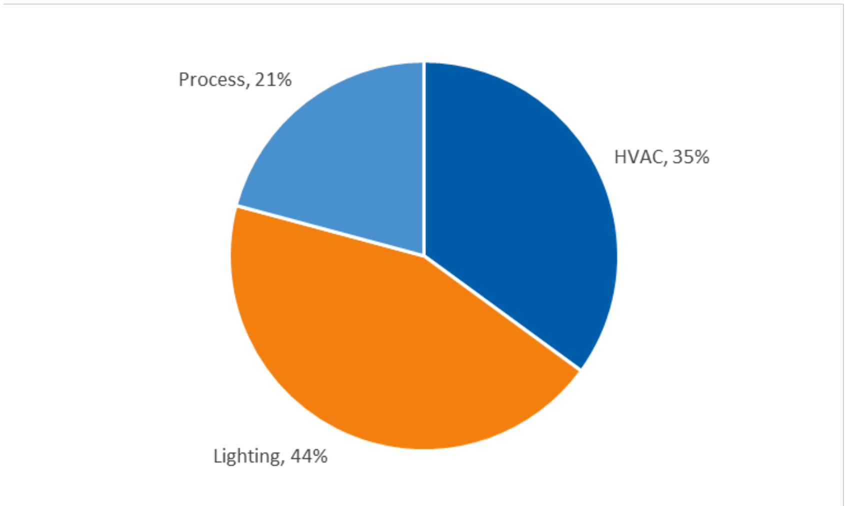
Figure 1. Expected Energy Savings by Project Type



n= 170,466,992 kWh

Summary of the Evaluation

For the impact evaluation, the team conducted a tracking system review, sample design and selection, engineering review of Custom Program applications, field M&V of selected projects, data analysis, and reporting.

Evaluation Objectives

The goal of the impact evaluation was to verify energy savings and calculate energy and demand realization rates for a sample of participants in each project type: lighting, HVAC, and process. The evaluation team estimated program-wide savings by applying the average realization rates to the evaluation period population by project type.

Researchable Issues

The evaluation team researched the following issues to complete this study:

- Energy, coincident peak, and non-coincident peak demand reduction for each sampled participant
- Causes for differences between evaluated savings and expected savings
- Energy and demand realization rates for each participant
- Average energy and demand realization rates for lighting, HVAC, and process participants, along with the associated confidence intervals

Methodology

Overview of the Evaluation Approach

Data Collection Methods, Sample Sizes, and Sampling Methodology

The evaluation team assigned participant applications to lighting, HVAC, and process categories. We then stratified all three categories by size and selected participants in each stratum either randomly (for smaller sites) or based on the magnitude of energy savings.

The evaluation team conducted M&V site visits at all sampled HVAC (n=6), lighting (n=16), and process (n=7) projects.

Study Methodology

The evaluation team prepared M&V plans for site visits following the options outlined by the International Performance Measurement and Verification Protocol (IPMVP).[1] We followed IPMVP Option A for all but two of the site M&V plans, which followed Option D. IPMVP Option A evaluates savings based on field measurement of key performance parameters, such as air compressor demand. The evaluation team estimates parameters that cannot be measured or are not selected for field measurement based on historical data, manufacturer's specifications, or engineering judgment. IPMVP Option D evaluated savings are determined through energy model simulations of the whole facility. The model must be calibrated to reflect actual energy use in the facility based on utility data. Option D is most useful when evaluating savings from interactive building systems.

We conducted site visits to verify measures, install metering equipment, and perform interviews about the pre-retrofit equipment and hours of operation with the site contacts. We used metered data or inputs collected on site to calculate evaluated energy savings and engineering analysis and statistical regression modeling for estimating demand reductions.

Number of Completes and Sample Disposition for Each Data Collection Effort

The evaluation team attempted to contact 32 program applicants. One program participant was concerned with the impact of site visits on business operations, one did not respond, and one agreed to be an alternate site. The team completed verifications of 29 projects across the three project types.

Expected and Achieved Precision

The evaluation team designed the sample to achieve 90% confidence with ±15% precision for the energy savings overall. The impact evaluation did not have a targeted precision for demand reduction.

Four of the 29 sampled projects were excluded from the energy saving realization rate and precision calculations as outliers: In one sampled project, DEC had calculated the savings using an incorrect

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[1] International Performance Measurement and Verification Protocol. *Concepts and Options for Determining Energy and Water Savings. Volume 1.* January 2012. EVO 10000 – 1:2012. www.evo-world.org.

baseline. Another sampled project was removed from the realization rate calculations due to insufficient data to calculate savings. Two other projects were statistical outliers among the sampled projects with realization rates that were either too high or too low.[2] We achieved 90% confidence with ±9% precision for energy saving based on the projects included in the energy saving realization rate calculations.

Description of Baseline Assumptions, Methods, and Data Sources

The evaluation team used the pre-retrofit equipment as a baseline for the saving calculations. We collected data on baseline equipment from the program incentive application documents and verified the equipment through interviews with the site contact or vendor. We used the post-retrofit schedules or industrial/occupancy demand to develop a pre-retrofit performance assessment equivalent to the post-retrofit conditions.

Use of Technical Reference Manual Values

We used primary data collection, engineering analysis, building energy simulation modeling, and linear regression modeling to calculate evaluated savings. To calculate savings for the sampled lighting participants, we used the saving algorithm outlined in the Indiana Technical Reference Manual for *Lighting Systems (Non-Controls) (Early Replacement, Retrofit),*[3] along with the energy and demand waste heat factors calculated in an earlier study of the Smart $aver Nonresidential Prescriptive Incentive Program.[4] We used the hours of operation data collected on site to estimate the peak demand coincidence factors.

Sample Design

Based on the categories identified in the DEC program tracking database, we grouped the participant applications into similar project types (lighting, HVAC, and process) to provide better accuracy in the overall program results for each category. We separated each technology category into energy savings size-based strata. The definitions for each of the savings size-based strata are provided in Table 7.

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[2] Statistical outliers are those projects that have realization rates more than two standard deviations above or less than two standards deviations below the statistical mean realization rate for all projects.

[3] Cadmus. *Indiana Technical Reference Manual Version 2.2.* Prepared for the Indiana Demand Side Management Coordination Committee EM&V Subcommittee. July 28, 2015.

[4] TecMarket Works. *Process and Impact Evaluation of the Non-Residential Smart $aver® Prescriptive Program in the Carolina System: Lighting and Occupancy Sensors*. April 2013.

Table 7. Stratum Definition Based on Expected Energy Savings

Group	Stratum	kWh Savings ≥
HVAC	1	3,000,000
	2	0
Lighting	1	2,000,000
	2	490,000
	3	0
Process	1	2,000,000
	2	0

We calculated the required sample size to meet our desired precision using the following equation, which incorporates the finite population correction:

$$n = \left[Z * \frac{CV}{P}\right]^2 * \sqrt{\frac{N-n}{N-1}}$$

Where:

n	=	Total sample size required
Z	=	z statistic (1.645 at 90% confidence)
CV	=	Coefficient of variation (defined as the mean divided by the standard deviation)
P	=	Desired precision
N	=	Population size

We allocated samples to each stratum using Neyman's Allocation, illustrated below:

$$n_k = n * \frac{N_k * CV_k * kWh_k}{\sum N_k * CV_k * kWh_k}$$

Where:

n_k	=	Total sample size required for stratum k
CV_k	=	Coefficient of variation for stratum k
kWh_k	=	Total expected savings for stratum k

Sample Status

The evaluation team pulled three sets of sampled applications, one for each phase. The original evaluation plan included projections for the number of program participants and expected energy savings during the evaluation period. The original evaluation sampling plan used an energy realization rate coefficient of variation for each technology type from a 2012 Custom Program evaluation in Ohio.[5] The team used data from the original evaluation plan and the 2012 Ohio Custom Program evaluation to determine the number of applications required to meet the targeted relative precision of ±15% at a 90% confidence level. The team pulled 19 applications for phases 1 and 2, based on this sampling plan.

Prior to selecting the remaining 10 sampled applications for phase 3, Cadmus revised the original sampling plan to incorporate the final number of program participants and expected energy savings during the evaluation period, along with the energy realization rate error ratios resulting from phase 1 and 2 verifications. We then selected the phase 3 verification sample in the lighting and HVAC strata that required additional sample points according to the updated sampling plan.

Table 8 summarizes the recommended and final phase 3 sample count based on Cadmus' update to the original sampling plan.

Table 8. Recommended and Achieved Sample Sizes Based on Phase 3 Sampling Plan Update

Group	Energy (kWh)	CV	Total Participants	Total Recommended Sample Size	Phase 1 and 2 Sampled Application Count	Phase 3 Final Sample Count	Total Evaluation Sample Count
HVAC 1	32,334,294	0.06	6	1	2	-	2
HVAC 2	27,406,066	0.50	35	5	1	3	4
Lighting 1	20,453,249	0.08	5	1	3	-	3
Lighting 2	27,447,709	0.97	31	8	2	4	6
Lighting 3	27,325,580	0.17	264	12	4	3	7
Process 1	21,080,433	0.22	5	1	2	-	2
Process 2	14,419,662	0.25	31	2	5	-	5
Total	**170,466,993**		**377**	**30**	**19**	**10**	**29**

[5] TecMarket Works. *Final Report Evaluation of the 2009 – 2011 Smart $aver Non-Residential Custom Incentive Program in Ohio*. Prepared for Duke Energy. September 2012.

Impact Evaluation Activities

This section includes a description of the review, M&V, and impact calculation activities performed for the selected sample of projects as part of this evaluation.

Documents Review

For all the sampled projects, the evaluation team performed a detailed review of program application documents, which included incentive applications, measure savings input and outputs from DSMore,[6] and supporting documentation or clarifications provided by the customer. We reviewed each application to gain an understanding of the measures included and the expected savings. We collected customer and contractor contact information, then decided on an appropriate M&V approach.

The DEC business relations manager or the key account managers associated with each sampled site contacted customers to secure their participation in the evaluation. Once they had established contact with the customer, the evaluation team followed up with the customer via phone calls and e-mails to gain additional information about the facility, installed measures, and operating schedule and procedures. We scheduled the site visits directly with the site contact.

Measurement and Verification Plan Development

The evaluation team developed an M&V plan for all 29 of the program participant applications we verified via site visits and metering. NORESCO developed M&V plans for phase 1 (as a subcontractor to TecMarket Works) and for phase 2 (as a subcontractor to Cadmus). Cadmus reviewed phase 2 plans and developed phase 3 M&V plans.

Each M&V plan covered the following topic areas:

- ***Introduction:*** a description of the project and the measures installed, including sufficient detail to understand the M&V project scope and methodology, proposed and DEC expected savings by measure, a list of M&V priorities for measures within the project, and baseline assumptions.
- ***Goals and objectives:*** a list of the overall goals and objectives of each M&V activity.
- ***Site location and contacts:*** the names, phone, email and address of site contacts.
- ***M&V option:*** a description of the IPMVP M&V Option appropriate for participant saving verification. We used Option A or Option D for each of the 29 projects verified on site.
- ***Field data points and survey plan:*** a list of specific field data points collected through the M&V plan, which included a combination of survey data, one-time measurements, and time series data collected from data loggers installed for the project or trend data collected from the site energy management system.

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6 DEC uses Demand Side Management Option Risk Evaluator (DSMore), a financial analysis tool, to estimate the costs, benefits, and risks associated with the Custom Program.

- ***Data accuracy:*** a list of meter and sensor accuracy for each field measurement point.
- ***Recording and data exchange format:*** specific values such as kWh savings, coincident and non-coincident kW savings, and therm savings and a list of raw and processed data to be supplied at the conclusion of the study.
- ***Verification and quality control:*** A list of steps taken to validate the accuracy and completeness of the raw field data.

From the M&V plans, the evaluation team created reports for each sampled project (provided in Appendix F. Site Measurement and Verification Reports – Full Customer Detail), which included the following additional topics:

- ***Data analysis:*** a list of the engineering methods and/or equations used to calculate the verified savings and a list of the data sources, which were either measured or stipulated values from secondary data sources.
- ***Conclusion:*** A summary of findings and the final realization rates, including an explanation for verified savings deviations from expected savings.

Measurement and Verification

Metering equipment included a combination of portable data acquisition equipment capable of measuring current and motor status, cellular data loggers capable of transmitting data remotely, true electric power meters, and trend logs from facility control systems. We also interviewed site personnel during meter installation, and configured the metering equipment to collect data for three weeks. Where available, we collected trend logs for one month or more.

Of the 29 sites metered, the evaluation team did not meter three HVAC projects that had permanent power meters on all controlled equipment. These were a data center, a hospital, and a large manufacturing facility. The participants' power meters recorded equipment-level demand (i.e., individual chiller, rooftop unit (RTU), and pumps). The evaluation team visited these sites (similar to others) to record equipment make and model, ensure that the trending periods were set up according to our verification schedules and requirements, and to review the sequence of operation with facility personnel.

For one lighting site, a meat processing plant, we could not install metering equipment due to operational requirements: the areas where lighting retrofits were installed were sprayed down for cleaning daily. Therefore, we inspected the lighting fixture data during our site visit and verified operation hours of use with the site contact.

At one process site, the voltage serving the equipment as listed in the application was greater than 480 volts, which is the maximum voltage we can meter. The evaluation team used the site's power meter, which collected M&V trend data points for the equipment included in the application.

This information is summarized in Table 15 in Appendix C. Sampled Participant Calculation Summary. Appendix F. Site Measurement and Verification Reports – Full Customer Detail describes the specific instrumentation used at each site.

Measurement and Verification Calculations

The evaluation team collected post-retrofit metered and trend data for the 29 verification site visit projects. The team analyzed the data according to the M&V plan developed for each project, except where on-site findings required changes to the original metering plan; for example, we could not install logging equipment due to high-voltage or operational limitations. To conduct data analysis, we compared the original application calculations to post-retrofit monitored data that we extrapolated to annual consumption and demand using simple engineering models or linear regression techniques (as described in the M&V plans).

Appendix C. Sampled Participant Calculation Summary provides a detailed list of all the projects where we conducted on-site visits and metering. This appendix includes a summary of the M&V plan approach, measurements taken, duration of measurement, and the calculations and analysis techniques used to estimate final impact savings and demand reduction results.

Appendix F. Site Measurement and Verification Reports – Full Customer Detail contains detailed site M&V calculations for each project.

Freeridership Calculations

[Redacted]

Table 9 shows the evaluated savings-weighted freeridership scores for 377 projects, along with the original calculated scores, by project type. The projects exhibited 12% freeridership overall across all project types. Spillover questions are not included in the program application. We did not calculate spillover for this program and assumed it to be 0%. We used the following net-to-gross calculation:

$$Net\_to\_Gross = 100\% - Freeridership + Spillover = 100\% - 12\% + 0\% = 88\%$$

Table 9. Custom Program Net-to-Gross Ratio

Project type	Number of Applicants with Calculated Freeridership Score	Energy Savings Weighted Freeridership Score	Net-to-Gross Ratio
HVAC	41	12%	88%
Lighting	300	7%	93%
Process	36	27%	73%
Total	**377**	**12%**	**88%**

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Impact Evaluation Results

This section provides the evaluation results, which includes annual energy, coincident peak and non-coincident peak demand reductions, and realization rates for each participant.

Annual Savings

Table 10 summarizes annual savings and realization rates (RR) calculated by project type for the evaluation period.

Table 10. Average Annual Gross Savings Realization Rate by Project Type

Project Type	Energy Savings (kWh)			NCP Savings (kW)			CP Savings (kW)		
	Evaluated	Expected	RR	Evaluated	Expected	RR	Evaluated	Expected	RR
HVAC	35,377,874	59,740,357	59%	6,452	11,327	57%	4,713	5,537	85%
Lighting	74,888,145	75,226,538	100%	8,020	9,167	87%	12,303	11,897	103%
Process	27,237,074	35,500,097	77%	4,748	5,052	94%	4,533	4,738	96%
Total	**137,503,094**	**170,466,992**	**81%**	**19,220**	**25,546**	**75%**	**21,550**	**22,172**	**97%**

The evaluation achieved ±9% relative precision at the 90% confidence interval for the energy saving realization rate analysis. We excluded a total of four applications from the energy realization rate analysis:

- Two lighting applications had very low and very high energy realization rates (-11% and 234%) indicating that they were outliers.[7]
- For another lighting application, our evaluated baseline was starkly different from the baseline DEC used in the application saving calculations. The project was part of a major retrofit to change the space usage from a fabric weaving space to a furniture warehouse. The evaluation team excluded this application due to the exceptional circumstances that affected its energy saving and demand reduction realization rates.
- We excluded one HVAC application sampled due to insufficient data available to calculate verified savings.

