Impact Evaluation of 2014 Custom HVAC Installations

National Grid

Final Report

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1 EXECUTIVE SUMMARY

This document summarizes the work performed by the DNV GL team, between 2016 and 2017 to quantify the actual energy and demand savings due to the installation of 88 custom heating, ventilation and air-conditioning (HVAC) measures installed through National Grid's 2012 (MA) and 2014 (RI) C&I New Construction and Major Renovation and C&I Large Retrofit programs.

This is the second evaluation of the large C&I custom HVAC programs for RI National Grid since 2011. The scope of work of this impact evaluation covered the 2014 custom HVAC end use, which includes high efficiency HVAC equipment, HVAC controls as part of Energy Management Systems (EMS), operations and maintenance (O&M) and retro-commissioning of HVAC measures, and building shell improvements that impact HVAC loads. This impact evaluation includes only measures which primarily reduce electricity consumption.

1.1 Methods

This evaluation of 2014 (RI) custom HVAC installations used an approach like those of previous evaluations. The primary objective of determining realization rates at the state (RI and MA National Grid territory) and overall end-use level was accomplished by conducting on-site M&V at a statistically selected sample of 57 participant sites from the 2012 (MA) and 31 participant sites from the 2014 (RI) program years. This impact study consists of the following five tasks:

1. Develop sample design.
2. Develop site measurement and evaluation plans.
3. On-site data gathering and site analysis.
4. Site report writing and follow-up.
5. Expansion analysis and evaluation report.

1.2 Sampling Strategy

The goal of the sample design was to monitor enough sites to produce aggregated realization rates for National Grid with reasonable precision. National Grid agreed that the target is 10% precision at the 90% confidence level for energy savings at a combined RI (state-wide) and MA (National Grid territory only) level. The sample design employed was a stratified ratio estimate approach, which is particularly efficient for programs with a wide variation in site-to-site savings and where a good predictor of site savings exists (the tracking savings).

1.3 Findings and Results

The site level evaluation results were aggregated using the final adjusted case weights. The realization rates were estimated and then applied to total tracking savings to determine their total measured savings. The state-level realization rate is the ratio of the total measured savings to the total tracking savings, each of which is calculated by summing across MA and RI. Table 1-1 summarizes the overall results of this analysis. The table shows the results for five of the six measures of savings.

The overall (MA+RI) realization rate for custom HVAC measures was found to be 78%. The relative precision for this estimate was found to be ±7.6% at the 90% level of confidence. The error ratio was found to be

0.37 and better than the estimate of 0.60 used in the sample design for this study. For the on-peak summer kW, the overall realization rate was 69%, with a relative precision of ±14.6% at an 80% confidence level. For on-peak winter kW, the realization rate was a bit lower, at 70% with a relative precision of ±14.7% at an 80% confidence level.

Table 1-1: 2012 (MA) + 2014 (RI) Custom HVAC Results

Level	Parameter	Annual Energy kWh (90% Confidence)	Summer On-Peak kW (80% confidence)	Winter On-Peak kW (80% confidence)	% On-peak (90% confidence)
Overall (MA-National Grid only+RI)	Tracking Savings	20,423,268	2,402	1,898	N/A
	Evaluated Savings	15,861,588	1,663	1,326	N/A
	Realization Ratio	78%	69%	70%	97%
	Relative precision	7.6%	14.6%	14.7%	13.5%
	Error ratio	0.37	1.05	0.88	0.84

The results of DNV GL's analysis of realization rates by states follow in Table 1-2. All relative precisions for kWh savings realization rates and %On-peak values were calculated at the 90% confidence interval, while all relative precisions for kW savings realization rates were calculated at the 80% confidence interval.

Table 1-2: 2012 Custom HVAC Results by State

Level	Parameter	Annual Energy kWh (90% Confidence)	Summer On-Peak kW (80% confidence)	Winter On-Peak kW (80% confidence)	% On-peak (90% confidence)
MA (National Grid only)	Tracking Savings	17,372,884	1,823	1,736	N/A
	Evaluated Savings	13,087,095	1,274	1,167	N/A
	Realization Ratio	75%	70%	67%	105%
	Relative precision	8.8%	18.7%	16.7%	18.9%
	Error ratio	0.40	1.26	0.95	1.05
RI Statewide	Tracking Savings	3,050,384	579	162	N/A
	Evaluated Savings	2,774,494	389	159	N/A
	Realization Ratio	91%	67%	98%	84%
	Relative precision	12.6%	11.7%	9.6%	7.9%
	Error ratio	0.24	0.34	0.35	0.35

1.4 Recommendations

1.4.1 Program Improvement Recommendations

More Refined Savings Assumptions

The accuracy of the tracking savings calculations could improve with more refined assumptions. For example, one project calculated savings from a reduction in hours of use of exhaust fans in a hospital. The tracking analysis assumed almost all values for the exhaust fans were equal, other than the motor horsepower. This significantly altered the savings rate for each exhaust fan. The evaluation recommends that the program

request a more refined analysis that incorporates the inherent differences of varying motor sizes and motor use cases.

Improve Baseline or Pre-Retrofit Documentation

For any future retrofit projects, DNV GL recommends National Grid to record ample pre-retrofit data. Several sites did not clearly document the pre-retrofit equipment operation or the basis for the base case in their project applications. For example, some technologies that use controls to change operations, such as ventilation control measures, economizers and others, are very common and the supporting documentation and baseline assumptions provided for HVAC control measures, were not as comprehensive as with other technologies. It is recommended that National Grid collect and document information on the actual HVAC system operations such as damper positions, outside air ventilation levels, etc. for existing equipment undergoing controls improvements.

Conduct Pre-Installation Metering for More Retrofit Projects

Short term pre-installation metering could be used to confirm assumptions about pre-existing equipment for some retrofit projects, particularly control type projects. The evaluator may not be able to simulate pre-retrofit operating conditions; therefore, metering done by the implementation vendor prior to installation could improve confidence in the pre-retrofit assumptions.

Improve use of Post Inspection to Verify Measure Operation

On few occasions, evaluators identified sites in which the controls or equipment installed were not operational. Post inspections are generally occurring on all custom projects, but the effectiveness of the post inspection could be improved by observing and documenting operating conditions at the time of the inspection rather than only verifying if the measure was installed. It is recommended that National Grid continue to use more rigorous post-installation inspections to further build on the efforts made in this area.

Use of prescriptive calculation methodology should be reduced

DNV GL recommends National Grid reduce the use of prescriptive demand values for custom measures especially when the measure involves pump or fan motors. For example, prescriptive deemed savings value (TRM) for a VSD retrofit on a pump motor (kWh/hp) may not produce accurate savings estimates in a custom project; the pre- and post- conditions could vary significantly therefore, deviating from the TRM savings estimate.

Require Trend Data Acquisition

Stipulate in customer participation agreements that for sites receiving controls measures, either customer staff are to be trained or the controls contractor will be required to assist with subsequent EMS trending in the event customer is chosen as an evaluation site. It would be helpful to include in the contract specifically which trends should be made available to National Grid and evaluators for evaluation. The engineers developing the project scopes could specify the required trends. Consider the feasibility of configuring controls systems to allow remote access by evaluators to allow for data downloads.

2 INTRODUCTION

2.1 Study Objectives

The objective of this Impact Study is to verify and re-estimate energy (kWh) savings for selected custom HVAC projects through site specific inspections, end use monitoring and analysis. The site-specific results will be aggregated to determine realization rates separately for National Grid's custom HVAC program in RI, and review the impact on overall results of adding RI custom HVAC program evaluation results to the Massachusetts (MA) sample (National Grid territory) which was evaluated in 2015. The evaluation sample for this study was designed in consideration of the 90% confidence level for energy (kWh) savings.

2.2 Background

In 2011 National Grid completed a similar type of impact study comprised of various Custom HVAC Installations for program year 2010. Like the 2011 study this impact evaluation will serve many purposes including independent estimation of program and measure impacts and provide recommendations to improve programs and projects.

2.3 Scope

The scope of work of this impact evaluation covered the 2012 (MA) and 2014 (RI) custom HVAC end use, which includes high efficiency HVAC equipment, HVAC controls as part of Energy Management Systems (EMS), operations and maintenance (O&M) and retro-commissioning of HVAC measures, and building shell improvements that impact HVAC loads. This impact evaluation includes only measures which primarily reduce electricity consumption.

This impact study consists of the following five tasks:

1. Develop sample design.
2. Develop site measurement and evaluation plans.
3. On-site data gathering and site analysis.
4. Site report writing and follow-up.
5. Expansion analysis and evaluation report.

2.4 Methods

2.4.1 Description of Sample Design

The primary focus of the sample design was to examine various precision scenarios for the custom HVAC measures in Massachusetts (National Grid territory) and Rhode Island. The study population of 88 Custom HVAC projects from the 2012 and 2014 program years is summarized in Table 2-1.

Table 2-1: Population of 2012/14 Custom HVAC Projects

State	Projects	Total Savings	Average Savings	Minimum	Maximum	Standard Deviation	CV
Massachusetts	57	17,372,884	304,787	629	2,288,693	472,612	1.55
Rhode Island	31	3,050,384	98,399	1,647	694,220	148,048	1.50

Total	**88**	**20,423,268**	

The goal of the study was to design a sample that will allow DNV GL to estimate realization rates for several measurements (annual kWh, percent of kWh savings on-peak, summer on-peak and seasonal kW, and winter on-peak and seasonal kW) with a relative precision of ±10% at the statewide level. The target for annual kWh was set at the traditional ±10% at 90% confidence, while the target for summer kW was set at ±10% precision at 80% confidence during the design. The summer kW target is based on the ISO-NE overall portfolio precision requirements, but need not be achieved in each individual study because the FCM precision may be calculated for each PA's overall portfolio of demand resources. Both energy and summer demand savings sample design considerations are assessed in the following sections.

All the sample design results for annual kWh were calculated at the 90% confidence level, while results for summer kW were calculated at the 80% confidence level.

2.4.1.1 Annual kWh Sample Design

For sampling purpose, both RI and MA HVAC population data were combined and then a Stratified Ratio Estimation approach was used to develop a sample design that expected to meet an overall relative precision of ±10% at the 90% confidence as shown in Table 2-3. The RI sample design includes a total of 6 sample points compared to 23 sample points in MA evaluation. The details of sample design considerations and constraints, and confidence and targeted relative precision are discussed in the Sample Design Memo that was submitted to National Grid July 30th, 2015.

Table 2-2 shows the stratum cut points and distribution of sample sites for the selected sample design.

Table 2-2: Sample Design Selected with Stratum Cut Points

State	Stratum	Maximum Total Gross Savings (kWh)	Projects	Total Gross Savings (kWh)	Planned Sample Size
MA	1	163,931	34	2,419,819	6
MA	2	360,197	11	3,036,824	6
MA	3	795,362	7	3,919,023	6
MA	4	2,288,693	5	7,997,218	5
RI	1	67,945	20	569,277	2
RI	2	138,880	6	700,290	2
RI	3	501,356	4	1,086,597	1
RI	4	694,220	1	694,220	1

Table 2-3 lists the calculated precision estimates for this scenario, following stratification. A precision of ±10% was estimated for the overall results at the 90% confidence level.

Table 2-3: Estimated kWh Precision for Selected Sample Design

State	Population (N)	Sample Sites (n)	Expected Relative Precision @ 90% Confidence	Program Savings (kWh)
Massachusetts	57	23	10%	85%
Rhode Island	31	6	38%	15%
Total	88	29	10%	100%

2.4.2 Description of Methodology

This section describes the methodology generally for both the development of site evaluation plans, the execution of the plans, and the final process for producing program results.

2.4.2.1 Measurement and Evaluation Plans

Following the final sample selection of custom HVAC applications and prior to beginning any site visits, the DNV GL team developed detailed measurement and evaluation plans for each of the 29 projects. The plans outlined: on-site methods and strategies; monitoring equipment selection, placement, calibration; and analysis issues. National Grid provided comments and edits to clarify and improve the plans prior to the plans being finalized.

Evaluators utilized the savings analysis methodologies from the Technical Assistance Study (TA) whenever possible. However, in a small number of cases, the TA methodology was unavailable or found to be incorrect or inappropriate.

The site evaluation plan played an important role in establishing approved field methods and ensuring that the ultimate objectives of the study were met. Each site visit culminated in an independent engineering assessment of the actual (e.g. as observed and monitored) annual energy, on-peak energy, diversified summer peak demand, and diversified winter peak demand savings associated with each project.

2.4.2.2 On-Site Data Gathering, Analysis and Reporting

Data collection included physical inspection and inventory, interview with facility personnel, observation of site operating conditions and equipment, short-term metering of usage and EMS trends. At each site, the DNV GL team performed a facility walk-through that focused on verifying the post-retrofit or installed conditions of each energy conservation measure (ECM). Several of the facilities utilized EMS controls, which were either part of the application itself or controlled equipment that was included in the application. Evaluators viewed EMS screens to verify schedules and operating parameters where applicable. Instrumentation such as power recorders, Time-Of-Use (TOU) lighting loggers, TOU current loggers, and temperature loggers were installed to monitor the usage of the installed HVAC equipment and conditions of the associated affected spaces. EMS trends were also collected, when available.

Savings analyses were used to estimate hourly energy use and diversified coincident peak demand. A typical meteorological year (TMY3) dataset of ambient temperatures from Chicopee Falls, MA and Providence, RI were used for all temperature sensitive calculations. Evaluators have been using one weather station for custom electric impact studies so that evaluated savings generated from 8,760 hourly TMY3 datasets may be additive across all sites. The ability to add peak savings values across sites using different TMY3 datasets is problematic due to the differences in how each individual TMY3 dataset is created. Each site report details the specific analysis methods used specific for each project including algorithms, assumptions and calibration methods where applicable. One site in RI was analyzed using building simulation models, including eQuest.

Engineers submitted draft site reports to National Grid upon completion of each site evaluation, which after review and comment resulted in the final reports found in Appendix B. This report provides a concise overview of the evaluation methods and findings.

2.4.2.3 Analysis Procedures

To aggregate the individual site results from the custom HVAC sample, DNV GL applied the model-assisted stratified ratio estimation methodology described in References [1] and [2] in Appendix A. The key parameter of interest is the population realization rate, i.e., the ratio of the evaluated savings for all population projects divided by the tracking estimates of savings for all population projects. This rate is estimated at the statewide level, as well as overall National Grid territory in both states combined. The sample realization rate is the ratio between the weighted sum of the evaluated savings for the sample projects divided by the weighted sum of the tracking estimates of savings for the same projects. The total tracking savings in the population is multiplied by the sample realization rate to estimate the total evaluated savings in the population. The statistical precisions and error ratios are calculated for each level of aggregation.

The results presented in the following section include realization rates (and associated precision levels) for annual kWh savings, on-peak kWh savings, and on-peak demand (kW) savings at the times of the winter and summer peaks, as defined by the ISO New England Forward Capacity Market (FCM). All coincident summer and winter peak reductions were calculated using the following FCM definitions:

- Coincident Summer On-Peak kW Reduction is the average demand reduction that occurs over all hours between 1 PM and 5 PM on non-holiday weekdays in June, July and August.
- Coincident Winter On-Peak kW Reduction is the average demand reduction that occurs over all hours between 5 PM and 7 PM on non-holiday weekdays in December and January.

3 RESULTS

The sample was post-stratified based on the final disposition of sample points. Case weights were recalculated based on this final sample and are shown in Table 3-1. The weights reflect the number of projects that each of the sample points represents in their respective populations and allow for the aggregation of results across the strata and PAs.

Table 3-1: Final 2012 Custom HVAC Case Weights

State	Stratum	Maximum Total Gross Savings (kWh)	Projects	Total Gross Savings (kWh)	Projects in Sample	Case Weights
MA	1	291,398	37	4,077,167	9	4.11
MA	2	394,967	11	1,379,476	6	1.83
MA	3	924,382	6	4,834,931	5	1.20
MA	4	1,802,999	3	7,081,310	3	1.00
RI	1	53,398	22	384,175	3	7.33
RI	2	644,500	6	1,967,752	1	6.00
RI	3	752,987	3	1,342,098	2	1.50

3.1 Site Level Results

Figure 3-1 presents a scatter plot of weighted evaluated annual kWh savings plotted against the National Grid tracking savings. The dashed line represents a realization rate of 100%. The slope of the solid line in this graph is an indication of the statewide realization rate and how it relates to a realization rate of 100%.

This sample data is scattered widely around the trend line, which is indicative of the variation in savings between the tracking estimates and evaluated savings.

Figure 3-1: Evaluated Savings vs. Tracking Savings (Weighted)

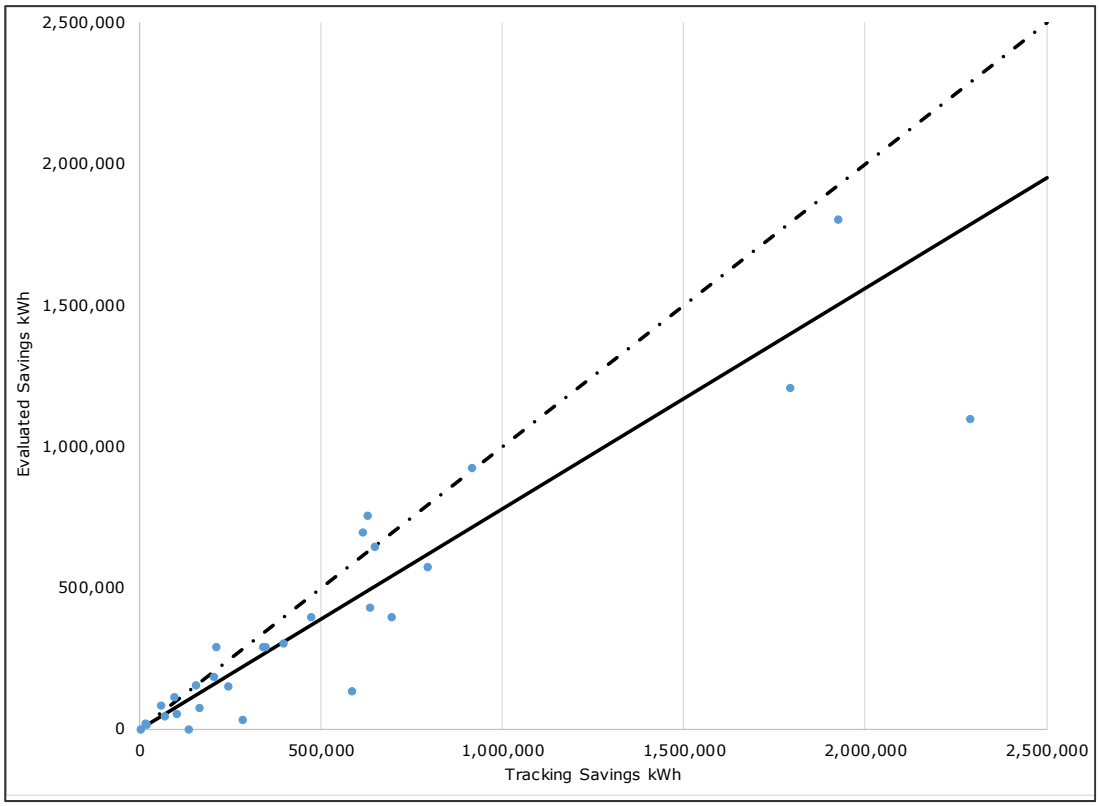


Table 3-2 presents a summary of the site level results for this impact evaluation.

Table 3-2: Detailed Site Results[1]

DNV GL Site ID	State	Application ID	Tracking Estimated Savings				Evaluation Savings			
			Annual Savings kWh/yr	On-Peak %	On-Peak demand Summer kW	On-Peak demand Winter kW	Annual Savings kWh/yr	On-Peak %	On-Peak demand Summer kW	On-Peak demand Winter kW
08	RI	2994828	16,205	50%	2.75	2.75	18,223	33%	0.68	2.97
09	RI	3544317	18,513	46%	4.20	1.00	17,688	46%	5.90	0.00
21	RI	3822272	100,820	57%	27.00	2.00	53,398	48%	22.04	0.00
25	RI	3575544	647,878	50%	124.09	57.40	644,500	43%	74.61	55.79
30	RI	2845921	626,695	72%	54.13	40.80	752,987	46%	80.40	76.35
31	RI	3786298	694,220	50%	129.29	65.00	393,660	58%	48.95	41.20

Table 3-3 summarizes the energy savings realization rates and primary reasons for discrepancies between the tracking and evaluation estimates of annual energy savings. The site energy savings realization rates ranged from a low of 0% for Site 8 to a high of 146% for Site 2 in MA and a low of 53% for site 21 to a high of 120% for site 30 in RI.

[1] MA sampled sites' findings can be found in the MA report in the MA EEAC website (@2012 MA Custom HVAC Impact Evaluation)

Table 3-3: Primary Site Discrepancies (RI Only)

DNV GL Site ID	State	Application ID	kWh RR	Primary Reasons for Discrepancies
08	RI	2994828	112%	This measure, exhaust fan savings, resulted from reduced exhaust fan operating hours when compared to the baseline's continuous 24/7 fan operations. The exhaust fans range in use cases such as for kitchen hoods, dish washers, and air handling units.
09	RI	3544317	96%	Savings for this project were expected to result from use of drier return air which improved the overall RTU's system efficiency. The annual estimated electric savings is 18,513 kWh. This includes interactive effects assumed to occur in the building.
21	RI	3822272	53%	The cooling loads in the facility are significantly different from tracking assumptions and are the primary reason for the savings reduction. The decrease in summer demand savings is also attributed to the change in cooling loads during the summer peak period.
25	RI	3575544	99%	Overall the measures are operating and working as per the designed criteria. There is some decrease in the cooling savings due to the revised AHU schedule in the post-retrofit condition of ECM2. The operational hours have increased by approximately 72% compared to the tracking analysis assumption of 3,393 hours. There was a discrepancy in ECM2 because the air handler savings in the evaluation calculation used metered data and the load of the AHUs varied in comparison to the tracking calculation. But the supply fan air flow in the tracking calculation was based on an estimate. Discrepancy in ECM3 was also due to the use of metered data vs some estimated hours and VFD speed. For ECM6, evaluation assumed that other VAV boxes that supply air are compensating by supplying less air.
30	RI	2845921	120%	Most of the tracking savings were calculated using prescriptive deemed savings values [kWh/HP; RI EE TRM])
31	RI	3786298	57%	The primary reason for the savings variance is the annual operating hours assigned to AHU operation. The tracking analysis assumed the AHUs operating hours as 8,760 both in the pre-and proposed conditions whereas the evaluation found the AHUs to be operating 4,654 a year which is 53.1% of full 8,760 annual operation. A data entry error was also made when the savings were entered the tracking savings database. The savings linked to the condenser water pumps were 9,277 kWh less than what was calculated in the TA report. Savings for all other measures were the same in the tracking database and the TA report. The total annual savings in the TA report is 703,497 kWh.

3.2 Realization Rates

The site level evaluation results were aggregated using the final adjusted case weights. The statewide realization rate is the ratio of the total measured savings to the total tracking savings, each of which is calculated by summing across the state. Table 3-4 summarizes the overall and state-level results of this analysis. The table shows the results for four measures of savings.

The statewide realization rate for custom HVAC measures was found to be 78%. The relative precision for this estimate was found to be ±7.6% at the 90% level of confidence. The error ratio was found to be 0.37, which is better than 0.48 found in the prior study, and better than the estimate of 0.6 used in the sample design for this study. For the on-peak summer kW, the overall realization rate was 69%, with a relative precision of ±14.6% at an 80% confidence level. For on-peak winter kW, the realization rate was at 70%.

Table 3-4: 2012 (MA)+ 2014 (RI) Custom HVAC Overall Results

Level	Parameter	Annual Energy kWh (90% Confidence)	Summer On-Peak kW (80% confidence)	Winter On-Peak kW (80% confidence)	% On-peak (90% confidence)
Overall (MA-National Grid only+ RI statewide)	Tracking Savings	20,423,268	2,402	1,898	N/A
	Evaluated Savings	15,861,588	1,663	1,326	N/A
	Realization Ratio	78%	69%	70%	97%
	Relative precision	7.6%	14.6%	14.7%	13.5%
	Error ratio	0.37	1.05	0.88	0.84

The results of DNV GL's analysis of realization rates at state-level follow in Table 3-5. All relative precisions for kWh savings realization rates were calculated at the 90% confidence interval, while all relative precisions for kW savings realization rates were calculated at the 80% confidence interval.

Table 3-5: 2012 Custom HVAC Results by PA

Level	Parameter	Annual Energy kWh (90% Confidence)	Summer On-Peak kW (80% confidence)	Winter On-Peak kW (80% confidence)	% On-peak (90% confidence)
MA (National Grid only)	Tracking Savings	17,372,884	1,823	1,736	N/A
	Evaluated Savings	13,087,095	1,274	1,167	N/A
	Realization Ratio	75%	70%	67%	105%
	Relative precision	8.8%	18.7%	16.7%	18.9%
	Error ratio	0.40	1.26	0.95	1.05
RI Statewide	Tracking Savings	3,050,384	579	162	N/A
	Evaluated Savings	2,774,494	389	159	N/A
	Realization Ratio	91%	67%	98%	84%
	Relative precision	12.6%	11.7%	9.6%	7.9%
	Error ratio	0.24	0.34	0.35	0.35

3.3 Sites with Largest Influence

DNV GL reviewed all sites to determine those that had the largest influence on the results based on a combination of site savings and sample weight.

Table 3-6 presents a list of the two RI sites that had the largest influence on their overall realization rate in order of their impact after weighting. National Grid MA had one site with zero savings due to the measure not operating (free cooling). One site resulted in fewer saving due to interactivity with other equipment that was not captured by the TA study. One site lost savings from not implementing the occupancy on/off control measure on all units that were proposed. The remaining sites differed mostly for operational reasons.

Table 3-6: National Grid Largest Influencers (RI Only)

Application ID	State	Measure Type	Tracking kWh/yr	Evaluated kWh/yr	Influence	Primary Reason
3822272	RI	VSD and Controls	100,820	53,398	Negative	Overestimated cooling loads
2845921	RI	Drives and pump upgrades	626,695	752,987	Positive	Tracking used prescriptive deemed savings value for pump savings for a custom project

4 CONCLUSIONS AND RECOMMENDATIONS

4.1 Realization Rate Precision levels

The overall energy realization rate precision was ±7.6%. The energy realization rate precision levels for MA and RI were ±8.8% and ±12.6%, respectively. The sample was designed to target 10% precision at the 90% confidence level for a combined National Grid territory in MA and RI states.

4.2 Program Improvement and Evaluation Recommendations

More Refined Savings Assumptions

The accuracy of the tracking savings calculations could improve with more refined assumptions. For example, one project calculated savings from a reduction in hours of use of exhaust fans in a hospital. The tracking analysis assumed almost all values for the exhaust fans were equal, other than the motor horsepower. This significantly altered the savings rate for each exhaust fan. The evaluation recommends that the program request a more refined analysis that incorporates the inherent differences of varying motor sizes and motor use cases. In RI, sites with these issues include:

- 2994828
- 3786298

Improve Baseline or Pre-Retrofit Documentation

For any future retrofit projects, DNV GL recommends National Grid to record ample pre-retrofit data. Several sites did not clearly document the pre-retrofit equipment operation or the basis for the base case in their project applications. For example, some technologies that use controls to change operations, such as ventilation control measures, economizers and others, are very common and the supporting documentation and baseline assumptions provided for HVAC control measures, were not as comprehensive as with other technologies. It is recommended that National Grid collect and document information on the actual HVAC system operations such as damper positions, outside air ventilation levels, etc. for existing equipment undergoing controls improvements. In RI, sites with these issues include:

- 2845921
- 3575544

Encourage More Comprehensive Commissioning and Updating of Tracking Estimates with Findings from Commissioning

Commissioning is a useful tool to help improve savings estimates for HVAC controls projects. While National Grid currently use commissioning in some capacity, there are areas where this tool can be improved. This will result in reducing any over-estimation pre-retrofit conditions more so than post-installation operation.

Conduct Pre-Installation Metering for More Retrofit Projects

Short term pre-installation metering could be used to confirm assumptions about pre-existing equipment for some retrofit projects, particularly control type projects. The evaluator may not be able to simulate pre-retrofit operating conditions; therefore, metering done by the implementation vendor prior to installation could improve confidence in the pre-retrofit assumptions. In RI, sites with these issues include:

- 2845921
- 3575544

Improve use of Post Inspection to Verify Measure Operation

On few occasions, evaluators identified sites in which the controls or equipment installed were not operational. Post inspections are generally occurring on all custom projects, but the effectiveness of the post

inspection could be improved by observing and documenting operating conditions at the time of the inspection rather than only verifying if the measure was installed. It is recommended that National Grid continue to use more rigorous post-installation inspections to further build on the efforts made in this area. In RI, sites with these issues include:

- 3575544
- 3544317
- 3786298

Use of prescriptive calculation methodology in the custom program should be reduced or eliminated

DNV GL recommends National Grid reduce the use of prescriptive demand values for custom measures especially when the measure involves pump or fan motors. For example, the prescriptive deemed savings value (from the TRM) for a VSD retrofit on a pump motor (kWh/hp) may not produce accurate savings estimates in a site specific custom project; the pre- and post- conditions could vary significantly leading to a significant deviation from the TRM savings estimate. In RI, site with these issues include:

- 2845921

Require Trend Data Acquisition

Stipulate in customer participation agreements that for sites receiving controls measures, either customer staff are to be trained or the controls contractor will be required to assist with subsequent EMS trending in the event customer is chosen as an evaluation site. It would be helpful to include in the contract specifically which trends should be made available to National Grid and evaluators for evaluation. The engineers developing the project scopes could specify the required trends. Consider the feasibility of configuring controls systems to allow remote access by evaluators to allow for data downloads.

APPENDIX A: REFERENCES

[1] *The California Evaluation Framework*, prepared for Southern California Edison Company and the California Public Utility Commission, by the TecMarket Works Framework Team, June 2005, Chapters 12-13.

[2] *Model Assisted Survey Sampling*, C. E. Sarndal, B. Swensson, and J. Wretman, Springer, 1992

APPENDIX B: SITE REPORTS

4.2.1.1 Site ID: DNV 08

Program Administrator	National Grid
Project ID(s)	2994828
Project Type	Retrofit
Program Year	2013
Evaluation Firm	DNV GL
Evaluation Engineer	Jerry Song
Senior Engineer	Amit Kanungo

Project Description

This report discusses the evaluation of programmed energy management system control points and interlocking on nine exhaust fans at a hospital in 2013. The exhaust fans range in size from 0.2 to 2.0HP. This measure interlocked the seven 0.2HP exhaust fans with two air handling units, interlocked the 0.8HP fan with a dish washer, and tied the 2HP fan to a Melink drive with temperature and optic sensors for the kitchen hood. This measure, exhaust fan savings, resulted from reduced exhaust fan operating hours when compared to the baseline's continuous 24/7 fan operations. The exhaust fans range in use cases such as for kitchen hoods, dish washers, and air handling units. Table 7 shows the overall evaluation results for this project.

Table 7: Project Results

Savings Quantity	Tracking Estimate	Evaluation Estimate	Realization Rate
Electric energy (kWh)	16,205	18,223	112%
% of Energy Savings on Peak	0	32.7%	-
Summer On-Peak Demand (kW)	2.75	0.68	25%
Winter On-Peak Demand (kW)	2.75	2.97	108%

Tracking Savings

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

Baseline Assumption

The exhaust fans in the pre-existing condition were assumed to run 24/7 with 85% fan efficiency and 80% load factor. There were no controls interlocking exhaust fan operation to air handlers or other operations.

Table 8: Baseline Key Parameters

	BASELINE SYSTEM		
Parameter	Value(s)	Source of Parameter Value	Notes
Exhaust Fan Horsepower	1x 0.8 HP, 1x 2.0 HP, 7x 0.2 HP	Tracking Analysis Assumption	
Exhaust Fan Efficiency	85%	Tracking Analysis Assumption	
Load Factor	80%	Tracking Analysis	

		Assumption	
Operating Schedule	24/7	Tracking Analysis Assumption	

Proposed Condition

The proposed exhaust fans had energy management system control set points. This linked the 2HP exhaust fan to temperature and optical sensors with a Melink drive, interlocked the 0.8HP dish machine exhaust fan to dish machine operation, and the remaining exhaust fans (0.2HP each) interlocked to air handling unit operation. The TA study assumed the set points would result in continuous exhaust fan operation from 6AM to 5PM on weekdays only. The exhaust fan power factor and efficiency remained the same between the baseline and proposed condition.

Table 9: Proposed Key Parameters

	PROPOSED SYSTEM		
Parameter	**Value(s)**	**Source of Parameter Value**	**Note**
Exhaust Fan Horsepower	1x 0.8 HP, 1x 2.0 HP, 7x 0.2 HP	Tracking Analysis Assumption	
Exhaust Fan Efficiency	85%	Tracking Analysis Assumption	
Load Factor	80%	Tracking Analysis Assumption	
Operating Schedule	6AM-5PM 5 days/week	Tracking Analysis Assumption	

Tracking Calculation Methodology

The tracking savings was calculated by taking the difference in operating hours between the proposed and baseline conditions and multiplying it by the constant exhaust fan kW.

The tracking savings was calculated using the following formula:

$$Annual\ Energy\ Savings = \sum_{1st\ Exhaust\ Fan}^{9th\ Exhaust\ Fan} \left(Operating\ Hours_{Proposed} - Operating\ Hours_{Baseline}\right) * ExhaustFan\ kW$$

Where:

The exhaust fan kW is

$$Exhaust\ Fan\ kW = Fan\ Motor\ HP * 0.746 \frac{HP}{kW} * Load\ Factor / Motor\ Efficiency$$

The proposed operating hours is

$$Proposed\ Operating\ Hours = 11\ hours\ per\ day * 5\ days\ per\ week * 52\ weeks\ per\ year$$

The assumed baseline operating hours were 8,760.

Evaluator Assessment of Tracking Savings

The evaluation has identified the following issue with the tracking analysis:

- It is not known why the proposed operating schedule of 6AM to 5PM was chosen for the proposed condition
- The savings did not seem to consider the outdoor temperatures or the Melink drive installed on the kitchen hood exhaust fan. In speaking with the facility manager, the exhaust fans are not set to a specific schedule, but interlocked with supply fan or kitchen equipment, resulting in temperature dependence or non-continuous operation.

PROJECT EVALUATION

This section summarizes the methodology and assumptions used to evaluate the savings for the project. The site evaluation includes a site visit, performing physical inspection to verify the installation of the measure, collecting on-site data, performing metering, performing engineering analysis with collected data and finally preparing a site report to report the evaluated savings.

Site Scheduling and Measure Verification

The evaluator verified the installation of the Melink drive system on the kitchen hood exhaust fan as well as EMS set points on the AHUs that the exhaust fans were interlocked to. The metered data was used to develop the operating profile for calculating exhaust fan energy savings. Table 10 shows how each measure was verified to be installed and operating.

Table 10: Measure Verification

Measure Name	Verification Method	Verification Result
Exhaust Fan	Nameplate Information of unit (manufacturer, Make and Model); Temperature set points (Kitchen hood and AHUs); HOBO power logger on kitchen hood exhaust fan with Melink drive; Time-Of-Use logger on all other exhaust fans	EF-9: 1.5HP Motor EF-11: 2HP Motor EF-22: 0.33HP EF-23: 0.17HP EF-21, 26, 27, 30, and 33: 0.2HP MeLink Drive and Interlocks were identified visually through the EMS system

Data Collection

Time-of-use loggers were installed on EF-9 and two on EF-11 and recorded their operating schedule. EMS data on kitchen hood exhaust CFM, exhaust fan on/off times, and AHU on/off times were collected during the return visit.

Table 11 and Table 12 show the data that was collected as part of this evaluation.

The exhaust fan motor size and nameplate data were collected during the site visit. The evaluator verified that all nine exhaust fans were connected to the EMS system and that the kitchen hood exhaust fan had a VFD, temperature sensor, and optical sensor. EMS data on kitchen hood exhaust CFM, exhaust fan on/off times, and AHU on/off times were collected during the return visit.

Table 11: Evaluation Data Collection – Installed Equipment

Parameter	M&V Equipment Brand and Model	Metering Start/Stop Dates	Metering Interval
EF-9 Operating schedule	Time of Use Logger	September 7th – October 12th	1 Minute
EF-11 Operating Schedule	Time of Use Logger	September 7th – October 12th	1 Minute

Table 12: Evaluation Data Collection – Data Received

Parameter	Source	Interval	Duration
AHU On/Off Status	Energy Management System	1 Minute	July 1st – September 30th

Exhaust Fan On/Off Status	Energy Management System	1 Minute	July 1st – September 30th
EF-11 CFM	Energy Management System	10 Minutes	July 1st – September 30th.

The collected exhaust fan motor data is listed in In addition, it appeared that some of the motors had been replaced at some point and were not exact size matches to the motors used in the tracking analysis.

Table 13. The evaluator was not able to obtain the efficiency values for most of the air handler interlocked exhaust fans due to access issues. Of the AHU-interlocked exhaust fans, only EF-22's efficiency was found, as shown in **Table 13**. The efficiency value for this exhaust fan, 56.4%, was assumed for the efficiencies of the other exhaust fans. In addition, it appeared that some of the motors had been replaced at some point and were not exact size matches to the motors used in the tracking analysis.

Table 13: Exhaust Fan Motor Data

Exhaust Fan	Tracking Horsepower	Evaluated Horsepower	Efficiency
EF-9 (Dishwasher)	0.8	1.5	74.3%
EF-11 (Kitchen Hood)	2	2	86.5%
EF-21 (AHU-Interlocked)	0.2	0.2	Unknown
EF-22 (AHU-Interlocked)	0.2	0.33	56.4%
EF-23 (AHU-Interlocked)	0.2	0.167	Unknown
EF-26 (AHU-Interlocked)	0.2	0.2	Unknown
EF-27 (AHU-Interlocked)	0.2	0.2	Unknown
EF-30 (AHU-Interlocked)	0.2	0.2	Unknown
EF-33 (AHU-Interlocked)	0.2	0.2	Unknown

Through discussion with the facility manager, the exhaust fans were not programmed for any observed holidays. The two air handlers and their interlocked exhaust fans were originally scheduled to turn on and off depending on a set schedule and temperature set points. Per the facility manager, however, the facility found that the load on the chiller was too low when the air handlers were not running, causing it to trip. Because of this, AHU-5 and AHU-6 run 24/7 during the cooling months, between April and November. Because the seven exhaust fans were interlocked to these air handlers, the exhaust fans also ran continuously. The continuous operation was corroborated by the exhaust fan EMS data collected for the monitoring period.

Evaluation Savings Analysis

Installed Energy Consumption

Dishwasher Exhaust Fan (EF-9)

The dishwasher exhaust fan savings were calculated using the time-of-use logger data and the fan motor nameplate data. First, the nameplate data was used to determine the motor kW using the formula below. An 80% power factor was assumed to match the value used in the tracking analysis

$$Motor\ kW = 1.5HP * 0.746\frac{kW}{HP} * 0.8\ Assumed\ Power\ Factor/74.3\%\ Motor\ Efficiency$$

The time-of-use logger data was used to calculate a day of week hourly operating profile. The estimated consumption for the typical week was calculated by multiplying the motor kW and hourly operating profile. The resulting weekly load profile was used to estimate consumption in all 8,760 hours of the year. There were no observed holidays for the exhaust fans. Figure 2 shows a very consistent schedule every day of the week, turning on at 4AM and turning off at 6PM.

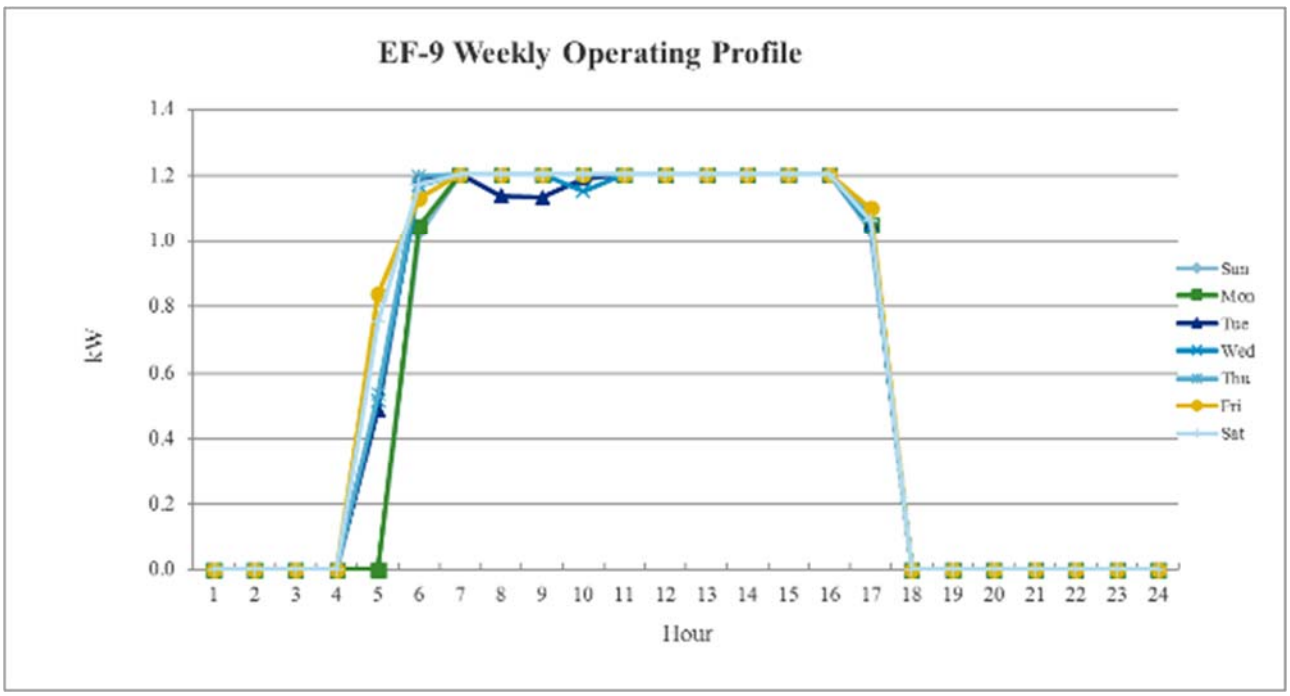


Figure 2: EF-9 Weekly Operating Profile

The baseline operating schedule was discussed and verified with the facility manager. Prior to interlocking, the dishwasher exhaust fan ran 24/7. The baseline energy consumption used the same motor running 8,760 hours per year. The motor's baseline energy consumption was calculated using the same values and formula as the installed case, as seen in the equation above. The baseline also used 1.5HP, 0.8 power factor, and 74.3% motor efficiency values. This resulted in the motor operating at a continuous 1.2kW.

