increased number of controlled fixtures yielded a 1% increase in savings. Interactive effects with on-site cooling equipment were found to increase evaluation savings by 8%. Site results are compared to the tracking system estimates in Table 1 below.

Table 3: Site Results

Savings Quantity	Tracking System Estimate	Evaluation Estimate	Realization Rate
Electric energy (kWh)	58,062	51,787	89%
% of Energy Savings on Peak	61%	52%	85%
Summer On-Peak Demand (kW)	7.80	7.50	96%
Winter On-Peak Demand (kW)	8.90	5.20	58%

Savings Quantity	Tracking System Estimate	Evaluation Estimate	Realization Rate
Lifetime energy (kWh) – if retrofit with dual baseline treatment	754,819	556,252	74%

Application Savings

Application savings were derived from the reduction in wattage caused when retrofitting interior fluorescent fixtures and exterior MH fixtures with LEDs. Annual hours of operation were assumed to be 6,571 for interior fixtures and 4,224 for exterior fixtures. A 24% reduction in operating hours was applied to fixture groups with proposed controls. More details on the baseline and proposed conditions will follow in the next few sections.

Baseline

The baseline condition was a single baseline consisting of T8, T12, and MH fixtures. Annual operating hours were assumed to be 6,571 and 4,224 for interior and exterior spaces respectively. The application did not include notes on lighting controls for pre-retrofit fixtures. Table 2 outlines a detailed inventory of the baseline condition.

Table 2: Baseline Inventory

Existing Quantity	Existing Fixture Description	Existing Lamp/Ballast Description	Existing Hours	Existing Wattage
62	Four Foot T8 Systems	2L4' T8/ELIG	6,571	60
3	Four Foot T8 Systems	3L4' T8/ELIG	6,571	88
56	Four Foot T8 Systems	4L4' T8/ELIG	6,571	112
4	Four Foot T12 Systems	2L4' T12/STD	6,571	94
4	Four Foot T12 Systems	3L4' T12/STD	6,571	151
3	Metal Halide (MH)	50W MH	4,224	65
2	Metal Halide (MH)	70W MH	4,224	95
1	Metal Halide (MH)	100W MH	4,224	120
4	Metal Halide (MH)	250W MH	4,224	295
1	Three Foot T8 / T12 Systems	1L3' T8/ELIG	6,571	24
1	Two Foot T8 / T12 Systems	2L2' T12/HPF	6,571	56

Proposed Condition

The proposal includes one-for-one LED replacements for all pre-retrofit fixtures. Savings for controls were included in the proposal where an annual operating hour reduction of 24% was applied to all controlled fixture groups. Savings associated with interactive effects were not found in the application. Hours of operation were equivalent to the baseline assumptions before applying the control reduction. Table 3 outlines a detailed inventory of the proposed condition.

Table 3: Proposed Inventory

Proposed Quantity	Proposed Fixture Description	Proposed Control Description	Proposed Hours	Proposed Wattage
59	26 WATT LED	Occupancy	4,994	26
1	18 WATT LED	Occupancy	4,994	18

Proposed Quantity	Proposed Fixture Description	Proposed Control Description	Proposed Hours	Proposed Wattage
12	60 WATT LED		6,571	60
33	15 WATT LED		6,571	15
19	30 WATT LED		6,571	30
6	20 WATT LED		4,224	20
1	1L3' 25W T8EE/ELEE LOW PWR		6,571	21
2	11 WATT LED		6,571	11
4	116 WATT LED		4,224	116
4	45 WATT LED		6,571	45

Applicant Calculation Methodology

Application savings were calculated by National Grid using a custom lighting tool. Annual hours of operation were assumed to be 6,571 for interior areas and 4,224 for exterior fixtures. LEDs proposed with controls were noted to have a 24% reduction in annual operating hours. The following formulas were used to calculate savings:

Baseline Fixture kWh = $\frac{Quantity_B * Wattage_B}{1000} * Baseline\ Operating\ Hours$

Proposed Fixture kWh = $\frac{Quantity_P * Wattage_P}{1000} * Proposed\ Operating\ Hours$

Fixture kWh Savings = $Baseline\ Fixture\ kWh\ - Proposed\ Fixture\ kWh$

Controls kWh Savings = $Proposed\ Fixture\ kWh - Proposed\ Fixture\ kW * (.24 * Proposed\ Hours)$

Total kWh Savings = $Fixture\ kWh\ Savings + Control\ kWh\ Savings$

Site Evaluation

The desk review began in June of 2018. An initial interview was held with the site contact to confirm general site information such as control methodologies for both baseline and proposed conditions. During this conversation, it was confirmed that occupancy and dimming controls were installed with the retrofitted LED fixtures for certain areas, although only one control type was installed for a single space. None of the areas had both control types operating with the fixtures. This was confirmed by both the site contact and thorough visual inspection of the fixtures in controlled areas. Pre-retrofit fixtures did not operate with controls. After the interview, the evaluator completed a Measurement and Verification plan outlining the proposal for the evaluation process; including the calculation methodology and general metering approach. To account for the possibility of dimming on-site, one DENT ELITEpro logger was installed to a breaker panel to gather power data for several different area types where channels were either on continuous or non-continuous schedules. This data was used to determine equivalent full load hours (EFLHs) of controlled fixtures along with one HOBO lumen level logger. Six DENT time of use (TOU) loggers were installed in several different areas in the station to obtain general operational data for occupancy-sensor controlled and manually controlled fixtures. The loggers were installed on July 20, 2018, and removed on December 6, 2018. The analysis was performed based on the logged data gathered on-site and the fixture data provided by National Grid, which was verified during the site visit. More details regarding the evaluation process will be expanded upon in the following sections.

Table 4: Measure Verification

Measure Name	Verification Method	Verification Result
Lighting Fixture & Controls Upgrade	DENT ELITEpro loggers (1)	Decreased EFLHs of operation.
Lighting Fixture & Controls Upgrade	HOBO Lumen loggers (1)	Decreased EFLHs of operation.
Lighting Fixture & Controls Upgrade	DENT TOU loggers (6)	Decreased EFLHs of operation.

Site Visit Summary

The Director of Public Works and the on-site electrician for the police station were the main contacts for this site. Through discussions with them both on the phone and through email, as well as visual inspection while on-site, the evaluator was able to verify many of the details associated with the project including baseline lamps/ballast types, wattages, and quantities; as well as the control methodologies that were in place. Occupancy and dimming controls were verified to be installed with the LEDs, although only one control type was installed in a single space. Discussion with the site contact revealed that all exterior fixtures operate on a timeclock where fixtures would operate from 7 PM to 7 AM. This schedule is adjusted in the winter, but there is always a 12-hour gap when lights are powered and shut down.

Metered and Logged Data

One DENT ELITEpro logger and one HOBO lumen logger were installed to gather power data and lumen levels respectively and determine EFLHs for dimmed fixtures. Six DENT TOU loggers were used to gather general operational data for occupancy controlled and non-controlled areas. Specific metering dates and data intervals are shown below in Table 5.

Table 5: Evaluation Data collection – Installed equipment

Parameter	M&V Equipment Brand and Model	Metering Start/Stop Dates	Metering Interval
Power Data – 1 units	DENT ELITEpro logger	7/20/2018-12/6/2018	5-minute
Lumen Levels – 1 unit	HOBO Lumen logger	7/20/2018-12/6/2018	5-minute
Time of Use – 6 units	DENT TOU loggers	7/20/2018-12/6/2018	15-minute

The eight lighting loggers deployed were strategically placed to capture on/off and occupancy or dimming operation for the diversity of area types present across the 12,000 ft^2 police station the lighting retrofit covered. For areas where loggers monitored lighting fixtures that operate on the installed occupancy or dimming controls, baseline operational schedules were created by applying full load operating values to intervals where multiple consecutive partial full-load values were present (more details on this analysis process is provided in the evaluation savings analysis section).

The ELITEpro logger monitored average current, voltage, power, and power factor for 5-minute intervals over the metering period. The logger measured three channels from the breaker panel. The areas monitored with ELITEpro loggers were confirmed to be dimming for all channels by both the site contact and through visual inspection while on-site. The analysis was also performed to compare the max metered kW for each channel with the max rated wattage for the fixtures in the metered area. These values were found to be comparable. Each channel measured several different areas under varying schedules. Channels 1 and 3 measured areas under continuous operation while channel 2 monitored non-continuous areas such as the server room and holding cells. The exterior fixtures were found to operate on a set schedule of 7 PM to 7 AM through a timeclock. These fixtures were initially on photocell control before switching to timeclock operation. The site contact conveyed his frustration with the photocell control as fixtures did not come on exactly when needed, causing the switch to the time clock control. The timeclock schedule is adjusted in the winter, but there is always a set gap of 12 hours when fixtures are powered and shut down. DENT TOU loggers were strategically placed in several other areas throughout the station to obtain operational data on continuous and non-continuous areas. These areas were mostly controlled manually, although a handful of fixtures were found to be controlled via occupancy.

Table 6 below outlines the evaluated operating hours obtained through metering in the station. The exterior lighting was the only area that was unable to be metered. This area represents a small portion of site savings and applies to approximately 7% of all retrofitted fixtures. The lighting schedule used in the evaluation for this space came from the site contact, which was verified on-site by checking the timeclock settings.

Table 6: Metered Hours of Use

Schedule ID	Logger #	Description	Annual Hours	On-Peak Hours
1	LL08040394	Hallway	8,550	3,968
2	LL08040496	Dispatch	5,559	2,458
3	LL08050871	Locker & Break Room	2,447	1,691
4	LL08101754	Records Division	1,325	690
5	LL08102516	Office	1,148	896
6	LL10120433	Restroom	5,497	3,029
7	LL20352170	Dimming	3,945	1,817
8	LL20352171	Dimming Baseline	8,760	4,016
9	LL13071231	Channel 1: Hallways and lobbies	4,822	2,304
10	LL13071232	Channel 2: Holding Cell, Hallways, Server Room	1,589	1,231
11	LL13071233	Channel 3: Other continuously operated areas	4,941	2,245
12	LL13071234	Channel 1 Baseline	8,760	4,016
13	LL13071235	Channel 2 Baseline	3,956	2,690
14	LL13071236	Channel 3 Baseline	8,760	4,016
15	Elite	Avg. Ch1 & Ch3 (9, 11)	4,569	2,122
16	Elite	Avg. Baseline Ch1 & Ch3 (12, 14)	8,760	4,016
17	Elite	Exterior Schedule	4,380	2,008

Figure 2 through 3 below depict the average daily trends for the 8,760-expanded model for the offices (schedule 5), arms locker and break room (schedule 3), and hallways and other continuous areas (schedule 15) respectively. Schedules for Figures 1 and 2 follow similar trends in operation as fixtures tend to power on around 7 AM and shut down around 4-5 PM. One of the offices metered (Figure 2) shows lower usage on Saturday and Monday; the occupant is out on those days. General operation for areas such as these is different than assumed for normal business operation as there is occasional usage on Saturday and much less Sunday and Monday. Both areas are primarily controlled manually with an exception of 4 occupancy sensor-controlled fixtures in the break room. The areas captured in Figure 3 operate continuously and on dimming controls. Percent illumination follows an even line between 48 and 57 percent.

Figure 2: Average Metered Data - Office

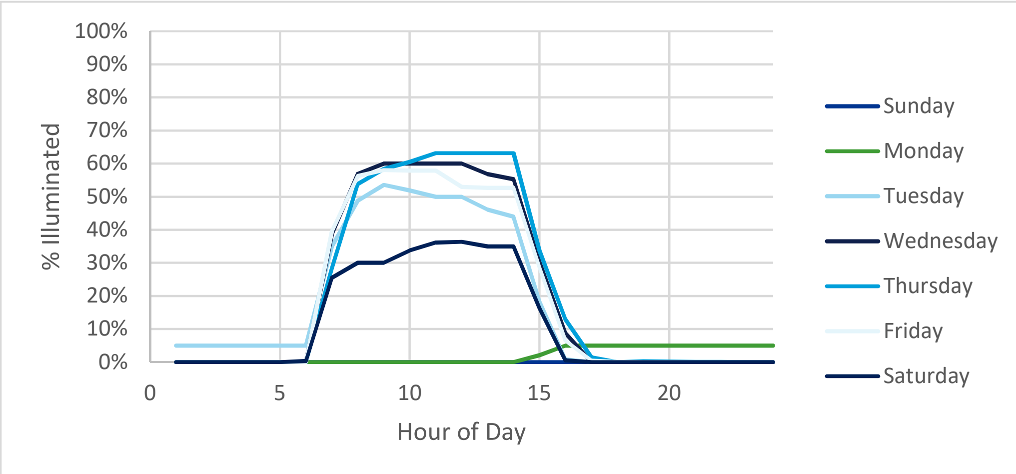


Figure 2: Average Metered Data - Locker & Break Room

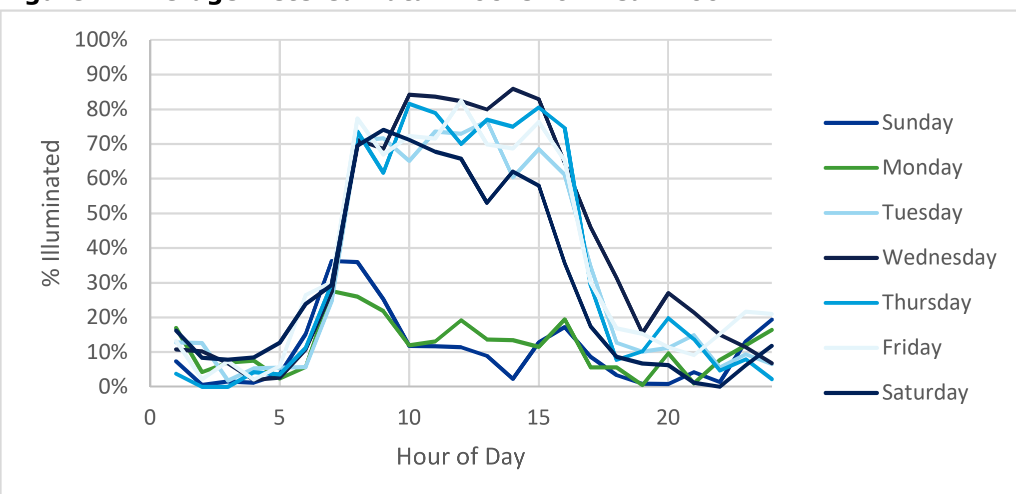
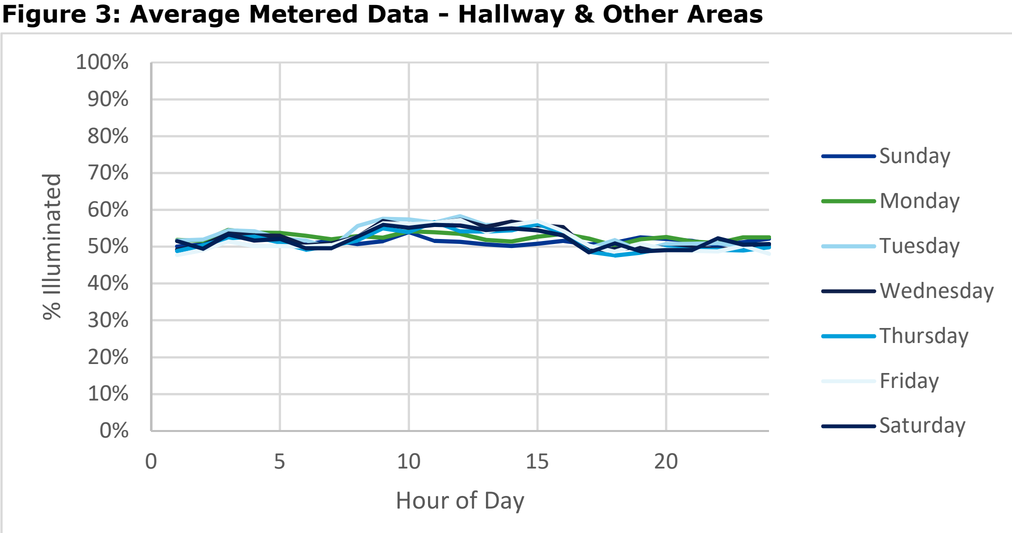


Figure 3: Average Metered Data - Hallway & Other Areas



Evaluation Baseline Review

The evaluator used a dual baseline for the analysis of lifetime savings. All regular lighting retrofit projects follow the model of 1/3 lifetime attributed to a baseline of the existing fixtures, and 2/3 will be assumed using a 60% fixture wattage reduction for that remaining period regardless of existing fixture age or reported condition. The baseline conditions were preexisting fluorescent and MH fixtures. The hours of operation were based on metered data. For the evaluated lighting control savings, the evaluator used a single baseline with a nine-year measure life.

Baseline schedules for occupancy-controlled fixtures were applied by using schedules metered from similar non-controlled areas. The schedule obtained for dispatch was used as the baseline schedule for the locker room, break room, detective area as it was found to operate in a manner by looking at the metered lumen logger data. Baseline schedules for dimming fixtures were determined by performing bin analysis to convert 5-minute intervals to hourly intervals and applying conditional formats to check the data for non-continuous intervals. Table 7 below provides an example of how the baseline hours of use are derived from the logger data of a fixture group or group of fixtures with dimming controls. The baseline value is calculated using the percent on from the logger data for the hour of interest and the hour before and/or after. If the logger data for the hour of interest is greater than 0% and is 0% for the hour before, the baseline percent on at that hour equals the percent on from the logger data (see hour two). If the logger data for the hour of interest and the hours before and after are all greater than 0%, the baseline value is set to 100%, which assumed that the fixtures(s) would have operated 100% during this hour if they were manually controlled (see hour three). If the logger data for the hour of interest is greater than 0% but is 0% for the hour after, the baseline percent on at that hour equals the percent on from the logger data (see hour four).

Table 7: Example of Baseline Schedule

Hour	Logged Data Percent On	Baseline Percent On
1	0%	0%
2	27%	27%
3	60%	100%
4	52%	52%
5	0%	0%
6	0%	0%
7	27%	27%
8	52%	100%
9	66%	100%
10	66%	100%

Evaluation Savings Analysis

For the lighting analysis phase, TOU, lumen, and power data were used to determine the operational schedule and EFLHs for metered fixture groups on-site. Averages for metered schedules were calculated and applied to areas found to operate under similar conditions. For all non-metered areas, metered schedules were applied based on operational similarities.

EFLHs for dimmed fixtures using the lumen level logger was calculated by comparing metered data intervals to a light level table determined from bi-level trends in the metered data. Max lumens would be equal to 100% of the total output, while % dimmed levels were determined by comparing each lumen interval to the max value in the data. Average data within the hourly interval was used to convert the TOU data to an hourly format.

ELITEpro meters were used to capture power data and operational trends for dimmable fixtures. Bin analysis was used to convert 5-minute power logger data into hourly intervals. Percent on values were determined by comparing operating kW at each data interval to the max connected kW value on each channel. The max connected kW for each channel was compared to the max rated wattage per the spec sheets for the areas metered. From this information, the evaluator determined that dimming reductions were observed as these max kW values were comparable. Raw data for channels 1 and 3 observed a handful of quick spikes where consumption was doubled compared to the normal max operation for the metered period. For these channels, the evaluator determined values for max kW based on normal operation and set up conditional formats for the raw data. Intervals found greater than this max kW were set equal to this value. Runtimes for all loggers were expanded to fit an 8760-model based on trends in the data to reflect general operation for space.

The following equations were used to calculate savings:

Baseline Fixture kWh = $\frac{Quantity_B * Wattage_B}{1000} * Evaluated\ Operating\ Hours\ without\ controls$

Proposed Fixture kWh = $\frac{Quantity_P * Wattage_P}{1000} * Evaluated\ Operating\ Hours\ without\ controls$

Fixture kWh Savings = $Baseline\ Fixture\ kWh\ - Proposed\ Fixture\ kWh$

Occupancy Sensor Control kWh Savings = $Proposed\ Fixture\ kW\ * (Evaluated\ Operating\ Hours\ without\ occupancy\ controls - Evaluated\ Operating\ Hours\ with\ occupancy\ controls)$

Dimming Control kWh Savings = $Proposed\ Fixture\ kW * (Evaluated\ Operating\ Hours\ without\ controls - EFLH\ of\ dimmable\ fixtures)$

HVAC Interactive Savings = $(pre\ conn\ kW - post\ conn\ kW) * Coincident\ Occupied\ Cooling\ Hours * \frac{0.8}{Cooling\ COP}$

Total kWh Savings = $Fixture\ kWh\ Savings + Occupancy\ Sensor\ Control\ kWh\ Savings + Dimming\ Control\ kWh\ Savings + \ HVAC\ Interactive\ Savings$

All spreadsheets used in the estimation of evaluation savings will be made available to the PAs for review at their request. For site cooling hours, the evaluator assumed cooling would only take place between the months of April and October. For each hourly interval within that range of months in the 8760-hours model, if dry bulb temperature taken from local weather data was more than the setpoint of 55°F, then that hour was determined to be a cooling hour. Cooling hours that coincided with the lighting hours were used to determine total annual cooling savings. Cooling COP is assumed to be 2.9 for the packaged DX units that served the space.

Comparison of Assumptions

The main assumptions made during the application process were the estimated annual operating hours used. Non-controlled areas were found to operate much less than assumed in the application, yielding a significant reduction in savings for fixtures. For a large portion of dimming controlled fixtures, baseline hours of use were found to be more than assumed in the tracking estimation of savings as tracking did not account for the areas that operated continuously without controls. The percent reduction for controlled fixtures was found to be greater compared to the application estimates yielding an increase in savings for controls. Detailed values are shown in Table 8 comparing changes in the baseline and proposed conditions for both the application and evaluation hours of use for each area.

Table 8: Comparison of Key Parameters

Area	Baseline		Proposed/Installed		Evaluated Savings (kW)
	Tracking Hours	Evaluation Hours	Tracking Hours	Evaluation Hours	
Exterior	4,224	4,380	4,224	4,380	1.101
Locker room, break room, detective area	6,571	2,447	4,994	2,447	0.862
Locker room, break room, detective area (occupancy sensor)	6,571	5,559	6,571	2,447	0.413
Holding cell & hallway (dimming)	6,571	3,956	4,994	1,589	1.855
Hallway & other areas (dimming)	6,571	8,760	4,994	4,569	3.883
Server room (dimming)	6,571	3,956	4,994	1,589	0.334
Office	6,571	1,148	6,571	1,148	1.472
Dispatch	6,571	5,559	6,571	5,559	0.751
Restroom	6,571	5,497	6,571	5,497	0.434
Records	6,571	1,325	6,571	1,325	0.917

End-Use Analysis

The largest discrepancy between the tracking and evaluation savings estimates are due to differences in operating hours. General evaluated hours for non-controlled fixtures were found to decrease compared to the application estimates, yielding a large decrease in savings. For controlled fixtures, the estimated baseline and percent reduction were found to be greater than assumed in the application, yielding to a slight increase in savings associated with operating hours. The sum of these discrepancies associated with hours of use was found to reduce the overall site savings by 20%. This key parameter is one of the main drivers that drove kWh savings down, considering the evaluated quantity and wattage of the fixtures were found to be consistent with the application values. This is a significant difference from the application as all fixtures proposed with occupancy were found to be controlled via dimming on-site. Out of the 6,708-kWh total evaluated controls savings estimate, only 408 kWh was due to occupancy control while the remaining 6,300 kWh was due to EFLH reductions associated with dimming. However, the four fixtures controlled via occupancy were found to be additional fixtures controlled compared to the application, leading to a 1% rise in savings associated with the increased quantity of controlled fixtures. An 8% increase in savings was found in the interaction between the new lighting and on-site cooling equipment. The difference in peak demand and % of energy savings on the peak can be attributed to the hours during which the fixtures operate. Table 9 below lists the discrepancies found during the evaluation and each impact on the final realization rate.

Table 9: Discrepancy Summary

End Use	Parameter(s)	Discrepancy	Impact on Results	Impact on Realization
Lighting & Controls	Hours of Operation	Operation	An overall decrease in evaluation hours yields a decrease in savings.	-20%
Controls	Occupancy Control	Quantity	An increase in controlled fixtures yields an increase in savings.	+1%
Lighting & Controls	Cooling	Interaction	Interactive effects with on-site cooling yield an increase in savings.	+8%

Ancillary impacts

For this measure, electric HVAC interaction savings occur in retrofitting the fluorescent fixtures to LED. The tracking estimate did not include HVAC interactive effects. The areas where all fixture retrofits took place are entirely served by packaged DX units with an assumed COP of 2.9. Adding this effect accounts for an 8% increase in savings compared to the tracking system application

Lifetime Savings

The evaluator classified this measure as a dual baseline to consider the lighting baseline at the time of the retrofit upgrade as well as the time the replaced working equipment would have reached EUL. The evaluator calculated the evaluated lifetime savings values using the following formula:

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

where:

LAGI = lifetime adjusted gross impact (kWh)

FYS = first-year savings (kWh)

EUL = measure life (years), 15 years

RUL = 1/3 of EUL (years)

outyear factor is equal to 60% for this dual-baseline measure

The total evaluated lifetime savings are smaller than the tracking lifetime savings primarily due to the baseline outyear factor applied to the evaluation fixture lifetime, and the shorter lifetime observed with controls. Table 10 provides a summary of key factors that influence the lifetime savings.

Table 10: Lifetime Savings - Summary of Key Factors

Fixture/Lamp Savings

Factors	Tracking	Application	Evaluator
Baseline classification	Single	Single	Dual
First year savings	55,615 kWh	55,615 kWh	45,080 kWh
Measure lifetime	13 years	13 years	15 years
Lifetime savings	722,995 kWh	722,995 kWh	495,880 kWh
Lighting Controls Savings			
Factors	Tracking	Application	Evaluator
Baseline classification	Single	Single	Single
First-year savings	2,448 kWh	2,448 kWh	6,708 kWh
Measure lifetime	13 years	13 years	9 years
Lifetime savings	31,824 kWh	31,824 kWh	60,372 kWh
Total	754,819 kWh	754,819 kWh	556,252 kWh

Improvement opportunities

The decrease in evaluation estimated operating hours over tracking hours and interactive cooling savings were the two factors that lead to a change in savings for this site. The interactive cooling savings for most LED retrofit projects can be significant when hours of use are high. Future programs could possibly look to incorporate interactive HVAC effects with projects that claim annual operating hours over 4,000 to ensure all significant savings impacts are being captured.

Site ID: 2016L043

Program Administrator	National Grid
Project ID(s)	6279032
Project Type	Lighting
Program Year	2016
Evaluation Firm	DNV GL
Evaluation Engineer	Jerry Song
Senior Engineer	Jeff Zynda

Site Description

The project was a retrofit of a major portion of a city's street lighting fixtures. The project consisted of replacing 15,911 high-pressure sodium (HPS) roadway fixtures of varying wattages with high efficiency LED fixtures. The estimated tracking savings were 9,183,114 kWh per year. The fixtures were controlled by photocells in both pre- and post-retrofit conditions.

The evaluation found the project energy savings to be 9,080,672 kWh, yielding a realization rate of 99%. The reason for the discrepancy is primarily due to higher than expected installed fixture wattage. Table 4 shows the results of the evaluation.

Table 4: Site results

Savings Quantity	Application Estimate	Evaluation Estimate	Realization Rate
Electric energy (kWh)	9,183,114	9,080,672	99%
% of Energy Savings on Peak	22%	27%	123%
Summer On-Peak Demand (kW)	0	0	-
Winter On-Peak Demand (kW)	2199.5	2,101.0	96%

Application Savings

This section will summarize the methodology and assumptions used to estimate the application savings claimed for the project.

Baseline

The baseline system consisted of 15,911 high-pressure sodium fixtures with wattages ranging from 65W to 1,085W. The fixtures were estimated to operate roughly dusk to dawn, or 4,175 hours annually. The tracking analysis did not provide any source for the hours' estimate beyond "dusk to dawn".

Table 5: Baseline Fixture Parameters

Baseline Quantity	Baseline Fixture Wattage
3,099	65
39	90
2,143	130
1	190
9,064	295
1,552	460
13	1,085

Proposed condition

The proposed condition replaces the HPS street lighting with LED lights 1:1 with varying wattages running on the same dusk to dawn schedule (4,175 hours). The LEDs' wattages do not necessarily align with the wattages of the HPS fixtures they replace as shown with the proposed wattages in the table below. This is due to some incongruity with the fixture types in the baseline case in which there were some fixtures with higher or lower wattages than needed for the area being replaced. Phase-2 of the project which installed dimming on all the fixtures was incentivized in the following program year (2017). Savings from dimming have not been included in the application that was evaluated. The evaluation team did collect some spot readings/metered data to verify dimming. Additional information is provided in the following section.

Table 6: Proposed Fixture Parameters

Proposed Quantity	Proposed Wattage
2,986	43
2,567	54
10,356	137
2	168

The project saves energy by reducing the total fixture wattage of the street lighting fixtures resulting in a project savings of 9,183,114 kWh annually.

The addition of dimming controls may also partially explain why some of the installed LED fixtures were a higher wattage than the HPS fixtures they replaced, as dimming controls may lower the operating wattage.

Application calculation methodology

Application savings were calculated using the National Grid Custom Lighting Tool. The tracking calculation assumes 4,175 hours annually. The operating hours stayed constant between the baseline and proposed fixtures, with the only change coming from the reduced fixture wattage. These values were used with the following formulas to calculate the savings

Total kWh Savings = $Fixture\ kWh\ Savings$

Baseline Fixture kWh = $\frac{Quantity_B * Wattage_B}{1000} * Baseline\ Operating\ Hours$

Proposed Fixture kWh = $\frac{Quantity_P * Wattage_P}{1000} * Baseline\ Operating\ Hours$

Fixture kWh Savings = $Baseline\ Fixture\ kWh\ - Proposed\ Fixture\ kWh$

Project Evaluation

The evaluator performed the on-site visit on April 20, 2019. The evaluator verified the baseline and installed retrofit fixture types and quantities based on conversations with the site contact and visual inspection of a sample of the fixtures. A small junction box is connected to the metal street light poles, where the short-term meters were installed to gather hours of operation and verify photocell operation. No meters were installed on 54, 43 and 167 Watt rated fixtures. Table 4 shows how the measure was verified to be installed and operating.

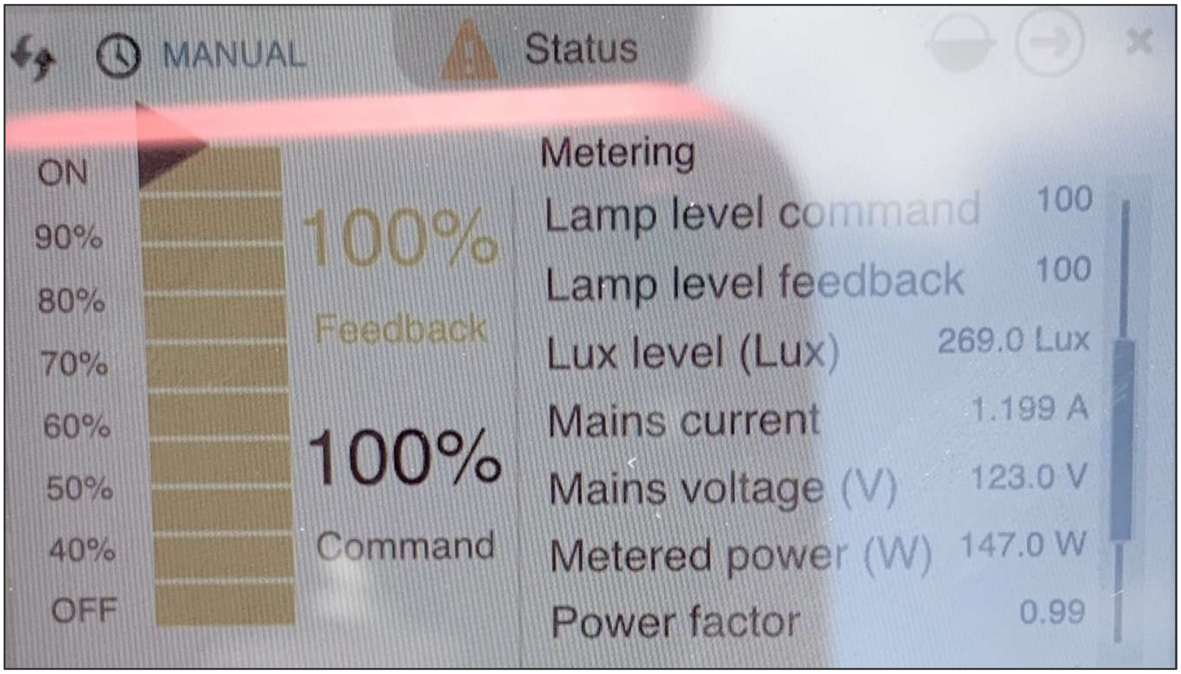
Table 7: Measure verification

Measurement	Verification Method	Verification Result
Hours of use	HOBO MicroStation	Operating hours were slightly higher than anticipated, resulting in higher savings
Installed Fixture wattage	HOBO MicroStation	The installed fixtures were slightly higher wattage than anticipated, resulting in a reduction in savings
Fixture counts	Visual Inspection	3% of the entire tracking count was verified by manual counts.
Spot wattage	Spot-Reading/Elite-pro	Actual-installed wattage at varying dimming levels.

The evaluation team installed multiple HOBO MicroStation meters to collect actual operating hours and during this process, the team also collected full load and varying partial (dimming) demand kW as shown in Figure 3 and Figure 4. Since the dimming savings were part of a different National Grid application, they were not analyzed as part of this study. Evaluated savings assumed a full load for all fixtures. These spot measurements were done at all 8 metered locations.

Figure 3: Elite-Pro Spot Reading

Figure 4: Vendor Application Screenshot



Data Collection

The evaluator spoke with the primary site contact, the energy efficiency manager, during the site visit. Based on the conversation, the fixtures were installed in 2016 while dimming controls were implemented in the program year 2017. The fixtures in both the pre- and post-retrofit case ran solely on photocell with additional savings coming from dimming once the fixture turned on.

The tracking documentation listed the fixtures by streets names and DNV GL used that as a starting point for verification of counts. DNV GL completed counts in 20 streets across the city, covering arterial, residential and main streets. The total count of 547 fixtures was about 3.5% of the total in tracking estimate and differed from the tracking estimate by 3% (tracking estimate of 565 fixtures).

A 3% discrepancy could be within the uncertainty range of the total counts. There is always an ambiguity around the first and the last fixture counted in any street, sometimes the fixtures could be in between two streets. Therefore, the evaluation assumes the tracking counts/estimate to be reasonable and no change of fixture counts has been accounted for in the evaluation analysis.

Visual observation found each individual street light was marked with a large sticker stating the fixture's wattage. The stickers corroborated the lighting groups claimed in the tracking analysis. However, fixture spot measurements found the full load wattage of the fixtures to be higher than marked. As mentioned in the previous section, DNV GL conducted spot-measurements at 8 metered locations using Elite-pro logger at 100% load. These fixtures were set to 100% load using a vendor-controlled application in a tablet onsite. An average value of all spot readings at 8 different locations was found to be 146.5 Watts, compared to the rated wattage of 137 Watts.

Due to the accessibility issues, these measurements can be taken only at fixtures installed on metal poles, which were essentially the 137 Watt rated fixtures. The evaluation team did not find any metal poles with other wattage fixtures. The average spot reading demand value shown in Table 5 was used in the analysis for 137 Watt rated fixtures, but the tracking wattage has been used for the remaining fixtures in the evaluation analysis.

Table 8: Discrepancy in full load wattage based on onsite spot measurements

Proposed Fixture Wattage	Installed Wattage
43	No measurements were taken
54	No measurements were taken
137	146.5 (8 fixtures' spot reading averaged value)

Metered and Logged Data

Eight Hobo MicroStation loggers were installed on 137-Watt fixtures with metal poles to measure hours of operation and power. Loggers could only be installed on fixtures with metal bases. These fixtures are typically only available on arterial streets. The loggers were installed at the widest differences in both longitudinal and latitudinal directions possible as well as in the dense downtown area. Table 6 lists more details on logger deployment

Table 9: Evaluation data collection – installed equipment

Parameter	M&V Equipment Brand and Model	Metering Start/Stop Dates	Metering Interval
Time of Use (TOU), Amperage	Hobo MicroStation	4/20/19-06/28/19	1-Minute
Spot measurements (kW)	Elite-Pro	Spot readings	N.A.

Figure 5 and Figure 6 below show two of the meters that were installed on-site. Figure 7 shows the final averaged profile used in the analysis. Both the metered data and actual sunset and sunrise time data for the respective dates were used to develop these profiles. Additional details are provided in the next section.

These profiles show the difference in operating hours, specifically during the seasonal changes. The figure also verifies the operation of photocell-based start and stop hours every day.

Figure 5: Monthly averaged operating profile for meter#2003926

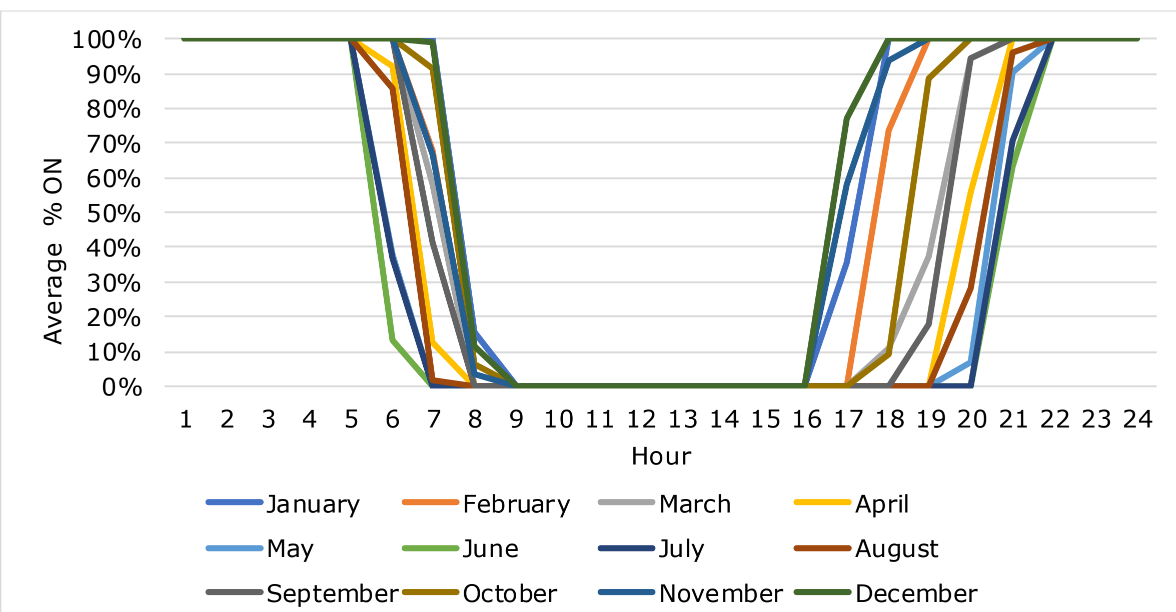


Figure 6: Monthly averaged operating profile for meter#2002688

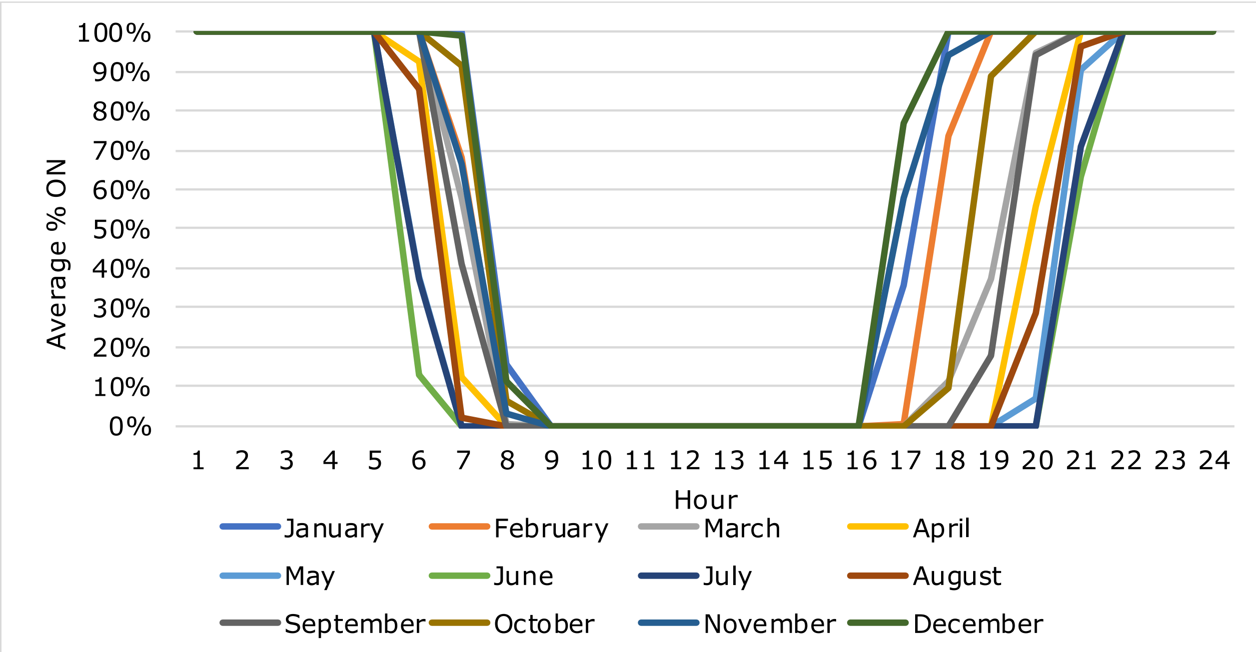
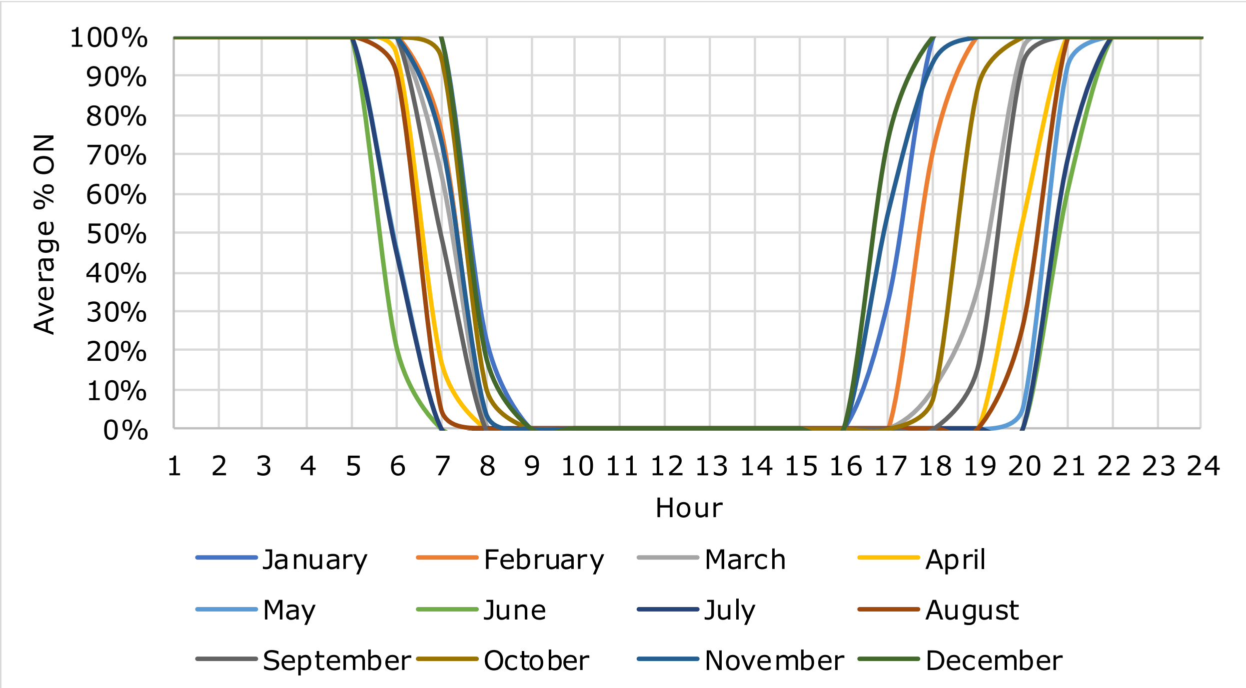


Figure 7: Monthly averaged operating profile (Average of all meters).



Evaluation Baseline Review

The evaluation found the baseline fixture wattages to be reasonable and consistent with the oral responses given by the site contact. Baseline operating hours were adjusted based on the logger data collected. The baseline condition was assumed to be the pre-existing fixtures with photocell controls based on discussions with the energy efficiency manager. Fixture quantities were assumed to be the same as tracking estimates. It was assumed that fixtures were replaced 1-to-1 with no additional fixtures being added.

Evaluated Savings Analysis

The lighting analysis was performed by using the collected logger data and comparing the data with daily sunrise and sunset times. This determined the photocell's sensitivity and on/off time of the fixtures relative to sunrise and sunset. The average offset between the daily darkness hours and logger hours was taken for the logging period. This value was then applied to every day of the year. This created a calibrated on/off schedule for the fixture, effectively mimicking an hourly 'Equivalent Full Load Hours' for the fixture accounting for the light-to-dark and dark-to-light transition periods. The evaluation found the fixtures were on for 4,322 hours annually – 20 additional hours over the dawn-dusk period and 147 hours more than the value used in the tracking analysis.

The collected amperage data also indicated that full load wattage was slightly higher than the rated wattage of the lamps, as shown in the table below. DNV GL used an Elite-pro logger to collect a full load kW during the 2nd visit. This was measured at 8 different poles with fixtures rated at 137 W and an average value of 146.5W was used in the evaluation analysis.

The savings were calculated using the evaluated annual operating hours and the lamp wattages found during the site visit using the following equations.

Baseline Fixture kWh = $\frac{Quantity_B * Wattage_B}{1000} * Evaluated\ Operating\ Hours$

Proposed Fixture kWh = $\frac{Quantity_P * Wattage_P}{1000} * Evaluated\ Operating\ Hours$

Fixture kWh Savings = $Baseline\ Fixture\ kWh\ - Proposed\ Fixture\ kWh$

Total kWh Savings = $Fixture\ kWh\ Savings$

The evaluation also investigated the impacts of the dimming controls implemented in Program Year 2017 and its impacts on savings. The logger data shown in Figure 1 shows the 137W fixtures had a significant drop in wattage due to the implemented controls. These results were not used in the final evaluated savings in this report as they were part of the next year's (2017) program year savings.

The actual demand loads at some of the streetlights show that the demand was a bit lower than what was used in the tracking analysis for the dimming controls. Evaluated installed demand on average was about 80W (60% of Rated 137Watts) and tracking assumed 90W which is 66% of the rated Watts. Further investigation would have to be done to confirm that this is happening at all the fixtures, but DNV GL recommends using post-installation metered data on a sample of street lights with dimming and also conduct customer interviews to measure the street lighting savings from dimming controls.

Evaluation Results

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

Table 10: Project results

Savings Quantity	Application Estimate	Evaluation Estimate	Realization Rate
Electric energy (kWh)	9,183,114	9,080,672	99%
% of Energy Savings on Peak	22%	27%	123%
Summer On-Peak Demand (kW)	0	0	-
Winter On-Peak Demand (kW)	2,199.5	2,339.0	106%
Lifetime energy (kWh) – if retrofit	119,380,482	131,420,510	110%

Table 11 compares the key parameters used in the Application analysis with those used in the Evaluation analysis. The purpose of this table is to show how different values changed.