The evaluation achieved ±21% relative precision at the 90% confidence interval for the non-coincident peak demand reduction realization rate analysis. We excluded four applications from the non-coincident peak realization rate analysis:

- One lighting application had a very high (918%) non-coincident peak demand reduction realization rate indicating that it was an outlier.

[7] Statistical outliers are those projects that have realization rates more than two standard deviations above or less than two standards deviations below the statistical mean realization rate for all projects.

- We excluded one lighting application sampled from the demand reduction realization rate analysis (similar to the energy saving realization rate analysis), due to the exceptional circumstances that affected its energy saving and demand reduction realization rates.
- One HVAC application was excluded since we attributed its very low non-coincident peak demand reduction realization rate (1%) to a clerical error in DEC's recording of the expected reduction.
- We did not have sufficient data for another HVAC application sampled to calculate verified savings.

The evaluation achieved ±16% relative precision at the 90% confidence interval for the coincident peak demand reduction realization rate analysis. We excluded three applications from the coincident peak demand reduction calculations:

- One HVAC application had a very high realization rate (222%), which indicated it was an outlier.
- We excluded one lighting application sampled from the demand reduction realization rate analysis (similar to the energy saving realization rate analysis), since our evaluated baseline was starkly different from the baseline DEC used in the application saving calculations.
- We did not have sufficient data for one HVAC application sampled to calculate verified savings.

Two other lighting applications sampled had no expected coincident peak demand reduction.

Table 11 through Table 13 list the estimated precision for energy, non-coincident peak demand, and coincident peak demand realization rates, respectively, at 90% confidence. We combined the planned HVAC 1 and HVAC 2 strata into one HVAC stratum for the final realization rate calculations.

Table 11. Energy Savings Realization Rates to Achieve Sampling Precision at 90% Confidence

Stratum	Population Size	Sample Size*	Actual Sample Error Ratio	Relative Precision
HVAC	41	4	0.28	33%
Lighting 1	5	3	0.08	13%
Lighting 2	31	5	0.29	28%
Lighting 3	264	6	0.28	23%
Process 1	5	2	0.27	123%
Process 2	31	5	0.24	23%
Total	**377**	**25**	**0.27**	**9%**

* The evaluation team excluded four sampled applications from the precision analysis as described above.

Table 12. Non-Coincident Peak Realization Rates to Achieve Sampling Precision at 90% Confidence

Stratum	Population Size	Sample Size*	Actual Sample Error Ratio	Relative Precision
HVAC	40	4	0.31	36%
Lighting 1	25	8	0.26	18%
Lighting 2	36	3	0.08	14%
Lighting 3	239	3	3.60	606%
Process 1	22	4	0.79	93%
Process 2	14	3	0.23	39%
Total	**376**	**25**	**0.60**	**21%**

* The evaluation team excluded four sampled applications from the precision analysis as described in detail above.

Table 13. Coincident Peak Realization Rates to Achieve Sampling Precision at 90% Confidence

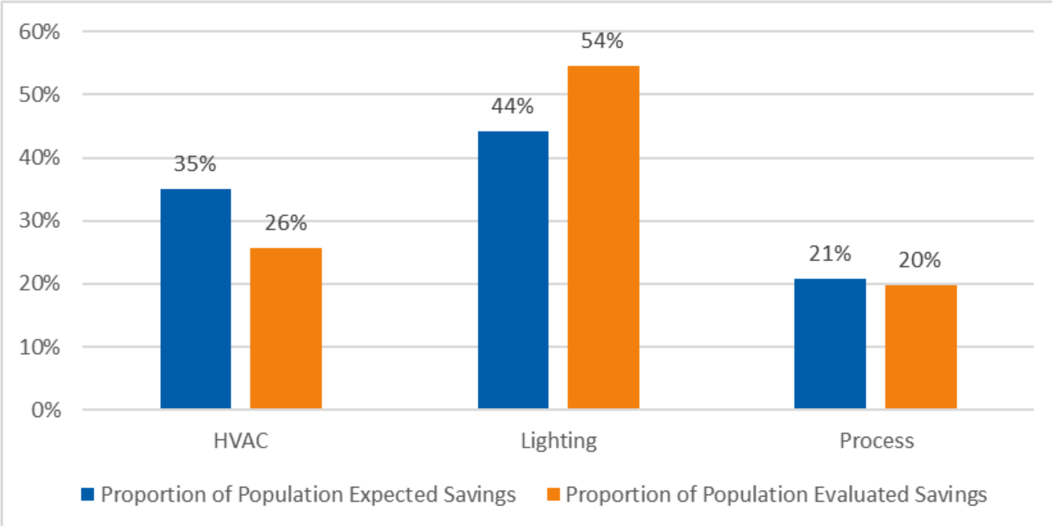
Stratum	Population Size	Sample Size*	Actual Sample Error Ratio	Relative Precision
HVAC	39	4	0.32	38%
Lighting 1	25	8	0.28	19%
Lighting 2	36	3	0.13	23%
Lighting 3	204	2	0.16	73%
Process 1	22	4	0.80	94%
Process 2	14	3	0.12	20%
Total	**340**	**24**	**0.46**	**16%**

* The evaluation team excluded three sampled applications from the precision analysis as described in detail above.

Findings

Figure 2 shows the breakdown of evaluated energy savings by project type compared to expected energy savings. Lighting projects contributed the most to the verified total program savings (54%), followed by HVAC project (26%) and process projects (20%).

Figure 2. Contribution of Expected* and Evaluated Energy Savings by Project Type**



*Expected energy savings are 170,466,992 kWh.
** Evaluated energy savings are 137,503,094 kWh.

The evaluation team's summary of findings are provided below and described in detail in Table 17 in Appendix D. Sampled Participant Detailed Results. The overall energy realization rate across all projects was 81%. The team found large variations between evaluated and expected savings in all three strata. Specific examples are provided by project type below.

HVAC

The average realization rate of HVAC projects is 59%, and these projects contributed 26% of the program evaluated savings. These projects included HVAC controls upgrades and retrofits, installation of variable frequency drives (VFDs), and installation of new high-performance HVAC systems.

Low realization rates were generally caused by control strategies that either did not perform as planned or were not fully implemented. In a few cases, the team determined that the evaluated loads were less than those originally expected in the application savings calculations. In one of the sampled applications, submitted for a high-performance HVAC system in a new data center, the expected energy savings and demand reduction would have been fully realized if all data center server racks were filled and the data center had reached design capacity. However, the project's current evaluated HVAC load (which is directly correlated with the server rack load in the data center) is only 17% of the full design load, and the site contact does not anticipate reaching full data center capacity for five to seven years. For this project, the evaluation team calculated projected energy savings and demand reduction at an assumed load growth period of seven years from the date of the evaluation. We calculated the present value savings and demand reduction using an assumed annual discount rate of 7.09%.[8] The overall projected

[8] This value is the weighted average cost of capital for North Carolina cost effectiveness tests according to DEC.

seven-year energy savings realization rate was 69% and the summer peak demand realization rate was 59%.

Lighting

Lighting projects, on average, had the highest realization rate (100%) and they contributed half of the evaluated program savings (54%).

Variations between evaluated and expected savings were due to differences between the expected lighting hours of use and those verified through site surveys and logging. Additionally, HVAC interactive effects were not included in the application saving calculations.

In one application, the lighting retrofits were part of a major retrofit to change the building's primary functional use from fabric weaving to a furniture warehouse. The project application savings calculations claimed savings resulting from the lighting retrofit, without taking the change in light levels into account. The evaluation team adjusted the pre-retrofit baseline lighting energy use based on the post-retrofit light level requirements and calculated the savings based on equivalent pre- and post-retrofit lighting levels. This resulted in 17% energy savings, 14% coincident peak demand reduction, and 28% non-coincident peak demand reduction realization rates. As noted previously under Annual Savings, the team did not include this project in the program realization rate calculations.

For major retrofit projects such as this, the expected savings should account for the changes in space usage and required light levels. The pre-retrofit baseline lighting system design lumen output in such cases can be adjusted to match the installed lighting design lumen output. Alternatively, the baseline lighting power density can be based on the prevalent building energy code's lighting power density requirement for the new space type, if the energy code is triggered by the retrofit.

Process

Process projects, on average, had a 77% energy realization rate and contributed 20% to the evaluated program energy savings. Only one project had an energy realization rate of less than 80%. The team's evaluation review of this air compressor retrofit project revealed that the application savings analysis contained a few minor errors that greatly impacted the energy use calculations. For example, the performance datasheet submitted as part of the application did not include site-specific inputs, and the post-retrofit installed air compressor energy performance was only slightly better than the performance of pre-retrofit air compressors. Additionally, the pre-retrofit documentation claimed having metered power, while the contractor had only metered the current in one of the three phases, then converted this to power. Also, there was no permanent airflow monitoring on the pre-retrofit or installed air compressors. It is difficult to accurately monitor airflow using a temporary meter, and it is recommended to install a permanent monitoring station. Without the airflow load profile, the team could not calculate the actual plant compressed air load. We based our evaluation calculations on trended power demand provided by the site, equipment performance data, and our best engineering judgement; this resulted in a 53% energy realization rate and 56% coincident peak demand realization rate.

Conclusions and Recommendations

The evaluation team offers the following conclusions and recommendations resulting from our Custom Program evaluation.

- **Conclusion:** Low realization rates caused by sub-optimal or incomplete control strategies indicate that post-retrofit inspections or project commissioning may be effective strategies for realizing the full energy savings available from HVAC control measures.
  - **Recommendation:** Where possible, require post-retrofit commissioning for HVAC projects to realize the full potential of retrofit savings.
- **Conclusion:** Significant permanent changes in occupancy rate or space usage from the pre-retrofit conditions need to be accounted for in the lighting saving calculation baseline.
  - **Recommendation:** For major retrofit projects, calculate the expected savings accounting for any changes in space usage and required light levels.
- **Conclusion:** Projects with completion schedules or periods of load growth longer than one to two years will not be completed in time to be evaluated.
  - **Recommendation:** Calculate savings for projects with longer than one to two-year completion or load growth schedules based on their present value.
- **Conclusion:** HVAC interactive effects were not included in the application saving calculations for lighting projects.
  - **Recommendation:** Include HVAC interactive effects in lighting project expected saving calculations.
- **Conclusion:** DEC can improve the accuracy of its expected saving calculations for process projects by ensuring that pre-retrofit energy use calculations are based on accurate power metered data and the specific industrial process load monitoring points.
  - **Recommendation:** Where feasible, consider using pre- and post-retrofit power measurements and collecting coincident industrial process load data to arrive at accurate realized savings.
  - **Recommendation:** Require permanent airflow monitoring devices be installed on all large (greater than 400 horsepower) compressed air system retrofits to establish accurate pre- and post-retrofit load profiles.

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Appendix A. Summary Form

DUKE ENERGY

Smart $aver Custom Incentive Program

Duke Energy Carolinas
Completed EMV Fact Sheet
2016 Evaluation – Cadmus

Program Description

The Duke Energy Smart $aver Custom Incentive Program supplements the Smart $aver Prescriptive Incentive Program, which provides prescriptive rebates for preselected measures. Customers wishing to install measures not included in the Smart $aver Prescriptive Incentive Program list may apply for a rebate through the Custom Program. Participation requires a pre-approval from the program before measure installation.

Date	February 3, 2017
Region(s)	Carolinas
Evaluation Period	Applications Paid from January 2013 through December 2015
Gross Energy Savings (kWh)	137,503,094
Net Coincident kW Impact (Summer)	18,899
Measure life	Various
Net Energy Savings (kWh)	120,661,569
Process Evaluation	Yes, reported separately.
Previous Evaluation(s)	Yes 2013

Evaluation Methodology

The evaluation team conducted the impact evaluation based on measurement and verification of a sample of 29 participants in HVAC, lighting and process project types. The evaluation team estimated average energy saving and demand reduction realization rates for each project category and projected them onto the full program participant population.

Impact Evaluation Details

- The overall energy realization rate across all projects was 81%.
- Lighting projects achieved the highest energy savings as compared to program estimates (realization rate of 100%), whereas HVAC projects achieved the lowest energy savings as compared to program estimates (realization rate of 59%). Industrial process projects had a 77% energy saving realization rate.
- Twelve percent of the evaluated program savings are associated with freeriders. Spillover was not included in the scope of the evaluation as it was expected to be minimal. Therefore, the program net-to-gross ratio is 88%.
- Lighting participants produced 54% of total program evaluated energy savings. HVAC and process participants produced 26% and 20% of the total program evaluated energy savings respectively.

Appendix B. Required Savings Table

The DEC-required summary parameters resulting from this evaluation are provided in Table 14.

Table 14. DEC-Required Program Evaluation Summary

Measure Name	Gross kWh RR	NCP kW RR	CP kW RR	Effective Useful Life	Net-to-Gross Ratio
Custom	81%	75%	97%	Custom	88%

Appendix C. Sampled Participant Calculation Summary

Table 15 includes a summary of the evaluation team's M&V approach, measurements taken, and calculations performed for each M&V participant sampled for this evaluation.

Table 15. Measurement and Verification and Impact Calculation Approach Summary

Site ID	Participant	Project Type	M&V Plan Summary	Measurements Taken	Monitoring Duration	Calculations
1	[Redacted]	HVAC	IPMVP Option D	Collected voltage, average current (Amps), average power (kW), and power factor for sampled air-handling unit/heat pump fans and compressors Collected supply air temperature, mixed air temperature, return air temperature, outside air temperature for sampled air-handling unit/heat pumps	Three weeks	Comparison of pre- and post-retrofit models calibrated based on equipment monitoring data
2	[Redacted]	Lighting	IPMVP Option A	Monitored lighting fixture operating hours in data suites, hallways, and office areas	Three weeks	Engineering equations with parameters from metered data
3	[Redacted]	Lighting	IPMVP Option A	Monitored light circuits affected by the retrofit	Three weeks	Engineering equations with parameters from metered data
4	[Redacted]	Process	IPMVP Option A	Collected voltage, average (Amps), average power (kW), and power factor for four aeration blower motors	Three weeks	Engineering equations with parameters from metered data
5	[Redacted]	Process	IPMVP Option A	Collected voltage, average (Amps), average power (kW), and power factor for three air compressors	Two weeks	Engineering equations with parameters from metered data

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Site ID	Participant	Project Type	M&V Plan Summary	Measurements Taken	Monitoring Duration	Calculations
6	[Redacted]	HVAC	IPMVP Option A	Collected trend data for chiller demand (kW), flow rate, supply and return temperatures, condenser water pump and chilled water pump demand (kW), cooling tower entering and leaving water temperatures and fan input demand (kW), and coincident outside air conditions (from the site metering system)	One year	Hourly model with typical meteorological year (TMY3) temperature data and parameters from trend data
7	[Redacted]	Lighting	IPMVP Option A	Monitored light circuits affected by the retrofit	Three weeks	Engineering equations with parameters from metered data
8	[Redacted]	Process	IPMVP Option A	Collected voltage, average current (Amps), average power (kW), and power factor for one 500-ton injection molding machine	Two weeks	Engineering equations with parameters from metered data
9	[Redacted]	Lighting	IPMVP Option A	Monitored lighting fixture operating hours in retail spaces	Three weeks	Engineering equations with parameters from metered data
10	[Redacted]	Lighting	IPMVP Option A	Monitored lighting fixture operating hours in warehouse and shop	Two weeks	Engineering equations with parameters from metered data
11	[Redacted]	HVAC	IPMVP Option A	Collected voltage, average current (Amps), average power (kW), and power factor for sampled RTUs Collected outside air temperature and relative humidity, supply air temperature, mixed air temperature, return air temperature, and supply fan current for sampled RTUs	Three weeks	Regression analysis of monitored data and environmental measurements
12	[Redacted]	HVAC	IPMVP Option A	Collected trend data for total input demand (kW) for 17 RTUs (out of 18), zone temperature for 11 RTUs, discharge and return air temperature for six RTUs, cooling status for seven RTUs, and outside air damper position for eight RTUs (all collected by the site metering system)	One month	Hourly model with TMY3 temperature data and parameters from trend data