Kitchen Hood Exhaust Fan (EF-11)

The kitchen hood exhaust fan (EF-11) operating load profile was determined using the EMS CFM data and verified with the time-of-use loggers. The CFM values were used to determine the load on the exhaust fan motor. This was used to calculate the motor kW in the weekly load profile. Per the facility manager, the EMS data collected is representative of full year operation, so the calculated weekly profile was extrapolated to all 8,760 hours per year. The motor model's power factor and efficiency were obtained from the manufacturer and was used to create a curve fit for the motor's efficiency at all power factors using the equations below where x is the percent load.

$$Efficiency = -2.827x^6 + 15.107x^5 - 32.306x^4 + 35.334x^3 - 20.946x^2 + 6.5044x + 8E-06$$

$$Power\ Factor = -0.1342x^5 + 0.5685x^4 - 0.7425x^3 - 0.0879x^2 + 1.0634x + 0.0799$$

The kitchen hood exhaust fan was verified to have a VFD, temperature sensor, and optical sensor installed. The exhaust fan was found to typically run at approximately 50% when operating and ramp up to 100% when the optical sensor detected smoke. During the monitoring period, the kitchen hood exhaust mostly operated between 2AM and 8PM every day of the week. The exhaust hood ran mostly at half load, 1.06kW, with very few spikes. Through the monitoring period, EMS data showed only three instances where the exhaust fan ran at full load for 10 minutes or more. Due to hourly averaging, the exhaust fan peaks well below 100% load in **Error! Reference source not found.**.

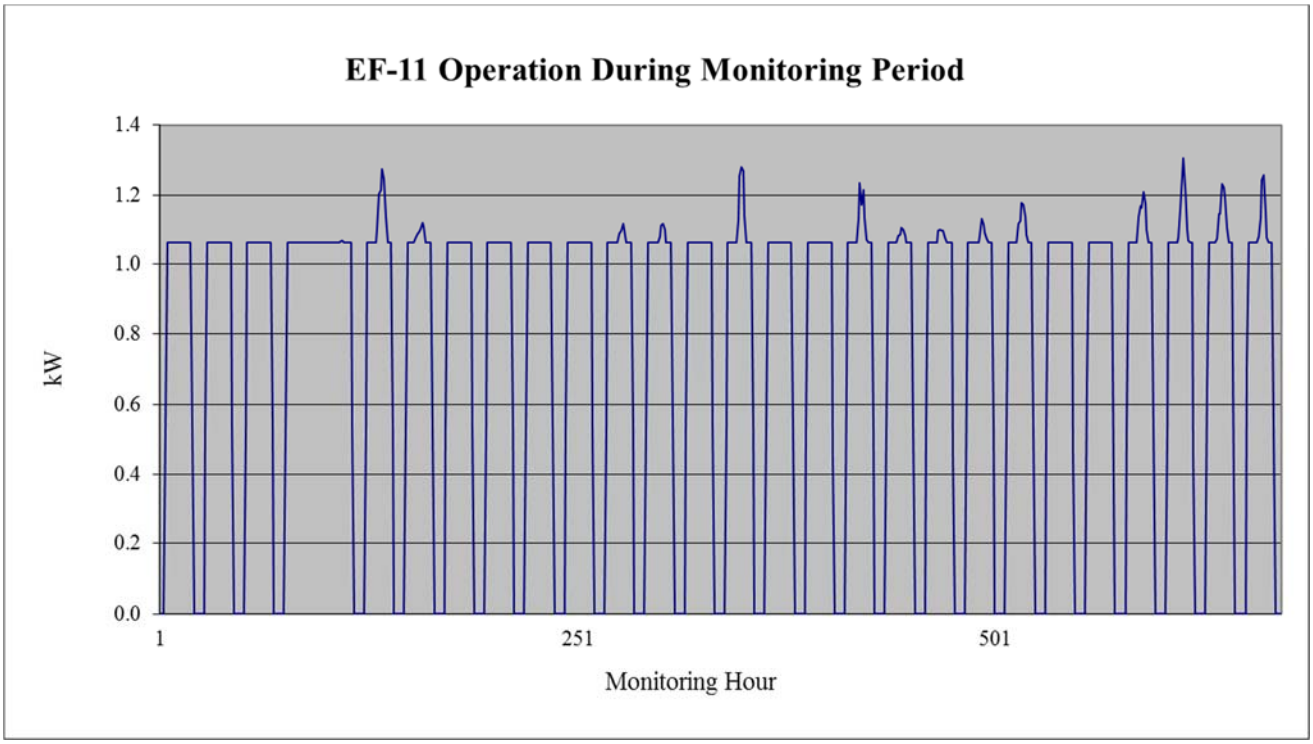


Figure 3: EF-11 Operation During Monitoring Period

The baseline operating schedule was discussed and verified with the facility manager. Prior to interlocking, the kitchen hood exhaust fan ran 24/7. The baseline energy consumption used the same motor running 8,760 hours per year. The baseline assumed the same 2HP motor with 86.5% efficiency. A 1.0 power factor

was used in the baseline to match the max kW and full load power factor in the installed case. The calculation resulted in a continuous 1.72 operating kW for baseline operations.

AHU interlocked Exhaust Fans (EF-21, 22, 23, 26, 27, 30, 33)

The AHU-interlocked exhaust fans were found to operate 24/7 throughout the cooling months (April-September) per the site contact and corroborated by EMS data. Per the facility engineer, this was due to the facility not having enough load on the chillers without the AHUs operating. Therefore, all the savings for the exhaust fans took place during the heating season of October through March. The site visits took place prior to the heating season and so there is a lack of data for the heating months. However, through interviewing the facility manager and the sequence of operations document, it was found that the occupancy hours for the areas served by the exhaust fans were Monday through Friday 6AM to 6PM. The occupancy hours were assumed to be the same as the air handler operating hours, so savings for the seven exhaust fans occurred only during non-occupied hours in October through March.

The operating hours were multiplied by the motor kW, which was calculated using the motor nameplate data. It was found that two of the seven exhaust fans were not 0.2HP as assumed in the TA study. Exhaust fan 22 was a 0.33 HP motor and exhaust fan 23 was a 0.167 HP motor. Other than for EF-22, efficiencies for the other AHU interlocked motors could not be found, so the EF-22 efficiency was used for all exhaust fan motors. In addition, an 80% power factor was used for all fans to match the tracking analysis assumptions.

The baseline operating schedule was discussed and verified with the facility manager. Prior to interlocking, the AHU exhaust fans ran 24/7. The baseline energy consumption used the same motors running 8,760 hours per year. The same assumptions were made for both the installed and baseline motors including the same horsepower values, 0.8 power factor, and 56.4% efficiency. This resulted in a combined and continuous 1.58kW for the seven motors throughout the year.

EVALUATION RESULTS

This section presents the evaluation results determined in the analysis above. The evaluation found an overall electric energy savings of 18,223 kWh per year with a realization rate of 112%, as shown in Table 14. The evaluation also found that 32.7% of energy savings were on peak. Summer On-Peak Demand savings was only 0.68kW, 25% of the tracking estimate. Winter On-Peak demand savings was 2.97kW, a 108% realization rate when compared to the tracking estimate.

Table 14: Project Results by Measure

Savings Quantity	Tracking Estimate	Evaluation Estimate	Realization Rate
Electric energy (kWh)	16,205	18,223	112%
% of Energy Savings on Peak	0	32.7%	-
Summer On-Peak Demand (kW)	2.75	0.68	25%
Winter On-Peak Demand (kW)	2.75	2.97	108%

While the tracking savings estimate was very close to what was found in the evaluation, the realization rate was achieved significantly differently than estimated in the tracking analysis. Most of the savings came from

EF-9 and EF-11, with only 2,264kW of annual savings being attributed to the seven AHU-interlocked air handlers as is shown in Table 15.

Table 15: Breakdown of Energy Savings

Savings Quantity	Tracking Estimate	Evaluation Estimate	Realization Rate
Dishwasher Exhaust (EF-9)	3,103 kWh	5,202 kWh	168%
Kitchen Hood Exhaust (EF-11)	8,275 kWh	8,779 kWh	106%
7 AHU-Interlocked Exhaust Fans	4,827 kWh	4,241 kWh	88%

The dishwasher exhaust (EF-9) saw significant savings primarily due to the discrepancy of the motor size and efficiency. The installed motor was a 1.5HP motor instead of the 0.8HP motor found in the tracking analysis and ran at 74.3% instead of 80% efficiency. Therefore, the savings during non-operating times was significantly higher than in the tracking analysis This made up for the significantly greater operating hours of 4AM to 6PM, compared to the 6AM-5PM assumed in the tracking analysis.

The kitchen hood exhaust (EF-11) savings were mostly in-line with the tracking analysis, but this too, was due to different reasons. The tracking analysis did not consider the load-lowering effects of the installed equipment. The exhaust fan operated almost entirely at 50% load, instead of the 100% load assumed in the tracking analysis. This made up for the exhaust fan's significantly greater operating hours. Instead of 6AM to 5PM on weekdays only, the exhaust fan operated every day of the week from 2AM to 8PM.

The AHU-interlocked fans had a lower realization rate due, mostly, to having no cooling season savings. In addition, the assumed operating hours were 6AM to 5PM on weekdays, which conflicts with the sequence of operations and facility manager's account of a 6AM to 6PM schedule, lowering the savings further. The difference in operating hours for the exhaust fans is illustrated in **Error! Reference source not found.**. The savings value was brought in-line due to the significantly lower efficiency of the motors than was assumed in the tracking analysis.

Table 16: Exhaust Fan Daily Operating Hours

Savings Quantity	Tracking Estimate (Proposed)	Evaluation Estimate (Installed)	Realization Rate
Dishwasher Exhaust (EF-9)	6AM-5PM	4AM-6PM	168%
Kitchen Hood Exhaust (EF-11)	6AM-5PM	2AM-8PM	106%
7 AHU-Interlocked Exhaust Fans	6AM-5PM	6AM-6PM (Heating Season)	47%

Due to the difference in operating hours and the skew of savings from AHU-interlocked exhaust fan to dishwasher exhaust, the summer savings decreased significantly and was slightly higher for the winter savings.

Comparison of Assumptions

The tracking analysis assumed all exhaust fans would operate with the same schedule, the motors had the same efficiency, and the same constant power factor as shown in **Table 17**. The assumed efficiency values in the tracking analysis are too high for the small exhaust fan motors seen on EF-21, 22, 23, 26, 27, 30, and 33. The

The tracking analysis assumed the kitchen hood exhaust fan (EF-11) ran at a flat and continuous 80% load when operating. However, the sensor systems installed for the measure allowed the exhaust fan to operate, typically at 50% load. In addition, the tracking analysis used the same operating hours of 6AM-5PM on weekdays only for all exhaust fans. This was unrealistic considering that the dishwasher and kitchen hood exhausts were running every day of the week.

Table 17: Comparison of Key Parameters

Exhaust Fan	Efficiency		Power Factor		Installed Operating Hours	
	Tracking Value(s)	Evaluation Value(s)	Tracking Value(s)	Evaluation Value(s)	Tracking Value(s)	Evaluation Value(s)
EF-9	85%	74.3%	80%	80%	2,922	4,641
EF-11	85%	86.5%	80%	51% (Average)	2,922	6,935
EF-21	85%	56.4%	80%	80%	2,922	7,330
EF-22	85%	56.4%	80%	80%	2,922	7,330
EF-23	85%	56.4%	80%	80%	2,922	7,330
EF-26	85%	56.4%	80%	80%	2,922	7,330
EF-27	85%	56.4%	80%	80%	2,922	7,330
EF-30	85%	56.4%	80%	80%	2,922	7,330
EF-33	85%	56.4%	80%	80%	2,922	7,330

Discrepancy Analysis

The primary discrepancy areas were driven by the assumptions made in the tracking analysis. The installed operating hours were significantly more than assumed in the tracking analysis and the actual motor efficiencies were significantly lower than in the tracking analysis. In addition to what was stated in the "Comparison of Assumptions" section, three of the exhaust fans were of a different size than in the tracking analysis. This could have been due to replacing of failing motors. A detailed summary of the discrepancies is shown in Table 18.

Table 18: Discrepancy Summary

Exhaust Fan	Efficiency	Power Factor	Installed Operating Hours
	% of Tracking (Evaluation / Tracking)	% Difference (Evaluation / Tracking)	% Difference (Evaluation / Tracking)
EF-9	87%	100%	159%
EF-11	102%	64%	237%
EF-21	66%	100%	251%
EF-22	66%	100%	251%
EF-23	66%	100%	251%
EF-26	66%	100%	251%
EF-27	66%	100%	251%
EF-30	66%	100%	251%
EF-33	66%	100%	251%

Improvement Opportunities

The accuracy of the tracking savings calculations could have been improved by making more refined assumptions. The tracking analysis assumed almost all values for the exhaust fans were equal, other than the motor horsepower. This significantly altered the savings rate for each exhaust fan. The evaluation recommends that the program request a more refined analysis that incorporates the inherent differences of varying motor sizes and motor use cases.

4.2.1.2 Site ID: DNV 09

Program Administrator	National Grid
Project ID(s)	3544317
Project Type	New Construction
Program Year	2013
Evaluation Firm	DNV GL
Evaluation Engineer	Paula Saaf
Senior Engineer	Mike Rudyk

Project Description

This document discusses the evaluation of one high efficiency roof top unit (RTU), installed in a new chain grocery store in 2014. This 20-ton unit provides humidity control, cooling, and heating to the sales floor of a grocery store in RI. The system uses return air for humidity control, variable cooling capacity and variable supply fan speed. Variable cooling capacity is achieved by using one dual stage compressor and one single stage compressor. The sales floor area is 9,338 sq.ft. and 24 feet high. Savings for this project were expected to result from use of drier return air which improved the overall RTU's system efficiency. The annual estimated electric savings is 18,513 kWh. This includes interactive effects assumed to occur in the building. Table 1 shows the overall evaluation results for this project.

Table 19: Project Results

Savings Quantity	Tracking Estimate	Evaluation Estimate	Realization Rate
Electric energy (kWh)	18, 513	17,688	96%
% of Energy Savings on Peak	46%	11%	24%
Summer On-Peak Demand (kW)	4.20	5.90	140%
Winter On-Peak Demand (kW)	1.00	0.0	0%

Tracking Savings

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

BASELINE ASSUMPTION

The RTU used in the baseline analysis is modelled to meet the IECC 2012 building energy code which includes DX cooling (9.8 SEER), an economizer controlled by the outside dry bulb temperature and gas heat (80% eff.). There are 2 fixed stages in a single compressor and the supply fan speed is constant. Gas heat is used to control space humidity.

Table 20: Baseline Key Parameters

	BASELINE SYSTEM		
Parameter	**Value(s)**	**Source of Parameter Value**	**Note**
Minimum Supply Temperature	55°F	eQuest Model	
Cooling EIR	0.2549	eQuest Model	
Condenser Fan Energy, W/BTU cooling output	14.7	eQuest Model	
Supply fan efficiency	0.48895	eQuest Model	
Supply fan speed	Constant	Final Report	
System Compressor Type	2-stage fixed	Final Report	
Latent and Sensible, Btu/hr, in the spaces adjacent to the space adjacent to the area being conditioned by the RTU	0.1, 0.9 respectively	eQuest Model	These are the spaces just north of the halfway mark of the store.
Sales floor humidity	55%	Final Report	

PROPOSED CONDITION

A high efficiency RTU uses a return air bypass to control the space humidity. It has a 5-HP supply fan with VFD controller, one digital scroll compressor and one 2-stage compressor. The outside air is controlled with CO_2 sensors.

Table 21: Proposed Key Parameters

	PROPOSED SYSTEM		
Parameter	**Value(s)**	**Source of Parameter Value**	**Note**
Minimum Supply Temperature	55°F	eQuest Model	
Space humidity	43%	Final Report	
Cooling EIR	0.2549	eQuest Model	
Condenser Fan Energy, W	7W/Btu cooling output or 1648 W	eQuest Model or Final Report	The final report shows the fan usage for the proposed condition
Supply fan efficiency	0.48125	eQuest Model	
Heat Recovery			
System Compressor Type	Variable Speed	eQuest Model	
Compressor Efficiency, EER	13.40	Final Report	
Latent and Sensible, Btu/hr, in the spaces adjacent to the area being conditioned by the RTU	0.07, 0.93 respectively	eQuest Model	
Sales floor humidity	43%	Final Report	

TRACKING CALCULATION METHODOLOGY

Tracking savings were calculated using two eQuest models; baseline and proposed/design models. This evaluation does not use an eQuest models to calculate savings for this project since the model used in TA analysis did not represent the building accurately and updating the model to on-site conditions was considered too expensive and time consuming relative to the 8,760 approach used.

EVALUATOR ASSESSMENT OF TRACKING SAVINGS

The tracking savings were calculated using eQuest Refrigeration building simulation software. The building model was derived from 6 similar stores located in Rhode Island and Massachusetts. The results predicted

savings but did not reflect the actual store layout. The model floorplan had multiple zones representing the display freezers, refrigerators and open cases, plus office and restroom spaces. Unfortunately, these zones ran the length of the building. The actual building layout has a rectangular sales floor with an L-shaped unconditioned space adjacent to two sides of that rectangle.

The purpose of using the Refrigeration version of eQuest is to see the impacts of refrigeration and freezer display cases located within the conditioned zone. The multiple small zones in the eQuest model all had temperatures set to 70ºF resulting in no impact to the RTU return air. This would have been an easy fix if the model floorplan had been correct.

Because it was a new construction building, basing the model on existing stores was a fair assessment approach. The baseline model was calibrated to the other 6 stores annual utility use although the energy use per area of each building was not taken into consideration.

Project Evaluation

This section summarizes the methodology and assumptions that will be used to evaluate the savings for the project.

MEASURE VERIFICATION

The evaluator visited the site on August 4, 2016 to verify the installation and begin data collection. The RTU was physically verified during the site visit and confirmed that it is operating as intended. Table 4 shows how each measure will be verified to be installed and operating. New construction baseline was ASHRAE 90.1 2007.

Table 22: Measure Verification

Measure Name	Verification Method	Verification Result
Identification/validation of the correct unit	Nameplate Information of unit (manufacturer, model and part number, capacities, voltages, # of compressors, etc.).	Visually verified and Unit metered to capture real-time usage (kW)
RTU Compressor Operation	Monitor the summer energy use of each compressor in 5 minute increments	Compressor operating energy use during occupied and unoccupied hours during the hottest part of the summer.
RTU Fan Operation	Installed Elite data loggers to track the cooling energy use of the fans	Fan operating energy use during occupied and unoccupied hours during the hottest part of the summer.
Space temperature and humidity verification	Monitor the conditioned and unconditioned zones temperature and humidity	Hourly average space conditions
Condenser fan	Installed Elite data loggers to track the cooling energy use of the fans	Fan operating energy use during occupied and unoccupied hours during the hottest part of the summer.

DATA COLLECTION

RTU Monitoring: Dent ElitePro Power Loggers were installed on both compressors, condenser fan and the supply fan VFD. The installation was done during a heat wave and the compressors were cycling at that time which indicates the unit was operating per design.

Space Monitoring: Four Hobo temperature/humidity sensors were installed inside the building: two in the unconditioned storage space and two on the sales floor. One logger on the sales floor was mounted across the aisle from a freezer wall. The other was mounted near the checkout counter and manager's office.

These sensors were mounted at opposite ends of the sales floor and as far away from the front door as possible, giving a good indication of the space conditions. Since the eQuest model was not used for this evaluation, the logger data for the unconditioned spaces were not used.

EMS Trends: A 3rd party contractor manages building controls for these grocery stores remotely. The RTU has its own proprietary control system so the data available to the contractor's EMS system is limited to temperatures and the local controller holds only 15 days of data. Table 5 shows the dates that the EMS trending data covers. The best data provided was the July – August data shown in the Figures below.

Table 5 shows the data that has been collected as part of this evaluation.

Table 23: Evaluation Data Collection – Installed Equipment

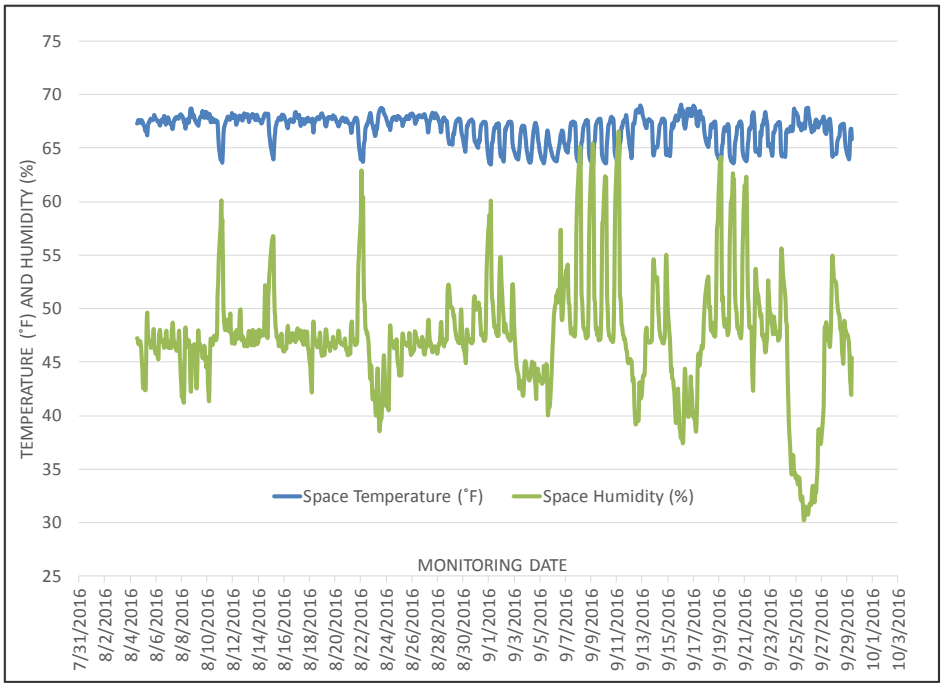
Parameter	M&V Equipment Brand and Model	Metering Start/Stop Dates	Metering Interval
Space humidity & temperature	Hobo Temperature/Humidity sensor	8/4/2016-9/29/2016	5 minutes
Supply & condenser fan motor power, kW	Dent Elite-Pro Logger	8/4/2016-9/29/2016	5 minutes
Outside air temperature and humidity	Local weather station	8/4/2016-9/29/2016	1 hour
Compressor power, kW	Dent Elite-Pro Logger	8/4/2016-9/29/2016	5 minutes

Table 24: Evaluation Data Collection – Data Received

Parameter	Source	Interval	Duration
Space Temperature	EMS Contractor	3 minute	7/29 – 8/12/2016 9/30 – 10/14/2016 10/10 – 10/24/2016
Supply Air Temperature	EMS Contractor	3 minute	7/29 – 8/12/2016 9/30 – 10/14/2016 10/10 – 10/24/2016
Return Air Temperature	EMS Contractor	3 minute	7/29 – 8/12/2016 9/30 – 10/14/2016 10/10 – 10/24/2016
Space Dew Point	EMS Contractor	3 minute	7/29 – 8/12/2016 9/30 – 10/14/2016 10/10 – 10/24/2016

Figure 1 shows metered temperature and humidity data for the sales floor. The space temperatures were observed to be below 70ºF for the entire monitoring period.

Figure 4. Sales Floor Space Temperature and Humidity at the Register (DNV GL)



The space temperatures from the EMS trend data shown in Figure 2 are slightly higher although they are always below the cooling set point temperatures of 74ºF (occupied) and 76ºF (unoccupied).

Figure 5. Space Temperatures provided by the EMS Contractor

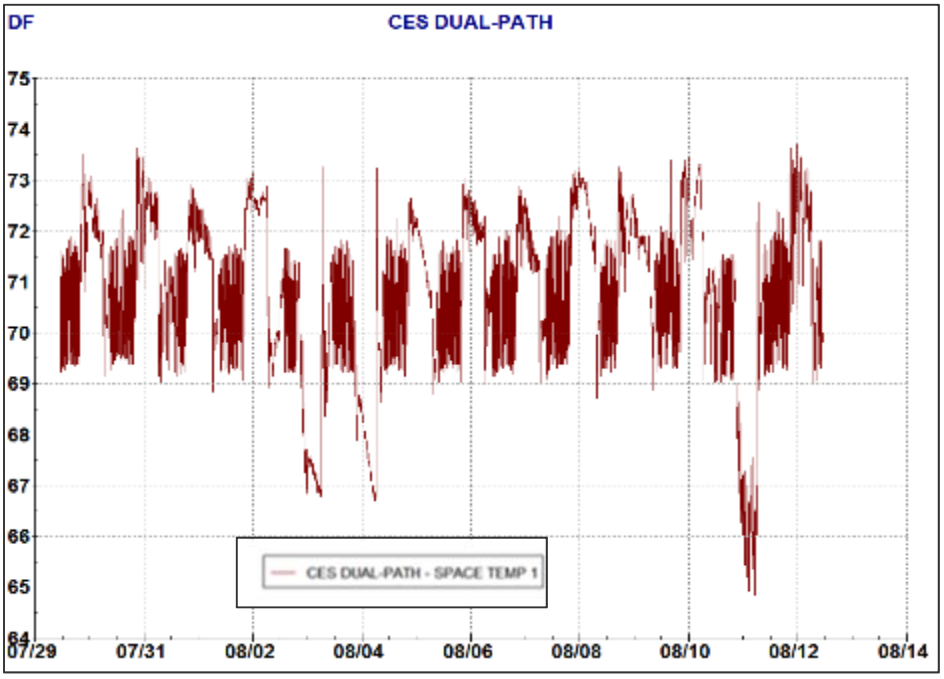
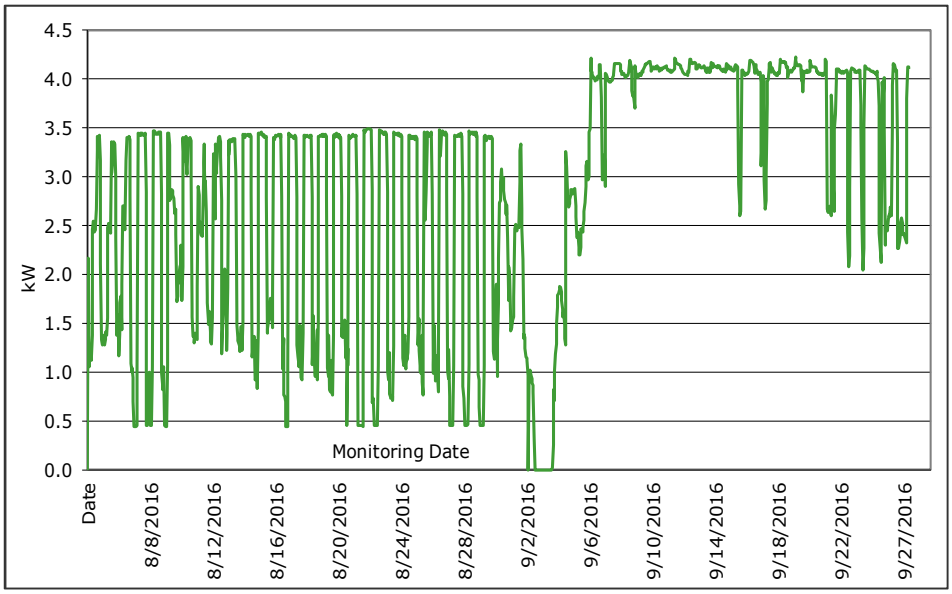
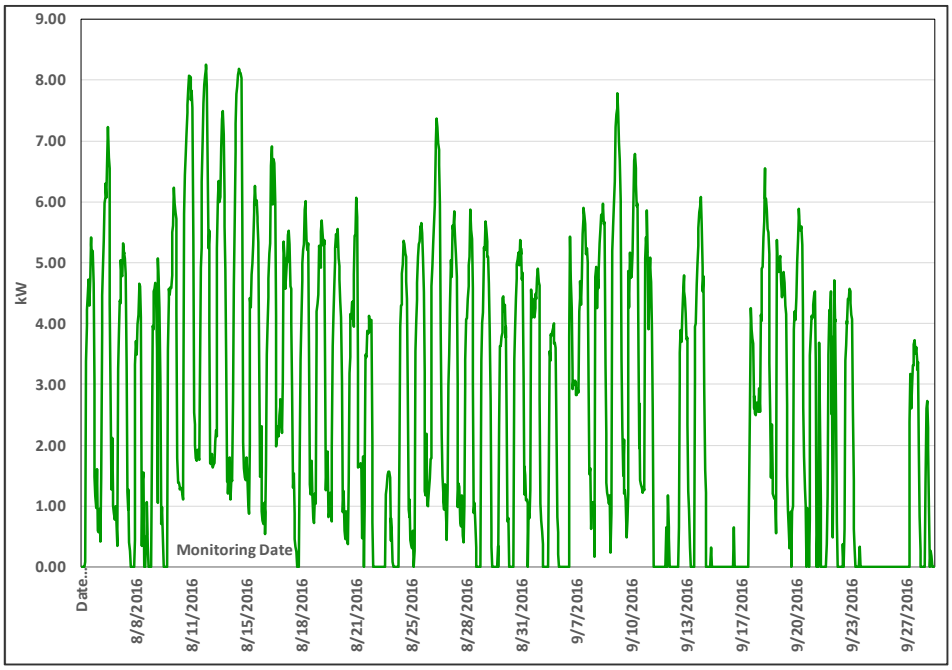


Figure 6. Supply Fan Operation During the Monitoring Period; 8/4 - 9/27 (DNV GL)



The meter data in Figure 3 shows that early in the metering process the average supply fan energy tracks the occupied/unoccupied schedule almost as a two-speed fan. At midnight, September 8 the supply fan energy jumped up to about 4 kW. There is some variation which matches the compressor operations shown in Figure 4 and Figure 5.

Figure 7. Compressor-1 Operation During the Monitoring Period (DNV GL)



The higher fan energy use occurs when the compressors are not running so no mechanical cooling is occurring. The space humidity is very high. The corresponding local weather data shows that the dry-bulb temperatures dropping to the 70's and 60's and the wet-bulb temperatures staying near the dry-bulb,

indicating that the outside humidity was high. The space temperatures were satisfied so no mechanical cooling was necessary. It appears that the supply fan energy follows the space humidity and vice versa. Which characteristic is driving being inconclusive from the metered data. Perhaps an average hourly occupant count would enlighten us.

Figure 8. Compressor-2 Operation During the Monitoring Period (DNV GL)

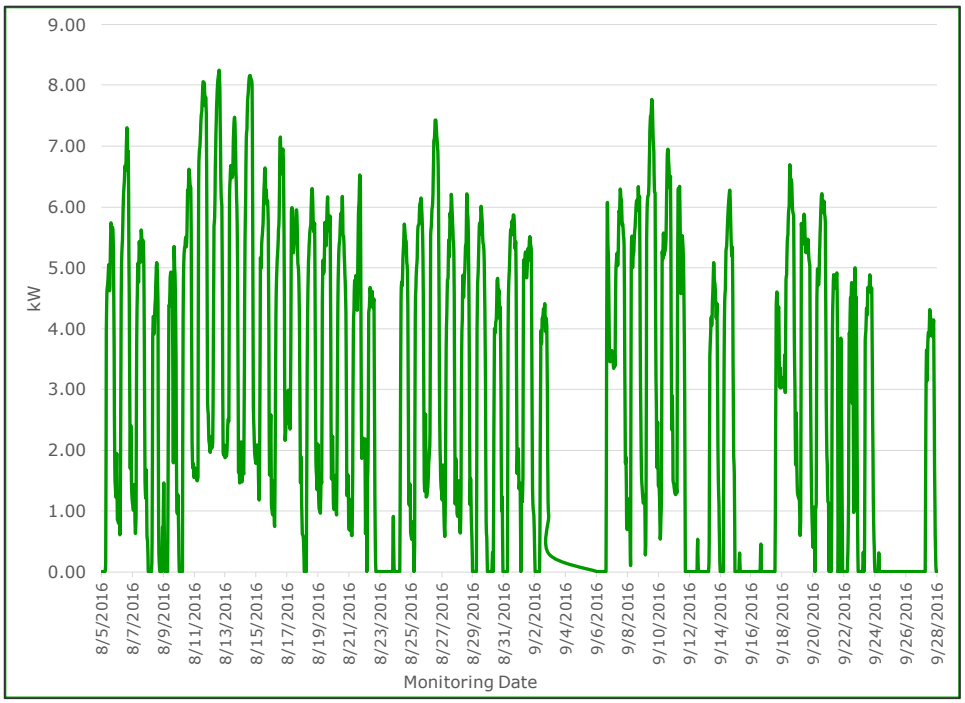


Figure 9. Supply Air Temperature from the BAS (EMS Contractor)

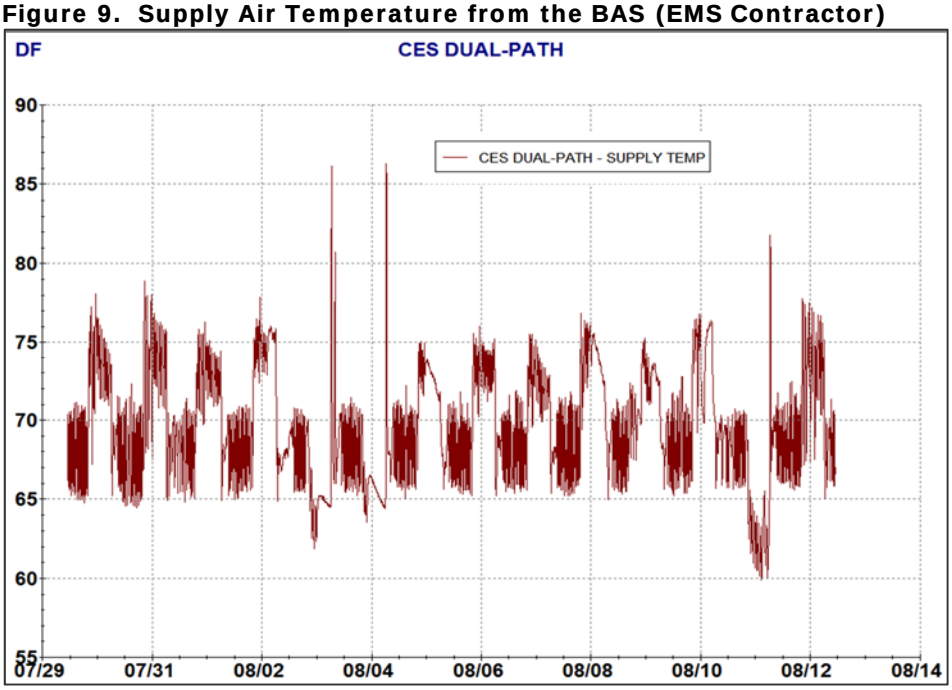


Figure 10. Return Air Temperature from the BAS (EMS Contractor)

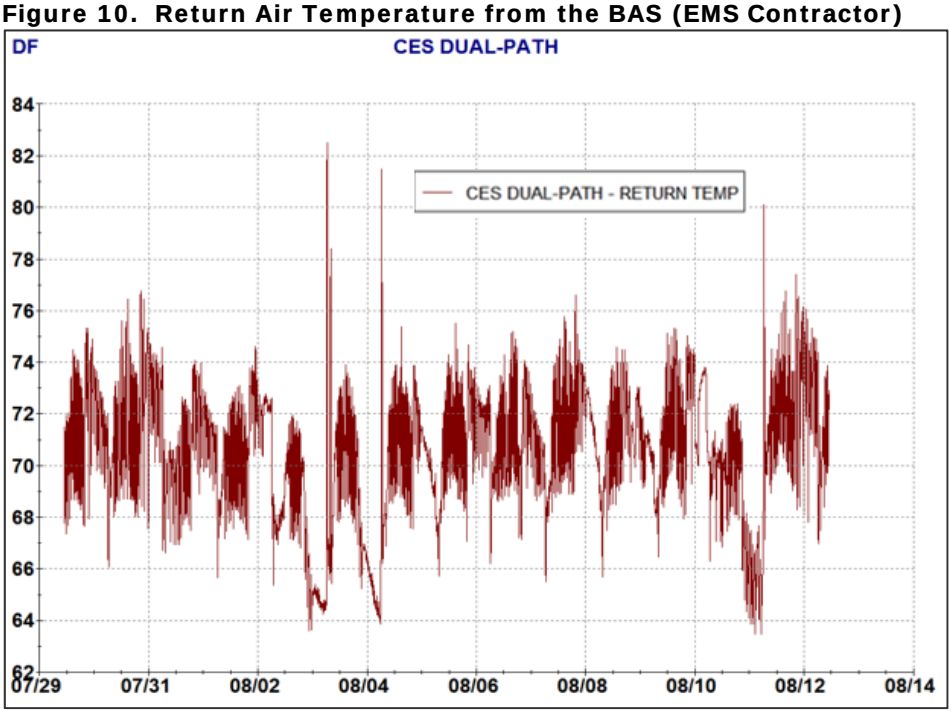


Figure 6 and Figure 7 show the supply and return air temperatures from EMS trends. The unit provides cold air even when the space set points have been met. Table 7 shows the EMS set points as reported by the EMS operator.

Table 25. BAS space set points

Occupancy	Cooling (˚F)	Heating (˚F)	Dehumidification (%)	Reheat/Reclaim (%)
Occupied	74	68	50	71
Unoccupied	75	60	52	67.5

EVALUATION SAVINGS ANALYSIS

This section describes the evaluation analysis to estimate achieved savings. The installed equipment is expected to operate more efficiently than the baseline equipment. Overall, the evaluation energy savings are based on the as found conditions with the metering equipment and its operating hours even if the evaluation's findings contrast with the conditions documented in the project files.

An 8760 spreadsheet was used to calculate the savings since the eQuest model did not accurately represent the actual building, and updating the model was not cost effective. The following information and equations were used to calculate the savings for this evaluation:

The facility operating hours were calculated first:

Open Hours: M-Sat 9 am – 8 pm

Sunday 9 am – 7 pm

Closed on the following holidays:

New Year's Day – assume weekday hours

Easter Sunday – always Sunday hours

Thanksgiving Day – always Thursday hours

Christmas Day - assume weekday hours

$$Weekly\ Closed\ Hours = 6 * 13 + 14$$

$$Annual\ Closed\ Hours = 51 * Weekly\ Closed\ Hours + 4 * 24 + 3 * 14$$

All the space temperature data show that the space does not exceed the cooling set point. It can be assumed that the open refrigerated display cases are providing most of the cooling occurring on the sales floor. Thus, only outside conditions are used to calculate savings.

Savings for the current project come from both

1. VFD on the supply fan (SF) and
2. Multi-stage Compressors.

Total Savings (kWh) = Annual SF Energy Savings + Annual Compressor Energy Savings

Savings from VFD on the supply fan:

Meter data shows that supply fan with VFD energy tracks the occupied/unoccupied schedule almost as a 2-speed fan. There is very little modulation. The baseline is a constant speed fan operating at 3.25 kW, 8760 hours per year. For this evaluation, the supply fan savings will come from the lower fan energy use, i.e. 2.075 kW an average fan energy during unoccupied hours. The annual supply fan energy savings will be calculated using the following equation:

$$Annual\ SF\ Energy\ Savings, kWh = (Average\ Occ\ SF\ kW - Average\ Unocc\ SF\ kW) * Annual\ Unocc\ hours$$

Where,

Average OCC SF kW (metered average kW during occupied hours) = 3.25 kW

Average Unocc SF kW (metered average kW during unoccupied hours) = 2.075 kW

Savings from Multi-Stage Compressor:

The combined compressor meter data energy show a correlation between outside air conditions and the compressor energy. Meter data show that when the outside dry bulb air temperature is below 68°F the compressors are off. Figure 8 shows the combined compressor energy as a function of the outside air dry-bulb temperature along with the regression analysis equation. The metered space humidity and temperature show that some non-rooftop cooling occurs in the space which indicates that the building does not operate as expected and the most efficient equipment is not being used to cool the space. The obvious clumping of the compressor energy shown in Figure 8 most likely comes from this internal cooling.