Table 11: Comparison of Key Parameters

Parameter	Tracking	Evaluated	% Savings Difference
Annual Operating Hours	4,175 Hours	4,322 Hours	+4%
Average Post-Retrofit Fixture Wattage per spot measurements	137W	146.5W	-5%

End-use analysis

Table 12 below shows the 2 parameters that caused the discrepancy in the total tracking energy savings.

Table 12: Discrepancy Summary

End-Use	Parameter(s)	Discrepancy	Impact on Results
Lighting	Hours of Operation	Operational	The evaluation found the operating hours to be higher than the tracking analysis

			assumed. This resulted in a +4% project savings
Lighting	Fixture Wattage	Operational	Installed fixture wattages were higher than anticipated, resulting in a 5% decrease in savings.

Ancillary impacts

There were no ancillary impacts from the project due to the fact that they were exterior fixtures.

Improvement opportunities

Ensure that the documentation has the most up-to-date fixture counts for the final analysis. This should be cross-checked during the post-inspection with the installers. According to National Grid, the hours of operation for these street lights in based on billing tariff hours. Consider using the actual street light operating hours in calculating savings, but not billing hours.

Site ID: 2016RIL0079

Program Administrator	National Grid
Project ID(s)	5774109
Project Type	Lighting
Program Year	2016
Evaluation Firm	DNV GL
Evaluation Engineer	Jerry Song
Senior Engineer	Jeff Zynda

Site Description

- The project was a retrofit of interior T8 lamps at a department store. The existing system consisted of 62 one-lamp, two-foot T8 lamps and 896 one-lamp, four-foot T8 lamps. The lamps were replaced one-to-one with 10W and 15W LEDs for the 2' and 4' lamps, respectively. Fixtures remain on manual controls, operating at an estimated 3,915 hours annually and remain unchanged. The change to more energy-efficient lamps was estimated to save 54,322 kWh, annually. Basic description of the site/facility involved in the project.

- The evaluation found a significantly greater quantity of installed lamps than stated in the application analysis. The site contact claimed all fixtures arrived at the facility around the same time. The fixtures matched the make and model of the lamps in the application analysis. However, because the evaluator did not find any documentation indicating the fixtures were purchased through the incentive program, the quantities used in the application analysis were used for the evaluation analysis.

- The evaluation found a realization rate of 118%, or 64,302 kWh annually. The primary reason for the higher than estimated savings is due to an 11% increase in annual operating hours and an 8% increase from taking into account HVAC interactive effects.

Table 13: Site results

Savings Quantity	Application Estimate	Evaluation Estimate	Realization Rate
Electric energy (kWh)	54,322	64,302	118%
% of Energy Savings on Peak	73%	67%	91%
Summer On-Peak Demand (kW)	13.90	15.81	114%
Winter On-Peak Demand (kW)	13.90	13.13	94%

Application Savings

Application savings were derived from a reduction in connected wattage due to the retrofit from T8 to LED. Hours of operation remained the same between the baseline and proposed condition.

Baseline

The baseline assumed all lamps ran 3,915 hours annually. The lamps consisted of 62 two-foot T8 lamps and 896 four-foot T8 lamps of 17 and 30 watts, respectively. All lamps are manually controlled.

Table 14: Baseline Inventory

Existing Quantity	Existing Fixture Description	Existing Hours	Existing Wattage
86	1L2’ T8/ELIG	3,963	17
896	2L4’ T8/ELIG	3,963	30

Proposed condition

The proposed condition assumed lighting schedules remained unchanged and retained manual controls. The baseline lamps were replaced one-to-one with TLEDs of the same length. The two-foot T8 lamps were replaced with 10W two-foot LEDs and the four-foot lamps with 15W four-foot LEDs.

This section will describe the proposed condition assumed in the application analysis. It will only discuss the assumptions made in the original analysis, not any information gained through this evaluation. Included will be information on the source of all key savings inputs used, if known.

Table 15: Proposed Inventory

Existing Quantity	Existing Fixture Description	Existing Hours	Existing Wattage
86	Osram 75146 10W TLED	3,963	10
896	Osram 75084 15W TLED	3,963	15

Application calculation methodology

Application savings were calculated using the National Grid Custom Lighting Tool. Hours of operation were assumed to be 3,915 hours annually. Lamps were controlled manually, and HVAC interactive effects were not taken into account. Application savings used the below formulas.

Total kWh Savings = $Fixture\ kWh\ Savings$

Baseline Fixture kWh = $\frac{Quantity_B * Wattage_B}{1000} * Operating\ Hours\ without\ controls$

Proposed Fixture kWh = $\frac{Quantity_P * Wattage_P}{1000}$*Operating hours without controls

Fixture kWh Savings = $Baseline\ Fixture\ kWh - Proposed\ Fixture\ kWh$

Project Evaluation

A site visit was conducted on September 6, 2018. The site is a three-story department store. The evaluator met with the on-site engineer and confirmed the store’s lamp retrofits. The site contact claimed most lamps turned on and off with the store hours. This was corroborated during the site visit as most lamps remained off until shortly before the store opened and turned off shortly after close. The engineer confirmed the store was closed for two holidays per year: Christmas and New Year’s Day; with different hours for Thanksgiving and Black Friday. During Thanksgiving, the store opened at 6PM and was open throughout Black Friday until 10PM. The evaluator verified the lighting count using as-builts available in the engineer’s office and the lighting technology was visually verified by the evaluator. Dent time-of-use (TOU) loggers were installed to capture any potential differences in lighting schedules in different areas of the store. The evaluator found significantly more installed lamps than described in the application analysis. This was confirmed both via a visual count as well as through the on-site as-builts.

The evaluator returned to the site on November 30, 2018 to retrieve the loggers. The savings analysis was performed based on the logger data gathered on-site and the schedule information provided by the site contact.

Data collection

- Based on visual inspection and conversations with the site contact, all lamp types and control methods were verified during the site visit. The evaluator found the lamps to be present in perimeter lamps, some floor display lamps, and around the center area ceiling near the escalators. The lamp quantities were further verified using as-builts found on-site. The total number of installed lamps were significantly greater than the amount listed in the application analysis. The evaluator found a total of 2,128 Osram 75084 four' TLED lamps and 237 Osram 75146 two' TLED lamps. The application analysis listed 896 of the four' lamps and 62 of the two' lamps. This represents a 238% and 382% increase in lamps, respectively. The site contact claimed all fixtures arrived at the facility around the same time. The fixtures matched the make and model of the lamps in the application analysis. However, because the evaluator did not find any documentation indicating the fixtures were purchased through the incentive program, the quantities used in the application analysis were used for the evaluation analysis.

The evaluator installed twelve Dent TOU loggers to capture the lamps' hours of operation binned into three different schedules: central display boxes, perimeter lamps, and central ceiling lamps. Loggers were installed on all three floors and varying locations on each floor to ensure that any floor/location-based changes in lighting schedules did not impact the analysis results. It was not possible to differentiate the lamps in the application analysis with the other lamps in the facility. Because of this, logger schedules were assigned to lamps in the same ratio as was found on-site.

Site Visit Summary

Discussions with the site contact confirmed general hours of operation and holiday schedule. The site contact stated that lamps largely followed store hours and verbally verified all lamps found were replaced through the incentive program. Site operating hours and schedules have not changed between the pre and post-retrofit cases and no other major renovations were performed.

Metered and Logged Data

The evaluator installed twelve Dent Time-of-Use lighting loggers on a representative sample of the installed lamp groups to determine the operating hours of the building. The logger data was able to capture standard holiday schedule (Thanksgiving and Easter) as well as the unique Black Friday hours. Each schedule's annual lamp operating hours and controlled lamps can be found in Table 16.

Table 16: Analysis Assumptions

Schedule Type	Lamp Count	Annual Operating Hours
Center lamps	22x 2' Lamps; 470x 4' Lamps	4,170
Perimeter lamps	40x 2' Lamps; 369x 4' Lamps	4,406
Display Boxes	57 x 4' Lamps	5,259

Evaluation baseline review

The evaluator agreed with the application analysis that lamps were replaced on a one-to-one basis through visual inspection of the installed lamps and lamps. However, the evaluator found significantly more replaced lamps than originally accounted for in the application analysis. The evaluator kept the same lamp count as in the application analysis as there was no documentation indicating the additional lamps came from the incentive program.

The baseline operating hours were adjusted based on the schedules retrieved from the loggers installed on-site. The on-site engineer verified that lighting schedules remained the same in the pre-retrofit and installed case.

Evaluation savings analysis

The analysis used an 8,760 spreadsheet to calculate savings based on the Time-of-Use logger data collected. The metering period captured standard operation as well as Thanksgiving and Black Friday schedules. The evaluator used the Thanksgiving schedule to confirm all lamps are off during holiday hours and used this to extrapolate for other closed holidays. The Black Friday schedule was accounted for separately as the store has unique hours on that day. Additional HVAC interactive savings from electric chillers were also accounted for in the analysis. The analysis used the following formulas in its calculations. A cooling COP of 5.5 was assumed based on a chiller size greater than 200-tons.

Total kWh Savings = $Fixture\ kWh\ Savings + HVAC\ Interactive\ Saving$

Baseline Fixture kWh = $\frac{Quantity_B * Wattage_B}{1000} * Evaluated\ Operating\ Hours\ without\ controls$

Proposed Fixture kWh = $\frac{Quantity_P * Wattage_P}{1000} * Evaluated\ Operating\ Hours\ without\ controls$

Fixture kWh Savings = $Baseline\ Fixture\ kWh - Proposed\ Fixture\ kWh$

HVAC Interactive Savings =

$Interactive\ Cooling\ Hours * (Baseline\ Connected\ kW\ \ - Installed\ Connected\ kW) * 0.8 / Cooling\ COP$

Evaluation Results

The evaluation analysis found three major discrepancies accounted for the high realization rate: increased operating hours and interactive HVAC savings.

The evaluation determined the retrofitted lamps averaged 4,336 annual operating hours across the three schedule types. This is an 11% increase from the proposed 3,915 annual operating hours. This accounted for a 7% increase in total realization rate over the application analysis.

The application analysis did not take into account the HVAC interactive effects of the lighting retrofit. The evaluation analysis found the project’s interactive HVAC savings to account for an 8% increase in savings.

Table 17 summarizes the evaluation’s findings.

Table 17: Project results

Savings Quantity	Application Estimate	Evaluation Estimate	Realization Rate
Electric energy (kWh)	54,322	64,302	118%
% of Energy Savings on Peak	73%	67%	91%
Summer On-Peak Demand (kW)	13.90	15.81	114%
Winter On-Peak Demand (kW)	13.90	13.13	94%
Lifetime energy (kWh) – if retrofit	N/A		N/A

Comparison of assumptions

The evaluation used different annual operating hours than the application analysis based on the on-site collected data. The comparison of annual operating hours is shown in Table 18 below.

Table 18: Comparison of Key Parameters

	BASELINE		PROPOSED / INSTALLED	
Parameter	Tracking Value(s)	Evaluation Value(s)	Tracking Value(s)	Evaluation Value(s)
Average Annual Operating Hours	3,915	4,336	3,915	4,336

End use analysis

There were two major drivers that accounted for the higher than expected realization rate:

2) increased operating hours
3) interactive HVAC savings

The evaluation determined the retrofitted lamps averaged 4,336 annual operating hours across the three schedule types. This is an 11% increase from the proposed 3,915 annual operating hours. This accounted for a 7% increase in total realization rate over the application analysis.

The application analysis did not take into account the HVAC interactive effects of the lighting retrofit. The evaluation analysis found the project's interactive HVAC savings to account for an 8% increase in savings.

Ancillary impacts

Electric chiller HVAC interaction savings occurred in retrofitting the existing lamps with LEDs. Since the LEDs produce less heat than the baseline lamps, the on-site cooling equipment does not have to counteract as much produced heat from the lamps, saving energy to cool the space. The cooling savings account for 8% of the measure's savings. The reduced heat production from the lamps also increased gas heating load slightly during the heating months but does not result in an electric heating penalty.

Improvement opportunities

A large discrepancy existed between the lamp quantity found on-site and the quantity in the application analysis. The quantity could be more easily verified and accounted for by showing the locations for which the lamps were to be installed.

Site ID: 2016RIN008

Program Administrator	National Grid
Project ID(s)	5648427 6299117
Project Type	Retrofit and Retro-commissioning
Program Year	2016
Evaluation Firm	DNV GL
Evaluation Engineer	Chris Williams
Senior Engineer	C.D. Nayak

Project Description

This site report covers the following project IDs: 5648427 and 6299117. The facility operates with a sister facility that is located a few blocks away. Efficiency projects were also implemented at the sister facility, claimed and evaluated under site ID 2016RIN093. Both facilities produce and process knitted fabrics.

- 5648427 – Compressed air leak repair – This measure repaired approximately 29 cfm of compressed air line leaks. The compressed air is generated at 125 psi by a 75 HP rotary screw compressor with variable speed controls. Electric savings are realized by reducing the compressor load.
- P6299117 – Boiler blower retrofit – This measure retrofitted two 10 HP forced-draft fans on two existing steam boilers with variable speed (VFD) and oxygen trim controls to improve combustion efficacy. The VFDs allow the fan motors to modulate speed to match the input signal from the oxygen trim controller. Electric savings are claimed by reducing the fan speed.

Both the compressed air and steam generated by the compressor and boilers serve process functions related to dying and processing rolls of fabric.

The table below summarizes the evaluation results.

Table 19: Project results for 5648427 (Air leak repair)

Savings Quantity	Tracking Estimate	Evaluation Estimate	Realization Rate
Electric energy (kWh)	45,902	46,536	101%
% of Energy Savings on Peak	47%	46%	99%
Summer On-Peak Demand (kW)	5.2	5.3	101%
Winter On-Peak Demand (kW)	5.2	5.3	101%

Table 20: Project results for 6299117 (Process boiler draft fan VFDs)

Savings Quantity	Tracking Estimate	Evaluation Estimate	Realization Rate
Electric energy (kWh)	40,385	20,643	51%
% of Energy Savings on Peak	57%	52%	91%
Summer On-Peak Demand (kW)	2.1	2.9	140%

Winter On-Peak Demand (kW)	2.1	2.9	139%

Table 21: Combined project results

Savings Quantity	Tracking Estimate	Evaluation Estimate	Realization Rate
Electric energy (kWh)	86,287	67,179	78%
% of Energy Savings on Peak	52%	48%	93%
Summer On-Peak Demand (kW)	7.3	8.2	112%
Winter On-Peak Demand (kW)	7.3	8.2	112%

The bullets below explain some key discrepancy findings:

6299117: Boiler Draft fan VFDs

- The key discrepancy reduced kWh savings by 23% because it accounts for the observed boiler operation. The evaluation savings assume that the boilers operate in lead/lag (i.e., they do not operate simultaneously) while the tracking assumes they operate simultaneously and under the same load.
- The observed boiler usage profile was significantly different than how it was described for calculating the tracking peak demand reduction. The tracking savings used an arbitrary method with no basis on actual facility operation. The evaluation method used roughly 12 weeks of boiler operation data to generate an 8,760 kW profile. This increased peak summer and winter demand reduction by 25%.

Tracking Savings

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

Baseline condition

The equipment and conditions for these projects are isolated from each other. There are no interactive effects between these projects or other equipment.

The baseline equipment and conditions for each project are summarized in the table below.

Table 22: Baseline conditions

Project Description	Baseline condition
Air leak repair (5648427)	Kaiser SFC55 75 HP rotary screw compressor with variable speed controls. The baseline leak load was estimated to be 185 cfm while the baseline air load was estimated to be 224 cfm (equates to an equipment air load demand of 224 – 185 = 39 cfm)[10]. The compressor is assumed to operate continuously 8,760 hours per year.
Process boiler draft fan VFDs (6299117)	Two Cleaver-Brooks forced draft boilers each with one 10 HP draft fan. Baseline boilers (shells) are over 30 years old. The pre-existing burners with no oxygen trim controls were reaching the end of their life. The fan motors are assumed to have 91% efficiency and run at 80% load during operation. They operate at full speed (60 Hz). Annual hours are estimated to be 7,200

[10] The air audit report commented that the measured air leak load was unusually high for a facility this size, but did not mention possible reasons for discrepancy

Proposed condition

The measures do not affect the equipment operating schedules. The air leak repair measure saves energy by reducing the air load on the compressor. The compressor does not have to work as hard as in the baseline. The boiler draft fan VFD measure saves energy by reducing the draft fan speed to match the oxygen trim signal output by the boiler burner module. The baseline had used a flow control method (not documented in tracking) that could not throttle the fan motor speed (ran 60 Hz). The new burners are capable of oxygen trimming which improves combustion efficiency. The controls require more precise control of the air intake so installing VFDs on the draft fans was a necessary step.

The proposed conditions are summarized as follows:

Table 23: Proposed conditions

Project Description	Proposed condition
Air leak repair (5648427)	Equipment and operating hours are the same as the baseline condition. The leak repair was estimated to save approximately 29 cfm.[11]
Process boiler draft fan VFDs (6299117)	Equipment and operating hours are the same as the baseline condition. The draft fans are equipped with VFDs and modulate speed to match the oxygen trim control signal.

Tracking calculation methodology

Spreadsheet calculations were used to estimate measure savings. Some of the assumed operating conditions and savings parameter values were based on pre- and post-implementation measurements like air and leak load audit performed by TA participants. The applicant methodology and savings results are discussed for the measures below.

Air leak repair (5648427)

Annual kWh Savings = $(kW_{pre} - kW_{post}) \times AnnualHours$ = 45,902 kWh

Where,

kW_{pre} = 42.57 kW (Kaiser SFC55 at a base load flow of 224 CFM)
kW_{post} = 37.33 kW (Kaiser SFC55 at a post load of 195 CFM, a drop of 29 CFM)
AnnualHours = 8,760 hours/year

The derivation of the assumed compressor kW values is not documented in the tracking data. The evaluator believes that the compressor kW values are based on the average flow rates measured during the airflow metering period (224 cfm for baseline, 195 cfm for proposed) and the nominal efficiency value (.194 kW/cfm) specified on the compressor's CAGI sheet. For example, the baseline air load of 224 cfm equates to an estimated compressor kW 0.194 kW/cfm x 224 cfm = 43.46 kW. The slight discrepancy may be due to slight differences in assumed compressor efficiency.

[11] The repairs claimed for this measure did not repair all leak load. Per the air audit report, "..after repairing the leaks, the final leak load showed 160 cfm plus the 4 cfm for the minimum pressure valve repair, which would be a savings of 29 cfm."

The applicant/tracking savings are listed by the measure below.

Table 24: Tracking savings by project ID

Process boiler draft fan VFDs (6299117)

The applicant savings are calculated using spreadsheet equations and engineering judgment. The baseline boiler draft fan's electric consumption assumes 7,200 annual operating hours, an 80% motor load, and 91% motor efficiency. The proposed boiler's annual energy consumption assumes that the motor speed ranges from 50% to 80% for equal portions of time over the 7,200 annual operating hours[12]. The fan power at reduced speeds is calculated using a fan law exponent of 2.

Details of the energy savings equation are shown below:

Participant energy savings = Baseline kWh – Proposed kWh = 40,385 kWh

Baseline kWh:

Baseline kWh = $kW_{FL} \times PL_{base} \times AnnualHours$ = 94,439 kWh

Where,

kW_{FL} = 16.40 kW (= 10 hp/fan x 2 fans x 0.746 kW/hp / 91% motor efficiency)

PL_{base} = 80% (assumed 80% motor load on both draft fans in base case)

AnnualHours = 7,200 hours/year (24 hours/day x 6 days/week x 50 weeks/year)

Proposed kWh:

Proposed kWh = $\sum PL_{post} \times kW_{FL} \times AnnualHours_{post}$ = 54,054 kWh

Where,

PLpost	$AnnualHours_{post}$
0.67 = $(80\%)^2$/95% VFD efficiency	1,800
0.52 = $(70\%)^2$/95% VFD efficiency	1,800
0.38 = $(60\%)^2$/95% VFD efficiency	1,800
0.26 = $(50\%)^2$/95% VFD efficiency	1,800

kW_{FL} = 16.40 kW (= 10 hp/fan x 2 fans x 0.746 kW/hp / 91% motor efficiency)

Measure	kWh savings	Summer kW reduction	Winter kW reduction
Air leak repair (5648427)	45,902	5.2	5.2
Process boiler draft fan VFDs (6299117)	40,385	2.1	2.1
Total	86,287	7.3	7.3

[12] In the participant savings equations, the base (constant speed motor) assumes 80% motor load. In the proposed case (variable speed motor), the calculations make it appear like the motor load is now considered 100% (1.0 factor) and the motor speeds range from 50%-80%. However, this may just be a calculation error.

Project Evaluation

Table 4 shows how each measure was verified to be installed and operating. If a measure was found to not be installed or installed but not operating correctly, it is noted in this table.

Table 25: Measure verification

Measure Name	Verification Method	Verification Result
Air leak repair (5648427)	Document review and site contact verification	Verified indirectly through site contact and leak repair document
Process boiler draft fan VFDs (6299117)	Visual	Installed and operating as intended

The M&V plan and project evaluation were generally conducted as planned.

- A site visit was performed on July 31, 2018, to install data loggers and interview the site contact.
- The process boiler draft fan VFDs were observed and verified to be installed and operating. The boilers did not operate simultaneously and were therefore metered separately using two H22K data loggers.
- The site visit discovered that the affected boilers (#1 and #2) operate as secondary trim boilers to the primary boiler (#3) in a lead/lag sequence. They are manually switched between lead/lag.
- The tags identifying the air leaks or air leak repairs had already been removed. The site contact was able to confirm the leak repair list that had been submitted with the project documentation and also mentioned that another air leak audit was going to be conducted in the near future.
- Nameplate information was collected for all affected equipment. An ElitePro kW logger was installed on the air compressor. Data loggers were retrieved in late October, making the metering period roughly 12 weeks.
- The site contact mentioned during the initial site visit that their schedule remains relatively the same throughout the year and they do not experience obvious, seasonal changes in production. Per the site contact, meaningful production data was not available but stated that the metering period would be a reasonable period to represent typical operation.

The evaluation savings methodologies that are explained in later sections were implemented as planned. 8,760-hour demand reduction profiles were generated for each measure, and specific discrepancies were found that attributed to the difference between evaluated and tracking savings estimates.

Data collection

The evaluator metering approach outlined in the M&V plan was implemented as planned. Nameplates and datasheets for the affected equipment (compressor and boiler draft fans) were collected while on-site and through internet searches. The following table describes specifications for the affected equipment. They match the information given in the tracking documentation.

Table 26: Measure specifications

Measure Name	Specifications	Notes
Air leak repair (5648427)	Kaiser SFC55 75 HP rotary screw compressor with variable speed controls	Observed operating at approximately 125 psi
Process boiler draft fan VFDs (6299117)	Identical Cleaver Brooks boilers (CB 428-300 300 HP) both with 1x 10 HP draft fan motor	Motors were not in range for nameplate verification but site contact verified to size. Boilers typically operate in lead/lag sequence

Data loggers were deployed to collect load profiles of compressor and boiler draft fans. Unfortunately, there was a scheduling mistake and the DNV GL 3rd party electrician did not arrive for the scheduled site visit. The site contact was very helpful and provided an in-house electrician to install the data loggers. However, this caused some time constraints and spot power measurements were not taken on equipment. During logger pickup, spot power measurement could not be taken on the boiler draft fans because the boilers were not in operation. The compressed air line had a permanent flow meter and the site contact was able to provide a compatible data logger to collect flow measurements during the metering period. The following table describes the types of time-series logger data collected for the evaluation.

Table 27: Data collection points

Data/equipment description	Data type	Logging duration (August – October 2018)
Kaiser SFC55 75 HP compressor with variable speed control	Full unit kW	12 weeks; 15-minute interval
CB boiler #1 draft fan	Draft fan motor current (amps)	12 weeks; 30-minute interval; 3-minute sample
CB boiler #2 draft fan	Draft fan motor current (amps)	12 weeks; 30-minute interval; 3-minute sample
Compressed air line flow	Airflow (scfm)	5 weeks; 1-minute interval

Evaluation savings analysis

The savings analysis for both project savings begins with using the logger data to estimate the typical operating profile of the compressor and the boiler draft fans. The typical operating profile is extrapolated to represent the observed annual energy consumption of the compressor and boiler draft fans. Details of the individual project savings analyses are presented below.

Air leak repair (5648427) savings analysis

Data loggers collected roughly 12 weeks of compressor power while operating under typical conditions. 5 weeks of airflow data (CFM) coinciding with the power metering period were also collected. The airflow data was used to sanity check the power data and the assumed compressor performance profile; however, it was not used to generate a regression between compressor power (kW) and airflow (cfm). The choice to use an assumed compressor profile (i.e., CAGI sheet) was arbitrary but also to maintain consistency of calculation methods across projects that involved compressed air measures but did not always have airflow data available. The figure below compares the collected flow data (in scfm) to the flow (acfm) calculated from the compressor power data.

Figure 8: Flow comparison. Measured scfm versus calculated acfm

The compressor power data was aggregated into a 168-hour week profile, averaged by the hour of day and weekday. This profile would represent the typical demand (kW) of the installed compressor. Using the facility's reported holiday list, the profile was extrapolated to a standardized year. The installed compressor kW profile is shown in the table below.

Table 28: Installed compressor (Kaiser SFC55 75 HP) kW profile

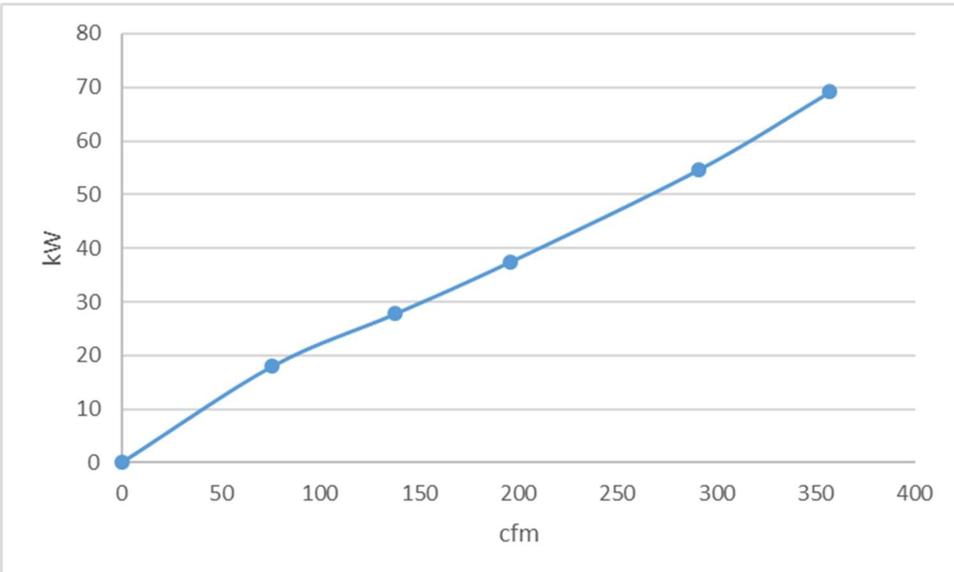
Hour	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
0	46.2	48.9	47.7	48.6	47.8	41.4	39.7
1	46.9	49.5	48.8	48.6	48.2	41.2	39.8
2	46.3	49.4	48.2	48.6	48.2	41.3	39.9
3	46.2	49.2	48.3	48.4	48.2	41.3	40.0
4	46.5	48.4	48.5	48.5	48.2	41.4	40.0
5	47.2	48.3	48.3	47.8	48.1	41.6	40.2
6	46.8	48.8	48.4	45.8	48.5	41.3	40.2
7	47.0	48.9	48.6	47.8	48.0	40.8	40.2
8	47.1	49.5	48.7	49.0	47.2	41.1	40.3
9	46.7	49.3	48.7	48.9	47.6	41.0	40.3
10	47.0	49.0	48.5	47.7	47.5	40.9	40.2
11	46.4	49.2	48.1	47.9	46.3	40.6	40.3
12	46.3	48.7	47.8	47.8	46.0	40.3	40.3
13	46.3	49.1	48.5	48.5	46.2	40.3	40.2
14	46.5	47.3	48.5	47.8	45.9	40.1	40.2
15	46.1	47.5	48.1	46.8	45.3	40.1	40.2
16	46.1	47.1	47.9	47.1	45.2	40.1	40.2
17	46.0	47.2	48.8	47.7	45.5	39.8	40.2
18	46.4	47.8	47.9	47.8	45.2	39.8	40.2
19	46.4	49.0	47.8	47.6	44.5	35.2	40.2
20	45.8	48.4	47.2	46.4	43.3	40.4	40.3
21	46.2	48.6	48.9	47.3	42.9	40.2	40.3
22	47.9	49.1	49.5	47.0	41.9	39.9	41.9
23	49.4	47.9	48.6	47.5	41.3	39.7	45.0

The profile shows that the facility has a relatively constant air demand, with slightly higher air demand during the weekdays. The airflow data validates the power data suggesting that the average weekday airflow is around 216 cfm while the average weekend airflow is 184 cfm.

Without detailed production data available, linear extrapolation of hourly averages (by the time of day and weekday) generated a reasonably accurate representation of 8,760-hour annual compressor usage.

The evaluator used the collected manufacturer data and CAGI sheet to estimate the installed average hourly airflow (cfm) corresponding to the average compressor kW values in the profile above. As shown in the figure below, the CAGI sheet provided part-load performance (kW/cfm) ranging from 100% to ~20% (unloaded) compressor capacity (cfm).

Figure 9: Performance curve for the installed compressor (SFC55 75 HP)



The evaluator assumed that the air leak repair was still functional and that the estimate (29 cfm) measured by the TA is still accurate. To represent the baseline air load profile, the air leak load of 29 cfm was added to each hourly air load value in the installed 8,760 air load profile.

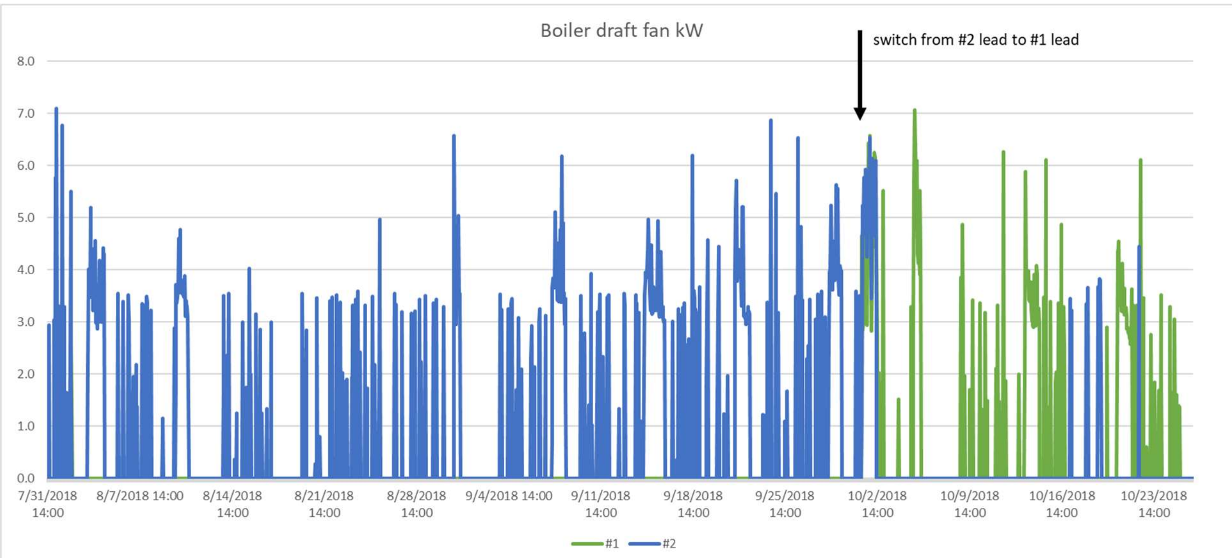
The performance curve mentioned above was then used again to estimate compressor kW as a function of capacity (cfm). This step developed the corresponding 8,760 hourly baseline compressor kW profile. The difference between the baseline 8,760 kW profile and the installed dryer 8,760 kW profile is equal to the evaluation savings for the air leak repair measure.

Process boiler draft fan VFDs (6299117) savings analysis

The boiler draft fan VFD savings analysis begins with the development of the installed boiler draft fan 8,760 kW profiles which follows a very similar procedure to the compressor kW profile developed for the previous measure.

Approximately 12 weeks of amp logger data were collected for both boiler draft fan motors. Based on the site contact interview and visualization of the boiler draft fan data, the evaluator determined that the affected boilers (#1 and #2) operate as secondary trim boilers (to the primary boiler #3) in a lead/lag sequence. They are manually switched between lead/lag "whenever they want". The logger data below shows very intermittent usage which agrees with their secondary operating sequence.

Figure 10: Boiler draft fan kW (for boiler #1 and #2)



Voltage and power factor assumptions were made to approximate the fan motor power (kW) corresponding to the measured current value. These kW estimates were then aggregated into 168-hour week profiles, averaged by the hour of day and weekday. Both boiler draft fan kW profiles were averaged to represent the boiler while it is in lead operation. The two boiler profiles were then averaged together to represent the typical average lead boiler draft fan demand. The "lag" boiler is assumed to not operate while the lead boiler is in operation. Using the facility's reported holiday list, the single lead boiler draft fan kW profile was extrapolated to a standardized year to generate the installed 8,760 boiler draft fan annual energy consumption.

The corresponding baseline boiler draft fan energy consumption was estimated by first making assumptions around the baseline flow controls and installed/baseline draft fan flow curve (% kW vs % flow).

The following assumptions were made to define baseline and installed flow controls and fan curves.

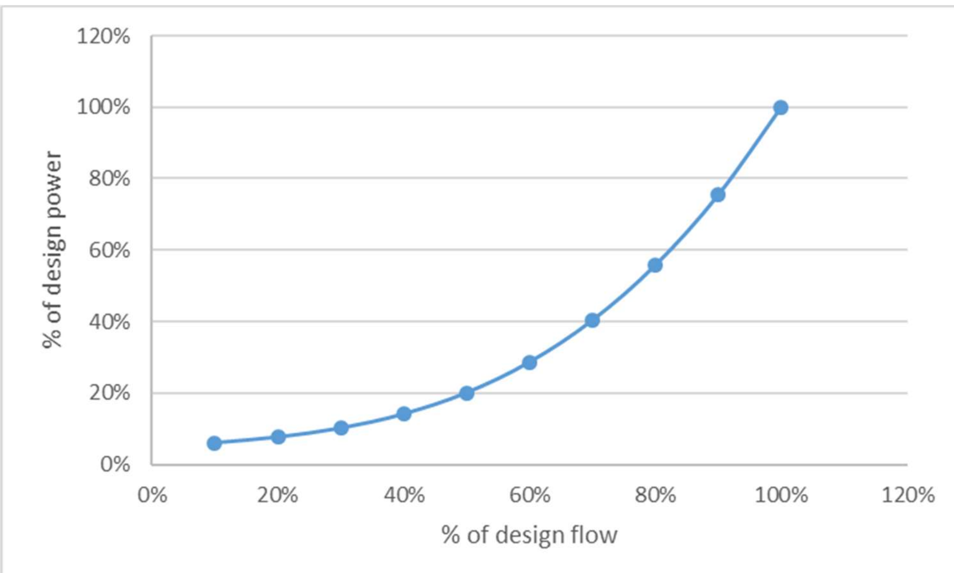
Table 29: Key savings assumptions

Savings Parameter	Value	Comment
VFD efficiency	95%	Assumed value
Motor efficiency	91%	Assumed value
Design motor kW (w/ VFD)	8.6 kW	10 HP x 0.746 kW/HP / 91% / 95%. This value is used to convert the profile kW values to % design kW

Installed fan curve (variable speed)	3rd order function correlating % power to % flow	Source: CEC DOE2 fan curve coefficients[13]
Baseline fan curve (inlet damper)	2nd order function correlating% power to % flow	Source: CEC[14]
Ideal excess air with VFD blower control (assumed installed condition)	10%[15]	Used to calculate the installed % flow profile
Excess air with inlet damper blower control	20%[16]	Used to estimate the baseline % flow profile

The installed lead boiler draft fan kW profile is converted to design kW % using the design motor kW assumption (8.6 kW) mentioned in the table above. It is then immediately converted to the design flow % for a "typical VSD fan" using the fan curve below.

Figure 11: Fan curve for "Typical VSD Fan"



Using the assumed installed ideal excess air %, the assumed baseline flow control method (inlet damper), and the assumed baseline excess air %, the installed design flow % profile is converted to represent the baseline design flow % profile, as defined below.

Baseline flow % = [Installed flow % x (100% - 10%)] x (100% + 20%) = Installed flow % x 108%

The baseline lead boiler draft fan kW profile is then produced by using the baseline fan curve to convert design flow % to design power %, and the design motor kW (minus the VFD efficiency loss) to convert design power % to kW. The baseline fan curve for inlet damper flow control correlating design flow % to design power % is shown in the figure below.

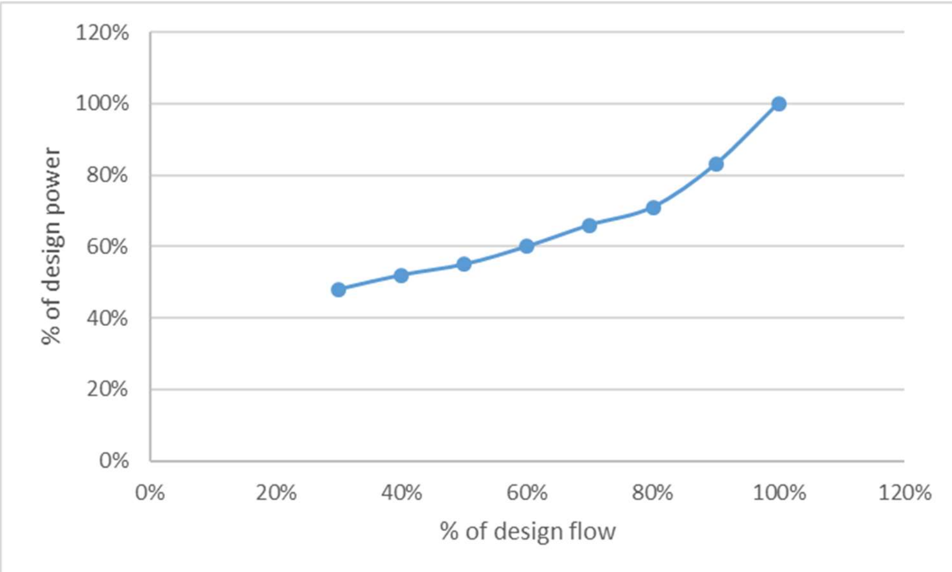
13 Advanced Variable Air Volume System Design Guide, CEC, Appendix 5 – DOE-2 Fan Curves, pg. 214 of 228

14 Nonresidential Alternative Calculation Method, Section 2-81, pg. 96 of 199

15 See the reference tab in the savings calculation workbook for source of assumption. A 2008 ACEEE study claims 10% is ideal but difficult

16 Ibid; a Cleaver Brooks reference manual suggests that 15-20% excess air is considered "reasonable"

Figure 12: Fan curve for "Typical inlet damper"



The baseline lead boiler draft fan kW profile is extrapolated to an 8,760 demand profile using the same method as the installed profile. The difference between the baseline and installed 8,760 kW profiles is equal to the evaluated savings.

Evaluation Results

The evaluated savings are presented in this section by the project. This section presents a comparison of key parameters and discrepancy analysis at the project level.

The table below summarizes evaluated savings at the project level. Each project contains only one measure.

Table 30: Project results

Project/Measure	Savings Quantity	Tracking Estimate	Evaluation Estimate	Realization Rate
Air leak repair (5648427)	Electric energy (kWh)	45,902	46,536	101%
	% of Energy Savings on Peak	47%	46%	99%
	Summer On-Peak Demand (kW)	5.2	5.3	101%
	Winter On-Peak Demand (kW)	5.2	5.3	101%
Process boiler draft fan VFDs (6299117)	Electric energy (kWh)	40,385	20,643	51%
	% of Energy Savings on Peak	57%	52%	91%
	Summer On-Peak Demand (kW)	2.1	2.9	140%
	Winter On-Peak Demand (kW)	2.1	2.9	139%

Total project	Electric energy (kWh)	86,287	67,180	78%
	% of Energy Savings on Peak	52%	48%	93%
	Summer On-Peak Demand (kW)	7.3	8.2	112%
	Winter On-Peak Demand (kW)	7.3	8.2	112%

Comparison of savings parameters

The evaluations' savings methods use savings parameters that sometimes cannot be directly compared to the savings parameters used in the applicant savings methods. Comparisons of tracking and evaluated savings parameter values were made when it was practical to do so. These comparisons are presented in the table below. Other comparisons are made in the discrepancy analysis section.

Table 31: Comparison of Key Parameters

	BASELINE		PROPOSED / INSTALLED	
Parameter	Tracking Value(s)	Evaluation Value(s)	Tracking Value(s)	Evaluation Value(s)
Average compressor demand (kW)	42.6	50.8	37.3	45.5
Average air load (cfm)	224	263	195	234
# of boilers operating simultaneously	2	1	2	1

Discrepancy analysis

This section describes the key drivers behind differences in the tracking and evaluation savings estimates. The following table will be used to summarize these differences. The purpose of this analysis is to measure and describe how changes to the key parameters influenced the final project savings.

Table 32: Discrepancy analysis results

Discrepancy	kWh	Peak Summer kW	Peak Winter kW	% on peak
Tracking Savings (no changes)	86,287	7.3	7.3	52%
Discrepancy #1 (AppID5648427 - Changed Compressor kW)	1%	1%	1%	0%
Discrepancy #2 (AppID5648427 - evaluated savings method)	0%	0%	0%	-1%
Discrepancy #3 (AppID6299117 - adjusted tracking method so boilers do not operate simultaneously)	-23%	-14%	-14%	0%
Discrepancy #4 (AppID6299117 - evaluated savings method)	1%	26%	25%	-6%
Final Evaluated GRR %	78%	112%	112%	93%

The table above illustrates sequential discrete changes made to savings parameter values or savings methods and the corresponding effect the change has on savings estimate relative to the tracking savings. For example, the first line ("Tracking Savings") lists the savings claimed in the tracking data. The next line, "Discrepancy #1", illustrates the impact made (in % of tracking savings) by the discrepancy. In the case of discrepancy #1, a discrete change was made to the compressor demand savings parameter for both baselines and proposed cases.

Discrepancy #1 (AppID5648427 – changed compressor kW)

This discrepancy accounts for the difference between the air load (cfm) and corresponding compressor demand (kW) estimated for the baseline and proposed cases. The tracking savings measured an average air load of 224 cfm for the baseline. 29 cfm of air leaks were repaired, resulting in an estimated proposed air load of 195 cfm. For the evaluation savings, the evaluator observed an average air load of 234 cfm. Assuming that the air leak repair reduced air load by 29 cfm, the evaluator added 29 cfm to the observed average air load to represent the baseline air load (263 cfm). This increase in air load increased the compressor demand by around 8 kW for the baseline and proposed cases. Since both baseline and proposed compressor demand increased by similar amounts, the discrepancy is small. This discrepancy increased savings by 1% or 634 kWh.

Discrepancy #2 (AppID5648427 – evaluated savings method)

This discrepancy accounts for the difference in savings methods. It was included to illustrate that the difference in savings methods, in this case, was not a significant factor because the compressor usage was observed to be very stable and the compressor operates continuously. The discrepancy does not change significantly affect savings (0% change).

Discrepancy #3 (AppID6299117 - adjusted tracking method so boilers do not operate simultaneously)

This discrepancy accounts for an operational difference between the tracking and evaluation assumptions. The tracking savings method assumes that both boilers operate simultaneously and have the same load and draft fan usage. Basically, usage and savings calculations are multiplied by 2 – the number of boiler draft fan motors retrofit with VFDs. However, the evaluator determined that the boilers typically do no operate simultaneously because they are manually sequenced to operate in a lead/lag configuration, acting as secondary trim boilers for the primary boiler #3. This discrepancy changes the tracking savings quantity from 2 to 1, effectively halving the project savings. This discrepancy affects the tracking savings by -23% or -20,192 kWh.

Discrepancy #4 (AppID6299117 - evaluated savings method)

This discrepancy accounts for the difference in savings method (and savings parameters) between tracking and evaluation savings. The evaluation method uses an 8,760 profile, assumed baseline flow control, and assumed fan curves to estimate the observed flow %, the estimated baseline flow %, and corresponding baseline fan power. This discrepancy has a minor positive kWh impact of 1%. The discrepancy has a larger impact (25%) on summer and winter peak demand reduction because the tracking savings method arbitrarily assumes the highest boiler load period to estimate demand reduction. This assumption, coincidentally, did not agree with the observed demand profile.

Site ID: 2016RIN023

Program Administrator	National Grid
Project ID(s)	4728393*
Project Type	Retrofit and Retrocommissioning
Program Year	2016
Evaluation Firm	DNV GL
Evaluation Engineer	Chris Williams
Senior Engineer	C.D. Nayak

*DNV GL ID 2016RIN023 was originally sampled to include application IDs 4728393, 5172277, and 5685728. During the evaluation, DNV GL team learned that the project was completed in multiple locations, after discussion and agreement with National Grid, DNV GL dropped application ID 5172277 and 5685728 from the evaluation.

Project Description

This project performed "phase 3" improvements at a hospital campus with approximately 450,000 square feet of conditioned space. The hospital campus consists of eight major buildings. The evaluation scope is limited to two buildings; TRN and EW. The particular buildings affected by the claimed measures had equipment and spaces that were renovated in 2000. The evaluated measures included a number of HVAC controls and re-commissioning/repair measures that are summarized below.

- EEM 1.00: Reprogrammed East Wing (EW) AHUs (AC-2, 3, 4 and 5) with dehumidifier mode that enables when the return air (RA) humidity is greater than 60%. In this mode, cooling discharge air temperature (DAT) setpoint is 50 °F and the reheat/final DAT is 55 °F. Cooling energy savings are realized when dehumidifier mode is disabled and the DAT setpoint is 55 °F.
- EEM 2.00: Installed sensors on kitchen hoods and a variable frequency drive (VFD) on the exhaust fan that enables the exhaust fan speed to modulate based on cooking activity.
- EEM 3.00: Added schedule to the terminal boxes of TRN AHU-1 to modulate them to a fully closed position during unoccupied periods.
- EEM 5.00: Added schedule to the terminal boxes of AC-2, 3, 4 and 5 to modulate them to fully closed position during unoccupied periods.
- EEM 7.00: Removed HEPA filters from EW AC-2 and -3 and replaced them with high-efficiency MERV-14 filters that lower pressure drop across the filters, thus saving fan energy.
- EEM 8.01: Implemented programming whereby the differential pressure (dP) setpoint is reset to satisfy the worst-case chilled water (CHW) valves in the building.
- EEM 8.02: Implemented condenser water (CW) supply temperature reset based on outside air temperature (OAT) to vary between 65 °F to 75 °F when OAT varies between 55 °F to 80 °F.
- EEM 8.03: Repaired or replaced sixteen dampers and actuators on VAV boxes to ensure design airflow setpoints.
- EEM 8:04: Repaired or replaced flow measuring stations and rebalanced airflow/setpoints to allow exhaust fans to control their respective setpoints.
- EEM 8.05: Repaired/replaced preheat valve actuator or preheat valve assembly on Turner AHU-1
- EEM 8.06: Repaired/replaced cooling valve actuator or cooling valve assembly on Turner AHU-3.