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Site ID	Participant	Project Type	M&V Plan Summary	Measurements Taken	Monitoring Duration	Calculations
13	[Redacted]	Lighting	IPMVP Option A	Collected voltage, average current (Amps), average power (kW), and power factor for one lighting circuit	Two weeks	Engineering equations with parameters from metered data
14	[Redacted]	Lighting	IPMVP Option A	Monitored lighting fixture operating hours in retail area	Two weeks	Engineering equations with parameters from metered data
15	[Redacted]	Lighting	IPMVP Option A	None (refrigerated spaces were sprayed down every day)	-	Engineering equations with updated fixture counts from site visit
16	[Redacted]	Lighting	IPMVP Option A	Monitored lighting fixture operating hours in offices, common areas, and parking garage	Three weeks	Engineering equations with parameters from metered data
17	[Redacted]	Lighting	IPMVP Option A	Monitored lighting fixture operating hours in warehouse and storage areas	Three weeks	Engineering equations with parameters from metered data
18	[Redacted]	Lighting	IPMVP Option A	Monitored lighting fixture operating hours in retail spaces	Two weeks	Engineering equations with parameters from metered data
19	[Redacted]	Lighting	IPMVP Option A	Monitored lighting fixture operating hours in office spaces	Three weeks	Engineering equations with parameters from metered data
20	[Redacted]	Lighting	IPMVP Option A	Monitored lighting fixture operating hours in offices, warehouse, and bulk storage areas	Three weeks	Engineering equations with parameters from metered data
21	[Redacted]	Lighting	IPMVP Option A	Monitored lighting fixture operating hours in offices and warehouse	Two weeks	Engineering equations with parameters from metered data
22	[Redacted]	Process	IPMVP Option A	Collected true electric power logging of the new injection molding machine	Three weeks	Engineering equations with parameters from metered data
23	[Redacted]	Process	IPMVP Option A	Collected voltage, average current (Amps), average power (kW), and power factor for the VFD air compressor	Two weeks	Engineering equations with parameters from metered data

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Site ID	Participant	Project Type	M&V Plan Summary	Measurements Taken	Monitoring Duration	Calculations
24	[Redacted]	HVAC	IPMVP Option A	Collected trend data for chiller flow rate, supply and return temperature, and input demand (kW) Collected chilled water and condenser water pump demand and speed, cooling tower fan demand and speed, and coincident outside air conditions (all collected by the site metering system).	Six months to one year (depending on trending data point)	Hourly model with TMY3 temperature data and parameters from trend data
25	[Redacted]	Process	IPMVP Option A	Collected voltage, average current (Amps), average power (kW), and power factor for VFD air compressor, two air dryers, and two cooling tower pumps. Collected trend data of total input power (kW) for two 900-hp air compressors (trended on site metering equipment)	Two weeks	Engineering equations with parameters from metered data
26	[Redacted]	Lighting	IPMVP Option A	Monitored light circuits affected by the retrofit (64 loggers total)	Three weeks	Engineering equations with parameters from metered data
27	[Redacted]	Process	IPMVP Option A	Collected voltage, average current (Amps), average power (kW), and power factor for VFD air compressor Collected spot measurements of airflow and temperature for heat recovery duct	Two weeks	Engineering equations with parameters from metered data

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Site ID	Participant	Project Type	M&V Plan Summary	Measurements Taken	Monitoring Duration	Calculations
28	[Redacted]	HVAC	IPMVP Options A and D	Collected billing data (monthly kWh and demand) for January 2011 to the present and confirmed trending capability in the energy management System Monitored the operation of supply fans, compressors, economizers, chilled water pumps, carbon dioxide levels, and outdoor air temperature and relative humidity for a sample of buildings	Three weeks	Comparison of pre- and post-retrofit models calibrated based on building/equipment monitoring data
29	[Redacted]	Lighting	IPMVP Option A	Monitored lighting fixture operating hours in offices, manufacturing, and warehouse areas	Three weeks	Engineering equations with parameters from metered data

Appendix D. Sampled Participant Detailed Results

Table 16 lists the average annual realization rates by project type for the sampled participants. Table 17 lists a summary of the specific findings from each project in the sample. Highlighted cells signify calculated or otherwise determined to be outliers for energy, coincident peak or non-coincident peak demand realization rate analyses.

Table 16. Gross Savings and Realization Rate Results by Sampled Participant

Site	Participant*	Project Type	kWh Savings			NCP kW Savings			CP kW Savings		
			Expected	Evaluated	RR	Expected	Evaluated	RR	Expected	Evaluated	RR
1	[Redacted]	HVAC	12,700	29,757	234%	29.20	28.70	98%	28.67	24.80	87%
2	[Redacted]	Lighting	1,454,592	1,523,258	105%	165.96	173.89	105%	166.05	273.15	164%
3	[Redacted]	Lighting	31,575	21,504	68%	10.40	9.50	91%	10.40	9.50	91%
4	[Redacted]	Process	2,885,315	2,670,198	93%	329.22	656.30	199%	329.40	673.60	204%
5	[Redacted]	Process	1,239,992	994,346	80%	141.47	113.50	80%	141.55	99.00	70%
6	[Redacted]	HVAC	2,618,060	2,444,156	93%	511.51	279.01	55%	416.96	414.26	99%
7	[Redacted]	Lighting	1,625,075	2,056,890	127%	185.41	247.80	134%	185.52	243.10	131%
8	[Redacted]	Process	135,308	131,758	97%	22.12	15.00	68%	22.12	20.80	94%
9	[Redacted]	Lighting	1,734,359	1,696,851	98%	106.56	193.70	182%	486.00	606.56	125%
10	[Redacted]	Lighting	1,412,989	715,665	51%	98.65	310.40	315%	310.35	55.90	18%
11	[Redacted]	HVAC	6,299,172	3,187,362	51%	1,339.50	11.30	1%	10.80	11.30	105%
12	[Redacted]	HVAC	1,909,006	812,169	43%	122.70	92.71	76%	2.45	4.87	199%
13	[Redacted]	Lighting	2,369,488	2,633,883	111%	32.75	300.67	918%	-	-	N/A
14	[Redacted]	Lighting	337,186	372,877	111%	55.82	68.50	123%	55.82	68.50	123%
15	[Redacted]	Lighting	490,520	578,518	118%	55.97	66.00	118%	56.00	66.00	118%
16	[Redacted]	Lighting	1,476,280	1,025,314	69%	156.10	117.04	75%	240.88	267.41	111%
17	[Redacted]	Lighting	1,396,127	235,845	17%	96.05	26.92	28%	398.28	57.56	14%
18	[Redacted]	Lighting	21,696	13,602	63%	4.68	5.30	113%	4.68	3.20	68%
19	[Redacted]	Lighting	469,064	(51,361)	-11%	39.11	(5.86)	-15%	-	-	N/A
20	[Redacted]	Lighting	488,514	359,800	74%	38.38	41.07	107%	160.89	80.60	50%
21	[Redacted]	Lighting	2,812,620	3,188,437	113%	361.26	437.90	121%	361.42	399.00	110%

Site	Participant*	Project Type	kWh Savings			NCP kW Savings			CP kW Savings		
			Expected	Evaluated	RR	Expected	Evaluated	RR	Expected	Evaluated	RR
22	[Redacted]	Process	402,674	412,822	103%	35.90	36.30	101%	47.55	36.30	76%
23	[Redacted]	Process	142,073	123,252	87%	20.80	14.10	68%	20.80	19.40	93%
24	[Redacted]	HVAC	2,914,790	1,996,787	69%	253.20	227.97	90%	233.67	137.09	59%
25	[Redacted]	Process	7,087,680	3,770,573	53%	809.13	430.43	53%	775.46	430.43	56%
26	[Redacted]	Lighting	7,901,837	7,360,561	93%	901.55	959.96	106%	902.05	917.10	102%
27	[Redacted]	Process	494,116	618,587	125%	69.69	78.30	112%	55.71	53.00	95%
28	[Redacted]	HVAC	4,602,694	2,104,233	46%	689.00	309.00	45%	414.35	921.00	222%
29	[Redacted]	Lighting	472,663	627,232	133%	68.31	71.60	105%	76.46	114.45	150%

* Note that participant names will be redacted in the public version of the report.

Highlighted cells signify applications calculated or otherwise determined to be outliers for energy, coincident peak or non-coincident peak demand realization rate analyses.

Table 17. Findings Summary by Sampled Participant

Site	Participant*	Project Type	kWh RR	CP RR	Findings Summary
1	[Redacted]	HVAC	234%	87%	The application calculations had underestimated the savings. Though the evaluated energy savings were greater than initially estimated, the reduction in energy use amounted to less than 2% of the building's annual energy consumption.
2	[Redacted]	Lighting	105%	164%	The evaluated energy savings and demand reduction were close to those originally estimated. One of the installed fixture types had a higher input wattage than expected, but the operating hours with controls were less than expected.
3	[Redacted]	Lighting	68%	91%	While the demand reduction realization rates were close to 100%, the hours of use were not accurately estimated in the application saving calculations, resulting in a reduction in energy savings compared to expected savings.
4	[Redacted]	Process	93%	204%	The evaluated energy savings were close to those expected, and the evaluated demand reduction was close to those proposed in the program participation application (but more than the savings expected by DEC).
5	[Redacted]	Process	80%	70%	The evaluated energy savings were less than those expected because the average metered demand for the compressed air system was 10% higher than expected.

Site	Participant*	Project Type	kWh RR	CP RR	Findings Summary
6	[Redacted]	HVAC	93%	99%	The evaluated energy savings were less than originally estimated because the cooling tower fans use more energy than the pre-retrofit case (to provide more area for heat transfer).
7	[Redacted]	Lighting	127%	131%	HVAC interactive effects were not included in the projected and expected saving estimates.
8	[Redacted]	Process	97%	94%	The evaluated energy savings and peak demand reduction were close to those expected because the metered demand data closely matched data collected for the application saving calculations.
9	[Redacted]	Lighting	98%	125%	HVAC interactive effects were not included in the projected and expected saving estimates.
10	[Redacted]	Lighting	51%	18%	The evaluated energy savings were less than those expected because the metered lighting fixture operating hours were less than expected. The peak demand reduction is less than expected because the metered data revealed that the lighting fixtures only operate during a portion of the peak coincident period.
11	[Redacted]	HVAC	51%	105%	The evaluated energy savings realization rates are low due to the fact that many of the monitored units showed no signs of economizing during the logging period. There is an apparent clerical error in the reported non-coincident peak expected demand reduction in the DEC program tracking database, which is much higher than the coincident peak expected savings.
12	[Redacted]	HVAC	43%	199%	The project contacts provided trend data for month of July only and did not permit third party metering. The trend data did not indicate economizer operation, but July is not typically an economizer month. Due to lack of data during economizer season, project was removed from sample.
13	[Redacted]	Lighting	111%	N/A	The evaluated energy savings and demand reduction were higher than expected due to higher operating hours, and because the metered input wattage for one of the fixture types was 5% less than expected in the original study.
14	[Redacted]	Lighting	111%	123%	The evaluated energy savings and demand reduction were higher than originally estimated because HVAC interactive effects were not included in the original savings estimates.

Site	Participant*	Project Type	kWh RR	CP RR	Findings Summary
15	[Redacted]	Lighting	118%	118%	The evaluated energy savings and demand reduction were higher than originally estimated because refrigeration system interactive effects were not included in the original savings estimates.
16	[Redacted]	Lighting	69%	111%	The evaluated energy savings were less than originally estimated due to a decrease in projected annual operating hours based on metered data.
17	[Redacted]	Lighting	17%	14%	The evaluated energy savings and peak demand reduction were less than originally estimated due to an inappropriate baseline that was used in the original analysis.
18	[Redacted]	Lighting	63%	68%	The evaluated energy savings and peak demand reduction were less than originally estimated due to a decrease in projected annual operating hours based on metered data.
19	[Redacted]	Lighting	-11%	N/A	The evaluation resulted in an energy penalty because there were more fixtures on emergency circuits than expected, fewer exterior parking lot pole fixtures than expected, higher operating hours for exterior fixtures than expected, and less aggressive zone control schedules than the pre-retrofit system.
20	[Redacted]	Lighting	74%	50%	The evaluated energy savings and peak demand reduction were less than originally estimated because the projected annual operating hours are 26% less than expected based on the metered data.
21	[Redacted]	Lighting	113%	110%	The evaluated energy savings and demand reduction were higher than expected due to higher operating hours than expected.
22	[Redacted]	Process	103%	76%	The evaluated savings were very close to expected savings, while coincident peak demand reduction fell slightly short of the estimate due to the molding machine's metered operating kW being higher than originally estimated.
23	[Redacted]	Process	87%	93%	The evaluated energy savings and demand reduction were less than originally estimated due to fewer annual operating hours than originally expected.
24	[Redacted]	HVAC	69%	59%	The evaluated energy savings and demand reduction were less than originally estimated because the original analysis did not account for load growth. The data center will not reach full capacity for a few years. The evaluation team accounted for the present value energy savings and demand reduction at full capacity by factoring in a discount rate of 7.09%.

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Site	Participant*	Project Type	kWh RR	CP RR	Findings Summary
25	[Redacted]	Process	53%	56%	The evaluated energy savings and peak demand reduction were less than originally estimated because the installed compressors have a lower performance than originally expected, and the original analysis contained minor errors that had a significant impact on overall savings.
26	[Redacted]	Lighting	93%	102%	The evaluated savings were very close to expected savings.
27	[Redacted]	Process	125%	95%	The evaluated energy savings were higher than originally estimated because the average metered demand was 18% less than expected. The peak demand reduction was slightly less than expected in the original study.
28	[Redacted]	HVAC	46%	222%	The low energy realization rate is mostly due to the fact that the controls energy conservation measure (ECM), which most buildings implemented, does not operate as anticipated to reduce energy use. The high coincident peak demand realization rate is mainly due to the fact that the demand reduction from the VFD ECM is much higher than projected. Typically, a VFD is not expected to reduce peak demand; however, in this case, the air handling unit supply fans appear to be significantly oversized. Even during peak cooling conditions, the fans only need to run at around 60% of full speed. As a result, the peak demand reduction is considerably higher than would normally be expected for the VFD ECM.
29	[Redacted]	Lighting	133%	150%	The evaluated energy savings and demand reduction were higher than originally estimated because the input wattages for the installed fixtures are lower than expected and the original analysis did not account for HVAC interactive effects.

* Note that participant names will be redacted in the public version of the report.

Highlighted cells signify applications calculated or otherwise determined to be outliers for energy, coincident peak or non-coincident peak demand realization rate analyses.

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Appendix E. Freeridership Questions

[Redacted]

Appendix F. Site Measurement and Verification Reports – Full Customer Detail

Application ID 13-1586579 DDC Control Retrofit M&V Report

Prepared for
Duke Energy Carolinas

January 2015, Version 1.0
(revised August 19, 2016)

Note: This project has been randomly selected from the list of applications for which incentive agreements have been authorized under Duke Energy's Smart $aver® Custom Incentive Program.

The M&V activities described here are undertaken by an independent third-party evaluator of the Smart $aver® Custom Incentive Program.

Findings and conclusions of these activities shall have absolutely no impact on the agreed upon incentive between Duke Energy and [redacted].

Submitted by:

Rob Slowinski
NORESCO, Inc.

Stuart Waterbury
NORESCO, Inc.

2540 Frontier Avenue, Suite 100
Boulder CO
80301

(303) 444-4149

NORESCO United Technologies

On August 19, 2016 the Duke Energy expected savings recorded in this report were corrected by Cadmus to reflect the values found in Duke Energy program tracking database.