The following regression analysis equation will be used to calculate the compressor energy:

$$Design\ Compressor\ Energy\ (DCE), kW = 0.008 * OAT^2 - 0.7246 * OAT + 15.253$$

The baseline is a single 2-stage compressor. When the outdoor dry bulb air temperature is between 68°F and 74°F the baseline compressor operates a single stage. Above 74°F both stages are used.

$$IF\ 68F < \ OAT < 74F, the\ BCE = \frac{1}{2} * Full\ Load$$

$$IF\ OAT \geq 74F, then\ BCE = Full\ Load$$

Where

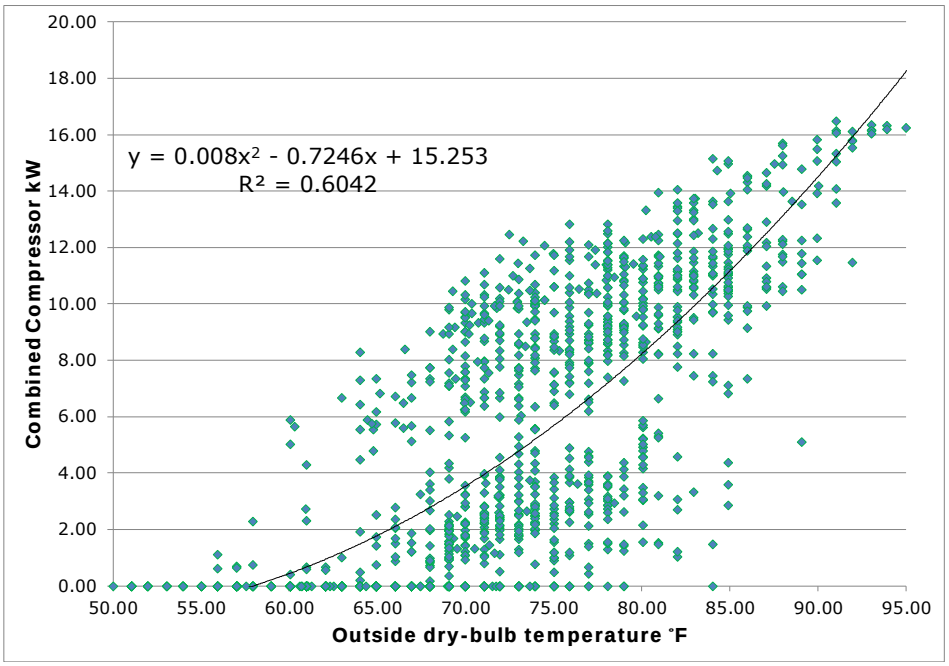
BCE = Baseline Compressor Energy

OAT = Outside Air Temperature – dry bulb

Compressor savings (kW) $_{\text{each hour}}$ = (BCE-DCE) $_{\text{each hour}}$

Annual Compressor energy savings (kWh)= Σ((BCE-DCE) $_{\text{each hour}}$) annual

Figure 11. Combined Compressor Energy as a Function of Outside Air Dry Bulb Temperature



ON-PEAK ENERGY AND DEMAND SAVINGS

The evaluation estimated on-peak energy and demand savings using an 8760-style spreadsheet analysis. On-Peak energy is defined as energy delivered between 6 am and 10 pm, while summer kW Demand is defined in RI as 1:00 PM – 5:00 PM on non-holiday weekdays in June, July and August and winter kW as non-holiday weekday 5-7p in December and January. The On-Peak energy savings is the sum of the energy saved during the peak defined hours. Percent On-Peak energy savings is the ratio of total On-Peak energy savings and total energy savings. Table 8 shows the results of this analysis. The supply fan savings has no impact on the On-Peak energy and Demand because all the lower energy operating hours occur during off peak periods.

Evaluation Results

This section will summarize the evaluation results determined in the analysis above. Table 8 summarizes both tracking and evaluation savings for the RTU. The electric energy savings realization rate is surprisingly

high since the eQuest model did not include cooling from the refrigerated display cases and assumed a much higher space temperature set point than that being maintained. The differences in the On-Peak realization rates do show that the eQuest model was not including the cooling coming from the space refrigeration cases.

Table 26: Project Results by Measure

Measure	Savings Quantity	Tracking Estimate	Evaluation Estimate	Realization Rate
Measure Name	Electric energy (kWh)	18, 513	17,688	96%
	% of Energy Savings on Peak	46%	11%	24%
	Summer On-Peak Demand (kW)	4.20	5.90	140%
	Winter On-Peak Demand (kW)	1.00	0.0	0%

COMPARISON OF ASSUMPTIONS

This high efficiency RTU was installed primarily to maintain humidity in the space by mixing a portion of return air with off-the-coil air. The associated savings was the natural gas used for reheating the off-the-coil air. In the TA analysis, the refrigerated zone temperatures were set to 70ºF which is just four degrees below the space set point temperature.

Table 27: Comparison of Key Parameters

	BASELINE		PROPOSED / INSTALLED	
Parameter	Tracking Value(s)	Evaluation Value(s)	Tracking Value(s)	Evaluation Value(s)
Space Temperature	74ºF	74ºF	74ºF	70ºF
Maximum Fan Energy				

DISCREPANCY ANALYSIS

The space temperature set point is supposed to be 74ºF but all the meter data and trend data show much lower temperatures. The compressor savings was based on the actual operation. This operation may have been different if the space were maintaining the prescribed set point. This may increase the percent On-Peak savings although it would lower the overall savings.

The eQuest model set point temperatures for open refrigerator display case zone was 70ºF so no cooling was added to the space. The meter data show that there is significant cooling from these cases in the space thus reducing the cooling load on the RTU. Since the meter data and OAT were used to create an RTU operating algorithm it is difficult to predict what the savings should be if there were no internal cooling. It can be assumed that it would be much higher than predicted in the eQuest model.

Space humidity is controlled using a return air bypass. A portion of the return air bypasses the coil and mixes with the off-the-coil air to reheat and dehumidify the supply air. One hundred percent of the outside air flows across the coil then mixes with the conditioned return air. The amount of air in the bypass varies based on the return air temperature and humidity. EQuest does include heat recovery from return air but does not have the capability to vary the air flow for humidity control. The code assumes that the outside and return air is precooled before the coil, rather than heating the off-the-coil air. Thus, the modeler had to reduce the humidity being added to the space in the "design" condition. This was done by reducing the source latent heat variable and the latent heat generated by people in the space.

Table 28: Discrepancy Summary

Parameter(s)	Discrepancy	Impact on Results
Lower space temperature is maintained	Supposed to be a set point of 74ºF. Meter and BAS trend data show it to be lower	The compressor savings would be higher if there were no internal cooling
Space cooling	Cooling coming from the refrigerated display cases is much higher than modelled	Less savings from the RTU
Heat recovery/humidity control	The eQuest model cannot do humidity control using RA heat recovery.	The natural gas savings may be higher or lower than predicted by the model. It was not part of this study

IMPROVEMENT OPPORTUNITIES

This section will document any opportunities for program improvement identified during the evaluation.

- DNV GL recommends the TA use as-built conditions or construction documents to calculate savings.
- It was not clear if the eQuest model was modeled before the construction was complete and if it was, calibrating the model to actual conditions specifically interior space temperature and humidity set-points is recommended to calculate more accurate savings.

4.2.1.3 Site ID: DNV 21

Program Administrator	National Grid
Project ID(s)	3822272
Project Type	New Construction
Program Year	2013
Evaluation Firm	DNV GL
Evaluation Engineer	Mike Rudyk

Project Description

This retrofit project installs variable speed drives upgrades on condenser water pumps and upgrades chiller plant controls to provide staged operation of the HVAC equipment on this college campus. Control modifications include condenser water reset, chilled water reset, and outside air lockout temperature set points. The annual savings are calculated across 2 measures. Measure 1 installs the variable speed drives on the CWPs and accounts for 23% of total tracking savings. Measure 2 estimates savings for the chiller control modifications and accounts for 77% of total tracking savings. Table 7 shows the overall evaluation results for this project. The cooling loads in the facility are significantly different from tracking assumptions and are the primary reason for the savings reduction. The decrease in summer demand savings is also attributed to the change in cooling loads during the summer peak period.

Table 29: Project Results

Savings Quantity	Tracking Estimate	Evaluation Estimate	Realization Rate
Electric energy (kWh)	100,820	53,398	53%
% of Energy Savings on Peak	57%	48%	85%
Summer On-Peak Demand (kW)	27.0	22.04	82%
Winter On-Peak Demand (kW)	2.0	0.0	0%

Tracking Savings

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

Baseline Assumption

The pre-existing condition consisted of existing equipment operating inefficiently. Both condenser water pumps were operated in the "hand" position. This means that EMS control was bypassed and the pumps were operating continuously. Condenser water pump 1 & 2 were each designed to deliver 518 GPM at 75 head-feet. Each pump is driven by a 15-HP motor operating without a variable speed drive. The discharge balance valve on each pump was fixed at 50% open.

The central cooling plant consisted of two 175-ton centrifugal chillers. Estimated chiller efficiency was 0.82 kW/ton from discussions with facility engineers. Two 20-HP chilled water pumps [450 GPM @ 110 head –feet] operate with the chillers. The chillers were turned on manually as needed. Chilled water pump and condenser water pumps operated continuously and all pumps operated regardless of the number of chillers on line. Chilled water temperatures and condenser water temperatures were fixed. No outside air lock-out controls were in place. The baseline parameters are shown in Table 8. Two seasonal operating profiles were

identified. The cooling season was determined to run from May 1st to October 31st. Two chillers were required from June 1st to August 15th. But, only one chiller was required during the remaining part of the cooling season.

Table 30: Baseline Key Parameters

	BASELINE		
Parameter	**Value(s)**	**Source of Parameter Value**	**Note**
Annual Cooling Hours	3,672	TA Study/Site data	May 1st to October 1st season
Maximum Tons	298	TA Study/Site data	92.5 DB bin
Chiller kW/ton	0.82	TA Study/Site data	
CHW temp set point °F	48.0	TA Study/Site data	Fixed
CW temp set point °F	75.0	TA Study/Site data	Fixed
CW pump HP	15.0	TA Study/Site data	
CW pump control	Fixed speed	TA Study/Site data	Operating in bypass mode

Proposed Condition

The existing chillers, condenser water pumps, and chilled water pumps were retained in the proposed case. The existing equipment was modified to improve operational efficiency and achieve savings. The check valves and balancing plug valves were proposed for removal for each condenser water pump. New lift checks and butterfly valves were proposed for each pump. A new variable speed drive was proposed for each CW pump.

Controls were proposed to allow chillers to be started and stopped by the energy management system. The program was to provide automated start/stop through the EMS and included automatic shut down when outside dry bulb temperatures drop below 62.5°F. The CW pumps were to be removed from the "hand" or by-pass position at the motor control center and placed under EMS control. The number of operating pumps would be dictated by the number of chillers online. The EMS would be programmed with a chilled water reset schedule and condenser water reset schedule. These schedules would be indexed to outside wet bulb temperatures.

Table 31: Proposed Key Parameters

	BASELINE		
Parameter	**Value(s)**	**Source of Parameter Value**	**Note**
Annual Cooling Hours	3,672	TA Study/Site data	May 1st to October 1st season
Maximum Tons	298	TA Study/Site data	92.5 DB bin
Chiller kW/ton	0.82	TA Study/Site data	
CHW temp set point °F	Variable	TA Study/Site data	
CW temp set point °F	Variable	TA Study/Site data	
CW pump HP	15.0	TA Study/Site data	
CW pump control	VFD	TA Study/Site data	

Tracking Calculation Methodology

Tracking savings were calculated using a 5.0°F weather bin spreadsheet. The spreadsheet uses a combination of wet bulb and dry bulb temperatures in the evaluation. Cooling load [tons] was calculated using wet bulb temperatures. The annual cooling hours per bin were based upon the dry bulb temperatures. Separate TABS are used to calculate the CW pump VFD measure and chiller control measure. Total cooling loads per bin were calculated using the combined CFM of the ventilation air of the air handling units and the unit ventilators in the buildings served by the central plant. Shell losses, internal gains, solar gains, and other factors were not included in the load analysis. For each bin, the cooling load is calculated as:

$$TONSbin = CFMoa\ x\ 4.5\ x\ hours\ x\ \frac{MAH - DAH}{12{,}000}$$

Where:

$TONS_{bin}$ = Tons of cooling per bin

CFM_{oa} = Total ventilation air in cubic feet per minute

4.5 = Conversion factor BTU/deg/Hour

Hours = Hours per bin

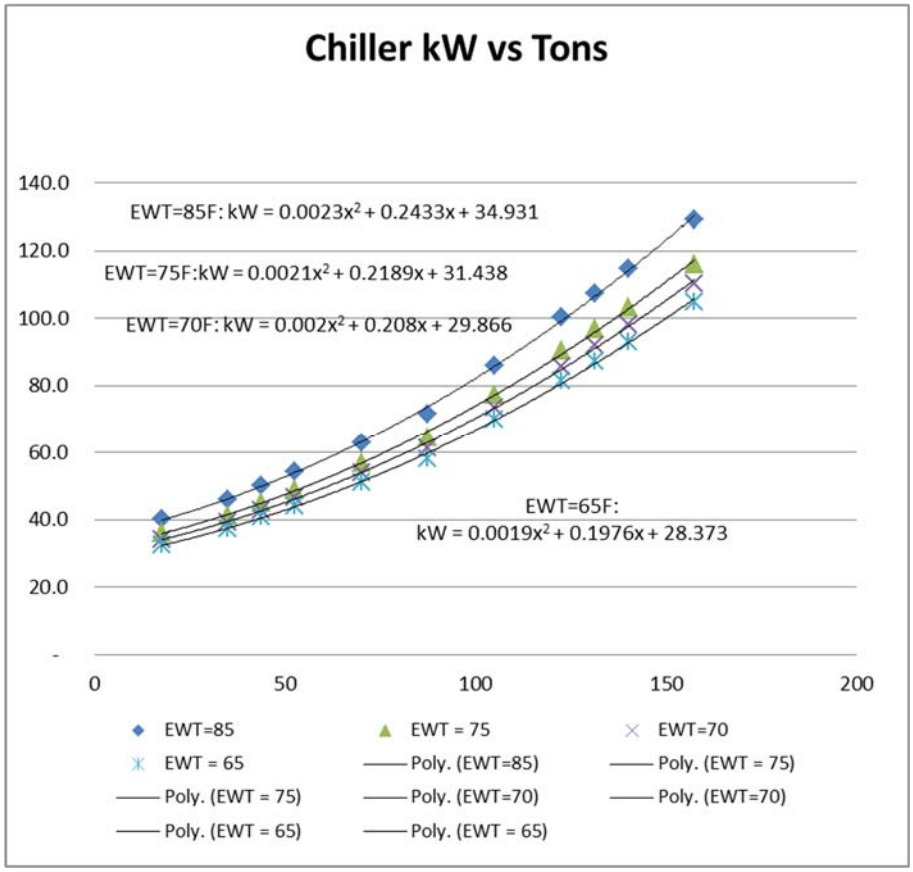
MAH = Average mixed air WB temperature

DAH = Average discharge air WB temperature

12,000 = Conversion factor BTUs to tons

Cooling tons are converted to kW for each bin using a regression analysis formula for the cooling efficiency. The regression formula used is for the EWT = 85°F plot shown in **Figure 12**.

Figure 12: Efficiency Regression Analysis



The baseline CW pump kW is calculated as:

$$kWhpump = \frac{\left(\frac{QNTY\ x\ TDH\ x\ GPM}{3960\ x\ EFFpump}\right) x\ hours\ x\ 0.746}{EFFmotor}$$

Where:

kWh_{pump}	= Condenser water pump kWh per bin
QNTY	= Quantity of pumps
TDH	= Total dynamic head
GPM	= Condenser water flow in gallons per minute
3960	= Constant
EFF_{pump}	= Pump efficiency
Hours	= Hours per bin

0.746 = Conversion factor HP to kW

EFF_{motor} = Motor efficiency

Two pumps are in use from June 1st through August 15th. One CW pump is used during the remainder of the bin hours. The same equation is used for the proposed condition. The total dynamic head drops from 110 head-feet in the base case to 43 head-feet in the proposed case. The reason for the change is not defined. The pumps operate at a single speed across all hours in both the base and proposed cases. Pump operation extends down to the 37.5°F bin in the base case and stops at the 47.5°F bin in the proposed case.

Savings for the chiller controls are calculated as minimizing chiller 2 operating hours. From June 1st through August 15th, both chillers are operating down to the 62.5°F temperature bin. Each chiller is assuming 50% of the total cooling load during this time. One chiller is operating for the rest of the year down to the 62.5°F temperature bin. In the proposed case, the savings are obtained by taking chiller #2 off-line below the 72.5°F temperature bin.

Evaluator Assessment of Tracking Savings

The tracking savings estimate cooling tonnage primarily using the ventilation air requirements provided by the HVAC units in the buildings served by the two chillers. A cooling season from May 1st to October 1st was obtained from facility personnel and HVAC schedules. Cooling requirements are calculated for a peak cooling period that runs from June 1st to August 15th. The chillers and pumps operate at a reduced load during the remainder of the season. While cooling loads are ventilation based, they do provide a base to calculate cooling loads and establish a seasonal cooling profile. However, the cooling loads do not include shell losses, solar gains, lighting and electrical plug loads, and occupancy. It is not possible to determine what the cooling base load is solely using ventilation CFM.

The calculations estimate cooling loads [tons] for each 5.0°F bin in the analysis using differential enthalpy between the outside air and mixed air conditions. Dry bulb temperatures are used to estimate the cooling hours for each bin. The methodology, while using both dry bulb and wet bulb approaches, provides a basic methodology to estimating savings. The estimated savings however is limited to ventilation loads only and does not include the impacts described above or establishes a true cooling base load.

Project Evaluation

Measure Verification

A site visit was conducted on July 21, 2016 to verify the installation and begin data collection. Discussions with facility personnel determined that the project has been completed and were fully operational. All equipment that was in the hand or bypass condition were now under control of the energy management system. The facility personnel also stated that no major changes were made in the buildings served by the central cooling plant. The schedules, ventilation requirements, and operation of those buildings coincided with the baseline conditions. The operating schedules and set points were reviewed in the energy management system. This review found the chilled/condenser water reset schedules were present in the system and that on/off and chiller staging operation was under EMS control.

The condenser water pumps were confirmed to be 15-HP units. Variable speed drives were installed and controlling the two CW pumps. The pump controls were no longer in the “hand” position and in the “auto” position indicating EMS control.

Two 175-ton chillers were identified and their specifications matched tracking values. The chilled water set point was 48.0°F which matches tracking documents. Both chillers were operational and under the control of the energy management system. A chiller lockout temperature was not identified during the site visit and facility personnel stated that this function has been disabled to help maintain constant temperatures in the buildings served by the chillers.

Data Collection

This project includes the installation of variable speed drives on two existing condenser water pumps. EMS controls were updated to improve chiller and pump operation. This includes staging the operation of the two existing 175-ton chillers. Three Elite power loggers were installed to monitor CW and chiller operation. The monitoring included 100% of the chillers and CW pumps included in this measure. EMS data on kitchen hood exhaust CFM, exhaust fan on/off times, and AHU on/off times were collected during the return visit.

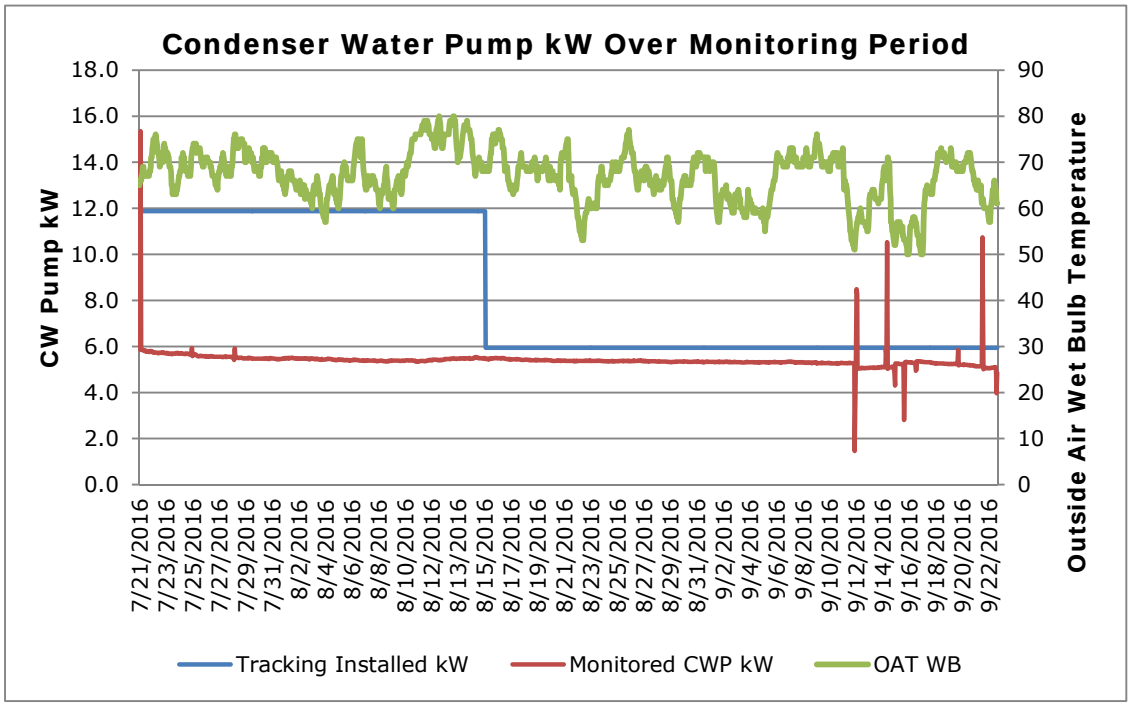
Table 11 shows the installed power loggers.

Table 32: Evaluation Data Collection – Installed Equipment

Parameter	M&V Equipment Brand and Model	Metering Start/Stop Dates	Metering Interval
CW pumps 1&2 - kW	Dent Elite-Pro Logger	7/21/2016 -9/23/2016	5-minutes
Chiller #1 - kW	Dent Elite-Pro Logger	8/4/2016-9/29/2016	5-minutes
Chiller #2 - kW	Dent Elite-Pro Logger	8/4/2016-9/29/2016	5-minutes
Outside air DB/WB temperatures - °F	Local weather station	8/4/2016-9/29/2016	1-hour

The monitored power data was viewed over the entire monitoring period. Figure 13 shows the average monitored hourly kW for the condenser water pumps. The graph also shows the corresponding hourly wet bulb temperatures and the estimated installed pump kW from the TA report. The trend data shows that the pumps operated nearly continuously during the monitoring period. Pump kW showed no modulation compared with wet bulb temperatures. The monitoring data shows that the pumps operated less that the TA study installed estimates. Only one pump was required to meet cooling loads. The spikes in monitored pump kW coincides with pump switchover when both pumps were on at the same time. Total combined operation during the monitoring period was 2.75 hours or 0.18% of the time.

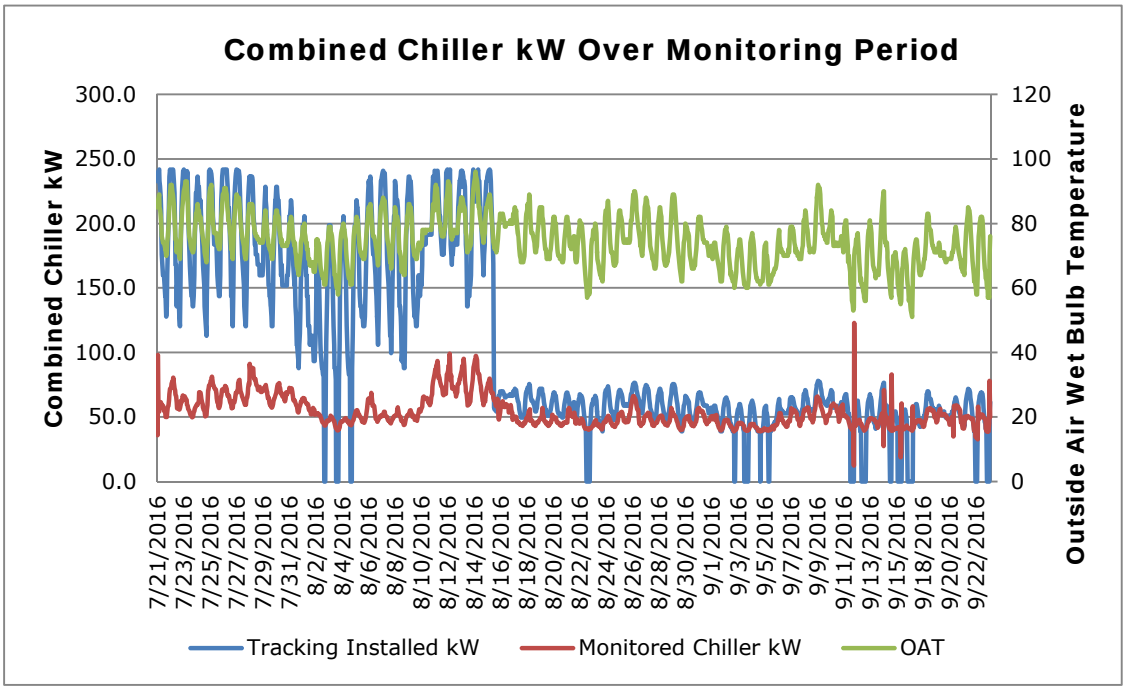
Figure 13: Condenser Water Pump Operation



The data from the two chiller loggers was combined to profile the operation of the chiller plant. The data was entered into a similar chart that compares total monitored power and outside wet bulb temperatures as shown in Figure 14. The power logger data shows that a single chiller operated throughout the monitoring period. The projected TA installed data anticipates that two chillers are required from June 1st through August 15th. The operation of the two chillers during the baseline period was confirmed during the site visit and through conversations with facility personnel after the logger data was downloaded and reviewed. The facility personnel suggested that our monitoring period may have been impacted by work being done in the facility. Some HVAC equipment was offline for needed O&M repair and some equipment was replaced. The facility engineer stated that he believed that the final maximum cooling load on the plant was around 210-tons. This is greater than the capacity of one chiller but less than the 298-ton maximum capacity in the tracking calculations.

Monitored chiller power represents a 120-ton maximum cooling load which is significantly lower than either the tracking cooling or the projected cooling provided by the site personnel.

Figure 14: Chiller Plant Operation



Evaluation Savings Analysis

The monitored power data was compared with outside air wet bulb temperatures concurrent with the monitoring period. The 5-minute hourly monitoring data was converted to hourly average values to match the hourly temperature format. The cooling season in the TA study was identified as May 1st through September 30th. That cooling schedule was confirmed by the facility personnel. The cooling season was broken into two time periods. The peak cooling period was identified in the TA study to be from June 1st through August 15th. Two chillers and pumps were anticipated to operate during that period. One chiller and CW pump was anticipated for the remaining non-peak hours. The monitoring period extended through both periods and data was reviewed to conform to this peak and non-peak intervals. Figure 15 shows the operation of the CW pump monitored power to wet bulb temperature. Figure 16 shows the same data for the non-peak cooling period. The monitoring power shows that the pumps are operating at close to fixed speeds and there is no correlation to power with outside air temperatures as indicates by the very low R^2 values. The monitoring data also finds that there is little power difference between peak and non-peak pumping requirements.

Figure 15: Peak Cooing Period CW Pump Operation

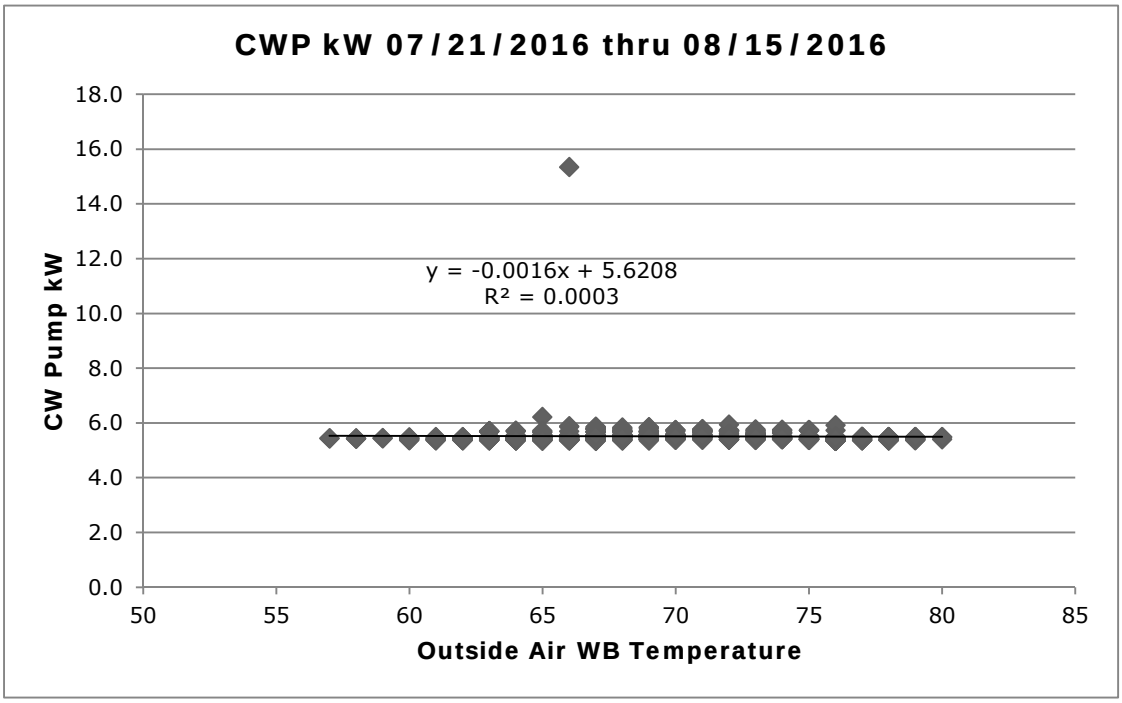
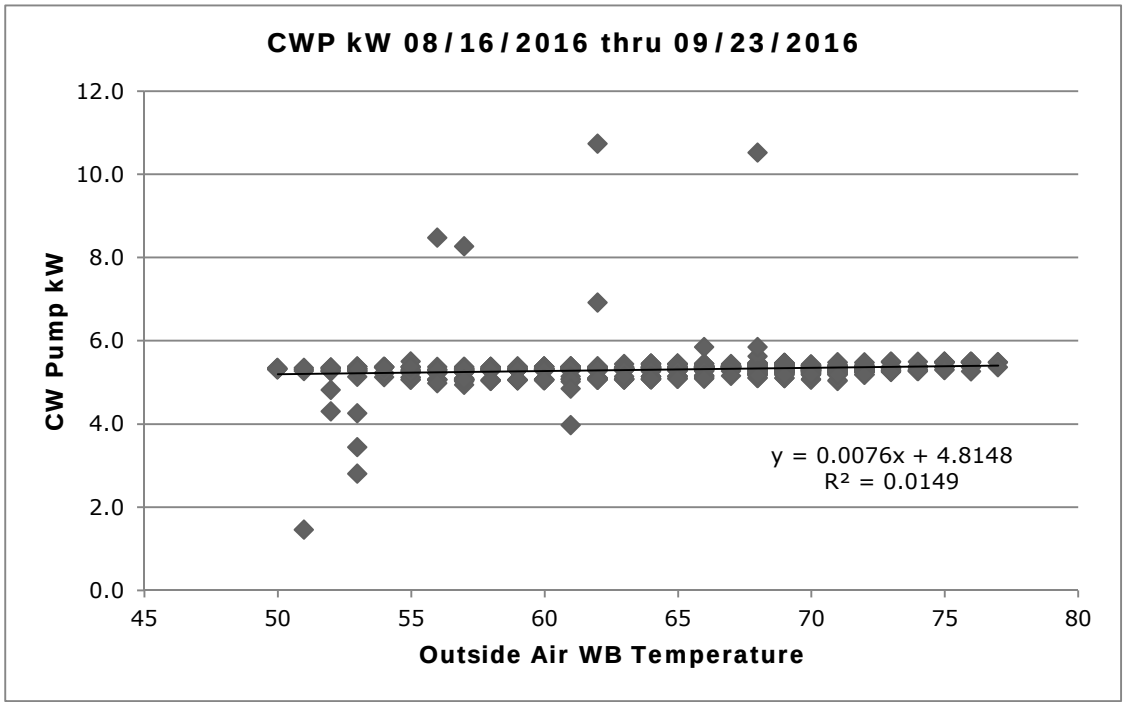


Figure 16: Non-Peak Period CW Pump Operation



The same analysis was performed on the chiller data. The data from the two power loggers was combined to create an operating profile for the entire chiller plant. The monitored average hourly chiller kW was compared against the corresponding outside air wet bulb temperatures. Figure 17 shows the chiller performance during the peak cooling period. The analysis shows that there is a clear relationship between total chiller power and wet bulb temperatures during that period as indicated by the 0.71 R^2. The power logger data shows that only one chiller is required to meet cooling requirements over the monitoring period. Cooling loads over the monitoring period are not reflective of actual total cooling requirements. Facility personnel stated that monitoring values may have been affected by HVAC work being done at the facility with HVAC units being taken off-line. Monitored power suggests a maximum cooling load of 120-tons. Facility personnel estimated the maximum load around 210-tons. The suggested maximum cooling load is 169.3% of the monitored load.

Figure 17: Peak Cooing Period Chiller Plat Operation

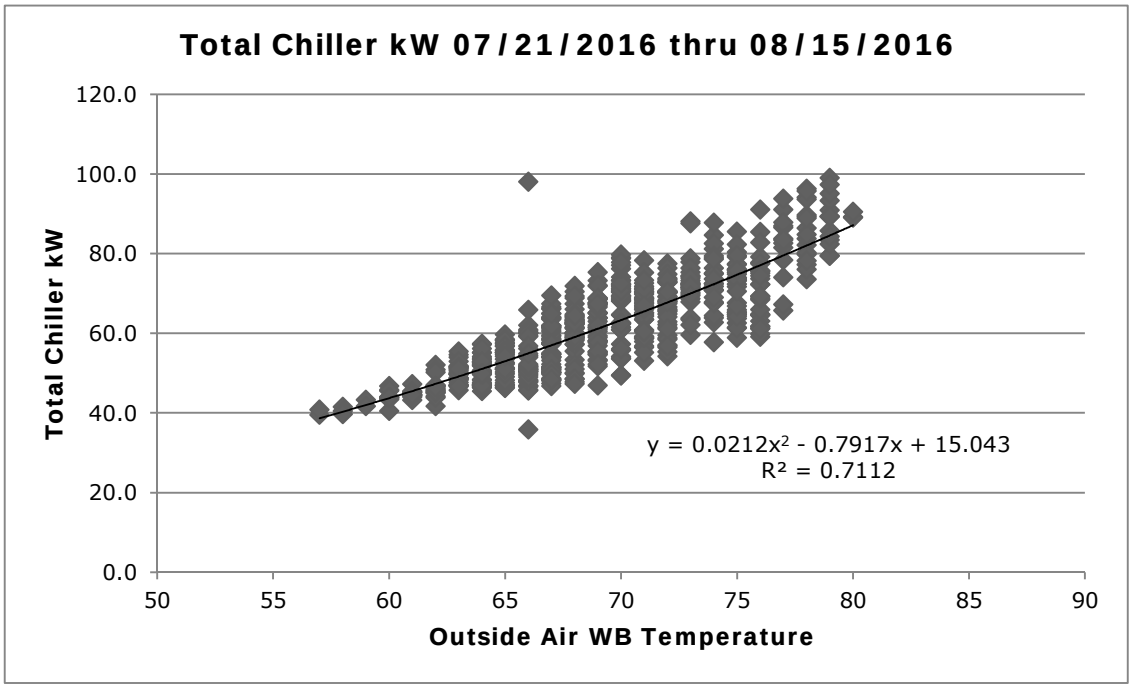
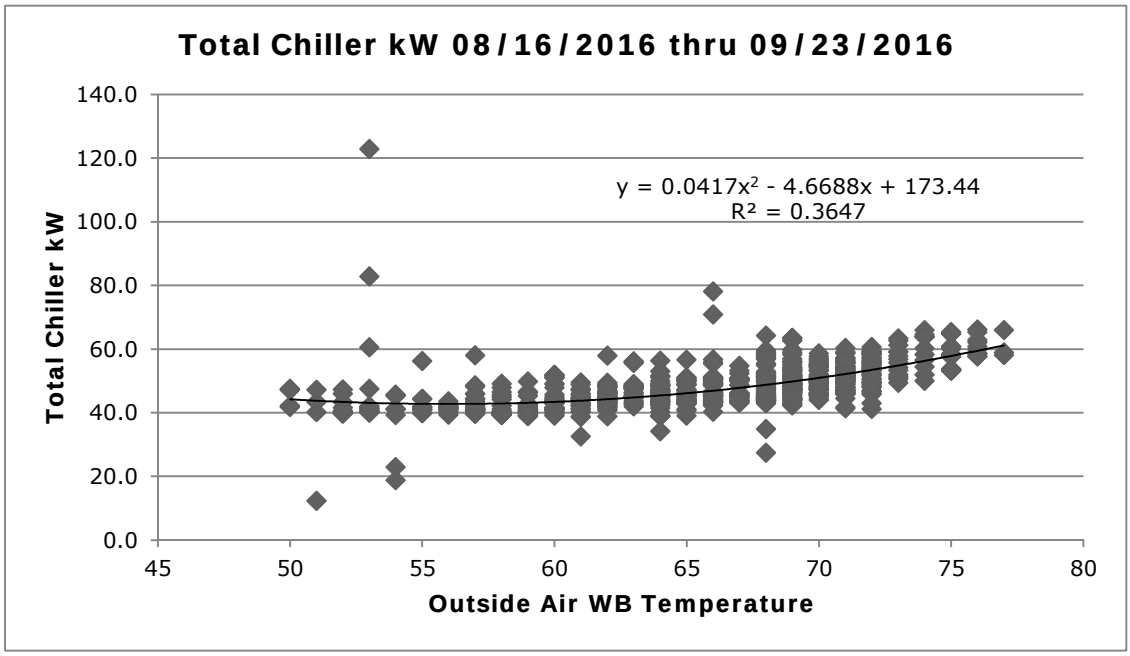


Figure 18: Non-Peak Period Chiller Plant Operation



The M&V savings are calculated using an 8,760-hour spreadsheet that uses the trended power values and TMY3 annual weather data. The cooling season of May 1st through September 30th was set as the cooling schedule. Peak [June 1st through august 15th] and non-peak [May 1st to June 1st and August 16th to October

1st] was scheduled to conform to tracking cooling season estimates. Savings were calculated for each defined cooling hour using the monitored power data.

There is little correlation between condenser water pump operation and outside air temperatures as shown in Figure 15 and Figure 16 above. The average hourly pumping kW from the trend data was used for the peak and non-peak cooling periods. These values are 5.51 kW and 5.31 kW respectively. Figure 19 shows is an excerpt from the 8,760-hour calculation spreadsheet. It shows savings for the last day of the peak cooling period [August 15th] and the first day of the non-peak cooling period [August 16th].