The campus space heating is achieved with a central steam plant with two 16 MMBTU/hr natural gas-fired boilers. There are three steam HHW converters and HHW is supplied to AHU preheat and reheat coils. The central chilled water plant consists of three 550-ton water-cooled chillers. The hospital uses approximately 12 GWh electricity, 500,000 Therms and 28,000 gallons of #2 fuel oil annually.

Table 33: Project tracking savings by measure

Measure	Building/location	Energy savings (kWh)	Summer peak demand reduction (kW)	Winter peak demand reduction (kW)	% on peak energy
EEM 1.00 - Add dehumidifier mode to EW AHUs (AC-2 to5)	EW	264,664	35.0	0.4	52%
EEM 2.00 – TRN Kitchen Hood controls	TRN	90,944	20.2	16.4	59%
EEM 3.00 Reduce Unoccupied zone airflow on TRNAHU-1	TRN	66,611	12.5	6.4	48%
EEM 5.00 – Reduce unoccupied zone airflow on EW AC -2, -3, -4, and -5	EW	87,330	0.0	2.4	6%
EEM 7.00 – Remove HEPA filters on EW AHU-2 and -3 with MERV-14 filters	EW	213,827	27.6	22.1	67%
EEM 8.01 – Secondary CHW loop dP reset	TRN – CHW	37,855	7.0	0.0	77%
EEM 8.02 – Optimize Condenser Water Temperature Control	TRN – CHW	39,121	8.0	0.0	81%
EEM 8.03: Repair Terminal Box Dampers in TRN & EW	TRN/EW	59,061	6.7	6.7	67%
EEM 8.04: Repair EF-1A & EF-1B VFD Control	TRN	22,913	2.6	2.6	67%
EEM 8.05: Repair HW Preheat Valve Leakby on Turner AHU-1	TRN	38,781	9.1	0.0	53%
EEM 8.06: Repair CHW Valve Leakby on Turner AHU-3	TRN	10,900	1.8	0.0	52%
Total		932,006	130.4	57.0	55%

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

Table 34: Project results for 4728393

Savings Quantity	Tracking Estimate	Evaluation Estimate	Realization Rate
Electric energy (kWh)	932,006	546,155	59%
% of Energy Savings on Peak	55%	40.6%	74%
Summer On-Peak Demand (kW)	130.4	74.2	57%
Winter On-Peak Demand (kW)	57.1	38.9	74%

The bullets below explain some key discrepancy findings:

- EEM1.00, which contributed 28% of the tracking savings, had an evaluated kWh GRR% of 42%. This low GRR% is largely because the AHUs were observed to be in the "dehumidifier" mode longer than estimated by the tracking calculation. When the AHUs are in dehumidifier mode, the cooling coil discharge air temperature setpoint is lower than the final discharge air temperature of 55 °F (in order to dehumidify air and then reheat air back to the desired DAT). The tracking calculation estimated that the AHUs would be in dehumidifier mode 775 hours per year. The evaluation found that the AHUs were in dehumidifying stages (between 50 °F and 55 °F) 4,413 hours per year. Higher dehumidification hours in the post case increased the annual cooling consumptions.
- EEM2.00, which contributed 10% of the tracking savings, had an evaluated kWh GRR% of 33%. This low GRR% is largely due to exhaust fan 2 (EF2) operating at nearly full speed, contrary to what was estimated in the tracking calculation. Three months of VFD speed data validated EF2 operation.
- EEM7.00, which contributed 23% of the tracking savings, had an evaluated kWh GRR% of 78%. This lower GRR% is attributed to a smaller delta kW between the base and proposed cases, as well as a different fan speed profile. AHU-2 and AHU-3 SFs were estimated to have a 43% and 25% smaller delta kW (between the base and proposed kW estimates, respectively) compared to their tracking estimates.
- EEM 8.01 contributed 4% of tracking savings and had an evaluated kWh GRR of 169%. The increase in savings was attributed to a higher observed pump power (for both base and post cases). The eQUEST model had auto-sized the secondary CHW pump based on a combination of default and site-specific design values for the secondary chilled water loop. Some of these values (loop head) were updated to calibrate the modeled secondary CHW pump power to match the observed pump power.

Tracking Savings

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

Baseline Condition

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

EEM 1.00 - Add dehumidifier mode to EW AHUs (2-5)

EW AHU CHW coil discharge air temperature (DAT) setpoints are 48 – 50 °F and reheat to a final DAT of 55 °F. With these conditions, the AHUs are effectively dehumidifying the supply air whenever the chilled water (CHW) plant is operating.

EEM 2.00 - TRN Kitchen Hood controls

AHU-6 in the TRN building serves kitchen air make-up needs. AHU-6 is 100% OA and equipped with a VFD. EF-2A operates at full speed and is manually controlled by kitchen personnel. The AHU operates on the kitchen occupancy schedule. Base EF and MUA fan power (8.9 kW and 11.8 kW) were estimated based on one-time motor voltage and current measurement and considered constant for 5,681 hours of annual operation.

EEM 3.00 - Reduce unoccupied zone airflow on TRN AHU-1

TRN building AHU-1 serves VAV boxes in the laundry, copy center, cafeteria, and patient areas. It operates 24/7, the supply fan is equipped with a VFD, and it provides 100% OA. For OAT between 35 to 75 °F, the baseline supply fan speed was measured to be between 77-80%.

EEM 5.00 – Reduce unoccupied zone airflow on EW AHU-2, -3, -4, and -5

All AHUs, spaces, and VAVs in EW are under 24/7 occupied control even when the spaces served are unoccupied (i.e., no unoccupied setbacks are programmed for individual VAV boxes). AHU-2 and -3 share common supply, as do AHU-4 and -5. All EW AHUs share a common return.

EEM 7.00 – Remove HEPA filters on EW AHU-2 and -3

EW AHUs 1, 2 and 3 are interconnected to provide redundancy for the operating room, but only AHU-1 needs HEPA filters for the operating room (AHU-2 and 3 serve offices).[17] In the baseline condition, all three AHUs are equipped with HEPA filters. HEPA filters increase the total static pressure causing the supply fans to work harder to deliver the required airflow.

EEM 8.01 – Secondary CHW loop dP reset

CHW primary loop is constant flow, while the CHW secondary loop is variable flow. The secondary loop resets the differential pressure (dP) setpoint based on how many chillers are online. When one chiller is on, the dP setpoint is 15 psi, when 2 chillers are on the dP setpoint is 20 psi, and 25 psi when all 3 chillers are online.

EEM 8.02 – Optimize Condenser Water Temperature Control

The chilled water plant uses a 1,680-ton, three cell cooling tower for heat rejection. The condensing water supply temperature (CWST) setpoint is 75 °F. However, the CWST floats up during high loads because the CT fans are limited to operate at 50% speed or below (due to prior noise complaints) and, as a consequence, the cooling tower does not have sufficient heat rejection capacity.

EEM 8.03 – EW and TRN Terminal Box Damper Repair

The airflow rates of approximately 16 VAV boxes throughout TRN and EW zones exceed the CFM setpoint when the dampers are commanded to 0% (closed) i.e., dampers or damper actuators are broken. Excess flow rates were measured to be between 60 and 2,632 CFM.

EEM 8.04 – Repair EF-1A & 1B VFD Control

EF-1A and -1B are equipped with VFDs but are stuck operating at 100% speed because of broken airflow sensors (stations).

EEM 8.05 - Repair HW Preheat Leakby on TRN AHU-1

[17] The idea is that if for some reason AHU-1 needs to be brought offline, they can switch to AHU-2 or AHU-3 to provide air to the operating rooms. But until that is actually needed, AHU-2 and AHU-3 do not need HEPA filters.

The hot water (HW) preheat coil valve on TRN AHU-1 is leaking, causing a 4 °F temperature rise across the coil when the HW valve is commanded fully closed (0%). The leakby is forcing the chilled water valve to open more than necessary to cool air back down to the DAT setpoint.

EEM 8.06 – Repair CHW Valve leakby on TRN AHU-3

The CHW cooling coil valve of TRN AHU-3 is leaking, causing a 16 °F temperature drop across the coil when the CHW valve is commanded closed (0%). This leakby is wasting chilled water and overcooling the air, also causing additional reheat load.

Proposed condition

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

EEM 1.00 - Add dehumidifier mode to EW AHUs (2-5)

The proposed measure adds programming to the existing EMS to toggle a "dehumidifier" mode. The dehumidifier mode resets DAT based on return air humidity (RAH). When RAH > 55% AHU cooling coil DAT = 50 °F. When RAH < 55%, AHU cooling coil DAT = 55 °F. The higher cooling coil DAT reduces chilled water load (and also reduces reheat load).

EEM 2.00 – TRN Kitchen Hood controls

The measure installs a VFD and premium efficiency motor on EF-2A. Smoke/cooking and temperature sensors are also installed near the kitchen hoods to detect when cooking is active. EF-2A and TRN AHU-6 modulate in unison down to 50% speed and ramp-up to full speed when smoke/cooking is sensed. The existing schedule for AHU-6 is also applied to EF-2A so manual operation is no longer required, although the measure installs a manual override to instantly ramp up both AHU-6 and EF-2A VFDs to full speed.

EEM 3.00 - Reduce unoccupied zone airflow on TRN AHU-1

The proposed measure adds programming to allow the unoccupied airflow setpoint to be 0 cfm during unoccupied hours. This requires new thermostats to be installed in the local spaces (a total of 8 VAV boxes, ~3000 cfm). The measure reduces fan load during unoccupied hours on TRN AHU-1.

EEM 5.00 – Reduce unoccupied zone airflow on EW AHU-2, -3, -4, and -5

The measure programs schedule-based setbacks on selected VAV boxes to reduce unoccupied airflow to 0 cfm. Many spaces are affected, totaling over 15,000 cfm.[18] The measure reduces fan load during unoccupied hours on EW AHU-2, -3, -4, and -5.

EEM 7.00 – Remove HEPA filters on EW AHU-2 and -3

HEPA filters had originally been installed on EW AC-1, AC-2, and AC-3 because they are interconnected for redundancy to serve AC-1 operating room areas. The proposed measure replaces AC-2 and AC-3 HEPA filters with low-pressure drop filters. The lower pressure drop will reduce fan power because they have to overcome less pressure to provide the required airflow. In the event that AC-1 fails or needs maintenance, AC-2 or AC-3 is switched to serve the operating rooms, and HEPA filters are temporarily installed on AC-2 or AC-3.

[18] Specific spaces are detailed in the calculation methodology section

EEM 8.01 – Secondary CHW loop dP reset

The proposed measure allows the secondary CHW loop dP setpoint to reset down to fulfill the worst-case CHW valve (typically the furthest valve from the pump) i.e., the dP setpoint resets down until only the worst-case CHW valve is 100% open. The measure allows the secondary CHW pump VFDs to modulate speed down in smaller and more frequent increments, saving on pump power.

EEM 8.02 – Optimize Condenser Water Temperature Control

This measure resets the CW supply temperature (CWST) when the chilled water plant is at part load. It resets CWST linearly with OAT with the following high and low boundaries: when OAT = 80 °F, CWST = 75 °F; when OAT = 55 °F, CWST = 65 °F. Savings are realized from the net reduction in plant demand (chillers operate more efficiently at lower CWST but cooling tower fan speed increases to meet stricter CWST).

EEM 8.03 – EW and TRN Terminal Box Damper Repair

The measure repairs or replaces dampers/actuators on VAVs with excess airflow. With properly operating dampers, the supply fan will be able to ramp speed down further, saving fan energy.

EEM 8.04 – Repair EF-1A & 1B VFD Control

EF-1A and EF-1B are proposed to have their airflow measuring stations repaired and/or re-calibrated. This will allow their VFDs to accurately control their setpoints and operate the EFs below 100% speed, saving fan energy.

EEM 8.05 - Repair HW Preheat Leakby on AHU-1

The proposed measure repairs or replaces the leaky preheat hot water valve. Repairing the valve will reduce the amount of CHW necessary to cool air.

EEM 8.06 – Repair CHW Valve leakby on AHU-3

The proposed measure repairs or replaces the leaky chilled water valve. Repairing the valve will reduce wasteful and unnecessary CHW cooling (and also reduce reheating load).

Tracking calculation methodology

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

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

Cooling (coil) load:

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

Where,

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

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

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

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

4.5 = unit conversion coefficient

Chilled water cooling energy:

$$EC_{kWh} = \frac{E_{\ cooling} \times BinHrs\ \times\ Eff}{12000}$$

Where,

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

BinHrs = annual hours within the temperature bin

Eff = chiller or cooling efficiency. Assumed to be 0.7 kW/ton

12000 = unit conversion coefficient

Fan energy:

$$E_{fan} = VFD^{2.5}_{\%,bin} \times kW_{fan,full\ spee} \ \times BinHrs$$

Where,

E_{fan} = total energy from fan, kWh

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

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

BinHrs = annual hours within the temperature bin

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

EEM 1.00 - Add dehumidifier mode to EW AHUs (2-5)

Electric savings for this measure were calculated using a temperature-hour bin model, available trend data, and TMY3 weather data (for Providence, RI). The applicant collected the following trend data for the affected AHUs[19]:

- Supply fan VFD speed
- Supply fan airflow, cfm
- Return air temperature
- Return air relative humidity
- Discharge air relative humidity

These trend data provided average baseline operating profiles for the temperature-hour bins. Fan and chilled water load were estimated for each temperature-hour bin, then summed up to estimate the annual fan and cooling energy for each AHU.

For this measure, the base case and proposed case fan profiles are equivalent, so the fan kW calculation is irrelevant. Savings are derived from the difference in cooling energy. The measure adds a conditional factor to the cooling coil DAT setpoint. The main drivers for the measure savings were:

- Return air relative humidity (RAH). This value determined whether the AHU would be in "dehumidifier" mode or not. The trend data that was collected had OAT range between 35 and 75 °F. The RAH ranged between 23% and 54%. To fill the (OAT) temperature bins above 75 °F with RAH values, the tracking method assumed a 3% RAH increase for each temperature bin. RAH remains constant at 20% for OAT less than 35 °F. With this assumption, the AHU is in dehumidifier mode for temperature bins above 75 °F.
- Cooling coil DAT. The setpoint for the cooling coil DAT changed depending on whether the AHU was in dehumidifier mode or not. When the RAH is above 55% the AHU is in the dehumidifier mode and the cooling coil DAT setpoint is 50 °F. When the RAH is less than 55%, the cooling coil DAT is 55 °F.

EEM 2.00 – TRN Kitchen Hood controls

Electric savings for this measure were calculated using a temperature bin model. The base case assumed that EF-2A and AHU-6 fans operated at a constant speed and operated on the same schedule (4a – 8p, 7 days). Spot power measurements determined that EF-2A had an input power of 8.9 kW and AHU-6 had an input power of 11.8 kW. AHU-6 also provided cooling for temperature bins above 55 °F. Cooling energy was calculated using the following formula.

$$E_{cooling} = \frac{1.08 \times CFM_{supply,bin} \times \Delta T_{MUA- \quad ,bin}}{12000} \times Eff \times BinHrs$$

Where,

$E_{cooling}$ = total energy from cooling, kWh

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[19] The collected trend data did not cover the entire temperature bin range so the applicant needed to assume values for certain temperature ranges (>75 °F and < 35 °F)

$CFM_{supply,bin}$ = The supply airflow for each bin, cfm. Since they operated at a constant speed, the value was constant at 17,452 cfm

$\Delta T_{MUA-OA,bin}$= difference between makeup air setpoint (55 °F) and outside air temperature, °F

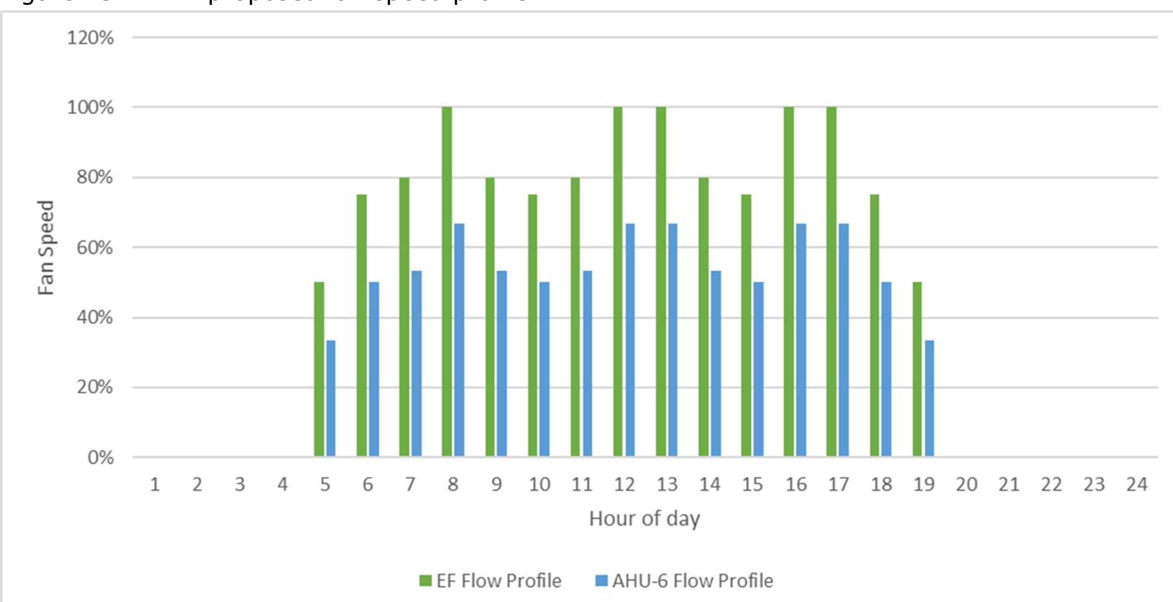
Eff = efficiency of the cooling system, 1 kW/ton

BinHrs = number of hours allocated under the temperature bin, hours

1.08 = unit conversion coefficient

The proposed case assumes that EF-2A and AHU-6 supply fan modulate speed in unison based on an assumed time-of-day profile. The time-of-day profile reportedly came from a National Grid custom express tool, but the tool was not referenced in the calculation workbook. The profile appears to follow an assumed cooking schedule where breakfast (8a-9a), lunch (noon-1p), and dinner (4p-5p) hours operate the fans full speed and other hours have reduced speeds. The reduced speed fan powers are calculated using the full speed powers from the base case and an assumed fan law exponent of 2.5. Cooling energy is calculated using the equation above, but with flow rates calculated based on the assumed fan speeds.

Figure 13: EEM2 proposed fan speed profile



EEM 3.00 - Reduce unoccupied zone airflow on Turner AHU-1

Measure savings are estimated using a temperature bin calculation. EMS screenshots and trend data were also utilized for occupied/unoccupied schedules and VFD fan speeds. The base case assumes a single "occupied" bin profile with 8,760 hours (the AHU operates continuously). The proposed case assumes an occupied bin profile with 4,015 hours (5a-4p, 7 days) and an unoccupied bin profile with the remaining 4,745 hours (4p–5a, 7 days) when the AHU has a reduced airflow profile.

The temperature bins use pre-implementation trend data to estimate supply fan VFD speeds for each bin. Since the trend data does not cover all temperature bins, some of the VFD speed bins are assumed (above 75 °F, increased by 2% each bin, maxing at 88%; and below 35 °F speed remains at 75%)

The tracking calculations assume that the cooling coil DAT is constant at 50 °F for both base and proposed cases. The proposed total unoccupied CFM reduction (5,227 CFM) was subtracted from the base case supply airflow profiles to estimate the proposed CFM for each temperature bin.

EEM 5.00 – Reduce unoccupied zone airflow on EW AHU-2, -3, -4, and -5

Measure savings are estimated using the same method as EEM3. The proposed case is modeled with 5,480 occupied hours and 2,920 unoccupied hours. The proposed total unoccupied CFM reduction is estimated to be 3,800, 3,800, 5,700, and 5,700 for AHU-2, AHU-3, AHU4, and AHU-5, respectively.

EEM 7.00 – Remove HEPA filters on AHU-2 and -3

Measure savings were estimated by developing 8,760 profiles regressing observed OAT to (trended) VFD speeds. Base case fan power was estimated by spot power measuring the fans at full load with the HEPA filters in place. 8,760 fan power profiles were estimated by using the VFD/OAT regression and an assumed ideal pump affinity cubic relationship between fan power and speed.

The static pressure was also measured across the unit (fan + filters + coils) and across the HEPA filters to determine the pressure change that would result from switching from a HEPA filter to a conventional filter. Using the pressure measurement, the proposed fan power could be estimated using the base case fan power, the difference in static pressure, and the exponential fan law relationship between pressure and power.

EEM 8.01 – Secondary CHW loop dP reset

The measure savings are estimated using an eQUEST model. The secondary chilled water loop head pressure setpoint control is changed from "fixed" to "valve reset". This simulation change in eQUEST allows the secondary chilled water (SCHW) pumps to modulate speed to maintain a dP setpoint that keeps the worst-case CHW valve open at 100%. The base case model simulates the dP as a fixed average of 1.94 chillers, 19.7 psi.

EEM 8.02 – Optimize Condenser Water Temperature Control

This measure was also simulated in eQUEST. The measure savings were modeled by changing the CW loop setpoint control from "fixed" to "OA reset". This allows the model to modulate cooling tower fans to control the CW supply temperature relative to a fixed approach temperature (ΔT between the OAT and CW supply temperature).

EEM 8.03 – Terminal Box Damper Repair

The measure savings were estimated using a spreadsheet calculation. The estimated excess flow (5,572 cfm) was multiplied by the estimated fan power (0.00121 kW/cfm) to calculate the fan demand reduction due to the repairs. The fan power reduction was multiplied by 8,760 hours to estimate annual fan energy savings.

EEM 8.04 – Repair EF-1A & 1B VFD Control

Measure energy savings were estimated using a one-line calculation. It was assumed that the proposed VFD speed would be an average of 80%. Both exhaust fans were assumed to operate 8,760 hours per year.

EEM 8.05 - Repair HW Preheat Leakby on AHU-1

Measure savings were calculated using a simplified temperature bin model. During cooling periods when the cooling coil is active, the spreadsheet assumes a 4 °F "leak by", meaning the cooling coil must cool the airstream by 4 more °F. The proposed case assumes that the leak by is fixed and the cooling coil only has to cool the airstream using the cooling load equation referenced above.

EEM 8.06 – Repair CHW Valve leakby on AHU-3

Measure savings were calculated using a simplified temperature bin model. During cooling periods when the cooling coil is active, the cooling coil valve has leakby and cools the airstream beyond the cooling coil DAT, wasting cooling energy. The 20.3 °F leak by cools the mixed air stream; if the air stream is cooled past 55 °F (the cooling coil DAT), the cooling energy is tagged as a penalty. The leak by only affects the temperature bins ranging from 90 to 50 °F.

Project Evaluation

Table 4 shows how each measure was verified to be installed and operating. If a measure was found to not be installed or installed but not operating correctly, it is noted in this table.

Table 35: Measure verification

Measure Name	Verification Method	Verification Result
EEM 1.00 - Add dehumidifier mode to east wing AHUs (2-5)	EMS and trend data	Functionality programmed into EMS
EEM 2.00 - Kitchen Hood controls	EMS and trend data	Functionality programmed into EMS; however, EF-2A exhibited near full speed
EEM 3.00 Reduce Unoccupied zone airflow on AHU-1	EMS and trend data	Functionality programmed into EMS
EEM 5.00 – Reduce unoccupied zone airflow on AC -2, -3, -4, and -5	EMS and trend data	Functionality programmed into EMS
EEM 7.00 – Remove HEPA filters on EW AHU-2 and -3 with MERV-14 filters	Visual	Measure implemented
EEM 8.01 – Secondary CHW loop dP reset	EMS and trend data	Measure implemented
EEM 8.02 – Optimize Condenser Water Temperature Control	EMS and trend data	Measure implemented
EEM 8.03: Repair Terminal Box Dampers in TRN & EW	EMS and trend data	Measure implemented
EEM 8.04: Repair EF-1A & EF-1B VFD Control	EMS and trend data	Measure implemented
EEM 8.05: Repair HW Preheat Valve Leakby on Turner AHU-1	Trend data and visual	The valve was replaced but preheat leakby is still observed using the same method that the TA used to measure leakby
EEM 8.06: Repair CHW Valve Leakby on Turner AHU-3	Trend data and visual	The valve was replaced but evaluation could not confirm or deny the base case conditions.

The M&V plan and project evaluation were generally conducted as planned. A site visit was performed on August 21, 2018, and October 17, 2018, to collect EMS screenshots, collect trend data, install data loggers, and interview the site contact.

Due to the size of the hospital campus, the limited time the site contact had to accommodate the evaluation, and the specificity of some of the measures, most measures were verified from EMS screenshots and trend data. Trend reports had been generated that gathered specific trend points to corroborate measure verification. For example, a specific trend report was already generated for EEM1. The trend report recorded data points (RAH, cooling coil DAT, supply fan cfm, etc.) that would assist in verifying that the measure was functioning as intended. The reports could also be used to update specific data fields that were used in the temperature bin analyses.

The evaluation savings methodologies that are explained in later sections were implemented as planned. For the majority of measures, the evaluation utilized the existing tracking calculation methods and updated them with observed operating conditions and profiles. Some measures (EEM2, EEM7) used slightly different savings methods to estimate evaluated savings. The evaluation did not produce 8,760-hour demand reduction profiles for each measure because not all tracking calculation methods utilized 8,760 profiles.

Data collection

The evaluator's metering and data collection approach outlined in the M&V plan was implemented as planned. The following table describes data points collected for the affected equipment.

Table 36: Data collection

Measure Name	Equipment	Data points	Duration
EEM 1.00 - Add dehumidifier mode to east wing AHUs (2-5)	EW AHU 2-5	• OAT/H • RAH • Cooling DAT, DAT SP • Reheat DAT, DAT SP • MAT • SF VFD Speed % • SF cfm • RF VFD Speed % • RF cfm • kW of AHU-2 and -4 SF	3 months
EEM 2.00 - Kitchen Hood controls	EF-2A; AHU-6	• AHU6 SF VFD Speed % • AHU6 Pre-heat DAT • AHU6 Cooling Coil DAT • AHU6 space temperature • AHU6 space occupancy signal • EF-2A VFD Speed % • OAT	3 months
EEM 3.00 Reduce Unoccupied zone airflow on TRN AHU-1	TRN AHU-1	• Cooling DAT, DAT SP • SF VFD Speed % • OAT/OAH • Pre-heat DAT, DAT SP • Reheat DAT/DAH • kW of AHU-1 SF • Space temperatures for (2) AHU-1 spaces	3 months
EEM 5.00 – Reduce unoccupied zone airflow on EW AC -2, -3, -4, and -5	EW AHU 2-5	• Final DAT, DAT SP • MA damper position % • OAT/OAH • Preheat DAT • Cooling coil DAT, DAT SP	3 months

		• RAH • SF cfm • kW of AHU-2 -4 SF • Space temperatures for (2) AHU-2 spaces; (2) AHU-4 spaces	
EEM 7.00 – Remove HEPA filters on EW AHU-2 and -3 with MERV-14 filters	EW AHU 2-3	• SF cfm • OAT/OAH	3 months
EEM 8.01 – Secondary CHW loop dP reset	TRN sCHWP 6A; TRN/EW/Sheffield AHU CCV;	• sCHW flow • sCHW dP / dp SP • sCHW # cooling valves open • AHU CCV position % • sCHWP 6A/6B VFD speed %	3 months
EEM 8.02 – Optimize Condenser Water Temperature Control	TRN CT; TRN CWP 4A-4C	• CWST, CWST SP • CWRT • CT fan VFD speed % • CWST Low SP, high SP • OAT • CWP Status • kW of CWP-4 • kW of CT-C fan	3 months
EEM 8.03: Repair Terminal Box Dampers in TRN & EW	15 Terminal boxes of affected EW AHUs	• Flow SP • Flow reading • Damper %	Instantaneous EMS screenshots
EEM 8.04: Repair EF-1A & EF-1B VFD Control	EF-1A; EF-1B	• EF-1A/-1B cfm • EF-1A/-1B VFD speed % • Spot power measurements	3 months; instantaneous
EEM 8.05: Repair HW Preheat Valve Leakby on Turner AHU-1	TRN AHU-1	• Cooling coil DAT, DAT SP • Preheat Valve position • Reheat valve position % • Cooling coil valve position % • OAT/OAH	3 months
EEM 8.06: Repair CHW Valve Leakby on Turner AHU-3	TRN AHU-3	• MAT • RAT • Final DAT • Preheat Valve position • Reheat valve position • Cooling valve position • MA damper position	3 months

Data loggers were deployed mainly to support and cross-check the trend data. The trend data provided numerous data points to support and update key equipment operating profiles.

Evaluation savings analysis

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

Details of the individual project savings analyses are presented below.

EEM 1.00 - Add dehumidifier mode to EW AHUs (2-5)

EMS screenshots and trend data confirmed that the dehumidification mode had been programmed into the existing EMS for AC 2-5. The sequence of operations for all AHUs are similar to what was proposed in the tracking calculations. The dehumidifier mode is enabled when the RAH is more than 55%. When the mode is active, the cooling DAT is 50 °F. However, it appears the cooling DAT is allowed to float between 50 °F and 55 °F as the RAH floats between 55% and 50%. Once the RAH is below 50%, the dehumidifier mode is disabled and the cooling DAT is 55 °F.

Trend data from 5/31/2018 through 8/30/2018 provided enough information to update the following operating conditions.

- SF VFD speed%, all-temperature bins
- SF cfm, all-temperature bins
- Return air humidity, 50-90 °F temperature bins
- Mixed air temperature, 50-90 °F temperature bins
- Proposed cooling coil DAT, 50-90 °F temperature bins

The critical savings parameter for this measure is the cooling coil DAT[20]. Table 37 shows the difference between the tracking and evaluated inputs for the cooling coil DAT.

Table 37: Comparison of tracking & evaluated EW AHU-2 cooling coil DAT

Weather bin, °F	Base Tracking CC DAT, °F	Base Eval CC DAT, °F	Proposed Tracking CC DAT, °F	Proposed Eval CC DAT, °F
> 90	50.0	50.0	50.0	50.0
85 - 90	50.0	50.0	50.0	52.0
80 - 85	50.0	50.0	50.0	51.8
75 - 80	50.0	50.0	50.0	51.4
70 - 75	50.0	50.0	55.0	50.8
65 - 70	50.0	50.0	55.0	51.1
60 - 65	50.0	50.0	55.0	51.3
55 - 60	50.0	50.0	55.0	52.6
50 - 55	50.0	50.0	55.0	53.0
45 - 50	50.0	50.0	55.0	55.0
40 - 45	50.0	50.0	55.0	55.0
35 - 40	50.0	50.0	55.0	55.0
30 - 35	50.0	50.0	55.0	55.0
25 - 30	50.0	50.0	55.0	55.0
20 - 25	50.0	50.0	55.0	55.0
15 - 20	50.0	50.0	55.0	55.0
10 - 15	50.0	50.0	55.0	55.0
5 - 10	50.0	50.0	55.0	55.0
< 5	50.0	50.0	55.0	55.0

[20] Supply fan speed, supply fan cfm, and return air humidity were also revised. However, the cooling coil DAT is the critical parameter that is reported here

The table below provides the evaluation results for EEM1. Evaluated savings were less than tracking because the proposed cooling coil DAT did not leave dehumidifier mode and increase to 55 °F as often as assumed in the tracking calculation. Since the cooling coil DAT was lower than expected, there was not as much cooling energy savings as expected in the tracking calculation.

Table 38: Evaluation results for EEM 1.00 - Add dehumidifier mode to EW AHUs (2-5)

Savings Quantity	Tracking Estimate	Evaluation Estimate	Realization Rate
Electric energy (kWh)	264,664	109,987	42%
% of Energy Savings on Peak	52%	50%	97%
Summer On-Peak Demand (kW)	35.0	14.5	41%
Winter On-Peak Demand (kW)	0.4	0.4	111%

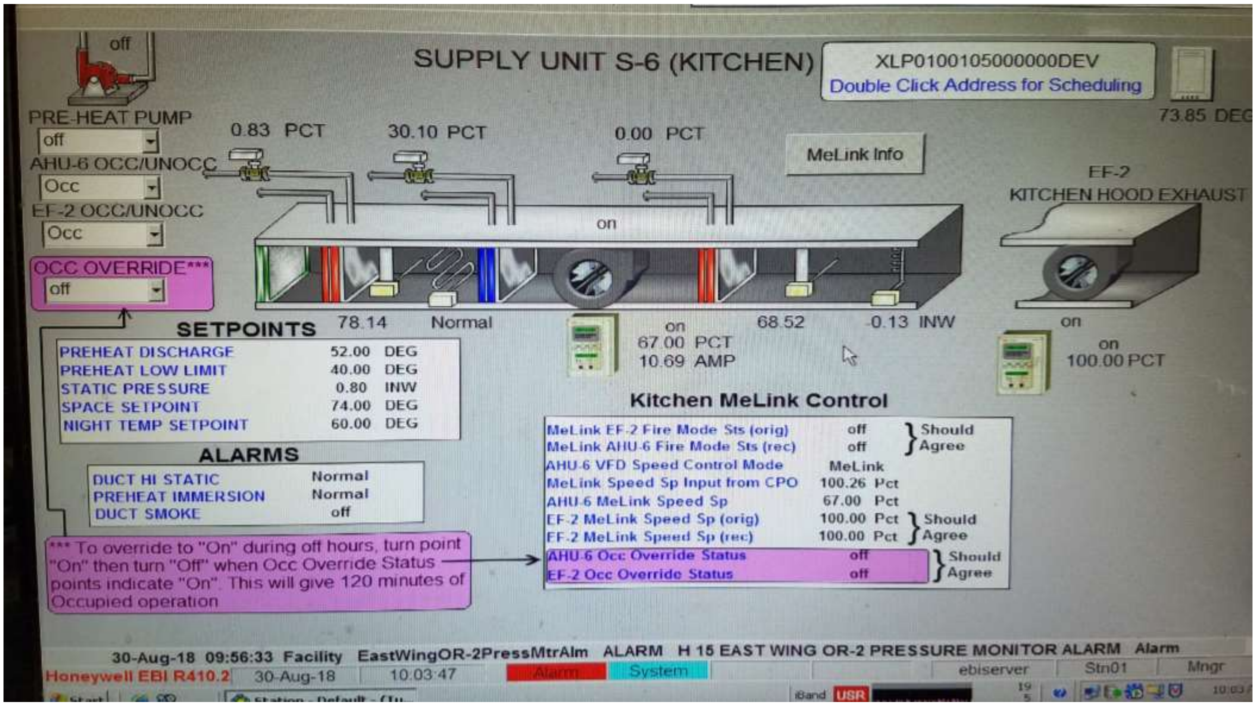
EEM 2.00 - Kitchen Hood controls in TRN

EMS screenshots (Figure 14) and trend data confirmed that the kitchen hood controls had been programmed into the existing EMS for EF-2A and AHU-6. Trend data were used to define the EF-2A and AHU-6 operating schedules, EF-2A fan speed, and AHU-6 SF fan speed.

The evaluator chose to approach the calculation method different from the tracking calculation because the trend data suggested that the fan schedule and fan speeds were not dependent on OAT. Fan speed data were binned into 168-hour weekly schedules that were then extrapolated into an 8,760-hour profile using a day of week and hour of the day to assign fan schedules and fan speeds. Fan kW was calculated by using the trended fan speeds, full speed fan kW estimates, and an assumed fan law exponent of 2.5 (no change from tracking assumption). Cooling energy was calculated using the same assumptions as to the tracking calculations except that 8,760 TMY3 weather was used rather than TMY3 weather bins.

While it appeared that the kitchen hood controls were active, the trend data showed that the fan speeds did not vary throughout the day as proposed in the tracking calculation. Instead, the fan speeds were observed to be fixed at 67% for AHU-6 SF and 100% for EF-2A.

Figure 14: EMS screenshot of kitchen hood controls



The table below provides the evaluation results for EEM2. The evaluation savings were less than the tracking savings because the evaluation adjusted base case fan powers that increased the base case total fan kWh, but the proposed fan energy also increased as EF2 was found to operate at fixed 100% speed and AHU6 SF was found to operate at fixed 67% speed.

Table 39: Evaluation Results for EEM 2.00 - Kitchen Hood controls in TRN

Savings Quantity	Tracking Estimate	Evaluation Estimate	Realization Rate
Electric energy (kWh)	90,944	29,847	33%
% of Energy Savings on Peak	59%	52%	89%
Summer On-Peak Demand (kW)	20.2	5.4	27%
Winter On-Peak Demand (kW)	16.4	5.4	33%

EEM 3.00 - Reduce unoccupied zone airflow on AHU-1

EMS screenshots of a sample of affected space terminal boxes and trend data confirmed that the measure had been implemented. The evaluator used observed occupancy schedules and 3 months of trend data to develop average supply fan VFD speed values to replace the assumed values in the tracking temperature bin analysis spreadsheet. Other trend data were also used to update the following calculation inputs:

- Final (reheat) DAT, 50-90 °F temperature bins
- Preheat DAT, 50-90 °F temperature bins

- Occupied SF VFD speed %, 50-90 °F temperature bins
- Unoccupied SF VFD speed %, 50-90 °F temperature bins
- Cooling DAT, 50-90 °F temperature bins
- Return air humidity, 50-90 °F temperature bins

The evaluator also noted that the base case and proposed case occupied SF VFD speed profiles used in the tracking temperature bin analysis were different; however, based on the measure changes, these profiles should have been equivalent. Only the proposed case unoccupied VFD speed profiles should have been affected by the measure. The evaluator updated the calculation inputs for the temperature bins noted in the above bullets and corrected the base case SF VFD speed profile so it matched the proposed case occupied SF VFD speed profile.

The updates reduced estimated savings compared to tracking estimates because the observed unoccupied SF VFD speeds were much closer to the observed occupied SF VFD speeds than what was estimated in the tracking savings. The tracking savings estimated that the unoccupied schedule would see a drop in supply airflow of 5,227 cfm, or 12% of the design supply flow. Trend data observations indicated that the VFD speed during unoccupied periods dropped between 1-3% relative to occupied periods. The table below summarizes the evaluation findings for EEM3.

Table 40: Evaluation results for EEM 3.00 - Reduce unoccupied zone airflow on AHU-1

Savings Quantity	Tracking Estimate	Evaluation Estimate	Realization Rate
Electric energy (kWh)	66,611	13,715	21%
% of Energy Savings on Peak	48%	67%	140%
Summer On-Peak Demand (kW)	12.5	0.0	0%
Winter On-Peak Demand (kW)	6.4	2.7	42%

EEM 5.00 – Reduce unoccupied zone airflow on AHU-2, -3, -4, and -5

EMS screenshots of a sample of affected space terminal boxes and trend data confirmed that the measure had been implemented. The evaluator used observed occupancy schedules and 3 months of trend data to develop average supply fan cfm values to replace the assumed values in the tracking temperature bin analysis spreadsheet. Other trend data were also used to update the following calculation inputs:

- Final (reheat) DAT, 50-90 °F temperature bins
- Mixed air temperature, 50-90 °F temperature bins
- Occupied SF VFD speed %, 50-90 °F temperature bins
- Unoccupied SF VFD speed %, 50-90 °F temperature bins
- Occupied SF cfm flow rate, 50-90 °F temperature bins

- Unoccupied SF cfm flow rate, 50-90 °F temperature bins
- Return air humidity, 50-90 °F temperature bins

The evaluator also noted that the base case and proposed case occupied SF VFD speed and cfm profiles used in the tracking temperature bin analysis were different for a few mid-bin temperatures; however, based on the measure changes, these profiles should have been equivalent. Only the proposed case unoccupied VFD speed and cfm profiles should have been affected by the measure. The evaluator updated the calculation inputs for the temperature bins noted in the above bullets and corrected the base case SF VFD speed and cfm profiles so they matched the proposed case occupied SF VFD speed and cfm profiles.

The updates reduced estimated savings compared to tracking estimates because the observed unoccupied SF VFD speeds were much closer to the observed occupied SF VFD speeds than what was estimated in the tracking savings. The tracking savings estimated that the unoccupied schedule would see a drop in supply airflow of 380 to 3,420 cfm or 1 to 9% of the design supply flow. Trend data observations indicated that the VFD speed during unoccupied periods changed between -3% (an increase in speed) to 9% relative to occupied periods. The table below summarizes the evaluation findings for EEM3.

Table 41: Evaluation results for EEM 5.00 – Reduce unoccupied zone airflow on AHU-2, -3, -4, and -5

Savings Quantity	Tracking Estimate	Evaluation Estimate	Realization Rate
Electric energy (kWh)	87,330	46,497	53%
% of Energy Savings on Peak	6%	10%	167%
Summer On-Peak Demand (kW)	-0.0	-1.6	7,949%
Winter On-Peak Demand (kW)	2.4	0.0	0%

EEM 7.00 – Remove HEPA filters on EW AHU-2 and -3

The evaluator confirmed that the HEPA filters on EW AHU-2 and AHU-3 were replaced with MERV14 filters with a rated resistance of 0.4” w.g. (@ 2,000 cfm).

Evaluation of trend data determined that AHU fan VFD speed did not correlate cleanly with OAT. With 3 months of trend data, the evaluator decided to develop a 168-hour weekly VFD speed profile and extrapolate the profile to an 8,760-hour annual profile by day of week and hour of the day.

The evaluator used spot current and speed measurements to estimate the full speed kW of the AHU fans without HEPA filters (the proposed AHU SF kW)[21]. These values updated the tracking estimates that had used pressure drop assumptions and fan laws relating fan power to fan pressure (second-order) to approximate the proposed AHU fan kW. The tracking calculations had estimated the proposed full speed AHU fan kW using this fan law relationship and the full speed kW measured when the HEPA filters were in place. The evaluator used the tracking estimates for the base case fan kW because they had been spot-power

[21] The evaluator installed a kW data logger on AHU-2 but did not collect trend data (VFD speed) that coincided with the kW data. The evaluator also failed to capture the observed VFD speed when the kW data logger was installed, so there was difficulty matching measured kW to observed VFD speed. As a compromise, the evaluator sanity checked the power estimated through the spot measure amps and speed to the logger data and VFD speed trends which resulted in a reasonable estimate.

measured with HEPA filters in place. Part-speed fan kW was approximated using the same VFD performance curve (an eQUEST curve) used in the tracking calculation[22].

The differences between the tracking and evaluated proposed AHU fan kW values had the largest impact on the change in evaluated savings. The full speed ΔkW in the tracking calculation were 20.2 and 16.1 kW; the evaluated estimates were 11.5 and 12.1 kW. The table below summarizes the evaluated measure savings.

Table 42: Evaluation results for EEM 7.00 – Remove HEPA filters on AHU-2 and -3

Savings Quantity	Tracking Estimate	Evaluation Estimate	Realization Rate
Electric energy (kWh)	213,827	166,375	78%
% of Energy Savings on Peak	67%	52%	78%
Summer On-Peak Demand (kW)	27.6	22.1	80%
Winter On-Peak Demand (kW)	22.1	21.5	97%

EEM 8.01 – Secondary CHW loop dP reset

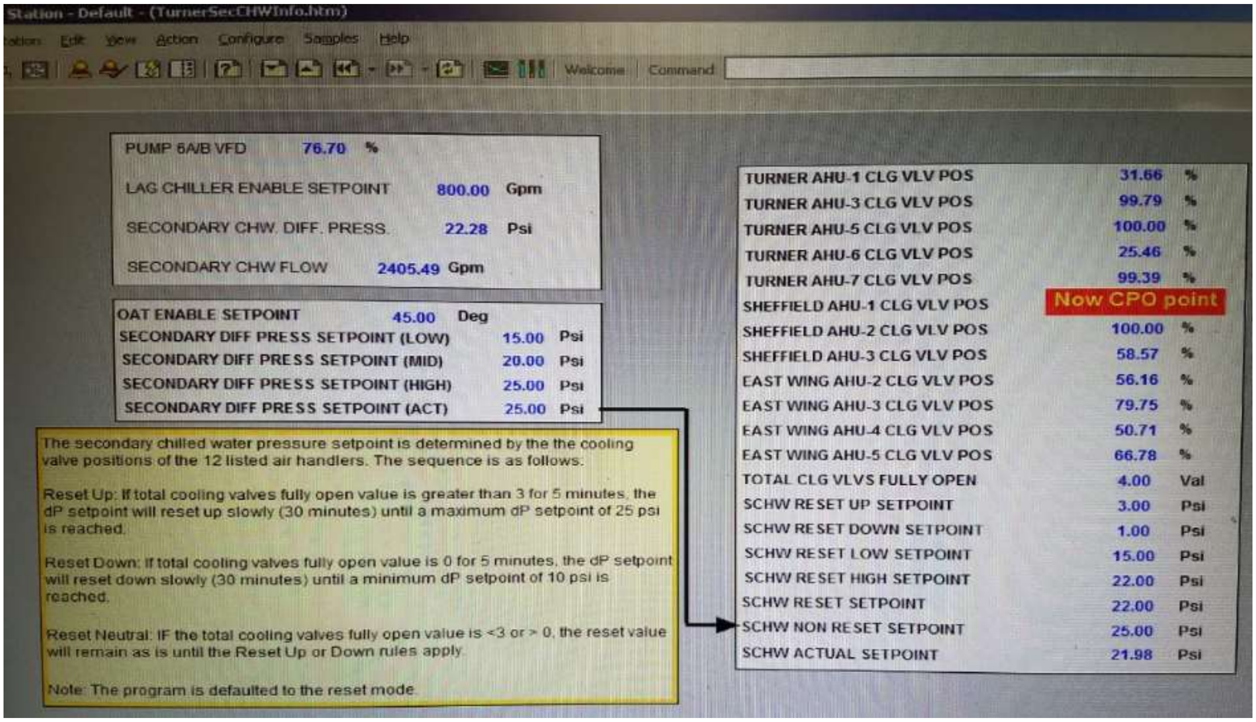
The measure was verified via EMS screenshots and trend data to be implemented and operating as intended. However, it appears that the observed sequence of operation is different than what was proposed in the TA report.

Per the TA report (also in yellow box in Figure 15), the secondary CHW dP resets up if the number of fully open CHW valves is more than 3 for more than 5 minutes and resets up slowly (every 30 minutes) to a max of 25 psi. When the cooling load drops, the dP drops if the number of fully open valves is 0 for more than 5 minutes, and resets down slowly to a minimum dP of 10 psi. If the load is relatively neutral (number of open valves remains between 0 and 3) the current dP is maintained.

The evaluator found (in white box in Figure 15) that the minimum dP is 15 psi and the maximum dP is 22 psi. The dP reset can also be overridden and the non-reset dP setpoint is 25 psi. Trend data shows that the dP reset was overridden for several days in July and August during days with peak temperatures.

Figure 15: Sequence of operation for EEM8.01 SCHW dP reset

[22] This method was different than the method used for other measures. A fan law exponent of 2.5 had been used for others. The evaluator thinks both methods are reasonable, so did not change it



The evaluator used the eQUEST model developed to estimate the tracking savings and updated key input values affected by the measure implementation. The following eQUEST keyword values were adjusted or checked for reasonableness.