Introduction

This report addresses M&V activities for the [redacted] custom program application. The application covered a DDC control retrofit and roof retrofit at one location in [redacted], North Carolina. The measures included:

ECM-1 – DDC Controls
New DDC controls were implemented to monitor and control newly installed HVAC equipment. This will allow for optimum start and stop times, as well as better precision in controlling all setpoints and schedules. The DDC system will control, among other things, (2) 10-ton unitary and rooftop AC units, (3) 10-ton and (1) 7.5-ton rooftop heat pumps and (1) 3-ton unitary and rooftop heat pump.

ECM-2 – Additional insulation / White Roof Replacement
This ECM involved replacing the old roof with a new, well insulated white roof. The new roof has an R-value of 30 or greater. The roof has a reflectivity of 0.77 and emissivity of 0.87, although since the roof was largely covered by solar collectors, this aspect of the measure was ignored.

This project was scheduled to be completed by May 2014, after having been started in January 2014.

This customer has also been advised to apply for incentives for RTU replacements through the prescriptive incentive programs. At the time the M&V plan was written, the prescriptive applications had not been received, and so the RTU replacements were not verified for the prescriptive program.

Goals and Objectives

The projected savings goals identified in the application were:

Facility	Proposed Annual kWh savings	Proposed kW Savings	Duke Projected Annual kWh savings	Duke Projected kW savings
redacted	14,132	2	12,700	**29**
Total	**14,132**	**2**	**12,700**	**29**

The objective of this M&V project was to verify the actual:

- Average pre/post load shapes by daytype for controlled equipment
- Facility peak demand (kW) savings

- Summer utility coincident peak demand (kW) savings
- Annual energy (kWh) savings

Project Contacts

Duke Energy M&V Coordinator	Frankie Diersing	p: 513-287-4096
NORESCO Engineer	Rob Slowinski	p: 303-459-7409 rslowinski@noresco.com
Customer Contact	redacted	

Site Locations/ECM's

Address
redacted

Data Products and Project Output

- Average pre/post load shapes by daytype for controlled equipment
- Facility peak demand (kW) savings
- Summer utility coincident peak demand (kW) savings
- Annual energy (kWh) savings
- kWh & kW Realization Rates

M&V Option

IPMVP Option D

M&V Implementation Schedule

- Conducted the post-retrofit survey after the customer had performed the roofing and DDC control retrofit.
  - Collected data during normal operating hours
  - Obtained and verified the post-retrofit HVAC schedules of equipment controlled by the DDC system. The building is occupied Monday through Friday from 8am to 5pm, with periodic second shifts until midnight. There are periodic Saturday shifts as well, but the system is set to go to sleep by reducing setpoints during unoccupied hours.

- Performed spot-measurements on selected controlled equipment.
- Deployed post-retrofit loggers to record temperature and power measurements on sampled equipment.

- Confirmed and updated the provided eQUEST energy model to reflect as-built conditions.
- Evaluated the energy and demand savings of the retrofit measure.

Field Survey Points

Pre – installation

- Nameplate data and quantity for all HVAC equipment.

Reviewed eQUEST energy model of pre-retrofit energy consumption.

Post – installation

- Obtained and verified schedules, setpoints and sequence of operation details for all controlled equipment POST-retrofit.
- Visual verification of roof installation and insulation type.

Spot measurements

- V/A/kW/PF for sampled AHU/heat pump fans and compressors

Time series data on controlled equipment

- V/A/kW/PF for sampled AHU/heat pump fans and compressors
- SAT, MAT, RAT, OAT for sampled AHUs and heat pumps

Loggers were setup for 5-minute instantaneous readings and deployed for 3 weeks. The monitoring period lasted from 8/29/14 to 9/25/14.

Field Data Logging

- **ECM-1**

  Field technicians installed data loggers to collect data on sampled HVAC units. Two AHUs and two heat pumps were sampled for fan current, compressor current, SAT, MAT and RAT. Outdoor air temperature and relative humidity were logged for 3 weeks with a 5-minute interval.

- **ECM-2**

No data logging was necessary—visual verification only.

Data Analysis

Trend data was gathered and analyzed for four rooftop units (2 heat pumps and 2 DX units). Time series data was then converted to a daily load profile based on daytype (weekday, Saturday or Sunday). The compiled daily load profiles for each of the monitored units can be seen in Figures 1 through 4. A time series plot of RTU 16 fan current can be seen in Figure 5.

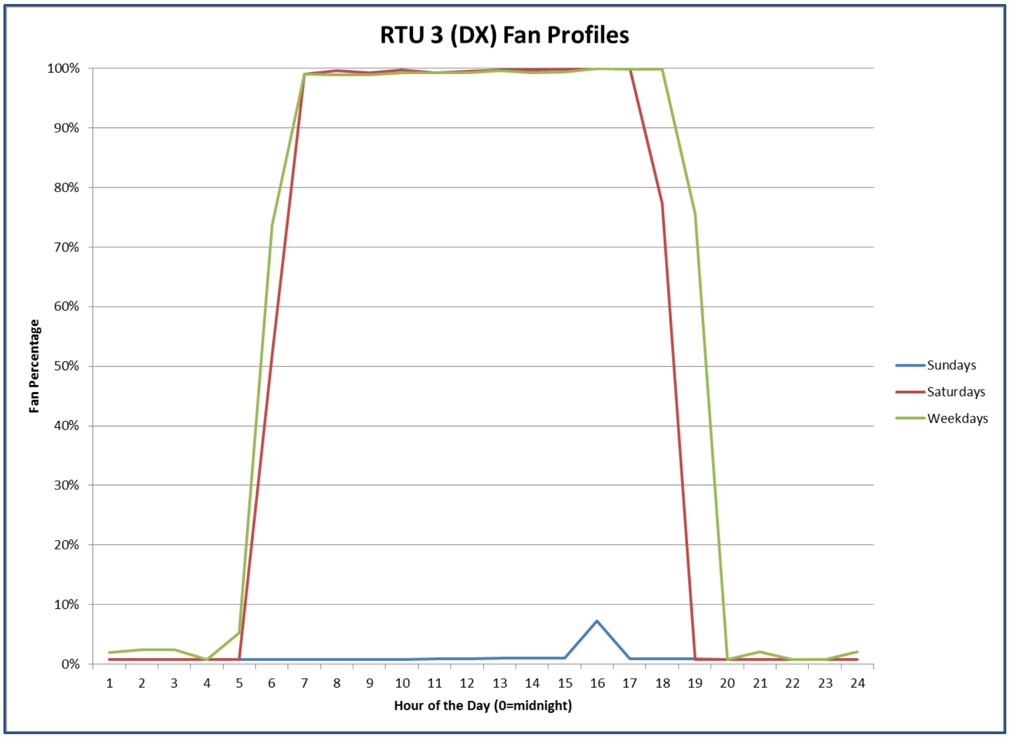

Figure 1: RTU 3 daily fan profiles. RTU 3 is a DX unit, and appears to be operating according to the schedule provided by the building contact.

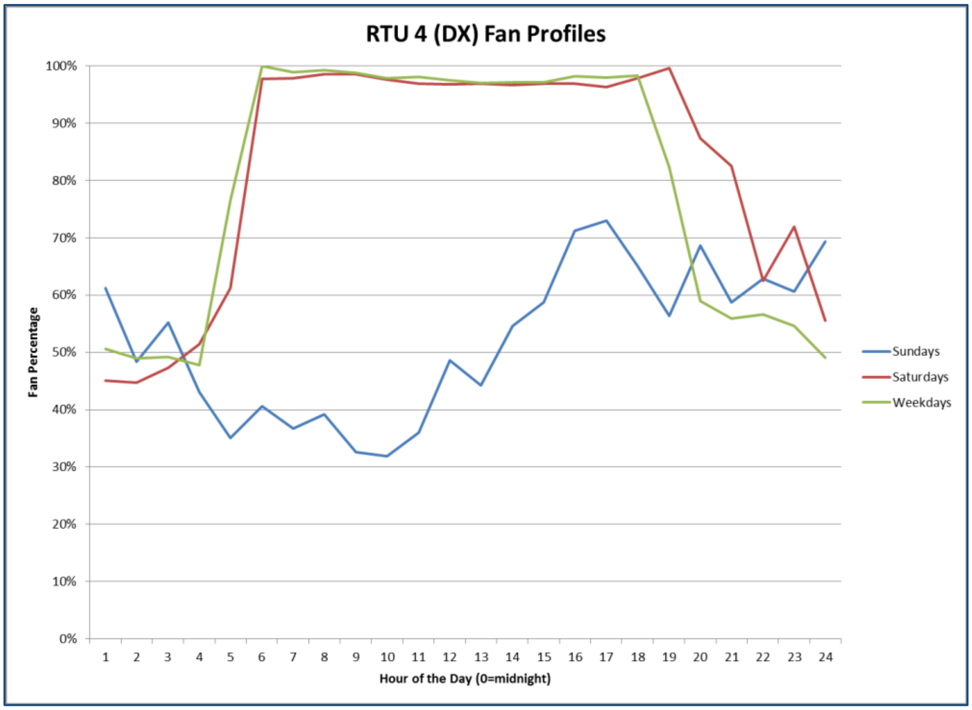

Figure 2: RTU 4 daily fan profiles. RTU 4 is a DX unit. Weekday and Saturday operation is close to the disclosed schedule, but fans also appear to be running on Sundays when they should be scheduled OFF.

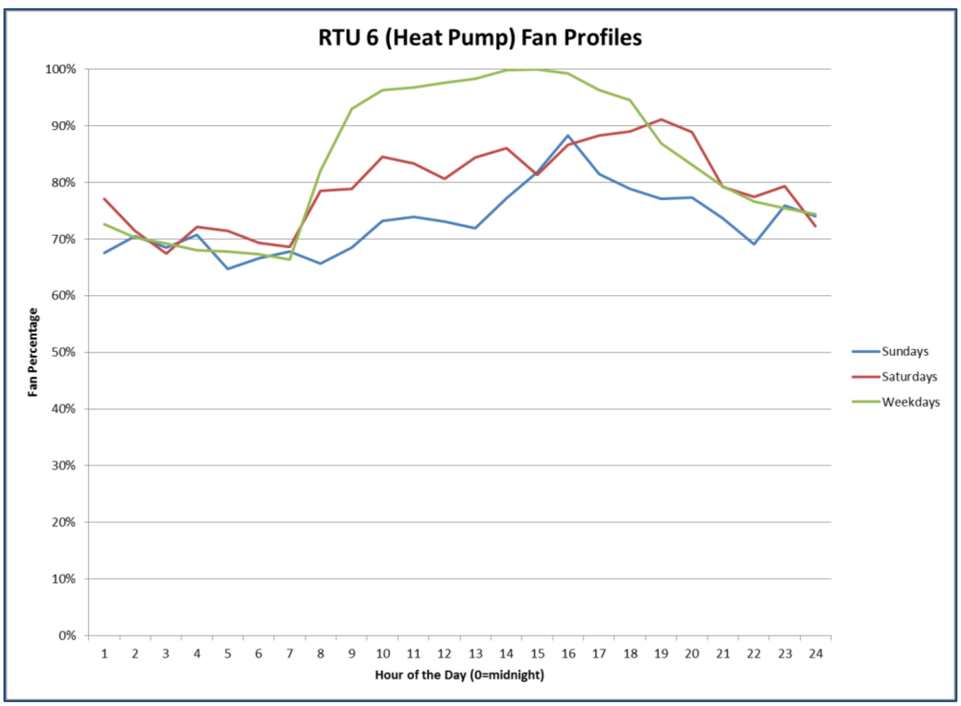

Figure 3: RTU 6 daily fan profiles. RTU 6 is a heat pump unit. There is some semblance of a schedule, but unoccupied operation does not appear to be working correctly.

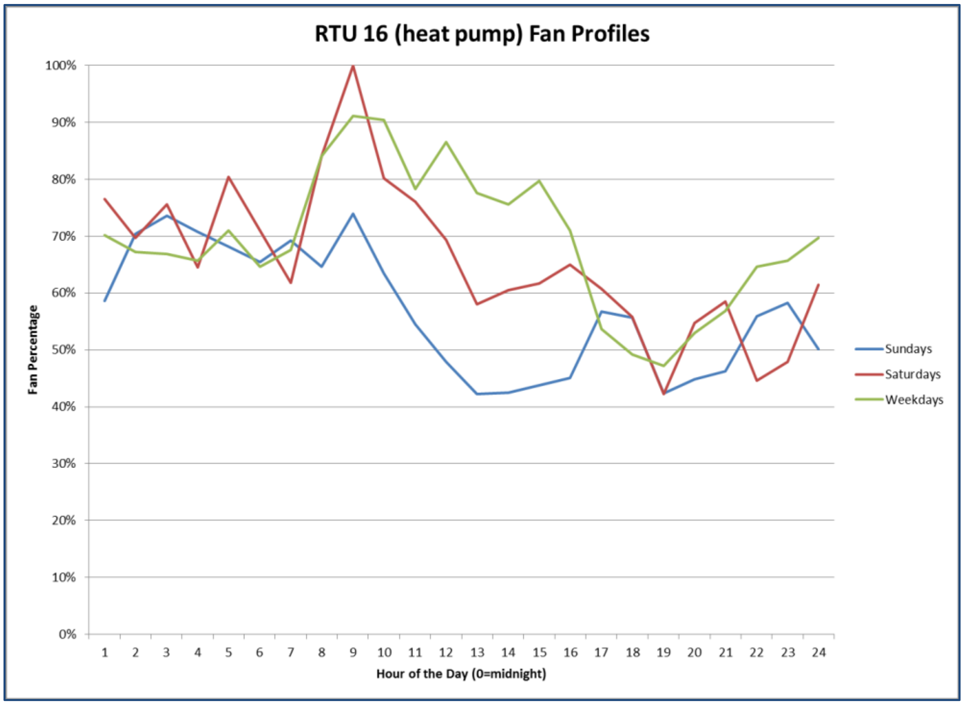

Figure 4: RTU 16 daily fan profiles. RTU 16 is a heat pump, without much of a coherent fan schedule during the monitoring period.

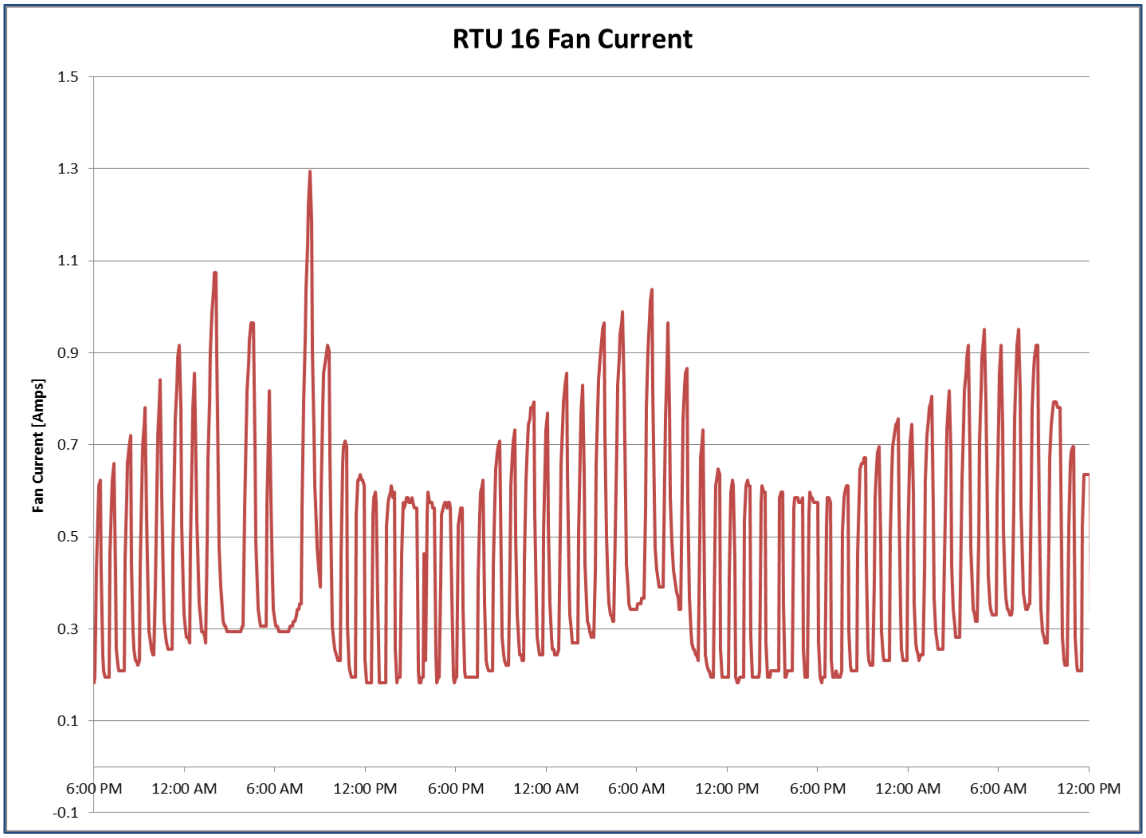

Figure 5: RTU 16 time series fan current. The fan cycles continuously during the entire monitoring period. If anything, higher fan power can be observed during the early morning hours.