Figure 19: Excerpt form 8,760 Calculation Spreadsheet

					Avg	5.3	86.5	64.5	80.8	14.8	94.8	66.3	95.3	
			81.0	95.0	Max	5.4	151.5	103.6	156.9	19.8	166.2	117.5	186.1	32.6
			3.0	4.0	Min	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		3,672			Totals	19,552	157,855	119,173	296,580	54,508	172,878	122,592	349,978	53,398
	Providence, RI		TMY 3 Temps				**INSTALLED KW**				**BASELINE KW**			
Month	Day	Total Cooling Hours	OWB Temp	ODB Temp	Hour	CWP	Chillers 06/01 thru 08/15	Chiller 05/01 to 06/01 and 08/16 to 10/01	Site Total kW	CWP	Chillers 06/01 thru 08/15	Chiller 05/01 to 06/01 and 08/16 to 10/01	Total Tracking kW	Total Houry kW Savings
Aug	Mon	1	75	77	1	5.4	126.1	0.0	131.49	19.8	144.1	0.0	163.98	32.49
Aug	Mon	1	74	75	2	5.4	122.1	0.0	127.51	19.8	139.8	0.0	159.65	32.14
Aug	Mon	1	73	74	3	5.4	118.2	0.0	123.59	19.8	135.4	0.0	155.21	31.62
Aug	Mon	1	73	76	4	5.4	118.2	0.0	123.59	19.8	135.4	0.0	155.21	31.62
Aug	Mon	1	73	76	5	5.4	118.2	0.0	123.59	19.8	135.4	0.0	155.21	31.62
Aug	Mon	1	73	77	6	5.4	118.2	0.0	123.59	19.8	135.4	0.0	155.21	31.62
Aug	Mon	1	75	79	7	5.4	126.1	0.0	131.49	19.8	144.1	0.0	163.98	32.49
Aug	Mon	1	76	81	8	5.4	130.1	0.0	135.55	19.8	148.3	0.0	168.17	32.62
Aug	Mon	1	78	84	9	5.4	138.5	0.0	143.89	19.8	156.2	0.0	176.03	32.14
Aug	Mon	1	78	87	10	5.4	138.5	0.0	143.89	19.8	156.2	0.0	176.03	32.14
Aug	Mon	1	81	89	11	5.4	151.5	0.0	156.92	19.8	166.2	0.0	186.07	29.15
Aug	Mon	1	80	91	12	5.4	147.1	0.0	152.50	19.8	163.2	0.0	182.99	30.49
Aug	Mon	1	79	92	13	5.4	142.7	0.0	148.16	19.8	159.8	0.0	179.64	31.48
Aug	Mon	1	78	92	14	5.4	138.5	0.0	143.89	19.8	156.2	0.0	176.03	32.14
Aug	Mon	1	78	91	15	5.4	138.5	0.0	143.89	19.8	156.2	0.0	176.03	32.14
Aug	Mon	1	79	90	16	5.4	142.7	0.0	148.16	19.8	159.8	0.0	179.64	31.48
Aug	Mon	1	78	87	17	5.4	138.5	0.0	143.89	19.8	156.2	0.0	176.03	32.14
Aug	Mon	1	77	84	18	5.4	134.3	0.0	139.68	19.8	152.4	0.0	172.20	32.51
Aug	Mon	1	75	83	19	5.4	126.1	0.0	131.49	19.8	144.1	0.0	163.98	32.49
Aug	Mon	1	71	81	20	5.4	110.6	0.0	115.97	19.8	126.3	0.0	146.10	30.13
Aug	Mon	1	71	80	21	5.4	110.6	0.0	115.97	19.8	126.3	0.0	146.10	30.13
Aug	Mon	1	71	79	22	5.4	110.6	0.0	115.97	19.8	126.3	0.0	146.10	30.13
Aug	Mon	1	71	78	23	5.4	110.6	0.0	115.97	19.8	126.3	0.0	146.10	30.13
Aug	Mon	1	71	78	24	5.4	110.6	0.0	115.97	19.8	126.3	0.0	146.10	30.13
Aug	Tue	1	71	78	1	5.2	0.0	88.3	93.54	9.9	0.0	97.2	107.14	13.60
Aug	Tue	1	71	75	2	5.2	0.0	88.3	93.54	9.9	0.0	97.2	107.14	13.60
Aug	Tue	1	71	74	3	5.2	0.0	88.3	93.54	9.9	0.0	97.2	107.14	13.60
Aug	Tue	1	71	75	4	5.2	0.0	88.3	93.54	9.9	0.0	97.2	107.14	13.60
Aug	Tue	1	71	74	5	5.2	0.0	88.3	93.54	9.9	0.0	97.2	107.14	13.60
Aug	Tue	1	71	75	6	5.2	0.0	88.3	93.54	9.9	0.0	97.2	107.14	13.60
Aug	Tue	1	71	77	7	5.2	0.0	88.3	93.54	9.9	0.0	97.2	107.14	13.60
Aug	Tue	1	72	79	8	5.2	0.0	90.5	95.73	9.9	0.0	100.2	110.09	14.36
Aug	Tue	1	72	80	9	5.2	0.0	90.5	95.73	9.9	0.0	100.2	110.09	14.36
Aug	Tue	1	73	85	10	5.2	0.0	92.8	98.07	9.9	0.0	103.3	113.23	15.16
Aug	Tue	1	71	83	11	5.2	0.0	88.3	93.54	9.9	0.0	97.2	107.14	13.60
Aug	Tue	1	72	82	12	5.2	0.0	90.5	95.73	9.9	0.0	100.2	110.09	14.36
Aug	Tue	1	71	81	13	5.2	0.0	88.3	93.54	9.9	0.0	97.2	107.14	13.60
Aug	Tue	1	70	78	14	5.2	0.0	86.3	91.49	9.9	0.0	94.5	104.37	12.88
Aug	Tue	1	69	76	15	5.2	0.0	84.4	89.58	9.9	0.0	91.9	101.79	12.20
Aug	Tue	1	70	76	16	5.2	0.0	86.3	91.49	9.9	0.0	94.5	104.37	12.88
Aug	Tue	1	69	76	17	5.2	0.0	84.4	89.58	9.9	0.0	91.9	101.79	12.20
Aug	Tue	1	68	75	18	5.2	0.0	82.6	87.82	9.9	0.0	89.5	99.40	11.58
Aug	Tue	1	65	72	19	5.2	0.0	78.1	83.36	9.9	0.0	83.5	93.40	10.04
Aug	Tue	1	65	71	20	5.2	0.0	78.1	83.36	9.9	0.0	83.5	93.40	10.04
Aug	Tue	1	64	69	21	5.2	0.0	76.9	82.16	9.9	0.0	81.9	91.79	9.63
Aug	Tue	1	63	67	22	5.2	0.0	75.9	81.10	9.9	0.0	80.5	90.37	9.28
Aug	Tue	1	63	67	23	5.2	0.0	75.9	81.10	9.9	0.0	80.5	90.37	9.28
Aug	Tue	1	62	64	24	5.2	0.0	55.2	60.42	9.9	0.0	54.4	64.36	3.94

Regression analyses are performed to calculate the peak and non-peak cooling plant savings. The regression formulas are obtained from the trending scatter plots shown in Figure 17 and Figure 18. The regression analysis equations allows the calculation of hourly power based upon the TMY3 wet bulb temperature for that hour. The regression formula used is:

$$Y = (X\text{^}2\ x\ X2variable) + (X\ x\ Xvariable) + Int$$

Where:

Y = Hourly kW

X = TMY3 hourly wet bulb temperature

$X2_{variable}$ = regression value for wet bulb temperature squared

$X_{variable}$ = regression value for wet bulb temperature

Int = regression formula intercept value

The regression equation for the peak cooling period is:

y = 0.0212x2 - 0.7917x + 15.043

R^2 = 0.7112

The regression equation for the non-peak cooling period is:

y = 0.0417x2 - 4.6688x + 173.44

R^2 = 0.3647

The regression analysis output values were adjusted by 169.3%. This accounts for the cooling load discrepancy between the monitored and estimated cooling loads. The maximum cooling load was estimated at 210-tons. No additional incremental cooling loads were provided.

Regression equations were created from the tracking data in the TA study. The estimated baseline chiller kW was compared against average bin temperatures. This regression allows for the estimation of hourly baseline kW using the TMY3 hourly weather values.

Cooling tons were estimated using the hourly chiller kW and the chiller efficiency curve where X is the hourly chiller kW:

y = -0.009x2 + 3.054x – 76.4

R^2 = 0.9975

The baseline chiller kW is calculated using the hourly cooling tons and the baseline cheer performance curve where X is tons:

y = -0.0021x2 + 0.2189x + 31.738

R^2 = 0.9827

The baseline R2 values are higher because they are based upon fewer temperature points. The monitored data consists of over 1,500 hourly temperatures while the baseline consists of only 10 temperatures. In the trend data, each WB temperature can have multiple different kW readings.

On-Peak Energy and Demand Savings

The 8,760-hourly spreadsheet also calculates the on-peak and demand savings. Each on-peak hour is identified in the spreadsheet and the savings for all those hours and summed. The winter and summer demand periods are precisely defined in the calculation spreadsheet and the savings for those seasonal demand periods are identified and reported.

Evaluation Results

This project consists of two measures. Measure 1 installs variable speed drives on existing condenser water pumps. Measure 2 installs controls on the existing chillers and pumps. Table 26 summarizes the savings for the two measures.

The calculated savings are greater than the projected TA study savings. The CW pumps are operating at lower capacity than anticipated. This is shown in Figure 13. The TA study was anticipating higher hourly usage and differences between peak and non-peak operation.

The TA study also anticipated that two chillers would be required during the peak cooling period. Only one chiller was required for most of the motioning period. Chiller 2 operated for 98% of the 63-day monitoring period. Chiller 1 was online for a total of 3-hours. Both chillers operated together for only a 10-minute period. This operating sequence is not indicative of final chiller operation. Both chillers will be needed during peak cooling as the total estimated cooling exceeds the capacity of a single chiller.

The TA study also assumed that the chillers would be locked out below a 62°F outside air temperature. The monitored power data shows that this is not the case. Chiller operation was recorded at 39°F wet bulb temperatures.

Table 33: Project Results by Measure.

Savings Measure	Tracking kWh	Evaluation Estimate	Realization Rate
Condenser Water Pump VFDs	22,814	34,956	153%
Chiller Controls	78,006	18,442	24%
Total	100,820	53,398	53%

Table 34 shows the on-peak and demand savings. The realization rate M&V evaluated on-peak savings is 85% of the tracking value. The summer demand savings is 82% of the tracking value.

There are no winter demand savings for this measure. All cooling occurs between May 1st and October 31st which is outside of the winter demand months.

Table 34: On-Peak and Demand savings

Savings Quantity	Tracking Estimate	Evaluation Estimate	Realization Rate
% of Energy Savings On-Peak	57%	48%	85%
Summer On-Peak Demand (kW)	27.0	22.04	82%
Winter On-Peak Demand (kW)	2.0	0.0	0%

Comparison of Assumptions

The primary reason for the savings variance is the change in total estimated chiller loads. Cooling loads in the TA study are calculated exclusively from OA ventilation CFM. Plug/light loads, UAΔT losses, solar gain, occupant loads and other factors are not considered. There are no monitored trends or test/balancing reports to confirm or provide a source for the ventilation capacity. Those loads may have been overstated, but it is not possible to estimate how much considering work has been done to the facility. The evaluation savings are based upon monitored cooling plant operation that is adjusted for site estimates of maximum cooling requirements.

Table 35: Comparison of Key Parameters

	BASELINE		PROPOSED / INSTALLED	
Parameter	Tracking Value(s)	Evaluation Value(s)	Tracking Value(s)	Evaluation Value(s)
Annual cooling hours	3,672	3,672	3,672	3,672
Chiller lockout temperature	62°F	None	62°F	None
Annual chiller operating hours	2,832	3,597	2,832	3,597
Average chiller kW	104.6	80.4	96.7	75.4
Maximum chiller kW	244.7	166.2	245.0	151.5
Annual pumping hours pump 1	3,672	3,613	3,672	3,613
Annual pumping hours pump 2	1,836	1,836	1,836	0
Average pump kW	14.8	14.8	8.9	5.3

Improvement Opportunities

No improvement opportunities are noted at this time.

4.2.1.4 Site ID: DNV 25

Project ID(s)	DNV 25
Project Type	Retrofit
Program Year	2014
Application ID/s	3575544
Evaluation Engineer/s	Rick Boswell, Srikar Kaligotla

1.1 Project Description

This retrofit project includes the following measures implemented at an office building. The building has different schedules and each floor is being served by a separate Air handling unit (AHU). Floors 1 (AHU1) and 2 (AHU2) have call centers and therefore are occupied for longer periods of time than usual office buildings (Tue-Sat 7AM thru 1AM, Sun-Mon: 24x7). Floors 3 (AHU3) and 4 (AHU4) are office and are occupied 6:30 AM thru 8:00 PM (M-F) and 6:30 AM through 5:00 PM on Saturday. The new energy efficient measures that were implemented:

1) Calibrate Thermostats on multiple floors
2) Adjusted AHU schedules (EMS)
3) Replaced AHU static pressure sensors
4) Replaced one VAV box
5) Fixed controls for another VAV box
6) Fixed Damper Controls for an ACU

This project includes multiple control measures where pre-retrofit data was required for energy savings calculation. In the absence of this data, evaluation team used ASHRAE 90.1 fan curves and made necessary assumptions when required based on the customer interview, tracking analysis trending data and standard practices. Even though measures #4 and #5 have some energy savings due to the retrofit but the net building energy remained the same. Table 36 shows the overall evaluation results for this project.

Table 36: Electric Project Results

Savings Parameter	Tracking	Evaluation	Realization Rate
Energy Savings (kWh)	647,878	644,500	99%
% of Energy Savings on Peak	50%	43%	86%
Summer On-Peak Demand (kW)	124.09	74.61	60%
Winter On-Peak Demand (kW)	57.40	55.79	97%

1.2 Tracking Savings

This section summarizes the methodology and assumptions used to estimate the tracking savings claimed for the project including Pre-retrofit assumptions, proposed equipment, tracking calculation method along with the underlying assumptions that were used in the calculations to estimate the tracking savings.

1.2.1 ECM1: CALIBRATE THERMOSTATS

1.2.1.1 Pre-retrofit

The facility has an estimated 69 pneumatically controlled and actuated VAVs. These did not communicate with the BAS as their controls were entirely pneumatic and are stand-alone. During tracking field investigation, most thermostats were found to be significantly out of calibration. Poor thermostat calibration was suspected to be one of the factors contributing to consistently high AHU supply fan VFD speeds.

1.2.1.2 Post-retrofit

61 pneumatic thermostats were calibrated upfront. A comparison of trend data during periods before and after thermostat calibration indicates a positive impact on the building's AHUs, especially AHU-2, by reducing supply fan VFD speeds.

All remaining pneumatic thermostats were calibrated in December 2013 as part of the Phase 1 measure implementation. All remaining thermostats were set to a temperature set-point of 73°F

1.2.1.3 Calculation Methodology

To estimate the annualized energy savings for AHU-2, weather bin models were created to approximate fan and cooling energy use of the air handler prior to and following thermostat calibration. Available trend data was used to establish most of AHU-2's existing case fan speed profile; however, extrapolation was necessary in the proposed case due to the limited amount of available data during cooler outdoor air temperatures.

Existing case weather bin models were also built for air handlers AHU-3 and AHU-4 using available trend data (Table 39, Table 40). Proposed case energy consumption was estimated using AHU-2's model results which were normalized by using a derating factor of 0.75 to reflect each air handler's unique existing case.

AHU#	Airflow CFM	Supply fan hp	Return fan hp
AHU1	23,220	30	15
AHU2	21,530	30	15
AHU3	21,365	30	15
AHU4	22,210	30	15

Table 42 and Table 43 below show the capacities and calculated savings by AHU.

Table 42: AHU details

AHU#	Airflow CFM	Supply fan hp	Return fan hp
AHU1	23,220	30	15
AHU2	21,530	30	15
AHU3	21,365	30	15
AHU4	22,210	30	15

Table 43: Tracking Savings for ECM1

AHU #	Baseline Fan Energy	Baseline Cooling Energy	Proposed Fan Energy	Proposed Cooling Energy	Savings: Fan Energy[1]	Savings: Cooling Energy
	kWh	kWh	kWh	kWh	kWh	kWh
AHU-1	173,627	78,109	94,117	64,952	59,633	9,868
AHU-2	173,533	73,697	94,066	61,283	79,468	12,414
AHU-3	89,594	42,263	48,566	35,144	30,772	5,339
AHU-4	58,331	39,081	31,619	32,498	20,034	4,937
TOTALS					**189,906**	**32,558**

Table 39: Trend data showing the decrease in AHU2 supply fan speed following calibration

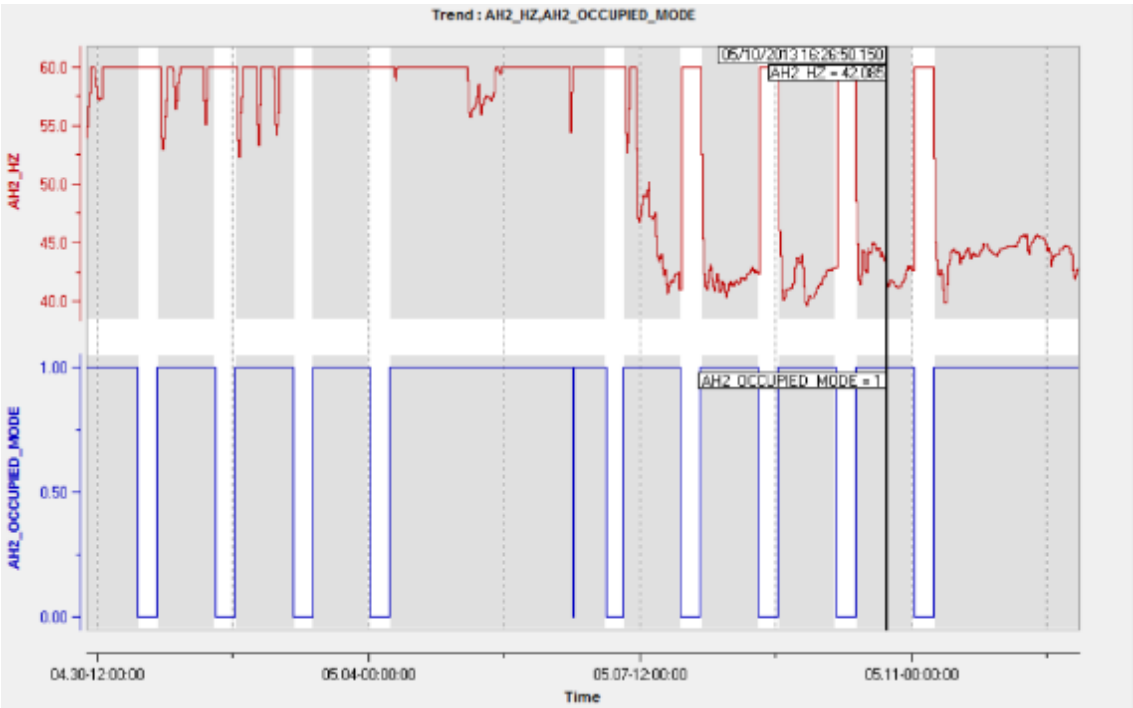
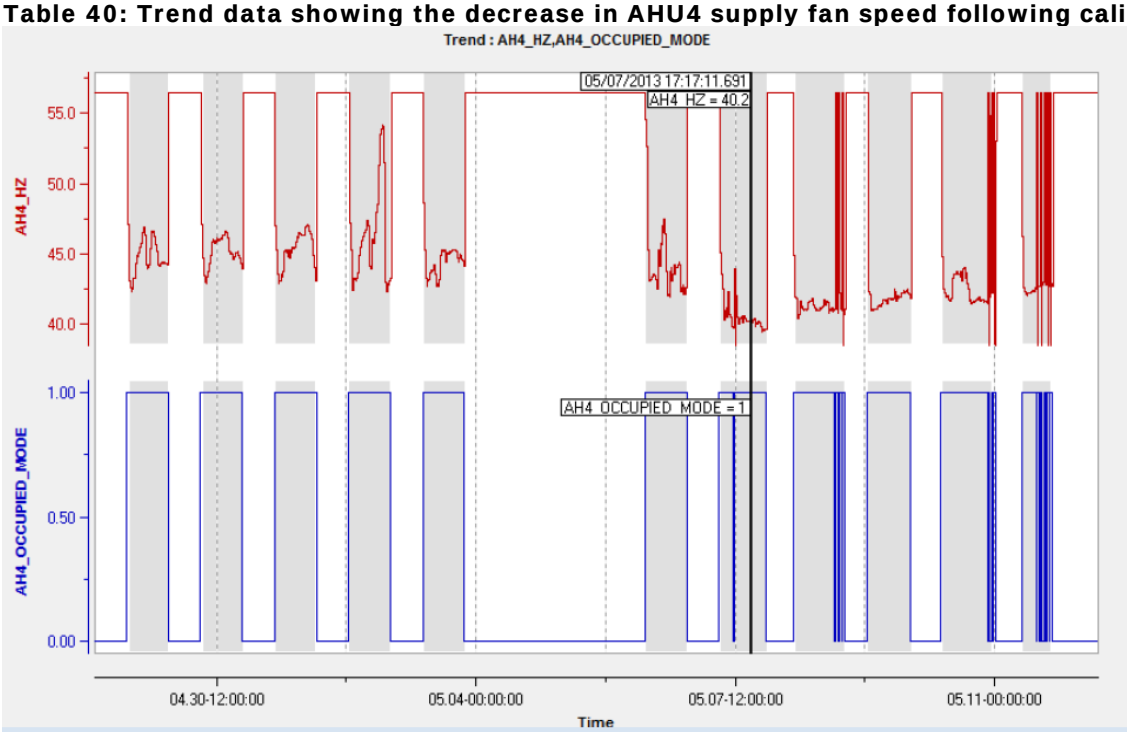


Table 40: Trend data showing the decrease in AHU4 supply fan speed following calibration



1.2.2 ECM2: RTU3 SCHEDULING

1.2.2.1 Pre-retrofit

Tracking analysis found RTU-3 to be operating 24/7 in the pre-retrofit data, which was inconsistent with the scheduled operation of RTU-1 and RTU-2. It was confirmed that RTU-3 was intended to have a schedule like the other RTUs at the building, but was operating continuously.

1.2.2.2 Post-retrofit

The reconfiguring of RTU-3's DDC control panel changed the operation per the occupancy schedule listed in the table below.

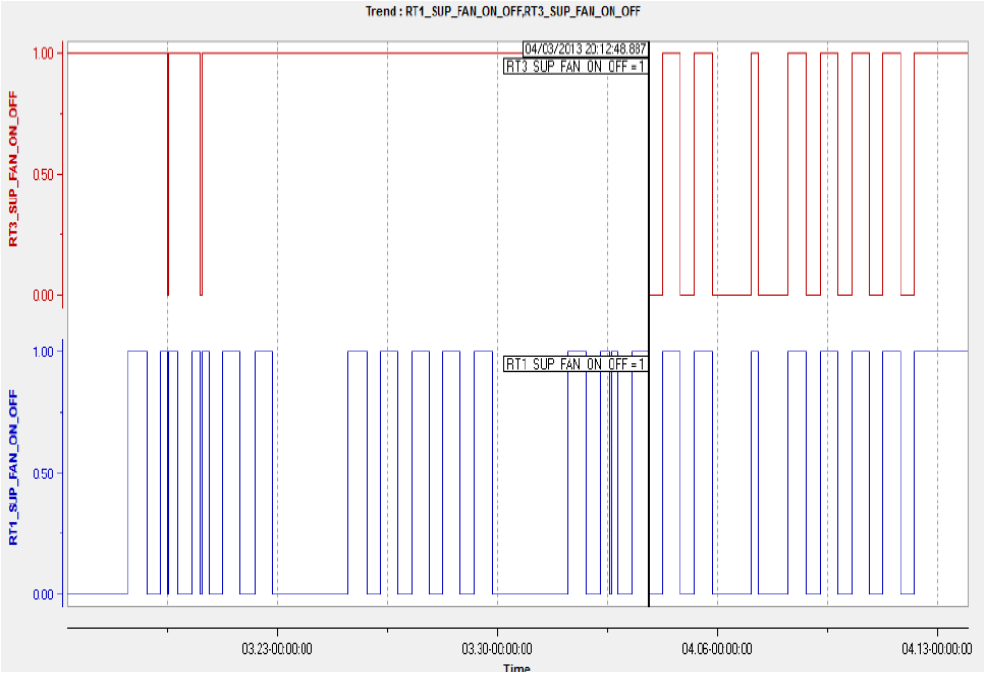
Table 46 RTU3 Tracking Analysis Schedule

Day	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
On	6:45am	6:45am	6:45am	6:45am	6:45am	-	-
Off	8:15pm	8:15pm	8:15pm	8:15pm	8:15pm	-	-

1.2.2.3 Calculation Methodology

A weather-based bin model was used to estimate the energy savings associated with implementing scheduling on RTU-3. An existing case model was configured to determine the energy consumption of the RTU under continuous operation. Figure 20 below shows the operation of RTU1 vs RTU3; Note RTU3 operating constantly while RTU1 operating in a specific schedule. The figure also shows the correction made post-retrofit. Tracking analysis used annual operating hours of 3,393 in the post-retrofit condition based on trend data, customer interviews and 8,760 for Pre- case.

Figure 20: shows the supply fan motor status for RTU-3 (red) and RTU-1 (blue) at the building



1.2.3 ECM3: REPLACE AHU STATIC PRESSURE SENSORS

1.2.3.1 Pre-retrofit

In Pre- case, AHU-2 and AHU-3 with their fan VFDs ran consistently at full or near full speed in pre-retrofit condition. In addition, the supply fans on AHU-1 and AHU-4 have been observed in trends not to modulate below approximately 40 Hz (67%). AHU-2's static pressure measurement reported by the BAS was tested for accuracy using a differential pressure gauge. A duct static pressure reading was measured in AHU-2's main 48" duct located on the second floor and compared to the pressure reported at the BAS. The field measured reading was found to be 0.5" WC higher than the static pressure reported by the BAS, indicating the sensor is out of calibration, or improperly located.

1.2.3.2 Post-retrofit

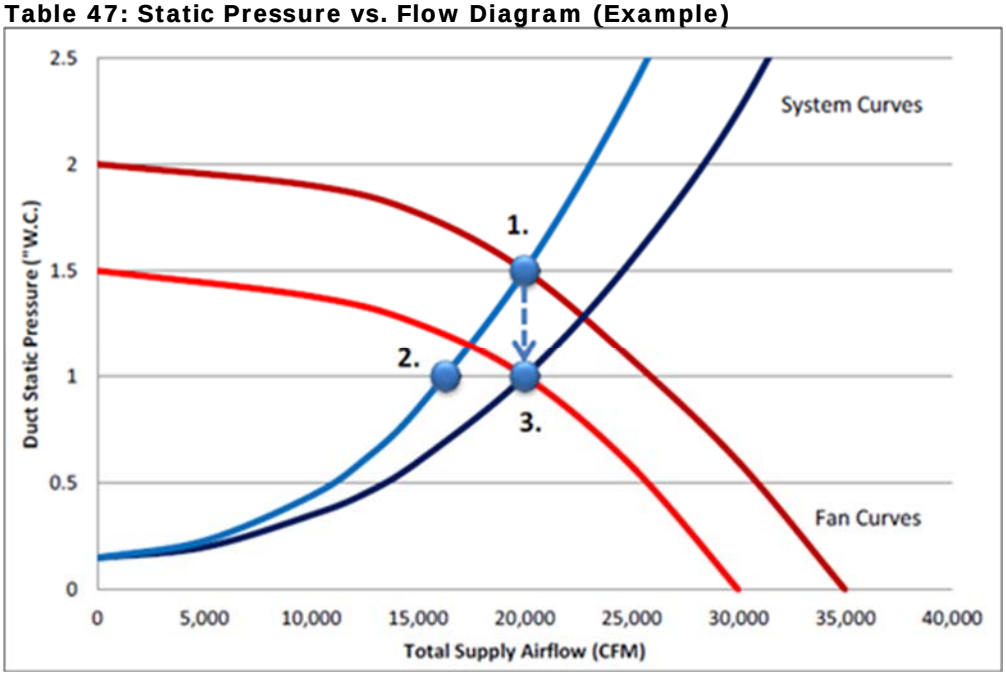
Measure involved replacing the static pressure sensors for AHU-1, 2, 3, and 4.

1.2.3.3 Calculation Methodology

The energy savings model assumed that terminal VAV boxes are pressure independent and have the turndown capabilities to meet their minimum airflow set-points per space loads with the existing (higher) duct static levels. Therefore, the energy calculations assumed that the total supply airflow of each AHU is not affected by calibrating and/or replacing the duct static sensors and establishing the proper set-point of 1.0" WC. The example chart below illustrates this assumption; by lowering the actual static pressure developed by each air handler, the fan VFD will ramp down along the system curve (1 => 2). However, in order for terminal box primary airflow set-points to be met, the box dampers will open and the AHU fan

speed will increase (2 => 3). The net result at the AHU is an overall reduction in fan speed with equal total supply airflow (1 = > 3).

Table 47: Static Pressure vs. Flow Diagram (Example)



This calculation was performed assuming that the static pressure sensors on AHU-1 and AHU-4 are out of calibration by 0.1" WC and the sensors on AHU-2 and AHU-4 are out of calibration by 0.5" WC. These assumptions were made because AHU-2 and AHU-3 ran at a higher average speed (at or near 60 Hz), and AHU-2 was observed to be 0.5" WC out of calibration with a field measurement as shown in the table below.

Table 48: Static pressure measurements in the pre- and post-retrofit condition

Avg Fan Speeds (Observed in Trends)					Static Pressure Before/After Fan (Based on Field Measurements)					
					Existing			Proposed		
#	SF Hz	SF %	RF Hz	RF %	SP @ Fan Exit	SP @ Fan Inlet	Fan SP	SP @ Fan Exit	SP @ Fan Inlet	Fan SP
AHU-1	37.44	62.4%	54.96	91.6%	1.8	-0.7	2.6	1.7	-0.7	2.5
AHU-2	52.21	87.0%	52.21	87.0%	2.5	-1.0	3.6	2.0	-1.0	3.1
AHU-3	52.41	87.4%	52.41	87.4%	2.5	-1.0	3.6	2.0	-1.0	3.1
AHU-4	46.55	77.6%	46.55	77.6%	2.0	-0.9	3.0	1.9	-0.9	2.9

Proposed case energy consumption was estimated using AHU-2's model results which were normalized to reflect each air handler's unique existing case. Savings calculations are shown in the table below. The source for the annual operating hours was not mentioned in the report but presumed to be from trend data. VFD speed was calculated to be an average speed from the trend data.

Table 49: Tracking savings for post- and pre-retrofit condition based on the static pressure and fan speed.

AHU #	Design Fan Shaft Power	Existing Fan Static	Existing Avg VFD Speed	Annual Run Hours	Existing Fan Energy	Proposed Fan Static	Proposed Avg VFD Speed	Annual Run Hours	Proposed Fan Energy	Annual Savings
	kW	" WC	%	Hrs	kWh	"WC	%	Hrs	kWh	kWh
Supply Fans										
AHU-1	17.5	2.6	62.4%	7590	44,810	2.5	61.1%	7590	42,432	2,378
AHU-2	16.2	3.6	87.0%	7512	94,386	3.1	80.0%	7512	76,629	17,757
AHU-3	16.1	3.6	87.4%	4212	53,122	3.1	80.4%	4212	43,151	9,972
AHU-4	16.8	3.0	77.6%	3835	37,349	2.9	76.1%	3835	35,609	1,740
TOTALS					229,667				197,820	31,846
Return Fans - Assumes the RAF's track the speed of the supply fans (Based on trend data observations)										
AHU-1	5.6	-	91.6%	7590	38,340	-	61.1%	7590	13,905	24,435
AHU-2	5.6	-	87.0%	7512	33,371	-	80.0%	7512	27,083	6,287
AHU-3	5.6	-	87.4%	4212	18,896	-	80.4%	4212	15,369	3,527
AHU-4	5.6	-	77.6%	3835	12,787	-	76.1%	3835	12,200	587
TOTALS					103,394				68,557	34,836
GRAND TOTALS										66,682

1.2.4 ECM5: REPLACE VAV

1.2.4.1 Pre-retrofit

Field inspection and functional testing was performed on a sample of (8) VAV boxes at the facility since they are not digitally controlled and therefore trend logs of equipment data could not be reviewed. VAV boxes were tested by modulating the thermostat which controls each VAV through its entire range; it was observed at one of the VAV boxes that the supply air velocity pressure at the maximum zone temperature set-point (about 80°F, full heating) was 0.0" WC, and at minimum temperature set-point (about 50°F) it was 0.5 " WC. This corresponds to 0 CFM at an 80°F set-point and 2,300 CFM at 50°F set-point. Design specifications for this malfunctioning VAV are 1,860 CFM maximum and 650 CFM minimum, based on nameplate information. It was observed that the ability to maintain the minimum CFM was no longer functional, and the control as observed was essentially ON/OFF with the device either providing 2,300 CFM or 0 CFM. The cause of this issue was that no feedback was available to the actuator from the reset device.

1.2.4.2 Post-retrofit

This measure proposed replacing the VAV box with malfunctioning controls with a new one that has controls which are fully functional. This allowed the VAV box to modulate properly and restored the proper minimum and maximum air flow controls.

1.2.4.3 Calculation Methodology

To estimate energy savings from replacing the malfunctioning VAV box, a weather bin model was constructed. It compared a VAV providing 2,300 CFM in all temperature bins to a profile that would be expected of a VAV that was properly modulating so that it had a maximum flow of 1,860 CFM (the intended design maximum for the VAV box) at extreme temperature bins and reduced flow down to a minimum of 650 CFM at moderate temperatures.

To translate the airflow savings at the VAV box to fan power savings at the air handler (AHU-3), the impact of reducing the VAV box's airflow at each temperature bin was translated to a change in the air handler's supply and return fan VFD speed. The scale of the speed reduction was based on the design airflow of the AHU, the existing VFD speed of the supply fan based on trend data observations, and the proposed VAV box

airflow reduction. Savings associated with reduced heating and cooling energy requirements were calculated using the airflow reduction at each temperature bin, as well as information from full weather bin models of the facility's AHUs developed for other measures.

Table 50: ECM5 Tracking Savings calculation

Weather Parameters		Existing Case (VAV-315/AHU-3)				Proposed Case (VAV-315/AHU-3)				
OAT Bin	Bin Hours	Existing Primary Airflow	Existing AHU-3 SF VFD Speed	Existing AHU Supply Flow	Existing Case Fan Energy	Proposed Primary Airflow	Proposed VFD Speed	Proposed AHU Supply Flow	Airflow Reduction	Proposed Case Fan Energy
DegF	Hrs	CFM	%	CFM	kWh	CFM	%	CFM	CFM	kWh
> 90	39	2,300	88.7%	18,956	729	1,860	86.7%	18,516	440	687
85 - 90	61	2,300	88.7%	18,953	1,139	1,860	86.6%	18,513	440	1,074
80 - 85	243	2,300	88.7%	18,949	4,536	1,726	86.0%	18,374	574	4,200
75 - 80	339	2,300	88.7%	18,945	6,325	1,591	85.4%	18,236	709	5,750
70 - 75	320	2,300	88.7%	18,942	5,968	1,457	84.7%	18,099	843	5,326
65 - 70	397	2,300	88.6%	18,939	7,401	1,322	84.1%	17,961	978	6,483
60 - 65	438	2,300	88.6%	18,935	8,161	1,188	83.4%	17,822	1,112	7,015
55 - 60	339	2,300	88.6%	18,931	6,313	1,053	82.8%	17,684	1,247	5,325
50 - 55	272	2,300	88.6%	18,928	5,064	919	82.1%	17,547	1,381	4,190
45 - 50	349	2,300	88.6%	18,924	6,494	784	81.5%	17,409	1,516	5,271
40 - 45	320	2,300	88.6%	18,921	5,952	650	80.8%	17,271	1,650	4,738
35 - 40	428	2,300	88.5%	18,917	7,956	650	80.8%	17,267	1,650	6,333
30 - 35	394	2,300	88.5%	18,913	7,321	852	81.7%	17,465	1,448	5,999
25 - 30	180	2,300	88.5%	18,910	3,343	1,053	82.7%	17,663	1,247	2,819
20 - 25	128	2,300	88.5%	18,907	2,376	1,255	83.6%	17,862	1,045	2,061
15 - 20	85	2,300	88.5%	18,903	1,577	1,457	84.5%	18,060	843	1,407
10 - 15	30	2,300	88.5%	18,899	556	1,658	85.5%	18,257	642	510
5 - 10	6	2,300	88.4%	18,896	111	1,860	86.4%	18,456	440	105
< 5	0	2,300	88.4%	18,890	0	1,860	86.4%	18,450	440	0
TOTALS	4,368				81,325					69,294

1.2.5 ECM6: VAV 331 CONTROL ISSUES

1.2.5.1 Pre-retrofit

Historical trend data indicated that VAV-331, which is served by AHU-3, is not performing per the intended sequence of operation. When the zone temperature set-point was met, the VAV box's airflow set-point resets to the minimum airflow set-point of 100 cfm; however, the VAV box's damper remained fully open and airflow ranges between 700-900 cfm. This excess flow requires AHU-3 to supply a greater amount of air than is necessary to maintain the zone at set-point, and used additional fan and mechanical cooling energy.

1.2.5.2 Post-retrofit

This measure proposed to investigate and resolve the issue stopping VAV-331's damper from modulating closed to meet the primary airflow set-point. The primary air damper should open and close as necessary to maintain the airflow set-point as determined by the zone temperature and set-point. This may be a problem with the programming logic for this box, or may be a mechanical/pneumatics issue at the box itself. Fixing this issue will allow the box to supply the proper amount of conditioned air to the zone and reduce AHU-3 fan and mechanical cooling energy consumption.

1.2.5.3 Calculation Methodology

A weather-based bin model previously created for AHU-3 was used to estimate fan and cooling energy savings associated with correcting the VAV damper issue described in the existing case. The proposed case model established a new airflow profile for VAV-331 based on the expected operation if the damper was to properly modulate in response to changing airflow set-points. In the proposed case, it was assumed that at design cooling conditions, the VAV box would require the maximum observed airflow (900 cfm) and when switching to heating, the box would require minimum design airflow (100 cfm). Airflow reductions at the VAV box level were translated back to the AHU as a corresponding reduction in supply airflow which results in fan, cooling, and heating energy savings.

1.2.6 ECM8: ACU5 DAMPER REPAIR

1.2.6.1 Pre-retrofit

Historical trend data suggested that ACU-5's outdoor air damper did not open fully in economizer mode. This suggests that the outdoor air damper was opening 40-50% and/or the mixed air damper is only closing 40-50%.

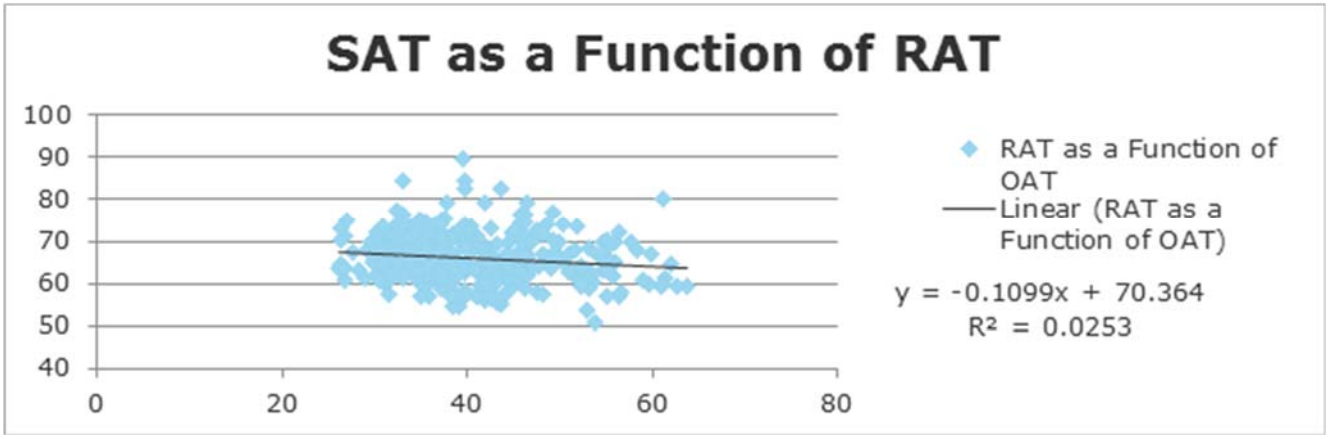
1.2.6.2 Post-retrofit

This measure proposed to investigate the damper issue described in the existing case and correcting the cause so that the equipment can take full advantage of economizer when conditions permit. This will reduce mechanical cooling energy consumption during periods when economizer is enabled and the chilled water system is active by increasing the amount of outdoor air used for cooling.

1.2.6.3 Calculation Methodology

Energy savings for this measure were estimated using a weather bin model of ACU-5 during occupied hours. Profiles of key parameters such as supply airflow, return air conditions, outdoor air quantity, and supply air conditions were developed using trend data available from March 2013 – July 2013. In the existing case model, the outdoor air fraction was limited to a maximum of 40% within weather bins for which economizer should be enabled. In the proposed case, the outdoor air percentages were adjusted to meet the discharge air temperature set-point at each bin, with a maximum of 100% at the 60-65°F outdoor air temperature weather bin.

Supply air temperatures (SAT; y-axis in the figure below) for each bin was developed using a regression equation developed based on Trend data (Supply air temperature SAT vs Return air temperature RAT (x)) as shown in the figure below. Note the low R^2 correlation between the two parameters.



1.3 Project Evaluation

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

Air handlers 1 through 4, ACU, AHU were monitored and trend data was obtained from the customer for this evaluation. Retrofitted VAV trend data was unavailable for the building as the controls are pneumatic. Evaluation team could not monitor the VAV as the space was restricted for access.

The following table will show how each measure will be or was verified to be installed and operating. If a measure was found to not be installed or installed, but not operating, it will be noted in this table.

Table 51: Measure Verification

Measure Name	Verification Method	Verification Result
Air Handler Fan VFDs	Power loggers, time-of-use loggers, EMS data, site observations, discussions with facility personnel	VFDs on all AHUs has been verified
AHU		Trend data, monitored was used to verify the AHU operation
ACU		Trend data verifies the ACU operation.

1.3.1 DATA COLLECTION

These tables will be shown the site plan and report.

Table 52: Evaluation Data Collection – Post-retrofit Equipment

Parameter	M&V Equipment Brand and Model	Quantity Retrofitted	Metering duration	Metering Interval
Air Handler Fan KW	Elite Pro Power Logger	4	64 days	5 minutes
AHU 3 Fan power kW	Elite Pro Power Logger	1	64 days	
ACU 5 hours of operation	Time-of-use logger	1	64 days	

Table 53: Evaluation Data Collection – Data Received.

Source	Parameter	Interval	Duration
Trend Data	ACU's: operation, supply air temperature, return air temperature;	1-hour	2 months
Real-time weather data	ODB-Outside dry-bulb temper (F)	1-hour	12 months

1.3.2 EVALUATION SAVINGS ANALYSIS

The savings were recalculated using an 8,760-hourly spreadsheet. The monitored data, EMS data, and information obtained from the facility personnel were used to create the schedules and cooling plant parameters identified. Savings were calculated using hourly wet bulb temperatures, average hourly power and monitored temperatures, and regression analyses.

All spreadsheets used in the estimation of evaluation savings will be made available to National Grid for review at their request.

1.3.3 EVALUATION RESULTS

1.3.3.1 ECM 1: Calibration of thermostats

The Evaluator monitored power (kW) of all 4 Air handlers (AHU1 through AHU4). Savings for all AHUs have been calculated by the same methodology shown below. This report shows savings calculation of AHU1 only and the remaining AHUs results are presented in the appendix.

AHU1 Details:

Total Supply Flow	= 23,220 CFM
Supply Fan hp	=30 hp
Return Fan hp	=15 hp
Supply Fan Power $_{Max}$ kW	= 19.08 kW
Return Fan Power $_{Max}$ kW	=8.73 kW

For this measure the savings are coming from the fan and cooling usage.

AHU 1 Fan Savings: The evaluation team metered supply and return fans separately from 8/25/16 through 10/27/16 (~64 days). Hourly averaged monitored data is shown in

Table 54. The AHU maintains a specific schedule during the week for the monitoring period and the trending data confirms that it remains the same for the entire year. Figure 21 shows that supply fan kW and outdoor dry bulb temperatures (ODB) have minimal correlation. Therefore, an average hourly schedule for the week was calculated for both supply and return fans.