Table 43: EEM 8.01 evaluation changes/checks to eQUEST model keywords

eQUEST keyword	Tracking value	Evaluation value	Reason for change
SCHW loop pipe + static head	43 feet (33 feet pipe and 10 feet static)	58.5 feet (48.5 feet pipe and 10 feet static)	This approximation was adjusted such that the auto-sized max SCHWP kW would match the max observed SCHWP kW (estimated to be 43.7 kW)[23]
SCHW pump power	Auto-sized, max is 34.5 kW	43.7 kW	Loop head change adjusted this max to 43.7 kW. The observed max speed was 88% (approximated to 43.7 kW)
Pump quantity	2	1	There are 2 pumps but they operate in a primary/standby sequence. Ultimately though, this change does not affect model energy usage
SCHW loop head dP setpoint	Default (44 feet)	44 feet	No change. The default is the maximum design head of the SCHW loop (plus pipe and static head)
SCHW loop head setpoint control	Base = fixed Proposed = valve reset	Base = fixed Proposed = valve reset	No change. This is the keyword that models the measure. Pumps are modulated so that the system head is just enough to provide required flow for worst-case coil

[23] It appears this value was adjusted to represent the average dP setpoint for the base case. The TA report claims that based from baseline trend data the annual average# of chillers on was 1.92. Based on the base case dP setpoint SOO (~ 1 chiller = 15 psi; 2 chiller = 20 psi; 3 chiller = 25 psi), the base case fixed dP head setpoint was reportedly set to 19.7 psi (~ 45.5 feet). It appears this was the target head pressure that the eQUEST base case model was calibrated to.

The evaluator changes increased the estimated measure savings because it effectively raised the modeled pump power to match the maximum observed pump power[24]. The table below summarizes evaluated measure savings.

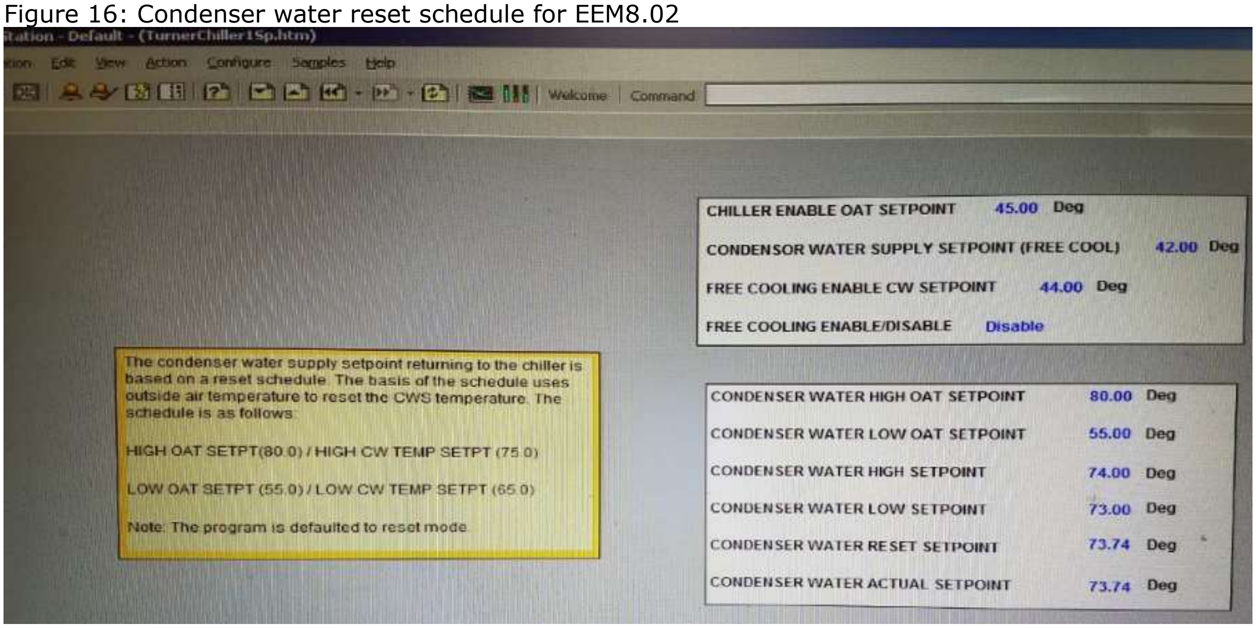
Table 44: Evaluation results for EEM 8.01 – Secondary CHW loop dP reset

Savings Quantity	Tracking Estimate	Evaluation Estimate	Realization Rate
Electric energy (kWh)	37,855	64,050	169%
% of Energy Savings on Peak	77%	77%	100%
Summer On-Peak Demand (kW)	7.0	15.6	223%
Winter On-Peak Demand (kW)	0.0	0.0	N/A

EEM 8.02 – Optimize Condenser Water Temperature Control

The condenser water temperature reset measure was implemented; however, the high/low setpoints appear to have been adjusted from what they have initially programmed into the EMS. The figure below shows in the yellow box the initial reset schedule that matches what was proposed in the TA report. The white box shows the current programmed reset schedule. It suggests that the condenser water temperature is allowed to float by 1 °F (effectively fixed) rather than by the proposed 10 °F (between 75 °F and 65 °F).

Figure 16: Condenser water reset schedule for EEM8.02



This observation was entered into the eQUEST model that was developed to estimate the tracking savings using the following keywords. A review of the eQUEST model also determined that the proposed reset schedule was entered incorrectly in the eQUEST model. The incorrect entry effectively reversed the intended schedule (entered as high CWST of 75 °F at the low 55 °F OAT and low CWST of 65 °F at the high 80 °F OAT). The tracking model also used different weekday and weekend schedules, which was not what had been proposed or intended in the TA report.

[24] Pump speed was observed through trends. Pump power was estimated using pump speed and pump nameplate HP

The table below documents the changes that the evaluator made to the eQUEST model.

Table 45: EEM 8.02 evaluation changes/checks to eQUEST model keywords

eQUEST keyword	Tracking value	Evaluation value	Reason for change
Condenser water reset schedule (weekday)	OAT high = 80 °F CWST high = 65 °F OAT low = 55 °F CWST low = 75 °F	OAT high = 80 °F CWST high = 74 °F OAT low = 55 °F CWST low = 73 °F	Changed based on observed schedule
Condenser water reset schedule (weekend)	OAT high = 85 °F CWST high = 85 °F OAT low = 65 °F CWST low = 65 °F	OAT high = 80 °F CWST high = 74 °F OAT low = 55 °F CWST low = 73 °F	Changed based on observed schedule

The model revision that matched the modeled schedule to the proposed schedule increased savings by 32%; however, the next revision that changed the modeled schedule from the proposed schedule to the observed schedule decreased savings by 15% (relative to tracking).

The summary of the evaluation results is shown in the table below.

Table 46: Evaluation results for EEM 8.02 – Optimize Condenser Water Temperature Control

Savings Quantity	Tracking Estimate	Evaluation Estimate	Realization Rate
Electric energy (kWh)	39,121	33,083	85%
% of Energy Savings on Peak	81%	81%	100%
Summer On-Peak Demand (kW)	8.0	8.2	102%
Winter On-Peak Demand (kW)	0.0	0.0	N/A

EEM 8.03 – Terminal Box Damper Repair

This measure was verified by collecting a sample of EMS screenshots of terminal boxes that had been affected by the repairs and comparing the flow reading to the flow setpoint. The tracking calculations show that the terminal boxes exhibited between 10% and 781% excess flow relative to the flow setpoints. There were fifteen terminal boxes that were sampled; EMS data showed that those terminal boxes exhibited between -8% and 8% excess flow relative to their flow setpoints, with their average excess flow estimated to be 1%.

The evaluation used the same calculation method as the tracking calculation, but with a 99% (because of the excess 1% flow) realization rate. The summary of the evaluation results is presented below.

Table 47: Evaluation results for EEM 8.03 – Terminal Box Damper Repair

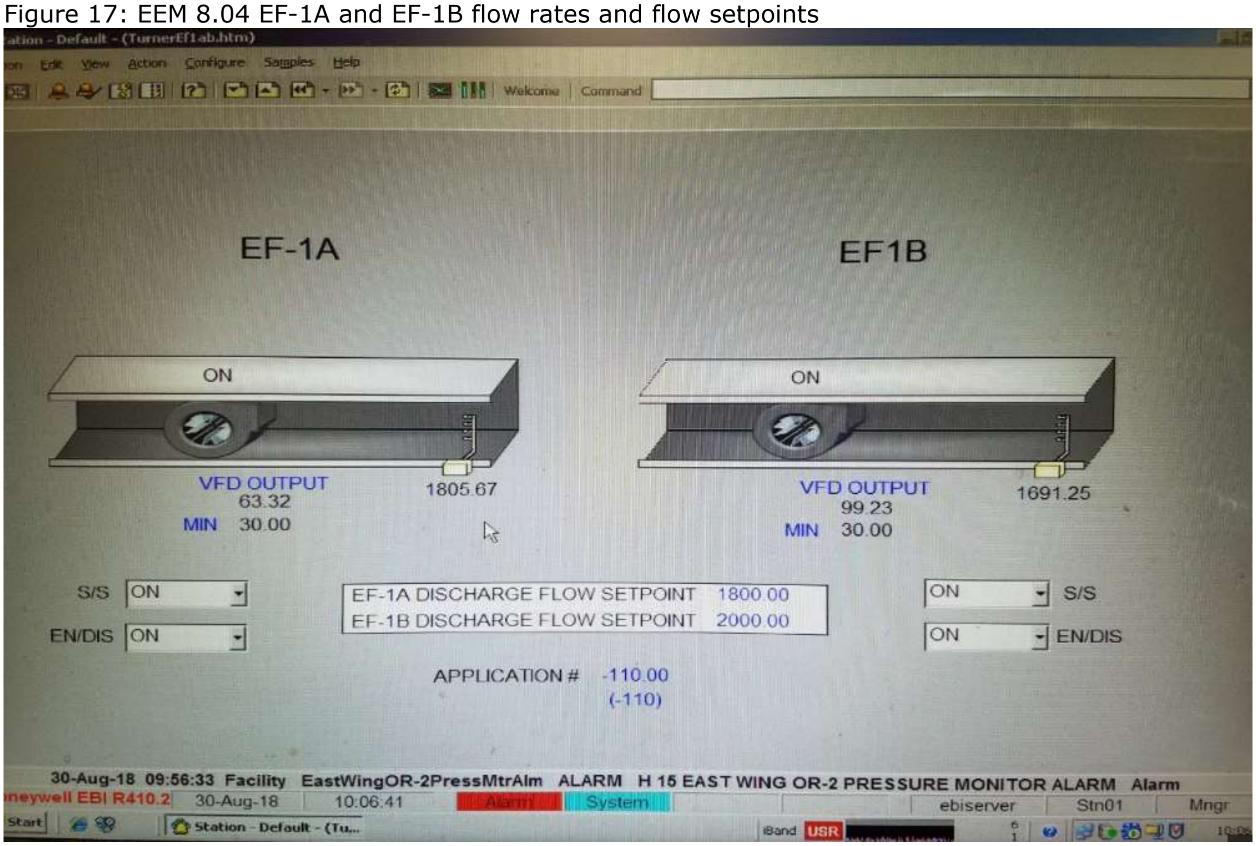
Savings Quantity	Tracking Estimate	Evaluation Estimate	Realization Rate
Electric energy (kWh)	59,061	58,381	99%
% of Energy Savings on Peak	67%	67%	100%

Summer On-Peak Demand (kW)	6.7	6.7	99%
Winter On-Peak Demand (kW)	6.7	6.7	99%

EEM 8.04 – Repair EF-1A & 1B VFD Control

The measure appears to have been implemented; however, the proposed flow setpoints were different than what was observed during the site visit. The TA report had claimed that the flow targets for EF-1A and EF-1B were 1,800 and 700 cfm, respectively. During the site visit, the EMS showed that the flow setpoints were 1,800 and 2,000 cfm, respectively (see Figure 17).

Figure 17: EEM 8.04 EF-1A and EF-1B flow rates and flow setpoints



Furthermore, the trend data that were collected for the exhaust fans showed that those setpoints observed during the site visit appear to be permanent and are not adjusted on a normal basis. Trend data showed that the EF-1A and EF-1B fans operated at constant speeds of 64% and 100%, respectively. EF-1A appears to be capable of reaching the flow setpoint while EF-1B is not – delivering only ~1,700 cfm at 100% speed. Since the observed speed of EF-1B is 100%, savings attributed to the fan were effectively zeroed out. EF-1A was observed to be operating at a speed 16% lower than proposed in the tracking calculation.

During the site visit, spot power measurements of both fans were taken. These spot power measurements were used to update the estimated full speed kW of both fans. This adjusted the full speed kW from the tracking estimate of 3.06 kW (for both EF-1A and EF-1B) to 3.4 kW for EF-1A and 2.5 kW for EF-1B.

These findings lowered evaluated savings by 13%, which are summarized below.

Table 48: Evaluation results for EEM 8.04 – Repair EF-1A & 1B VFD Control

Savings Quantity	Tracking Estimate	Evaluation Estimate	Realization Rate
Electric energy (kWh)	22,913	19,821	87%
% of Energy Savings on Peak	67%	46%	87%
Summer On-Peak Demand (kW)	2.6	2.3	86%
Winter On-Peak Demand (kW)	2,6	2.3	70%

EEM 8.05 - Repair HW Preheat Leakby on AHU-1

The evaluation of this measure was difficult to isolate and determine with certainty because there was not a reasonable way to physically verify whether there was leakby in the pre-heat coil valve. Per the contact and verified with visual observation, the existing pre-heat valve had been replaced with a new valve. However, using the same method that was used in the tracking calculation, there appeared to be leakby because the preheat coil DAT was often greater than the OAT (while the pre-heat valve was closed)[25].

This observation could be due to inaccuracies in one or both the temperature sensors, but the tracking method used the same trend data points (corresponding to the same temperature sensors). There is a possibility that there was no leakby, to begin with, and temperature sensor inaccuracies gave the appearance of leakby.

The evaluator decided that without evidence to claim inaccuracy on the temperature measurements, the same method would be used to estimate leakby. Using 3 months of trend data (during warmer months when the preheat valve was closed for the majority of the period), the evaluator determined that the average leakby temperature was 3.4 °F, 0.6 °F less than the tracking estimate of 4 °F[26]. The following temperature bin inputs were also updated using trend data:

- Supply fan VFD speed %, temperature bins 50 – 90 °F
- Final DAT, temperature bins 50 – 90 °F
- Cooling coil DAT, temperature bins 50 – 90 °F
- Leakby temperature, temperature bins 50 – 90 °F

Using the tracking savings calculation, the evaluator updated the temperature bin inputs mentioned above. The summary of the evaluation savings is presented in the table below.

Table 49: Evaluation results for EEM 8.05 - Repair HW Preheat Leakby on AHU-1

Savings Quantity	Tracking Estimate	Evaluation Estimate	Realization Rate
Electric energy (kWh)	38,781	3,608	9%
% of Energy Savings on Peak	53%	52%	99%
Summer On-Peak Demand (kW)	9.1	1.2	13%

[25] "Closed" was interpreted as trend data showing values less than 1.00, or 1%

[26] Leakby temperature was estimated for each temperature bin, and ranged from 1.8 °F to 4.8 °F

Winter On-Peak Demand (kW)	0.0	0.0	N/A

EEM 8.06 – Repair CHW Valve leakby on AHU-3

Similar issues around verifying "leakby" for EEM 8.05 were experienced for this measure. The evaluator confirmed with the site contact that the CHW valve had been replaced with a new valve. Visual observation was also made of the new valve.

A method that could be considered to verify the presence of a leakby with higher certainty would be to capture shoulder periods when the chillers are still active but the CHW valve is commanded closed due to low cooling load and/or free cooling from economizers. This method is similar to what the TA report presented as proof of the leakby. However, the trend data that was available to the evaluator captured warmer summer periods when the CHW valves were open.

The tracking calculations used a temperature bin method to approximate the impact that the CHW valve leakby had on the CHW coil DAT. The leakby affected the CHW coil DAT by cooling the incoming mixed air past the CHW coil DAT setpoint (of 55 °F). However, the tracking calculation used equation logic rather than CHW coil DAT trend data to estimate the leakby effect on CHW coil DAT[27].

The evaluator was able to replace the assumed proposed CHW coil DAT profile (55 °F when OAT > 50 °F and 50 °F when OAT < 50 °F) with actual observed CHW coil DAT from trend data. The evaluator retained the equation logic used in the tracking calculation for the base case CHW coil DAT but updated the MAT profile with actual measurements from trend data. The supply fan motor temperature rise estimate was also adjusted. The evaluator retained the equation logic for the base case CHW coil DAT because there were no reasonable alternatives. The base case leak by amount was documented using ΔT without describing the mass flow. Further, it appears that even though the base case trend data showed that the CHW valve was closed, it also showed that the DAT setpoint was being satisfied and was not overcooling. There were also periods in the trend data where the MAT was less than the DAT setpoint but the CHW valve was wide open. These observations indicate that the CHW valve readings may have been inaccurate and that although the sensor reading was 0 in the trend data, the valve could have been functioning as intended for the system to meet the DAT setpoint.

Without more data to describe the base case conditions, the evaluator limited the analysis of updating known data points within the tracking calculation method. The following table shows the change from what the tracking temperature bins assumed in the tracking proposed profile to what the trend data measured.

Weather bin	Tracking Estimate for proposed CHW Coil DAT (without leakby)	Evaluation Estimate for proposed CHW coil DAT using trend data (without leakby)	Tracking Estimate for base case CHW Coil DAT (without leakby)	Evaluation Estimate for base case CHW coil DAT using trend data (without leakby)
> 90	55.0	55.0	55.0	55.0
85 - 90	55.0	54.8	54.7	55.0

[27] The equation took the maximum of: 50 °F and the minimum between: 55 °F or MAT – 20.3 °F (the effect of leakby). This forced the CHW coil DAT to be between 50 °F and 55 °F

80 - 85	55.0	54.7	53.4	55.0
75 - 80	55.0	54.8	52.3	55.0
70 - 75	55.0	54.9	51.4	55.0
65 - 70	55.0	55.2	50.2	55.0
60 - 65	55.0	55.3	50.0	55.0
55 - 60	55.0	55.2	50.0	54.6
50 - 55	55.0	55.2	50.0	54.3

The combination of these CHW coil profile changes dramatically lowered the estimated savings. A summary of the evaluated savings is presented in the table below.

Table 50: Evaluation results for EEM 8.06 – Repair CHW Valve leakby on AHU-3

Savings Quantity	Tracking Estimate	Evaluation Estimate	Realization Rate
Electric energy (kWh)	10,900	791	7%
% of Energy Savings on Peak	52%	45%	88%
Summer On-Peak Demand (kW)	1.8	-0.1	-3%
Winter On-Peak Demand (kW)	0.0	0.0	N/A

Evaluation Results

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

Table 51: Evaluation results for project ID 4728393

Project/Measure	Savings Quantity	Tracking Estimate	Evaluation Estimate	Realization Rate
EEM 1.00 - Add dehumidifier mode to east wing AHUs (2-5)	Electric energy (kWh)	264,664	109,987	42%
	% of Energy Savings on Peak	52%	50%	97%
	Summer On-Peak Demand (kW)	35.0	14.5	41%
	Winter On-Peak Demand (kW)	0.4	0.4	111%
EEM 2.00 – Turner Kitchen Hood controls	Electric energy (kWh)	90,944	29,847	33%
	% of Energy Savings on Peak	59%	52%	89%
	Summer On-Peak Demand (kW)	20.2	5.4	27%
	Winter On-Peak Demand (kW)	16.4	5.4	33%

EEM 3.00 Reduce Unoccupied zone airflow on Turner AHU-1	Electric energy (kWh)	66,611	13,715	21%
	% of Energy Savings on Peak	48%	67%	140%
	Summer On-Peak Demand (kW)	12.5	0.0	0%
	Winter On-Peak Demand (kW)	6.4	2.7	42%
EEM 5.00 – Reduce unoccupied zone airflow on EW AC -2, -3, -4, and -5	Electric energy (kWh)	87,330	46,497	53%
	% of Energy Savings on Peak	6%	10%	167%
	Summer On-Peak Demand (kW)	-0.0	-1.6	7,949%
	Winter On-Peak Demand (kW)	2.4	0.0	0%
EEM 7.00 – Remove HEPA filters on EW AHU-2 and -3 with MERV-14 filters	Electric energy (kWh)	213,827	166,375	78%
	% of Energy Savings on Peak	67%	52%	78%
	Summer On-Peak Demand (kW)	27.6	22.1	80%
	Winter On-Peak Demand (kW)	22.1	21.5	97%
EEM 8.01 – Secondary CHW loop dP reset	Electric energy (kWh)	37,855	64,050	169%
	% of Energy Savings on Peak	77%	77%	100%
	Summer On-Peak Demand (kW)	7.0	15.6	223%
	Winter On-Peak Demand (kW)	0.0	0.0	N/A
EEM 8.02 – Optimize Condenser Water Temperature Control	Electric energy (kWh)	39,121	33,083	85%
	% of Energy Savings on Peak	81%	81%	100%
	Summer On-Peak Demand (kW)	8.0	8.2	102%
	Winter On-Peak Demand (kW)	0.0	0.0	N/A
EEM 8.03: Repair Terminal Box Dampers in TRN & EW	Electric energy (kWh)	59,061	58,381	99%
	% of Energy Savings on Peak	67%	67%	100%
	Summer On-Peak Demand (kW)	6.7	6.7	99%
	Winter On-Peak Demand (kW)	6.7	6.7	99%
EEM 8.04: Repair EF-1A & EF-1B VFD Control	Electric energy (kWh)	22,913	19,821	87%
	% of Energy Savings on Peak	67%	46%	87%
	Summer On-Peak Demand (kW)	2.6	2.3	86%
	Winter On-Peak Demand (kW)	2,6	2.3	70%

EEM 8.05: Repair HW Preheat Valve Leakby on Turner AHU-1	Electric energy (kWh)	38,781	3,608	9%
	% of Energy Savings on Peak	53%	52%	99%
	Summer On-Peak Demand (kW)	9.1	1.2	13%
	Winter On-Peak Demand (kW)	0.0	0.0	N/A
EEM 8.06: Repair CHW Valve Leakby on Turner AHU-3	Electric energy (kWh)	10,900	791	7%
	% of Energy Savings on Peak	52%	45%	88%
	Summer On-Peak Demand (kW)	1.8	-0.1	-3%
	Winter On-Peak Demand (kW)	0.0	0.0	N/A
Total project (4728393)	Electric energy (kWh)	932,006	546,155	59%
	% of Energy Savings on Peak	55%	40.6%	74%
	Summer On-Peak Demand (kW)	130.4	74.2	57%
	Winter On-Peak Demand (kW)	57.1	38.9	74%

Site ID: 2016RIN028

Program Administrator	National Grid
Project ID(s)	5631781
Project Type	Retrofit and Retro-commissioning
Program Year	2016
Evaluation Firm	DNV GL
Evaluation Engineer	Chris Williams
Senior Engineer	C.D. Nayak

Project Description

This project performed several controls upgrades using the existing building EMS. The building supports multiple occupancy types including office spaces, a small retail space, and a large package-sorting warehouse. The project implemented the following measures:

- Ventilation optimization. The measure claimed to save cooling and fan energy by repairing economizers and re-commissioning outside airflow rates of existing air handlers to code minimums.
- Space temperature cooling setpoint setbacks. The measure claims to save cooling energy by programming zone thermostats to set back the space temperature setpoints during unoccupied hours.
- Demand control ventilation. The measure installed CO2 sensors to monitor office space CO2 concentration. Using this ventilation control method, the air handlers supporting office space areas are allowed (by code) to modulate outside air dampers to positions (0% or 5%) below the code minimum (typically 15-20% depending on space type and AHU sizing). The dampers open when free cooling is available or when space CO2 concentration exceeds 1,000 ppm. The demand control ventilation measure appears to have been implemented in an office space that was separate from some spaces affected by the ventilation optimization measure.

The tracking savings utilizes a Trane TRACE^{TM} 700 model to estimate total project savings. The model did not use separate parametric runs to simulate individual measure savings so only project-level savings were available. The table below summarizes the evaluation results for the project.

Table 52: Project results for 5631781

Savings Quantity	Tracking Estimate	Evaluation Estimate	Realization Rate
Electric energy (kWh)	1,182,614	225,463	19%
% of Energy Savings on Peak	62%	-46%	-74%
Summer On-Peak Demand (kW)	237.0	60.7	26%
Winter On-Peak Demand (kW)	96.0	44.4	46%

The bullets below explain some key discrepancy findings. The discrepancy analysis section near the end of the report explains all discrepancies in more detail.

- The largest and most impactful discrepancy adjusted the design cooling setpoints such that the base case and proposed case setpoints were equivalent. The tracking model had erroneously adjusted the *design* setpoints for the post model; the appropriate parameters to simulate the space temperature cooling set back are the *thermostat schedule* setpoints. The tracking model had mistakenly adjusted the size and capacity of the HVAC systems to simulate measure impacts (e.g., base case equals 25-ton RTU with 10 HP fan; proposed case equals 20-ton RTU with 7.5 HP fan). Further explanation of what design setpoints do to a model is described in the discrepancy analysis section.
- The % of energy savings on peak changed from positive to negative because of the cooling schedule discrepancy. The tracking model did not use a thermostat schedule for the base or proposed models. The evaluator added a set back schedule for the proposed model and a fixed schedule for the base model. The evaluator believes that the energy savings are negative during on-peak hours (hours 7 to 22) because the proposed model is performing extra cooling (compared to the base model) to make up for the setback cooling hours.

Tracking Savings

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

Baseline Condition

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

Ventilation optimization

Economizer dampers and/or actuators are either broken, dilapidated, or were not working/programmed properly. The pre-existing conditions were modeled using an assumed higher-than-code ventilation rate. The modeled AHU systems represented specific areas in the building and each area was assigned a base case ventilation rate shown in the table below.

Table 53: Base case ventilation conditions

Modeled AHU system (area served)	Ventilation rate (cfm/sf)	Minimum ventilation rate (2007 ASHRAE 62.1 category 1 area)[28]	Floor area (sf)
RTUs (Northeast end)	0.105	0.06 cfm/sf	159,489
AHUs (Front lobby/southwest end & South end)	0.106		153,463 (Front lobby/SW end); 50,770 (south end)

[28] Table 6-A: R_a and R_p Value by Occupancy Type. Pg. 85. 6-6 Procedure: Ventilation Rate Procedure

AHU offices (SW offices)	0.123		48,782

It appears that these (OA) ventilation rates were calculated based on an assumed 15% of the design cooling airflow rate. Design cooling airflow is calculated in the program based on other design parameters that estimate building space cooling loads.

Space temperature cooling setpoint setbacks

Cooling setpoints for all conditioned spaces were assumed to be 72 °F. The model does not have an assigned thermostat schedule, so the spaces hold this setpoint continuously.

Demand control ventilation

Outside air ventilation is determined by the assigned percentage (15%) of cooling/heating airflow. This equates to 16,684 cfm for System 2 (RTUs – Northeast end); 21,732 cfm for System 3 (AHUs – Front Lobby/SW end and South end); 6,015 cfm for System 4 (AHU Offices – SW Offices)

Proposed condition

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

Ventilation optimization

The measure is modeled to effectively repair the outside air dampers and reduce the outside air ventilation rates to near code minimums. Each modeled AHU system is adjusted to follow the design ventilation conditions of 0.06 cfm/sf and 5 cfm/person. The effective proposed outside air ventilation rates of the modeled AHU systems are shown in the table below.

Table 54: Proposed case ventilation conditions

Modeled AHU system (area served)	Ventilation rate (cfm/sf)
RTUs (Northeast end)	0.066
AHUs (Front lobby/southwest end & South end)	0.065
AHU offices (SW offices)	0.08

Space temperature cooling setpoint setbacks

The proposed conditions that were modeled in the tracking TRACE 700 model were intended to simulate a thermostat schedule with a relaxed cooling temperature setpoint and unoccupied set back setpoint. The “occupied” cooling temperature setpoint was increased to 76 °F and the “unoccupied” cooling drift point setpoint (the set back) was increased to 80 °F (see Table 55).[29] The model does not define thermostat schedules, so the “unoccupied” periods where the set back is in effect is not defined.

Table 55: Tracking TRACE 700 model setpoint changes for cooling setback measure

TRACE 700 Parameter	Base case (Alt.1) value	Proposed case (Alt. 3) value
System 2, 3 and 4 design cooling dry-bulb setpoint	72	76
System 2, 3 and 4 design cooling dry bulb drift point setpoint	72	80
System 2, 3 and 4 design heating dry-bulb setpoint	69	65
System 2, 3 and 4 design heating dry bulb drift point setpoint	69	60

Demand control ventilation

The proposed case model adds demand control ventilation (DCV) control to the “southwest offices” space. The minimum DCV outside air intake is modeled to be 0% of the design cooling airflow.

Tracking calculation methodology

The applicant savings is based on a “calibrated” Trane TRACE 700 model. Calibration is based on 12 months of base case electric consumption (kWh). Calibration efforts do not mention a statistical target which suggests acceptance of calibration efforts was arbitrary. The TA report does not mention what input parameters, if any, were adjusted to calibrate the model.

The TA memos that summarize the review of the model describe that the savings were generated using the following parameter changes between the base case and proposed models.

Table 56: Tracking parameter adjustments made to model

Measure	Parameter changes
Ventilation Optimization	Ventilation air volume reduced from 15% of design cooling flow rate to code minimum based on area- and people-based ASHRAE 62.1-2004 ventilation rates of 0.06 cfm/sf and 5 cfm/person
Space cooling temperature setback	“Unoccupied” cooling setpoint set back from 72 °F to 80 °F. *The design cooling dry bulb temperature (represents the thermostat setpoint for the room during cooling design i.e., sizing calculations) was also changed from 72 °F to 76 °F*[30].
Demand control ventilation	48,782 sf office zone equipped with DCV. DCV allows the AHU OA damper to be 0% until free cooling is available or zone CO2 concentration is greater than 1,000 ppm, at which point the OA

[29] As discussed in the evaluation section, these adjustments as entered in the tracking model do not work as intended. The tracking model does not define a thermostat schedule, so the cooling set back is never called for. Additionally, the “occupied” setpoint change fundamentally changes the design conditions of the model, which is not an appropriate way to model the realistic adjustments made by the measure (programming thermostat schedule changes intothe existing EMS)

[30] Changing the design cooling temperature setpoint has a significant impact on how the program autosizes the AHU cooling coil capacity and design cooling airflow (i.e., fan size). The evaluator believes that the cooling design temperature setpoint must remain fixed across the base case and proposed case simulations in order to isolate savings to the specific measures described in the project. Otherwise, savings is attributed to a simulated change in system size (e.g., the base case system supplies 100,000 cfm using 40 HP motor, the proposed case system is sized differently because of the design temperature adjustment, and supplies 70,000 cfm using a 25 HP motor, so “savings” comes from supplying less cfm using a smaller motor) which is not what the measure represents.

	damper opens until free cooling is no longer available or CO2 concentration reduces to below 1,000 ppm.

Project Evaluation

Table 4 shows how each measure was verified to be installed and operating. If a measure was found to not be installed or installed but not operating correctly, it is noted in this table.

Table 57: Measure verification

Measure Name	Verification Method	Verification Result
Ventilation Optimization	EMS and site contact verification	EMS reported OA damper position to be less than the assumed base case position
Space cooling temperature setback	EMS and trend data	Verified AHU and RTU schedules via EMS; however, trend data was inconclusive
Demand control ventilation	EMS and site contact verification	EMS reported CO2 concentrations and maximum concentration setpoints for some AHUs; however, the AHUs supporting the office spaces (AHU-14 through AHU-17), did not appear to have DCV.

The M&V plan and project evaluation were generally conducted as planned. Site visits were performed on August 20, 2018, and September 26, 2018, to collect EMS screenshots, collect trend data, install data loggers, and interview the site contact.

Most measures were verified from EMS screenshots and visual analysis of limited trend data. The evaluator also used trend data that was submitted during the post-verification period. That data was available through the tracking documentation.

The evaluation savings method utilized the existing Trane TRACE model and updated it with observed findings.

Data collection

The following table describes data points collected for the affected equipment.

Table 58: Data collection

Measure Name	Equipment	Data points	Duration
Ventilation Optimization	Supply fan for AHU-2; AHU-7; AHU-8; AHU-15	• Supply fan kW	3.5 months
Space cooling temperature setback	Workroom; lobby; 3rd-floor break room; 2nd-floor office	• Space temperature	3.5 months
Demand control ventilation	AHU-1 to AHU-3; AHU-5 to AHU-9; AHU-25 to AHU-26	• CO2 concentration (EMS screenshots and trend data)	1-6 weeks
Ventilation optimization	AHU-1 through AHU-26	• Damper position • Minimum damper position	1-6 weeks
Space cooling temperature setback	AHU-1 through AHU-26	• Supply temperature • Representative space temperature • Return air temperature	1-6 weeks

		• Occupied/unoccupied cooling/heating setpoints	
All	Monthly utility kWh (March 2018 to February 2019)	Monthly utility kWh for model calibration	12 months

Mechanical schedules with design AHU flow rates were not available. The design flow rates were critical for the evaluator to estimate kW/cfm for the metered AHUs. Data loggers were still deployed on a sample of AHUs to confirm the general operating schedule but were not used to update the Trace model with measured fan power.

The plant operator was not knowledgeable about the existing EMS system. The site contact claimed that they previously contracted with a controls contractor to maintain the desired EMS operating characteristics; however, the contract had expired, and the plant operators had resorted to manually controlling many aspects of plant operation (e.g., controlled chillers and pumps manually, ran pumps at full speed).

The evaluator attempted unsuccessfully to set up trend reports during the onsite visits. While the trend reports did appear to retain some data points (1 day to 3 weeks), the report did not retain the trend period that was expected. The evaluator believes this was due to limited memory that the EMS had to retain historical trends.

The evaluator did utilize trend data that had been collected during the post-verification period. The data was used to visually verify CO2 concentration and room temperature.

Evaluation savings analysis

The evaluation utilized the existing Trane TRACE model and updated key parameters based on observed findings. The evaluator also reviewed the model to determine if the parameter changes that were used to simulate measure savings were appropriate and if they weren’t, updated those parameters and explained why the adjustment was warranted.

Each measure was evaluated using similar approaches involving verifying setpoints, functionality, and operating conditions through EMS screenshots and trends.

Ventilation Optimization

This measure could not be verified directly because the evaluator could not accurately approximate minimum ventilation flow rates; however, the evaluator was able to determine the minimum damper positions (5%) of the affected AHUs and determined that the “proposed” ventilation rates (based on ASHRAE 62.1-2004) modeled in TRACE provided more ventilation than the 5% minimum damper position. The DCV controls measure extends ventilation savings beyond that of the ventilation optimization measure and so no specific changes were made to the model’s ASHRAE-based ventilation rate input values. Instead, updates were made to the modeled minimum outside air damper position. These changes are described in the DCV controls measure section and in the Discrepancy Analysis section.

Space cooling temperature setback

This measure was verified using EMS screenshots and room temperature logger data. The EMS screenshots verified occupied and unoccupied temperature setpoints and the corresponding occupancy schedule. The room temperature data was an indirect approach to verify that the spaces were indeed entering unoccupied modes and increasing in temperature during cooling periods. The room temperature data actually showed relatively stable temperatures and an obvious temperature setback was not visible; however, the evaluator could not conclude with certainty that the rooms and systems were not entering set back modes. The rooms may have just been holding their "occupied" temperatures during "unoccupied" periods because of a lack of internal loads and interior (core) positioning in the building. Without confident evidence proving that the setback schedules were not functioning properly, the evaluator chose to accept the temperature and occupancy schedules that were active in the EMS[31].

Demand control ventilation

The evaluator verified using EMS screenshots and trends that the DCV control measure was implemented and functioning; however, the DCV measure was not observed to be installed in the AHUs supporting the office areas (AHU-14 to AHU-17) that were claimed by the TA report and simulated in the TRACE model. The evaluator adjusted the model to represent accurately the AHU systems and spaces where the DCV measure was installed. Still, it appears that modeling accurately the placement of the DCV controls would not affect savings because it does not appear that the simulated CO_2 concentration ever reaches the threshold for the outside air dampers to ventilate the space. This simulated operation matches what was observed in the trend data and cross-verified by the site contact – the CO_2 concentration never exceeds the "DCV-enabled" threshold of 1,000 ppm. The CO_2 concentration was observed to range between 500 and 700 ppm.

The model does not break down measures into individual parametric runs ("alternative" runs using TRACE terminology), so the evaluator provides a table (below) showing all modifications made to the model, the savings change due to the modifications, and why the modifications were made. Additional reasoning for why these changes were made is described in the Discrepancy Analysis section.

Table 59: Evaluator modifications to the Trane Trace model

Run #	Modification	kWh change[32]	Purpose of modification
0	N/A - Tracking model	N/A	N/A
1	Change simulation to use to full-year weather data	208,830	Change let model simulate 8,760-hour results
2	Change design cooling setpoints of proposed model to match base case model	-1,183,311	Design setpoints should not change to simulate these measure impacts
3	Add thermostat schedules to base and proposed case models	16,949	Tracking model did not use thermostat schedules
4	Added DCV control and changed minimum DCV OA% from "none" to 5%	382	Several spaces beyond what was simulated had DCV controls. Minimum OA% was observed to be 5%

[31] An EMS trend data point that could have helped identify the occupancy schedule operating is the occupancy status. However, it did not appear that this data point was set up for trending so the evaluator could not collect it.

[32] The kWh change is the incremental change from the preceding run.

The TRACE model was also reviewed to determine how reasonable the plant equipment and operating conditions (e.g., plant setpoints and controls, schedules) matched with what was observed on site. The evaluator determined that the model sufficiently represented the observed conditions.

The model's annual energy (electric) consumption was compared against actual utility energy consumption to determine how well the model represented actual energy usage. The simulated monthly energy consumption fit reasonably well with the actual monthly energy consumption (March 2018 to February 2019), with a mean bias error (MBE) of 8% and a coefficient of variation with the root mean square error (CV(RMSE)) of 13%. Typical targets for MBE and CV(RMSE) are <10% and <30%, respectively.

The table below provides the evaluation results for the project.

Table 60: Evaluation results for project ID 5631781

Savings Quantity	Tracking Estimate	Evaluation Estimate	Realization Rate
Electric energy (kWh)	1,182,614	225,463	19%
% of Energy Savings on Peak	62%	-46%	-74%
Summer On-Peak Demand (kW)	237.0	60.7	26%
Winter On-Peak Demand (kW)	96.0	44.4	46%

Discrepancy analysis

The discrepancy analysis follows the run numbers given in Table 59.

Run 1

This first change adjusted the simulation output to an 8,760-hour report. The tracking model energy consumption results had been simulated using the "reduced year" option where the program simulates building operation for a typical weekday and weekend for each month of the year then scales the output to create an annual profile. The evaluator changed the program option so that the program would simulate a full 8,760-hour year. This increased kWh savings by 18% (of tracking).

Run 2

This run constitutes the most significant impact on savings. The evaluator adjusted the model's design cooling setpoints so the base case design setpoints matched the proposed case design setpoints. The tracking savings project's modeler had mistakenly adjusted the design setpoints instead of adjusting the thermostat schedule.

The cooling design dry-bulb setpoint that was adjusted by the project's modeler to represent the cooling temperature set back measure is used by the program to calculate cooling loads, design cooling coil capacities, and design fan capacities. When the cooling design setpoint is adjusted, the program recalculates these loads and equipment capacities. This adjustment essentially changes the sizes of modeled equipment and therefore does not realistically simulate the actual cooling temperature setback measure.

The appropriate method to simulate this measure is to create hourly thermostat schedules with "unoccupied" temperature setpoints that are set back from the "occupied" setpoints. The project modeler did not create thermostat setpoints so, as a result, the program uses the cooling design setpoint as the thermostat setpoint (whenever the people/occupancy schedule reads greater than 5%).

The cooling drift point was used by the project modeler to represent the space cooling temperature setback measure's set back temperature setpoint. This parameter was also used incorrectly. The cooling drift point represents the highest temperature that the modeled space is allowed to drift up to during periods of low (5% or less) or no occupancy. The model uses an occupancy schedule that is never below 5% so the model is never allowed to use the cooling drift point. Therefore, the simulated savings represented using the tracking model does not simulate a set back temperature schedule at all. Rather, it represents the hypothetical representation of equipment cooling coil and fan capacity changes between the base case and proposed case.

The specific setpoint changes that were made by the evaluator for Run 2 are shown in the table below.

Table 61: Run 2 parameter values changes[33]

Parameter	Tracking value	Evaluated value
Alternative 3 ("proposed case") - System 2, 3 and 4 design cooling dry-bulb setpoint	76	72
Alternative 3 ("proposed case") - System 2, 3 and 4 design heating dry-bulb setpoint	65	69

The cooling drift point was not changed because the model's occupancy schedule prevents the drift point from ever being used. This discrepancy accounts for a -100% decrease in kWh savings (relative to the tracking savings), signaling that the majority of savings that was claimed for this project was based on erroneous modeling practices.

Run 3

This discrepancy accounts for the evaluator creating thermostat schedules for the modeled spaces. The proposed schedules were based on the observed occupancy schedule and corresponding cooling/heating setpoints. The base case schedules were based on the information given in the tracking documentation. The base case and proposed case schedules entered into the Trace model are listed in the table below.

Table 62: Base case thermostat schedules for evaluated model

Parameter	Tracking value	Evaluated value
Cooling thermostat schedule	None	All hours 72 °F

[33] The heating setpoints are included to show that they were adjusted; however, they have no impact on electric energy use

Heating thermostat schedule	None	All hours 69 °F

Table 63: Proposed thermostat schedules for evaluated model

Parameter	Tracking value	Evaluated value
Cooling thermostat schedule	None	Monday to Sunday 7a to 5p – 72 °F Monday to Sunday 5p to 7a – 82 °F
Heating thermostat schedule	None	Monday to Sunday 7a to 5p – 68 °F Monday to Sunday 5p to 7a – 60 °F

This adjustment had an insignificant effect on savings, increasing kWh savings by 1%.

Run 4

The Run 4 adjustments accounted for modeled DCV controls not applied to all applicable AHU systems. The evaluator observed that DCV controls and “below code” (5%) OA positions were installed on most AHUs; however, the tracking model only accounted for DCV controls for the office areas. The evaluator adjusted the model to simulate DCV controls for all areas that were observed to have DCV installed. The evaluator also adjusted those rooms’ “DCV minimum OA intake” input value from “none” to “5%” to match what was observed as the minimum OA damper position.

This adjustment had a negligible effect, increasing kWh savings by 382 kWh (0%).

Site ID: 2016RIN038

Program Administrator	National Grid
Project ID(s)	3855780
Project Type	Renovation of existing equipment
Program Year	2016
Evaluation Firm	DNV GL
Evaluation Engineer	Chris Williams
Senior Engineer	C.D. Nayak

Project Description

This project performed a compressed air audit and implemented three energy conservation measures:

- EEM1: repaired air leaks to reduce average leak load by 26 CFM at approximately 150 psi;
- EEM2: replaced an existing 200 HP compressor with a 200 HP rotary screw compressor with VFD controls to optimize trim loading and sequencing of the compressed air system; and
- EEM3: reduced wasteful air draining methods by installing two new thermal storage (refrigerated) air dryers, totaling 3,136 CFM.

The industrial facility is approximately 120,000 square feet and uses compressed air to "texturize" and produce looped yarn. The project was categorized as a renovation of existing equipment because the facility installed new nozzles that would affect the air consumption and production rates.

Table 64 below summarizes the evaluation results.

Table 64: Project results

Savings Quantity	Tracking Estimate	Evaluation Estimate	Realization Rate
Electric energy (kWh)	283,049	255,948	90%
% of Energy Savings on Peak	80%	84%	105%
Summer On-Peak Demand (kW)	66.3	52.6	79%
Winter On-Peak Demand (kW)	66.3	52.9	80%

The bullets below explain some key discrepancy findings:

- The tracking savings for the air dryer had a baseline error. It included a hypothetical "standard" dryer for the baseline but also included compressed air losses associated with purging condensate as a method for drying. The discrepancy is further explained at the end of the report. This baseline scenario was considered inappropriate because the standard dryer could have performed all the drying and condensate draining functions. This "purging" compressor usage was removed from the baseline scenario, which decreased the estimated dryer savings by 127,241 kWh, or 45% of the claimed project savings.

- There was an error in the EEM2 (new compressor) tracking savings calculation. Savings from another (canceled) measure had been subtracted from the EEM2 savings as a method to prevent double counting. Since the measure was not implemented, it should have been removed from the EEM2 savings calculation. This subtraction was removed by the evaluator which increased EEM2 savings by 15,028 kWh, or 5% of the claimed savings.
- The difference in savings method and air demand profile (cfm) for EEM2 had a 40% impact on electric savings, increasing it by 112,487 kWh. The evaluator used 12 weeks of logger data to observe that typical compressor demand (therefore, air load) was ~100% greater than what the tracking calculations assumed.

Tracking Savings

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

Baseline

The facility has a compressed air system served by 6 compressors. The compressors are listed in an arbitrary order, below:

- "#4" – Sullair 75 HP (rated pressure 150/160 psig)
- "#3" - Sullair 200 HP 2-stage with inlet valve modulation controls. The lead or primary compressor. It is located in the warehouse.
- "#2" – Sullair 200 HP 2-stage with inlet modulation controls
- "#1" – Sullair 125 HP with inlet modulation controls
- "#6" – Sullair 75 HP (rated pressure 100/110 psig)
- "#5" – Sullair 30 HP

The facility had one 1,060 gallon air receiver.

For the purposes of creating an energy boundary to estimate measure savings, compressors #3 and #2 are considered the affected baseline compressors. They acted as the trim compressors in the baseline scenario. All other compressors served base air demand and were assumed to be fully loaded.

The facility did not have air dryers and used a manual draining method to remove condensate from the system. The manual draining method involved keeping a valve near the low point of the distribution piping open all the time, wasting a significant amount of compressed air. The applicant documentation claims that the air loss using the manual draining method was approximately the capacity of the 30 HP compressor ("#5") – 131 cfm.

In addition to the manual draining method, the facility had significant air leak loads. Approximately 26.8 cfm of air leaks were identified during the pre-implementation air audit.

All equipment affected by the measures used the general facility schedule of 4,480 annual hours (80 hours/week x 50 weeks/year + 10 hours/weekend x 48 weekends/year).

For the purposes of comparison, the following table lists the key savings parameters and assumptions made for the baseline conditions. The air dryer measure assumes an industry-standard baseline where "standard-efficiency" dryers are sized equivalently to the proposed dryers.

Table 65: Baseline conditions

Measure Description	Baseline condition
EEM1 – Air Leak Repair	26.8 cfm of air leaks from a total of 10 physical locations. Compressed air is produced by the proposed compressor (from EEM2) with an efficiency of 4.61 cfm/kW
EEM2 – 200 HP compressor with variable speed controls	Pre-existing 200 HP compressor ("#2") with inlet modulation controls
EEM3 – Thermal storage air dryers	(2) noncycling air dryers (Great Lakes GRF-800A and GRF-2000) and compressor #5 (compressed air used to remove condensate) are used to dry and remove condensate from airlines.