Due to the somewhat inconsistent nature of the gathered trend data, as well as the input format required by DOE-2 energy simulation software, the fan schedules were consolidated into an equivalent full load hours (EFLH) schedule (including separate schedules for DX units and for heat pumps). Pre- and post-retrofit fan schedules can be seen in Table 1.

Table 1: Energy model schedule details.

	Pre-Retrofit (from provided energy model)	**Post-Retrofit (from trend data)**
DX Units: Monday-Saturday	ON: 3am-9pm, OFF/cycling: all other hours	ON: 4am-8pm (16 EFLH), OFF/cycling: all other hours
DX Units: Sunday	OFF/cycling: all hours	ON: 7am-2pm (7 EFLH), OFF/cycling: all other hours
Heat Pump Units: Monday-Saturday	ON: 3am-9pm, OFF/cycling: all other hours	ON: 6am-5pm (11 EFLH), OFF/cycling: all other hours
Heat Pump Units: Sunday	OFF/cycling: all hours	ON: 7am-4pm (9 EFLH), OFF/cycling: all other hours

In the energy model, the only modifications to the model between pre- and post-retrofit were to the daily fan schedules and the roof insulation. All other parameters are identical between the two models. The breakdown of rooftop units is a 2:1 ratio of heat pumps to DX units, to reflect the total tonnage of the installed systems. RTUs were modeled to cycle on any call for heating or cooling, to account for loads that occurred even when fans were scheduled to OFF.

The roof insulation measure involved modifying roof insulation layers from the baseline construction of 3/8" built-up roofing, 1.5" of polyurethane foam and 5/8" of plywood and an additional R-2.8 insulation layer to the ECM construction of 3/8" built-up roofing, a 6" layer of polyisocyanurate, 5/8" plywood and an additional insulation R-8.1 insulation layer.

The energy models were run and checked to ensure that there are no hours throughout the year with loads unmet or hours outside of temperature throttling range.

Energy savings was calculated by comparing the annual electrical energy consumption (kWh) data predicted the two models. Coincident peak demand data was taken from the hourly reports of kW, and compared on July 17^{th} at 3pm (standard for North Carolina). Non-coincident kW savings was calculated by comparing demand savings between the two models for all hours of the year and taking the maximum value.

Verification and Quality Control

1. Visually inspected logger data for consistent operation. Sorted by day type and removed invalid data. Identified out of range data and data combinations that are physically impossible.
2. Verified that pre-retrofit and post retrofit equipment specifications and quantities are consistent with the application.
3. Verified electrical voltage of equipment circuits.
4. Inspected energy model .SIM files for unusual operation.

Recording and Data Exchange Format

1. Survey Form and Notes.
2. Building Automation System data files OR data logger files
3. Excel spreadsheets
4. eQUEST files
5. DOE-2 energy model data files

Results Summary

Figure 6 shows the behavior of fan energy in the energy model. The results are as expected, with lower fan energy peaks in the post-retrofit model due to the more efficient building envelope. The new schedule also provides for reduced fan operation on weekdays and Saturdays, while slightly increasing fan usage on Sundays.

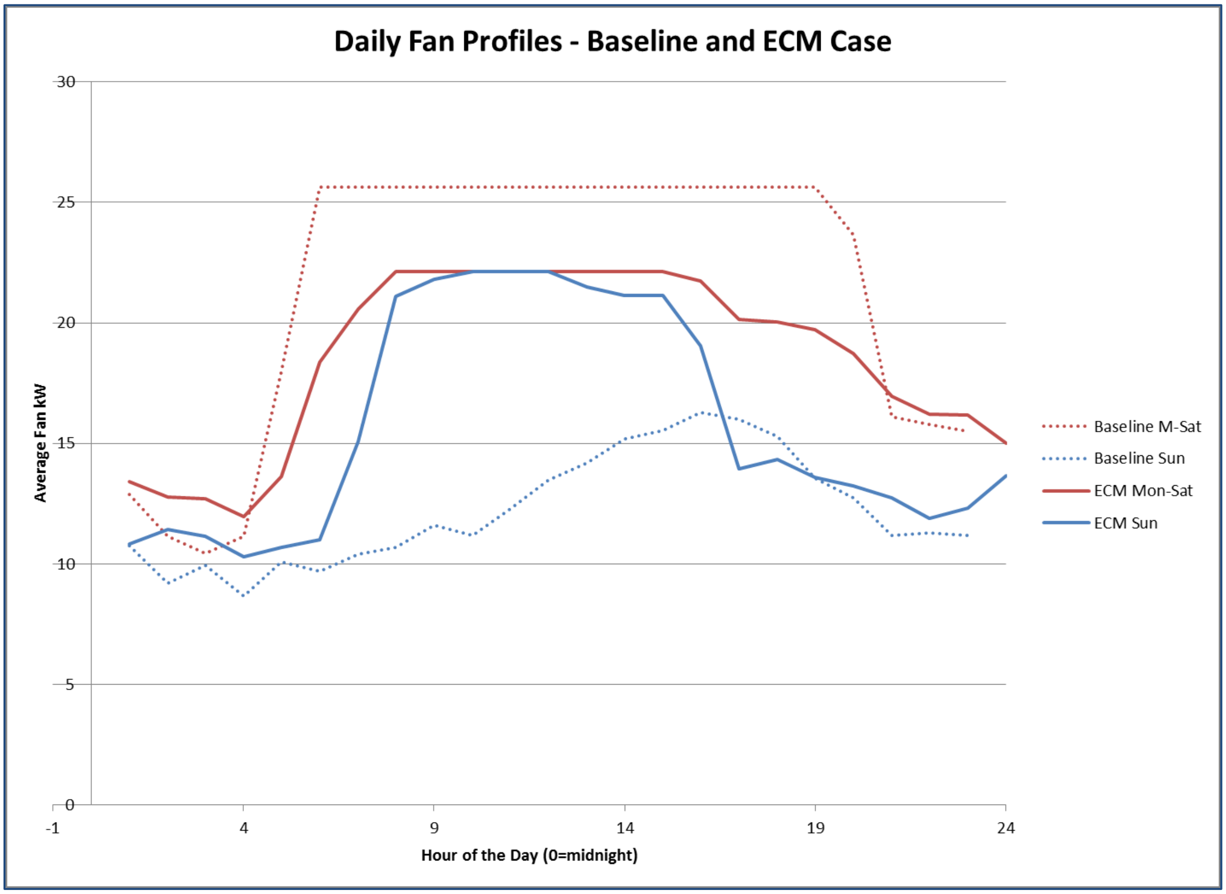

Figure 6: Fan energy profiles based on the DOE-2 energy model.

In summary, while trend data does not result in data as consistent as might be expected, the scheduling and insulation measure do provide savings that were greater than initially estimated, according to the energy model. Final savings results can be seen in Table 2.

Table 2: Savings Summary.

	Duke Projected			Observed			Realization Rates		
	kWh	CP kW	NCP kW	kWh	CP kW	NCP kW	kWh Realization Rate	CP kW Realization Rate	NCP kW Realization Rate
Total	12,700	29	29	29,757	24.8	28.7	234%	87%	98%

While realization rates are quite high, this amount is less than 2% of the building's overall energy consumption, and is reasonable within that context.

Application ID 14-1706865
Lighting
M&V Report

August 26, 2016

Duke Energy
139 East Fourth Street
Cincinnati, OH 45201

The Cadmus Group, Inc.

An Employee-Owned Company • www.cadmusgroup.com

CADMUS

Prepared by:
Dave Korn
Christie Amero

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Introduction

This report outlines Cadmus' measurement and verification (M&V) activities for two new construction energy conservation measures (ECMs) as part of the [redacted], Smart $aver custom incentive program application. Specifically, [redacted] installed high-efficiency LED lighting fixtures and occupancy sensors above code requirements at their new construction data center project in [redacted], North Carolina. Energy savings were expected to result from the reduced fixture wattages and operating hours.

[Redacted]'s new data center is called FRC3, and is divided into suites A, B, C, and D. Suites A and B are approximately 117,500 square feet combined and include data storage and administration offices. Suites C and B are approximately 80,000 square feet combined and contain data storage equipment only. Descriptions of the measures as submitted in the original project documentation follow; ECM-1 pertains to lighting in Suites A and B and ECM-2 pertains to lighting in Suites C and B.

ECM-1: Suites A & B LED Fixtures and Occupancy Sensors

Baseline: The baseline was a standard 128-watt T8 fluorescent fixture. The lighting power densities for the equipment rooms and offices were code compliant (at 1.25 watts per square foot on a total building basis). In the original application, the T8 fixtures were assumed to operate 70% of the year (6,132 hours per year).

Installed: The facility installed 1,450 20-watt LED lighting fixtures with automated occupancy sensors. In the original application, the installed LED lamps were assumed to operate 20% of the year (1,752 hours per year).

ECM-2: Suites C & D LED Fixtures and Occupancy Sensors

Baseline: The baseline was a standard 128-watt T8 fluorescent fixture. The lighting power density for the equipment room was code compliant (at 1.3 watts per square foot). In the original application, the T8 fixtures were assumed to operate 70% of the year (6,132 hours per year).

Installed: The facility installed 1,033 20-watt LED lighting fixtures with automated occupancy sensors. In the original application, the installed LED lamps were assumed to operate 20% of the year (1,752 hours per year).

Goals and Objectives

Table 1 shows the projected savings goals identified in the project application.

Table 1. Project Goals

ECM	Application		Duke Energy			
	Annual kWh Savings	Average kW Reduction	Projected Annual kWh Savings*	Claimed Annual kWh Savings	Claimed Coincident Peak kW Reduction	Claimed Non-CP kW Reduction
1	873,369	N/A	854,038	854,023	97.49	97.44
2	605,299	N/A	600,580	600,569	68.56	68.52
Total	**1,478,668**	**0**	**1,454,618**	**1,454,592**	**166.05**	**165.96**

* Source: DSMore input spreadsheet.

For this M&V project, Cadmus sought to verify actual numbers for the following:

- Facility peak demand reduction (kW)
- Summer utility coincident peak demand reduction (kW)
- Annual energy savings (kWh)
- Annual realization ratios (kW and kWh)

Project Contacts

Table 2 lists the Duke Energy contact who granted Cadmus approval to plan and schedule the site visit for this M&V effort, along with the Cadmus contact and the customer contact.

Table 2. Project Contacts

Organization	Contact	Contact Information
Duke Energy	Monica Redman, Senior DSM & Retail Programs Analyst	monica.redman@duke-energy.com
Cadmus	Christie Amero, Senior Analyst	office: 303-389-2509 christie.amero@cadmusgroup.com
Customer	redacted	

Site Location

The site location is listed in Table 3.

Table 3. Site Location

Address	ECM
redacted	1 & 2

M&V Option

To assess this site, Cadmus followed IPMVP Option A.

Implementation

Cadmus reached out to the site contact provided by Duke Energy to review the evaluation plan and to schedule the site visit. Christie Amero of Cadmus performed the site visit on June 20, 2016.

Field Survey

During the site visit, Cadmus met with the facility manager to review the lighting survey and to collect general operating information. The data center section of the facility operates all day, year round, but the data suites are usually unoccupied. The administrative offices are typically occupied from Monday through Friday, 8:00 a.m. to 5:00 p.m., year round. The site observes approximately 10 standard holidays per year.

The offices are conditioned by electric air-source heat pumps. The data center is cooled by rooftop direct expansion systems with economizer control to provide free-cooling when outside air conditions allow. There is no heating for the data suites. The site uses hot aisle containment in the data center and maintains a space temperature between 60°F and 85°F.

The site installed 40-watt LED troffers in the data rack aisles and 20-watt LED downlights in the center and side aisles. There are ceiling-mounted occupancy sensors in all four data suites.

Field Data

After completing the lighting survey, Cadmus performed a walkthrough of the facility with the site contact to verify the installed lighting fixture types and to install light loggers. Due to the sensitive nature of the site and equipment, Cadmus did not take any photographs inside the data center. We confirmed that the four data suites have occupancy sensors and visually inspected the LED fixtures. According to the site contact, the installed LED troffer is a Philips Lightolier model 6830; the specification sheet for this model is shown in Figure 1.

Figure 1. Installed LED Downlight Specification Sheet

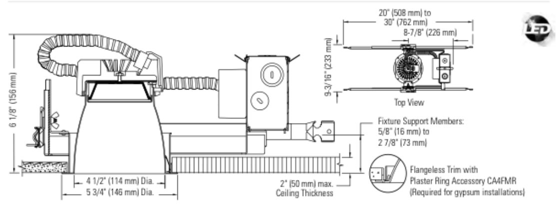
C4L10DL

Calculite 4 ½" LED downlight

Page 1 of 5

Catalog number:

Notes: Type:



Ordering guide: Light engines

Light engine series	Style	Color temp	Reflector finish	Flange	Options
C4L10	**DL** (Downlight)	**27K** (2700K) **30K** (3000K) **35K** (3500K) **40K** (4000K)	**CL** (Clear) **CCL** (Comfort clear) **CCD** (Comfort clear diffuse) **CCZ** (Champagne bronze) **WH** (Painted white)	**W** (Painted white) **P** (Aperture-matching/polished) **FT** (Flush-mount/flangeless)[1]	**EM** (Integral emergency test switch)[2]

Example: C4L10DL35KCCLWEM

[1]Accessory CA4FMR required for gypsum applications. Reflector flange is 1/4". New construction frame-in kits only.

[2]See LED-EM for details and restrictions.

Ordering guide: Frame-in kits

Frame-in kit series	Installation options	Input voltage	Driver	Options
C4L10 (1000 lumen) **C4L15** (1500 lumen)	**N** (New construction) **R** (Remodeler - 1000 lumen only)	**1** (120V) **2** (277V)	**Z10V** (0-10V dimming) **LD** (Lutron driver - 1000 lumen only)	**EM** (Emergency - 1000 lumen only)
CUL10 (1000 lumen)	**J** (J-box mount retrofit) **S** (Screw-in base retrofit - 120V only)	**1** (120V) **2** (277V)	**Z10V** (0-10V dimming) **LD** (Lutron driver)	

Example: C4L10N1Z10VEM

Features

Aperture: 4 1/2" (114mm) I.D., 5 3/4" (146mm) O.D.
Input wattage: 20W (1000 lumen), 30W (15 lumen)
Reflector cone: Aluminum. Provides 50° cutoff to source & source image. Self-flanged.
Depth (including frame-in kit): 6 1/8" (156mm)
Power connection: Attaches to frame-in kit via push-in connector (on frame). Removable cover provides access.

Technology

LED board: Array of high brightness royal blue LED's.
Remote phosphor technology: Remote phosphor technology provides increased efficiency and color consistency. Phosphor lens assembly positioned in front of LED array converts blue light to white. Color shift will not exceed +/- 100K over life.
Optical mixing chamber: Lightolier-specific mixing chamber redirects back-reflected light through aperture resulting in 20% increase in efficiency.
Thermal management: Heat sink and thermal design along with clean room assembly ensures specified performance.