Figure 21: AHU1 hourly averaged supply and return fan kW, respective real-time outside dry bulb temperature (˚F)

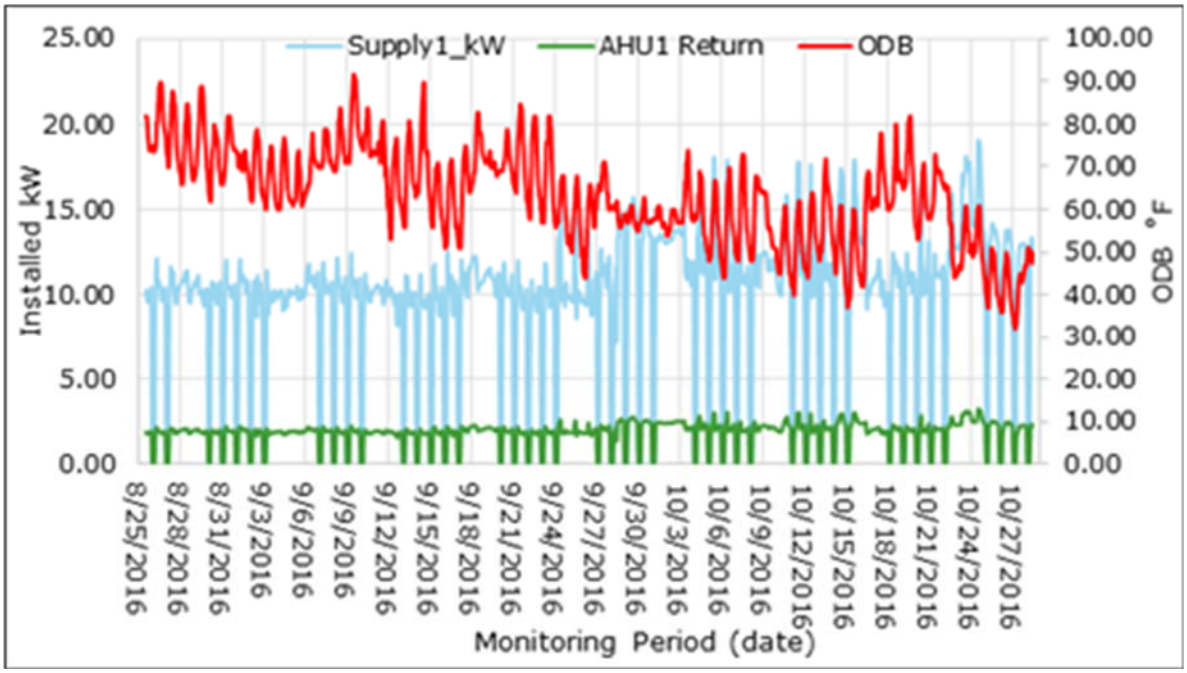
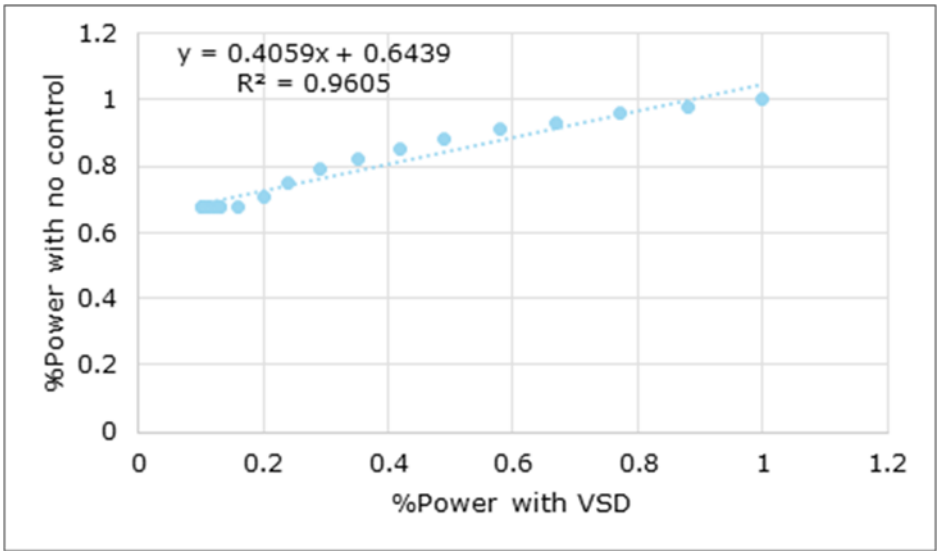


Table 54: Supply Fan-1 % power

Supply1	Sun	Mon	Tue	Wed	Thu	Fri	Sat
1	60.04%	60.35%	58.21%	60.92%	60.90%	60.91%	59.42%
2	60.29%	59.48%	57.54%	30.51%	30.13%	30.75%	29.61%
3	60.38%	58.70%	31.86%	0.25%	0.25%	0.25%	0.25%
4	60.72%	58.68%	6.33%	0.25%	0.25%	0.25%	0.26%
5	60.77%	58.67%	6.61%	0.26%	0.26%	0.25%	0.26%
6	61.00%	58.63%	6.86%	0.26%	0.26%	0.26%	0.26%
7	61.22%	58.62%	6.88%	0.25%	0.25%	0.25%	0.26%
8	61.11%	58.67%	34.67%	32.84%	33.42%	33.73%	32.92%
9	60.88%	58.85%	59.05%	56.74%	61.52%	61.73%	62.28%
10	62.09%	59.54%	60.96%	60.38%	62.86%	63.82%	61.73%
11	63.12%	59.54%	63.82%	63.21%	66.51%	65.18%	63.10%
12	63.11%	59.96%	63.32%	62.07%	66.57%	61.92%	62.56%
13	61.58%	62.46%	63.84%	64.49%	63.73%	60.47%	62.15%
14	62.24%	60.62%	64.11%	59.98%	60.35%	61.47%	61.58%
15	62.14%	60.34%	62.95%	61.28%	58.66%	61.51%	63.66%
16	60.06%	61.48%	63.62%	57.94%	58.69%	61.06%	64.55%
17	60.14%	60.62%	61.94%	57.46%	58.23%	61.50%	64.22%
18	59.66%	59.52%	58.54%	57.63%	57.63%	58.90%	62.38%
19	59.22%	58.55%	57.08%	58.51%	56.92%	58.52%	59.51%
20	59.52%	57.31%	57.12%	57.66%	56.19%	58.33%	59.21%
21	60.24%	56.83%	58.07%	60.27%	57.90%	59.70%	60.18%
22	61.13%	57.35%	59.98%	60.93%	59.19%	59.45%	61.14%
23	61.26%	57.98%	60.92%	60.51%	59.00%	58.77%	60.75%
24	61.18%	58.30%	61.24%	60.53%	60.40%	58.82%	60.20%

Table 54 shows the modulation of the AHU power and verifies that the thermostats are working as expected. Pre-retrofit kW at each hour was calculated using a regression equation developed using ASHRAE fan curves, VSD vs fan with no controls as shown below. Table 61 in Appendix A shows that the AHU2 operates on Sunday and turned off for few hours Tuesday thru Saturday which was confirmed by the customer.

Figure 22: Regression Analysis using ASHRAE curves for a fan with VSD vs No control



%power for supply and return fan calculated and using the following equation % power with no control was used to calculate the Pre-retrofit power kW at each hour.

Equation 1:

y = 0.4059x + 0.6439

where, y: % power with no Control

x: % power with VSD, (
Table 54, averaged monitored data).
Equation 2:

Supply fan Power kW at each hour = %Power* Supply Fan Power $_{max}$

Supply Fan Power $_{max}$ = 19.08 kW

Return fan power kW was also calculated using the same methodology.

AHU Fan Savings = Pre-retrofit Fan kW (Supply + Return)- Post-retrofit Fan kW (Supply + Return)

AHU1 Cooling Savings

Using the ASHRAE fan curves and the maximum air flow of the AHU, air flow (CFM) at each hour was calculated as shown below (see Figure 23**Error! Reference source not found.**).

Equation 3:

$$y = -1.2024x^2 + 2.1064x + 0.0336$$

Where

y: Post-retrofit CFM at each hour	= CFM/CFM $_{max}$
x: %Power	= Power kW/Power $_{max}$ kW
CFM $_{max}$	= 23,220 CFM
Power $_{max}$ kW	=19.08 kW

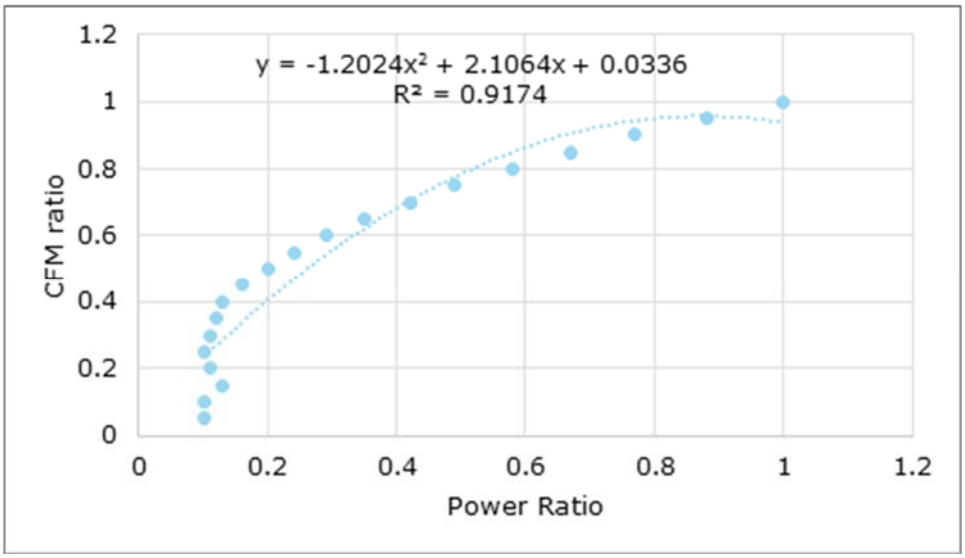
Air flow was then converted to cooling tons based on the design set-points in the building.

i.e. Interior Temperature Set-point = 73°F and 50% Relative humidity.

Equation 4:

Design Enthalpy @ 73F and 50% Rh Enthalpy $_{design}$= 27.07 btu per lb of dry air.

Figure 23: Regression analysis using ASHRAE curves (Power with VSD vs CFM ratio)



Equation 5:

Post-retrofit Cooling Tons = 4.5*(TMY3 Enthalpy- Enthalpy $_{design}$) * Post-retrofit CFM/12000

Post-retrofit Cooling kW = Post-retrofit Cooling Tons * Cooling Efficiency

Where cooling efficiency = 0.9 kW/ton.

Pre-retrofit Cooling Tons = 4.5*(TMY3 Enthalpy- Enthalpy $_{design}$) * Pre-retrofit CFM/12000

Where Pre-retrofit CFM = CFM max = 23,220 CFM (no control in Pre-retrofit condition).

Pre-retrofit Cooling kW = Pre-retrofit Cooling Tons * Cooling Efficiency

Therefore, AHU Cooling Savings = Pre-retrofit Cooling kW – Post-retrofit Cooling kW.

Table 55: ECM1 total savings

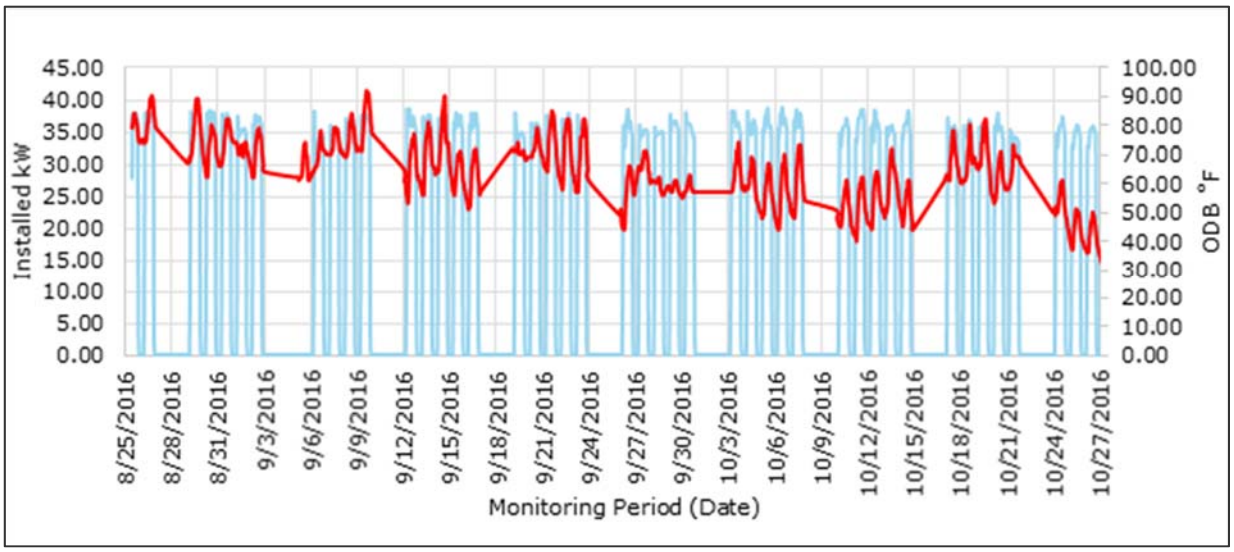
	Fan			Cooling		
System	Pre-retrofit kWh	Post-retrofit kWh	Savings kWh	Pre-retrofit kWh	Post-retrofit kWh	Savings kWh
AHU1	177,419	99,426	77,994	60,074	47,689	12,385
AHU2	222,007	179,923	42,084	56,426	48,776	7,650
AHU3	115,684	82,634	33,050	36,589	32,279	4,310
AHU4	186,852	98,574	88,278	58,210	40,253	17,956
Total	**701,962**	**460,556**	**241,406**	**211,299**	**168,997**	**42,302**

1.3.3.2 ECM2: RTU3 Scheduling

Evaluation team monitored RTU3 fan for 2 months and Post-retrofit kW for the RTU is shown in Figure 24 below.

In the above figure, RTU fan power (kW) has no correlation with outside dry-bulb temperature. And RTU operation has been consistent during the entire monitoring period. Trending data also confirms the operation of RTU to be consistent throughout the year. For this measure, there are savings from both fan and cooling loads. Savings for each load is calculated as shown below.

Figure 24: RTU3 operation during the monitoring period



RTU Fan Savings:

Monitored Post-retrofit RTU usage was calculated by averaging daily hourly kW in the week as shown in Table 56 below.

Table 56: RTU daily averaged Post-retrofit kW heat map

Hour	Sun	Mon	Tue	Wed	Thu	Fri	Sat
1	0.04	0.04	0.04	0.04	0.04	0.04	0.04
2	0.04	0.04	0.04	0.05	0.04	0.04	0.04
3	0.04	0.04	0.04	0.04	0.05	0.05	0.04
4	0.04	0.04	0.04	0.04	0.04	0.04	0.05
5	0.05	9.54	3.17	0.04	0.05	0.05	0.05
6	0.04	27.93	19.00	12.71	12.74	12.71	0.04
7	0.04	26.79	35.77	36.33	36.85	36.84	9.60
8	0.04	25.87	34.17	34.55	34.91	35.13	27.51
9	0.04	26.35	34.05	34.78	35.33	35.32	26.60
10	0.04	26.93	34.11	35.40	36.03	36.43	27.18
11	0.04	26.86	34.45	35.70	36.09	36.22	27.21
12	0.04	27.05	34.92	35.70	35.68	36.05	27.16
13	0.04	27.13	35.20	35.87	35.82	35.99	26.95
14	0.04	26.99	35.54	36.14	36.00	36.14	27.28
15	0.04	26.85	35.80	36.23	36.04	36.48	27.66
16	0.04	27.04	35.87	36.18	36.49	36.75	27.99
17	0.04	26.91	35.72	36.14	36.68	36.76	16.13
18	0.04	26.53	35.53	35.86	36.36	36.42	0.04
19	0.04	26.07	35.23	35.55	35.64	35.61	0.04
20	0.04	25.88	34.81	35.31	35.39	35.50	0.05
21	0.04	1.91	2.60	2.63	2.67	2.67	0.04
22	0.04	0.04	0.04	0.04	0.04	0.05	0.04
23	0.04	0.04	0.04	0.04	0.05	0.05	0.04
24	0.04	0.05	0.04	0.04	0.04	0.04	0.04

In Pre-retrofit or pre-retrofit condition, the unit ran at full speed 24x7 and with no pre-retrofit data and no information on the RTU's load modulation during unoccupied hours, evaluation assumed maximum Post-retrofit kW during the occupied hours and average Post-retrofit [2] kW from the monitored data (during occupied hours M-F, 7:00 AM thru 7:00 PM).

RTU Fan Savings = (Pre-retrofit kW - Post-retrofit kW)

RTU cooling savings

Based on the customer interview and tracking assumptions, cooling kicks-in when ODB>55°F. Using ASHRAE fan curves and regressing CFM ratio vs Fan with inlet vane control (from tracking calculation) CFM at every was hour calculated as shown in Figure 25 below.

Equation 6:

$$y = -4.0466x^2 + 7.3248x - 2.3564$$

[2] Average Installed kW = 34.89; Max kW = 48.87 kW

Where y: Post-retrofit CFM at each hour = CFM/CFM $_{max}$

x: %Power = Power kW/Power $_{max}$ kW

CFM $_{max}$ = 38,000 CFM.

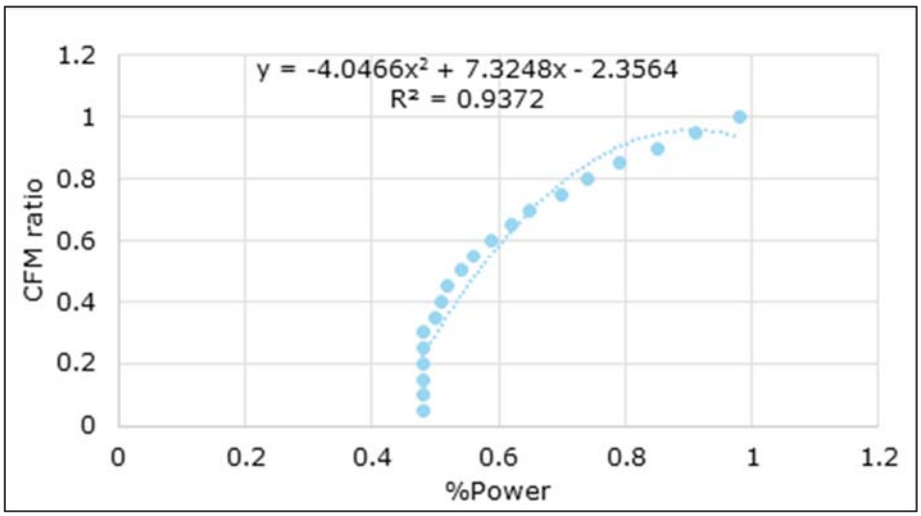
Power $_{max}$ = 48.87 kW (Tracking kW)

Post-retrofit Cooling tons at each hour = 4.5*(TMY3 Enthalpy-Design Enthalpy[3]) * y /12000

Post-retrofit Cooling Load = Post-retrofit Cooling Tons * Cooling Unit Efficiency in kW/ton

Where Cooling Unit Efficiency =0.9 kW/ton

Figure 25: Regression analysis of % power vs CFM ratio.



Pre-retrofit cooling kW was also calculated using the same methodology (regression equation) based on the respective kW value and calculated CFM.

Cooling Savings kW = Pre-retrofit kW- Post-retrofit kW

Table 57 Total ECM2 savings

System	Fan			Cooling		
	Baseline kWh	Installed kWh	Savings kWh	Baseline kWh	Installed kWh	Savings kWh
RTU3	387,281	148,326	238,956	110,134	49,058	61,076
Total RTU3 Savings					**300,031**	

1.3.3.3 ECM3: Replace AHU Static Pressure Sensors

This measure requires monitoring static pressure at inlet and exhaust of the supply fan. Due to inaccessibility of the air handler discharge areas, evaluation team used tracking analysis's static pressure readings in both pre-and post-retrofit and calculated airflow correction factors (ratio of pre-and post- retrofit average fan speed) as shown in **Error! Reference source not found.**.

Error! Reference source not found.Monitored AHU kW data was converted to post-supply airflow (CFM) at each hour using regression analysis of the ASHRAE fan curves i.e. VSD kW vs CFM ratio as shown below.

[3] Equation 4

Table 58: Pressure sensor readings and the correction factor for savings calculation

System	Design	Pre-retrofit Fan Static Pressure	Pre-retrofit Average VFD Speed	Post-retrofit Fan Static	Post- retrofit Average VFD Speed	Correction factor
	CFM	" WC	%	"WC	%	#
AHU1	23,220	2.6	62.4%	2.5	61.1%	1.022051
AHU2	21,530	3.6	87.0%	3.1	80.0%	1.086939
AHU3	21,365	3.6	87.4%	3.1	80.4%	1.086716
AHU4	22,210	3.0	77.6%	2.9	76.1%	1.019264

1.3.3.4 ECM5 Replace VAV 315

This VAV box supplies air to open office areas and per onsite personnel interview, there is no trend data available for this VAV box. Typically, with one malfunction VAV, other VAV readjust the airflow in the area. And for these open office areas, evaluation assumed that other VAVs will reduce the supply of air to compensate the excess air supplied by a malfunctioning VAV315. Therefore, there would be no additional savings for this measure i.e. ECM5 Savings = 0 kWh.

1.3.3.5 ECM6 VAV 331 control issues

This measure is like ECM5 where other VAVs in the area compensate the excess air supplied to the zone and therefore no savings have been assigned. ECM6 Savings= 0 kWh.

1.3.3.6 ECM8: ACU5 Damper Repair

Evaluation used tracking analysis methodology (Bin-Analysis) to calculate savings for this measure but updated the discharge air temperature used in the bin. Customer supplied trend data for period of approximately 4.5 months in the year 2016.

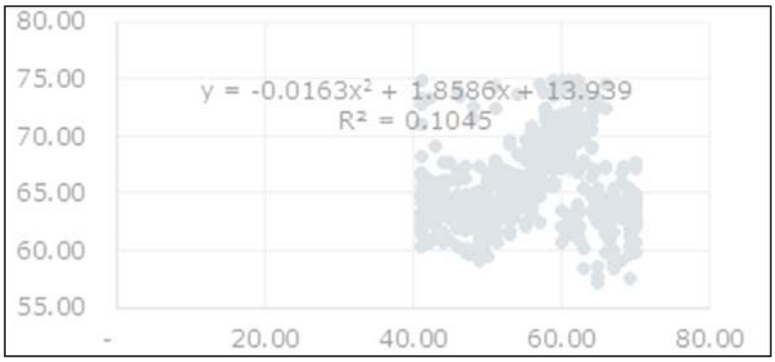
Trend data includes

1. Fan operation (ON/OFF)
2. Supply Air temperature (°F)
3. Discharge Air temperature-DAT (°F)
4. Return Air temperature (°F)

The main objective of this measure installation is to take advantage of the favorable outside conditions (Economizer).

Using the DAT from the trend data, evaluation developed a regression equation based on the real-time ODB.

Figure 26 Regression Analysis of ODB vs DAT



Equation 7:

$y = -0.0163x^2 + 1.8586x + 13.939$

Where,

Y = Discharge Air temperature (°F)

X= ODB (°F)

This equation was used in the tracking analysis spreadsheet (Appendix) specifically for the DAT for bins that are in between 40 (°F) and 70 (°F).

ECM8 Savings due to a fixed damper control = 3,334 kWh

Table 59: Project Results by Measure.

Measure	Tracking Savings (kWh)	Evaluation Savings (kWh)	Realization Rate
ECM1: Calibration of thermostats	222,465	283,708	128%
ECM2: RTU3 Scheduling	334,907	300,031	90%
ECM3: Replace AHU Static Pressure sensors	66,682	57,427	86%
ECM5: Replace VAV box	17,625	0	0%
ECM6: Fix VAV box control issues	2,103	0	0%
ECM8: ACU damper repair	4,096	3,334	81%
Total	**647,878**	**644,500**	**99%**

1.4 Conclusion and Recommendations

Overall the measures are operating and working as per the designed criteria (see Table 60). There is some decrease in the cooling savings due to the revised AHU schedule in the post-retrofit condition of ECM2. The operational hours have increased by approximately 72% compared to the tracking analysis assumption of 3,393 hours.

There was a discrepancy in ECM2 because the air handler savings in the evaluation calculation used metered data and the load of the AHUs varied in comparison to the tracking calculation. But the supply fan air flow in the tracking calculation was based on an estimate.

Discrepancy in ECM3 was also due to the use of metered data vs some estimated hours and VFD speed.

For ECM6, evaluation assumed that other VAV boxes that supply air are compensating by supplying less air.

For any future retrofit studies, DNV GL recommends National Grid to record ample Pre-retrofit data and make sure the analysis using well correlated weather data to generate savings.

Table 60: Comparison of Tracking and Evaluation savings

ECM#	Measure	Tracking Savings (kWh)	Evaluation Savings (kWh)	Realization Rate
ECM1	Fan	189,906	241,406	127%
ECM1	Cooling	32,558	42,302	130%
ECM2	Fan	177,041	238,956	135%
ECM2	Cooling	157,867	61,076	39%
ECM2	RTU operational hours	3,393	5,840	172%
ECM3	AHU1 Savings	26,813	4,744	18%
ECM3	AHU2 Savings	24,044	29,287	122%
ECM3	AHU3 Savings	13,499	10,891	81%
ECM3	AHU4 Savings	2,327	12,504	537%
ECM5	VAV replacement	17,625	0	0%
ECM6	VAVControls	2,103	0	0%
ECM8	Damper Controls	4,096	3,334	81%
Total Energy Savings kWh		**647,878**	**644,500**	**99%**

Appendix A Results from other AHUs

Figure 27: AHU2 hourly averaged supply and return fan kW, respective real-time outside dry bulb temperature (˚F)

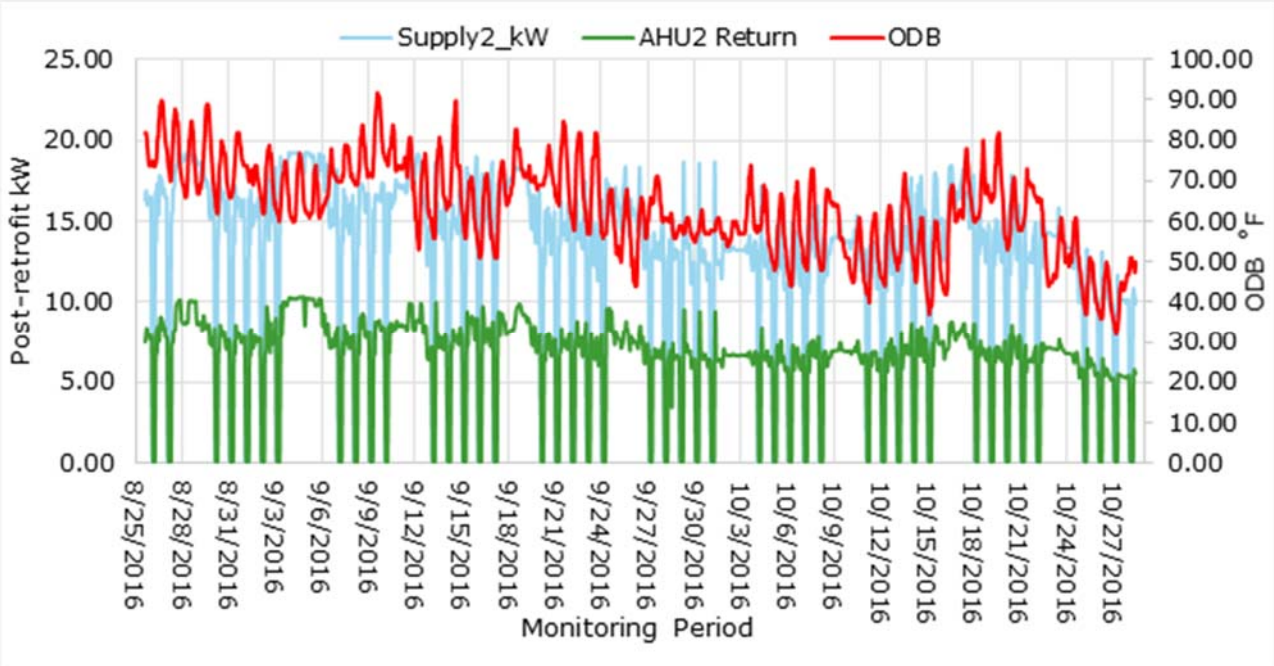


Figure 28: AHU3 hourly averaged supply and return fan kW, respective real-time outside dry bulb temperature (˚F)

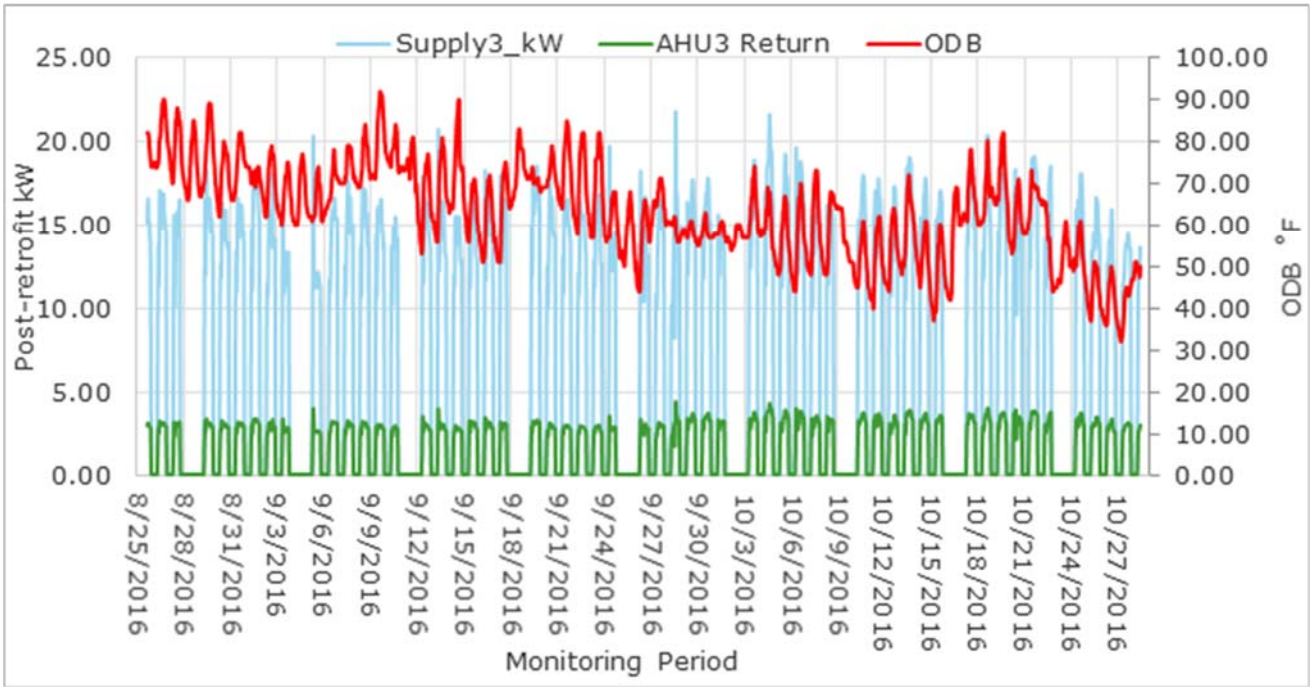


Figure 29: AHU4 hourly averaged supply and return fan kW, respective real-time outside dry bulb temperature (˚F)

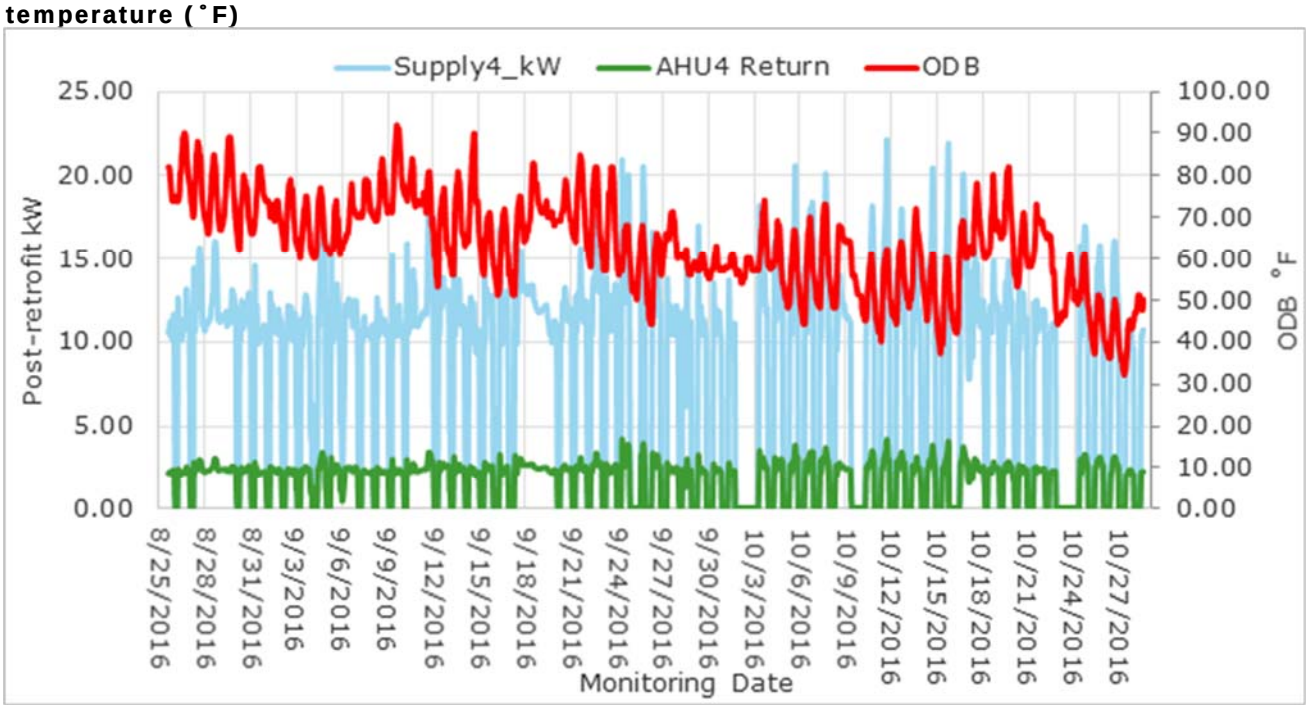


Table 61: Supply Fan-2 % power

Supply2	Sun	Mon	Tue	Wed	Thu	Fri	Sat
1	84.83%	85.49%	79.24%	75.85%	74.50%	80.80%	83.41%
2	84.42%	85.93%	79.08%	37.50%	37.35%	39.96%	41.88%
3	83.34%	85.61%	45.94%	0.29%	0.28%	0.29%	0.29%
4	83.41%	85.81%	11.37%	0.29%	0.29%	0.29%	0.29%
5	83.75%	86.27%	10.79%	0.29%	0.29%	0.29%	0.29%
6	83.90%	86.27%	10.08%	0.29%	0.29%	0.29%	0.29%
7	83.52%	85.71%	10.48%	0.29%	0.29%	5.82%	6.88%
8	83.25%	85.19%	71.16%	67.81%	67.69%	68.45%	70.51%
9	84.17%	85.56%	79.74%	74.07%	82.90%	80.23%	83.87%
10	85.12%	84.89%	71.59%	66.51%	67.88%	72.72%	76.57%
11	87.39%	83.73%	76.34%	75.30%	74.20%	77.31%	82.61%
12	88.30%	82.78%	74.98%	74.84%	78.73%	77.07%	83.02%
13	88.23%	83.78%	73.84%	73.53%	76.40%	77.12%	82.97%
14	88.32%	81.70%	73.40%	71.72%	74.92%	77.24%	83.01%
15	89.62%	80.95%	73.50%	76.59%	76.86%	80.54%	82.95%
16	88.24%	81.97%	74.48%	74.49%	78.42%	79.90%	83.86%
17	87.70%	79.96%	75.49%	74.29%	77.53%	81.94%	83.45%
18	86.75%	77.65%	73.83%	72.68%	75.50%	78.63%	81.80%
19	85.87%	71.52%	68.93%	68.62%	72.51%	74.60%	83.03%
20	85.10%	70.16%	66.64%	68.49%	70.33%	72.53%	83.20%
21	84.15%	71.93%	68.77%	70.68%	71.07%	73.75%	83.05%
22	84.78%	75.27%	72.22%	73.53%	74.48%	78.47%	85.14%
23	85.70%	77.80%	74.77%	73.41%	77.79%	80.57%	85.53%
24	85.23%	79.31%	75.90%	73.92%	80.75%	81.67%	85.11%

Table 62: Supply Fan-3 % power

Supply3	Sun	Mon	Tue	Wed	Thu	Fri	Sat
1	0.29%	0.29%	0.29%	0.29%	0.29%	0.29%	0.28%
2	0.28%	0.29%	0.28%	0.28%	0.28%	0.28%	0.28%
3	0.28%	0.29%	0.28%	0.28%	0.28%	0.28%	0.28%
4	0.28%	0.29%	0.28%	0.28%	0.28%	0.28%	0.28%
5	0.28%	0.29%	0.28%	0.28%	0.28%	0.28%	0.28%
6	0.28%	0.28%	0.28%	0.28%	0.28%	0.28%	0.28%
7	0.28%	5.51%	0.28%	0.28%	0.28%	0.28%	0.28%
8	0.29%	52.43%	45.34%	46.16%	45.68%	44.94%	42.82%
9	0.30%	82.16%	74.40%	68.36%	78.71%	75.47%	84.25%
10	0.30%	66.39%	62.42%	58.85%	62.33%	60.21%	61.90%
11	0.30%	79.41%	75.40%	71.29%	78.15%	77.24%	68.20%
12	0.30%	80.78%	83.06%	78.55%	79.87%	82.60%	75.45%
13	0.30%	76.64%	83.72%	79.24%	78.94%	81.97%	74.73%
14	0.30%	78.77%	82.55%	76.54%	80.29%	85.11%	77.58%
15	0.30%	83.60%	85.03%	86.72%	84.70%	86.13%	81.93%
16	0.30%	88.15%	92.00%	88.04%	88.25%	88.23%	82.05%
17	0.30%	88.02%	89.60%	87.53%	88.89%	91.96%	81.23%
18	0.30%	81.87%	83.61%	81.75%	84.77%	83.04%	81.63%
19	0.30%	78.63%	81.71%	77.26%	82.16%	79.75%	0.37%
20	0.30%	68.46%	78.07%	74.53%	76.83%	76.64%	0.29%
21	0.30%	67.13%	75.85%	74.19%	74.86%	75.19%	0.29%
22	0.30%	0.36%	0.36%	0.36%	0.37%	0.37%	0.30%
23	0.30%	0.31%	0.30%	0.30%	0.30%	0.30%	0.29%
24	0.30%	0.30%	0.30%	0.30%	0.30%	0.29%	0.29%

Table 63: Supply Fan-4 % power

Supply4	Sun	Mon	Tue	Wed	Thu	Fri	Sat
1	30.85%	22.85%	29.18%	41.55%	27.76%	24.73%	22.91%
2	27.33%	18.25%	22.39%	20.78%	10.33%	9.34%	13.09%
3	27.47%	18.42%	14.97%	0.32%	0.32%	0.32%	0.32%
4	27.49%	19.09%	4.17%	0.32%	0.32%	0.32%	0.32%
5	27.36%	19.54%	5.65%	0.32%	0.32%	0.32%	0.32%
6	27.40%	19.44%	7.40%	0.32%	0.32%	0.32%	0.32%
7	27.66%	23.84%	7.25%	0.32%	0.32%	6.82%	9.38%
8	27.94%	51.41%	49.09%	51.41%	46.15%	50.46%	45.89%
9	22.92%	73.27%	64.14%	58.06%	65.42%	62.95%	69.18%
10	22.66%	61.98%	59.00%	57.90%	54.77%	56.42%	57.82%
11	28.58%	63.76%	62.93%	61.58%	59.03%	61.52%	58.27%
12	32.01%	66.50%	67.20%	65.98%	65.07%	63.53%	60.33%
13	37.89%	68.03%	66.55%	65.10%	64.26%	62.88%	63.32%
14	38.36%	68.42%	64.43%	62.71%	63.59%	60.83%	66.59%
15	51.11%	71.62%	67.90%	71.74%	66.45%	62.13%	70.01%
16	55.26%	73.69%	73.10%	73.96%	68.84%	66.82%	73.20%
17	57.79%	72.80%	75.30%	72.21%	66.67%	71.57%	76.82%
18	60.82%	69.70%	69.21%	66.51%	63.85%	68.46%	77.15%
19	58.56%	66.06%	65.75%	63.60%	63.41%	66.17%	51.55%
20	55.20%	64.60%	65.51%	62.80%	63.63%	63.53%	47.86%
21	42.79%	63.88%	64.80%	62.64%	62.22%	63.05%	39.13%
22	38.07%	35.18%	42.70%	33.26%	32.59%	44.52%	34.67%
23	34.03%	32.57%	42.77%	31.23%	27.66%	34.89%	31.36%
24	29.10%	30.84%	42.19%	31.09%	25.27%	33.79%	29.77%

4.2.1.5 Site ID: DNV 30

Project ID(s)	DNV 30
Project Type	Retrofit
Program Year	2014
Application ID/s	2845921
Evaluation Engineer/s	Rick Boswell

1.5 Project Description

This retrofit project involved pump motor upgrades and variable speed drives installed in various buildings on nine chilled water (CHWP), three hot water (HWP), and nine Electronic & Auxiliary Fresh Water (EAFW) system pumps. Modifications were also made to the chilled water systems three way valves to partially isolate the bypass legs to allow for variable primary pumping. Most of the tracking savings were calculated using prescriptive deemed savings values, or energy savings factors [kWh/HP] developed by the Rhode Island Technical Reference Manual [TRM]. The following report will detail the prescriptive and custom analysis approach taken by the tracking analysis, how they were developed, and finally how the evaluators approached each measure using their own custom analysis. Table 36 shows the overall evaluation results for this project.