EEM1 – Air Leak Repair

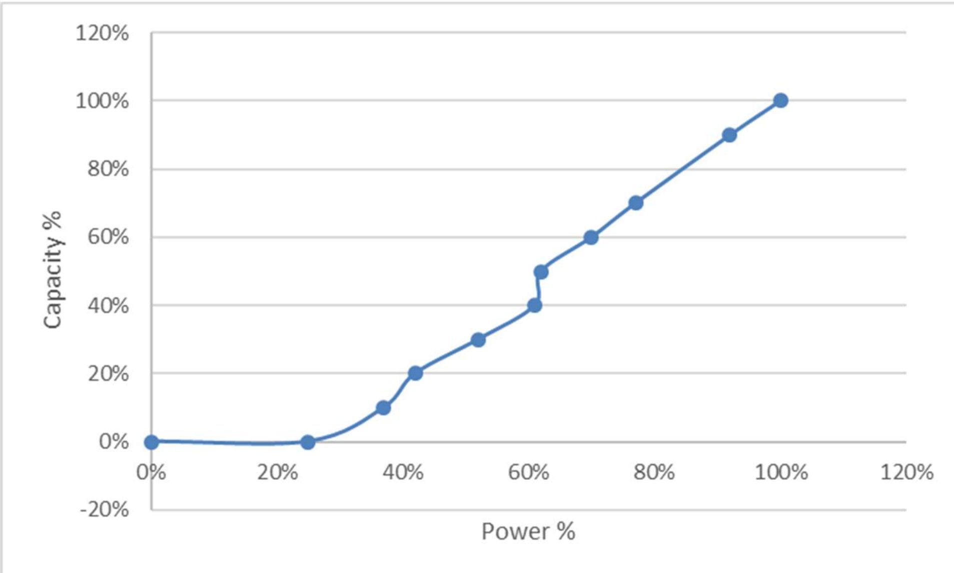
The pre-implementation audit determined there was 26.8 cfm of air leaks that could be repaired. The applicant savings assume that the compressed air that is lost due to the leaks is produced by the proposed compressor from EEM2.

EEM2 – 200 HP compressor with variable speed controls

The baseline compressor ("#2" Sullair 20TS 200 HP inlet modulation) served trim air demand with another Sullair 20TS ("#3"). It is assumed that they equally share the trim load while "#1" – the preexisting 125 HP compressor – handles the baseload. The applicant metered all compressors for one week. Using the performance curves shown in the table below and the assumed baseline sequence described above, the applicant found that together the baseline trim compressors (#2 and #3 200 HP compressors) consumed 16,687 kWh per week. This kWh value was used as the baseline weekly kWh consumption[34].

Figure 18: Performance curve for Sullair 20TS (baseline compressor)

[34] The performance curves were used with the meter kW data to estimate the compressor cfm for the 200 HP compressors. The 125 HP cfm values are hard-entered and their source is unknown. The full load kW of the 200 Hp compressors was hard entered as 183.6 kW



EEM3 – Thermal air storage dryers

The pre-existing condition for drying and condensate removal used open-air valves located near the bottom of the airlines entering the knitting equipment. These valves remained open all the time and were a significant waste of compressed air. There were no pre-existing air dryers. The measure savings baseline appears to include both the pre-existing open airline cfm "loss" and the hypothetical selection of non-cycling refrigerated air dryers that are equivalently sized to the proposed thermal storage dryers[35]. Therefore, the tracking baseline erroneously uses two air-drying methods – the pre-existing open airline draining method and the "standard" baseline air dryer method.

The applicant's key savings parameters and values are shown in the table below.

Table 66: Baseline air drying and air load

Equipment	Capacity (cfm) at 150 psi	kW[36]	Comments
GRF 2000 non cycling air dryer	1560	14.7	Appears to assume the full capacity
GRF 800 non cycling air dryer	988	5.7	Appears to assume the full capacity
New 200 HP compressor supplying air for condensate draining	131[37]	28.4	Compressor efficiency at full load (4.61 cfm/kW)

[35] This appears erroneous because it is "double counting" baseline electric load –from the compressor usage necessary to produce the air lost from the open line condensate draining; and from the dryer electric load necessary to remove condensate from compressed air (and drained using either the dryer's internal drain or an alternative drain).

[36] The capacity and power values are based on the manufacturer data sheets. Capacity % values are estimates based on air load estimates made for EEM2

[37] Amount of air estimated to be purged while draining condensate in the baseline

Proposed condition

The measures do not affect the facility or equipment operating schedules. Operating hours remain the same as the values assumed in the baseline (4,480).

The proposed conditions are summarized as follows:

Table 67: Proposed conditions

Measure Description	Proposed condition
EEM1 – Air Leak Repair	26.8 cfm of air leaks (produced at 4.61 cfm/kW) are repaired
EEM2 – 200 HP compressor with variable speed controls	Pre-existing 200 HP compressor ("#2") with inlet modulation controls is replaced with a new 200 HP compressor with variable speed control. Compressor #3 and the new VFD compressor ("#2") equally share the trim load
EEM3 – Thermal storage air dryers	(2) cycling thermal storage air dryers (MTA DE-0800 and MTA DE-2000) dry air and remove condensate from the system

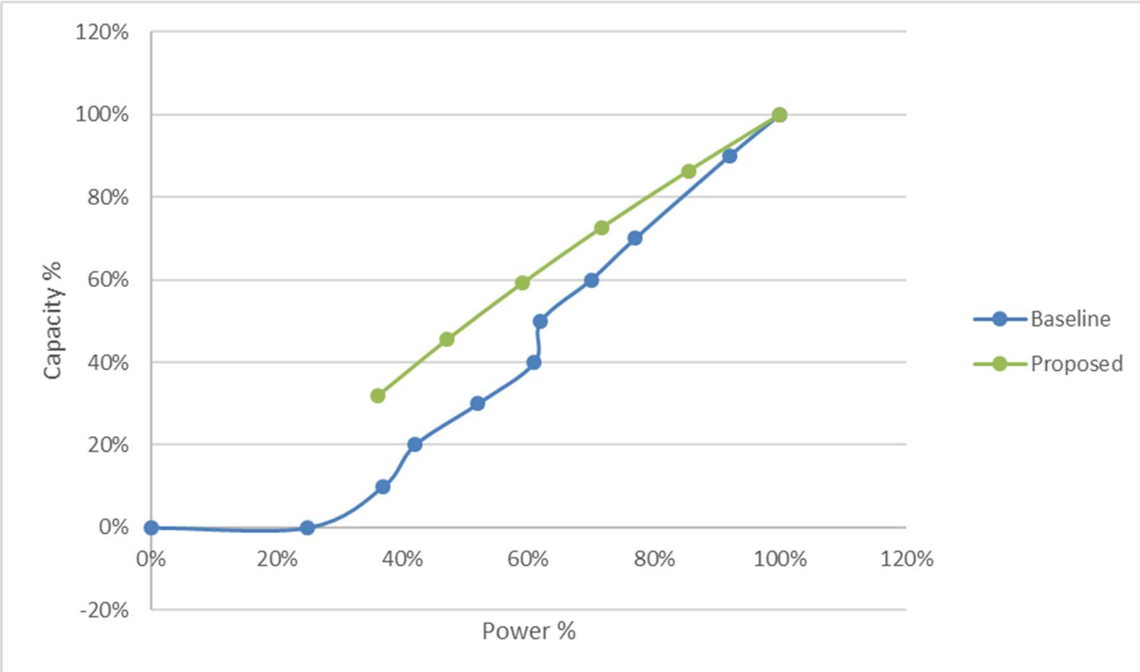
EEM1 – Air Leak Repair

The measure assumes that all identified leak load (26.8 cfm) are repaired.

EEM2 – 200 HP compressor with variable speed controls

Compressor #2 is replaced with a 200 HP compressor with variable speed controls. The new compressor is assumed to serve the same load as the compressor #2. Savings occur because the new compressor operates more efficiently than the baseline compressor. The comparison of the performance curves that the applicant used to estimate the baseline and proposed compressors performance is shown in Figure 19 below.

Figure 19: Comparison of baseline and proposed performance curves



EEM3 – Thermal storage dryers

The proposed air drying system does not require compressed air to drain condensate. Instead, drying and condensate draining is served by two cycling thermal storage dryers. Their assumed operating conditions are shown below.

Table 68: Proposed air drying

Equipment	Full load capacity (cfm) at 150 psi	% Capacity (weekday/weekend)	Full load kW	Operating kW[38] (weekday/weekend)
MTA DE-0800 cycling thermal storage air dryer	896	70%/49%	4.28	3.0/2.1
MTA DE-2000 cycling thermal storage air dryer	2,240	28%/0%	10.75	3.0/0

Tracking calculation methodology

Spreadsheet calculations were used to estimate measure savings. The applicant methodology and savings results are discussed for the measures below.

EEM1 – Air Leak Repair

[38] Operating kW is assumed to be linearly proportional to the % capacity and full load kW

The measure savings are calculated using a one-line equation. The air leak repair savings are assumed to be derived from reducing the air load on the proposed compressor.

$$Annual\ kWh\ Savings\ =\ CFM_{leak}\ \times\ CFM_{eff}\ \times\ hours = 25{,}601\ kWh$$

Where,

CFM_{leak} = 26 CFM, air leak load repaired
CFM_{eff} = 4.61 cfm/kW; proposed (i.e., the new 200 HP VFD compressor) compressor efficiency (from CAGI)
hours = 4,480 hours (= 80 hours/week x 50 weeks/year + 10 hours/weekend x 48 weekends/year)

EEM2 – 200 HP compressor with variable speed controls

Savings are based on one of the two baseline 200 HP inlet modulation compressors being replaced with the proposed 200 HP VFD compressor. The VFD compressor is modeled to act as a trim compressor that equally shares air load with the other baseline compressor. Since the VFD compressor is more efficient than an inlet modulation compressor at part load, savings are realized.

$$Annual\ kWh\ Savings\ = (WeeklykWh_{\ pre} - WeeklykWh_{post})\ \times AnnualWeeks - ECM\hat{} - ECM1 = 63{,}744\ kWh$$

Where,

$WeeklykWh_{pre}$ = 16,687 kWh per week (from 1 week of pre-install kW data of the 2x 200 HP Sullair IM compressors)

$WeeklykWh_{post}$ = 14,600 kWh per week (from the 1 week of pre-install kW data being converted to cfm data and then kW estimated using VFD compressor performance curve)

AnnualWeeks = 50 weeks per year

ECM^ = 15,028 kWh/year (estimated savings for a canceled measure. This should have been removed from the savings calculation)
ECM1 = 25,601 kWh/year (the air leak repair savings. It appears the savings estimator was removing air leak repair savings from the compressor savings to avoid double counting for the air leak repairs.)

EEM3 – Thermal air storage dryers

The applicant uses the following equation to calculate measure savings for the thermal storage air dryers.

$$Annual\ kWh\ Savings\ = \sum(kW_{pre} - kW_{post})_{WD} \times\ hours_{WD} + \sum(kW_{pre} - kW_{post})_{WE} \times\ hours_{WE} = 193{,}704\ kWh$$

Where,
Table 69: EEM3 weekday savings parameter values

$kW_{pre,\ WD}$	$kW_{post,\ WD}$	$hours_{WD}$	Comments
5.72	3.00	4,000	Dryer load assumed to be 70% for the proposed 896 CFM dryer

14.71	3.01	4,000	Dryer load assumed to be 28% for the proposed 2,240 CFM dryer
28.40	0	4,000	Assumed compressed air load needed to drain condensate through open line

Table 70: EEM3 weekend savings parameter values

$kW_{pre,\ WE}$	$kW_{post,\ WE}$	$hours_{WE}$	Comments
5.72	2.10	480	Dryer load assumed to be 49% for the proposed 896 CFM dryer
14.71	0	480	Dryer load assumed to be 0% for the proposed 2.240 CFM dryer
28.40	0	480	Assumed compressed air load needed to drain condensate through open line

The baseline assumes that both baseline air dryers operate on the weekend, compared to only one of the proposed dryers. The baseline also assumes that in addition to the baseline dryers, equivalent energy from the new 200 HP compressor is used to drain the airline condensate. In the baseline, condensate was drained manually and continuously. The draining air load was estimated to be approximately 131 CFM at approximately 130 psig. This equated to 28.40 kW demand on the new 200 HP compressor.

The applicant/tracking savings are listed by the measure below.

Table 71: Tracking savings by measure

Measure	kWh savings	Summer kW reduction	Winter kW reduction
EEM1 – Air Leak Repair	25,601	5.7	5.7
EEM2 – 200 HP compressor with variable speed controls	63,744	17.8	17.8
EEM3 – Thermal storage air dryers	193,704	42.8	42.8
Total	283,049	66.3	66.3

Project Evaluation

Table 4 shows how each measure was verified to be installed and operating. If a measure was found to not be installed or installed but not operating correctly, it is noted in this table.

Table 72: Measure verification

Measure Name	Verification Method	Verification Result
EEM1 – Air Leak Repair	Document review and site contact verification	Verified indirectly through site contact and leak repair document
EEM2 – 200 HP compressor with variable speed controls	Visual	Installed and operating as intended
EEM3 – Thermal storage air dryers	Visual	Installed and operating as intended

The M&V plan and project evaluation were generally conducted as planned. A site visit was performed on August 6, 2018, to install data loggers and interview the site contact[39]. The air compressor and dryers were observed and verified to be installed and operating. The pre-existing 200 HP IM air compressor was retired

[39] A revisit was conducted on August 20 to install kW loggers. The previous amp loggers had CTs that were potentially undersized for the equipment

and removed from the airline but was still present at the facility. The tags identifying the air leaks or air leak repairs had already been removed. The airlines that had been previously open to drain condensate were still present but were closed. The site contact claimed that they are no longer used at any point for draining condensate. The site contact was able to confirm the leak repair list that had been submitted with the project documentation.

The compressors are sequenced using discharge pressure setpoints as means for sequencing. The "base" load compressors and the 200 HP IM compressor (purported to be one of the trim compressors in the applicant savings) have a discharge set point of 150 psi. The new VFD compressor has a discharge set point of 140 psi.

Nameplate information was collected for all affected equipment. The site contact was not aware of and could not provide historical trend data. ElitePro kW loggers were installed on the new VFD air compressor and the baseline 20TS compressor. H22K amp loggers were installed on the air dryers. The airline had a permanent CDI flow meter; however, the site contact did not actively collect flow data[40]. Data loggers were retrieved in late October, making the metering period roughly 11 weeks. The site contact mentioned during both site visits that their schedule remains relatively the same throughout the year. Weekday schedule is typically constant while the weekend hours can shift occasionally to compensate for small fluctuations in workload or work efficiency. Per the site contact, meaningful production data was not available but stated that the metering period would be a reasonable period to represent typical operation.

The evaluation savings methodologies that are explained in later sections were implemented as planned. 8,760-hour demand reduction profiles were generated for each measure, and specific discrepancies were found that attributed to the difference between evaluated and tracking savings estimates.

Data collection

The evaluator metering approach outlined in the M&V plan was implemented as planned. Nameplates and datasheets for the affected equipment (compressors and dryers) were collected while on-site and through internet searches. The following table describes specifications for the affected equipment.

Table 73: Measure specifications

Measure Name	Specifications	Notes
EEM1 – Air Leak Repair	N/A	Site contact confirmed the list of 10 locations that had been repaired
EEM2 – 200 HP compressor with variable speed controls	(1x) Sullair 20TS inlet modulation 200 HP; 868 cfm (1x) Sullair V200TS variable speed 200HP; 815 cfm	Observed discharge pressure for 20TS/V200TS = 150/140 psi.
EEM3 – Thermal storage air dryers	(1x) Great Lakes GTX-800A thermal storage; 7.2 kW (1x) Great Lakes GTX-2000 thermal storage; 15.208 kW	Ratings are based on 100 psi and 38F dew point

[40] The site contact was interviewed before the site visit to confirm whether there was a flow meter or not. The site contact claimed there was not. When the evaluator visited the facility, the flow meter was observed in the airline; however, the site contact did not collect flow data and did not have a data logger compatible with the flow meter.

Data loggers were deployed to collect load profiles of compressors and dryers. Spot power measurements were taken on all equipment to improve the accuracy and confidence of power estimates for the dryers. The following table describes the types of time-series logger data collected for the evaluation.

Table 74: Data collection points

Data/equipment description	Data type	Logging duration (August – October 2018)
Sullair 20TS "#3" compressor	Full unit kW	9 weeks; 15-minute interval
Sullair V200TS (replaced #2) compressor	Full unit kW	9 weeks; 15-minute interval
Great Lakes GTX-800A dryer	Full unit current (amps)	12 weeks; 15-minute interval
Great Lakes GTX-2000 dryer	Full unit current (amps)	12 weeks; 15-minute interval

Evaluation savings analysis

The evaluator approached the project savings analysis in a manner that would allow the evaluator to compare evaluated savings to tracking savings, and to ensure that the measures were properly loaded, and to prevent double-counting measure savings. The savings analysis follows the sequence presented below.

1. Data loggers measured "installed" operating profile (kW) for the affected compressors (the 20TS and V200TS "trim" compressors) and dryers.
2. EEM3 (Thermal storage air dryers) savings profile (kW) is estimated. Dryers were chosen arbitrarily to be analyzed first because the savings do not interact with the other measures.
3. EEM1 (Air leak repair) savings profile is estimated. This measure loading approach follows the tracking savings method (baseline for EEM1 = new compressor with airline leaks, proposed case = new compressor without airline leaks).
4. EEM2 (200 HP compressor with variable speed controls) savings profile is estimated. It "includes" the air load reduction (air leak repairs) from EEM1, meaning the base and proposed air load profiles for EEM2 are equivalent and the profiles are estimated from the observed compressor load.

Thermal storage air dryer (EEM3) savings analysis

Data loggers collected roughly 12 useful weeks of the installed dryers operating under typical conditions.

The dryer logger data (amps) were first converted to kW using volts, power factor, and phase current ratios collected through spot measurements while on site. The data was then aggregated into a 168 hour week profile. This profile would represent the typical demand (kW) of the installed dryers. Using the facility's reported holiday list, the profile was extrapolated to a standardized year. The installed dryer demand profiles are shown in the table below.

Table 75: Installed dryer (MTX-2000) kW profile

Hour	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
0	0.00	1.91	2.30	2.53	2.47	0.24	0.00
1	0.00	0.00	0.00	0.10	0.11	0.00	0.00
2	0.00	0.00	0.00	0.10	0.11	0.00	0.00
3	0.00	0.00	0.00	0.10	0.11	0.00	0.00
4	0.00	0.00	0.00	0.10	0.11	0.00	0.00
5	3.34	5.32	5.34	5.25	0.11	0.00	0.00
6	2.35	4.83	4.81	5.13	0.26	0.00	0.00
7	2.51	4.92	4.82	5.49	3.09	0.71	0.30
8	2.52	5.23	5.65	5.19	3.18	0.75	0.22
9	2.64	5.44	5.67	5.38	3.63	0.69	0.22
10	2.32	5.65	5.28	5.38	2.94	0.57	0.27
11	3.17	5.56	5.63	5.97	3.40	0.56	0.27
12	3.59	5.58	5.19	5.63	3.23	0.57	0.33
13	3.25	5.86	5.31	5.13	3.57	0.51	0.28
14	3.68	6.12	5.96	6.02	3.39	0.68	0.22
15	4.33	7.34	6.36	6.43	3.05	0.68	0.28
16	5.28	8.75	7.93	8.02	3.82	0.68	0.33
17	5.44	8.83	8.49	8.23	3.47	0.74	0.38
18	5.25	8.27	8.35	8.06	3.25	0.79	0.22
19	5.50	8.57	7.86	7.57	3.35	0.78	0.32
20	5.16	8.29	7.89	7.87	2.95	0.51	0.27
21	5.35	7.62	7.51	7.32	3.35	0.77	0.27
22	5.39	7.57	8.04	7.32	2.17	0.47	0.12
23	5.83	7.52	7.93	7.06	0.78	0.00	0.00

Table 76: Installed dryer (MTX-800A) kW profile

Hour	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
0	0.00	1.35	2.18	2.20	2.25	0.46	0.00
1	0.00	0.17	0.17	0.00	0.00	0.00	0.00
2	0.10	0.08	0.00	0.17	0.18	0.00	0.00
3	0.00	0.17	0.09	0.17	0.10	0.00	0.09
4	0.00	0.00	0.00	0.17	0.18	0.09	0.00
5	0.91	2.14	2.12	2.02	0.28	0.00	0.09
6	1.07	2.49	2.65	2.74	0.00	0.00	0.00
7	1.14	2.52	2.76	2.70	0.58	0.00	0.00
8	1.22	2.64	2.70	2.71	0.64	0.09	0.09
9	1.02	2.73	2.70	2.77	0.59	0.00	0.00
10	1.68	2.75	2.76	3.07	0.70	0.09	0.00
11	1.53	2.74	2.82	3.01	0.65	0.00	0.00
12	1.70	2.86	2.87	3.04	0.56	0.00	0.09
13	1.63	2.83	2.97	3.10	0.67	0.00	0.00
14	1.69	2.96	2.92	3.09	0.58	0.00	0.00

15	1.67	2.84	2.86	3.04	0.57	0.00	0.09
16	1.79	2.97	3.00	3.12	0.58	0.00	0.00
17	1.78	2.96	2.93	3.16	0.68	0.00	0.09
18	1.81	3.00	2.98	3.12	0.59	0.09	0.00
19	1.73	2.97	2.96	3.07	0.67	0.00	0.09
20	1.74	2.87	2.99	3.05	0.58	0.00	0.00
21	1.84	2.87	2.87	3.08	0.66	0.00	0.00
22	1.78	2.88	2.87	3.07	0.56	0.00	0.00
23	1.82	2.91	2.93	3.07	0.57	0.09	0.00

Without detailed production data available, linear extrapolation of hourly averages (by the time of day and weekday) generated a reasonably accurate representation of annual dryer usage.

When the evaluator initially reviewed the tracking savings for this measure, there appeared to be irregularities with what was selected as affected baseline equipment. After a brief e-mail exchange with the National Grid technical representative that reviewed this project, the evaluator determined that the savings calculation and perceived baseline selection was erroneous.

The technical reviewer claimed that the project had determined the baseline for the thermal air dryer measure to be the pre-existing case where airlines were manually opened in order to drain condensate[41].

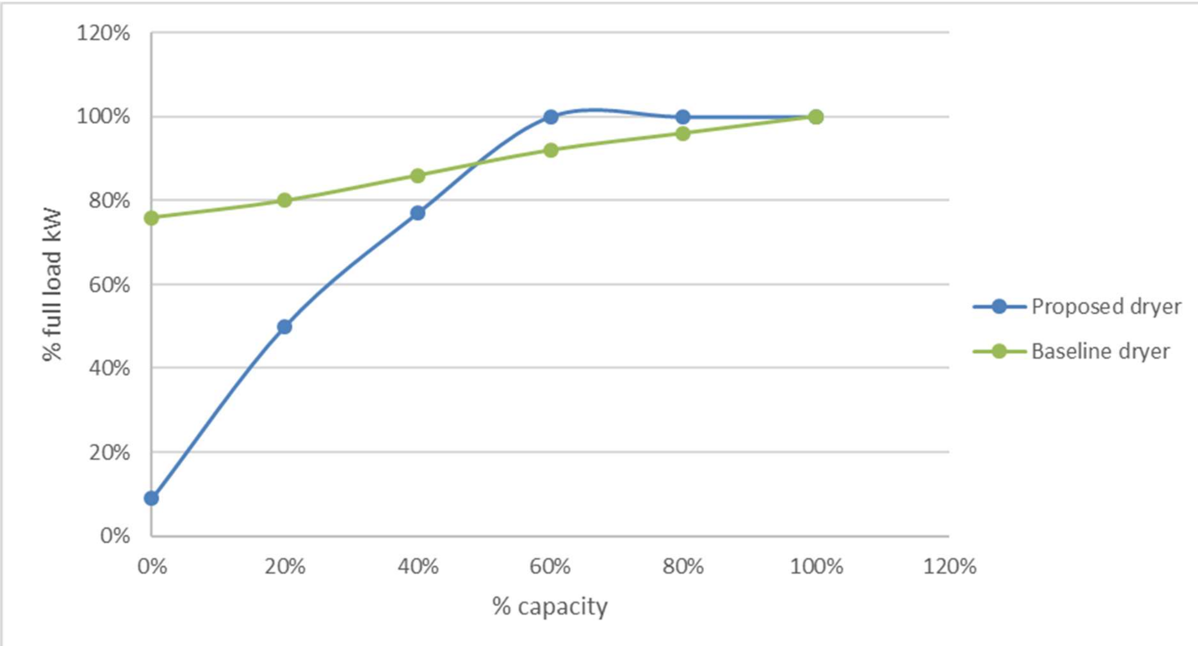
However, the measure savings baseline appears to include both the open airline cfm “loss” and the hypothetical selection of non cycling refrigerated air dryers that are equivalently sized to the proposed thermal storage dryers. This appears erroneous because it is “double counting” baseline electric load –from the compressor usage necessary to produce the air lost from the open line condensate draining; and from the dryer electric load necessary to remove condensate from compressed air (and drained using either the dryer’s internal drain or an alternative drain).

The evaluator agrees with the applicant to use a hypothetical selection of equivalently sized non-cycling refrigerated air dryers as the industry-standard baseline. However, the evaluator believes that the baseline compressed air load used for draining condensate in the applicant savings was erroneous. This baseload was not used in the evaluation savings.

The manufacturer’s data sheets for the installed and baseline dryers were collected. They listed the rated full load kW but did not include part-load performance. The evaluator chose to use performance curves from a Gardner Denver brochure comparing various drying technologies including thermal storage and non-cycling. These performance curves were used to estimate both the installed dryer part load capacity (cfm) and the corresponding baseline dryer part load demand (kW). The figure below compares the two performance curves.

Figure 20: Performance curves for installing and baseline dryers

[41] The technical reviewer proposed standard efficiency dryers to act as the hypothetical baseline, but the team compromised on the solution mentioned above



The performance curve mentioned above was used to estimate capacity (in % or cfm) as a function of dryer kW. This step developed the corresponding hourly dryer capacity (cfm) profiles experienced by the two installed dryers. With these profiles (kW and cfm) for the two installed dryers, the evaluator extrapolated to a standardized year to estimate annual electric consumption (kWh)[42].

With the installed dryer 8,760 kW profiles generated, the evaluator then developed the corresponding baseline dryer 8,760 kW profiles by using the baseline performance curve mentioned above to convert the installed 8,760 dryer capacity (cfm) profiles to the corresponding baseline 8,760 dryer kW profiles.

The difference between the sum of the two baseline dryer 8,760 kW profiles and the sum of the two installed dryer 8,760 kW profiles is equal to the evaluation savings for EEM2.

Air leak repair (EEM1) savings analysis

The air leak repair savings analysis begins with the development of the installed compressor 8,760 kW and cfm profiles which follows a very similar procedure to the installed air dryer kW and cfm profiles.

Approximately 8 weeks of compressor kW logger data were aggregated into a 168-hour week profile, averaged by weekday and hour of the day. The profiles would represent the typical demand (kW) of the installed compressors (the new 200 HP VFD compressor and the baseline 200 HP inlet modulation compressor). Using the facility's reported holiday list, the profiles were extrapolated to a standardized year.

Compressor manufacturer data sheets and CAGI sheets were collected for the V200TS and 20TS compressors to develop the compressor performance curves. The CAGI sheets provided part-load capacities

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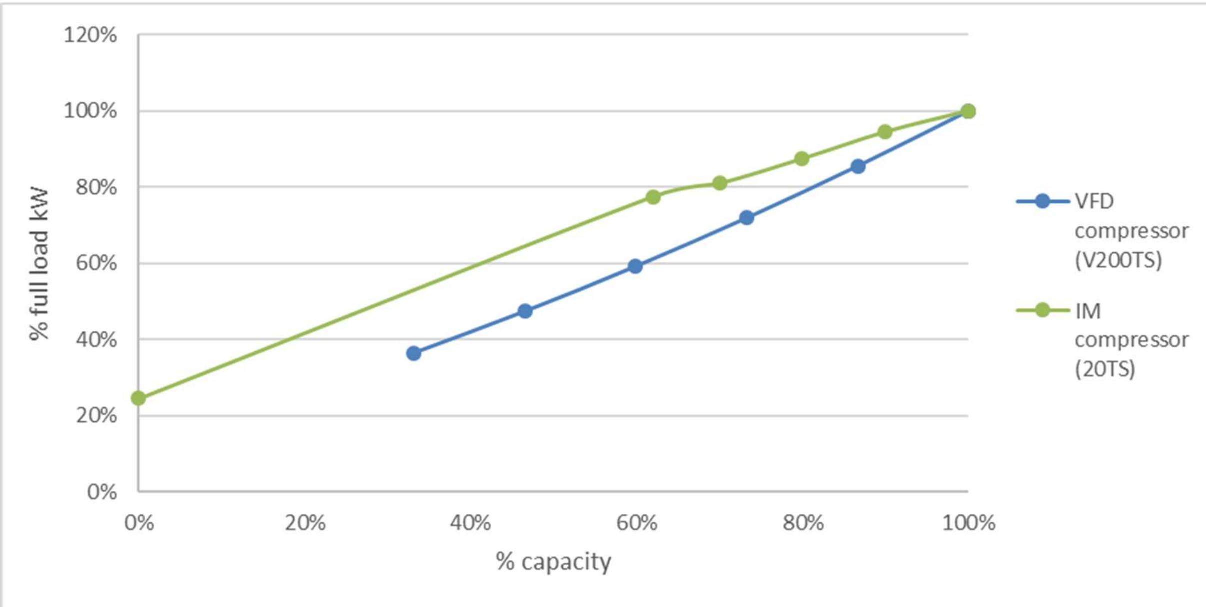
[42] 1985 was used arbitrarily but also because the TMY3 weather data for Providence is standardized to the 1985 year.

in cfm and the corresponding part load kW, as well as full load capacity and kW at the rated pressure (150 psi). The performance curves of the V200TS and the 20TS compressors are compared in the figure below.

Figure 21: Comparison of V200TS (VFD) and 20TS (IM) installed compressor performance profiles[43]



The performance curves were used to estimate airflow (cfm) as a function of compressor kW. This step developed the corresponding hourly air demand (cfm) profiles experienced by the two metered compressors. With these profiles (kW and cfm) for the two compressors, the evaluator extrapolated to a standardized year to estimate annual air consumption (CF) and electric consumption (kWh).

The evaluator modeled the savings analysis to follow the applicant's assumption that all air "saved" from the air leak repair is generated by the new VFD compressor. The 8,760 air profile for the VFD compressor is considered the "proposed" air profile (i.e., leaks repaired). The baseline air profile is generated by adding the air leak load (26.8 cfm) to the 8,760 air profile for the VFD compressor. The baseline 8,760 kW profile is then estimated using this altered air profile and the performance curve mentioned above. The difference between the baseline and proposed 8,760 kW profiles is equal to the evaluation savings for EEM1.

200 HP compressor with variable speed controls (EEM2) savings analysis

The savings analysis procedure for EEM2 begins with the 8,760 kW and cfm profiles that were described in the previous measure analysis (EEM1). These profiles were considered to estimate the proposed conditions

[43] The V200TS compressor profile assumes 140 psi discharge pressure (the observed set point). The 20TS compressor assumes 150 psi (the observed set point and the assumed baseline pressure)

and annual energy consumption for EEM2. The evaluator's baseline conditions assume that the baseline compressors (two 20TS inlet modulation) equally share the hourly air load estimated from summing the 8,760 air profiles of the two proposed compressors.

This method is different from the tracking method, which assumes that in both baseline and proposed scenarios, the compressors equally share the same load. For the evaluation method, this is only true for the baseline. The proposed scenario uses whatever ratio of load sharing that was observed through the logger data. The methods are different because the evaluator measured "post-implementation" conditions and found that the compressor sequencing was different than what was assumed for the proposed case in the tracking savings method. The evaluator observed that the VFD compressor is sequenced based on pressure setpoints to act as the trim compressor while the IM compressor is sequenced as the baseload compressor[44]. However, the evaluator believes that in the baseline, the two compressors would have both been sequenced identically (i.e., their discharge pressure set points would have been the same).

After the baseline 8,760 air profiles are calculated using this savings method assumption, the corresponding baseline 8,760 compressor kW profiles are calculated using the performance profile (for the TS20 compressor) illustrated in the figure above. The difference between the sum of the baseline compressor 8,760 kW profiles and the installed compressor 8,760 kW profiles is equal to the evaluations EEM2 savings.

Evaluation Results

The evaluated savings are presented in this section by project and summarized briefly by measure. EEM3 (thermal storage air dryers) accounts for the majority (68%) of the claimed savings. This section presents a comparison of key parameters and discrepancy analysis at the project level; however, some of the discrete discrepancies apply to specific measures.

The table below summarizes evaluated savings at the measure level and project level.

Table 77: Project results

Measure	Savings Quantity	Tracking Estimate	Evaluation Estimate	Realization Rate
EEM1 – Air Leak Repair	Electric energy (kWh)	25,601	26,841	105%
	% of Energy Savings on Peak	N/A[45]	83%	N/A

[44] VFD compressor is sequenced "manually" as trim by setting discharge pressure (140 psi) lower than the base compressor (150 psi)

[45] % on peak savings by measure is not reported in tracking savings

	Summer On-Peak Demand (kW)	5.7	5.4	95%
	Winter On-Peak Demand (kW)	5.7	5.6	98%
EEM2 – 200 HP compressor with variable speed controls	Electric energy (kWh)	63,744	191,259	300%
	% of Energy Savings on Peak	N/A	85%	N/A
	Summer On-Peak Demand (kW)	17.8	40.0	225%
	Winter On-Peak Demand (kW)	17.8	40.7	229%
EEM3 – Thermal storage air dryers	Electric energy (kWh)	283,049	37,848	13%
	% of Energy Savings on Peak	N/A	81%	N/A
	Summer On-Peak Demand (kW)	42.8	7.1	17%
	Winter On-Peak Demand (kW)	42.8	6.6	15%
Total project	Electric energy (kWh)	283,049	255,948	90%
	% of Energy Savings on Peak	80%	84%	105%
	Summer On-Peak Demand (kW)	66.3	52.6	79%
	Winter On-Peak Demand (kW)	66.3	52.9	80%

Comparison of savings parameters

The evaluator's savings methods use savings parameters that sometimes cannot be directly compared to the savings parameters used in the applicant savings methods. Comparisons of tracking and evaluated savings parameter values were made when it was practical to do so. These comparisons are presented in the table below. Other comparisons are made in the discrepancy analysis section.

Table 78: Comparison of Key Parameters

	BASELINE		PROPOSED / INSTALLED	
Parameter	Tracking Value(s)	Evaluation Value(s)	Tracking Value(s)	Evaluation Value(s)
Annual operating hours	4,480	V200TS: 4,036 20TS: 3,985 GRF800: 7,074 GRF2000: 6,186	4,480	V200TS: 4,036 20TS: 3,985 GTX800: 7,074 GTX2000: 6,186
Average compressor kW	95	113	83	91

Average air drying equipment kW (includes compressor load for tracking baseline)	48.8	11.0	5.6	5.5

Discrepancy analysis

This section describes the key drivers behind differences in the tracking and evaluation savings estimates. The following table will be used to summarize these differences. The purpose of this analysis is to measure and describe how changes to the key parameters influenced the final project savings.

Table 79: Discrepancy analysis results

Discrepancy	kWh	Peak Summer kW	Peak Winter kW	% on peak
Tracking Savings (no changes)	283,049	66.3	66.32	80%
Discrepancy #1 (EEM3: Air Dryer Baseline change - removed compressor load)	-45%	-43%	-43%	0%
Discrepancy #2 (Removed error from EEM2 savings)	5%	5%	5%	0%
Discrepancy #3 (Operating Hours changed from ~4,480 to 4,036)	-3%	0%	0%	0%
Discrepancy #4 (Air Demand Profile & Calculation Method for EEM1)	1%	0%	0%	4%
Discrepancy #5 (Air Demand Profile & Calculation Method for EEM2)	40%	28%	29%	2%
Discrepancy #6 (Air Demand Profile & Calculation Method for EEM3) - evaluated savings	-8%	-11%	-12%	-1%
Final Evaluated GRR %	90%	79%	80%	105%

The table above illustrates sequential discrete changes made to savings parameter values or savings methods and the corresponding effect the change has on evaluated savings estimates relative to the tracking savings. For example, the first line ("Tracking Savings") lists the savings claimed in the tracking data. The next line, "Discrepancy #1", illustrates the impact made (in % of tracking savings) by the discrepancy. In the case of discrepancy #1, a discrete change was made to the baseline drying load savings parameter.

Discrepancy #1 (Air dryer baseline change – removed compressor load)

This discrepancy is discussed in the tracking and evaluation section for EEM3. The tracking savings used an erroneous method to describe the baseline air drying load. The evaluator believes a mistake was made and the baseline compressor demand value was simply not removed from the final savings calculation. This discrepancy reduced savings by 45% or -127,241 kWh.

Discrepancy #2 (Removed error from EEM2 savings)

The evaluation found that savings from a measure ("aspirator replacement") that had not been implemented were still being deducted from the EEM2 savings calculation. The removal of this canceled measure increased savings by 5% or 15,028 kWh.

Discrepancy #3 (Operating Hours changed from ~4,480 to 4,036)

This discrepancy attempts to account for and quantify the difference in estimated annual operating hours between the tracking and evaluated savings methods. Since the methods are not similar, the evaluator simplified the approach by assuming the equivalent annual operating hours parameter is equal to the (extrapolated) run time observed (4,036 hours) for the new VFD compressor. Note that the dryers were observed to run more than the compressors because it appears that the facility does not de-energize them as they do with the compressors during unoccupied periods[46]. This discrepancy had a small negative impact, reducing savings by 3% or -9,124 kWh.

Discrepancy #4 (Air Demand Profile & Calculation Method for EEM1)

This discrepancy accounts for the difference in savings method (and savings parameters) for EEM1. The evaluation method uses an 8,760 profile and a continuous part-load performance function to estimate savings due to the air leak repair. The tracking savings use a constant full load efficiency values to estimate savings. This discrepancy has a minor positive impact of 1%.

Discrepancy #5 (Air Demand Profile & Calculation Method for EEM2)

Similar to discrepancy #4, this discrepancy accounts for the difference in air demand (cfm) profile and calculation method between the tracking and evaluation savings. The evaluator observed a compressor demand that was higher than what was estimated in the tracking savings. As shown in Table 31, the average compressor kW reduction estimated in the tracking calculation is 12 kW. The average compressor kW reduction for the evaluated calculation is 22 kW, an 83% increase over the tracking estimate. The evaluator believes that the logger data used to estimate the baseline compressor consumption in the tracking savings underestimated typical operation. The TA report mentions that the tracking logger data was collected for 1 week in April 2014 and that it "represents a compressed air usage that is about 75% of that which is considered normal by the owner" but was used to represent typical operation for "conservative reasons". The evaluator also believes that the data collected for the evaluation (~12 weeks August through October) better represents typical average usage. The discrepancy has a large impact on savings, increasing savings by 40% or 112,487 kWh, primarily because of higher total compressed air use than assumed in the tracking savings estimate.

Discrepancy #6 (Air Demand Profile & Calculation Method for EEM3)

This discrepancy accounts for the difference in the air dryer load and calculation method between the tracking and evaluation savings. Most of the discrepancy impact derives from the difference between the tracking and evaluated baseline average dryer loads. The tracking baseline dryer load (just dryers, not the compressor load excluded in discrepancy #1) was estimated to be 20.4 kW. The evaluation estimated the baseline dryer load to be 11.0 kW. The difference is largely because the evaluator uses a baseline dryer performance curve that assumes a significantly different part-load demand. The tracking savings assumes that the dryers operate continuously at full load in the baseline. The evaluator uses a performance curve that allows for part-load operation. This discrepancy has a negative impact on tracking savings by -8% or -22,028 kWh.

[46] The dryers were observed to have very small loads during the unoccupied hours, likely from being in standby mode. For standby hours, the baseline and installed kW were considered equivalent

Site ID:2016RIN093

Project ID(s)	5384747 5648426 5853340 6299115
Project Type	5384747 – Retrofit 5648426 - Retrofit (CAIR) 5853340 – New construction 6299115 – New construction
Program Year	2016
Evaluation Engineer	Chris Williams
Senior Engineer	C.D. Nayak

Project Description

This site report covers the following project IDs: 5384747, 5648426, 5853340, and 6299115. The facility operates with a sister facility that is located a few blocks away. Efficiency projects were also implemented at the sister facility, claimed and evaluated under site ID 2016RIN008. Both facilities produce and process knitted fabrics. The projects implemented the following measures:

- 5384747 – New humidification system – This measure improved the existing humidification system for a knitting area. The pre-existing system used a 75 HP air compressor to produce low pressure (72 psi) air that vaporized water using 186 nozzles situated throughout the knitting room. The new system replaced the compressed air system. A 3 HP pump rate at 3.5 GPM pressurizes a new water line to 1000 psi and vaporizes the water through new high-pressure nozzles.
- 5648426 – Compressed air leak repairs – This measure repaired leaks in two separate compressed airlines. The "low" pressure line repair reduced leakage by 101 cfm and the "high" pressure line repair reduced leakage by 5 cfm.
- 5853340 – New knitting machine – A new knitting machine that is capable of higher efficiency (yards of knitting/kWh) and capacity (yards/day) replaced a pre-existing knitting machine. The pre-existing machine is capable of producing 653 yards/day using a 15 HP motor. The new knitting machine is capable of producing 1,072 yards/day using a 10 HP motor.
- 6299115 – New high-efficiency RTUs – Two new 12.6 EER DX rooftop units (RTU) totaling 25 tons were installed to condition a space that was renovated to serve a new "warping production" area. The units exceed the efficiency of the upstream program units (12 EER). The new warping production area contains large knitting machines that generate significant space heat and whose process requires somewhat controlled humidity levels (between 55-65% RH).

The table below summarizes the evaluation results.

Table 80: Project results for 2016RIN093

Project/Measure	Savings Quantity	Tracking Estimate	Evaluation Estimate	Realization Rate
New humidification system (5384747)	Electric energy (kWh)	283,325	284,651	100%
	% of Energy Savings on Peak	48%	50%	106%

	Summer On-Peak Demand (kW)	33.7	36.8	109%
	Winter On-Peak Demand (kW)	33.7	36.6	109%
Air leak repairs (5648426)	Electric energy (kWh)	163,286	8,630	5%
	% of Energy Savings on Peak	47%	42%	89%
	Summer On-Peak Demand (kW)	18.8	1.0	5%
	Winter On-Peak Demand (kW)	18.9	1.0	5%
New knitting machine (5853340)	Electric energy (kWh)	29,423	23,033	78%
	% of Energy Savings on Peak	55%	52%	95%
	Summer On-Peak Demand (kW)	4.4	2.8	64%
	Winter On-Peak Demand (kW)	4.4	3.1	70%
New high efficiency RTUs (6299115)	Electric energy (kWh)	21,826	10,450	48%
	% of Energy Savings on Peak	56%	48%	86%
	Summer On-Peak Demand (kW)	2.7	1.6	60%
	Winter On-Peak Demand (kW)	0	1.0	N/A
Total project	Electric energy (kWh)	497,860	326,764	66%
	% of Energy Savings on Peak	48%	50%	104%
	Summer On-Peak Demand (kW)	59.6	42.2	71%
	Winter On-Peak Demand (kW)	57.1	41.7	73%

The bullets below explain some key discrepancy findings:

- Double counting of baseline low-pressure compressor usage was removed (technically from the air leak repair measure). This reduced total 2016RIN093 tracking savings by 31%.
- Part load usage was considered in the evaluation method for estimating savings for the new knitting machine
- Differences in savings methods led to other minor discrepancies summarized in the final section of this report

Tracking Savings

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

Baseline condition

The baseline equipment and conditions for each project are summarized in the table below.

Table 81: Baseline conditions

Project Description	Baseline condition
New humidification system (5384747)	Existing 75 HP compressor providing 72 psi ("low" pressure) air for the humidification process. However, baseline system was adjusted to account for increased capacity (50 more nozzles than the pre-existing, for a total of 236 nozzles) in the proposed system.
Air leak repairs (5648426)	Existing condition of "high" and "low" pressure lines with leaks measured to be 132 cfm and 22 cfm, respectively. High-pressure line served by a 50 HP Sullair V-120 compressor. The low-pressure line served by a 75 HP Sullair V-160.
New knitting machine (5853340)	Baseline considered to be an "upgrade to the existing machine to match what a new machine can do", in terms of capacity. Existing knitter capable of 653 yards/day using 15 HP motor.
New high-efficiency RTUs (6299115)	New construction baseline - two identical 12.5-ton RTUs rated at 10.8 EER (1.111 kW/ton). The baseline RTUs are considered new construction baseline units that meet minimum efficiency requirements.

Based on tracking documentation, the pre-existing 75 HP compressor served only this humification process and that the compressor drew an average of 28.3 kW (~51% loaded) while serving the existing 186 nozzles.

The base case description for 5853340 suggests that the intended base case knitting machine efficiency would match the existing machine efficiency (kWh/yard); however, the base case capacity (yards/day) would equal the proposed machine capacity (1,072 yards/day). This base case description was not ultimately used in the tracking savings calculation, which is detailed in another section.

Proposed condition

The measures do not affect equipment operating schedules. All measures either improve operating efficiency or capacity.

The proposed conditions are summarized as follows:

Table 82: Proposed conditions

Project Description	Proposed condition
New humidification system (5384747)	Completely removes compressed air load and replaces with 3 HP pump rated at 3.5 GPM pressurizes to 1,000 psi. Proposed system also replaces 186 existing nozzles with 236 high-pressure nozzles (existing nozzles were not compatible with new system)
Air leak repairs (5648426)	Low pressure line leaks reduced by 101 cfm. High-pressure line leaks reduced by 5 cfm.
New knitting machine (5853340)	New knitting machine capable of 1,072 yards/per day using 10 HP motor.
New high-efficiency RTUs (6299115)	Two identical 12.5-ton DX RTUs rated at 12.6 EER

The proposed RTUs serve a new processing space where knitting machines add to space heat. Space requires a slightly controlled climate (55-65% RH, 70°F) for both the process and occupant comfort.

Tracking calculation methodology

Spreadsheet calculations were used to estimate measure savings. Some of the assumed operating conditions and savings parameter values were based on pre- and post-implementation measurements like air and leak load audit performed by TA participants. The applicant methodology and savings results are discussed for the measures below.

New humidification system (5384747)

The tracking savings are calculated using spreadsheet calculations, one week of current (amps) interval data (of the compressor), and engineering judgment. The compressor current data was used to estimate the average compressor power draw over the assumed annual operating hours. The base annual compressor energy consumption (kWh) is estimated using the equation below.

<u>Baseline annual energy consumption (75 HP compressor):</u>
Annual kWh (75 HP compressor) = $kW_{comp} \times AnnualHours$ = 302,124 kWh

Where,

kW_{comp} = 36.0 kW (average measured 28.3 kW using 186 nozzles + 7.62 kW for an additional 50 nozzles at 0.15 kW/nozzle[47])
Annual Hours = 8,400 hours/year (= 24 hours/day x 7 days/week x 50 weeks/year)

The proposed system replaces the 75 HP air compressor, airlines, and air nozzles with a 3 HP high-pressure pump and high-pressure water nozzles. The proposed system serves the same humidification process as the existing system but adds 50 additional nozzles. The annual energy consumption of the proposed pumping system is estimated using the equation below.

<u>Proposed case annual energy consumption (using 3 HP pump):</u>
Annual kWh (3 HP pump) = $kW_{pump} \times AnnualHours$ = 18,799 kWh

Where,

kW_{pump} = 2.2 kW (= 3 HP x 0.746 kW/HP)
Annual Hours = 8,400 hours/year (= 24 hours/day x 7 days/week x 50 weeks/year)

The difference between the base case and proposed case annual energy consumption is the tracking of annual energy savings (283,325 kWh).