Technology (continued)

Rated life: Based on IESNA LM-80-2008 50,000 hrs at 70% lumen maintenance.
Photometric performance: Tested in accordance to IESNA LM-79-2008

Options

Dimming capability: See LED-DIM specification sheet.
Emergency capability (integral): Add "EM" suffix. See LED-EM spec sheet.
Emergency capability (inverter): See LED-LMI specification sheet.

Labels

UL (suitable for wet locations), cUL, I.B.E.W.
5 year warranty

PHILIPS
LIGHTOLIER

Cadmus installed nine light loggers throughout the facility to collect fixture operating hours for a three-week period. Table 4 summarizes the locations of installed light loggers and monitored fixture types.

Table 4. Summary of Fixture Counts and Installed Light Loggers

#	Suite	General Location	Fixture Description	Light Logger Serial Number
1	A	Data rack row	LED troffer, 40 watts	10272535
2	A	Center aisle	LED recessed can, 20 watts	10326625
3	B	Side aisle	LED recessed can, 20 watts	10187384
4	C	Data rack row	LED troffer, 40 watts	10327344
5	C	Center aisle	LED recessed can, 20 watts	10380626
6	D	Center aisle	LED recessed can, 20 watts	10161259
7	D	Data rack row	LED Troffer, 40 watts	10255362
8	Connecting Hallway	On wall conduit	LED can	10260263
9	Administrative Offices	Top of fire alarm on wall	LED cans, LED troffers	10326440

Data Analysis

Cadmus used the survey and light logger data to verify demand and operating hours for the installed lighting fixtures. Table 5 summarizes the light logger data.

Table 5. Summary of Light Logger Data

#	Suite / Fixture	Total Metered Hours	Total Operating Hours	Percentage Operating	Average Coincidence Factor
1	A – Troffer	592.7	210.3	35%	35%
2	A – Can	592.6	524.4	89%	75%
3	B – Can	594.4	5.3	1%	1%
4	C – Troffer	592.5	45.2	8%	23%
5	C – Can	592.5	39.5	7%	15%
6	D – Can	592.4	34.7	6%	18%
7	D – Troffer	592.4	28.7	5%	12%
8	Connecting Hallway – Can	592.2	36.4	6%	13%
9	Administrative Offices – Troffer	592.0	308.3	52%	42%

The eight loggers in the data center suites and hallways produced a mean projected annual runtime of 1,708 hours and a mean coincidence factor of 24%. The logger in the office area produced a projected annual runtime of 4,563 hours and a mean coincidence factor of 42%.

Cadmus used an invoice submitted in the original project application to confirm the installed fixture quantities. The total installed case connected load is 88.4 kW and the overall lighting power density is 0.45 watts per square foot.

Cadmus verified the baseline lighting power densities in the original application of 1.3 watts per square foot for the data suites and 1.0 watts per square foot for the offices using technical reference manuals, then deemed these to be reasonable. The overall baseline lighting power density is 1.27 watts per square foot and the connected lighting load is 251.4 kW. Cadmus also confirmed that the baseline lighting control method submitted in the original application (manual control only) was reasonable based on the state energy code at the time of the application.

The energy savings and peak demand reduction without HVAC interactive effects are 1,382,253 kWh and 229.69 kW, respectively.

Cadmus also calculated energy savings and demand reductions with HVAC interactive effects, based on the heating and cooling system types collected on site. Cadmus used the waste heat factors listed in TechMarket Works' Process and Impact Evaluation of the Non-Residential Smart $aver® Prescriptive Program in the Carolina System: Lighting and Occupancy Sensors report submitted in April 2013. The energy waste heat factor for a small office near Charlotte, North Carolina with heat pump cooling and heating and no economizer is 0.047, and the demand factor is 0.152. The energy waste heat factor for a warehouse near Charlotte, North Carolina with air conditioner cooling, gas heating, and an economizer is 0.106, and the demand factor is 0.192. The following equations are used to calculate savings with HVAC interactions:

$$kWh_{savings\ with\ HVAC} = kWh_{savings}\ x\ (1 + WHFe)$$

$$kW_{savings\ with\ HVAC} = kW_{savings}\ x\ (1 + WHFd)$$

Where:

WHFe = Waste heat factor for energy

WHFd = Waste heat factor for demand

The total evaluated energy savings were 1,523,258 kWh. The evaluated total summer coincident peak demand reduction (for the month of July, Monday through Friday from 4:00 p.m. to 5:00 p.m.) was 273.15 kW, and the average, or non-coincident, peak demand reduction was 173.89 kW.

Conclusion

The overall energy savings realization rate was 105%, compared to Duke Energy claimed savings. The summer peak demand realization rate was calculated as 164%. The average (or non-coincident) peak demand reduction realization rate was 105%.

Cadmus found a discrepancy in the installed LED fixture wattage. The energy savings calculations in the original application assumed that one 20-watt LED fixture type would be installed in all areas. During the evaluation site visit, Cadmus observed that a 20-watt LED downlight and a 40-watt LED troffer were installed. However, the annual operating hours for the data suite lighting fixtures were less than expected in the original application, which negated the impact of the additional installed fixture wattage.

The original application did not include an estimate of peak coincidence factors, and divided the total energy savings by 8,760 hours to calculate the peak demand reduction of 166.05 kW. Using the peak coincidence factors from the metered data increased the evaluated peak demand reduction to 273.15 kW.

Table 6 provides a comparison of the applicant, Duke Energy claimed, and Cadmus evaluated energy savings and demand reduction. Table 7 provides realization rates comparing energy savings and demand reductions claimed by Duke Energy to those calculated by Cadmus.

Table 6. Comparison of Applicant, Duke Energy Claimed, and Evaluation Energy Savings and Demand Reduction

ECM	Applicant		Duke Energy Claimed			Evaluation		
	Annual kWh Savings	Average kW Reduction	Annual kWh Savings	Coincident Peak kW Reduction	Non-CP kW Reduction	Annual kWh Savings	Coincident Peak kW Reduction	Non-CP kW Reduction
1	873,369	N/A	854,023	97.49	97.44	886,542	159.58	101.20
2	605,299	N/A	600,569	68.56	68.52	636,716	113.57	72.68
Total	**1,478,668**	**N/A**	**1,454,592**	**166.05**	**165.96**	**1,523,258**	**273.15**	**173.89**

Table 7. Energy Savings and Demand Reduction Realization Rates

ECM	Annual kWh Savings	Coincident Peak kW Reduction	Non-CP kW Reduction
1	104%	164%	104%
2	106%	166%	106%
Total	**105%**	**164%**	**105%**

Application ID 13-1539878
Lighting Retrofit
M&V Report

Prepared for
Duke Energy Carolinas

January 2015, Version 1.0
(Revised August 22, 2016)

Note: This project has been randomly selected from the list of applications for which incentive agreements have been authorized under Duke Energy's Smart $aver® Custom Incentive Program.

The M&V activities described here are undertaken by an independent third-party evaluator of the Smart $aver® Custom Incentive Program.

Findings and conclusions of these activities shall have absolutely no impact on the agreed upon incentive between Duke Energy and [redacted].

Submitted by:

Katie Gustafson
NORESCO, Inc.

Stuart Waterbury
NORESCO, Inc.

2540 Frontier Avenue, Suite 100
Boulder CO
80301

(303) 444-4149

NORESCO
United Technologies

On August 22, 2016 the Duke Energy projected savings in this report were corrected by Cadmus to correspond to Duke Energy expected savings as found in the Duke Energy program tracking database.

Introduction

This document addresses M&V activities for the lighting retrofit at the [redacted]'s [redacted], South Carolina Location. This lighting retrofit was rebated through Duke Energy's Smart $aver Custom Lighting Incentive program.

- **ECM-1 –**Retrofitted (31) 4L T12 fixtures with 3L HPT8 fixtures.
- **ECM-**2 – Retrofitted (13) 8L incandescent fixtures with 2L HPT8 HO fixtures.

Goals and Objectives

The projected savings goals identified in the application are:

Facility	Proposed Annual kWh savings	Proposed kW Savings	Duke Expected Annual kWh savings	Duke Expected kW savings
redacted	31,526	10.4	31,575	10.4
Total	**31,526**	**10.4**	**31,575**	**10.4**

The objective of this M&V project will be to verify the actual:

- Annual gross kWh savings
- Summer peak kW savings
- Coincidence Peak kW savings
- kWh & kW Realization Rates

Project Contacts

Duke Energy M&V Coordinator	Frankie Diersing	p: 513-287-4096
NORESCO Engineer	Katie Gustafson	p: 303-459-7430 kgustafson@noresco.com
Customer Contact	redacted	

Site Locations/ECM's

Address	ECMs Implemented
redacted	1-2

Data Products and Project Output

- Post retrofit survey of lighting fixtures.
- Average post-retrofit lighting fixture load shapes.
- Equivalent Full Load Hours (HOURS) by day type (weekday/weekend).
- Summer peak demand savings.
- Summer utility coincident peak demand savings.
- Annual Energy Savings.

M&V Option

IPMVP Option A

Field Data Points

Post-Installation

Survey data

- Fixture count and Wattage.
- Verified that all fixture specifications and quantities were consistent with the application.
- Determined how the lighting is controlled and recorded controller settings.
- Verified that all pre (existing) fixtures were removed.
- Determined what holidays the building observes over the year.
- Determined if the lighting zones are disabled during the holidays.

Data Accuracy

Measurement	Sensor	Accuracy
Current	CTV-A 20A	$\pm$4.5%

Field Data Logging

The following table summarizes the quantities and locations of lighting loggers that were deployed to monitor the retrofitted fixtures.

ECM	Hobo (U12)	CTV-A 20A
1-2	1	4
Total	**1**	**4**

Data Analysis

- Used the standard calculation template for estimating pre and post demand and energy consumption that incorporates the methodology described below.
- From survey data calculated the actual pre and post fixture kW.
- Weight the time-series data according to connected load per control point. Methodology included in analysis worksheet.
- From time-series data determined the actual schedule of post operation.

$$\mathrm{LF(t)} = \frac{\sum_{i=1}^{N_{Logged}} \left(\mathrm{Current}_{\mathrm{ControlPoint}_i} * \mathrm{ScaleFactor}_i\right)}{\sum_{i=1}^{N_{Logged}} \mathrm{kWControlPoint}_i}$$

$$\mathrm{kW}_{\mathrm{Lighting}}(t) = \mathrm{LF(t)} * \sum_{i=1}^{N_{\mathrm{ControlPoints}}} \mathrm{kWControlPoint}_i$$

Where

LF(t) = Lighting Load factor at time = t

$\mathrm{kWControlPoint}_i$ = connected load of control point i

$\mathrm{CurrentControlPoint}_i$ = logged current at control point i from time series data

$\mathrm{ScaleFactor}_i$ = Convert logged current to kW

NLogged = population of logged control points

NControlPoints = population of all control points

- Created separate schedules for weekdays and weekends using LF(t).
- Tabulated average operating hours by daytype (e.g. weekday and weekend).
- Extrapolated annual operating hours from the recorded hours of use by daytype.
- Generated the post load shape by plotting surveyed fixture kW against the actual schedule of post operation for each daytype.
- Calculated pre annual operating hours using the pre-retrofit schedules by daytype and extrapolated to the full year.
- Calculated energy savings and compared to project application:

$$kWh_{savings} = (N_{Fixtures} * kW_{Fixture} * Hours)_{PRE} - (N_{Fixtures} * kW_{Fixture} * Hours)_{Post}$$

$$NCP\ kW_{savings} = (N_{Fixtures} * kW_{Fixture})_{PRE} - (N_{Fixtures} * kW_{Fixture})_{Post}$$

$$CP\ kW_{savings} = NCP\ kW_{savings}\ x\ CF$$

where:

$N_{Fixtures}$ = number of fixtures installed or replaced

$kW_{Fixture}$ = connected load per fixture

HOURS = equivalent full load hours per fixture
NCP $kW_{savings}$ = non-coincident peak savings
CP $kW_{savings}$ = coincident peak savings
CF = coincidence factor

- The savings with HVAC interactions are calculated from:

$$kWh_{savings\ with\ HVAC} = kWh_{savings}\ x\ (1 + WHFe)$$
$$kW_{savings\ with\ HVAC} = kW_{savings}\ x\ (1 + WHFd)$$

where:

WHFe = waste heat factor for energy
WHFd = waste heat factor for demand

Verification and Quality Control

1. Visually inspected lighting logger data for consistent operation. Sorted by day type and removed invalid data.
2. Verified the post retrofit lighting fixture specifications and quantities were consistent with the application.
3. Verified that pre-retrofit lighting fixtures were removed from the project. Inspected storeroom for replacement lamps or fixtures.

Recording and Data Exchange Format

- Hobo logger binary files
- Excel spreadsheets

Results Summary

This retrofit included both warehouse and restroom spaces. The warehouse space is heated with gas but is not cooled. The restrooms are heated and cooled with a heat pump. The waste heated interaction factors were only applied to the restroom savings. The following tables summarize the total estimated savings for the lighting retrofit.

Table 1. Energy Savings and Realization Rates.

	Duke Savings	Realized Savings		Realization Rate	
		Lighting Only	Lighting and HVAC	Lighting Only	Lighting and HVAC
Energy (kWh)	31,575	21,596	21,504	68%	68%
Peak Demand (kW)	10.4	8.2	9.5	79%	91%

CP Demand (kW)	10.4	8.2	9.5	79%	91%

The energy and demand savings calculation summary is shown in Table 2**Error! Reference source not found.**. Demand savings details are shown in Table 3 at the end of this report.

Table 2. Summary of Energy and Demand Savings Calculations.

	Base kW	EE kW	HOURS	CF	Lighting Only			With HVAC interactions ECM2 Only WHFe= -0.005 WHFd= 0.184		
					kWh savings	NCP kW	CP kW	kWh savings	NCP kW	CP kW
ECM1	3.97	2.7	2633	1.0	3,441	1.3	1.3	3,441	1.3	1.3
ECM2	7.84	0.9	2633	1.0	18,149	6.9	6.9	18,057	8.2	8.2
Total	11.81	3.6	2633	1.0	21,596	8.2	8.2	21,504	9.5	9.5

- Used the NORESCO-developed HVAC interaction factors for heat pump heating and cooling for the restroom spaces only. The warehouse space is heated with gas and not cooled and therefore does not have energy or demand interaction factors.

Figure 1 shows the average daily load shape. When extrapolated to the year, the M&V annual operating hours are 2633, which are 16% less than the 3120 hours stated in the application.