Table 64: Project Results

Building #	Measure	Tracking Savings kWh	Evaluation Savings kWh	Realization Rate
115	Install VFDS on CHWP	27,400	33,193	121%
1258	Install VFDs on EAFWP System	61,650	85,524	139%
1259	Install VFDs on EAFWP System	82,200	86,575	105%
1319	Install VFDs on CHWP Pumps	51,375	28,966	56%
1320	Install VFDs on EAFWP System	41,100	57,716	140%
1371	Install VFDs on HWP and CHWP Pumps	56,788	90,458	159%
1258	Variable CHWP Primary Pumping with Bypass Leg Isolation	112,759	128,885	114%
1259	Variable CHWP Primary Pumping with Bypass Leg Isolation	193,423	241,670	125%
Total Project Savings		**626,695**	**752,987**	**120%**

Table 65: Total Evaluated Project On-Peak Results.

All Buildings	Summer Peak kW	Winter Peak kW	% On Peak Energy
CHWP	9.71	9.71	46.39%
EAFWP	16.62	36.01	46.26%
HWP	0.00	5.00	40.94%
CHWP (with Variable Pumping bypass)	54.06	25.63	46.16%
Total Savings	**80.40**	**76.35**	**46.04%**

1.6 Tracking Savings

This section summarizes the methodology and assumptions used to estimate the tracking savings claimed for the project including PA's pre-retrofit assumptions, proposed equipment, tracking calculation method along with the underlying assumptions that were used in the calculations to estimate the tracking savings.

1.6.1 PRE-EXISTING

In the pre-existing condition, the chilled water, hot water, and EAFW chilled water pumps operate at a constant speed regardless of the system load and flow requirements. There were two types of measures implemented for this project; variable primary pumping with bypass leg isolation and installing VFD's on pump motors. The variable primary pumping measures were installed in buildings 1258 and 1259. Tracking calculations for this measure were calculated using a custom cooling load bin analysis. The VFD portions of the project were installed in six buildings (115, 1258, 1259, 1320, 1319, 1371). Tracking calculations for this portion of the project were calculated prescriptively using deemed savings values for kWh per HP.

In buildings 1258 and 1259, the pre-existing condition of the primary chilled water loop pumps were constant speed and flow rate, modeled as operating in four discrete pumping stages depending on the cooling load demand on the chiller system. This is because of a lack of control points from which to direct the drive speeds as well as limitations of the existing valves and piping. In building 1258, cooling is provided by three 300 ton VFD modulated centrifugal chillers, though the TA audit report states that, "only two are needed on peak days when offices are occupied and only a single chiller is needed for much of the year." Key pre-retrofit parameters of the building 1258 variable primary pumping system are presented below in Table 66.

Table 66: Pre-existing Key Parameters, Building 1258 Variable Primary Pumping Measure

Parameter	Value(s)	Source of Parameter Value
Pumping power [kW], stage 1	14.09	Calculation of pump draw using motor HP, efficiency, and load factor
Pumping power [kW], stage 2	28.17	
Pumping power [kW], stages 3 & 4	42.26	
Motor horsepower [HP], stages 1, 2, & 3/4	20, 40, 60	Nameplate value
Motor efficiency [%]	90	Assumed motor efficiency
Motor load factor	0.85	Assumed load factor

In building 1259, cooling is provided by three 350 ton, VFD modulated centrifugal chillers, though the TA report states that like building 1258, "only two are needed on peak days when offices are occupied and only a single chiller is needed for much of the year." Key pre-retrofit parameters of the building 1259 variable primary pumping system are presented below in Table 67.

Table 67: Pre-existing Key Parameters, Building 1259 Variable Primary Pumping Measure

Parameter	Value(s)	Source of Parameter Value
Pumping power [kW], stage 1	23.20	Calculation of pump draw using motor HP, efficiency, and load factor
Pumping power [kW], stage 2	46.40	
Pumping power [kW], stages 3 & 4	69.27	
Motor horsepower [HP], stages 1, 2, & 3/4	40, 70, 110	Nameplate value
Motor efficiency	90%	Assumed motor efficiency
Motor load factor	0.70, 0.80, 0.76	Assumed load factors

Between buildings 115, 1258, 1259, 1319, 1320, and 1371 there are 26 pump motors: 14 EAFWP,9 CHWP, and 3 constant speed HWPs that operate in the pre-existing condition. However not all 26 pumps operate together as the pre-existing systems have redundancy in case of pump failure. Table 68 shows the building location, pump description, pump size, number of pump motors as well as the active motor HP.

Table 68: Pre-existing Constant Speed Pump Motor Parameters

Building	Pump Description	HP	# of Motors	Active motor HP
115	CHWP	20	2	20

1258	EAFWP	15	6	45
1259	EAFWP	15	6	60
1319	CHWP	7.5	2	7.5
1319	CHWP	15	3	30
1320	EAFWP	30	2	30
1371	CHWP	20	1	20
1371	CHWP	15	1	0
1371	HWP	5	1	5
1371	HWP	3	1	3
1371	HWP	7.5	1	7.5

1.6.2 PROPOSED CONDITION

The proposed condition has variable frequency drives (VFDs) installed on the chilled and hot water pumps and the appropriate hardware and programming installed for integration into the buildings existing (DDC) control system. For the EAFW chiller water systems, the proposed condition has variable drives installed on one of each pair of pumps. Additionally, one of the existing motors at each of the two buildings receiving EAFW system retrofits were upgraded to new premium efficiency, inverter duty rated motors. The EAFW system pumps were reprogrammed to maintain a specific operating pressure, with existing regulators used to maintain proper flow rates. The use of a VFD in these systems allow the pump speed to modulate to meet the load requirements thus reducing the amount of energy consumed by the motor. The motor horsepower, quantity, active motor horsepower, and number of VFDs to be installed are presented below in Table 69.

Table 69: Pump Motor Characteristics and Proposed VFD Installations

Building	Pump Description	HP	# of Motors	Active motor HP	# of VFDs Post-retrofitted
115	CHWP	20	2	20	2
1258	EAFWP	15	6	45	3
1259	EAFWP	15	6	60	4
1319	CHWP	7.5	2	7.5	2
1319	CHWP	15	3	30	3
1320	EAFWP	30	2	30	2
1371	CHWP	20	1	20	1
1371	CHWP	15	1	0	1
1371	HWP	5	1	5	1
1371	HWP	3	1	3	1
1371	HWP	7.5	1	7.5	1

The proposed modifications to the primary chilled water loops involved installation of controls to monitor building cooling loads and enable modulation of chilled water flow through the system and isolating a portion of the bypass legs via manual shut offs at the three-way valves to ensure the VFD's supply minimum CHW flow through the system. The motor horsepower, quantity, active motor horsepower, and number of VFDs to be installed are presented below in Table 70.

Table 70: Pump Motor Characteristics and Proposed VFD Installations

Building	Pump Description	HP	# of Motors	Active motor HP	# of VFDs post-retrofitted

1258	Variable Primary Pumping with Bypass Leg Isolation	20	3	60	3
1259	Variable Primary Pumping with Bypass Leg Isolation	40	2	80	2
		30	1	30	1

1.6.3 TRACKING CALCULATION METHODOLOGY

Tracking savings for the CHWP, HWP and EAFWP VFD measures were calculated using prescriptive savings factors from Table 14[4] of Appendix A of the 2014 National Grid Rhode Island TRM. The measures utilized savings factor values for the office building type, and are on a savings (kWh, kW) per motor horsepower basis. The values applied to these measures are provided below in Table 71.

Table 71: RI TRM Savings Factors for Variable Speed Drives in Office Buildings

Energy Savings Factors for Offices	Annual Energy (kWh/hp)	Summer Demand (kW/hp)	Winter Demand (kW/hp)
Chilled Water Pumps[5]	1370	0.056	0.457
Hot Water Pump	1896	0.457	0.444

For the variable primary chilled water pump measures, tracking savings were calculated using a 2°F weather bin spreadsheet. The spreadsheet uses dry bulb temperatures for each of the bins and segregates a bin hours by occupied and unoccupied periods. Constant and weather variable cooling loads were developed from equipment capacities and assumptions of peak loads and amount (%) of weather dependency. The existing condition chilled water pumping power for each of the four CHWP pump operating stages was calculated using motor horsepower, efficiency, and load factor in the following equation:

Equation 8:

$$Pump\ Power\ (kW) = \frac{hp\ \times 0.746\ \frac{kW}{hp} \times load\ factor\ (\%)}{pump\ efficiency\ (\%)}$$

Where:

Pump power (kW) = Kilowatt power demand of pump operating stage

Hp = the sum of rated motor horsepower for pumps operating in a given stage

0.746 = Conversion factor HP to kW

Load factor = assumed motor load, as a percent of total

Pump efficiency = rated motor efficiency for pumps operating in each stage

[4] Savings factors in Table 14 credited to Chan, Tumin (2010). Formulation of a Prescriptive Incentive for the VFD and Motors & VFD impact tables at NSTAR. The derivation of these values is not available at the time of the development of this document.

[5] EAFW pump VFD measure utilized the chiller water pump savings factor values.

Pumping energy is then calculated for each temperature bin, month of the year, and occupancy status, by multiplying the number of annual hours for each bin by the corresponding pump stage power, which is governed by a step-function of the cooling load for those conditions (temp, month, and occupancy). Existing pump energy is then rolled up to the monthly level and then finally into an annual kWh value.

The proposed condition chilled water pumping power for the VSDs utilized the same bin framework, but in place of discretely staged pumping power, substitutes a fourth order polynomial pump power curve as a function of pump speed, for which the quotient of cooling load over chiller capacity is utilized as a proxy for pump speed. The variable pump power curve coefficients are presented below in Table 72.

Table 72: Variable Pump Power Curve Function Coefficients

Function Term	Value
1 (x^0)	0
2 (x^1)	0.56
3 (x^2)	-1.14
4 (x^3)	2.22
5 (x^4)	-0.646

The proposed pump energy is also rolled up to the monthly level and then finally into an annual kWh value. Annual energy savings is then calculated as the difference in annual energy between the proposed and existing cases.

1.6.4 EVALUATOR ASSESSMENT OF TRACKING SAVINGS

Cooling and heating requirements remained the same between the pre-existing and post-retrofitted systems between each building. In the pre-existing condition, pump operation was constant speed no matter the cooling and heating requirements called upon. In the post-retrofitted condition pump speed varies based upon the load.

Tracking savings were calculated differently between the variable primary pumping measure, and the VFD measure. The variable primary pumping savings were implemented in buildings 1258 and 1259 and were calculated using a cooling load weather bin analysis. In this custom savings analysis, chiller capacity remains constant but the cooling loads change between each building depending on the outside air temperature. Evaluators agree that the custom calculations were performed correctly and represent pre-existing and post-retrofitted conditions accurately.

The tracking savings for the VFD measure were calculated using a prescriptive savings analysis. A deemed energy savings factor for offices was used for kWh/HP to calculate VFD savings from the Rhode Island Technical Reference Manual [TRM]. It is unknown why the TA decided to use a combination of prescriptive and custom savings analyses. Evaluators do not agree with the prescriptive method used for this portion of the project and believe a custom approach should have been used for the entire project.

1.7 Project Evaluation

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

Measure Verification

A site visit was performed on September 13th, 2016 to perform a physical inspection to verify the installation of the measures and install data loggers to monitor energy use. Due to security protocols and facility time constraints, evaluators were only able to document installation and intended operation of measures installed in two out of six buildings. Each type of pump (CHWP, HWP, EAFWP) was documented between these buildings, including pumps with VFD's and variable primary pumping. Table 73 shows the location and how each measure was verified to be installed and operating.

Table 73: Measure Verification

Location	Measure Name	Verification Method	Verification Result
Bldg. 1258	EAFW pump VFD's	Quantity, Nameplate information	(2) - 15 HP,91% eff, 87% PF, 1.15 SF
Bldg. 1258	Chilled Water pump VFD's	Quantity, Nameplate information	(2) - 20 HP, 93% eff, 86% PF, 1.15 SF
Bldg. 1371	Chilled Water pump VFD's	Quantity, Nameplate information	**4.2.1.6** (1) - 20 HP, 93% eff, 86% PF, 1.15 SF (2) – 15 HP, 91.7% eff, 81.4 PF, 1.15 SF
Bldg. 1371	Hot Water pump VFD's	Quantity, Size	(1) – 3 HP (1) – 5 HP (1) - 7.5 HP

1.7.1 DATA COLLECTION

Pump Monitoring: The evaluators monitored 2 EAFW, four CHW and three HW pumps between two buildings. Dent ElitePro loggers were installed to monitor kW and operation. The pumps in both buildings were monitored between 9/13/16 and 1/12/17 for 120 full days. Due to time constraints, evaluators were unable to visit each building and monitor pumps in all locations.

Based on the customer interviews, the CHWP usage/schedules were determined identical between buildings 1258 and 1259. Therefore, representative sample of pumps monitored in 1258 would represent 1259. The EAFW pumps provide cooling to server rooms and computer labs that require cooling year around. Evaluators determined that the EAFW pumps monitored in 1258 would represent the remaining EAFW pumps in the other buildings due to similar operation. Cooling trend data was requested but was unavailable due to building/facility security constraints.

Table 74: Evaluation Data Collection – Post-retrofitted Equipment

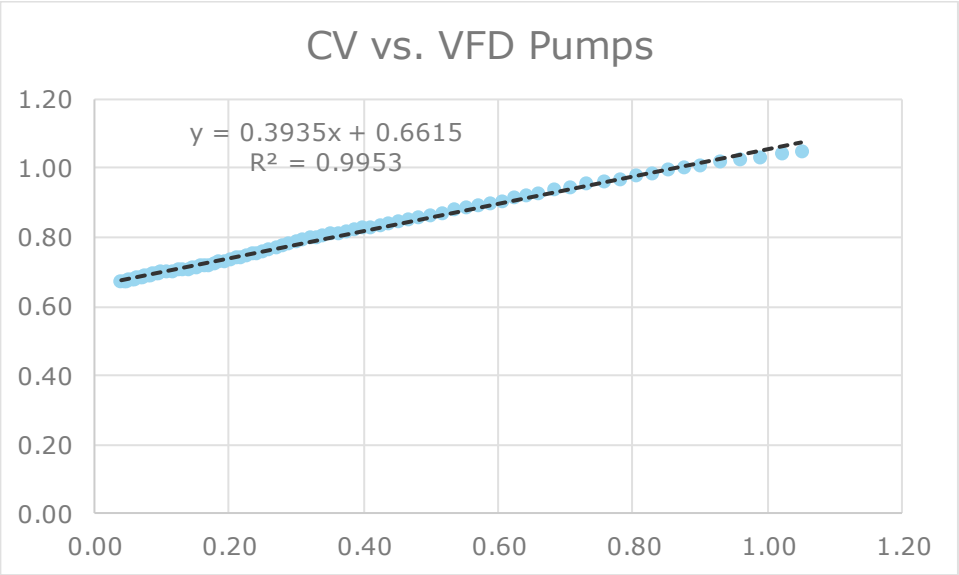
Parameter	M&V Equipment Brand and Model	Metering Start/Stop Dates	Quantity	Metering Interval
Chilled water pump motor kW	Dent ElitePro Logger and HOBO Microstation	9/13/16 – 1/12/17	2 – Dent ElitePro 1 - HOBO	5 minutes
EAFW pump motor kW	Dent ElitePro Logger	9/13/16 – 1/12/17	2	5 minutes
Hot water pump motor kW	HOBO Microstation	9/13/16 – 1/12/17	3	5 minutes

1.7.2 EVALUATION SAVINGS ANALYSIS

This section briefly describes our basic analysis plan and shows how the analysis is going to use the data planned to be collected to estimate annual energy savings. Overall, the evaluation energy savings will be based on the as found conditions with the installed pump VFDs.

Savings for the pump VFDs and variable primary pumping measure were both calculated using the same 8,760 methodology. No pre-retrofit pump trends were provided by the site, so evaluators used on-site measured VFD pump power [kW] to calculate the pre-retrofit power using EPRI pump curves. The EPRI data uses pump speed to estimate the percent power that a constant volume and VFD pump would use. The constant volume and VFD pump percent power were plotted against one another to determine a regression formula as seen in Figure 30 below. The regression was paired with measured VFD pump power to calculate what the constant volume pre-retrofit percent power would draw. To calculate what the actual power of the pre-retrofit pump would be, the percent power was multiplied by the actual max power that the pump could produce. It was often the case that the max monitored power was lower than the actual max. To correct for this, the calculated max power considers the pump HP, efficiency, load factor, and a 3% correction factor to account for VFD losses at full speed (60 HZ). This methodology was used consistently between CHWP, EAFWP and HW pumps.

Figure 30: Pre-retrofit CV pump regression (EPRI)



Equation 9:
$y = 0.3935x + 0.6615$
$R^2 = 0.9953$
Where, y: Pre-retrofit %Power

X: Post-retrofit %power

1.8 Evaluation Results

Overall, the project is achieving more energy savings than claimed. This is primarily due to the tracking analysis using a deemed prescriptive methodology when approximating savings for the VFD portion of the project. In this methodology, a deemed kWh/HP energy savings factor is assigned to each pump based upon size. These savings factors come from the RI TRM.

1.8.1 EAFWP

This measure includes VFD's on a total of nine pumps, but the customer confirmed that only eight pumps are in operation. Therefore, two out of eight EAFWP were monitored and an average demand (kW) of those two (2) monitored pumps (both summer and winter) were calculated and used in the evaluation savings calculation of the remaining six EAFWP's.

Post-Retrofit:

The electronic and auxiliary fresh water pumps provide chilled water to computer rooms and labs through air handlers that operate 24/7. These air handlers cool the lab spaces in 100% recirculation mode with 100% outside air. Unless the lab occupants physically change the quantity and configuration of the EAFW pump apparatus that gets connected by hoses to the EAFWP manifolds in the labs, neither the flow rate nor cooling load varies to any extent. The system is setup to deliver EAFW to the labs at a non-varying temperature set point that is different for specific labs. These set points range from 65 to 72 degrees Fahrenheit. Two out of eight EAFW pumps (P#13, P#16) were monitored. There was no day of week, time of day, or outside air correlation to these pumps, however there is a drop in the pump demand starting in November for both monitored pumps. Per the customer, variability in load for P#13 in the first half (9/14 thru 10/29) of the monitoring period could be due to change in VFD mode (auto to manual), which explains the drop-in P#13 (Figure 31) demand but no change in P16 (

Figure 32) usage. The monitoring data also shows a sharp decrease in demand at the beginning of November and remained constant throughout the remainder of the monitoring period (winter) with no correlation of temperature in Figure 31. Therefore, evaluation used two constant demand values for post-retrofit case i.e. one of winter and the other for summer (averaged monitored kW September through early November for Summer and averaged monitored kW for remaining months as winter).

Figure 31: EAFWP#13 (Bldg1258) operation and ODB during monitoring period

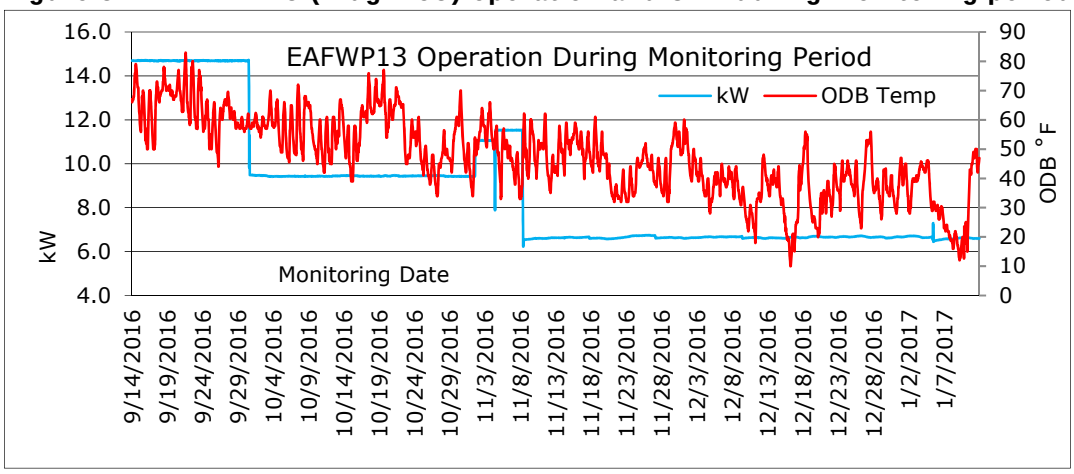
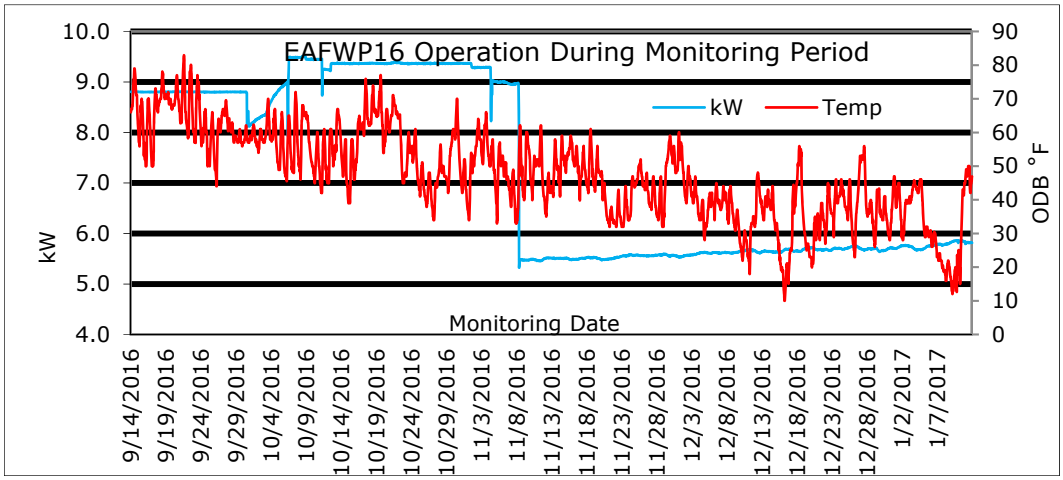


Figure 32: EAFWP#16 (Bldg1258) operation during monitoring period



Pre-retrofit:

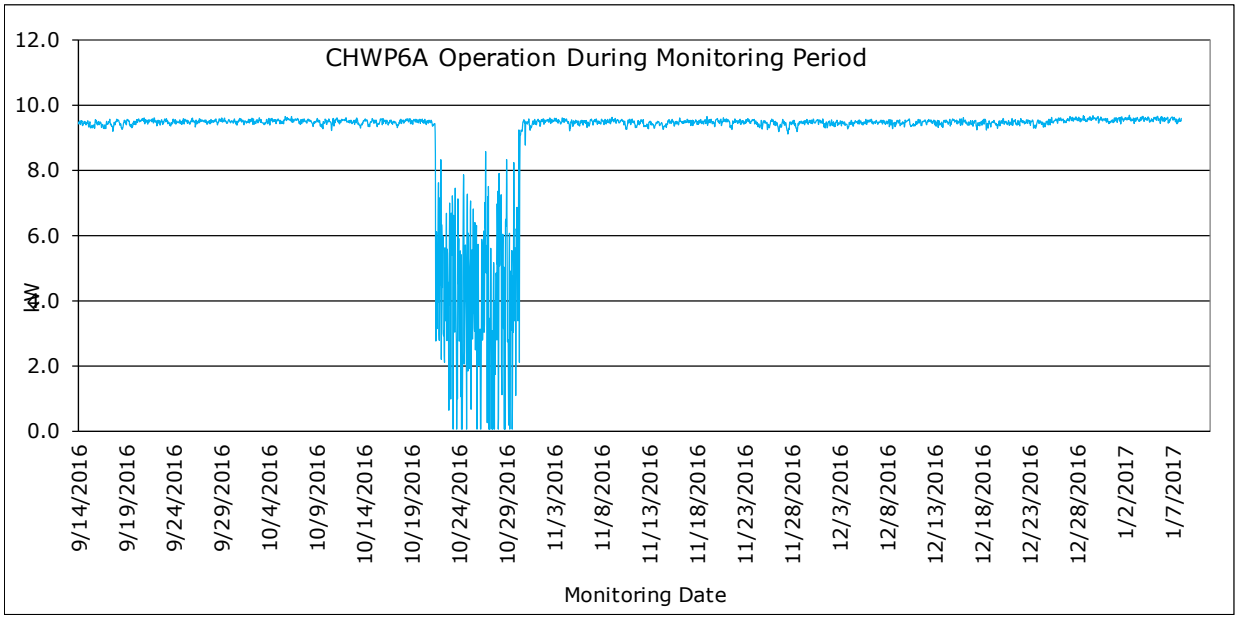
Pre-retrofit demand was calculated using EPRI pump curves without VFD based on a regression **Equation 9.** % power of post-retrofit case calculated using a maximum monitored kW for the respective pump.

1.8.2 CHWP

Chilled water pump operation also had some abnormalities in the monitored data. As seen in the above figures, the CHWP load remained constant through much of the monitoring. Per the site contact, "more times than not, VFD's for the chilled water and EAFW pumps have been shifted out of full auto mode and it is unknown why." VFD's were observed on site to be in hand mode on several pumps by the evaluators. This manual shift is evident in the data collected as the figures above show random varying to constant loading and vice versa.

Evaluation monitored one 20-hp and one 15-hp pump. The measure includes a total of one 7.5-hp, two 15-hp and two 20-hp pumps. Per the site contact all chilled water pumps of comparable size operate with similar loading. Since evaluators were only able to monitor two of five active chilled water pumps, the missing pumps were analyzed based upon the pumps monitored of the same size and loading. The evaluation team verified all CHWP but could not gather any data on a 7.5-hp pump. Therefore, the measure receives credit for savings but without any data on the pump, evaluation assigns the same savings as tracking. The 15-hp pump ran continuously at approximately 92% constant power therefore a reduction in savings was observed when the 20-hp pump ran at lower power i.e. ~@65% producing more savings.

Figure 33: CHWP6A (Bldg1371) operation during monitoring period



1.8.3 HWP

Per the site personnel, hot water pump controls lock out operation between day 140 and 280 of the calendar year. When the pumps are not locked out by calendar, the pumps are commanded on when outdoor air falls below 48 degrees and are commanded off when outdoor air rises above 55 degrees during occupied hours or above 50 during unoccupied hours. Evaluators observed no temperature correlation in HWP operation. However, because monitoring did not occur during peak summer hours, the savings analysis reflects the assumed temperature and calendar set points. Also, monitoring data shows that one of the HWP had very low usage (~0.53% power average), therefore the analysis assumed that pump would be used as back-up when/if the other primary pump fails.

Figure 34: HWP1A (Bldg1371) operation during monitoring period

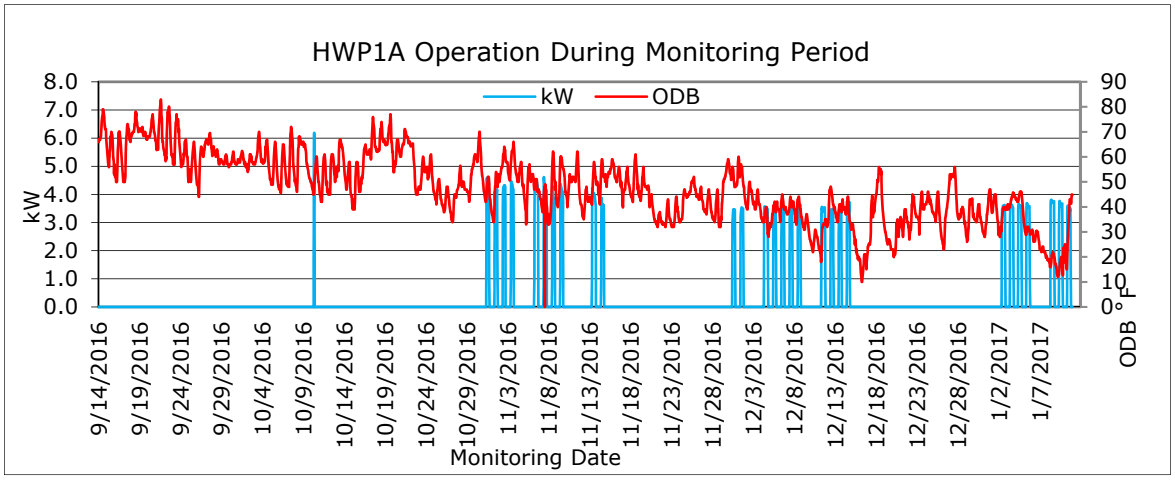
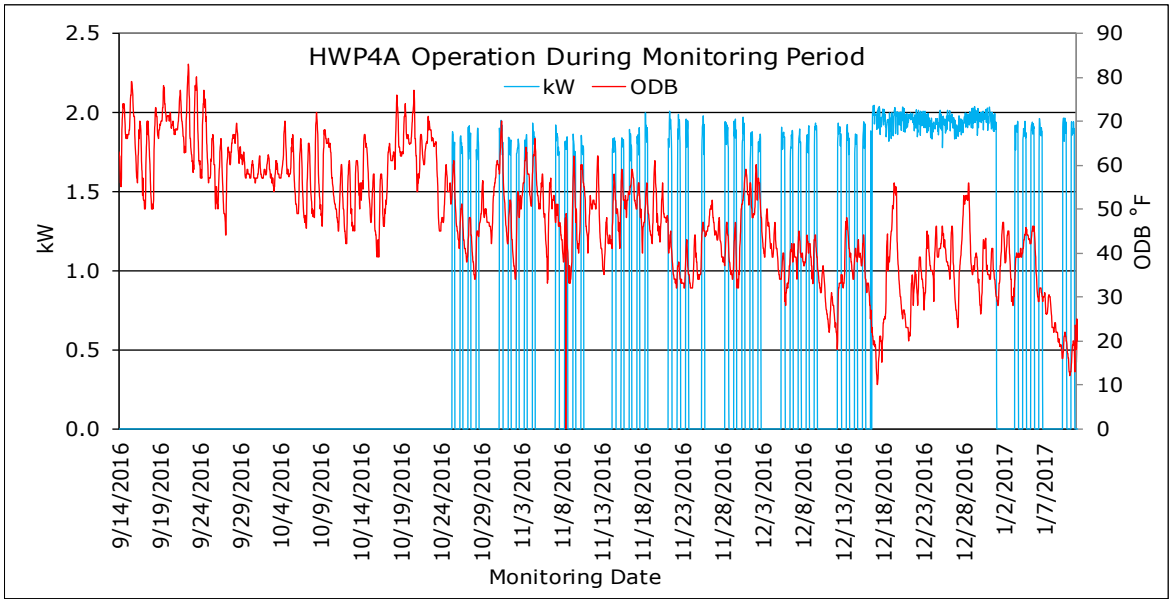


Figure 35: HWP4A (Bldg1371) operation during monitoring period



1.8.4 VARIABLE PRIMARY PUMPING WITH BYPASS LEG ISOLATION

The site contact expressed that controls and sequence of operations change without warning at random periods as the facility works to optimize their systems. This unknown user discretion was also seen in the variable primary pumping chilled water pumps. The six-variable volume chilled water pumps operate with their respective six separate chillers. There are three chillers in building 1258 and three in 1259. These buildings have comparable schedule/operation %loads per the site contact. Evaluators could monitor two of these pumps both in building 1258. On-site, it was observed that although all three chillers in 1258 were turned on, two of the three chillers were "active" with one in auto not running and the other bypassed in "hand" (VFD disengaged) mode running. The third chiller was set to auto and was in standby. Of the two monitored chilled water pumps, one of them (CHWP 5) ran during the entire monitoring period. CHWP 5 pump demand rose during the December monitoring period from an average of 9.8 kW to 21.7 kW. The other monitored pump (CHWP 6) only ran for 12 consecutive days towards the end of the monitoring period at an average demand of 2.8 kW. Evaluators have assumed that the spike in CHWP 5 is due to the reduced load on one of the chillers and only one CHWP is needed to operate the winter load reduction. At the same time the spike occurs in CHWP 5, CHWP 6 comes online which evaluators have assumed corresponds to the offline chiller which was in auto during the installation. Evaluators assigned a summer and winter schedule based upon observations made in the monitored data (as shown in

Figure 36 and Figure 37).

Figure 36: Variable primary pumping CHWP 5 (Bldg1258) operation during monitoring period

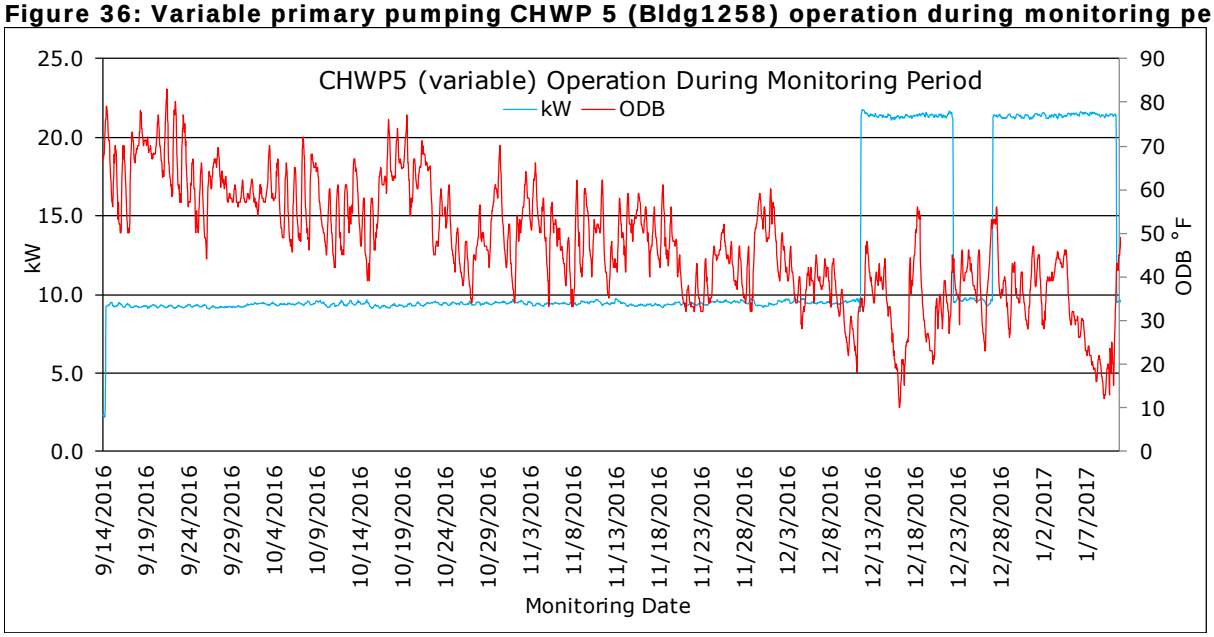
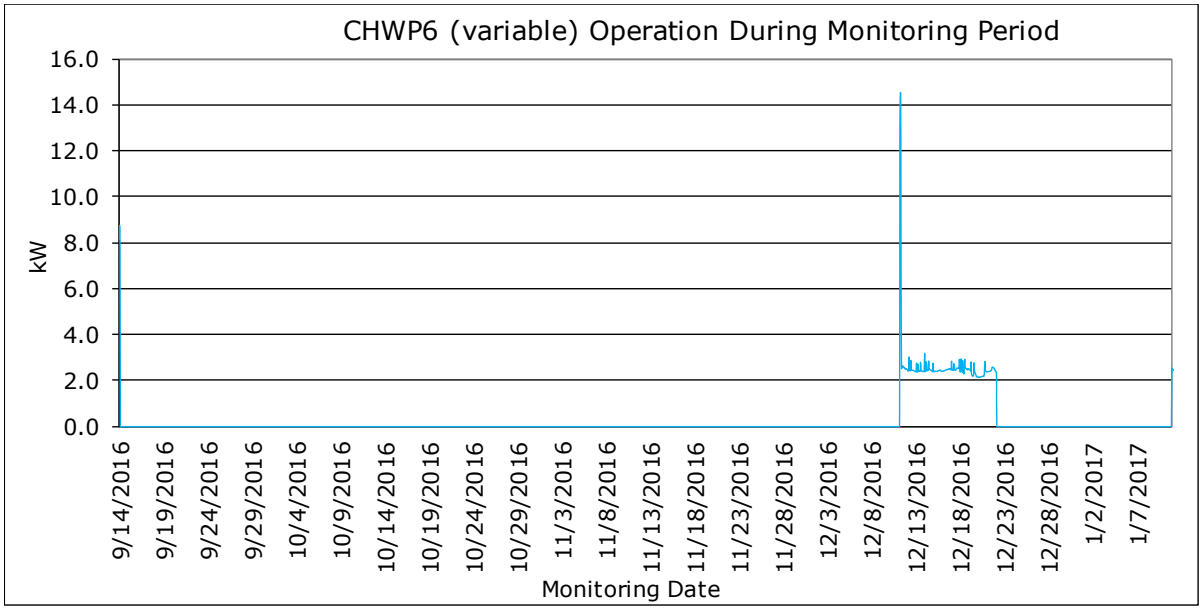


Figure 37: Variable primary pumping CHWP6 (Bldg1258) operation during monitoring period



Average winter and summer demand for CHWP5 were calculated 19.38 and 9.35 kW respectively. Summer demand is higher due to the assumption that this CHWP picks up another chiller running at low loads during winter. CHWP 6 was assigned a winter only schedule with an average demand of 2.8 kW. This CHWP is assigned to a standby chiller and operated only as needed during winter. The third unmonitored CHWP was running during the evaluation's first visit and was assumed to be running in summer at the same load and demand as CHWP 5 that ran consistently throughout the monitoring period. The remaining three chilled water pumps in building 1259 have been analyzed to reflect the same operation as 1258. In the tracking analysis, savings were based upon an occupied and unoccupied schedule however the evaluation found no evidence this as pump demand did not change consistently based upon time of day or day of week.