Air leak repairs (5648426)

The tracking savings are calculated using single-line equations and pre-/post-repair average air loads (in CFM) to estimate the corresponding air compressor demand (in kW). The savings method uses proxy

[47] 0.15 kW/nozzle was calculated by taking the measured kW of 28.3 kW divided by # of nozzles (186)

compressor CAGI performance sheets to correlate measured CFM to estimated compressor kW.[48] The high and low-pressure line savings are described using the equations below.

<u>High-pressure line air leak repair savings:</u>
Annual kWh Savings = $\left(kW_{pre} - kW_{post}\right) \times AnnualHours$ = 9,986 kWh

Where,

kW_{pre} = 6.43 kW (Sullair 3709V at a base load flow of 28 CFM)
kW_{post} = 5.29 kW (Sullair 3709V at a post load of 23 CFM, a drop of 5 CFM)
Annual Hours = 8,760 hours/year

<u>Low pressure line air leak repair savings:</u>
Annual kWh Savings = $\left(kW_{pre} - kW_{post}\right) \times AnnualHours$ = 153,300 kWh

Where,

kW_{pre} = 36.48 kW (Sullair 5507VB at a base load flow of 183 CFM)
kW_{post} = 18.98 kW (Sullair 5507VB at a post load of 82 CFM, a drop of 101 CFM)
Annual Hours = 8,760 hours/year

New knitting machine (5853340)

The tracking savings are calculated using single value inputs for equipment power, annual operating hours, and knitting capacity (yards/day). The annual energy usage of the baseline and proposed knitting machines are calculated using the following equations:

<u>Baseline knitting machine annual energy consumption:</u>
Annual kWh = $\left(\frac{HP}{eff} \times 0.746 \frac{kW}{hp}\right) \times (AnnualHours)$ = 83,359 kWh

Where,

HP = base case knitting machine motor horsepower = 15 HP
eff = base case knitting machine motor efficiency = 89%
Annual Hours = 130 hours/week x 51 weeks/year = 6,630 hours/year

<u>Proposed case knitting machine annual energy consumption:</u>
Annual kWh = $\left(\frac{HP}{eff} \times 0.746 \frac{kW}{hp}\right) \times (AnnualHours)$ = 53,937 kWh

Where,

HP = proposed case knitting machine motor horsepower = 10 HP
eff = proposed case knitting machine motor efficiency = 91.7%
Annual Hours = 130 hours/week x 51 weeks/year = 6,630 hours/year

[48] The high-pressure compressor is a 50 HP Sullair V-120 but the applicant used a Sullair 3709A CAGI sheet because they could not find the V-120 compressor CAGI sheet. Similarly, with the low-pressure compressor, the actual compressor is a 75 HP Sullair V-160 but a Sullair 5507B CAGI sheet was used.

The applicant notes that the baseline "would be to upgrade the existing machine to match what a new machine can do. Currently [the base case] produces 653 yards/day and operates with a 15 hp motor. This application very similar to App#5685710."

This baseline description suggests that the intended baseline knitting machine efficiency would match the existing machine efficiency (kWh/yard); however, the baseline capacity (yards/day) would equal the proposed machine capacity (1,072 yards/day).

This baseline description was not ultimately used in the participant savings calculation. Instead, the machine capacities were not explicitly used; the savings are ultimately derived from the difference in knitting machine motor and efficiency size.

New high-efficiency RTUs (6299115)

The tracking savings use a PNNL savings estimator for rooftop units[49]. It is a gray box calculator that estimated 21,826 kWh savings. The tracking savings sanity checks the PNNL savings estimate by using the following (erroneously input*) equation:

Energy Savings kWh = $\Delta kW \times Operating\ Hours \times Quantity$ = 23,214 kWh

Where,

$$\Delta kW = \left(Baseline\frac{kW}{ton} - Installed\frac{kW}{ton}\right) \times Tons = \left(1.111\frac{kW}{ton} - 0.952\ kW/ton\right) \times\ 25\ tons =\ 4.0\ kW$$
$$Operating\ Hours = 2{,}925\ hours$$
$$Quantity = 2$$

*The equation input is erroneous because it effectively double counts the number of units. The ΔkW calculation already accounts for the sum of the two rooftop unit capacities (each unit is 12.5 tons, summing to 25 tons). Therefore, the "quick" savings sanity check estimates savings are based on 50 tons, not 25 tons, and should be 11,607 kWh.

The applicant/tracking savings are summarized by the measure below.

Table 83: Tracking savings by project ID

Measure	kWh savings	Summer kW reduction	Winter kW reduction
New humidification system (5384747)	283,325	33.7	33.7
Air leak repairs (5648426)	163,286	18.8	18.9
New knitting machine (5853340)	29,423	4.4	4.4
New high efficiency RTUs (6299115)	21,826	2.7	0
Total	497,860	59.6	57.1

49 https://www.pnnl.gov/uac/costestimator/main.stm

Project Evaluation

Table 4 shows how each measure was verified to be installed and operating. If a measure was found to not be installed or installed but not operating correctly, it is noted in this table.

Table 84: Measure verification

Measure Name	Verification Method	Verification Result
New humidification system (5384747)	Visual	Installed and operating as intended
Air leak repairs (5648426)	Document review and site contact verification	Verified indirectly through site contact and leak repair document
New knitting machine (5853340)	Visual	Installed and operating as intended
New high-efficiency RTUs (6299115)	Visual	Installed and operating as intended

The M&V plan and project evaluation were generally conducted as planned. A site visit was performed on July 31, 2018, to install data loggers and interview the site contact.

The site contact was able to confirm the leak repair list that had been submitted with the project documentation and also mentioned that another air leak audit was going to be conducted in the near future.

Nameplate information was collected for all affected equipment. Data loggers were installed on the high pressure (50 HP) compressor, RTUs, humidification pump, and new knitting machine. Data loggers were retrieved in late October, making the metering period roughly 12 weeks. The site contact mentioned during the initial site visit that their schedule remains relatively the same throughout the year and they do not experience obvious, seasonal changes in production. Per the site contact, meaningful production data was not available but stated that the metering period would be a reasonable period to represent typical operation.

The evaluation savings methodologies that are explained in later sections were implemented as planned. 8,760-hour demand reduction profiles were generated for each measure, and specific discrepancies were found that attributed to the difference between evaluated and tracking savings estimates.

Data collection

The evaluator metering approach outlined in the M&V plan was implemented as planned. Nameplates and data sheets were collected while on-site and through internet searches for the affected compressors, RTUs, and humification pumps. The following table describes specifications for the affected equipment. They match the information given in the tracking documentation.

Table 85: Measure specifications

Measure Name	Specifications	Notes

New humidification system (5384747)	AMCO humification system with 3 HP pump serving 3 zones with RH setpoint at 59%, 62.5%, and 56%	The system serves #1 nylon warping room, #2 nylon warping room, and bldg. #6 knitting room
Air leak repairs (5648426)	N/A	The low-pressure compressor was retired (because it was no longer needed to support humidification system)
New knitting machine (5853340)	Karl Mayer HKS 3-M KAMCOS 180" wide	The new machine is in position #63. Per tracking documents, old knitting machine #60 was removed and knitter #63 was moved to position #60
New high-efficiency RTUs (6299115)	Two (2) identical Carrier 50L units	Serves a new knitting room

Data loggers were deployed to collect load profiles of the installed equipment (compressor, knitting machine, humidification pump, and RTUs). Unfortunately, the third party licensed electrician that was scheduled to install the data loggers for DNV GL was not available. Rather than reschedule (site contact preferred to do it that day) the site visit, the site contact offered their on-site electrician to perform the data logger installs. This allowed DNV GL to install the data loggers as planned; however, the on-site electrician had limited time, so some measuring activities were not performed[50]. The evaluators also needed to expedite the visit because the site contact preferred to do both sites (2016RIN093 and 2016RIN008) that day, if possible.

The knitting machines had instantaneous knitting rates (yards/day) but, per the site contact, they did not record interval rates. The rated knitting capacities of the machines were indirectly verified with the site contact.

The airline had a permanent CDI flow meter and the site contact was able to provide a compatible data logger to collect flow measurements during the metering period. The following table describes the types of time-series logger data collected for the evaluation.

Table 86: Data collection points

Data/equipment description	Data type	Logging duration (August – October 2018)
Sullair V120-50H 50 HP compressor	Full unit kW	12 weeks; 15-minute interval
3 HP pump on humidification system	Current (amps) of single phase of 3 phase connection	12 weeks; 30-minute interval; 3-minute sample
Knitter #63	Current (amps) of single phase of 3 phase connection	12 weeks; 30-minute interval; 3-minute sample
Carrier 50L RTU #1	Full unit kW	12 weeks; 15-minute interval
Carrier 50L RTU #2	Full unit kW	12 weeks; 15-minute interval
High-pressure airline	Airflow (scfm)	5 weeks; 1-minute interval

Evaluation savings analysis

The savings analysis begins with using the logger data to estimate the typical operating profile of the pertinent equipment. The typical operating profile is extrapolated to represent the observed annual energy consumption of the equipment. Details of the individual project savings analyses are presented below.

50 For example, spot power measurements were postponed and would be taken on the pickup site visit. However, similar issues arose on the pickup visit where time was limited to escort the field technician around to pick up loggers.

New humidification system (5384747) savings analysis

The humidification savings analysis begins with the development of the installed humidification pump 8,760 kW profile. Approximately 12 weeks of amp logger data were collected for the humidification pump.

Voltage and power factor assumptions were made to approximate the pump motor power (kW) corresponding to the measured current value. These kW estimates were then aggregated into 168-hour week profiles, averaged by the hour of day and weekday. The humidification system appears to have a relatively stable average load, with an average demand of 1.0 kW and a weekly kWh consumption of 167 kWh. Using the facility's reported holiday list, the pump kW profile was extrapolated to a standardized year to generate the installed 8,760 humidification system annual energy consumption.

The evaluated baseline humidification system was different than what was hypothesized in the tracking savings method. The evaluation credits the humidification system measure for air leak repair impacts. The evaluation does this because, in the tracking savings methods, savings from the air leak repair for the low pressure compressed air system is ultimately credited twice – once for the air leak repair measure and once for the humification system measure. The tracking savings method for these measures both assumes that the baseline compressed air system has leaks. In the air leak repair measure, the tracking method assumes leaks are repaired and the compressed air system continues to be used (by the humidification system only). In the humification system measure, the tracking method assumes that the compressed air system has leaks and is replaced by the humidification pumping system, thereby removing the compressed air system entirely from operation (because the low pressure compressed air system was only used for the humidification process).

The "loading" sequence of these measures is difficult to define because technically the air repair savings on the low-pressure system is short-lived. The leaks were repaired and shortly thereafter the system was retired because the new humidification system was installed. The evaluator thought it appropriate to credit the project for removing leaky compressed air load and replacing it with an efficient humidification pumping system.

The evaluator did account for the additional 50 nozzles that would have been installed to support the expansion had the project not installed the new humidification system. The additional 50 nozzles would have added an additional compressed air load on the low pressure compressed air system.

The sequence for developing the corresponding baseline energy consumption for the pre-existing humidification system is shown below.

1. Start with "pre" compressor power interval data submitted with the tracking documentation. It was assumed that this data represented the pre-existing humidification system with 186 nozzles and pre-existing air leaks;
2. The compressor power data is converted into air load (cfm) using the same CAGI performance sheet (Sullair 5507) that the tracking method uses[51];

[51] The CAGI sheet performance data, listed at the rated pressure of 100 psi, is first converted to the assumed operating pressure of 65 psi

3. Additional compressed air load (in cfm) is estimated for the additional 50 nozzles that were proposed to be installed with the new humidification system;
4. The additional air load is converted back into power. This data set now represents the baseline humidification system with 186 + 50 nozzles and pre-existing air leaks. This compressor demand is removed when the new humidification system is installed.

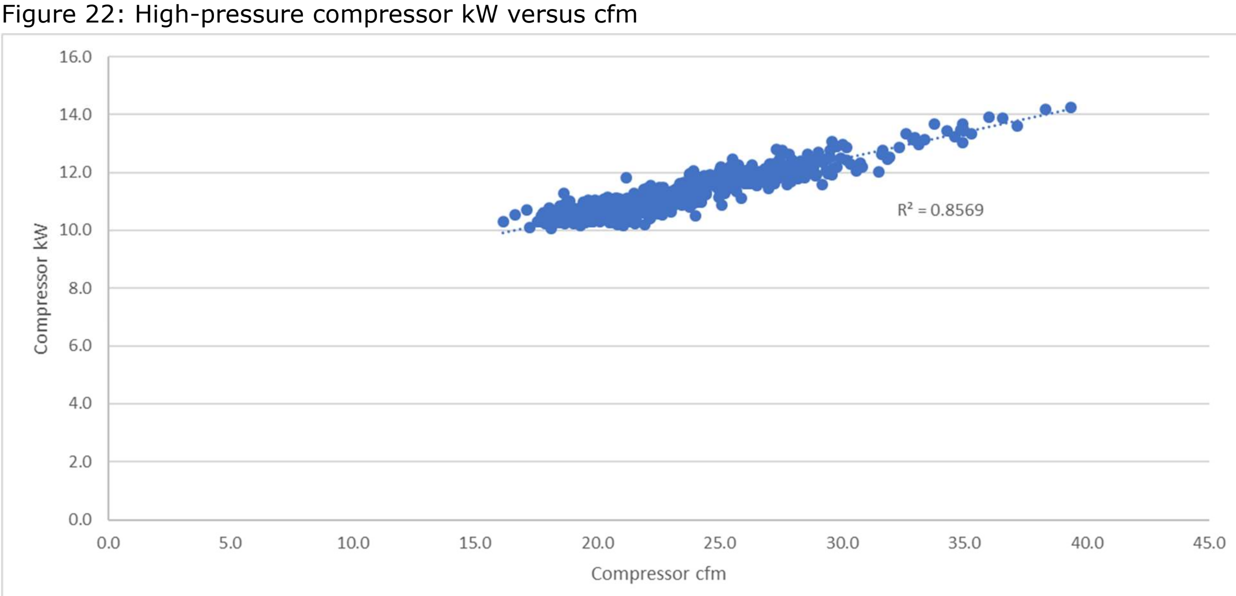
One week of pre-implementation compressor usage was measured by the applicant in the pre-implementation period. The additional air load resulting from 50 additional humidifying nozzles is added to the pre-implementation compressor usage. Since the pre-existing compressor served only the humidification system, the kW estimates from that data were aggregated into 168-hour week profile to represent the baseline system. Using the facility’s reported holiday list, the compressor kW profile was extrapolated to a standardized year to generate the baseline 8,760 humidification system annual energy consumption. The difference between the baseline and installed 8,760 kW profile is equal to the evaluated savings for this measure.

Air leak repair (5648426) savings analysis

The evaluator chose to remove the low-pressure air leak repair portion from this measure and applied it to the humidification system measure (5384747). The following savings method procedure applies only to the high pressure compressed air system.

Data loggers collected roughly 12 weeks of the high-pressure compressor power while operating under typical conditions. 5 weeks of airflow data coinciding with the power metering period were also collected. Comparing the flow and power data illustrated that there was a strong correlation, as can be seen in the figure below.

Figure 22: High-pressure compressor kW versus cfm



Based on the logger data, the compressor appears to operate consistently near the minimum load. The airflow data collected for evaluation was compared to the pre-implementation air flow data presented in the TA report. The airflow rates are similar suggesting that compressed air usage has remained relatively unchanged since the measure was implemented.

The airflow (cfm) data was aggregated into a 168-hour week profile, averaged by the hour of day and weekday. This profile would represent the typical air load of the installed compressor. Without detailed production data available, linear extrapolation of hourly averages (by the time of day and weekday) generated a reasonably accurate representation of 8,760-hour annual compressed air usage. Using the facility's reported holiday list, the profile was extrapolated to a standardized year. The measured correlation of kW to cfm (from the figure above) was then used to estimate the 8,760-hour profile for the compressor kW.

The evaluator assumed that the air leak repair was still functional and that the estimate (5 cfm) measured by the TA is still accurate. To represent the baseline air load profile, the air leak load of 5 cfm was added to each hourly air load value in the installed 8,760 air load profile.

The measured performance curve in the figure above (Figure 22) was then used againto estimate compressor kW as a function of capacity (cfm). This step developed the corresponding 8,760 hourly baseline compressor kW profile. The difference between the baseline 8,760 kW profile and the installed 8,760 kW profile is equal to the evaluation savings for the air leak repair measure.

New knitting machine (5853340)

The new knitting machine in position #63 had it's currently logged (in 15-minute intervals) for 12 weeks. Voltage and power factor assumptions were used with the current data to estimate the machine's interval kW over that period. The data was aggregated into a 168-hour week profile which was then extrapolated to an 8,760-kW profile using the same method as previously described for the other measures.

While this method does not correlate demand or usage to production units, it still provides a reasonable method to extrapolate observed usage to an hourly annual profile. The site contact claimed that he did not believe the production data that he could provide would offer a more accurate extrapolation because the production figures are delayed from the actual equipment usage.

The baseline knitting machine 8,760 profile was created by taking the ratio of the old machine's efficiency (0.46 kWh/yard) to the new machine's efficiency (0.299 kWh/yard), adjusted so old and new machine annual capacities match. The efficiency values use the following assumptions which are taken directly from the tracking documentation[52]. Without specific production rates from individual machines, the rated efficiency values were the most reasonable to use.

Table 87: Knitting machine parameter values

Savings Parameter	Baseline	Proposed	Notes
Annual fabric production capacity (yards/year)	180,391 yards/year	180,391 yards/year	
Daily fabric production capacity(yards/day)	653	1,072	The proposed daily production capacity is not used

[52] The tracking savings, however, did not use the efficiency values to calculate savings.

Machine efficiency (kWh/yard)	0.462	0.299	276 days/yr x 24 hrs/day x motor HP x 0.746 kW/HP / motor efficiency / (annual fabric production)

That efficiency ratio was applied to the installed 8,760 kW profile to create the baseline 8,760 kW profile. The difference between the baseline and installed 8,760 kW profiles is equal to the evaluated savings.

New high-efficiency RTUs (6299115)

12 weeks of full unit interval kW data were collected for the two 12.5-ton RTUs. NOAA weather was also collected from the closest station so the correlation of RTU demand to outside air conditions could be tested.

The evaluator tested the correlation of several independent variables to the dependent variable of interested – unit demand (kW)[53]. None of the combinations had a very strong correlation. Without obvious indicators for choosing independent variables, the evaluator chose to use outside dry bulb temperature as the sole predictor for RTU demand. The comparison of RTU kW to outside air temperature (OAT) is shown in the figure below. The resulting linear regression equation is shown in the following table.

Figure 23: Installed RTU 1 & 2 average demand (kW) versus OAT

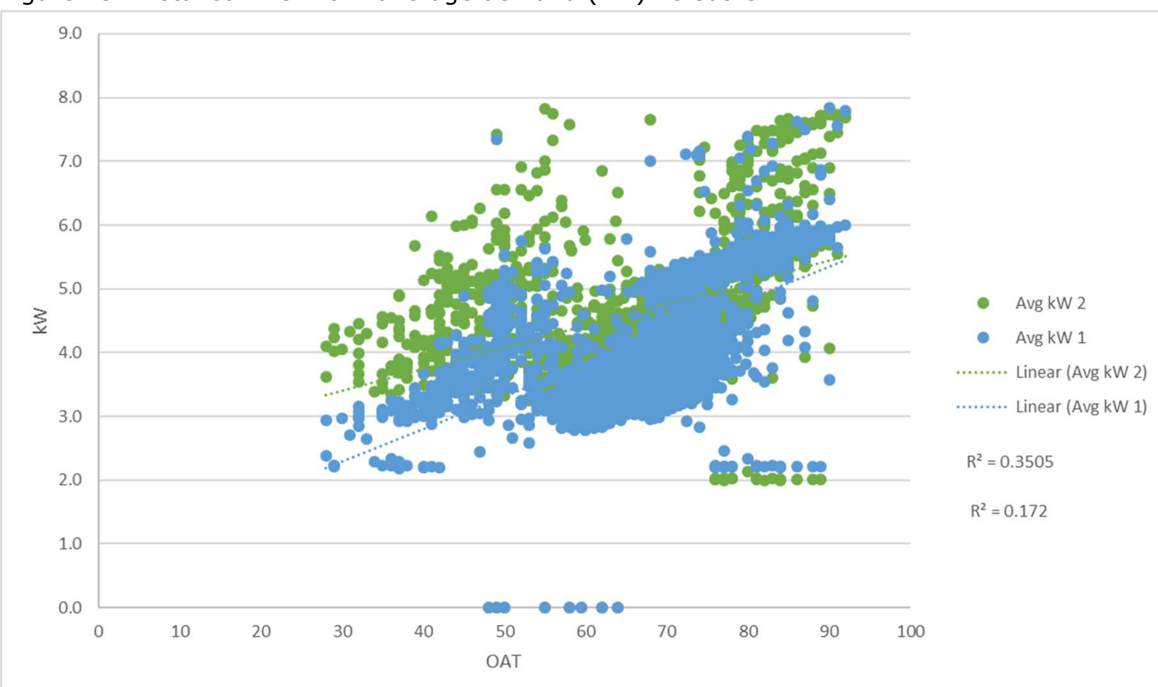


Table 88: Installed RTU regression formula coefficients

Regression formula	A	B
RTU 1 kW = f(OAT) = A*OAT + B	0.05096	0.76928
RTU 2 kW = f(OAT) = A*OAT + B	0.03393	2.3859

[53] The evaluator tested as independent variables outside dry bulb temperature, outside wet bulb temperature, hour of day and day of week. The regression outputs suggested that the model was most sensitive to dry bulb temperature and least sensitive to hour of day and day of week.

Using the regression formulas above and TMY3 weather data for Providence, the installed 8,760 kW profiles for both RTUs were produced to represent the installed energy consumption. The baseline 8,760 kW profiles are created by applying the ratio of baseline efficiency (10.8 EER or 1.111 kW/ton) to installed efficiency (12.6 EER or 0.952 kW/ton) to the installed 8,760 kW profiles. The difference between the baseline and installed 8,760 kW profiles is equal to the evaluated savings.

Evaluation Results

The evaluated savings are presented in this section by the project. This section presents a comparison of key parameters and discrepancy analysis at the project level.

The table below summarizes evaluated savings at the project level. Each project contains only one measure.

Table 89: Project results

Project/Measure	Savings Quantity	Tracking Estimate	Evaluation Estimate	Realization Rate
New humidification system (5384747)	Electric energy (kWh)	283,325	284,651	100%
	% of Energy Savings on Peak	48%	50%	106%
	Summer On-Peak Demand (kW)	33.7	36.8	109%
	Winter On-Peak Demand (kW)	33.7	36.6	109%
Air leak repairs (5648426)	Electric energy (kWh)	163,286	8,630	5%
	% of Energy Savings on Peak	47%	42%	89%
	Summer On-Peak Demand (kW)	18.8	1.0	5%
	Winter On-Peak Demand (kW)	18.9	1.0	5%
New knitting machine (5853340)	Electric energy (kWh)	29,423	23,033	78%
	% of Energy Savings on Peak	55%	52%	95%
	Summer On-Peak Demand (kW)	4.4	2.8	64%
	Winter On-Peak Demand (kW)	4.4	3.1	70%
New high efficiency RTUs (6299115)	Electric energy (kWh)	21,826	10,450	48%
	% of Energy Savings on Peak	56%	48%	86%
	Summer On-Peak Demand (kW)	2.7	1.6	60%
	Winter On-Peak Demand (kW)	0	1.0	N/A
Total project	Electric energy (kWh)	497,860	326,764	66%

	% of Energy Savings on Peak	48%	50%	104%
	Summer On-Peak Demand (kW)	59.6	42.2	71%
	Winter On-Peak Demand (kW)	57.1	41.7	73%

Comparison of savings parameters

The evaluations' savings methods use savings parameters that sometimes cannot be directly compared to the savings parameters used in the applicant savings methods. Comparisons of tracking and evaluated savings parameter values were made when it was practical to do so. These comparisons are presented in the table below. Other comparisons are made in the discrepancy analysis section.

Table 90: Comparison of Key Parameters

	BASELINE		PROPOSED / INSTALLED	
Parameter	Tracking Value(s)	Evaluation Value(s)	Tracking Value(s)	Evaluation Value(s)
Average low-pressure compressor demand (kW) for air leak repair measure	36.5	0	19.0	0
Average high-pressure compressor demand (kW) for air leak repair measure	6.4	12.2	5.3	11.1
Average high-pressure air load (cfm)	28	28.3	23	23.3
Humidification system kW	36.0	34.9	2.2	1.0
Average knitting machine kW	12.6	7.4	8.1	5.0

Discrepancy analysis

This section describes the key drivers behind differences in the tracking and evaluation savings estimates. The following table will be used to summarize these differences. The purpose of this analysis is to measure and describe how changes to the key parameters influenced the final project savings.

Table 91: Discrepancy analysis results

Discrepancy	kWh	Peak Summer kW	Peak Winter kW	% on peak
Tracking Savings (no changes)	497,860	59.6	57.1	48%
Discrepancy #1 (Remove double counting + Humidification System 5384747 Savings Method)	-31%	-24%	-26%	0%
Discrepancy #2 (Knitting Machine 5853340 Savings Method)	-1%	-3%	-2%	0%
Discrepancy #3 (Air Leak Repair 5648426 Savings Method)	0%	0%	0%	0%
Discrepancy #4 (New RTU 6299115 Savings Method) - evaluated savings	-2%	-2%	2%	4%
Final Evaluated GRR %	66%	71%	73%	104%

The table above illustrates sequential discrete changes made to savings parameter values or savings methods and the corresponding effect the change has on savings estimate relative to the tracking savings.

For example, the first line ("Tracking Savings") lists the savings claimed in the tracking data. The next line, "Discrepancy #1", illustrates the impact made (in % of tracking savings) by the discrepancy. The final evaluated gross realization rate (GRR) line at the bottom is equal to 100% (tracking savings) plus the sum of discrepancy lines.

Discrepancy #1 (Remove double-counting + Humidification System 5384747 Savings Method)

This discrepancy accounts for the removal of double-counted savings for the air leak repair measure and for the savings method utilized by the evaluator. Both the air leak repair and humidification system measures use the same low pressure compressed air system to justify baseline energy consumption; however, the humidification system measure completely removes the need for the low pressure compressed air. The evaluator confirmed that the low-pressure compressor is now considered a backup if the new humidification system goes down.

The savings method used to evaluate the humidification system measure savings is different from the tracking method. It employs an 8,760-demand reduction profile developed from 12 weeks of observed system usage while the tracking method assumes a constant load profile over the annual operating hours. Coincidentally, there was no difference between the tracking and evaluated annual operating hours (8,400). This discrepancy decreased savings by 31% of -151,974 kWh.

Discrepancy #2 (Knitting Machine 5853340 Savings Method)

This discrepancy accounts for the difference in savings methods. The evaluated savings method ultimately took into account part load equipment operation that was measured over 12 weeks. The tracking method assumed that the knitting machines operated at full load whenever active. Accounting for part-load operation led to a discrepancy in the average knitting machine load. As reported in Table 31, the difference in knitting machine kW for the tracking savings was 4.5 kW. The difference in knitting machine kW for the evaluated savings was roughly half (2.4 kW) the tracking value. This discrepancy reduced savings by 1% or -6,389 kWh.

Discrepancy #3 (Air Leak Repair 5648426 Savings Method)

This discrepancy was included simply to note that there was a difference in savings methods between the evaluated and tracking savings. However, the difference in savings methods did not amount to a significant difference (0% or -1,357 kWh) in savings. This is because the demand reduction and operating hours were very similar between tracking and evaluated methods.

Discrepancy #4 (New RTU 6299115 Savings Method)

This discrepancy accounts for the difference in savings method (and savings parameters) between tracking and evaluation savings. The tracking method uses an online calculation tool. The savings calculations are not reported in the tracking documentation. The evaluation method collected 12 weeks of RTU kW interval data and hourly NOAA weather data to develop a regression model to estimate RTU load corresponding to outside dry bulb temperature. The regression model was then extrapolated to an annual year using the facility's operating schedule and TMY3 weather data[54].

The evaluator cannot explain specific differences because the online calculator output does not define savings parameters (e.g., annual operating hours, average RTU kW) that can be compared against; however, there are no discrepancies for the known baseline and proposed equipment specifications like quantity and efficiency (EER). This discrepancy reduced savings by 2% or -11,376 kWh.

54 Providence RI TMY3

Site ID: 2016RIN094

Program Administrator	National Grid
Project ID(s)	5389177
Project Type	New construction / expansion
Program Year	2016
Evaluation Firm	DNV GL
Evaluation Engineer	Chris Williams
Senior Engineer	C.D. Nayak

Project Description

This project made improvements to the existing compressed air system at an industrial facility that produces high-quality plastic cups. The project replaced existing compressors with two (2) new 150 HP Gardner Denver VS110 variable speed air compressors, a new 1,500 CFM Gardner Denver cycling refrigerated dryer, a 1,550-gallon air receiver, low pressure (LP) filters, and three (3) no loss auto drains. The measures save energy by generating compressed air or drying compressed air more efficiently than the base case equipment.

The project was categorized as new construction for a new process or expanded operation. The equipment was purchased to replace existing end-of-life compressors, enhance plant performance, and to satisfy future planned expansions. Because of the planned expansion, the proposed compressors have a larger capacity than the pre-existing compressors. The project's baseline uses a new construction industry-standard 300 HP compressor with load/unload controls and a non-cycling 1,500 CFM refrigerated dryer. There was also pressure drop savings from the base case system pressure of 125 psi to the assumed post-installation pressure of 117 psi. The facility could decrease discharge pressure because of the LP filters and the additional air receiver capacity.

The table below summarizes the evaluation results.

Table 92: Project results

Savings Quantity	Tracking Estimate	Evaluation Estimate	Realization Rate
Electric energy (kWh)	494,168	588,714	119%
% of Energy Savings on Peak	66%	61%	93%
Summer On-Peak Demand (kW)	73.4	89.9	123%
Winter On-Peak Demand (kW)	73.4	91.3	124%

The bullets below explain some key discrepancy findings:

- The evaluation determined the average air load (cfm) of the facility is much lower than estimated in the tracking savings. The evaluation estimated an average plant air load of 288 while the tracking savings use a weighted average of 693. This lower air load increases the demand reduction at part load between the installed and baseline compressors.

- The annual operating hours (6,388) estimated by the evaluation is slightly greater than the tracking estimate (6,240). This discrepancy increased energy savings by 2%.
- The pressure reduction was observed to be 10 psi, 2 more psi than the tracking estimate. This discrepancy increased compressor energy savings by 2%.

Tracking Savings

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

Baseline

The baseline system is as follows:

Compressor: Industry-standard selection – Quincy QSI-1250 (300 HP, 1,255 CFM) rotary screw compressor with load/unload control (full load kW = 245.2)

Air dryer: Industry-standard selection – Gardner Denver 1,500 CFM noncycling refrigerated air dryer

No Loss Drains: Industry-standard timed drains

Discharge Pressure: Compressor target discharge pressure = 125 psi

Filters: Industry-standard filters (no specific pressure drop)

The baseline compressor, dryer, and drains were selected based on "industry standard" practice, though no specifics were given about why they were considered industry standard. Industry-standard was chosen over pre-existing equipment because the project took in to account the planned capacity expansion (i.e., "new construction" project type) of the facility.

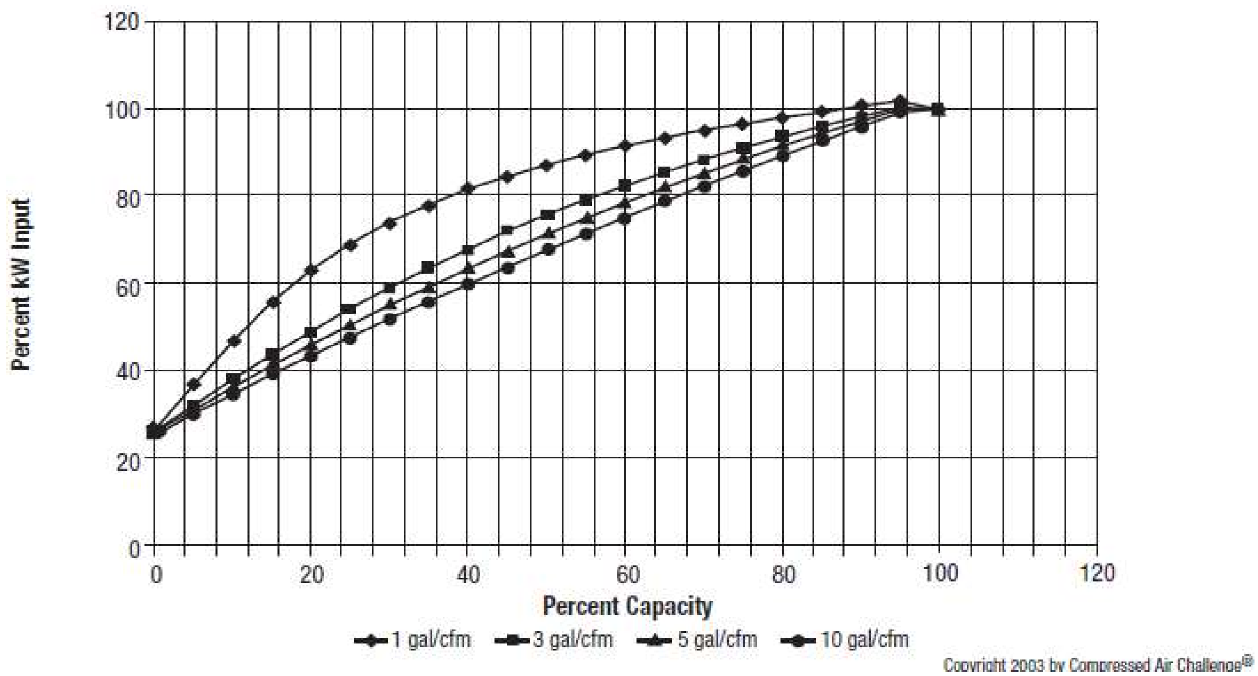
The baseline CFM load profile was developed from one week of flow measurements. The applicant binned the airflow data into four categories then extrapolated those percentages to a full year using the facility's operating schedule. The baseline annual compressed air load profile is shown in the table below.

Table 93: Baseline CFM profile

CFM	Annual hours (% of annual period)
804	187 (3%)
753	3,182 (51%)
702	2,184 (35%)
360	687 (11%)
Total hours	6,240 (100%)

The baseline compressor power demand profile corresponding to the baseline air load profile is estimated using the baseline compressor's full load kW and a standard compressor performance curve for load/no-load controls (and 1 gal/cfm capacity) sourced from Compressed Air Challenge™. That curve is shown in the figure, below.

Figure 24: Baseline compressor performance curve (1 gal/cfm)



The baseline compressor kW profile in the table below is produced by applying the baseline compressor performance curve to the full load compressor kW and corresponding cfm from each air load bin in Table 2.

Table 94: Baseline compressor annual usage

CFM	% Air Capacity	% full load kW	kW	Hours/yr	kWh/yr
804	64%	89%	218.2	187	40,809
753	60%	87%	213.3	3,182	678,797
702	56%	84.5%	207.2	2,184	452,512
360	29%	66%	161.8	687	111,179
			Total	6,240	1,283,296

The baseline compressor discharge pressure is 125 psi. Savings attributed to the system pressure drop measure (LP filters and air capacity expansion) uses this pressure as the baseline.

The baseline air dryer was assumed to be a noncycling refrigerated air dryer with 1,500 cfm drying capacity and a full load kW of 9.47 kW. The applicant savings assumes that the full load kW for the dryer is used for all corresponding air load bins, as shown in the table below.

Table 95: Baseline air dryer annual usage

CFM	% Air Capacity	% full load kW	kW	Hours/yr	kWh/yr
804	64%	100%	9.47	187	1,771
753	60%	100%	9.47	3182	30,134
702	56%	100%	9.47	2184	20,682
360	29%	100%	9.47	687	6,506
			Total	6,240	59,093

The baseline for the no loss drains measure assumes three timed drains that drain 52 cfm while open. The baseline ultimately assumes that each baseline drain loses 0.58 cfm while the compressed air system is in operation.

Proposed condition

The proposed system is as follows:

Compressors: Two (2) Gardner Denver VS80-110 variable speed screw compressors; full load kW = 137.9 kW; full load cfm = 663

Air dryer: Gardner Denver 1,500 CFM cycling air dryer; full load kW = 8.68

No Loss Drains: Three (3) drains that lose 0 cfm while draining

Discharge Pressure: Compressor target discharge pressure = 117 psi

Filters: Low-pressure drop filters (no specific pressure drop)

For the efficient compressor measure, the proposed compressed air system serves the same air demand as in the baseline scenario. The proposed compressors operate more efficiently than the baseline compressor at part load. The applicant uses the proposed compressor manufacturer's datasheet which lists part-load performance (kW/cfm). The proposed compressor kW profile in the table below (Table 96) is produced by applying the proposed compressor performance curve and corresponding cfm from each air load bin in Table 2.

Table 96: Proposed compressor annual usage

CFM	% Air Capacity	% full load kW	Compressor 1 kW	Compressor 2 kW	Hours/yr	kWh/yr
804	64%	61%	79.91	79.91	187	29,886
753	60%	57%	74.48	74.48	3182	473,991
702	56%	53%	69.12	69.12	2184	301,916
360	29%	54%	70.46	0	687	48,406
			Total		6,240	854,199

The proposed compressor discharge pressure is the same as the baseline pressure: 125 psi. The proposed condition for the system pressure drop measure (LP filters and air capacity expansion) uses a discharge pressure of 117 psi. This pressure was observed as the operating pressure when the post-implementation visit was performed by the PA. The applicant savings assumes that the system pressure drop savings apply to the proposed compressed air system (i.e., no double counting)

The proposed air dryer was assumed to be a cycling refrigerated air dryer with 1,500 cfm drying capacity and a full load kW of 8.68 kW. The applicant savings assumes that the proposed air dryer kW scales proportionally with its drying capacity (+ fixed 10% full load kW). The proposed air dryer kW profile is shown in the table below.

Table 97: Proposed air dryer annual usage

CFM	% Air Capacity	kW	Hours/yr	kWh/yr
804	64%	5.52	187	1,032
753	60%	5.23	3182	16,627
702	56%	4.93	2184	10,768
360	29%	2.95	687	2,027
		Total	6,240	30,455

The proposed no-load drains are assumed to have no losses (0 cfm lost while the drain is draining). Both baseline and proposed cfm losses from the drains are assumed to be served by the proposed compressors operating at full load efficiency (0.208 kW/cfm)

Tracking calculation methodology

Spreadsheet calculations were used to estimate measure savings. The applicant methodology and savings results are discussed in the following order:

- Efficient air compressors
- Cycling air dryer
- System pressure drop
- No loss drains

Efficient air compressors

For the air compressors, the baseline and proposed compressors' annual energy consumption were compared against assuming the same discharge operating pressure (125 psi) and air demand profile. The measure savings is the difference between the annual energy consumptions.

Table 98: Efficient air compressors scenario comparison

Baseline Compressor kW	Proposed Compressor 1 kW	Proposed Compressor 2 kW	Hours/yr	Baseline kWh/yr	Proposed kWh/yr
218.2	79.91	79.91	187	40,809	29,886
213.3	74.48	74.48	3,182	678,797	473,991
207.2	69.12	69.12	2,184	452,512	301,916
161.8	70.46	0	687	111,179	48,406
	Total		6,240	1,283,296	854,199

$$Annual\ kWh\ Savings\ = \sum \Delta kW_i \times hours_i = 429{,}097\ kWh$$

Where,

Table 99: Efficient compressor savings

ΔkW_i	$hours_i$	kWh Savings
58.4	187	10,922
64.4	3,182	204,806

69.0	2,184	150,596
91.4	687	62,773
Total	6,240	429,097

Cycling air dryer

Similar to the compressor savings, the measure savings is equal to the difference between the baseline and proposed air dryer annual consumptions. The savings methodology assumes that the air load profile is the same between scenarios.

Table 100: Cycling air dryer scenario comparison

Baseline dryer kW	Proposed dryer kW	Hours/yr	Baseline kWh/yr	Proposed kWh/yr
9.47	5.52	187	1,771	1,032
9.47	5.23	3,182	30,134	16,627
9.47	4.93	2,184	20,682	10,768
9.47	2.95	687	6,506	2,027
Total		6,240	59,093	30,455

$$Annual\ kWh\ Savings\ = \sum \Delta kW_i\ \times\ hours_i = 28{,}638\ kWh$$

Where,

Table 101: Cycling air dryer savings

ΔkW_i	$hours_i$	kWh Savings
3.9	187	739
4.2	3,182	13,506
4.5	2,184	9,915
6.5	687	4,478
Total	6,240	28,638

System pressure drop

System pressure drop savings were estimated by observing the pre and post-implementation compressor discharge air pressure set points. The applicant claims that because of the low-pressure drop filters and additional air storage, the facility operators were allowed to lower the discharge air pressure of the compressors and still satisfy production air pressure requirements. The discharge air pressure dropped from the baseline pressure of 125 psi to the proposed pressure of 117 psi (which was observed in the post-implementation site visit). The pressure drop of 8 psi leads to energy savings because the air compressor has to work less to pressurize the discharge air to the desired set point. Savings are calculated using the pressure drop (8 psi), an assumed rule of thumb that each psi in pressure drop is equivalent to 0.5% full load power of the compressed air system, and the annual proposed compressor usage.

$\frac{kW\ reduction}{ps}$ = 0.5% compressor power per 1 psi drop (rule of thumb)

$$Annual\ kWh\ Savings\ =\ Annual\ Post\ Compressor\ Energy\ \times Pressure\ Drop\ \times \frac{kW\ reduction}{psi} = 34{,}168\ kWh$$

Where,

$Annual\ Post\ Compressor\ Energy$ = 854,199 kWh (from the efficient compressor calculations)

$Pressure\ Drop$ = 8 psi

No loss drains

The applicant assumes that the savings from no loss drain are attributed to the proposed air compressors not having to produce extra air to make up for the air being lost when the timed drains open to drain condensate. The savings method estimates the average cfm saved due to the no loss drains, then applies the proposed full load compressor efficiency (kW/cfm) and annual hours to estimate annual kWh savings.

The applicant assumes that each 0.25-inch draining orifice pass 104 cfm when discharging to atmospheric pressure and that only 50% of that flow is compressed air (the other half is condensate). The calculation assumes a 10 second open, 1 minute closed draining frequency. Using this draining flow rate and draining frequency, each baseline drain loses 0.58 cfm[55]. The full load efficiency (kW/cfm) of the proposed compressor is used to estimate the kW reduction due to the no loss drains.

hours = 6,240 hours

$$Annual\ kWh\ Savings\ =\ Quantity\ \times kWsaved\ \times hours = 2{,}265\ kWh$$

Where,

Quantity = 3 drains
kW saved = 0.121 kW per drain*

The applicant/tracking savings are listed by the measure below.

Table 102: Tracking savings by measure

Measure	kWh savings	Summer kW reduction	Winter kW reduction
Efficient air compressors	429,097	68.8	68.8
Cycling air dryer	28,638	4.6	4.6
System pressure drop	34,168	0	0
No loss drains	2,265	0	0
Total	494,168	73.4	73.4

Project Evaluation

Table 4 shows how each measure was verified to be installed and operating. If a measure was found to not be installed or installed but not operating correctly, it is noted in this table.

[55] 104 cfm per drain x 50% air x (10 second opening /15 minute close) x (1 minute / 60 seconds)

Table 103: Measure verification

Measure Name	Verification Method	Verification Result
Efficient compressors	Visual	Installed and operating as intended
Cycling air dryer	Visual	Installed and operating as intended
System pressure drop (low-pressure drop filters and 1,550-gallon air receiver)	Visual	Installed and operating as intended
No loss drains	Visual	Installed and operating as intended

The M&V plan and project evaluation were conducted as planned. A site visit was performed on August 2, 2018, to install data loggers and interview the site contact. The air compressors, dryers, drains, filters, and air receivers were observed and verified to be installed and operating. The pre-existing air compressor and dryer were retired to be standby/backup units.

The evaluation team learned that the installed compressors have been experiencing operating issues that have all appeared to lead to warranty claims (as per contact); however, the issues have caused some operational headaches and the system has not been operating as efficiently as intended. In mid-September, the site contact stated that the compressors appeared to be operating as intended, where the air demand is shared equally by the two new variable speed compressors. The culprit may have not been related to the compressors themselves but may have been due to accidental piping constraints. Some piping feeding through the pre-existing air dryer should have been valved off. The site contact believes this may have led to strange supply-side pressure undulations. The site contact claimed that the discharge air pressure setpoint was not changed after the issue was resolved.

Nameplate information was collected for all affected equipment. The site contact was not aware of and could not provide historical trend data. ElitePro kW loggers were installed on the new air compressors and an H22K amp logger was installed on the air dryer. The airline had a permanent CDI flow meter so the evaluator also obtained several weeks of airflow data coinciding with the power logging period. Data loggers were retrieved in late October, making the metering period roughly 11 weeks. The site contact mentioned during both site visits that their production has remained "about the same" over the past few years, and he could not give a more descriptive estimate, nor could he provide useful production data. The facility does not experience seasonality and the contact stated that the metering period (omitting the period of operational issues, ~2 weeks) would be a reasonable period to represent typical operation.

The evaluation savings methodologies that are explained in later sections were implemented as planned. 8,760-hour demand reduction profiles were generated for each measure, and specific discrepancies were found that attributed to the difference between evaluated and tracking savings estimates.

Data collection

The evaluator metering approach outlined in the M&V plan was implemented as planned. Nameplates and datasheets for the new equipment (compressors, dryer, air receiver, filters, and drains) were collected while on-site and through internet searches. The following table describes specifications for the affected equipment.

Table 104: Measure specifications

Measure Name	Specifications	Notes
Efficient compressors	(2x) Gardner Denver VS-110 variable speed 150 HP; 663 cfm	Observed discharge pressure = 115 psi. This is slightly different than the

		pressure claimed by the applicant (117 psi)
Cycling air dryer	Gardner Denver RSD1500 cycling refrigerated air dryer 1,500 cfm	
System pressure drop (low pressure drop filters and 1,550 gallon air receiver)	Steel Fab. 1,550 gallon receiver Gardner Denver FME-5 filter	
No loss drains	(3) Drain all no loss drains	

Data loggers were deployed to collect load profiles of compressors and dryers. The following table describes the types of time-series logger data collected for the evaluation.

Table 105: Data collection points

Data/equipment description	Data type	Logging duration (August – October 2018)
Gardner Denver VS-110 compressor "#2"	Full unit kW	12 weeks; 15-minute interval
Gardner Denver VS-110 compressor "#3"	Full unit kW	12 weeks; 15-minute interval
Gardner Denver RSD1500 dryer	Full unit current (amps)	12 weeks; 15-minute interval
Compressed air flow rate	Full compressed air system flow rate (scfm)	10 weeks; 2-minute interval

Evaluation savings analysis

The evaluator approached the project savings analysis in a manner that would allow the evaluator to compare evaluated savings, and to ensure that the measures were properly loaded to tracking savings and to prevent double-counting measure savings. The savings analysis follows the sequence presented below.

5. Data loggers measured "installed" operating power profile (new compressors and new dryer).
6. EEM1 (Efficient compressors) + EEM3 (System pressure drop) savings profile is estimated. These were grouped initially simply based on arbitrary preference. EEM3 savings were separated from EEM1 savings and measures are loaded in the same order as the tracking savings.
7. EEM2 (air dryer) savings profile is estimated. This savings profile is independent of other measures.
8. EEM3 (system pressure drop) savings profile is estimated.
9. EEM4 (No loss drains) savings profile is estimated.