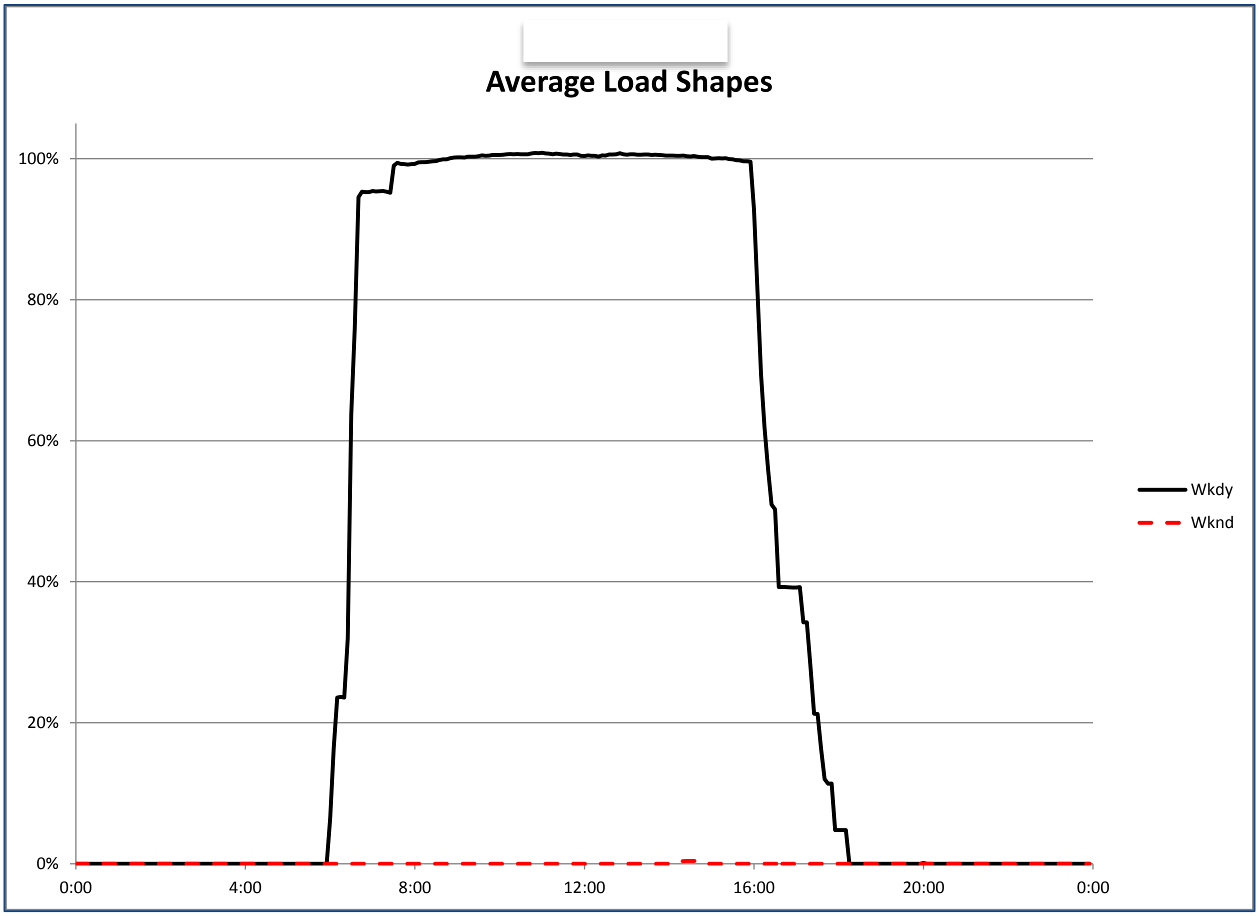


Figure 1: Average daily load shapes.

Table 3. Demand Savings Detail.

ECM	EE Technology						Base Technology				
	Quantity	EE Fixture Type	W/ Fixture	Source	Cut Sheet W/ Fixture	Connected kW	Quantity	Base Fixture Type	W/ Fixture	Source	Connected kW
1	31	4' 3L T8	85.8	Spot measured	88	2.7	31	1) F40T12/ES Mag-ES (144 W/ fixture) 2) F40T12/ES Electronic (120 W/fixture)	128	1, 3	4.0
2	13	4' 2L T8	72.9	Spot measured	74	0.9	13	Eight 100 W Lamp Incandescent Bath Strip	603	2	7.8

Notes:

1. SPC Apdx B – Appendix B 2013-14 Table of Standard Fixture Wattages. See http://www.aesc-inc.com/download/spc/2013SPCDocs/PGE/App%20B%20Standard%20Fixture%20Watts.pdf
2. The EISA phase out of 100W incadecent lamps began in 2012, these lamps are to be replaced with 72W halogen lamps. TechMarket Works has recommended baseline wattages for the 100W lamp through 2018 at that time it is unlikely that there will be 100W lamps remaining in the marketplace. TechMarket Works Memo - "Residential Lighting Program – Mystery Shopper CFL Baseline Real-Time Feedback Memo." 7 Feb. 2014. TecMarket Works Evaluation Team. Table 4 shows the changing baseline for 100W lamps as well as the fixtures that were replaced with ECM2. .

Table 4. Changing Baseline for 100W Lamps

Measure Life	Year	Tech Market Works Baseline W/ Lamp	Watts/ Fixture
Year 1	2013	84.6	676.8
Year 2	2014	83.2	665.6
Year 3	2015	80.4	643.2
Year 4	2016	77.6	620.8
Year 5	2017	74.8	598.4
Year 6	2018	72	576
Year 7	2019	72	576
Year 8	2020	72	576
Year 9	2021	72	576
Year 10	2022	72	576
Year 11	2023	72	576
Year 12	2024	72	576
Average		75.4	603.1

3. Because magnetic ballasts are currently being phased out of the market place, we adjusted the base fixture wattage to account for this changing base line for ECM1. The Duke Energy FES papers assume a 12 year measure life for linear fluorescent fixtures. We assumed that the baseline for the four years of the useful life would be a similar T12 fixture with a magnetic ballast. For the last eight years of the useful life we assume the baseline would be a similar T12 fixture with an electronic ballast. The two fixtures and wattages used to determine the adjusted baseline are included in **Error! Reference source not found.** above. We used the following equation to determine the adjusted baseline.

$$\frac{Adjusted\ W}{fixture} = \frac{4}{12}\left(\frac{144W}{fixture}\right) + \frac{8}{12}\left(\frac{120W}{fixture}\right)$$

Table 5 below details the application annual savings over the measure life.

Table 5. Annual Measure Life Savings

Measure Life	Lighting Only			With HVAC interactions		
	kWh savings	NCP kW	CP kW	kWh savings	NCP kW	CP kW
Year 1	25,426	9.7	9.7	25,321	11.1	11.1
Year 2	25,043	9.5	9.5	24,939	10.9	10.9
Year 3	24,276	9.2	9.2	24,177	10.6	10.6
Year 4	23,509	8.9	8.9	23,414	10.2	10.2
Year 5	20,783	7.9	7.9	20,692	9.1	9.1
Year 6	20,017	7.6	7.6	19,929	8.8	8.8
Year 7	20,017	7.6	7.6	19,929	8.8	8.8
Year 8	20,017	7.6	7.6	19,929	8.8	8.8
Year 9	20,017	7.6	7.6	19,929	8.8	8.8
Year 10	20,017	7.6	7.6	19,929	8.8	8.8
Year 11	20,017	7.6	7.6	19,929	8.8	8.8
Year 12	20,017	7.6	7.6	19,929	8.8	8.8
Total	259,153	98.4	98.4	258,045	113.6	113.6
Measure Life Yearly Average	21,596	8.2	8.2	21,504	9.5	9.5

Application ID 12-441
Aeration System Upgrade
M&V Report

Prepared for
Duke Energy Carolinas

January 2015, Version 1.1
(revised August 19, 2016)

Note: This project has been randomly selected from the list of applications for which incentive agreements have been authorized under Duke Energy's Smart $aver® Custom Incentive Program.

The M&V activities described here are undertaken by an independent third-party evaluator of the Smart $aver® Custom Incentive Program.

Findings and conclusions of these activities shall have absolutely no impact on the agreed upon incentive between Duke Energy and [redacted].

Submitted by:

Doug Dougherty
NORESCO, Inc.

Stuart Waterbury
NORESCO, Inc.

2540 Frontier Avenue, Suite 100
Boulder CO
80301

(303) 444-4149

NORESCO
United Technologies

On August 19, 2016 the Duke Energy projected savings recorded in this report were corrected by Cadmus to reflect the expected values found in Duke Energy program tracking database. The last paragraph was revised to reflect the fact that the realized energy savings were close to those expected, and the realized demand savings were close to those proposed.

Original application ID for the project verified here was 12-441; however the savings under 12-441 were rolled over to 12-442 along with four other projects implemented at the waste treatment plan. Only claimed savings under application ID 12-443 (formerly attributed to application ID 12-441) were verified as part of this M&V effort and reflected in the expected savings discussed here.

Introduction

This report addresses M&V activities for the [redacted] Aeration System Smart $aver Custom program application. The measure includes:

ECM-1 –Aeration System Modification

- Replace the existing coarse bubble diffused air system with a fine bubble diffused aeration system. Installing fine bubble diffusers significantly reduces air requirements, thus reducing the energy required for blower operation as well.
- The aeration system has four multistage centrifugal blowers. The original blowers were modified to handle the [new, increased] pressure requirements of the fine bubble diffused aeration system. This required adding an additional stage and changing the shaft and impellers in each blower.
- The original 300-HP blower motors remain.
- The process load on the Waste Treatment plant is continuous (24/7) and independent of Outdoor Air Temperature (OAT). According to information provided with the application documents, a review of data for the years 2004 – 2008 showed no seasonal differences in WWTP loads that would affect the energy usage of the aeration system.
- In the actual pre-retrofit operation, two blowers were needed to meet the average air delivery requirement, resulting in an estimated total power requirement of 493 kW. At peak loads, four blowers were required, for a total power requirement of 986 kW.
- In the post-retrofit operation, accounting for both the reduced airflow and higher pressure requirements, one blower alone was expected to be able to meet the average air delivery requirement, with a power requirement of 137 kW. At peak loads, two blowers were expected to be required, with a total power requirement of 303 kW.

Note: The ECM has already been implemented. Only post- retrofit measurements were taken.

Goals and Objectives

The projected savings goals identified in the application are:

Application Proposed Annual savings (kWh)	Application Proposed Peak Savings (kW)	Duke Expected savings (kWh)	Duke Expected Coincident Peak savings (kW)	Duke Expected Non-coincident Peak savings (kW)
3,118,560	683	2,885,315	**329**	**329**

The objective of this M&V project is to verify the actual:

- Annual gross electric energy (kWh) savings
- Summer peak demand (kW) savings
- Utility coincident peak demand (kW) savings
- Energy, demand and coincident demand Realization Rates.

Project Contacts

NORESCO Contact	Doug Dougherty	ddougherty@noresco.com	o: 303-459-7416
Duke Energy M&V Coordinator	Frankie Diersing	Frankie.Diersing@duke-energy.com	o: 513-287-4096 c: 513-673-0573
Customer Contact	redacted		

Site Locations/ECM's

Address
redacted

Data Products and Project Output

- Average pre/post load shapes for included equipment
- Summer peak demand savings
- Coincident peak demand savings
- Annual energy savings

M&V Option

IPMVP Option A

M&V Implementation Schedule

- Post-retrofit data was collected for a thorough evaluation.
- The monitoring period included both normal workday and weekend periods and one holiday (Labor Day).

Field Survey Points

Survey data (for all equipment logged)

- Obtained the sequence of operations for the four aeration blowers in both the pre- and post-installation cases.
- Obtained the blowers' make/model/serial number and other nameplate data.
- Obtained the blower motors' make/model/serial number and other nameplate data.
- Obtained utility bill (kWh and kW) information from July 2010 through July 2014.

One-time measurements for all equipment logged (to check and validate Elite Pro data)

- Motor volts, amps, kW and power factor.

Data Accuracy

Measurement	Sensor	Accuracy	Notes
Current	Magnelab CT	±1%	Recorded load must be < 130% and >10% of CT rating
Power	Elite-Pro	±1%	

Field Data Logging

- **ECM-1 – Installed Elite Pro data loggers to log the following data points at 5-minute intervals. Collected data for a minimum of 3 weeks.**

  For the aeration blower motors (qty of 4), configured the Elite Pro loggers to record the following information:

  - Voltage
  - Average Current (amps)
  - Power factor
  - Average Power (kW).

Logger Table

The following table summarizes all logging equipment needed to accurately measure the above noted ECM's:

Equipment	Elite-Pro's	Magnelab CT's
Aeration Blower Motors	4	(8) 500 A
Totals	**4**	**8**

Note: CT sizes are based on 300-HP motors.

Data Analysis

- **ECM-1**

1. Converted time series data on logged equipment into post-retrofit average load shapes by day type.
2. Generated pre-retrofit model from pre-retrofit performance information and post retrofit consumption field data.
3. Developed pre- and post-retrofit estimates of weekly average demand (kW) and total weekly energy (kWh) consumption.
4. Developed pre- and post-retrofit estimates of coincident and non-coincident peak demand (kW).
5. Estimated peak demand savings by subtracting post-retrofit peak from pre-retrofit estimate. Calculated coincident peak savings by subtracting peak demand values at 3-4 PM local time on weekdays.
6. Extrapolated calculated total weekly energy (kWh) consumption to annual consumption. Estimated annual energy savings by subtracting post-retrofit consumption from pre-retrofit estimate.

Verification and Quality Control

1. Visually inspected time series data for gaps
2. Compared readings to nameplate and spot-watt values; all data was within range.

Recording and Data Exchange Format

1. Elite Pro logger and weather station binary files
2. Excel spreadsheets

Attachments

1. Blower and motor nameplate data collection form
2. Spot watt data collection form

Results

Utility data was collected from the site and is graphed below. The data reflects more power than just the aeration blowers that are the subject of this report, but it is clear that the facility has reduced its electrical demand and energy consumption substantially over the past three years.

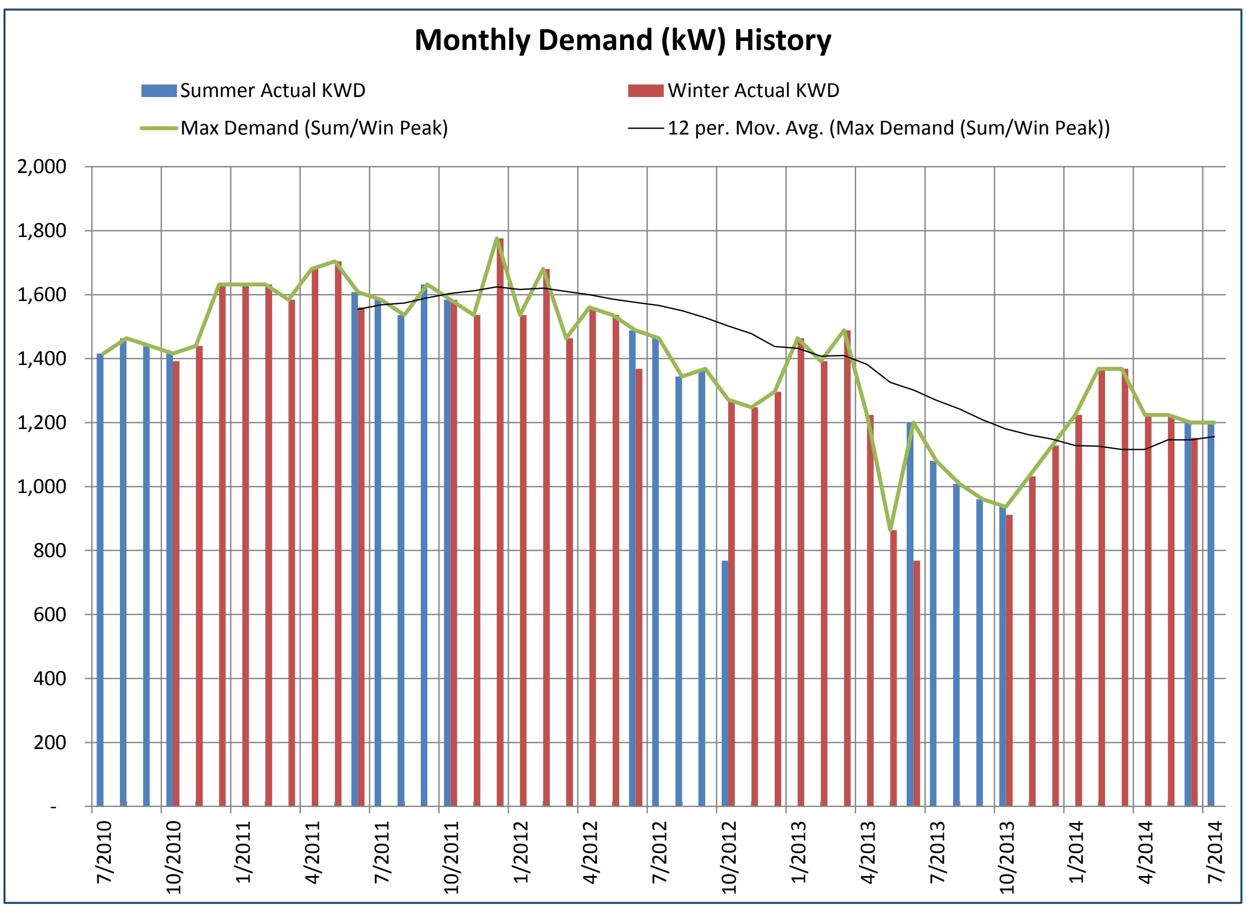


Figure 1: Utility Billing History – Demand.