Bldg#1258: Total 3 CHWPs (3x20 hp)

Summer Load: two 20-hp CHWPs operating constant full load; one 20-hp OFF

Winter Load: one 20-hp CHWP operating constant full load, one 20-hp CHWP operating at partial load; one 20-hp OFF

Bldg#1259: Total 3 CHWPs (2x40 hp, 1x30 hp)

Summer Load: two 40-hp CHWPs operating constant full load; one 30-hp OFF

Winter Load: one 40-hp CHWP operating constant full load, one 30-hp CHWP operating at partial load; one 40-hp OFF

Figure 38 Screenshot of the evaluated 8,760 savings analysis spreadsheet

RI - HVAC NUWC Variable Pun																											0
				0.62	0.19	0.43		Avg	13.51	2.82	9.36	17.36	12.03	4.05	46.25	19.77	10.80	18.14	25.42	23.32	14.60	88.55	
				0.9	0.2	0.4		Max	19.4	2.8	9.4	24.9	12.0	4.0	51.2	22.1	10.8	18.1	28.4	23.3	15.5	96.8	54.1
				0	0	0		Min	9	0	0	12	0	0	43	18	0	0	23	0	14	77	26
							Providence, RI	Totals	118,321	10,207	48,072	152,112	61,801	14,673	405,187	173,180	39,151	93,154	222,638	119,758	127,860	775,742	370,555
8,760		2014					TMY 3 ODB		INSTALLED KW							BASELINE KW							
Line	Date	Year	Hour Ending	CWP 5 % Power	CWP 6 % Power	CWP 7 % Power	ODB Temp (F)	Hour	Bldg 1258 CHWP 5	Bldg 1258 CHWP 6	Bldg 1258 CHWP 7	Bldg 1259 P1 (40 HP)	Bldg 1259 P2 (40 HP)	Bldg 1259 P3 (30 HP chwp 6)	Total Installed kW	Bldg 1258 CHWP 5	Bldg 1258 CHWP 6	Bldg 1258 CHWP 7	Bldg 1259 P1 (40 HP)	Bldg 1259 P2 (40 HP)	Bldg 1259 P3 (30 HP chwp 6)	Total Baseline kW	Total Hourly kW Savings
1	1/1/2014	2014	1	88.7%	19.22%	0.00%	21	1	19.38	2.82	0.00	24.92	0.00	4.05	51.17	22.08	10.80	0.00	28.39	0.00	15.53	76.80	25.63
2	1/1/2014	2014	2	88.7%	19.22%	0.00%	24	2	19.38	2.82	0.00	24.92	0.00	4.05	51.17	22.08	10.80	0.00	28.39	0.00	15.53	76.80	25.63
3	1/1/2014	2014	3	88.7%	19.22%	0.00%	24	3	19.38	2.82	0.00	24.92	0.00	4.05	51.17	22.08	10.80	0.00	28.39	0.00	15.53	76.80	25.63
4	1/1/2014	2014	4	88.7%	19.22%	0.00%	21	4	19.38	2.82	0.00	24.92	0.00	4.05	51.17	22.08	10.80	0.00	28.39	0.00	15.53	76.80	25.63
5	1/1/2014	2014	5	88.7%	19.22%	0.00%	23	5	19.38	2.82	0.00	24.92	0.00	4.05	51.17	22.08	10.80	0.00	28.39	0.00	15.53	76.80	25.63
6	1/1/2014	2014	6	88.7%	19.22%	0.00%	21	6	19.38	2.82	0.00	24.92	0.00	4.05	51.17	22.08	10.80	0.00	28.39	0.00	15.53	76.80	25.63
7	1/1/2014	2014	7	88.7%	19.22%	0.00%	19	7	19.38	2.82	0.00	24.92	0.00	4.05	51.17	22.08	10.80	0.00	28.39	0.00	15.53	76.80	25.63
8	1/1/2014	2014	8	88.7%	19.22%	0.00%	20	8	19.38	2.82	0.00	24.92	0.00	4.05	51.17	22.08	10.80	0.00	28.39	0.00	15.53	76.80	25.63
9	1/1/2014	2014	9	88.7%	19.22%	0.00%	24	9	19.38	2.82	0.00	24.92	0.00	4.05	51.17	22.08	10.80	0.00	28.39	0.00	15.53	76.80	25.63
10	1/1/2014	2014	10	88.7%	19.22%	0.00%	29	10	19.38	2.82	0.00	24.92	0.00	4.05	51.17	22.08	10.80	0.00	28.39	0.00	15.53	76.80	25.63
11	1/1/2014	2014	11	88.7%	19.22%	0.00%	33	11	19.38	2.82	0.00	24.92	0.00	4.05	51.17	22.08	10.80	0.00	28.39	0.00	15.53	76.80	25.63
12	1/1/2014	2014	12	88.7%	19.22%	0.00%	36	12	19.38	2.82	0.00	24.92	0.00	4.05	51.17	22.08	10.80	0.00	28.39	0.00	15.53	76.80	25.63
13	1/1/2014	2014	13	88.7%	19.22%	0.00%	36	13	19.38	2.82	0.00	24.92	0.00	4.05	51.17	22.08	10.80	0.00	28.39	0.00	15.53	76.80	25.63
14	1/1/2014	2014	14	88.7%	19.22%	0.00%	36	14	19.38	2.82	0.00	24.92	0.00	4.05	51.17	22.08	10.80	0.00	28.39	0.00	15.53	76.80	25.63
15	1/1/2014	2014	15	88.7%	19.22%	0.00%	36	15	19.38	2.82	0.00	24.92	0.00	4.05	51.17	22.08	10.80	0.00	28.39	0.00	15.53	76.80	25.63
16	1/1/2014	2014	16	88.7%	19.22%	0.00%	36	16	19.38	2.82	0.00	24.92	0.00	4.05	51.17	22.08	10.80	0.00	28.39	0.00	15.53	76.80	25.63
17	1/1/2014	2014	17	88.7%	19.22%	0.00%	36	17	19.38	2.82	0.00	24.92	0.00	4.05	51.17	22.08	10.80	0.00	28.39	0.00	15.53	76.80	25.63
18	1/1/2014	2014	18	88.7%	19.22%	0.00%	35	18	19.38	2.82	0.00	24.92	0.00	4.05	51.17	22.08	10.80	0.00	28.39	0.00	15.53	76.80	25.63
19	1/1/2014	2014	19	88.7%	19.22%	0.00%	35	19	19.38	2.82	0.00	24.92	0.00	4.05	51.17	22.08	10.80	0.00	28.39	0.00	15.53	76.80	25.63
20	1/1/2014	2014	20	88.7%	19.22%	0.00%	36	20	19.38	2.82	0.00	24.92	0.00	4.05	51.17	22.08	10.80	0.00	28.39	0.00	15.53	76.80	25.63
21	1/1/2014	2014	21	88.7%	19.22%	0.00%	35	21	19.38	2.82	0.00	24.92	0.00	4.05	51.17	22.08	10.80	0.00	28.39	0.00	15.53	76.80	25.63
22	1/1/2014	2014	22	88.7%	19.22%	0.00%	34	22	19.38	2.82	0.00	24.92	0.00	4.05	51.17	22.08	10.80	0.00	28.39	0.00	15.53	76.80	25.63
23	1/1/2014	2014	23	88.7%	19.22%	0.00%	34	23	19.38	2.82	0.00	24.92	0.00	4.05	51.17	22.08	10.80	0.00	28.39	0.00	15.53	76.80	25.63
24	1/1/2014	2014	24	88.7%	19.22%	0.00%	34	24	19.38	2.82	0.00	24.92	0.00	4.05	51.17	22.08	10.80	0.00	28.39	0.00	15.53	76.80	25.63
25	1/2/2014	2014	1	88.7%	19.22%	0.00%	35	1	19.38	2.82	0.00	24.92	0.00	4.05	51.17	22.08	10.80	0.00	28.39	0.00	15.53	76.80	25.63
26	1/2/2014	2014	2	88.7%	19.22%	0.00%	36	2	19.38	2.82	0.00	24.92	0.00	4.05	51.17	22.08	10.80	0.00	28.39	0.00	15.53	76.80	25.63
27	1/2/2014	2014	3	88.7%	19.22%	0.00%	37	3	19.38	2.82	0.00	24.92	0.00	4.05	51.17	22.08	10.80	0.00	28.39	0.00	15.53	76.80	25.63
28	1/2/2014	2014	4	88.7%	19.22%	0.00%	38	4	19.38	2.82	0.00	24.92	0.00	4.05	51.17	22.08	10.80	0.00	28.39	0.00	15.53	76.80	25.63
29	1/2/2014	2014	5	88.7%	19.22%	0.00%	38	5	19.38	2.82	0.00	24.92	0.00	4.05	51.17	22.08	10.80	0.00	28.39	0.00	15.53	76.80	25.63

1.8.5 COMPARISON OF ASSUMPTIONS

The purpose of Table 75 below is to provide a comparison of the key inputs of the tracking and evaluation calculations to demonstrate the sources of savings discrepancies. The realization rates calculated provide an indication of the discrepancies' contribution to the savings variance. CHWP, EAFWP, HWP deemed savings values were not evaluated as evaluators chose a custom approach to determine annual energy savings.

Table 75: Comparison of Key Parameters

	Pre-existing		Retrofit		
Parameter	Tracking Value(s)	Evaluation Value(s)	Tracking Value(s)	Evaluation Value(s)	Note
HWP Energy savings factor [kWh/HP]	1896	1896	NA	NA	Tracking calculations used prescriptive deemed savings while evaluation used custom 8,760
CHWP/EAFWP Energy savings factor [kWh/HP]	1370	1370	NA	NA	Tracking calculations used prescriptive deemed savings while evaluation used custom 8,760
Average Occupied Variable Pumping Summer Demand [kW]	28.17	28.17	12.40	9.35	

Average Unoccupied Variable Pumping Summer Demand [kW]	16.19	16.19	3.87	9.35	
Average Occupied Variable Pumping Winter Demand [kW]	28.17	28.17	10.39	19.38	
Average Unoccupied Variable Pumping Winter Demand [kW]	14.08	14.08	3.19	19.38	

1.8.6 IMPROVEMENT OPPORTUNITIES

- The savings can be better estimated by conducting metering of the pre-existing and post-retrofitted conditions over a period. This should improve pump power estimation and capture actual operation.

- It is also recommended to use one methodology in tracking estimates. As such with this custom project, a combination of prescriptive (TRM values) and custom methodologies were used. Savings estimates would be more accurate with a full custom approach.

4.2.1.7 Site ID: DNV 31

Program Administrator	National Grid
Project ID(s)	3786298
Project Type	New Construction
Program Year	2013
Evaluation Firm	DNV GL
Evaluation Engineer	Mike Rudyk
Senior Engineer	Amit Kanungo

Project Description

This retrofit project installs variable speed drives on chilled water pumps, condenser water pumps, domestic hot water booster pumps, heating hot water pumps, and air-handling unit [AHU] fan motors. New premium efficiency motors were installed with the new variable speed drives on all the pumps. An upgrade of EMS controls occurred at the same time, but savings is not claimed for those control modifications. Table 7 presents a summary of the tracking and evaluation savings results. The primary reason for the savings variance is the annual operating hours assigned to AHU operation. The tracking analysis assumed the AHUs operating hours as 8,760 both in the pre-and proposed conditions whereas the evaluation found the AHUs to be operating 4,654 a year which is 53.1% of full 8,760 annual operation. A data entry error was also made when the savings were entered the tracking savings database. The savings linked to the condenser water pumps were 9,277 kWh less than what was calculated in the TA report. Savings for all other measures were the same in the tracking database and the TA report. The total annual savings in the TA report is 703,497 kWh.

Table 76: Project Results

Savings Quantity	Tracking Estimate	Evaluation Estimate	Realization Rate
Electric energy (kWh)	694,220	393,660	57%
% of Energy Savings on Peak	50%	58%	116%
Summer On-Peak Demand (kW)	129.3	48.95	38%
Winter On-Peak Demand (kW)	65.0	41.2	63%

Tracking Savings

This section summarizes the methodology and assumptions used to estimate the tracking savings claimed for the project including baseline assumptions, proposed equipment, tracking calculation method along with the underlying assumptions that were used in the calculations to estimate the tracking savings.

Project Description

This facility is a thirteen-story office building was built in 1990. The building has 224,952 rentable square feet and consists of multiple tenants. Floor areas include open offices, individual offices, conference rooms, data rooms, break rooms, restrooms, and first floor retail spaces.

This project installed variable speed drives on two existing chilled water pumps, two condenser water pumps, two heating hot water pumps, and two domestic hot water booster pumps. The project also installs variable speed drives on 25 supply fans and 1 exhaust fan.

Baseline Assumptions

Fan Motors

Fan motors represent the largest load and the greatest savings in this project. There are 25 air-handling supply fans in this project and each fan is driven with a 15-HP motor. The total supply fan power is 375-HP. The project includes one 10-HP exhaust fan. The maximum fan power for all fans is 267.9 kW. All fans operated with inlet guide vanes controls and all fans were assumed to run 8,760 hours. Table 8 shows the existing baseline kW for the occupied period temperature bins. Table 78 shows the same data for the unoccupied hours. The Percent of Design column indicates the percent of the maximum rated CFM flow. The Percent of Time at CFM is the percentage of 8,760 operating hours.

Table 77: Occupied Fan Baseline

Occupied (°F) Bin	Percent of Design	Percent of Time at CFM	Existing kW
95	76.9%	0.13%	173.5
90	71%	0.59%	160.7
85	63%	1.24%	139.3
80	63%	2.48%	139.3
75	63%	3.51%	139.3
70	63%	3.82%	139.3
65	63%	3.57%	139.3
60	63%	3.71%	139.3
55	63%	3.63%	139.3
50	63%	3.56%	139.3
45	63%	3.69%	139.3
40	63%	3.46%	139.3
35	63%	3.98%	139.3
30	63%	3.20%	139.3
25	66%	1.81%	150.0
20	85%	1.20%	186.2
15	98%	0.45%	243.1
10	100%	0.29%	267.9
5	100%	0.02%	267.9

Table 78: Unoccupied Fan Baseline

Unoccupied (°F) Bin	Percent of Design	Percent of Time at CFM	Existing kW
95	63%	0.02%	139.3
90	63%	0.21%	139.3
85	63%	0.51%	139.3
80	63%	1.40%	139.3
75	63%	3.20%	139.3
70	63%	5.22%	139.3
65	63%	4.81%	139.3
60	63%	4.48%	139.3
55	63%	4.35%	139.3
50	63%	4.92%	139.3
45	63%	5.51%	139.3
40	63%	4.85%	139.3
35	63%	5.34%	139.3
30	76%	4.61%	173.5
25	95%	2.67%	218.3
20	100%	2.08%	267.9
15	100%	0.73%	267.9
10	100%	0.71%	267.9
5	100%	0.03%	267.9

Chilled Water Pumps

There are two existing chilled water pumps serving the facility. The assumed baseline operation was 2,595 annual cooling hours per year. They operated at a fixed speed and flow and the baseline power per pump is 37.7 kW/per pump (lead/lag) for each operating hour. Table 79 shows the chilled water pump baseline parameters.

Table 79: Chilled Water Pumps

Equipment	Quantity	Size (HP)	Control
P-6 CHW Dist. Pump	1	40.0	Bypass with Lead/lag
P-7 CHW Dist. Pump	1	40.0	Bypass with Lead/lag

Condenser Water Pumps

Two 30-HP primary existing condenser water pumps operate in the facility. The assumed baseline operation was 2,595 annual cooling hours per year. Only one condenser water pump is required at any time. One pump operates as primary and the second waits as backup. The TA calculations assume that the CW pump

will operate at 60% of full load for most of the cooling season. Incremental CW operation is in Table 80. All operation during the unoccupied hours is fixed at 17.1 kW. The CW pumps operate above 17.1 kW for 62 annual hours. This corresponds with occupied hours when outside air temperature exceed 89°F.

Table 80: Condenser Water Pump Baseline Operation

Occupied (°F) Bin	Percent of Design	Percent of Time at GPM	Existing kW
95	77%	0.4%	21.4
90	71%	2.0%	19.9
85	62%	4.2%	17.1
80	60%	8.4%	17.1
75	60%	11.9%	17.1
70	60%	12.9%	17.1
65	60%	12.1%	17.1
60	60%	12.5%	17.1

Heating Hot Water Pumps

Two heating hot water [HHW] pumps serve the facility. They operate lead/lag at fixed speed and flow. The total HHW pump load is estimated at 11.2 kW per hour. The heating season was estimated at 4,340 annual hours but the pumps were predicted to operate 92% of the time or for 3,989 annual hours. Heating is required when outside air temperatures are 45°F and below in the occupied mode. Heating is required when outside temperatures are 50°F and below during unoccupied hours. Table 81 provides HHW pump data.

Table 81: Heating Hot Water Pumps

Equipment	Quantity	Size (HP)	Control
P-12 HW Dist. Pump	1	15.0	Bypass with Lead/lag
P-13 HW Dist. Pump	1	15.0	Bypass with Lead/lag

Domestic Hot Water Booster Pumps

Two domestic hot water pumps operate in the facility. These pumps maintain pressure 8,760 hours and operate at a fixed speed and capacity. The required baseline hourly booster pump power is 10.9 kW. The baseline DHW booster pump information in shown in Table 82.

Table 82: Domestic Hot Water Booster Pumps

Equipment	Quantity	Size (HP)	Control
DHW Booster Pump #1	1	15.0	On/off with Lead/lag
DHW Booster Pump #2	1	15.0	On/off with Lead/lag

Proposed Condition

Fan Motors

Variable speed drives are installed on the existing 15-HP AHU supply fan motors and on the 10-HP exhaust fan. The total supply fan power remains at 375-HP. The project 10-HP exhaust fan also remains the same. The maximum fan power for all fans is 256.4 kW. Fan operation remains at 8,760 hours. Table 83: Occupied Fan Installed Operation shows the proposed kW for the occupied periods calculated using bin analysis. Table 84 shows the same data for the unoccupied hours. The Percent of Design column indicates the percent of the maximum rated CFM flow. The Percent of Time at CFM is the percentage of 8,760 operating hours. These are unchanged from the baseline assumptions.

Table 83: Occupied Fan Installed Operation

Occupied (°F) Bin	Percent of Design	Percent of Time at CFM	Installed kW
95	76.9%	0.13%	122.7
90	71%	0.59%	107.9
85	63%	1.24%	78.3
80	63%	2.48%	78.3
75	63%	3.51%	78.3
70	63%	3.82%	78.3
65	63%	3.57%	78.3
60	63%	3.71%	78.3
55	63%	3.63%	78.3
50	63%	3.56%	78.3
45	63%	3.69%	78.3
40	63%	3.46%	78.3
35	63%	3.98%	78.3
30	63%	3.20%	78.3
25	66%	1.81%	93.1
20	85%	1.20%	140.0
15	98%	0.45%	220.3
10	100%	0.29%	256.4
5	100%	0.02%	256.4

Table 84: Unoccupied Fan Installed Operation

Unoccupied (°F) Bin	Percent of Design	Percent of Time at CFM	Installed kW
95	63%	0.02%	78.3
90	63%	0.21%	78.3
85	63%	0.51%	78.3
80	63%	1.40%	78.3
75	63%	3.20%	78.3
70	63%	5.22%	78.3
65	63%	4.81%	78.3
60	63%	4.48%	78.3
55	63%	4.35%	78.3
50	63%	4.92%	78.3
45	63%	5.51%	78.3
40	63%	4.85%	78.3
35	63%	5.34%	78.3
30	76%	4.61%	122.7
25	95%	2.67%	187.9
20	100%	2.08%	256.4
15	100%	0.73%	256.4
10	100%	0.71%	256.4
5	100%	0.03%	256.4

Chilled Water Pumps

Variable speed drives and 40-HP premium efficiency motors were installed on the existing chilled water pumps. Cooling hours remain unchanged at 2,595 annual hours. The pumps still operate as lead/lag but operate with variable flow with the VSDs. Savings were calculated using occupied and unoccupied schedules. Table 85 shows the power requirements for the occupied hours [1,670 hours]. The pump kW for the 925 hour unoccupied period is fixed at 5.3 kW for all hours based upon a minimum 60% flow. The reason for the 60% flow is not stated in the TA report.

Table 85: Chilled Water Pump Installed Operation

Occupied (°F) Bin	Percent of Design	Percent of Time at CFM	Installed kW
95	77%	0.4%	17.8
90	71%	2.0%	15.7
85	62%	4.2%	11.4
80	60%	8.4%	7.5
75	60%	11.9%	6.0
70	60%	12.9%	5.3
65	60%	12.1%	5.3
60	60%	12.5%	5.3

Condenser Water Pumps

Variable speed drives and 30-HP premium efficiency motors were installed on the existing condenser water pumps. Cooling hours remain unchanged at 2,595 annual hours. The pumps still operate as lead/lag but operate with variable flow with the VSDs. Savings were calculated using occupied and unoccupied schedules. Table 86 shows the power requirements for the occupied hours [1,670 hours]. The pump kW for the 925 hour unoccupied period is fixed at 8.6 kW for all hours.

Table 86: Condenser Water Pump Installed Operation

Occupied (°F) Bin	Percent of Design	Percent of Time at CFM	Installed kW
95	77%	0.4%	13.4
90	71%	2.0%	11.8
85	62%	4.2%	8.6
80	60%	8.4%	8.6
75	60%	11.9%	8.6
70	60%	12.9%	8.6
65	60%	12.1%	8.6
60	60%	12.5%	8.6

Heating Hot Water Pumps

Variable speed drives and 15-HP premium efficiency motors were installed on the existing heating hot water pumps. Heating hours remain unchanged at 4,340 annual hours with the 92% estimated HHW pump operation. The pumps still operate as lead/lag but operate with variable flow with the VSDs. Savings were calculated using occupied and unoccupied schedules. Table 87 shows the proposed operation during the 1,457 hours occupied period. Table 88 shows the data for the 2,533 hours unoccupied period.

Table 87: Heating Hot Water Pump Installed Occupied Operation

Occupied (°F) Bin	Percent of Design	Percent of Time at CFM	Installed kW
45	40%	6.85%	1.5
40	40%	6.41%	1.5
35	40%	7.39%	1.5
30	49%	5.93%	1.7
25	66%	3.36%	3.8
20	85%	2.22%	5.7
15	98%	0.83%	8.9
10	100%	0.53%	10.4
5	100%	0.03%	10.4

Table 88: Heating Hot Water Pump Installed Unoccupied Operation

Unoccupied (°F) Bin	Percent of Design	Percent of Time at CFM	Installed kW
50	40%	9.13%	1.5
45	40%	10.22%	1.5
40	43%	9.01%	1.5
35	58%	9.92%	2.5
30	76%	8.55%	5.0
25	95%	4.96%	7.6
20	100%	3.86%	10.4
15	100%	1.35%	10.4
10	100%	1.31%	10.4
5	100%	0.06%	10.4

Domestic Hot Water Booster Pumps

Variable speed drives and 15-HP premium efficiency motors were installed on the existing DHW booster pumps. These pumps still operate 8,760 hours, but operation is broken into 10% load bins as shown in Table 89.

Table 89: DHW Booster Pump Installed Operation

Percent of Design	Percent of Time at % of load	Installed kW
100%	2.00%	10.4
90%	6.00%	7.6
80%	8.00%	5.7
70%	16.00%	4.4
60%	18.00%	3.2
50%	18.00%	2.1
40%	16.00%	2.1
30%	8.00%	2.1
20%	6.00%	2.1
10%	2.00%	2.1

TRACKING CALCULATION METHODOLOGY

Tracking savings were calculated using a 5.0°F weather bin spreadsheet. A savings TAB is created for each measure [AHU fans, CHWPs, CWPs, HHWPs, and booster DHWPs]. The weather bins are in dry bulb temperatures and range from 95°F to 5°F. Two weather bins are generated within each measure. One bin analysis is for the occupied period and the second is for the unoccupied period. Annual operating hours are estimated for each measure and are shown in Table 90.

Table 90: Tracking Calculation Variables

VSD Measure	Total Annual Hours	Occupied Hours	Unoccupied Hours	Baseline Max Motor kW	Installed Max Motor kW	Baseline Control
AHU Fans	8,760	3,885	4,875	267.9	248.7	Inlet Vanes
CHWPs	2,595	1,670	925	37.7	36.1	CV bypass
CWPs	2,595	1,670	925	28.5	27.2	On/off cycling
HHWPs	4,340	1,457	2,883	11.2	10.0	CV bypass
DHWPs	8,760	8,760	0	10.9	10.0	Constant volume

Maximum baseline and installed kW is presented for each measure. Motor kW is calculated as:

$$kWmotor = \frac{HPtotal\ x\ 0.746\ x\ \%load}{Motoreff}$$

Where:

kW_{motor} = Total maximum kW

HP_{total} = Total motor horsepower in the measure

0.746 = Conversion factor HP to kW

%Load = Estimated maximum motor load

$Motor_{eff}$ = Nameplate motor efficiency

The baseline and installed control strategies are identified. A 97% VSD efficiency is assumed to all installed measures. Lookup tables are created for each control strategy that provides an operating percentage using the estimated percent of design for each 5°F bin. Savings for each temperature bin is calculated using the following equation:

$$kWhsaved = \left((kWbase\ x\ \%OPbcontrol) - \left(\frac{kWinstalled\ x\ \%OPinscontrol}{VSDeff} \right) \right) x\ Hours\ x\ Bin\%$$

Where:

kWh_{saved} = Annual kWh saved per bin

kW_{base} = Maximum baseline kW

$\%OP_{bcontrol}$ = Percent of motor kW from lookup table for baseline control

$kW_{installed}$ = Maximum installed kW

$\%OP_{inscontrol}$ = Percent of motor kW from lookup table for installed control

VSD_{eff} = Variable speed drive efficiency

Hours = Annual operating hours

Bin% = Percent of operating hours per bin

Evaluator Assessment of Tracking Savings

The tracking savings are calculated for each measure with a 5.0°F weather bin format. These bins are based upon dry bulb temperatures. Each 5.0°F is assigned a "Percent of Design" value and a "Percent of Time" value. Table 91 shows these parameters for the AHU fan measure. The table shows two complete 5.0°F bin profiles. The first set of bins is for the occupied period and the second bin-set is for unoccupied hours. The percent of time is summed at the bottom and is 100%. This percentage spread is applied to pre-defined annual operating hours for each system. In this case annual operation is assumed to be continuous [8,760 annual hours]. The occupied/unoccupied schedules are not defined in the report and they vary from measure-to-measure as shown in Table 90.

Table 91: AHU Fan Tracking Savings Weather Bin Analysis

Bin Temperature (°F)	Percent of Design	Percent of Time at CFM
95	76.9%	0.13%
90	71%	0.59%
85	63%	1.24%
80	63%	2.48%
75	63%	3.51%
70	63%	3.82%
65	63%	3.57%
60	63%	3.71%
55	63%	3.63%
50	63%	3.56%
45	63%	3.69%
40	63%	3.46%
35	63%	3.98%
30	63%	3.20%
25	66%	1.81%
20	85%	1.20%
15	98%	0.45%
10	100%	0.29%
5	100%	0.02%
95	63%	0.02%
90	63%	0.21%
85	63%	0.51%
80	63%	1.40%
75	63%	3.20%
70	63%	5.22%
65	63%	4.81%
60	63%	4.48%
55	63%	4.35%
50	63%	4.92%
45	63%	5.51%
40	63%	4.85%
35	63%	5.34%
30	76%	4.61%
25	95%	2.67%
20	100%	2.08%
15	100%	0.73%
10	100%	0.71%
5	100%	0.03%
		100%

The equations generating the "Percent of Design" and "Percent of Time" values are not shown. These are cut-and-paste values in each cell and the variables creating them are not defined or noted. The "Percent of Design" value is used to index a "Percent of Power" value from lookup tables. The factors for inlet vanes in the AHU base case is shown in Table 92. AT the 85% "Percent of Design" above [occupied bin-set @ 20.0°F] the returned power modified from Table 92 is 76.0%. While the approach may be solid, the lack of equations and hard copy numbers make it difficult to identify if the loads are applicable.

Table 92: AHU Fan Power Modifier

Load	Backward Curved Centrifugal - Inlet Vanes	Any VFD
0%		
5%		
10%	39%	7%
15%	39%	7%
20%	39%	8%
25%	40%	8%
30%	41%	10%
35%	43%	11%
40%	45%	14%
45%	47%	16%
50%	48%	20%
55%	50%	24%
60%	52%	31%
65%	56%	36%
70%	60%	42%
75%	65%	48%
80%	70%	55%
85%	76%	62%
90%	82%	73%
95%	91%	86%
100%	100%	100%

The bin analyses use the dry bulb bins to estimate incremental loads. Dry bulb temperatures are applicable for heating measures. Cooling based measures, the CHWPs, CWPs, and summer AHU fan operation should be based upon wet bulb temperatures. The "Any VFD" modifies above is used for all the drive measures including the fans and pumps. There is no distinction in that modifier to differentiate between the heating measures and latent/sensible cooling measures.

There same VSD savings modifier is used for the AHU fans and the pumping measures. The affinity laws and power calculations differentiate between fan and pumping measures. In the affinity laws the ^3 function is a perfect relationship. Fan operation may apply a ^2.75 function while pumping measures may be in the ^2.2 range. These operational distinctions are not included in this analysis.

The occupied/unoccupied schedules were spread across the weather bins. Total operating hours were identified for each system, but no discussion was included describing the schedules. They appear to be inconsistent across the measures. The fans operate in the occupied period for 55.0% of total operation, the heating hot water pump unoccupied operation is 66.0%, and it is 35.0% for the cooling pumps.

There were errors in calculating the maximum kW for the base/installed chilled water pumps and condenser water pumps. The equation omitted the 0.746 kW/HP conversion factor. This increased maximum kW by 34%.

Project Evaluation

The evaluation process included:

- A full review of tracking documentation
- Evaluating the equations and reconstructing tracking energy savings for each measure in the TA bin analysis spreadsheet
- Obtaining additional information and methodology clarifications
- Identifying key variables used to generate savings and to be verified during the site visit
- Creating the M&V plan outlining the evaluation approach for each measure
- Conducting a comprehensive site visit that includes installation of power loggers, discussing the project and facility operation with site personnel, and collecting nameplate and other relevant data
- Retrieving installed loggers and downloading/analysing the monitored data

Measure Verification

A site visit was conducted on August 2, 2016 to verify the installation and begin data collection. Discussions with facility personnel determined that the project has been completed and all measures were fully operational. No major operational changes have occurred in the facility since the project was completed. No major temperature changes were made in the energy management system and ventilation air damper positions are in-line with pre-installation conditions. The facility personnel stated that occupied/unoccupied scheduling was in place prior to the installation of the variable speed drives.

Each of the chilled water pumps, condenser water pumps, heating hot water pumps, and domestic hot water booster pumps were observed in the field. The motor nameplate data for each pump matched the tracking data. Air handler fan motors were observed on the 3rd, 8th, and 13th floors including the outside air unit. These motors matched tracking data. Variable speed drives were installed on all these units. Variable speed drives were observed in the remaining mechanical spaces. All fans and pumps inventoried in the tracking documentation were equipped with new variable speed drives. All units were operating in the "auto" position with no units operating in an override condition.

Data Collection

This project installed variable speed drives on existing chilled water pumps, condenser water pumps, heating hot water pumps, domestic hot water booster pumps, an exhaust fan, and on AHU supply fans. No changes were made to pump/fan operating schedules, ventilation air, space temperatures, or on chilled and condenser water temperatures.

Three Elite power loggers were installed to monitor pump operation. The monitoring included 100% of the chilled water pumps, condenser water pumps, and domestic hot water booster pumps included in this measure. Monitoring occurred during the cooling season and no heating hot water was generated or required. The heating hot water pumps were not operating, so monitoring equipment was placed on hot water pumps.

Three additional loggers were installed to monitor fan operation. These included air handlers on the 3rd floor, 8th floor, 13th floor, and the outside air ventilation unit located in the 13th floor mechanical room. The 10-HP exhaust fan was not monitored but the facility personnel stated that the exhaust was linked with the 13th floor air handling unit and mirrored that operation. No on-site power data was available in the energy management system to supplement the monitoring

data. EMS data on kitchen hood exhaust CFM, exhaust fan on/off times, and AHU on/off times were collected during the return visit.

Table 11 shows the installed power loggers.

Table 93: Evaluation Data Collection – Installed Equipment

Parameter	M&V Equipment Brand and Model	Metering Start/Stop Dates	Metering Interval
(2) Chilled Water Pumps	Dent Elite-Pro Logger	8/2/2016-9/23/2016	5-minutes
(2) Condenser Water Pumps	Dent Elite-Pro Logger	8/2/2016-9/23/2016	5-minutes
(2) DHW Booster Pumps	Dent Elite-Pro Logger	8/2/2016-9/23/2016	5-minutes
AHU 3-1	Dent Elite-Pro Logger	8/2/2016-9/23/2016	5-minutes
AHU 8-2	Dent Elite-Pro Logger	8/2/2016-9/23/2016	5-minutes
AHU 13-1	Dent Elite-Pro Logger	8/2/2016-9/23/2016	5-minutes
OA AHU	Dent Elite-Pro Logger	8/2/2016-9/23/2016	5-minutes
Outside air DB/WB temperatures °F	Local weather station	8/2/2016-9/23/2016	1-hour

The monitored power data was viewed over the entire monitoring period. Figure 13, Figure 14, and Figure 41 presents the operation of the three air handling units over the monitoring period. The three units were selected to represent different building elevations and zones. The monitored profiles are very similar and indicate that there is uniform operation across all the air handling units. There are minor differences in operation as occupied schedules are slightly different from zone to zone and are primarily due to programming staggered start-up to prevent high inrush power of multiple units starting at the same time. The 13th floor AHU serves the executive offices and HVAC schedules can be modified per need during busy times of the year. Figure 42 shows the operation of the OA air handling unit. There is limited weekend occupancy in the facility and the OA unit is not on during those hours unless required. A composite operation was made for all the monitored AHUs. That profile is presented in Figure 43.

Figure 39: Third Floor AHU

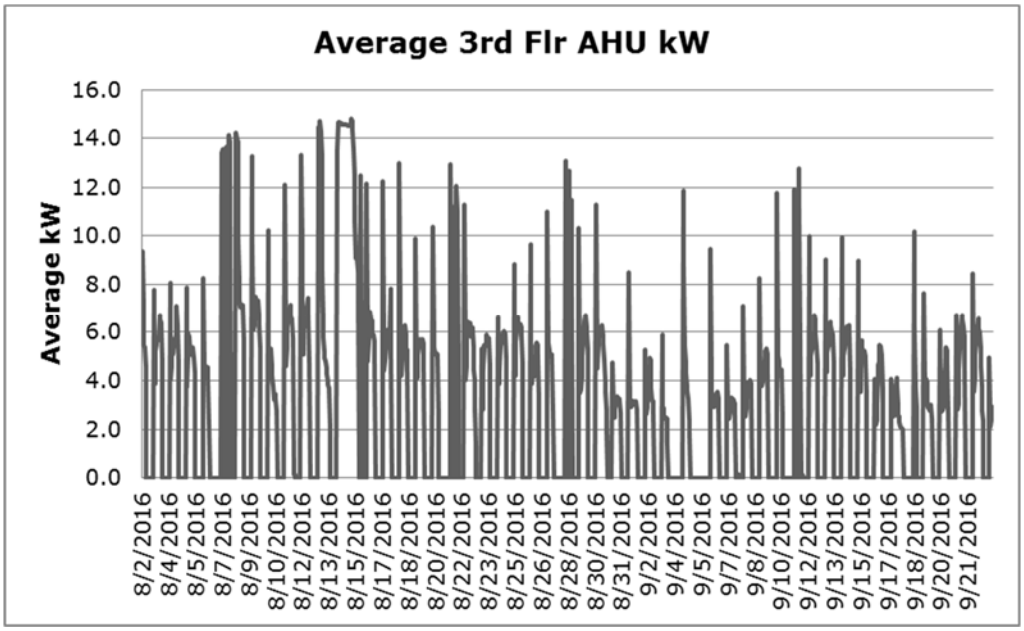


Figure 40: Eighth Floor AHU

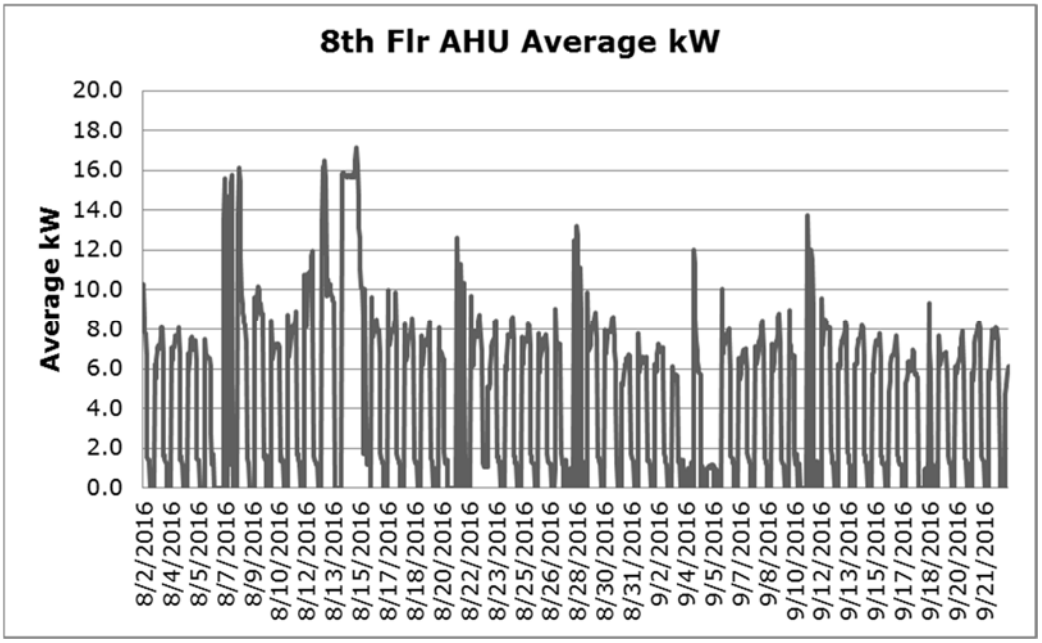


Figure 41: Thirteenth Floor AHU

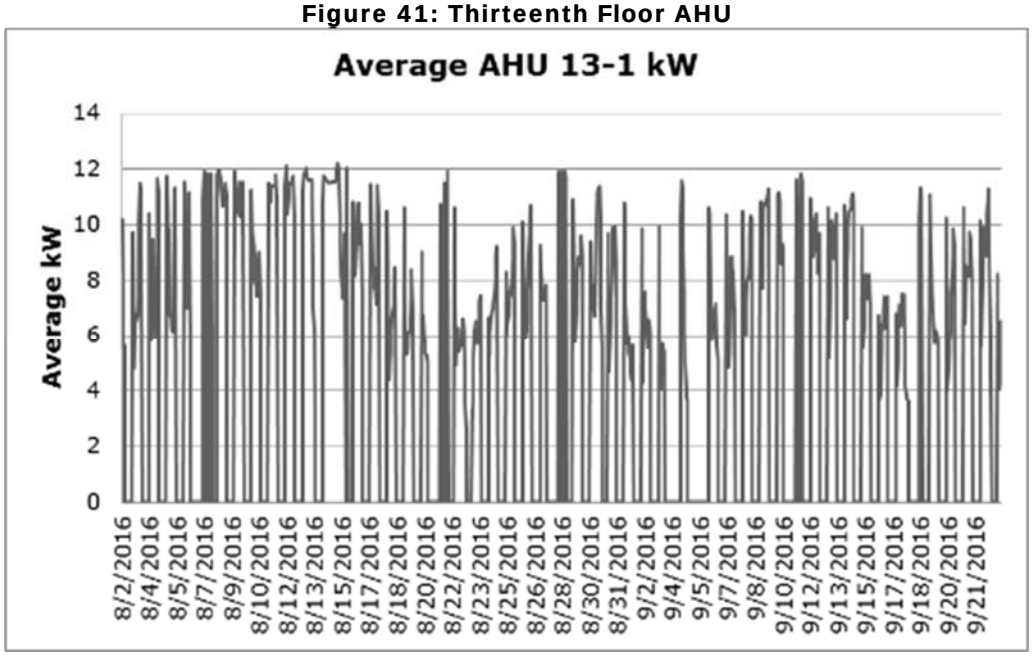


Figure 42: Outside Air Unit

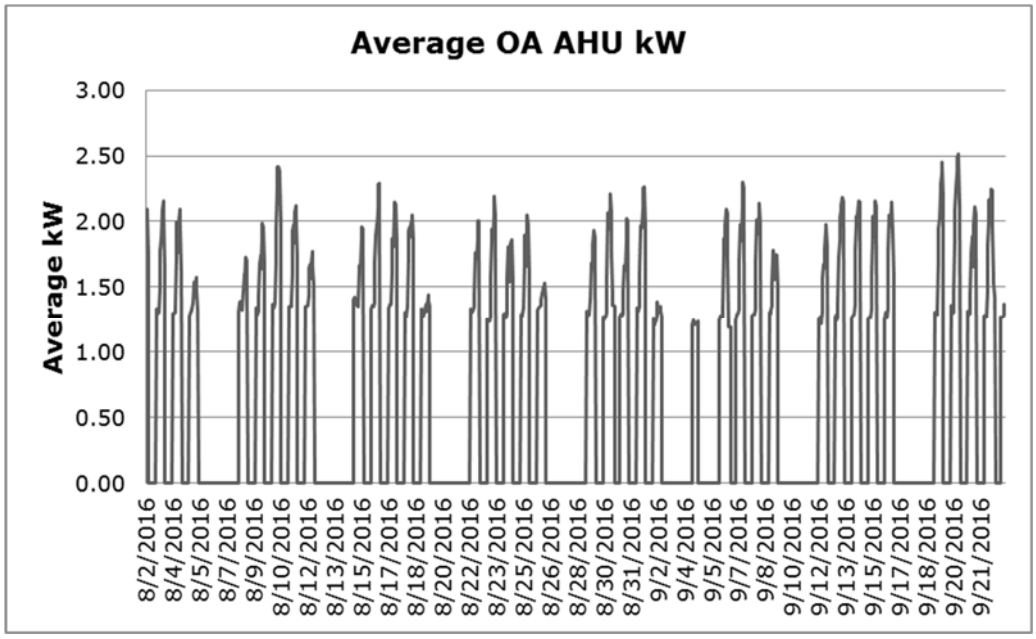
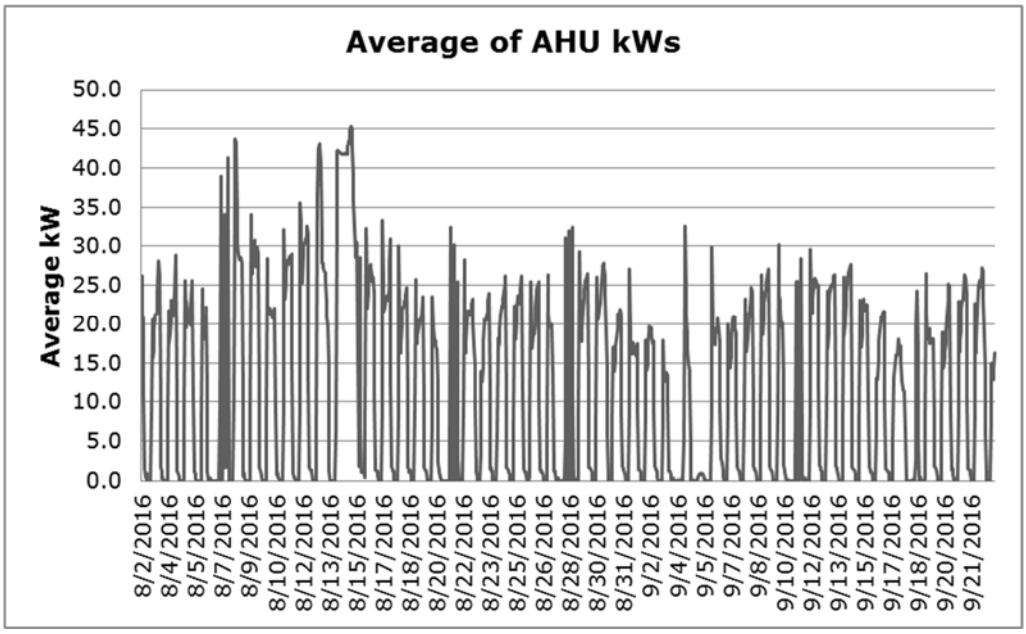
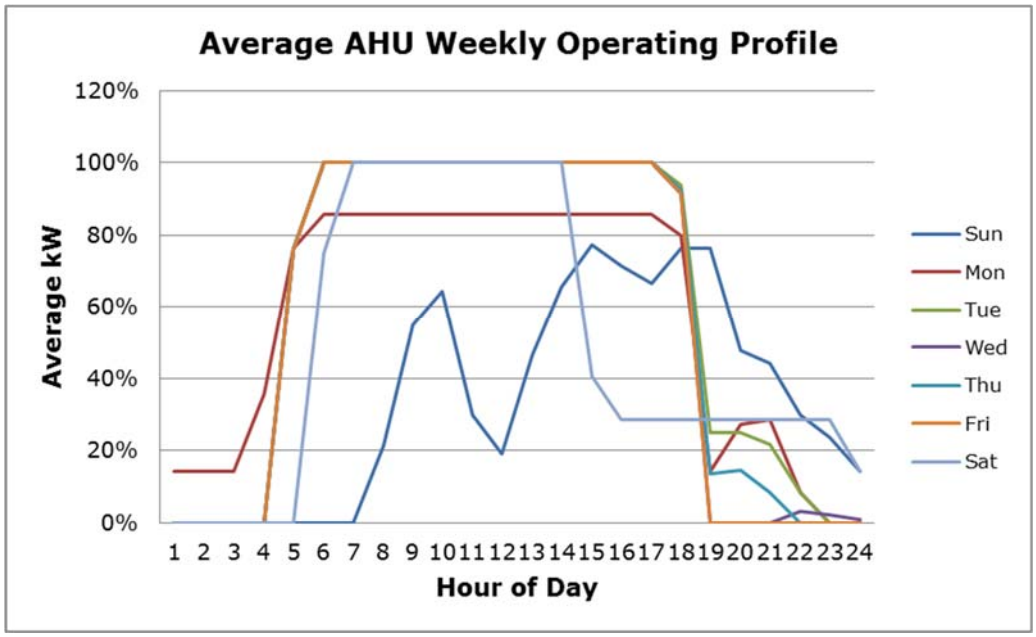


Figure 43: Combined AHU Operation



A weekly operating profile was created from the combined fan monitoring data. That profile is shown in Figure 44. The profile shows a pronounced weekday and weekend schedules are in place.