Efficient compressors and system pressure drop (EEM1 + EEM3) savings analysis

Data loggers collected roughly 10 useful weeks of the installed compressors operating under "typical" conditions. There were some logger data that were omitted because the site contact stated that the backup compressor was running during that period.

The compressor logger data (kW) were aggregated into a 168 hour week profile. This profile would represent the typical non-seasonal demand (kW) of the installed compressors. Using the facility's reported holiday list, the profile was extrapolated to a standardized year. The installed compressor demand profiles are shown in the table below.

Table 106: Installed compressor ("#2") kW profile

Hour	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
0	0.0	6.0	12.8	0.0	14.5	17.5	0.0
1	0.0	9.3	9.9	3.8	14.6	12.4	0.0
2	0.0	11.8	6.4	7.7	27.3	14.5	0.0
3	0.0	11.8	6.3	7.7	30.0	14.1	0.0
4	17.5	20.9	17.3	17.0	31.9	15.7	0.0
5	21.3	52.8	59.6	50.7	32.5	16.6	0.0
6	35.6	41.3	56.7	50.8	42.3	16.7	0.0
7	39.9	31.6	58.3	67.2	42.8	15.8	0.0
8	42.9	44.2	57.3	55.3	43.0	15.5	0.0
9	48.7	44.4	60.6	38.3	42.4	15.8	0.0
10	53.4	45.4	60.7	43.0	36.0	7.6	0.0
11	53.4	42.7	61.0	33.9	40.6	0.0	0.0
12	53.0	46.4	60.4	50.9	47.8	0.0	0.0
13	52.8	46.1	59.7	52.6	35.7	0.0	0.0
14	53.7	46.9	62.0	50.4	41.9	0.0	0.0
15	53.1	37.9	61.0	60.3	43.6	0.0	0.0
16	17.9	15.2	23.4	20.9	16.3	0.0	0.0
17	12.2	12.7	17.4	17.8	13.0	0.0	0.0
18	14.2	12.7	16.0	18.7	12.6	0.0	0.0
19	11.8	12.7	18.9	15.5	12.8	0.0	0.0
20	11.9	12.7	19.0	15.6	10.5	0.0	0.0
21	11.3	12.7	14.1	15.6	12.1	0.0	0.0
22	11.0	12.7	11.0	15.1	23.9	0.0	0.0
23	6.5	12.8	6.4	14.6	30.0	0.0	0.0

Table 107: Installed compressor (“#3”) kW profile

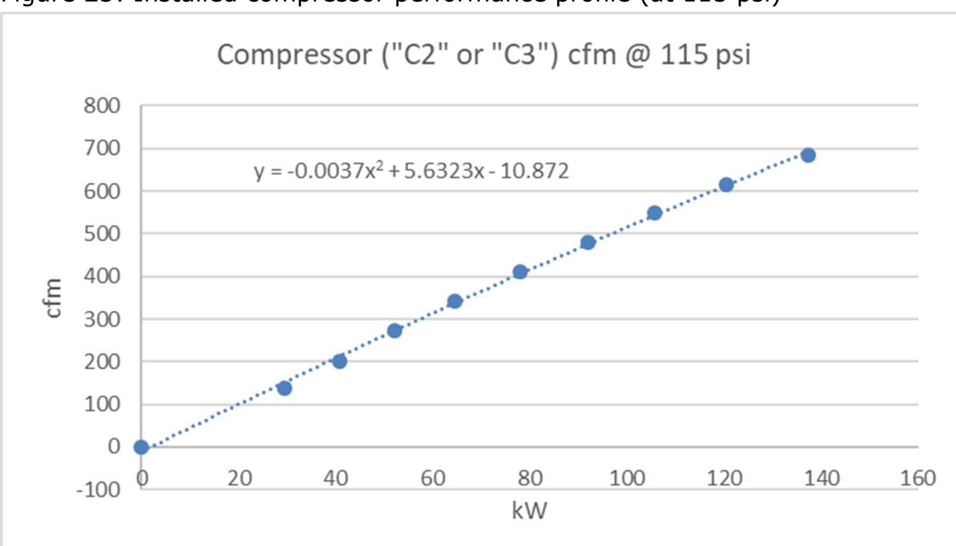
Hour	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
0	0.0	10.0	18.0	19.8	12.3	0.0	0.0
1	0.0	7.1	18.2	19.2	12.3	0.0	0.0
2	0.0	4.4	18.3	19.1	12.3	0.0	0.0
3	0.0	4.3	19.0	19.1	12.1	0.0	0.0
4	7.4	9.8	24.5	34.9	8.6	0.0	0.0
5	9.4	22.4	51.9	73.9	29.4	0.0	0.0
6	13.2	43.1	59.2	49.2	31.9	0.0	0.0
7	13.9	55.6	58.2	43.0	31.8	0.0	0.0
8	29.4	50.9	46.2	54.3	31.4	0.0	0.0
9	46.5	52.2	58.2	75.0	31.9	0.0	0.0
10	39.5	52.3	61.5	69.9	30.4	0.0	0.0
11	48.1	54.7	61.1	75.0	30.6	0.0	0.0
12	47.6	54.9	61.4	80.6	30.7	0.0	0.0
13	47.6	52.6	60.6	79.7	29.3	0.0	0.0
14	46.9	53.9	62.4	77.6	29.2	0.0	0.0

15	47.3	52.1	61.8	68.3	26.8	0.0	0.0
16	11.2	22.8	17.5	19.5	19.4	0.0	0.0
17	9.6	19.1	14.8	13.7	16.3	0.0	0.0
18	5.9	19.9	16.2	12.6	11.7	0.0	0.0
19	5.9	19.0	12.8	11.4	12.0	0.0	0.0
20	5.9	19.0	13.0	11.2	4.0	0.0	0.0
21	5.9	18.7	17.8	11.5	0.0	0.0	0.0
22	5.8	18.2	19.4	11.9	0.0	0.0	0.0
23	9.8	18.4	19.0	12.0	0.0	0.0	0.0

The evaluator considered it reasonable to extrapolate the compressor demand profile using this method because the compressor demand does not have a strong correlation to weather or production seasonality (no seasonal schedules per the site contact). Without detailed production data available, linear extrapolation of hourly averages (by the time of day and weekday) generated a reasonably accurate representation of annual compressor usage.

The CAGI sheet and manufacturer's datasheet for the installed compressor (Gardner Denver VS110) were collected for the available rated operating pressures (e.g., 100 psi, 125, psi, 150 psi). These data sheets list part-load capacities in cfm and the compressor's corresponding part load kW. The compressor's performance profile for the observed operating pressure of 115 psi was interpolated from these datasheets. The performance curve is shown in the figure below.

Figure 25: Installed compressor performance profile (at 115 psi)

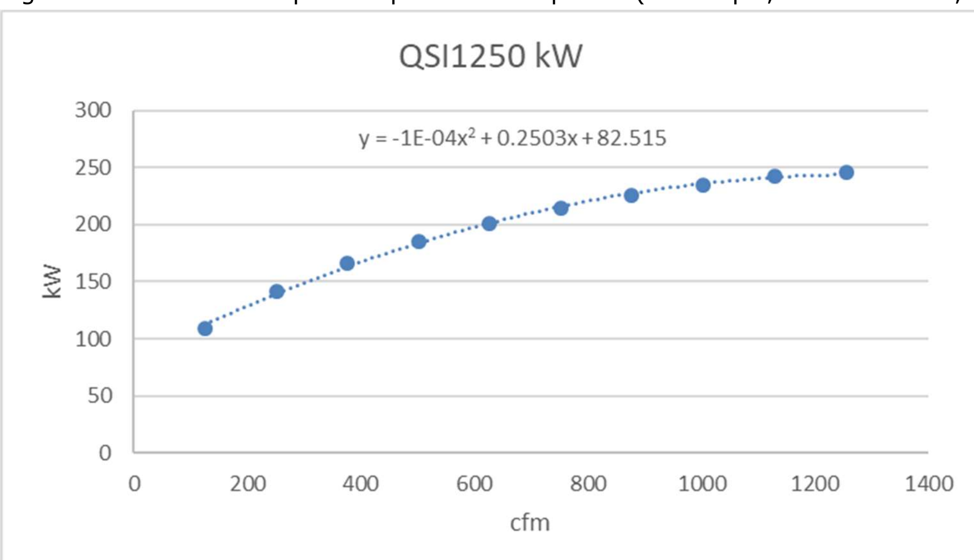


The performance curve mentioned above was used to estimate airflow (cfm) as a function of compressor kW. This step developed the corresponding hourly air demand (cfm) profiles experienced by the two installed compressors. With these profiles (kW and cfm) for the two installed compressors, the evaluator extrapolated to a standardized year to estimate annual air consumption (CF) and electric consumption (kWh)[56].

With the installed compressor 8,760 kW profiles generated, the evaluator then developed the corresponding baseline compressor 8,760 kW profile by first summing the hourly airflow of the two installed compressors. In the baseline scenario, only one compressor generates air demand. The evaluator used the same baseline compressor (Quincy QSI1250) as the applicant because it was considered a reasonable selection. The baseline compressor profile was also adjusted from the installed profile by modifying the discharge pressure from the observed 115 psi to the assumed baseline discharge pressure of 125 psi. The total air storage capacity was also adjusted to remove the effects of the installed 1,550-gallon air receiver.

AIRMaster+, a DOE software package, was used to estimate the baseline compressor part-load performance. A representative load/no-load fixed speed rotary screw compressor was selected in AIRMaster+ and its key performance factors (full load kW, no-load kW, rated capacity, CAS volume in CF) were updated in the software to approximate the baseline compressor part-load performance. The baseline compressor performance curve is illustrated below.

Figure 26: Baseline compressor performance profile (at 125 psi, without new 1,550gal tank)



This performance curve was used to approximate the 8,760 baseline compressor kW profile corresponding to the installed air demand profile. The difference between the baseline compressor kW profile and the sum of the two installed compressor kW profiles is effectively equal to the evaluated savings for EEM1 + EEM3 (savings from the new compressors, air tank, and filter).

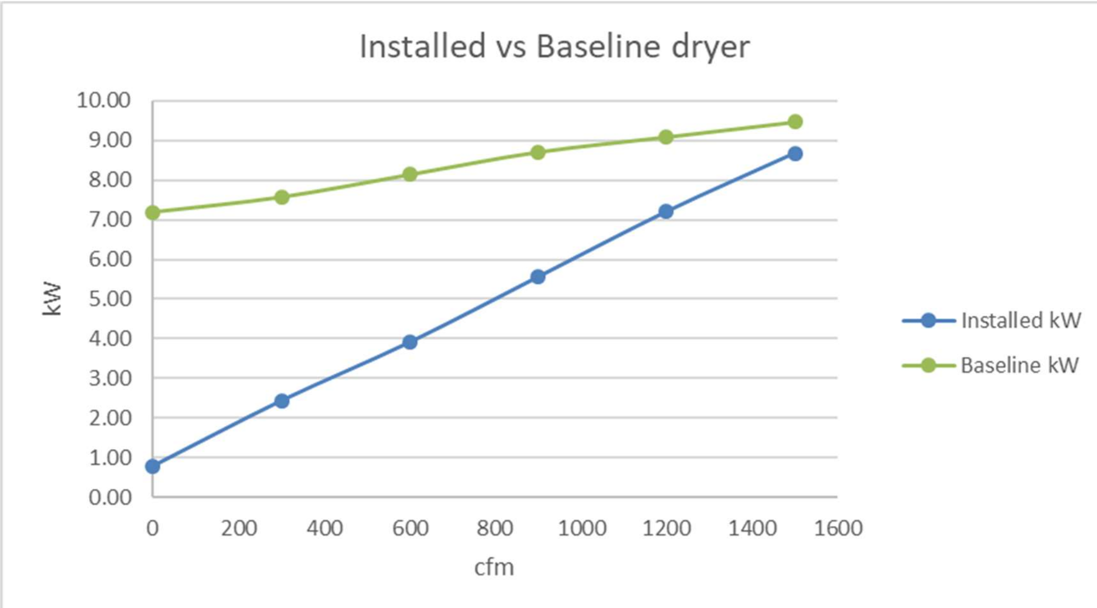
Air dryer (EEM2) savings analysis

The air dryer savings methodology is similar to the compressor methodology. A data logger collected nearly 12 weeks of 15-minute current (amps) data. Spot power measurements (volts, power factor) were also taken while on-site in order to more accurately approximate power (kW) from the current data. An hourly 8,760 kW profile for the installed dryer was generated using the same method that was used for the compressor profiles. The evaluator used Gardner Denver data sheets and literature to approximate the

[56] 1985 was used arbitrarily but also because the TMY3 weather data for Providence is standardized to the 1985 year.

performance curves of both the installed (RSD series cycling digital scroll) and the baseline (RSC series noncycling) dryers. The figure below compares the two performance curves.

Figure 27: Performance curves for installed and baseline dryer



The installed dryer kW profile was then used with the performance curve to estimate the corresponding installed dryer load (capacity, cfm) profile[57]. The baseline dryer kW profile was estimated by using the installed dryer load profile and the baseline performance curve. The difference between the baseline and installed 8,760 kW profiles is equal to the evaluated savings for EEM2.

System pressure drop (EEM3) savings analysis

The savings analysis for EEM3 removes the specific pressure drop savings from the EEM1 + EEM3 savings analysis explained earlier in this section. The baseline scenario for EEM3 includes the new installed variable speed compressors operating at 125 psi but does not include the additional tank and low-pressure drop filter (which allowed the facility to lower their compressor discharge pressure from 125 psi to 115 psi). The installed scenario has the new compressors operating at 115 psi – an outcome attributed to the low-pressure drop air filter and air receiver[58].

The installed scenario's 8,760 kW profile for EEM3 was already generated from the EEM1 + EEM3 analysis. The baseline 8,760 kW profile was generated by using the installed compressor performance curve modified to account for the change in discharge pressure (from 115 psi to 125 psi)[59]. A comparison of the baseline and installed performance curves for EEM3 is shown in the figure below.

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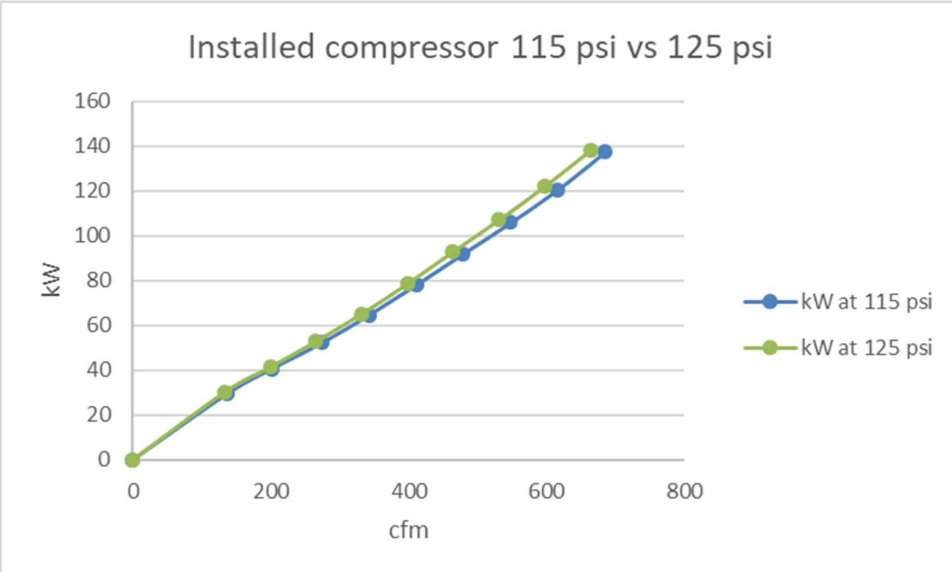
[57] Note that the cfm load estimated using this method was not compared to the compressor air load. It was used as an arbitrary unit to compare relative part loads of the installed and baseline dryers.

[58] Note that the evaluator believes that the facility was able to lower compressor discharge pressure because of the increased air load stability from the variable speed compressors and additional air receiver (LP filter helps but is probably not main driver). These two additions provide a buffer between supply and demand air loads that had previously been compensated for by the higher discharge pressure.

[59] Actually, it was the 115 psi performance curve that was modified/interpolated from the "original". The 125 psi curve is unmodified from the manufacture's data sheet

Figure 28: Comparison of baseline vs installed compressor performance, EEM3



The difference between the baseline and installed 8,760 kW profiles is equal to the evaluated savings for EEM3.

No loss drains (EEM4) savings analysis

The savings analysis for the no loss drains accounts for a small air load (the air lost when the timed drains are draining) in the baseline scenario that does not have to be produced in the installed scenario. The installed scenario's 8,760 kW profile for EEM4 is equivalent to the baseline 8,760 kW profile for EEM3 (i.e., new variable speed compressors operating at 125 psi). The baseline scenario for EEM4 adds the air loss from the 3 timed drains to the installed 8,760 air load profile. The drain's air loss was assumed to be equal to the applicant's estimate: 0.58 cfm per drain (1.73 cfm total). This step generates the baseline 8,760 air load profile for EEM4. The baseline 8,760 kW profile is then generated by using this air load profile and the compressor performance curve. The difference between the baseline and installed 8,760 kW profiles is equal to the evaluated savings for EEM4.

Evaluation Results

The evaluated savings are presented in this section by project and summarized briefly by measure. EEM1 (efficient compressors) accounts for the majority (86%) of the claimed savings. This section presents a comparison of key parameters and discrepancy analysis at the project level; however, some of the discrete discrepancies apply to specific measures.

The table below summarizes evaluated savings at the measure level and project level.

Table 108: Project results

Measure	Savings Quantity	Tracking Estimate	Evaluation Estimate	Realization Rate
EEM1 (Variable speed compressors)	Electric energy (kWh)	429,097	534,791	125%
	% of Energy Savings on Peak	N/A[60]	62%	N/A
	Summer On-Peak Demand (kW)	68.8	82.0	119%
	Winter On-Peak Demand (kW)	68.8	85.3	124%
EEM2 (Air Dryer)	Electric energy (kWh)	28,638	35,098	123%
	% of Energy Savings on Peak	N/A	45%	N/A
	Summer On-Peak Demand (kW)	4.6	3.8	83%
	Winter On-Peak Demand (kW)	4.6	4.1	89%
EEM3 (System pressure reduction)	Electric energy (kWh)	34,168	14,830	43%
	% of Energy Savings on Peak	N/A	79%	N/A
	Summer On-Peak Demand (kW)	0	3.5	N/A
	Winter On-Peak Demand (kW)	0	1.2	N/A
EEM4 (No loss drains)	Electric energy (kWh)	2,265	3,995	176%
	% of Energy Savings on Peak	N/A	67%	N/A
	Summer On-Peak Demand (kW)	0	0.7	N/A
	Winter On-Peak Demand (kW)	0	0.6	N/A
Total project	Electric energy (kWh)	494,168	588,714	119%
	% of Energy Savings on Peak	66%	61%	93%
	Summer On-Peak Demand (kW)	73.4	89.9	123%
	Winter On-Peak Demand (kW)	73.4	91.3	124%

Comparison of savings parameters

The evaluator's savings methods use savings parameters that sometimes cannot be directly compared to the savings parameters used in the applicant savings methods. Comparisons of tracking and evaluated savings parameter values were made when it was practical to do so. These comparisons are presented in the table below. Other comparisons are made in the discrepancy analysis section.

60 % on peak savings by measure is not reported in tracking savings

Table 109: Comparison of Key Parameters

Parameter	BASELINE		PROPOSED / INSTALLED	
	Tracking Value(s)	Evaluation Value(s)	Tracking Value(s)	Evaluation Value(s)
Annual operating hours	6,240	6,388	6,240	6,388
Average air demand (cfm)	693 (weighted average)	288	~692 (weighted average)	287
Compressor discharge pressure (psi)	125	125	117	115
Average dryer kW	9.5	8.2	4.9	4.2

One key parameter comparison to note is the large difference between the tracking and evaluated average air demand (cfm). This discrepancy is detailed in the discrepancy analysis section under "Discrepancy #4".

Discrepancy analysis

This section describes the key drivers behind differences in the tracking and evaluation of savings estimates. The following table will be used to summarize these differences. The purpose of this analysis is to measure and describe how changes to the key parameters influenced the final project savings.

Table 110: Discrepancy analysis results

Discrepancy	kWh	Peak Summer kW	Peak Winter kW	% on peak
Tracking Savings (no changes)	494,168	73.4	73.4	66%
Discrepancy #1 (Annual operating hours adjusted from 6,240 to 6,388)	2%	0%	0%	0%
Discrepancy #2 (EEM3 pressure reduction changed from 8 psi to 10 psi)	2%	0%	0%	0%
Discrepancy #3 (EEM4 Savings Method Change - use CAGI/datasheet performance at part load)	0%	1%	1%	0%
Discrepancy #4: evaluated savings (EEM1, EEM2 and EEM3 savings method changed - use power and air flow data)	15%	22%	24%	-7%
Final Evaluated GRR %	119%	123%	124%	93%

The table above illustrates sequential discrete changes made to savings parameter values or savings methods and the corresponding effect the change has on savings estimate relative to the tracking savings. For example, the first line ("Tracking Savings") lists the savings claimed in the tracking data. The next line, "Discrepancy #1", illustrates the impact made (in % of tracking savings) by the discrepancy. In the case of discrepancy #1, a discrete change was made to the annual operating hours' savings parameter.

Discrepancy #1 Annual operating hours adjusted from 6,240 to 6,388

This discrepancy lay in the estimated annual operating hours of the compressed air system. The discrepancy increased estimated energy savings because the demand reduction of the measures was applied to more hours.

Discrepancy #2 (EEM3 pressure reduction changed from 8 psi to 10 psi)

The evaluation found that the facility was able to reduce the discharge pressure from 125 psi (baseline) to the observed 115 psi. This discharge pressure was 2 psi less than the applicant estimate of 117 psi. The facility contact did not comment on a specific reason why they were able to further reduce the pressure from

117 psi. Note that there is no kW demand reduction difference for this discrepancy because the applicant's calculation method uses a savings factor applied to the annual energy consumption of the compressor.

Discrepancy #3 (EEM4 Savings Method Change - use CAGI/datasheet performance at part load)

The applicant savings method for EEM4 assumes a constant full load compressor efficiency when estimating the savings from installing no loss drains; however, the observed compressors operated almost exclusively at part load. This discrepancy applies the evaluator's savings method to EEM4, which accounts for part-load compressor performance. The discrepancy is small (1,676 kWh) relative to total project savings; however, it increased the specific measure savings by 76%.

Discrepancy #4 (Final evaluation savings – EEM1, EEM2, and EEM3 savings methods changed to evaluation method)

This discrepancy accounts for the remaining differences in savings methods (and savings parameters) between the tracking savings and evaluated savings. The evaluated savings methods utilize 8,760-hour profiles and continuous performance functions to estimate compressor and dryer loads. The evaluation method also uses actual manufacturer data sheets of compressor performance at different (rated) discharge pressures to estimate compressor savings due to pressure reduction (EEM3). The largest driver for this discrepancy, however, was the difference in the average compressed air demand between tracking and evaluated savings. As shown in Table 31, the tracking average air load is 240% greater than the evaluated average air load. The evaluator compared the pre-implementation air flow data (approximately 2 weeks in April 2015) collected by the applicant to the post-implementation flow data (approximately 4 weeks in September/October 2018). The visual comparison showed that the post-implementation air load followed a much shorter schedule than the pre-implementation schedule. As can be seen in Figure 29 below, the post-implementation (evaluated) air load is relatively low (~ 110 cfm) from midnight to 3 a.m., and from 4 p.m. through 11 p.m. on weekdays. The pre-implementation (tracking) air load profile was consistently high (~715 cfm) throughout the weekdays. Energy savings increased because higher demand reduction is possible at lower part loads for the installed variable speed compressors, so the compressors saved more energy than the tracking estimate during the weekday mornings and evenings.

Figure 29: Comparison of tracking (left) and evaluated (right) air load profiles

	Tracking (Pre-implementation) Air Profile							Evaluated (Post-implementation) Air Profile						
	1	2	3	4	5	6	7	1	2	3	4	5	6	7
Hour	Monday	Tuesday	Wednesd	Thursday	Friday	Saturday	Sunday	Monday	Tuesday	Wednesd	Thursday	Friday	Saturday	Sunday
0	1	711	718	740	714	669	2	0.0	82.4	108.8	84.6	93.2	54.0	0.3
1	1	712	724	725	705	709	2	0.0	83.0	105.6	96.8	101.7	41.6	0.2
2	1	713	728	693	707	718	2	0.1	81.4	106.8	111.3	193.9	49.6	0.2
3	5	710	727	716	676	573	2	6.9	80.7	108.2	113.6	193.5	47.4	0.3
4	336	722	717	618	700	183	2	131.2	295.6	341.3	392.4	213.6	62.4	0.3
5	587	732	718	693	717	204	2	301.3	542.8	728.8	717.5	375.3	60.6	0.2
6	622	652	739	738	705	199	2	472.6	674.9	714.3	571.5	429.3	63.8	0.3
7	614	731	741	742	716	201	2	484.1	707.1	624.8	626.8	440.6	71.1	0.3
8	611	730	733	740	722	198	2	588.7	700.7	630.6	630.6	433.7	66.6	0.3
9	657	723	729	734	692	189	2	556.0	710.1	758.7	675.2	420.9	65.1	0.3
10	734	710	698	732	721	187	2	555.1	708.8	760.8	639.6	338.8	48.4	0.3
11	740	721	730	738	719	131	2	600.9	749.1	754.1	667.0	403.8	13.2	0.3
12	736	710	740	729	716	24	2	583.5	745.9	753.3	776.6	420.6	1.7	0.2
13	733	711	736	737	715	1	2	592.7	726.7	752.0	773.2	316.0	0.0	0.3
14	720	705	727	733	715	1	2	584.9	730.2	766.0	744.0	378.3	0.1	0.1
15	716	706	737	727	714	1	2	505.8	604.6	605.5	668.2	342.4	0.1	0.1
16	714	702	737	724	713	1	2	93.3	127.7	123.9	129.3	173.4	0.1	0.1
17	719	707	731	727	710	1	2	76.3	120.4	120.7	135.2	148.9	0.0	0.1
18	716	711	736	718	713	2	1	78.1	121.7	118.3	114.5	128.7	0.0	0.0
19	721	705	736	724	714	2	1	85.1	112.4	117.4	93.7	128.2	0.1	0.0
20	715	706	706	660	714	1	1	85.6	111.5	112.5	93.9	47.9	0.1	0.0
21	711	711	737	694	716	2	1	84.4	111.5	113.6	94.7	71.9	0.1	0.1
22	704	711	747	722	676	2	1	82.2	109.6	109.3	94.5	128.6	0.1	0.0
23	711	716	741	714	607	2	1	82.6	110.7	93.4	92.9	143.7	0.1	0.1

The evaluator interviewed the site contact during the site visit to query if the facility schedule had changed significantly since the implementation. While the site contact stated that the purpose of the project was to enable them to increase capacity in the future, the operating schedule had generally remained unchanged. The site contact stated that the facility operates on two 12-hour shifts Monday through Friday. Some weeks the facility only operates 4 days (with Friday closed). Both air profiles generally reflect this schedule, but it appears that different work functions are performed during the “night” shift than before in the pre-implementation time period.

Site ID:2016RIN118

Project ID(s)	6316395; 6421680
Project Type	6316395: Retrofit 6421680: Retrofit
Program Year	2016
Evaluation Engineer	Chris Williams
Senior Engineer	C.D. Nayak

Project Description

This site report details the impact evaluation for the project IDs 6316395 and 6421680. The projects retrofitted or upgraded existing equipment at a local chain grocery store. The project descriptions are as follows:

- Project ID 6316395: Installed 100 linear feet of French-style doors with LEDs on to existing refrigerated cases that previously had no doors.
- Project ID 6421680: Replaced an existing refrigeration rooftop air-cooled condenser with a higher efficiency unit and implemented a floating head pressure (FHP) strategy by programming the saturated condensing temperature (SCT) to follow a fixed approach temperature (TD) based on outside dry bulb temperature. The new system has a minimum SCT of 70 °F and 12 °F TD.

The table below summarizes evaluation results.

Table 111: Project results for 2016RIN118

Project	Savings Quantity	Tracking Estimate	Evaluation Estimate	Realization Rate
6316395: French-style doors with LEDS on existing refrigerated cases	Electric energy (kWh)	42,610	50,183	118%
	% of Energy Savings on Peak	46%	43%	95%
	Summer On-Peak Demand (kW)	4.9	2.5	52%
	Winter On-Peak Demand (kW)	4.9	5.4	111%
6421680: High efficiency condenser with FHP controls	Electric energy (kWh)	69,735	51,733	74%
	% of Energy Savings on Peak	49%	51%	103%
	Summer On-Peak Demand (kW)	4.8	6.2	128%
	Winter On-Peak Demand (kW)	12.8	5.2	41%
Combined Total	Electric energy (kWh)	112,345	101,916	91%
	% of Energy Savings on Peak	48%	47%	98%
	Summer On-Peak Demand (kW)	9.7	8.7	90%
	Winter On-Peak Demand (kW)	17.7	10.6	60%

The bullets below explain some key discrepancy findings:

- The model for project ID 6316395 had, in effect, an incorrect count for the measure. The model had accounted for only 94 feet of display case doors. The evaluated model added 6 feet and this adjustment increased kWh savings by 10%.
- The model for project ID 6421680 applied measure adjustment to refrigeration equipment that was not involved in the claimed measure retrofit. The evaluator removed these adjustments, reducing kWh savings by 34%.

Tracking Savings

This section summarizes the methodologies and assumptions used to estimate the tracking savings claimed for the projects.

Baseline condition

The baseline equipment and conditions for the projects are summarized in the bullets below. Note that this information is what was described in the tracking documentation.

Project ID 6316395: Pre-existing refrigerated cases with no doors. 64 linear feet have cheese, dairy, and butter products and 36 linear feet have milk products, totaling 100 feet.

Project ID 6421680: Pre-existing air-cooled condenser (appears to have been a Bohn BNX-D04-A020) serving rack "C" with a total of (8) 1.5 HP single speed fans. The fans were modeled to have an efficiency of 1.92 kW/fan.[61] The previous head pressure strategy is described as being a fixed SCT set point of 87 °F.

Proposed condition

The proposed equipment and operating conditions for the projects are summarized below.

Project ID 6316395: The 100' of pre-existing refrigerated cases were retrofitted with 2' French-style doors with LEDs. The quote mentions that the doors are "Anthony Vista Eco kits with the horizontal top LED lights and vertical Optimax Pro LED lights".

Project ID 6421680: The pre-existing air-cooled condenser serving rack "C" was replaced with a more efficient condenser with a total of (8) 1 HP single speed fans. The fans were modeled to have an efficiency of 1.12 kW/fan. The proposed head pressure strategy is described and modeled as being a floating SCT set point with a minimum temperature of 70 °F and 12 °F TD to the outside dry-bulb temperature.

Tracking calculation methodology

Both projects used some form of building simulation modeling to estimate savings. Details of the modeling methodologies are explained below.

Project ID 6316395

The tracking savings utilizes the EnergySmart Grocer (ESG) program methodology to estimate savings. Upon the initial documentation review, specifics about the ESG program were not available. The tracking

[61] As entered in the eQUEST model using the keyword "KW/FAN" on condenser "CONDENSER_SG-AF3BC"

documentation contained a hard-entered tracking savings value (42,610 kWh) that happened to mention the ESG program[62].

The evaluator requested more information from the program administrator and received a response from an engineering manager that provided background information on the ESG program, a summary of program savings input methodology, and the eQUEST Refrigeration models that could be used to re-create the tracking savings.

The eQUEST model is generated from a proprietary audit tool that maps an on-site data collection to a proprietary database. The database is a collection of refrigeration equipment data and specification sheets that have been modified such that the database outputs are compatible with eQUEST parameter keywords. For example, an on-site audit data collection form is used to gather display case manufacturer and model information (e.g., HillPhoenix medium temperature multi-deck; 36 foot; standard linear fluorescent T8 lighting; manufacture date 2010). That information from the data collection tool is then fed into the ESG database to produce output values that are compatible with eQUEST. If specific manufacturer information is not known, the database contains average equipment specifications that are based on proprietary information collected from refrigeration projects, audits, and studies. The database outputs shape the eQUEST model to match observed equipment specifications (e.g., number of refrigeration fixtures, case heat conduction rate, case lighting power, suction groups, etc.) that were collected through the on-site audit.

The ESG program was launched in 2002 and large state utility commissions (e.g., CPUC, BPA) have sponsored the program and provided audits and third-party evaluations of the efficiency projects claimed under the program. Bonneville Power Authority sponsored an impact and process evaluation (conducted by Summit Blue in 2009) for the Grocer program. The evaluation claims that the "program is likely achieving its reported energy savings." and that "the program achieved savings slightly higher than the estimated savings…measure savings very close (1.02) to the predicted first-year energy savings reported by [the program]."

The evaluator compared the input files of the base case and proposed case eQUEST Refrigeration models to determine what input keywords are the drivers for savings. The comparison is shown below; an explanation of the DOE2R/eQUEST keywords follows the table.

Table 112: Difference between the base and proposed case eQUEST models for 6316395

DOE2R/eQUEST keyword	Base Case value	Proposed case value	Note
CONDUCTION/LEN	132.678	59.71	Applies to REFG-FIXTURE: C17FFB897D8D3; C1AFFB897D8D3
INF-LOAD/LEN	1194.1	298.53	Applies to REFG-FIXTURE: C17FFB897D8D3; C1AFFB897D8D3
INF-SCH	Night Cover_Sch	Inf_Sched	Applies to REFG-FIXTURE: C17FFB897D8D3; C1AFFB897D8D3
CANOPY-KW/LEN	0.056	0.0175	Applies to REFG-FIXTURE: C17FFB897D8D3; C1AFFB897D8D3
SST-SUPPLY-TD	8	4	Applies to REFG-FIXTURE: C17FFB897D8D3; C1AFFB897D8D3
CONDUCTION/LEN	136.5	61.43	Applies to REFG-FIXTURE: C20FFB897D8D3
INF-LOAD/LEN	1228.5	307.13	Applies to REFG-FIXTURE: C20FFB897D8D3
CANOPY-KW/LEN	0.0204	0.0175	Applies to REFG-FIXTURE: C20FFB897D8D3
SST-SUPPLY-TD	3	4	Applies to REFG-FIXTURE: C20FFB897D8D3

[62] Peak demand reduction (summer and winter) are calculated by dividing the electric savings (kWh) by 8,760 hours. % on peak savings calculations are not described in the tracking documentation and appears to be given a deemed 46% value

CONDUCTION/LEN	134.392	60.48	Applies to REFG-FIXTURE: C22FFB897D8D3
INF-LOAD/LEN	1209.53	302.38	Applies to REFG-FIXTURE: C22FFB897D8D3
CANOPY-KW/LEN	0.01076	0.0175	Applies to REFG-FIXTURE: C22FFB897D8D3
SST-SUPPLY-TD	7	4	Applies to REFG-FIXTURE: C22FFB897D8D3

"LINE-UP_LENGTH" (i.e., refrigeration fixture/case length in feet) in the eQUEST models are as follows:

Table 113: Affected fixture case lengths in 6316395[63]

REFG-FIXTURE	LINE-UP_LENGTH
C17FFB897D8D3	8
C1AFFB897D8D3	6
C20FFB897D8D3	44
C22FFB897D8D3	36
Total	94

Explanation of DOE2R/eQUEST keywords:

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

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

[63] Note that the total affected case length in the model is 94 feet. The project claims that 100 feet of display cases were retrofitted with doors

Table 114: Case door measure assumptions

DOE2R/eQUEST keyword	Proposed value	Source
CONDUCTION/LEN	Baseline CONDUCTION/LEN * 0.45	Faramarzi, Ramin T., B.A. Coburn, and R. Sarhadian, 2002. *Performance and Energy Impact of Installing Glass Doors on an Open Vertical Deli/Dairy Display Case.* ASHRAE Transactions, AC-02-7-2, pp. 673-679
INF-LOAD/LEN	Baseline INF-LOAD/LEN * 0.25	Ibid
SST-SUPPLY-TD	4	Ibid
CANOPY-KW/LEN	0.0125	Research of LEDs installed in PECI programs, summary found in WP for Reach-in Case Lighting, Fluorescent to LED, with and without motion sensors, Figure 1.

Project ID 6421680

The tracking savings utilizes an eQUEST model to estimate savings. The tracking documentation does not describe how the eQUEST model was developed; however, the evaluator believes that the base model was generated using inputs (ESG) from project ID 6316395. That project collected store and refrigeration equipment specifications and operating conditions using the ESG program audit tool. The following DOE2R/eQUEST keywords and values are adjusted between the base and proposed models.

Table 115: Difference between the base and proposed case eQUEST models for 6421680

DOE2R/eQUEST keyword	Base Case value	Proposed case value
SCT-CTRL for "SG-EC354"	FIXED	DRYBULB-RESET
SCT-THROTTLE for "SG-EC354"	2	1
BACKFLOOD-SETPT for "SG-EC354"	80	68
SCT-AMBIENT-DT for "SG-EC354"	N/A	12
OVERRIDE-MIN-SCT for "SG-EC354"	N/A	70
SCT-CTRL for "SG-15380"	FIXED	DRYBULB-RESET
SCT-THROTTLE for "SG-15380"	2	1
BACKFLOOD-SETPT for "SG-15380"	80	68
SCT-AMBIENT-DT for "SG-15380"	N/A	12
OVERRIDE-MIN-SCT for "SG-15380"	N/A	70
SCT-CTRL for "SG-AF3BC"	FIXED	DRYBULB-RESET
SCT-THROTTLE for "SG-AF3BC"	2	1
BACKFLOOD-SETPT for "SG-AF3BC"	85	68
SCT-AMBIENT-DT for "SG-AF3BC"	N/A	12
OVERRIDE-MIN-SCT for "SG-AF3BC"	N/A	70
KW/FAN for "CONDENSER_SG-AF3BC"	1.92	1.12

Explanation of DOE2R/eQUEST keywords:

- SCT-CTRL: defines the control sequence for the saturated condensing temperature of the suction group.

- SCT-THROTTLE: defines the throttling temperature range for the SCT control sequence. For example, condenser fans will be at a maximum when the condensing temperature climbs to the top of the throttling range, and at a minimum/off when the condensing temperature is at the bottom of the throttling range.
- BACKFLOOD-SETPT: defines the saturated condensing temperature set point of the backflooding controls[64].
- SCT-AMBIENT-DT: Also known as the approach temperature (DT), it defines the differential temperature between the SCT and the outdoor dry-bulb temperature.
- OVERRIDE-MIN-SCT: Defines the lower limit on the SCT. As the SCT approaches this limit, the fans will modulate down. If condenser load is low and SCT exceeds this limit with the fans off, backflooding occurs.
- KW/FAN: defines the kW per fan.

The applicant/tracking savings are summarized below.

Table 116: Tracking savings for project IDs 6316395 and 6421680

Savings Quantity	Project ID 6316395	Project ID 6421680
Electric energy (kWh)	42,610	69,735
% of Energy Savings on Peak	46%	49%
Summer On-Peak Demand (kW)	4.9	4.8
Winter On-Peak Demand (kW)	4.9	12.8

Project Evaluation

Table 4 shows how the measures were verified to be installed and operating.

Table 117: Measure verification

Project ID	Verification Method	Verification Result
6316395: French-style doors with LEDS on existing refrigerated cases	Visual	Door count, model, and lighting type were confirmed to be installed
6421680: High-efficiency condenser with FHP controls	Visual and measurement	Condenser model and FHP controls were confirmed to be installed and operating

The M&V plan and project evaluation were generally conducted as planned. A site visit was performed on August 21, 2018, to install data loggers and collect information about the refrigeration systems. Data loggers were retrieved in January 2019.

[64] Backflooding the condenser prevents the SCT from dropping below the minimum set point during periods of low ambient temperature

The evaluation savings methodology that is explained in a later section was generally implemented as planned. The evaluator utilized the eQUEST models included in the tracking documentation and updated key input parameters with as-found measurements to estimate evaluated savings. The evaluator also performed a literature review of a specific ESG program evaluation and the main sources of display case door savings assumptions that the program assumes to drive measure savings. It was determined that the eQUEST model development methodology and key savings assumptions had been vetted by reputable organizations and were considered reasonable to use for this evaluation.

Data collection

The evaluator metering approach outlined in the M&V plan was implemented as planned.

Nameplate information was collected for the project-affected and ancillary equipment. This includes the "rack C" condenser, the compressor rack, refrigerated case doors, and refrigerated cases. The evaluator also collected operating setpoints for the compressor rack to confirm that FHP controls were implemented as claimed. An Elite Pro kW logger was installed on the "rack C" condenser – Bohn BNXD08A052. Spot power measurements (volts, amps, power factor, kW) were also taken for the entire condenser unit and for a single fan. A data logger with pipe temperature sensors was installed to measure the exterior pipe temperature of the condenser's liquid line. This measurement was intended to approximate the saturated condensing temperature. The pipe sensor was covered in a few layers of insulation tape; however, low outside air temperatures (and low condenser loads) proved to be dominating in the measurements. The illustration of this finding is shown later in the evaluation analysis section.

Weather data from a local station was collected from the NOAA website for August 2018 through January 2019.

The following table describes the types of time-series loggers and weather data collected for the evaluation.

Table 118: Data collection points

Data/equipment description	Data type	Logging duration (August 2018–January 2019)
Condenser C	Full unit kW	Approximately 22 weeks; 15-minute interval
Condenser C	Liquid line temperature °F	Approximately 22 weeks; 15-minute interval
NOAA hourly weather data	Dry-bulb and wet-bulb temperature	Approximately 22 weeks; 1-hour interval

Evaluation savings analysis

As discussed in the M&V plan for both projects, the evaluator utilized the eQUEST models as a basis for evaluation analyses.

The site visit verified the refrigerated display case door count, length, lighting type (LED), and display case contents. They matched what the applicant had described in the tracking documentation. Display case and case door model specifications were collected for the affected cases. Compressor rack and suction groups were identified and matched to the display cases they served.

The tracking documentation contained the refrigeration audit that appears to have been used as data input for informing the creation of the eQUEST model. That audit document was reviewed and compared to what was observed through the evaluator's on-site visit. The audit appeared complete and accurate.

The evaluator assessed the reasonableness of the assumptions made by the ESG program case door measure. Specifically, the effects that the "CONDUCTION/LEN" and "INF-LOAD/LEN" reduction factors (0.45 and 0.25, respectively) had on modeled refrigerated compressor and fixture fan usage were compared to another ASHRAE study that measured the effects of refrigerated case doors.[65]

To assess how those factors impacted energy consumption the evaluator adjusted all refrigeration fixtures by the same reduction factor as applied to the measure-affected fixtures. This resulted in a modeled 52% refrigeration compressor savings. This compared reasonably well (and conservative) to the 61% compressor savings estimated in the ASHRAE paper comparing a "no heat w/LED" doored display case to an open display case.

The evaluator considered the specific program measure assumptions noted in Table 114 to be reasonable. However, there were other adjustments that the evaluator made to the eQUEST model that was related to the operating conditions of the display cases and measure "count". The evaluator observed that the case temperature was reading 30 °F. The thermostat was located at the bottom of the case, near the evaporator fan. From this observation, the evaluator adjusted the modeled fixture supply setpoint from 35 °F to 33 °F. It was assumed that the thermostat reading of 30 °F was at the low end of the throttle range, which was modeled to be 3 °F.

The other adjustment that the evaluator made to the eQUEST model accounted for the total fixture length that was modeled to be affected by the measure. The total case length affected by the measure was modeled at 94 feet; however, the project claimed 100 feet. It appears that the modeler may have left out adjusting a 6-foot fixture (fixture "C09FFB") that was under the applicable suction group. The evaluator adjusted the eQUEST keywords values of the 6-foot fixture to match the proposed values of the other measure-affected fixtures. The evaluator changes are shown in the table below.

Table 119: Evaluation changes to PID 6316395 eQUEST model

DOE2R/eQUEST keyword	Tracking value	Evaluated value
CONDUCTION/LEN for fixture C09FFB (SG-EC354)	Base/proposed = 134.39	Base = 134.39 Proposed = 60.48
INF-LOAD/LEN for fixture C09FFB (SG-EC354)	Base/proposed = 1209	Base = 1209 Proposed = 302.3
CANOPY-KW/LEN for fixture C09FFB (SG-EC354)	Base/proposed = 0.024	Base = 0.024 Proposed = 0.0077
SST-SUPPLY-TD for fixture C09FFB (SG-EC354)	Base/proposed = 7	Base = 7 Proposed = 4
TEMP-SETPT for fixture C17FFB	Base/proposed = 35	Base/proposed = 33
TEMP-SETPT for fixture C1AFFB	Base/proposed = 35	Base/proposed = 33

[65] B.A. Fricke, PhD, B.R. Becker, PhD, PE. *Comparison of Vertical Display Cases: Energy and Productivity Impacts of Glass Versus Open Vertical Display Cases. The paper was based on findings resulting from ASHRAE Research Paper RP-1402*

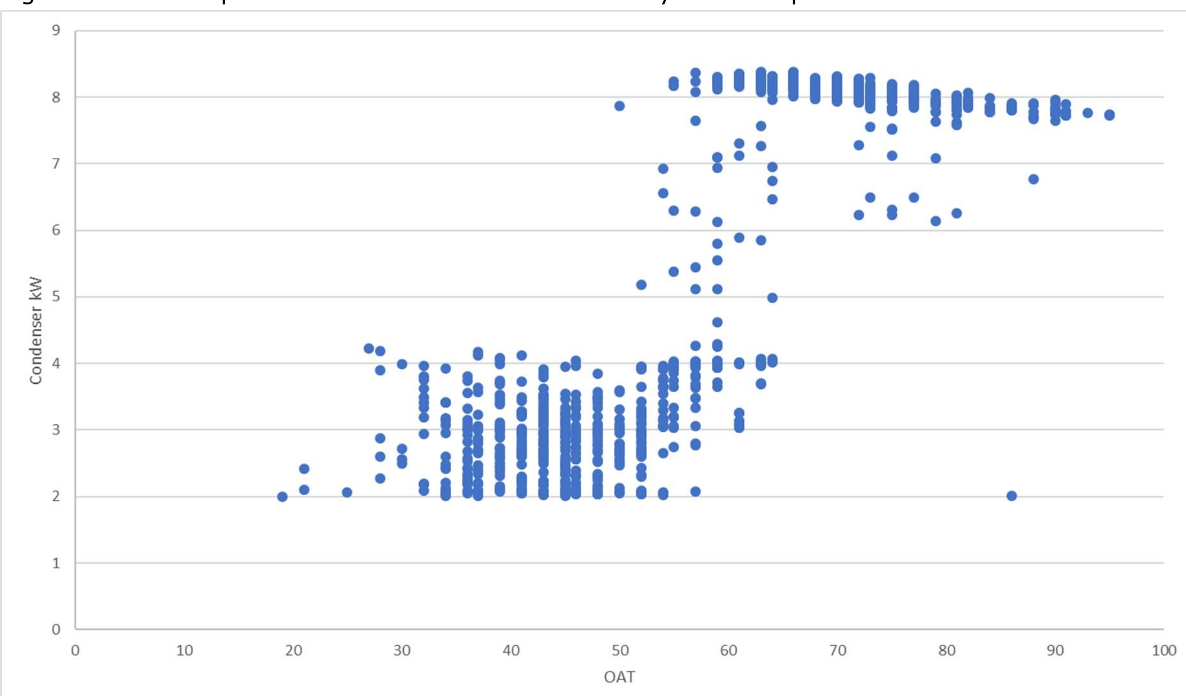
TEMP-SETPT for fixture C22FFB	Base/proposed = 35	Base/proposed = 33
TEMP-SETPT for fixture C20FFB	Base/proposed = 35	Base/proposed = 33
TEMP-SETPT for fixture C09FFB	Base/proposed = 35	Base/proposed = 33

Project ID 6421680

The savings analysis began with visualizing the condenser power and temperature logger data. Reviewing the data visualization would inform the evaluator on how to update the relevant eQUEST keyword values. The evaluator also reviewed whether the eQUEST keyword changes made by the applicant were reasonable to use as drivers for the measure savings.

The condenser was observed to operate continuously over the metering period and, as visualized in Figure 30, condenser capacity increased with lower outside air temperature. This is evident because, assuming that refrigeration load remained similar over the metering period, the condenser did not have to operate its fans to assist in rejecting heat as frequently when outside air temperature dropped.

Figure 30: Scatterplot of condenser kW and outside dry-bulb temperature



Single fan spot power measurements were measured to be 0.938 kW. This value was used to update the KW/FAN eQUEST parameter.

The condenser temperature logger data measured saturated condensing temperature. As discussed in the data collection section, the effects of low condenser load (i.e., low liquid refrigerant flow) and low outside air temperature caused the ambient pipe temperature to dominate the sensor's measurement[66]. Figure 31 below illustrates the temperature compared to the outside dry-bulb temperature. As a reference, the ideal saturated condensing temperature line is also shown. The ideal SCT has a minimum/maximum temperature of 70 °F/95 °F and a TD of 10 °F. This is based on the observed FHP controls set points found on the rack C compressor controller interface (see Figure 32).

Figure 31: Scatterplot of Measured SCT and outside dry-bulb temperature

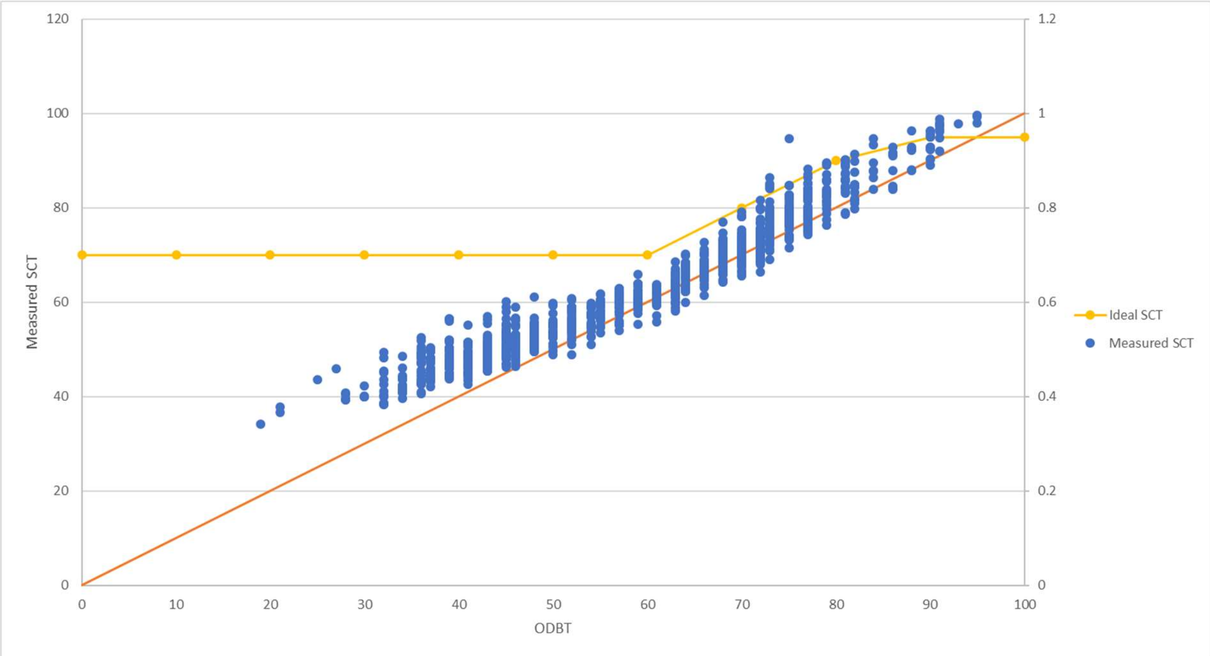
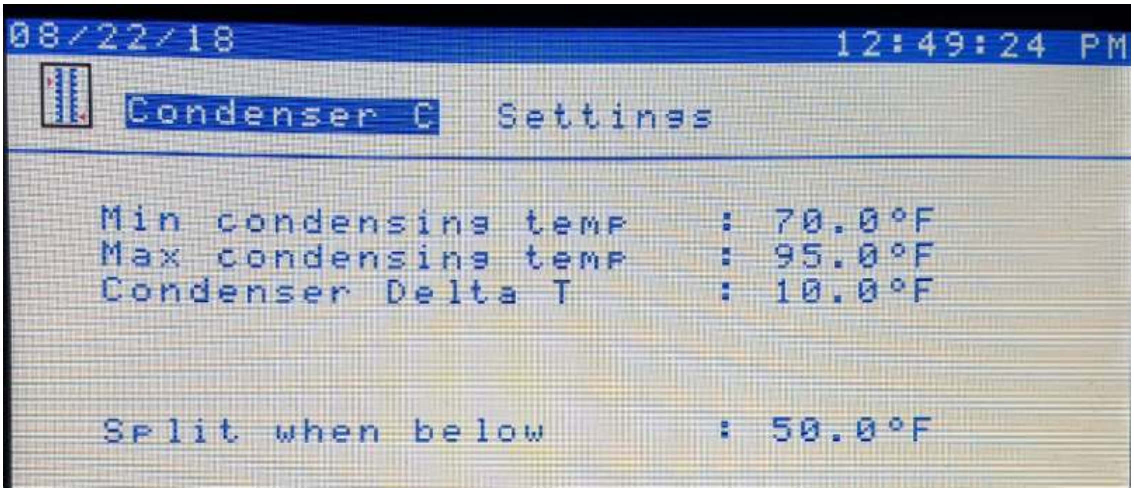


Figure 32: Rack C controller floating head pressure settings



[66] The pipe sensor was located on the exterior surface of the refrigerant pipe and was covered in a few layers of insulation tape. The sensor's measurement is a combination of heat conducted by the refrigerant flowing through the pipe (and the pipe itself) and the heat convection of air surrounding the pipe.

The evaluator decided that the temperature data could not be used specifically to adjust the eQUEST parameters defining SCT set points. Instead, the data was used to corroborate the FHP settings found in the rack C controller interface.

The following table shows the difference between tracking and evaluated eQUEST keyword values and why the evaluator adjusted the values. A relatively significant adjustment involved removing suction group "SG-15380" and "SG-EC354" keyword changes; the evaluator believes that these changes were made in error in the tracking models because those suction groups were not affected by the measure. Only suction group "SG-AF3BC" (rack C) was affected by the condenser and FHP controls upgrade claimed under this project.

Table 120: Evaluation changes to PID 6421680 proposed eQUEST model

DOE2R/eQUEST keyword	Base Case value - tracking	Proposed case value - tracking	Proposed case value - evaluated	Reason for change
SCT-CTRL for "SG-EC354"	FIXED	DRYBULB-RESET	FIXED	Measure did not affect suction group
SCT-THROTTLE for "SG-EC354"	2	1	2	Measure did not affect suction group
BACKFLOOD-SETPT for "SG-EC354"	80	68	80	Measure did not affect suction group
SCT-AMBIENT-DT for "SG-EC354"	N/A	12	N/A	Measure did not affect suction group
OVERRIDE-MIN-SCT for "SG-EC354"	N/A	70	N/A	Measure did not affect suction group
SCT-CTRL for "SG-15380"	FIXED	DRYBULB-RESET	FIXED	Measure did not affect suction group
SCT-THROTTLE for "SG-15380"	2	1	2	Measure did not affect suction group
BACKFLOOD-SETPT for "SG-15380"	80	68	80	Measure did not affect suction group
SCT-AMBIENT-DT for "SG-15380"	N/A	12	N/A	Measure did not affect suction group
OVERRIDE-MIN-SCT for "SG-15380"	N/A	70	N/A	Measure did not affect suction group
SCT-CTRL for "SG-AF3BC"	FIXED	DRYBULB-RESET	DRYBULB-RESET	N/A
SCT-THROTTLE for "SG-AF3BC"	2	1	1	N/A
BACKFLOOD-SETPT for "SG-AF3BC"	85	68	68	N/A
SCT-AMBIENT-DT for "SG-AF3BC"	N/A	12	10	As found setting
OVERRIDE-MIN-SCT for "SG-AF3BC"	N/A	70	70	As found setting
OVERRIDE-MAX-SCT for "SG-AF3BC"	N/A	87	95	As found setting
KW/FAN for "CONDENSER_SG-AF3BC"	1.92	1.12	0.938	Measured value

Evaluation Results

The evaluated savings are presented in this section. This section also presents a comparison of key parameters and discrepancy analysis.

The combination of eQUEST model changes described in the evaluation savings analysis section for 6316395 and 6421680 adjusted the tracking savings to the evaluated savings. Table 121 and Table 122 present the evaluated savings for project ID 6316395 and 6421680, respectively. Table 123 presents the combined results.

Table 121: Project 6316395 evaluation results

Project	Savings Quantity	Tracking Estimate	Evaluation Estimate	Realization Rate
6316395: French-style doors with LEDS on existing refrigerated cases	Electric energy (kWh)	42,610	50,183	118%
	% of Energy Savings on Peak	46%	43%	95%
	Summer On-Peak Demand (kW)	4.9	2.5	52%
	Winter On-Peak Demand (kW)	4.9	5.4	111%

Table 122: Project 6421680 evaluation results

Project	Savings Quantity	Tracking Estimate	Evaluation Estimate	Realization Rate
6421680: High efficiency condenser with FHP controls	Electric energy (kWh)	69,735	51,733	74%
	% of Energy Savings on Peak	49%	51%	103%
	Summer On-Peak Demand (kW)	4.8	6.2	128%
	Winter On-Peak Demand (kW)	12.8	5.2	41%

Table 123: Combined evaluation results

Project	Savings Quantity	Tracking Estimate	Evaluation Estimate	Realization Rate
Combined total of 6316395 and 6421680	Electric energy (kWh)	112,345	101,916	91%
	% of Energy Savings on Peak	48%	47%	98%
	Summer On-Peak Demand (kW)	9.7	8.7	90%
	Winter On-Peak Demand (kW)	17.7	10.6	60%

Comparison of savings parameters

The evaluations' savings methods used the eQUEST models that were used to estimate the tracking savings. However, the models were updated with operating conditions and setpoints that were applicable to affected equipment. Comparisons of tracking and evaluated eQUEST keyword values were made for each project in the evaluation analysis section. Other comparisons are made in the discrepancy analysis section.

Discrepancy analysis

This section describes the key drivers behind differences in the tracking and evaluation of savings estimates. Table 124 and Table 125 summarize these differences. The purpose of this analysis is to measure and describe how changes to eQUEST keyword values influenced the final project savings.

Table 124: Discrepancy analysis results for project ID 6316395

Discrepancy	kWh	Peak Summer kW	Peak Winter kW	% on peak
Tracking Savings (no changes)	42,610	4.9	4.9	46%
Discrepancy #1 (Tracking models run using eQUEST Refrigeration v.3.65.7173)	3%	-55%	-3%	-6%
Discrepancy #2 (Changed the fixture supply temperature of affected cases from 35 °F to 33 °F)	5%	-5%	4%	0%
Discrepancy #3 (Added fixture C09FBB to affected cases. This adjusts the modeled fixture length affected by measure from 94 feet to 100 feet)	10%	13%	9%	0%
Final Evaluated GRR %	118%	52%	111%	43%

Table 125: Discrepancy analysis results for project ID 6421680

Discrepancy	kWh	Peak Summer kW	Peak Winter kW	% on peak
Tracking Savings (no changes)	69,735	4.8	12.8	49%
Discrepancy #1 (Tracking models run using eQUEST Refrigeration v.3.65.7173)	1%	-5%	-21%	-3%
Discrepancy #2 (Changed condenser kW/fan from 1.12 to 0.938)	5%	18%	1%	1%
Discrepancy #3 (Changed max SCT from 87 °F to 95 °F and approach temp from 12 °F to 10 °F)	2%	17%	0%	1%
Discrepancy #4 (Reverted post model changes of suction groups SG-EC354 and SG-15380 back to base model values)	-34%	-2%	-39%	5%
Final Evaluated GRR %	74%	128%	41%	103%

The tables above illustrate sequential discrete changes made to the eQUEST models and the corresponding effect the change has on savings estimate relative to the tracking savings. For example, the first line ("Tracking Savings") lists the savings claimed in the tracking data. The next line, "Discrepancy #1", illustrates the impact made (in % of tracking savings) by the discrepancy. The final evaluated gross realization rate (GRR) line at the bottom is equal to 100% (tracking savings) plus the sum of discrepancy lines.

<u>Project ID 6316395</u>

Discrepancy #1 (Tracking models run using eQUEST Refrigeration v.3.65.7173)

This discrepancy accounts for the difference between the savings claimed in the tracking documentation and the savings when the eQUEST model was run by the evaluator. While the evaluator cannot explain with certainty why the discrepancy exists, differences in kWh savings are often a result of using different program versions or from different output result calculations (e.g., tracking may have used rounded values). Differences in peak demand reduction and ON peak % are usually a result of the calculation method. For example, the tracking calculation assumes an operating schedule and divides the kWh savings evenly by the assumed operating hours' estimate. The evaluator uses an 8,760 peak profile.

Discrepancy #2 (Changed the fixture supply temperature of affected cases from 35 °F to 33 °F)

This discrepancy was discussed in the evaluation savings analysis section. The evaluator found that 33 °F would reflect observed display case temperatures more accurately than the tracking assumption. The discrepancy had a small effect on savings, increasing estimate kWh savings by 5%.

Discrepancy #3 (Added fixture C09FBB to affected cases. This adjusts the modeled fixture length affected by measure from 94 feet to 100 feet)

This discrepancy addresses what amounts to an incorrect measure count. The tracking eQUEST model-simulated changes due to the case door measure for 94 feet of refrigerated fixtures (cases). However, the tracking documentation (confirmed by the evaluator’s site visit) claims 100 feet of display cases were retrofitted with case doors. This discrepancy adjustment increases kWh savings by 2%.

<u>Project ID 6421680</u>

Discrepancy #1 (Tracking models run using eQUEST Refrigeration v.3.65.7173)

This discrepancy accounts for the difference between the savings claimed in the tracking documentation and the savings when the eQUEST model was run by the evaluator. While the evaluator cannot explain with certainty why the discrepancy exists, differences in kWh savings are often a result of using different program versions or from different output result calculations (e.g., tracking may have used rounded values). Differences in peak demand reduction and ON peak % are usually a result of the calculation method. For example, the tracking calculation assumes an operating schedule and divides the kWh savings evenly by the assumed operating hours' estimate. The evaluator uses an 8,760 peak profile.

Discrepancy #2 (Changed condenser kW/fan from 1.12 to 0.938)

This discrepancy accounts for the difference in the modeled condenser fan efficiency (in kW/fan). The evaluator measured the condenser fan power and determined it to be 0.938 kW/fan. This discrepancy increased kWh savings by 5%.

Discrepancy #3 (Changed max SCT from 87 °F to 95 °F and approach temp from 12 °F to 10 °F)

The evaluator found that the operating conditions for the FHP controls were different than what was modeled in eQUEST. The maximum SCT set point had not been entered in the tracking mode; the evaluator entered a maximum SCT value of 95 °F. Also, the approach temperature was adjusted from the tracking value of 12 °F to the observed value of 10 °F. This discrepancy had a small effect on savings, increasing kWh savings by 2%.

Discrepancy #4 (Reverted post model changes of suction groups SG-EC354 and SG-15380 back to base model values)

The tracking model adjusted suction groups unrelated to the “rack C” condenser and FHP controls upgrades that were claimed by the project. The evaluator believes that this may have been a mistake in the “parametric run” – a function in eQUEST that allows the modeler to make modifications to the base model without creating a whole new model (i.e., “save as” base model to another name and then change) to represent the proposed case. The parametric run representing the measure de-selected the condensers not affected by the measure but did not de-select the suction groups not affected by the measure. This discrepancy adjustment had the largest effect on savings, decreasing kWh savings by 34%.

Site ID:2016RIN125

Project ID(s)	6594244
Project Type	Retrofit
Program Year	2016
Evaluation Engineer	Chris Williams
Senior Engineer	C.D. Nayak

Project Description

This site report details the impact evaluation for project ID 6594244. This project upgraded existing variable speed controls for the supply air fans of two existing rooftop units (RTUs). The supply fan motors are 15 HP and 20 HP and serve a grocery store. The upgraded VFDs optimize the supply fan speed according to programmed operating modes (e.g., cooling, ventilation only, etc.).

The table below summarizes the evaluation results.

Table 126: Project results for 2016RIN125

Project	Savings Quantity	Tracking Estimate	Evaluation Estimate	Realization Rate
Upgraded variable speed controls for 15 HP and 20 HP RTU supply fans	Electric energy (kWh)	46,646	15,022	32%
	% of Energy Savings on Peak	67%	56%	84%
	Summer On-Peak Demand (kW)	9.5	6.5	68%
	Winter On-Peak Demand (kW)	4.0	-0.4	-10%

The bullets below explain some key discrepancy findings:

- Higher post case fan speed: The target fan speeds assumed in the tracking calculations for cooling and heating modes did not match the observed fan speeds. The observed fan speeds were higher than what was assumed in tracking, reducing energy savings by 31%.
- Calculation method: The evaluator used a step function method to regress observed fan speeds and fan power to outside air temperature. This method was very different than the method used in the tracking calculation. Fan motor kW estimates were also improved, from tracking calculations using fan affinity laws to estimate fan kW to the evaluated calculations using a measured speed-to-kW relationship developed from multiple spot power measurements. The fans were observed to operate at higher fan speeds than predicted in the tracking calculation, with AHU-1 operating on average at 67% and AHU-2 operating on average at 71%. The tracking assumptions proposed that the AHU-1/AHU-2 fan speeds would average at 54%. This discrepancy reducing energy savings by 37%.

Tracking Savings

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

Baseline condition

The baseline equipment and conditions for the project are summarized in the table below. The affected equipment specifically is the supply fans for AHU-1 and AHU-2. The AHU-1 supply fan is 15 HP and the AHU-2 supply fan is 20 HP.

Table 127 documents the percentage annual operating hours and baseline percentage speed of AHU-1 during ventilation, heating and cooling modes. Table 128 documents the percentage annual operating hours and baseline percentage speed of AHU-2 during ventilation, heating and cooling modes.

Table 127: Baseline conditions for AHU-1

AHU-1 Operating Mode	% of annual hour (8,760 total)	Baseline VFD speed
Ventilation only	27%	62%
Heat Stage 1	35%	85%
Heat Stage 2	13%	85%
Cool Stage 1	13%	90%
Cool Stage 2	12%	90%

Table 128: Baseline conditions for AHU-2

AHU-2 Operating Mode	% of annual hour (8,760 total)	Baseline VFD speed
Ventilation only	27%	50%
Heat Stage 1	8%	50%
Heat Stage 2	27%	50%
Heat Stage 3	10%	85%
Heat Stage 4	2%	85%
Cool Stage 1	13%	85%
Cool Stage 2	12%	85%

Proposed condition

The measure does not affect equipment operating schedules; both AHUs are assumed to continue operating 8,760 hours per year. The measure upgrades the supply fan VFD and reprograms them to operate at optimal speeds for each operating mode.

The proposed conditions are summarized in the tables below.

Table 129: Proposed conditions for AHU-1

AHU-1 Operating Mode	% of annual hour (8,760 total)	Proposed VFD speed
Ventilation only	27%	50%
Aux Heat	35%	53%
Heat Stage 2	13%	53%
Cool	13%	61%
Cool Stage 2	12%	61%

Table 130: Proposed conditions for AHU-2

AHU-2 Operating Mode	% of annual hour (8,760 total)	Proposed VFD speed
Ventilation only	27%	50%
Heat Reclaim	8%	53%
Heat Stage 2	27%	53%
Aux Heat	10%	53%
Heat Stage 4	2%	53%
Cool	13%	61%
Cool Stage 2	12%	61%

Tracking calculation methodology

Spreadsheet calculations were used to estimate measure savings. Some of the assumed operating conditions and savings parameter values were based on pre-implementation measurements like spot power measurements at full speed (60 Hz). The applicant methodology and savings results are discussed below.

The tracking savings assumes that both RTUs operate continuously 8,760 hours per year. The savings method uses an operating hour bin calculation which breaks down the annual operating hours into operating mode bins. Each operating mode bin has a corresponding supply fan speed. The proposed case assumes a different and more efficient distribution of operating modes and corresponding fan speeds. With the fans proposed to operate at lower speeds than in the base case, fan energy savings are realized. Table 131 and Table 132 provides the percentage of fan speed reductions at different operating modes for AHU-1 and AHU-2.

Table 131: Difference between AHU-1 baseline and proposed fan speeds

AHU-1 Operating Mode	% of annual hour (8,760 total)	% Speed difference (pre-post)
Ventilation only	27%	12%
Aux Heat	35%	32%
Heat Stage 2	13%	32%
Cool	13%	29%
Cool Stage 2	12%	29%

Table 132: Difference between AHU-2 baseline and proposed fan speeds

AHU-2 Operating Mode	% of annual hour (8,760 total)	% Speed difference (pre-post)
Ventilation only	27%	0%
Heat Reclaim	8%	-3%
Heat Stage 2	27%	-3%
Aux Heat	10%	32%
Heat Stage 4	2%	32%
Cool	13%	24%
Cool Stage 2	12%	24%

The applicant estimated the full speed supply fan motor power (kW) of AHU-1 and AHU-2 by measuring volts and amps and assuming a power factor of 0.9.

Fan power (kW) = volts x amps x 0.9 x 1.73 / 1000[67]

Table 133: AHU full speed kW

AHU	Supply Fan HP	Estimated full speed kW
AHU-1	15	9.3
AHU-2	20	12.6

Savings are calculated by applying the difference in fan speeds between pre and postconditions, and the assumed fan affinity law equating power to the cube of the % fan speed.

67 Volts measured phase-phase, and amps measured from each phase, then averaged together

Demand reduction (kW) = (Pre-speed%^3 – Post-speed^3) x Full speed fan power

kWh savings for operating mode = Demand reduction x 8,760 hours x % of annual hours

Table 134: AHU-1 kWh savings by operating mode

AHU-1 Operating Mode	% of annual hours	Demand reduction (kW)	kWh savings
Ventilation only	27%	1.01	2,400
Aux Heat	35%	4.30	13,196
Heat Stage 2	13%	4.30	4,901
Cool	13%	4.64	5,289
Cool Stage 2	12%	4.64	4,882
Total		18.91	30,667

Table 135: AHU-2 kWh savings by operating mode

AHU-2 Operating Mode	% of annual hour	Demand reduction (kW)	kWh savings
Ventilation only	27%	0	0
Heat Reclaim	8%	-0.3	-217
Heat Stage 2	27%	-0.3	-720
Aux Heat	10%	5.85	5,036
Heat Stage 4	2%	5.85	1,213
Cool	13%	4.87	5,547
Cool Stage 2	12%	4.87	5,120
Total		20.85	15,979

The summer and winter peak demand reduction are estimated by assuming all summer/winter peak hours coincide with the "cool stage 2" or "heat stage 2" operating modes. Using this assumption, the summer/winter peak demand reduction is the demand reduction estimated for those operating modes.

The applicant/tracking savings are summarized below.

Table 136: Tracking savings for project ID 6594244

Project	Savings Quantity	AHU-1	AHU-2	Total
Upgraded variable speed controls for 15 HP and 20 HP RTU supply fans	Electric energy (kWh)	30,667	15,979	46,646
	% of Energy Savings on Peak	61%	67%	67%
	Summer On-Peak Demand (kW)	4.6	4.9	9.5
	Winter On-Peak Demand (kW)	4.3	-0.3	4.0

Project Evaluation

Table 4 shows how the measure was verified to be installed and operating. There were some critical findings that occurred during the meter pickup and analysis that are noted in the data collection section.

Table 137: Measure verification

AHU	Verification Method	Verification Result

AHU-1 (15 HP supply fan)	Visual	VFD observed to be operating in auto mode at 42 Hz
AHU-2 (20 HP supply fan)	Visual	VFD observed to be operating in auto mode at 42 Hz

The M&V plan and project evaluation were generally conducted as planned. A site visit was performed on August 22, 2018, to install data loggers and interview the site contact.

The evaluation savings methodology that is explained in a later section was generally implemented as planned. The evaluator did not acquire specific operating modes from the controls contractor so the alternate evaluation plan (regressing fan speed to outside air temperature) was utilized to estimate 8,760-hour usage profiles for the proposed and baseline scenarios. Specific discrepancies were found that attributed to the difference between evaluated and tracking savings estimates. Those discrepancies are described at the end of the report.

Data collection

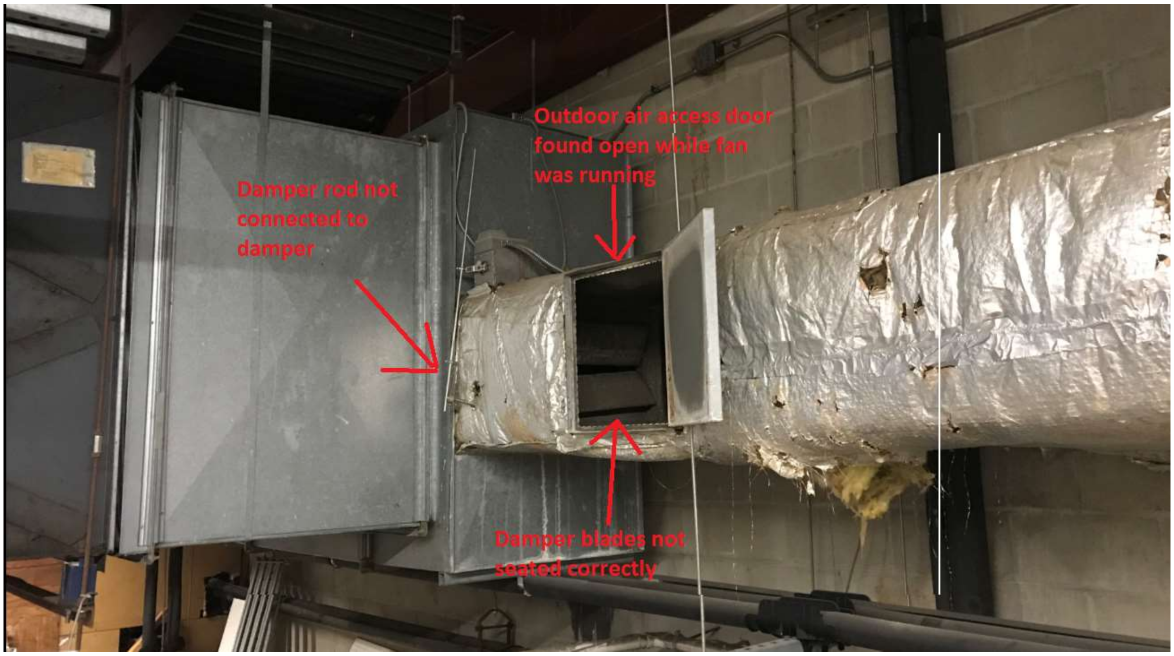
The evaluator metering approach outlined in the M&V plan was implemented as planned.

The site contact (store manager) could not provide information about the HVAC schedule or operating conditions. The contact claimed that HVAC schedules, setpoints, and operating modes are controlled remotely by a third-party contractor. The evaluator attempted several times via e-mail and cell phone to contact the contractor; unfortunately, the evaluator did not get a response from the contractor.

Nameplate information was collected for both AHU-1 and AHU-2. Elite Pro kW loggers were installed on the AHU-1 and AHU-2 supply fan motors. Spot power measurements (volts, amps, power factor, kW, fan speed) were taken at two different fan speeds. The evaluator utilized the spot power measurements taken by the applicant to estimate full speed power. Data loggers were installed on August 22, 2018, and retrieved in January 2019; however, some critical findings prevented the evaluator from utilizing the entire metering period.

During the pick-up visit, AHU-1 was found to be operating at 30 Hz in “hand” mode which means that the VFD speed was manually set and not following the program set in the VFD. Additionally, the outside air damper appeared to be inoperable and the outside air ducting was being bypassed with the damper access hatch left open to conditioned space. Logger data appears to show that the fan was placed into a manual “hand” operation on December 6th, 2018.

Figure 33: AHU-1 outside air damper/duct condition during logger pick-up



The data logger that was installed on AHU-2 had been removed before the pick-up site visit. The evaluator suspects that AHU-2, specifically the supply fan motor drive, had been serviced during the metering period and that the HVAC technician had removed the evaluator's data logger. The data logger's last recorded time was on November 29th, 2018.

Weather data was collected from the NOAA website in October 2018. Another attempt to retrieve weather data through the remaining metering period was not successful due to the ongoing (as of January 24, 2019) partial closure of the U.S. Government.

The following table describes the types of time-series loggers and weather data collected for the evaluation.

Table 138: Data collection points

Data/equipment description	Data type	Logging duration (August 2018–January 2019)
AHU-1 15 HP supply fan	Full unit kW	Approximately 14 weeks; 15-minute interval
AHU-2 20 HP supply fan	Current (amps) of single phase of 3 phase connection	Approximately 13 weeks; 15-minute interval
NOAA hourly weather data	Dry-bulb and wet-bulb temperature	Approximately 10 weeks; 1-hour interval

Evaluation savings analysis

The savings analysis began with converting the logger data (kW) into corresponding fan speeds using the spot power measurements that correlated fan speed to fan kW.

The logger data were visually analyzed to determine if there were discrete fan speeds that reasonably matched the fan speeds documented for the proposed operating modes. While there were some discrete fan speeds that appeared to correspond to heating and cooling modes (because they tended to be during periods of high and low outside air temperature), there were also periods in the data where the fan speeds were scattered and inconsistent with the operating fan speeds that were expected to be seen. Scatterplots for AHU-1 and AHU-2 fan speeds are illustrated in the figures below.

Figure 34: Average speed % for AHU-1 versus outside air temperature (8/22 – 10/26)

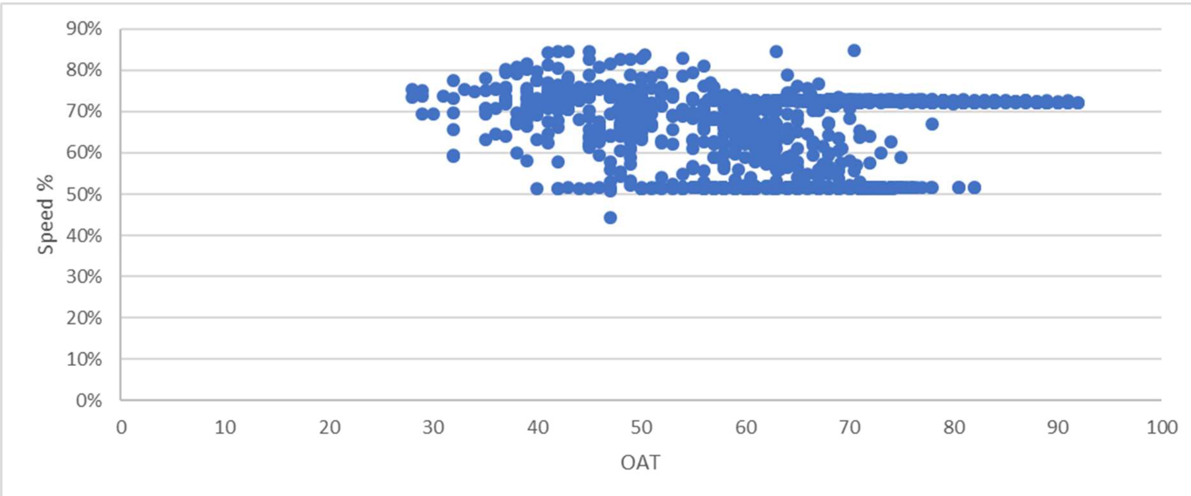
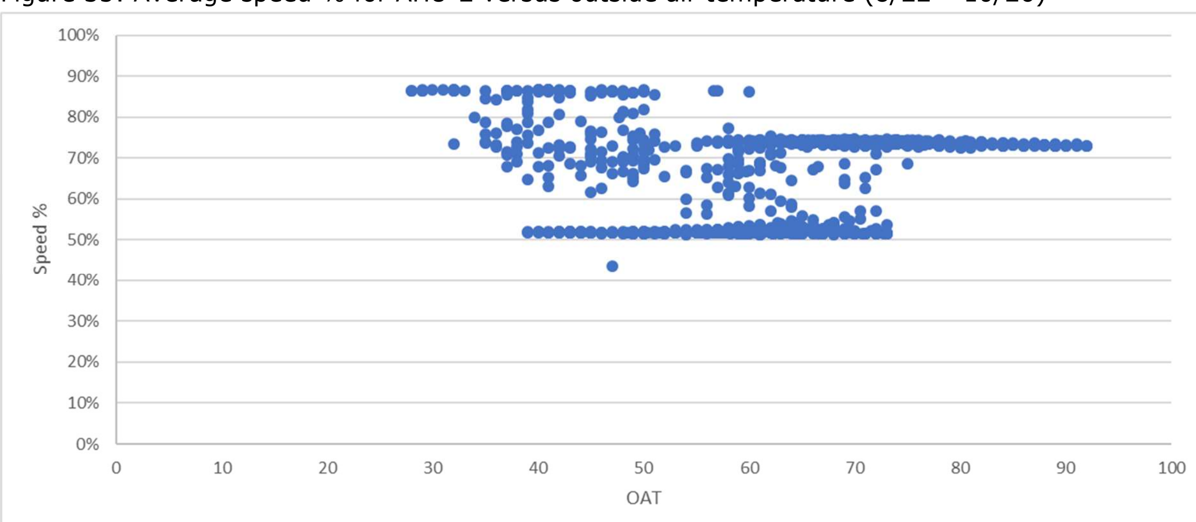


Figure 35: Average speed % for AHU-2 versus outside air temperature (8/22 – 10/26)



The evaluator could not assign specific operating modes (e.g., heating, cooling, ventilation only) to the observed fan kW/speed data. However, there were definitive periods where the fan speed (i.e., operating mode) was consistent with observed outside air temperatures. For example, in Figure 35, the fan speed is approximately 72% for outside air temperatures above 74 °F. Similarly, for temperatures below 33 °F, the fan speed is approximately 87%. However, there are also temperature ranges where multiple discrete fan speeds (operating modes) are observed. From approximately 40 °F up to 73 °F, AHU-2 data contains three observable discrete fan speeds (~87%, ~52%, and ~72%) mixed with pockets of random fan speed data points. The evaluator also analyzed the fan speed data along a time series axis to determine if the fan speeds were schedule-driven; however, that exercise showed that the AHU fans run continuously and do not adjust, for example, from heating/cooling during the occupied periods, to ventilation only (or another mode) during unoccupied periods.

The evaluator decided to regress fan speed to outside air temperature using step functions defined by outside temperature ranges. The temperature ranges were chosen using visual judgment to best fit groups of fan speed data. The step regression functions predicting fan speed are shown in the figures below.

Figure 36: Predicted AHU-1 fan speed as a function of outside air temperature

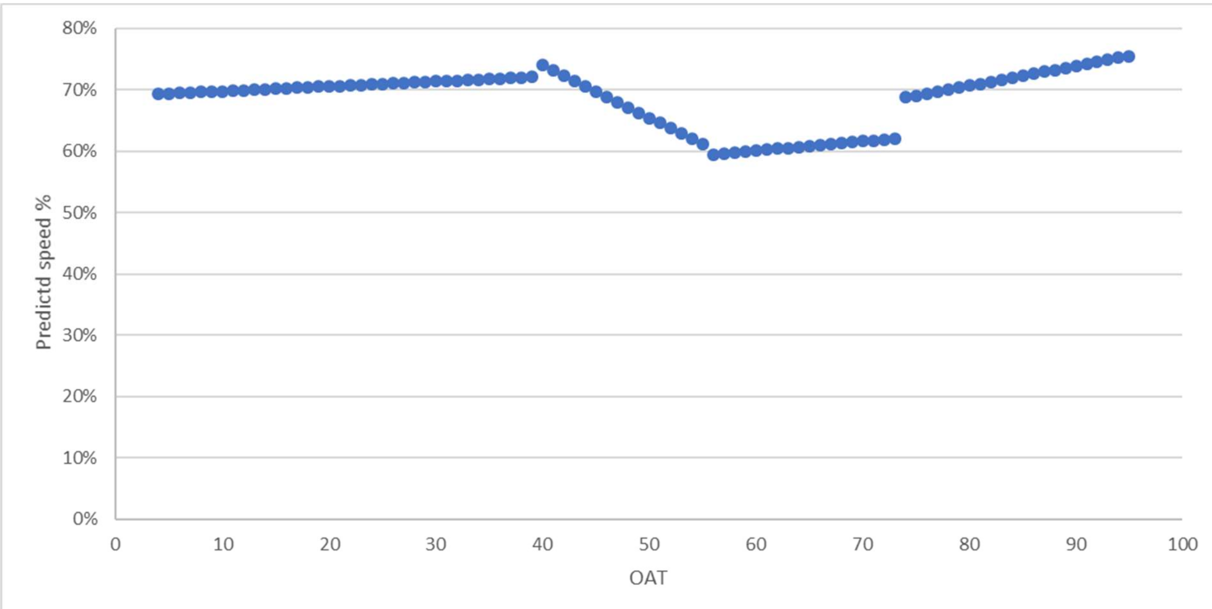
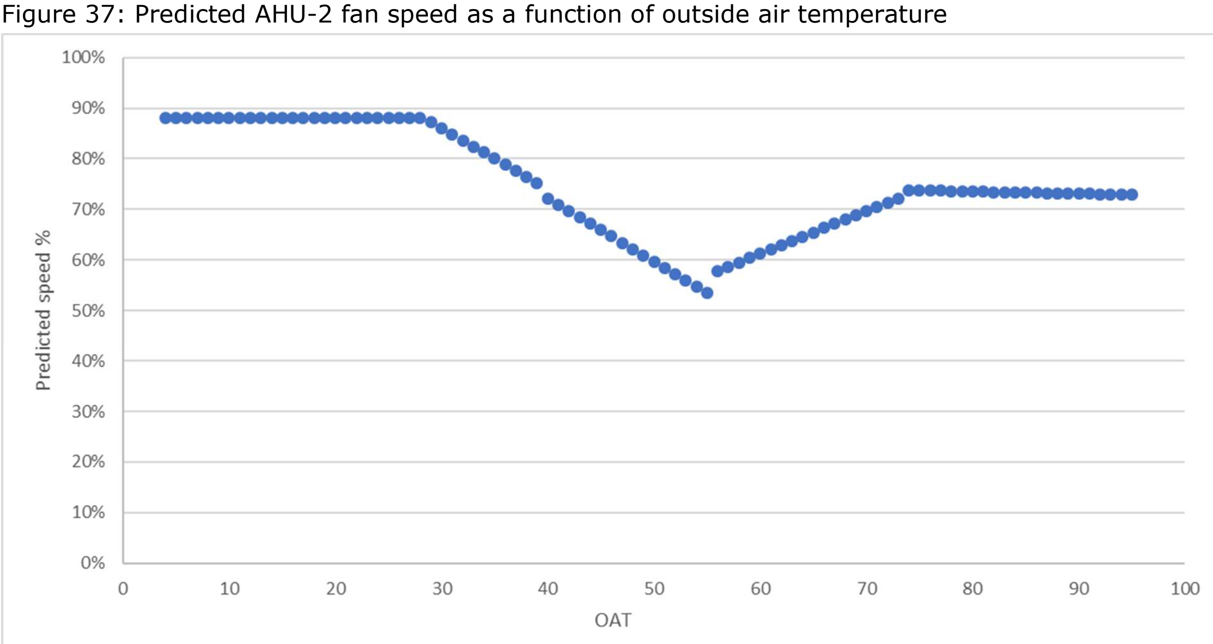


Figure 37: Predicted AHU-2 fan speed as a function of outside air temperature



The evaluator then used TMY3 hourly weather data to predict corresponding hourly fan speed and fan kW for the AHU-1 and AHU-2 supply fans. This generated the installed 8,760-hour demand (kW) profiles for the AHU-1 and AHU-2 supply fans.

Baseline operating mode or fan speed data was not available for the evaluator to collect. Without specific data describing baseline operating conditions or characteristics, the evaluator resorted to using the tracking estimates for operating modes and time distribution of those operating modes to estimate the baseline 8,760-hour demand profiles for the AHU-1 and AHU-2 supply air fans. The tracking baseline distribution of % time spent in the various operating modes, shown in

Table 127 and Table 128, were applied to the TMY3 8,760-hour such that the % time for each operating mode remained as closely equivalent as possible to the baseline values. There were minor differences due to the expansion of % time values to an 8,760-hour profile. The mapping of the operating modes was also assumed to be temperature-dependent, as shown in the tables below.

Table 139: Evaluated baseline operating mode conditions for AHU-1

AHU-1 Operating Mode	Tracking % of annual hour (8,760 total)	Baseline VFD speed	TMY °F range	Evaluated % of annual hour (8,760 total)
Ventilation only	27%	62%	50 – 66	28%
Heating Stages	48%	85%	4 – 49	48%
Cooling Stages	25%	85%	67 - 95	24%

Table 140: Evaluated baseline operating mode conditions for AHU-2

AHU-2 Operating Mode	Tracking % of annual hour (8,760 total)	Baseline VFD speed	TMY °F range	Evaluated % of annual hour (8,760 total)
Ventilation + Heating Stage 1 + 2	63%	50%	30 - 65	62%
Heating Stage 3 + 4	12%	85%	4 – 29	13%
Cooling Stages	25%	85%	66 - 95	26%

Using the distribution of operating modes and corresponding fan speeds described in the tables above, the evaluator used the 8,760-hour TMY3 weather data to assign fan speeds and corresponding fan kW to each hour. This generated the evaluated baseline 8,760-hour demand profile. The evaluated energy (kWh) savings is equal to the difference between the evaluated installed and baseline 8,760-hour demand profiles.

Evaluation Results

The evaluated savings are presented in this section. This section also presents a comparison of key parameters and discrepancy analysis.

The table below summarizes the evaluated savings for project ID 6594244.

Table 141: Project results

Project	Savings Quantity	Tracking Estimate	Evaluation Estimate	Realization Rate
Upgraded variable speed controls for 15 HP and 20 HP RTU supply fans	Electric energy (kWh)	46,646	15,022	32%
	% of Energy Savings on Peak	67%	56%	84%
	Summer On-Peak Demand (kW)	9.5	6.5	68%

	Winter On-Peak Demand (kW)	4.0	-0.4	-10%

Comparison of savings parameters

The evaluations' savings methods use savings parameters that sometimes cannot be directly compared to the savings parameters used in the applicant savings methods. Comparisons of tracking and evaluated savings parameter values were made when it was practical to do so. These comparisons are presented in the table below. Other comparisons are made in the discrepancy analysis section.

Table 142: Comparison of Key Parameters[68]

	AHU-1		AHU-2	
Parameter	Tracking Value(s)	Evaluation Value(s)	Tracking Value(s)	Evaluation Value(s)
Fan kW at 90%	6.7	6.4	N/A	
Fan kW at 85%	5.7	5.1	7.7	7.4
Fan kW at 62%	2.2	1.6	N/A	
Fan kW at 50%	N/A		1.6	1.8
Proposed cooling speed %	61%	72%	61%	74%
Proposed auxiliary heat speed %	N/A		53%	86%
Operating hours	8,760			
Average proposed fan speed	54%	67%	54%	71%
Baseline annual kWh	43,796	38,728	33,803	34,398

Discrepancy analysis

This section describes the key drivers behind differences in the tracking and evaluation savings estimates. The following table will be used to summarize these differences. The purpose of this analysis is to measure and describe how changes to the comparable key parameters or savings methods influenced the final project savings.

Table 143: Discrepancy analysis results

Discrepancy	kWh	Peak Summer kW	Peak Winter kW	% on peak
Tracking Savings (no changes)	46,646	9.5	4.0	67%
Discrepancy #1 (Difference in cooling target fan speeds for AHU-1/AHU-2 and heating target fan speeds for AHU-2	-31%	-38%	0%	0%
Discrepancy #2 (Calculation method – remaining difference in proposed target fan speeds and estimated fan kW)	-37%	6%	-110%	-16%
Final Evaluated GRR %	32%	68%	-10%	84%

The table above illustrates sequential discrete changes made to savings parameter values or savings methods and the corresponding effect the change has on savings estimate relative to the tracking savings. For example, the first line ("Tracking Savings") lists the savings claimed in the tracking data. The next line, "Discrepancy #1", illustrates the impact made (in % of tracking savings) by the discrepancy. The final

68 "N/A" entries mean that either (1) those specific parameter values do not show up in the tracking calculations, so they are not comparable; or (2) the parameter does not technically exist in the evaluation savings method

evaluated gross realization rate (GRR) line at the bottom is equal to 100% (tracking savings) plus the sum of discrepancy lines.

Discrepancy #1 (Difference in cooling target fan speeds for AHU-1/AHU-2 and heating target fan speeds for AHU-2)

This discrepancy accounts for the difference between observed fan speeds and the proposed fan speeds assumed in the tracking calculation. While the evaluator cannot verify with certainty the cooling fan speeds for AHU-1/AHU-2 and the auxiliary heating fan speed for AHU-2 (because the operating modes could not be measured/verified), fan logger data exhibited consistent speeds at the observed extreme outdoor air temperatures (ranging from 28 °F to 92 °F). The evaluator assumed that at the low temperatures AHU-2 was operating in its auxiliary heating mode and, while at the high temperatures AHU-1 and AHU-2 were operating in their cooling modes[69]. This discrepancy decreased savings by 31% of -14,418 kWh.

Discrepancy #2 (Calculation method – remaining difference in proposed target fan speeds and estimated fan kW)

This discrepancy accounts for the remaining differences between the evaluated and tracking savings. The largest contributor to this discrepancy is the difference in the average proposed fan speeds. In Table 31, the weighted average proposed fan speeds in the tracking calculation are 54% for AHU-1 and AHU-2. The evaluation found that the average proposed fan speeds were higher than what the tracking assumed, with the average AHU-1 fan speed equal to 67% and the average AHU-2 fan speed equal to 71%.

The evaluated savings method does not match discrete fan speeds to operating modes because the operating modes could not be measured. Instead, the evaluation method uses at least 12 weeks of fan power and weather data to create step-functions regressing outside air temperature to fan power/speed. Using this method, the evaluator is able to generate (proposed) 8,760-hour profiles of AHU-1 and AHU-2 fan power using standardized TMY3 weather data. The baseline 8,760-hour profiles are developed by mapping the distribution (% of hours) of operating modes and corresponding fan speeds assumed in the tracking method to the TMY3 weather data set. This method creates an evaluated baseline that is very similar to the tracking baseline (see Table 31). The differences in baseline annual kWh arise from them using different methods to estimate fan kW from corresponding speeds and from the minor discrepancy of expanding discrete operating mode distributions (in % of hours) to an 8,760-hour format. This combination of discrepancies reduced savings by 37% or -17,206 kWh.

[69] AHU-1 did not exhibit consistent fan speeds at low temperatures and therefore the operating mode could not be reasonably verified