Figure 44: Combined Fan Profile



The monitored CHWP and CWP data is shown in Figure 45 and Figure 46 respectively. The condenser water pump operated with little modulation over most of the monitoring period.

Figure 45: Chilled Water Pump Operation

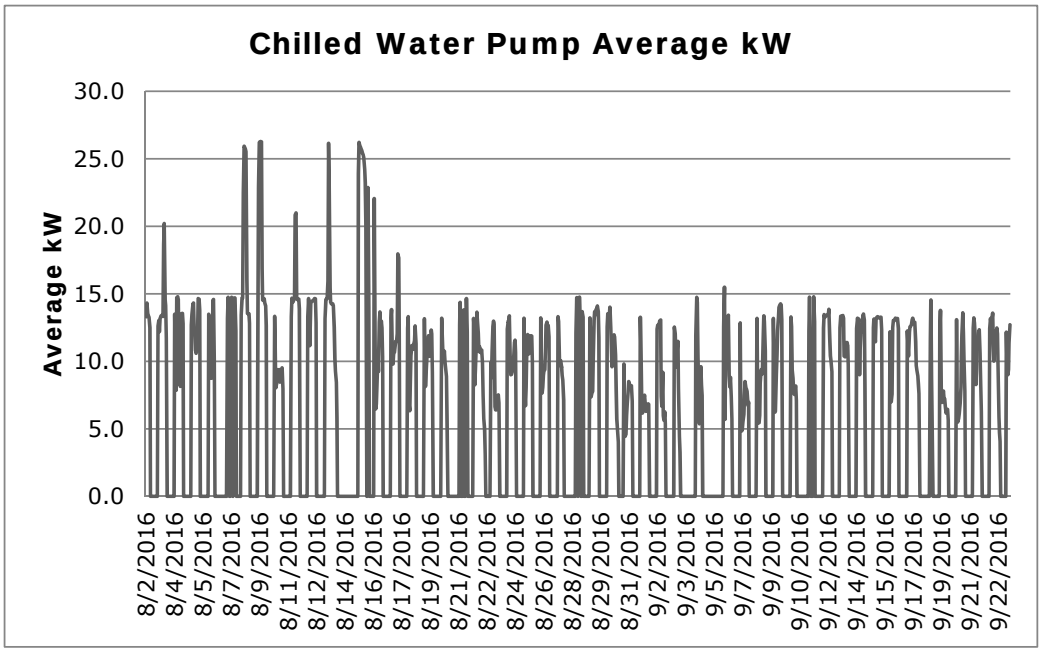
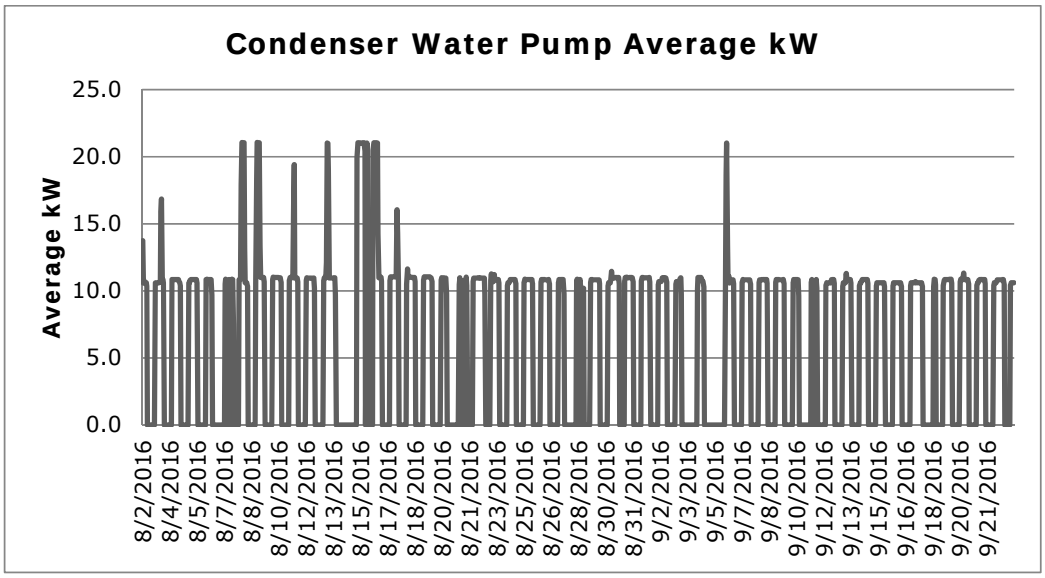


Figure 46: Condenser Water Pump Operation



Weekly profiles were created for the chilled and condenser water pumps as shown in Figure 47 and Figure 48. There is little need to provide chilled or condenser water when the air-handling units are off during the unoccupied periods. The CHWP and CWP profiles show that they follow similar scheduling.

Figure 47: Chilled Water Pump Weekly Profile

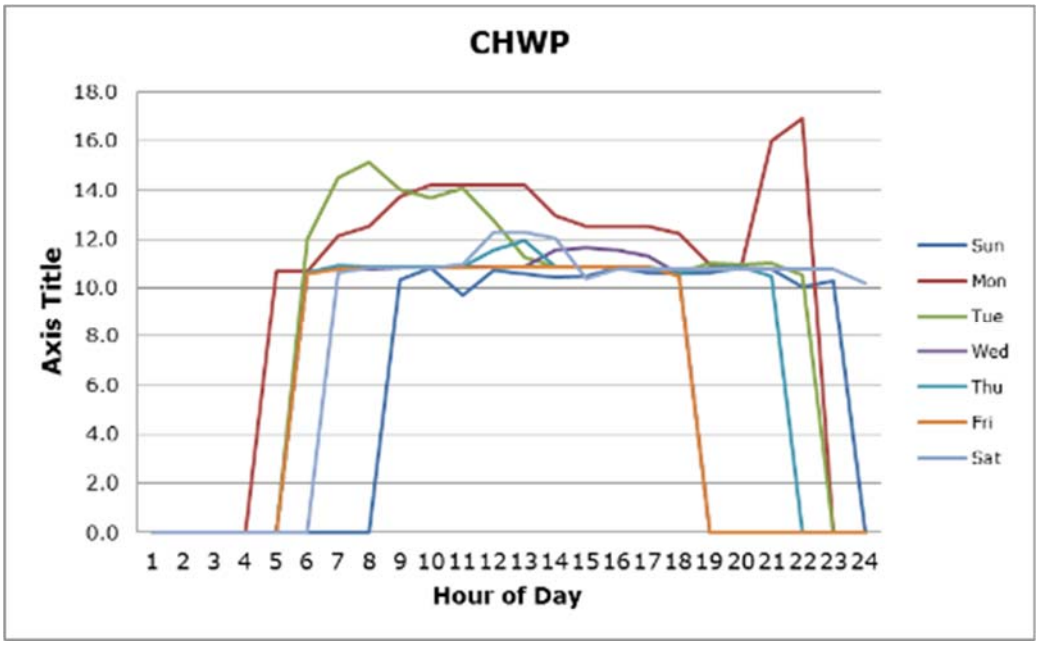


Figure 48: Condenser Water Pump Weekly Profile

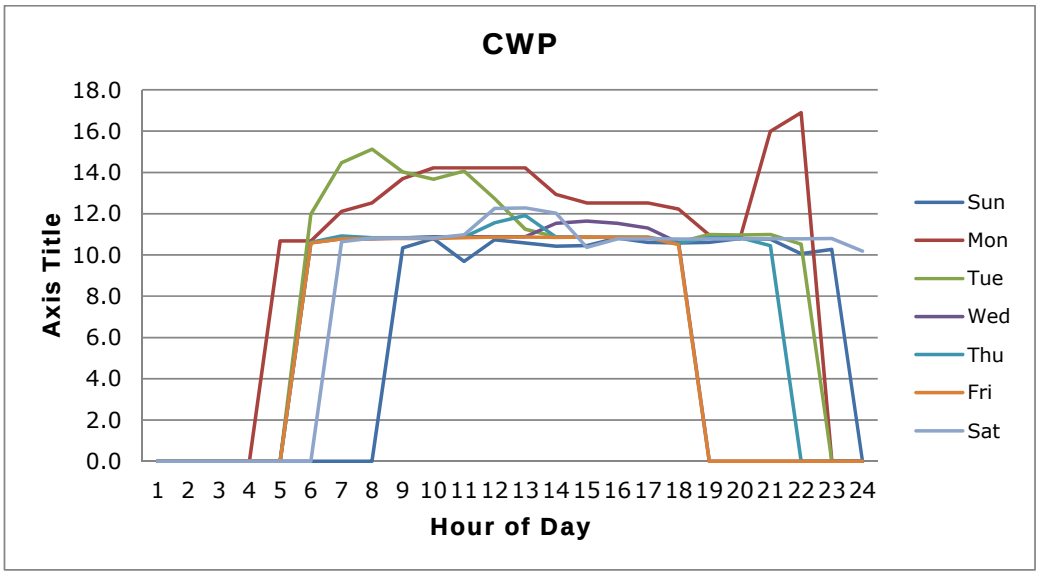


Figure 49 and Figure 50 shows the operational data for the DHW booster pumps. The trend data shows that dumping is continuous – the trend data never dropped to 0 at the horizontal axis – and the VSD was modulating flow.

Figure 49: DHW Booster Pump Operation

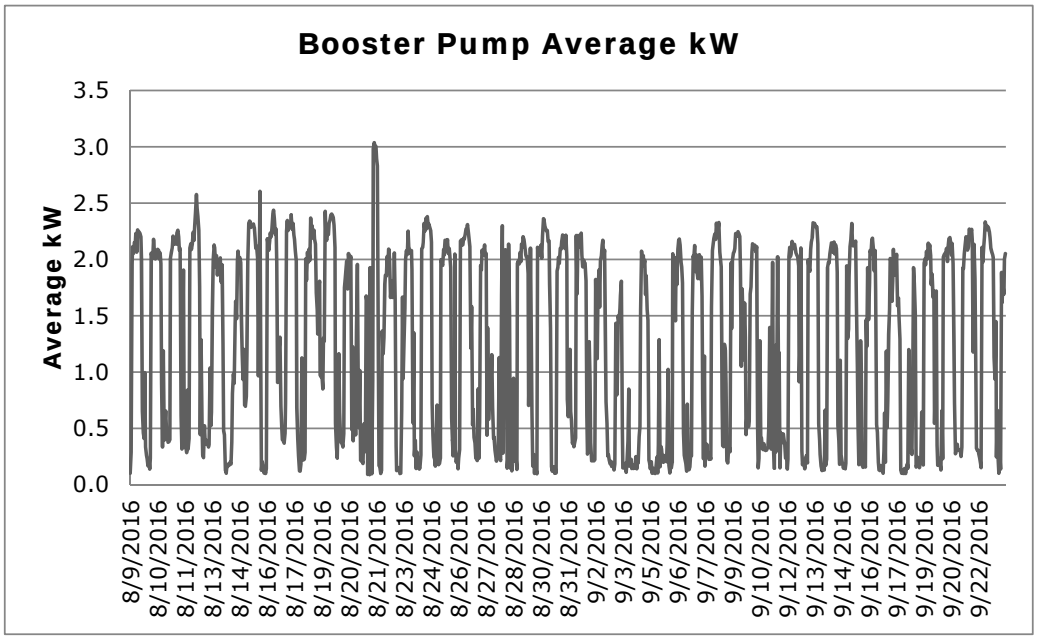
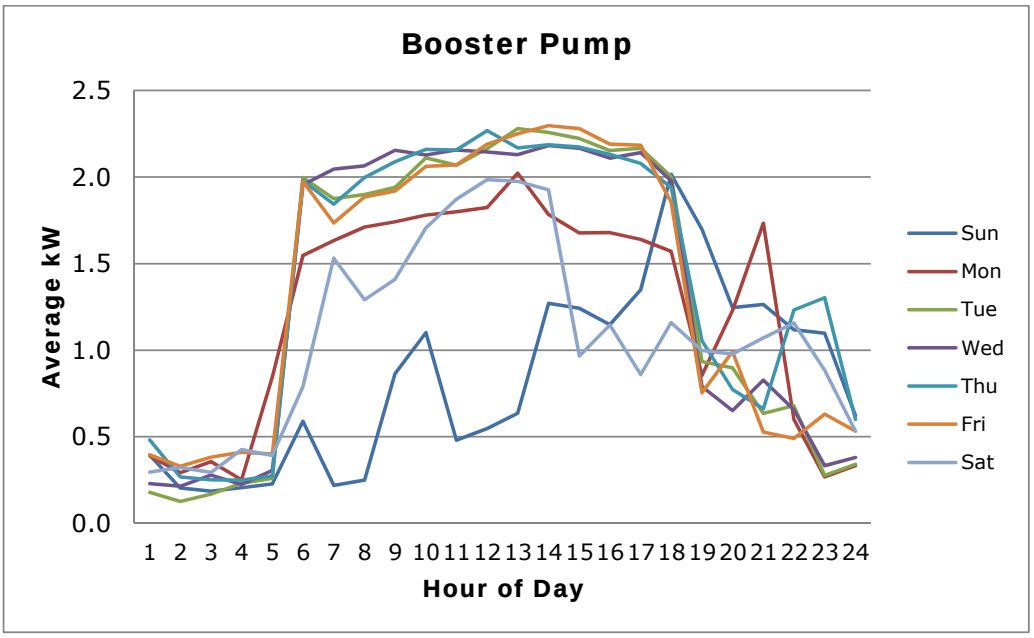


Figure 50: DHW Booster Pump Weekly Profile



The heating hot water pumps were not operating during the monitoring period. No trending was possible.

Evaluation Savings Analysis

The monitored power data for the chilled water pumps [Figure 15] and the condenser water pumps [Figure 16] was compared with outside air wet bulb temperatures concurrent with the monitoring period. The 5-minute hourly monitoring data was converted to hourly average values to match the hourly temperature

format. The facility stated that the primary cooling season is from May 1st through October 15th. The start/stop dates can be extended both earlier and later depending projected temperatures.

Figure 51: Chilled Water Pumps

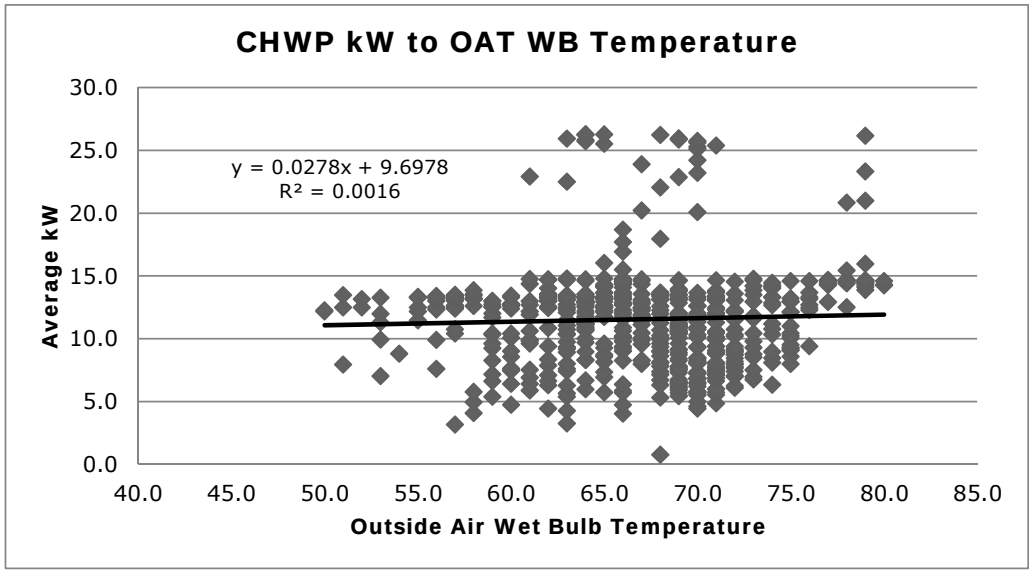
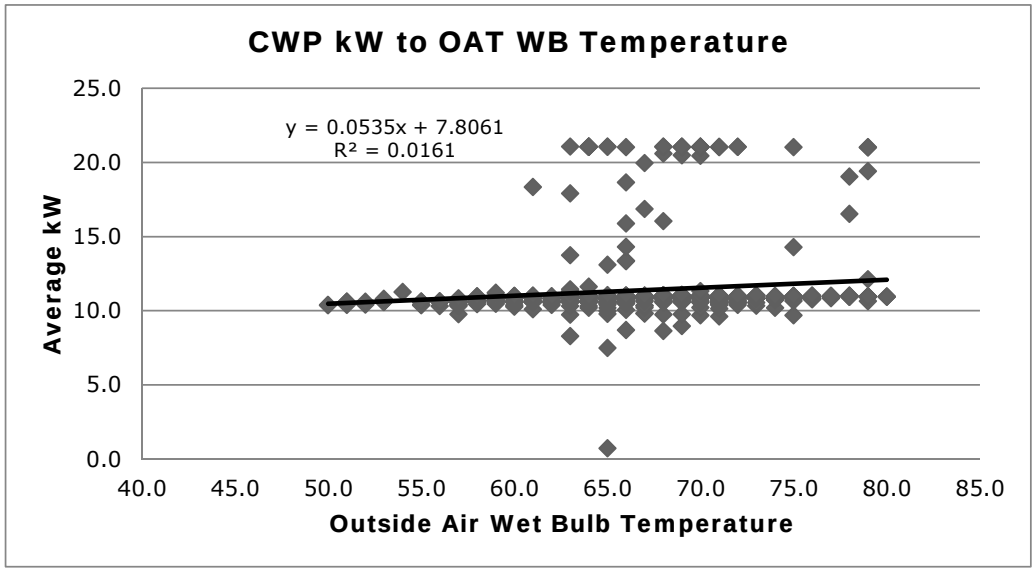
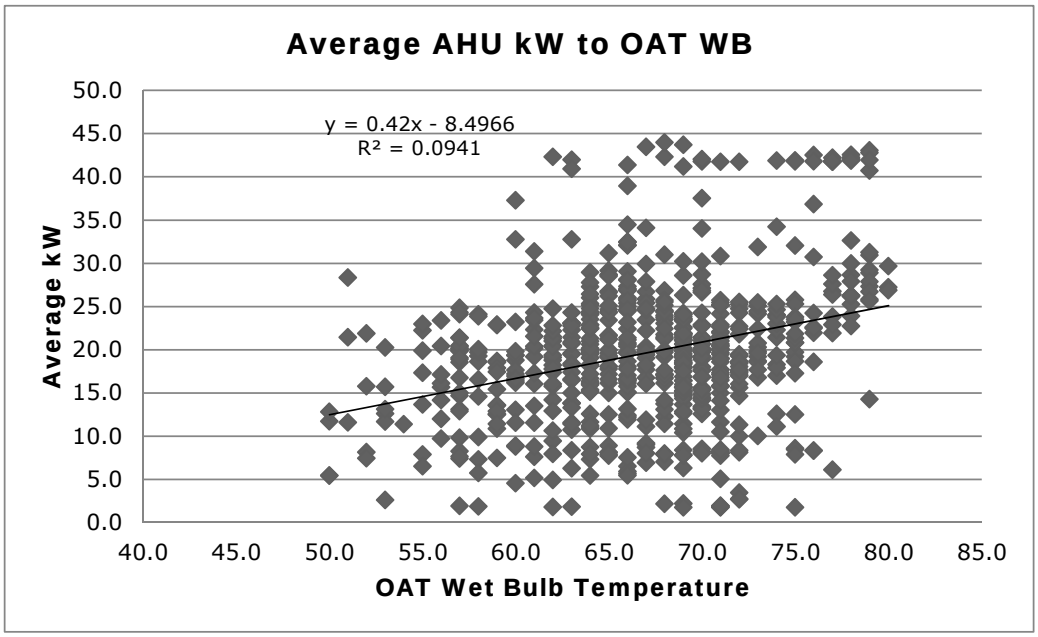


Figure 52: Condenser Water Pumps



The same analysis was performed on the AHU fan data. The data from the three power loggers was combined to create an operating profile for the representative fans. Fans were selected to monitor low, middle, and top floor units. The monitored average hourly fan kW was compared against the corresponding outside air wet bulb temperatures. Figure 17 shows average monitored fan performance during the cooling period. The pump and fan analyses shows that there is a poor relationship between pump/fan power and wet bulb temperatures. The low 0.0941 R^2 values suggest that most cooling is base load and internal gain driven with minimum ventilation air provided.

Figure 53: AHU Supply Fans



The M&V savings are calculated using an 8,760-hour spreadsheet that uses the trended power values and TMY3 annual weather data. The cooling season of May 1st through October 14th was set as the cooling season. The remaining hours were assigned to the heating season. Monitoring occurred during the cooling season so direct heating operation was monitored. Savings were calculated for each defined cooling hour using the monitored power data. Tracking heating conditions and assumptions were used to estimate AHU fan and heating hot water pump savings. The facility personnel stated that there no changes in occupied/unoccupied periods between the heating and cooling seasons. The monitored occupied/unoccupied schedules calculated from the monitored cooling data were used for the heating schedule. These schedules were generated from the weekly profiles discussed above. The tables provide a unique operating percentage for each hour of the week. 100% indicates that the unit operated during the monitoring hour an 0% shows no operation over the monitoring period. Figure 54 and Figure 55 provides the schedules for the pumps and AHU fans respectively.

Figure 54: Pumping Occupied / Unoccupied Weekly Schedules

Pumps							
Hour	Sun	Mon	Tue	Wed	Thu	Fri	Sat
1	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
2	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
3	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
4	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
5	0.0%	26.2%	0.0%	0.0%	0.0%	0.0%	0.0%
6	0.0%	67.9%	91.7%	91.7%	91.7%	91.7%	0.0%
7	0.0%	83.3%	100.0%	100.0%	100.0%	100.0%	91.7%
8	0.0%	85.7%	100.0%	100.0%	100.0%	100.0%	100.0%
9	29.8%	85.7%	100.0%	100.0%	100.0%	100.0%	100.0%
10	56.0%	85.7%	100.0%	100.0%	100.0%	100.0%	100.0%
11	17.9%	85.7%	100.0%	100.0%	100.0%	100.0%	100.0%
12	4.8%	85.7%	100.0%	100.0%	100.0%	100.0%	100.0%
13	2.4%	85.7%	100.0%	100.0%	100.0%	100.0%	100.0%
14	36.9%	85.7%	100.0%	100.0%	100.0%	100.0%	100.0%
15	45.2%	85.7%	100.0%	100.0%	100.0%	100.0%	40.5%
16	48.8%	85.7%	100.0%	100.0%	100.0%	100.0%	28.6%
17	40.5%	85.7%	100.0%	100.0%	100.0%	100.0%	28.6%
18	46.4%	79.8%	92.7%	91.7%	92.7%	91.7%	28.6%
19	51.2%	14.3%	12.5%	0.0%	12.5%	0.0%	28.6%
20	32.1%	15.5%	12.5%	0.0%	12.5%	0.0%	28.6%
21	28.6%	28.6%	12.5%	0.0%	8.3%	0.0%	28.6%
22	15.5%	8.3%	8.3%	0.0%	0.0%	0.0%	28.6%
23	9.5%	0.0%	0.0%	0.0%	0.0%	0.0%	28.6%
24	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	15.5%

Figure 55: AHU Occupied / Unoccupied Weekly Schedules

Air Handling Unit Fans							
Hour	Sun	Mon	Tue	Wed	Thu	Fri	Sat
1	0.0%	14.3%	0.0%	0.0%	0.0%	0.0%	0.0%
2	0.0%	14.3%	0.0%	0.0%	0.0%	0.0%	0.0%
3	0.0%	14.3%	0.0%	0.0%	0.0%	0.0%	0.0%
4	0.0%	35.7%	0.0%	0.0%	0.0%	0.0%	0.0%
5	0.0%	76.2%	76.2%	76.0%	76.0%	76.0%	0.0%
6	0.0%	85.7%	100.0%	100.0%	100.0%	100.0%	75.0%
7	0.0%	85.7%	100.0%	100.0%	100.0%	100.0%	100.0%
8	21.4%	85.7%	100.0%	100.0%	100.0%	100.0%	100.0%
9	54.8%	85.7%	100.0%	100.0%	100.0%	100.0%	100.0%
10	64.3%	85.7%	100.0%	100.0%	100.0%	100.0%	100.0%
11	29.8%	85.7%	100.0%	100.0%	100.0%	100.0%	100.0%
12	19.0%	85.7%	100.0%	100.0%	100.0%	100.0%	100.0%
13	46.4%	85.7%	100.0%	100.0%	100.0%	100.0%	100.0%
14	65.5%	85.7%	100.0%	100.0%	100.0%	100.0%	100.0%
15	77.4%	85.7%	100.0%	100.0%	100.0%	100.0%	40.5%
16	71.4%	85.7%	100.0%	100.0%	100.0%	100.0%	28.6%
17	66.7%	85.7%	100.0%	100.0%	100.0%	100.0%	28.6%
18	76.2%	79.8%	93.8%	91.7%	92.7%	91.7%	28.6%
19	76.2%	14.3%	25.0%	0.0%	13.5%	0.0%	28.6%
20	47.6%	27.4%	25.0%	0.0%	14.6%	0.0%	28.6%
21	44.0%	28.6%	21.9%	0.0%	8.3%	0.0%	28.6%
22	29.8%	8.3%	8.3%	3.1%	0.0%	0.0%	28.6%
23	23.8%	0.0%	0.0%	2.1%	0.0%	0.0%	28.6%
24	14.3%	0.0%	0.0%	1.0%	0.0%	0.0%	14.3%

The savings for June 1st is presented in Figure 19. A summer month was chosen to show all monitored equipment. The savings were calculated using a combination of regression analyses and schedule data defined above. The DHW booster pumping is not a weather sensitive load but is related to occupancy and DHW usage. A weekly kW profile [Figure 56] was created from the monitored data and this profile is considered as "typical" for each week of the year.

Figure 56: Booster Pump Weekly/Hourly kW

DHWP Average kW							
Hour	Sun	Mon	Tue	Wed	Thu	Fri	Sat
1	0.39	0.39	0.18	0.23	0.48	0.40	0.30
2	0.20	0.29	0.13	0.21	0.27	0.33	0.32
3	0.19	0.36	0.17	0.28	0.25	0.38	0.29
4	0.21	0.25	0.23	0.22	0.25	0.41	0.43
5	0.23	0.85	0.26	0.31	0.27	0.40	0.39
6	0.59	1.55	2.00	1.96	1.98	1.98	0.79
7	0.22	1.63	1.88	2.05	1.84	1.73	1.53
8	0.25	1.71	1.90	2.07	2.00	1.89	1.29
9	0.86	1.74	1.94	2.15	2.09	1.92	1.41
10	1.10	1.78	2.11	2.13	2.16	2.06	1.71
11	0.48	1.80	2.07	2.16	2.16	2.07	1.87
12	0.55	1.82	2.16	2.15	2.27	2.19	1.99
13	0.64	2.02	2.28	2.13	2.17	2.25	1.97
14	1.27	1.78	2.26	2.18	2.19	2.30	1.93
15	1.24	1.68	2.22	2.17	2.17	2.28	0.97
16	1.15	1.68	2.15	2.11	2.13	2.19	1.14
17	1.35	1.64	2.17	2.14	2.08	2.18	0.86
18	2.02	1.57	2.00	1.98	1.94	1.86	1.16
19	1.70	0.85	0.93	0.79	1.05	0.75	1.00
20	1.25	1.23	0.90	0.65	0.77	0.99	0.98
21	1.26	1.73	0.63	0.83	0.66	0.53	1.07
22	1.12	0.60	0.68	0.66	1.23	0.49	1.16
23	1.10	0.27	0.28	0.33	1.30	0.63	0.88
24	0.62	0.33	0.34	0.38	0.60	0.53	0.53

Figure 57: Excerpt form 8,760 Calculation Spreadsheet

			Avg	8.2	8.0	1.2	75.7	71.1	3.7	62.0	28.1	12.9	10.9	105.9	11.2	106.9		
	81.0	95.0	Max	11.9	12.0	2.3	152.2	276.5	10.4	288.9	28.1	15.9	10.9	274.1	11.2	296.2	142.9	
	3.0	4.0	Min	0.0	0.0	0.1	0.0	0.0	0.0	0.1	0.0	0.0	10.9	0.0	0.0	10.9	7.2	
Totals			Totals	21,585	20,974	10,773	223,967	249,680	16,092	543,071	73,678	33,772	95,484	684,628	49,168	936,731	393,660	
	TMY 3 Temps			EVALUATION KW							BASELINE KW							
Date	OWB Temp	ODB Temp	Hour	CHWP	CWP	DHW Booster	Summer AHUs	Winter AHUs	HWP	Site Total kW	CHWP	CWP	DHW Booster	AHU	HWP	Total Tracking kW	Total kW Savings	
6/1/2011	57	61	1	0.0	0.0	0.23	0.0	0.0	0.0	0.2	0.0	0.0	10.9	0.0	0.0	10.9	10.7	
6/1/2011	54	57	2	0.0	0.0	0.21	0.0	0.0	0.0	0.2	0.0	0.0	10.9	0.0	0.0	10.9	10.7	
6/1/2011	51	54	3	0.0	0.0	0.28	0.0	0.0	0.0	0.3	0.0	0.0	10.9	0.0	0.0	10.9	10.6	
6/1/2011	47	50	4	0.0	0.0	0.22	0.0	0.0	0.0	0.2	0.0	0.0	10.9	0.0	0.0	10.9	10.7	
6/1/2011	48	49	5	0.0	0.0	0.31	54.7	0.0	0.0	55.0	0.0	0.0	10.9	105.9	0.0	116.8	61.8	
6/1/2011	48	49	6	10.1	9.5	1.96	71.9	0.0	0.0	93.5	28.1	12.8	10.9	139.3	0.0	191.1	97.6	
6/1/2011	48	49	7	11.0	10.4	2.05	71.9	0.0	0.0	95.4	28.1	12.8	10.9	139.3	0.0	191.1	95.7	
6/1/2011	48	49	8	11.0	10.4	2.07	71.9	0.0	0.0	95.4	28.1	12.8	10.9	139.3	0.0	191.1	95.7	
6/1/2011	49	50	9	11.1	10.4	2.15	74.5	0.0	0.0	98.2	28.1	12.8	10.9	139.3	0.0	191.1	92.9	
6/1/2011	49	51	10	11.1	10.4	2.13	74.5	0.0	0.0	98.1	28.1	12.8	10.9	139.3	0.0	191.1	93.0	
6/1/2011	51	54	11	11.1	10.5	2.16	79.7	0.0	0.0	103.5	28.1	12.8	10.9	139.3	0.0	191.1	87.6	
6/1/2011	52	55	12	11.1	10.6	2.15	82.3	0.0	0.0	106.2	28.1	12.8	10.9	139.3	0.0	191.1	84.9	
6/1/2011	53	56	13	11.2	10.6	2.13	84.9	0.0	0.0	108.8	28.1	12.8	10.9	139.3	0.0	191.1	82.3	
6/1/2011	52	54	14	11.1	10.6	2.18	82.3	0.0	0.0	106.2	28.1	12.8	10.9	139.3	0.0	191.1	84.9	
6/1/2011	51	54	15	11.1	10.5	2.17	79.7	0.0	0.0	103.5	28.1	12.8	10.9	139.3	0.0	191.1	87.6	
6/1/2011	51	53	16	11.1	10.5	2.11	79.7	0.0	0.0	103.5	28.1	12.8	10.9	139.3	0.0	191.1	87.6	
6/1/2011	50	52	17	11.1	10.5	2.14	77.1	0.0	0.0	100.8	28.1	12.8	10.9	139.3	0.0	191.1	90.3	
6/1/2011	50	52	18	10.2	9.6	1.98	70.7	0.0	0.0	92.4	28.1	12.8	10.9	127.7	0.0	179.5	87.1	
6/1/2011	49	51	19	0.0	0.0	0.79	0.0	0.0	0.0	0.8	0.0	0.0	10.9	0.0	0.0	10.9	10.1	
6/1/2011	50	51	20	0.0	0.0	0.65	0.0	0.0	0.0	0.7	0.0	0.0	10.9	0.0	0.0	10.9	10.2	
6/1/2011	50	51	21	0.0	0.0	0.83	0.0	0.0	0.0	0.8	0.0	0.0	10.9	0.0	0.0	10.9	10.1	
6/1/2011	51	52	22	0.0	0.0	0.66	2.5	0.0	0.0	3.1	0.0	0.0	10.9	4.4	0.0	15.3	12.1	
6/1/2011	51	52	23	0.0	0.0	0.33	1.7	0.0	0.0	2.0	0.0	0.0	10.9	2.9	0.0	13.8	11.8	
6/1/2011	52	53	24	0.0	0.0	0.38	0.9	0.0	0.0	1.2	0.0	0.0	10.9	1.5	0.0	12.4	11.1	

Regression analyses are performed to calculate the peak and non-peak cooling plant savings. The regression formulas are obtained from the trending scatter plots shown in Figure 15, Figure 16, and Figure 53. The regression analysis equations allows the calculation of hourly power based upon the TMY3 wet bulb temperature for that hour. Linear regressions were used when there was no correlation between wet bulb temperatures and monitored kW. Non-linear [polynomial] regressions were used for other measures. The regression formulas used are:

$$YLin = \left((X\ x\ Xvariable) + Int\right) x\ Season\ x\ \%Week$$

and

$$Ypoly = (X\text{^}2\ x\ X2variable) + (X\ x\ Xvariable) + Int)\ x\ Season\ x\ \%Week$$

Where:

Y_{Lin} = Hourly kW [linear regression]

Y_{poly} = Hourly kW [polynomial]

X = TMY3 hourly wet bulb temperature

$X2_{variable}$ = regression value for wet bulb temperature squared

$X_{variable}$ = regression value for wet bulb temperature

Int = regression formula intercept value

Season = Heating or cooling hour

%Week = Percent on hour-of-day/day-of-week from weekly profile

The base case assumptions outlined in Tables 2 through 7 were used to establish the base case kW's for each measure. Base case operating hours were determined from the power loggers and site visit data. Corresponding base case kW is applied to each monitored hour. No base case kW is applied to periods with no operation in the site monitored data.

On-Peak Energy and Demand Savings

The 8,760-hourly spreadsheet also calculates the on-peak and demand savings. Each on-peak hour is identified in the spreadsheet and the savings for all those hours and summed. The winter and summer demand periods are precisely defined in the calculation spreadsheet and the savings for those seasonal demand periods are identified and reported.

Evaluation Results

This project consists of two measures. Measure 1 installs variable speed drives on existing air handler unit supply fan motors and one exhaust fan motor. Measures 2 and 3 installs variable speed drives on existing chilled water pumps and condenser water pumps. Measure 4 installs VSDs on the existing HHW pumps and Measure 5 installs VSDs on existing DHW booster pumps. Table 26 summarizes the savings for the measures.

The total savings for this project from the TA study is 703,497 kWh. A data entry error was made when the savings were entered into the tracking savings database. The savings linked to the condenser water pumps were 9,277 kWh less than what was calculated in the TA report. Total tracking savings are 694,220 kWh per year. Table 26 provides the realization rates for the corrected and entered tracking energy savings.

VSDs - AHU Fans – Realization Rate 42.0%

The primary reason for the lower savings is reduced annual operation compared with the baseline assumptions. The tracking savings are calculated assuming 8,760 annual fan operating hours. Even though fan operation is continuous, occupied and unoccupied operating conditions are considered. The occupied period is 3,885 annual hours and the unoccupied period is 4,875 hours. However, the average unoccupied fan power is greater than during the occupied period.

Table 94: Fan Power

Period	Average Tracking kWh Baseline	Average Tracking kWh Installed
Occupied	143.3	83.8
Unoccupied	154.1	98.6

No explanations are provided indicating why the fans are operating continuously in the tracking scenarios or what conditions result in unoccupied loads being greater than occupied loads.

The power loggers identified an occupied period of 5:00 am through 6:00 pm on Mondays through Fridays and from 6:00 and through 3:00 pm on Saturdays. This 80 hour per week coincides with scheduling information provided by the site contacts. Monitoring also picked up incremental AHU operation on Sundays and after schedules hours. This coincides with additional occasional extended occupancy. Total annualized operation for the fans is 4,654 hours.

The maximum total tracking fan kW is 267.9 kW. This is a hard copy value without equations or variables explaining its origin. The average installed tracking kW is 92.1 kW. The average monitored power is 25.4 % lower at 73.4 kW. The higher average tracking value is likely do to the greater kW requirements during the unoccupied period.

VSDs - CHW Pumps – Realization Rate 63.5%

The tracking equations that calculated pump kW omitted the 0.746 kW/HP conversion factor. This increased the baseline kW by 31.7%. The tracking calculations estimated that annual operation was 1,670 occupied hours and 925 unoccupied hours for 2,595 total hours. Monitored operation is 1,892 annual hours. The evaluation calculations performed regression analyses using wet bulb temperatures to determine hourly pumping kW. The tracking calculations used an undefined load reduction percentage that was applied to fans and pumps. The monitored average installed pump kW is 34.4% greater than the average tracking installed kW [8.2 kW vs. 6.1 kW].

VSDs - CW Pumps – Realization Rate 58.0%

The same calculation omission and annual operation parameters discussed with the chilled water pumps apply to this measure. The tracking installed pumps average kW is 8.7 kW greater than the monitored average.

VSDs - HW Pumps – Realization Rate 103.3%

The heating equipment was not operating during the monitoring period and these pumps could not be monitored. The tracking data was used to estimate savings. The variances identified for the cooling pumps could not be inferred or applied to this heating application. Baseline operation was modelled using the tracking fixed pump kW. A regression equation was generated from the tracking installed data. The 3.3% increase in savings is attributed to the finer detail of the hourly approach compared with the bin analysis.

VSDs - DHW Booster Pump – Realization Rate 129.7%

This is a non-weather sensitive load. The tracking savings use 8,760 hours of annual operation. This was confirmed by the power loggers. The reason for the increased savings is the monitored pumps are using less power than predicted. Tracking installed power was estimated at 3.4 kW. Monitoring average power is 1.2 kW. Pump power increases with increased domestic hot water usage. The tracking documentation did not explain how DHW usage was estimated but it appears to be overestimated.

Table 95: Project Results by Measure.

Savings Measure	Tracking kWh	Evaluation Estimate	Realization Rate
VSDs - AHU Fans	502,115	210,981	42.0%
VSDs - CHW Pumps	82,002	52,093	63.5%
VSDs - CW Pumps	22,074	12,798	58.0%
VSDs - HW Pumps	32,015	33,076	103.3%
VSDs - DHW Booster Pump	65,291	84,711	129.7%
Corrected Total Savings	*703,497*	*393,660*	*56.0%*
Tracking Total Savings	694,220	393,660	56.7%

Table 34 shows the on-peak and demand savings. The evaluated on-peak savings is 16% greater than the tracking value. This is due to the reduction of total annual run hours of the AHUs during off-peak periods. The summer demand savings is 62% less than the tracking value and winter demand savings are 37% less than predicted. The evaluation demand savings are derived from the performance of the installed equipment compared to the baseline during the specified seasonal demand hours. The tracking savings are derived from a weather bin analysis that does not identify the performance at specific hours. The tracking savings are based upon the estimated percent reduction of total loads.

Table 96: On-Peak and Demand savings

Savings Quantity	Tracking Estimate	Evaluation Estimate	Realization Rate
% of Energy Savings On-Peak	50%	58%	116%
Summer On-Peak Demand (kW)	129.3	48.95	38%
Winter On-Peak Demand (kW)	65.0	41.2	63%

Comparison of Assumptions

The major parameters used to create and verify the savings for this measure are shown in Table 97. The primary parameters are annual operating hours, tracking baseline/installed maximum power, evaluation baseline/installed maximum power, tracking baseline/installed average power, and evaluation baseline/installed average power.

Table 97: Comparison of Key Parameters

Parameter	BASELINE		PROPOSED / INSTALLED	
	Tracking Value(s)	Evaluation Value(s)	Tracking Value(s)	Evaluation Value(s)
Annual AHU Hours	8,760	4,654	8,760	4,654
Average AHU kW	149.4	105.9	92.1	73.4
Maximum AHU kW	267.9	274.1	256.4	276.5
Annual CHWP Hours	2,595	1,892	2,595	1,892
Average CHWP kW	37.0	28.1	6.1	8.2
Maximum CHWP kW	37.0	28.1	17.8	11.9
Annual CWP Hours	2,595	1,892	2,595	1,892
Average CWP kW	17.2	12.9	8.7	8.0
Maximum CHWP kW	21.4	15.9	13.4	12.0
Annual HHWP Hours	3,989	4,390	3,989	4,390
Average HHWP kW	11.2	11.2	3.2	3.7
Maximum HHWP kW	11.2	11.2	10.4	10.4
Annual Booster Pump Hours	8,760	8,760	8,760	8,760
Average Booster Pump kW	10.9	10.9	3.4	1.2
Maximum Booster Pump kW	10.9	10.9	10.4	3.9

Improvement Opportunities

No improvement opportunities are noted at this time.

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