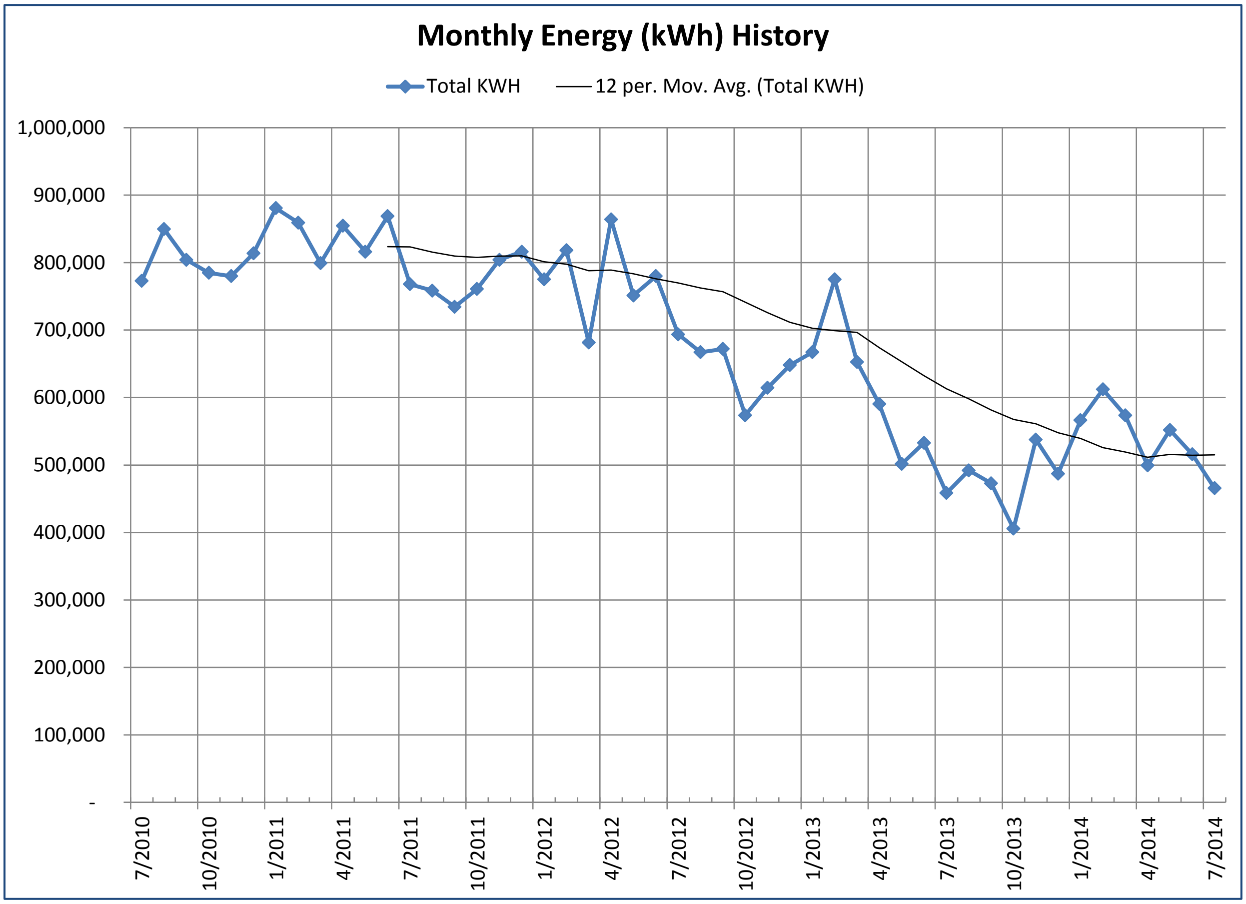


Figure 2: Utility Billing History – Energy (kWh).

The operating power of each of the four blowers was monitored with data loggers for over three weeks. The normal schedule (post-retrofit) for cycling the blowers is that only two blowers are operational at any given time with one of them as lead and the other as lag (backup). Every two weeks, the lag blower becomes the lead blower and a blower that was off becomes the lag blower. Given that schedule, three weeks of monitoring would not have been long enough to observe all four blowers in operation, so the facility contact agreed to rotate the blowers more often than usual during the monitoring period.

The following charts show the logged power values of the four blowers, and the total power. According to the data, the number of blowers running was generally one or two, was rarely none, and never three or four. This matches what the facility anticipated for the post-retrofit operation of the fine bubble diffused aeration system. In the pre-retrofit situation, two blowers were required to handle average process loads and four blowers were required for peak loads.

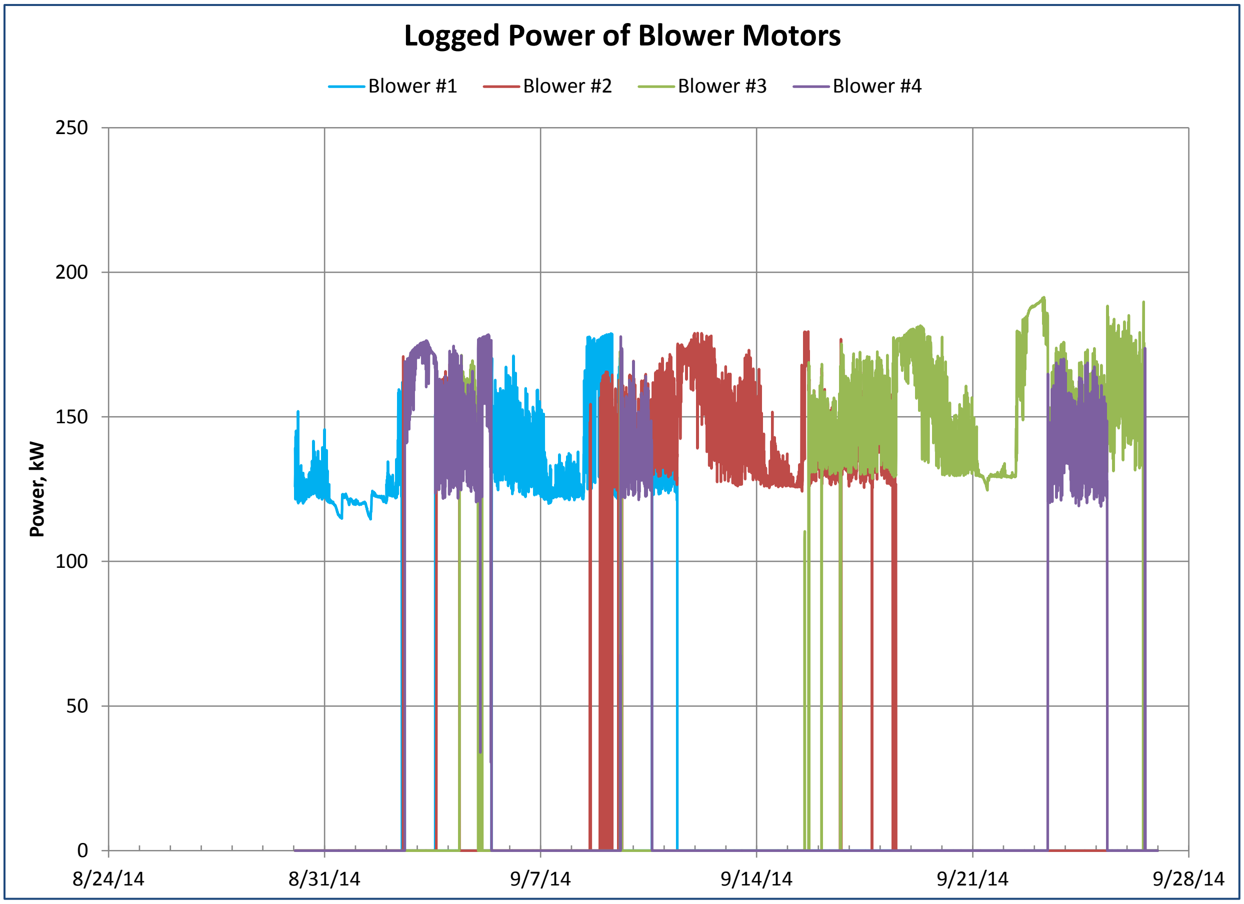


Figure 3: Logged Power of Individual Blower Motors, Post-Retrofit.

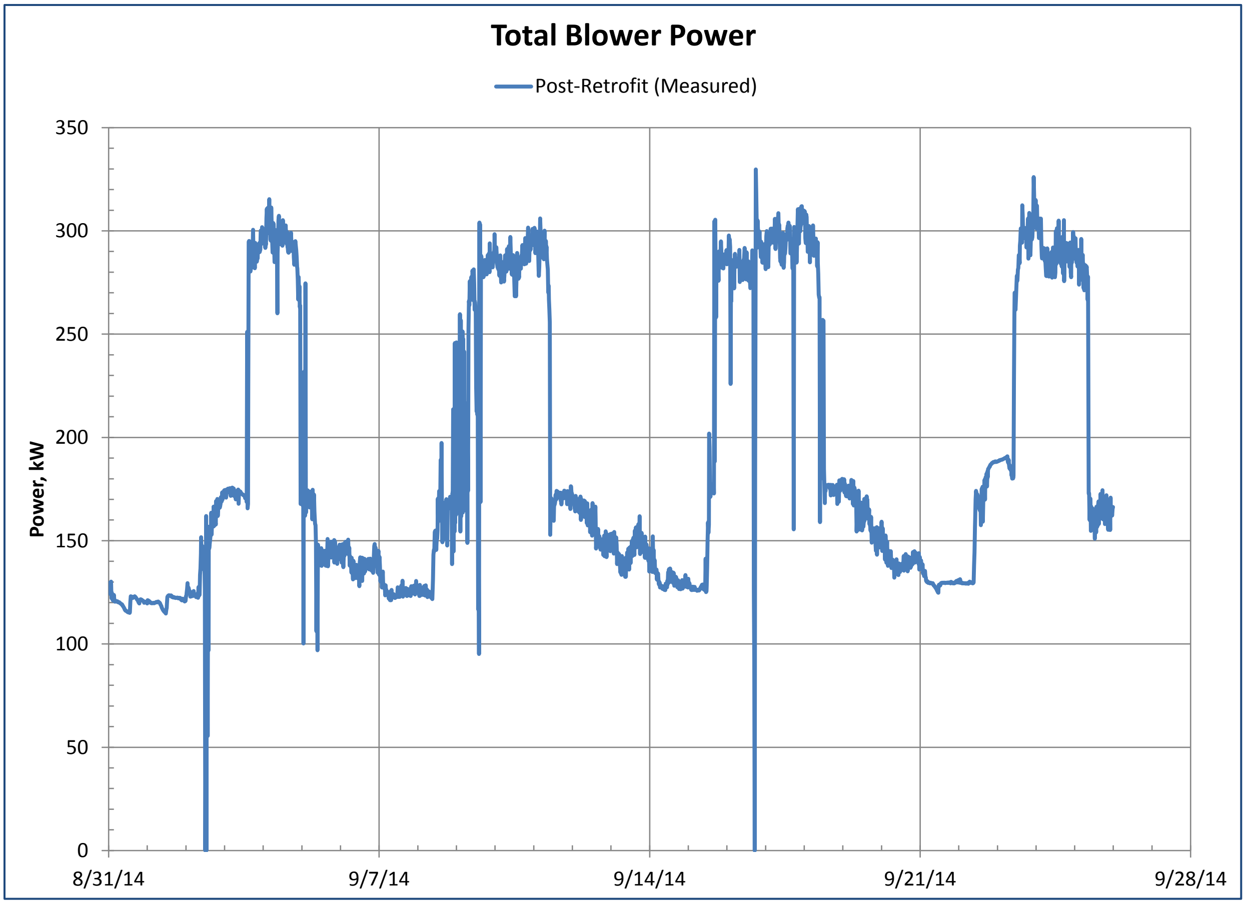


Figure 4: Total Blower Motor Power, Post-Retrofit.

There is a definite pattern of increased blower usage in the middle of the week. The maximum observed power during the monitoring period was 329.7 kW. The maximum coincident peak power observed during the monitoring period was 312.4 kW. For 2014, the coincident peak hour for North Carolina is on July 17th from 3-4 p.m. Since this date and time was not captured in the monitored data, the coincident peak demand was estimated as the maximum demand observed in the 3-4 PM hour on any weekday of the monitoring period.

The following two charts show the total energy consumption per day during the monitoring period, and a weekly profile of average power requirements. The average energy consumption per day ranges from 3050 kWh/day on Sundays to 6540 kWh/day on Wednesdays, with an average of 4516 kWh/day or 31,615 kWh/week. Extrapolating to an average value gives an annual energy consumption of about 1,648,500 kWh per year.

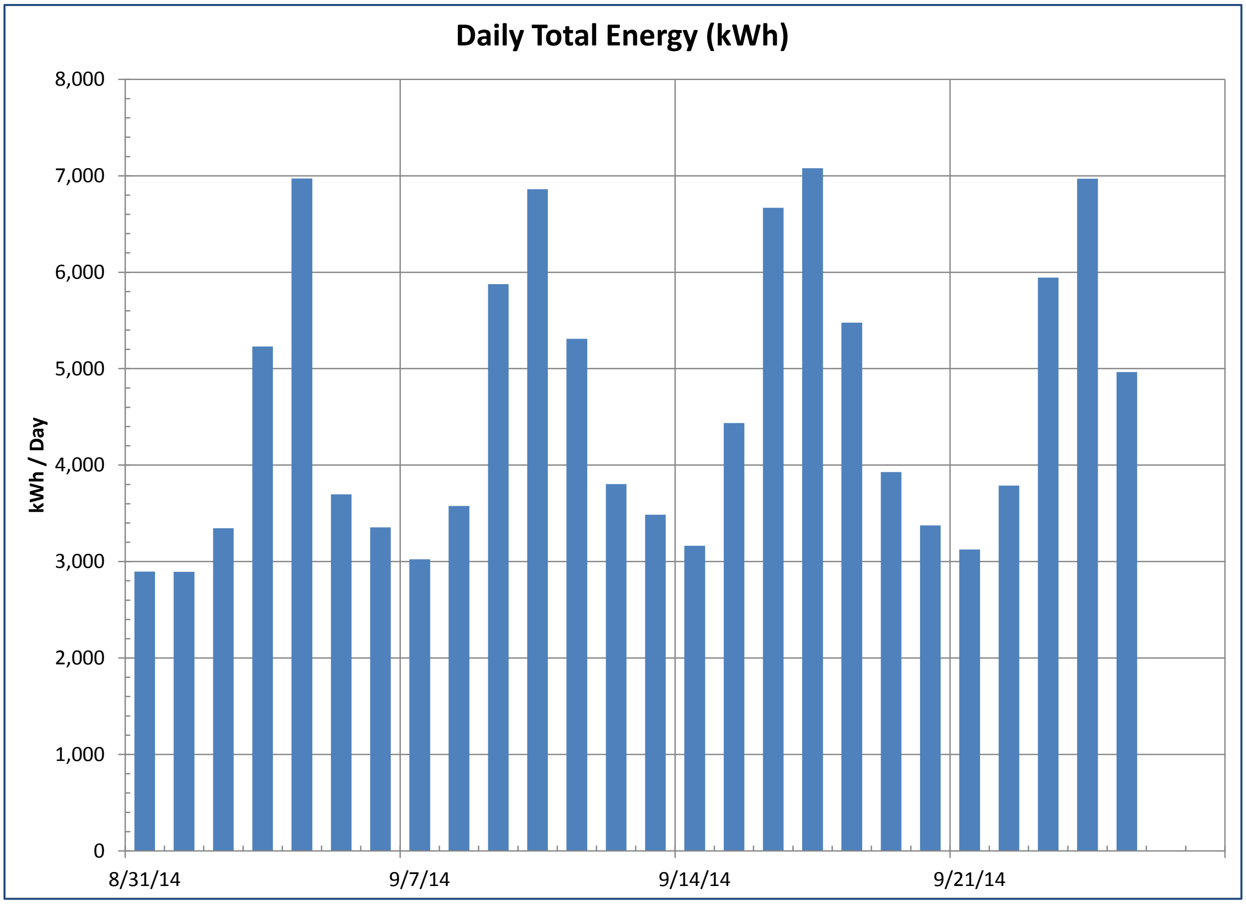


Figure 5: Daily Total Energy Consumption.

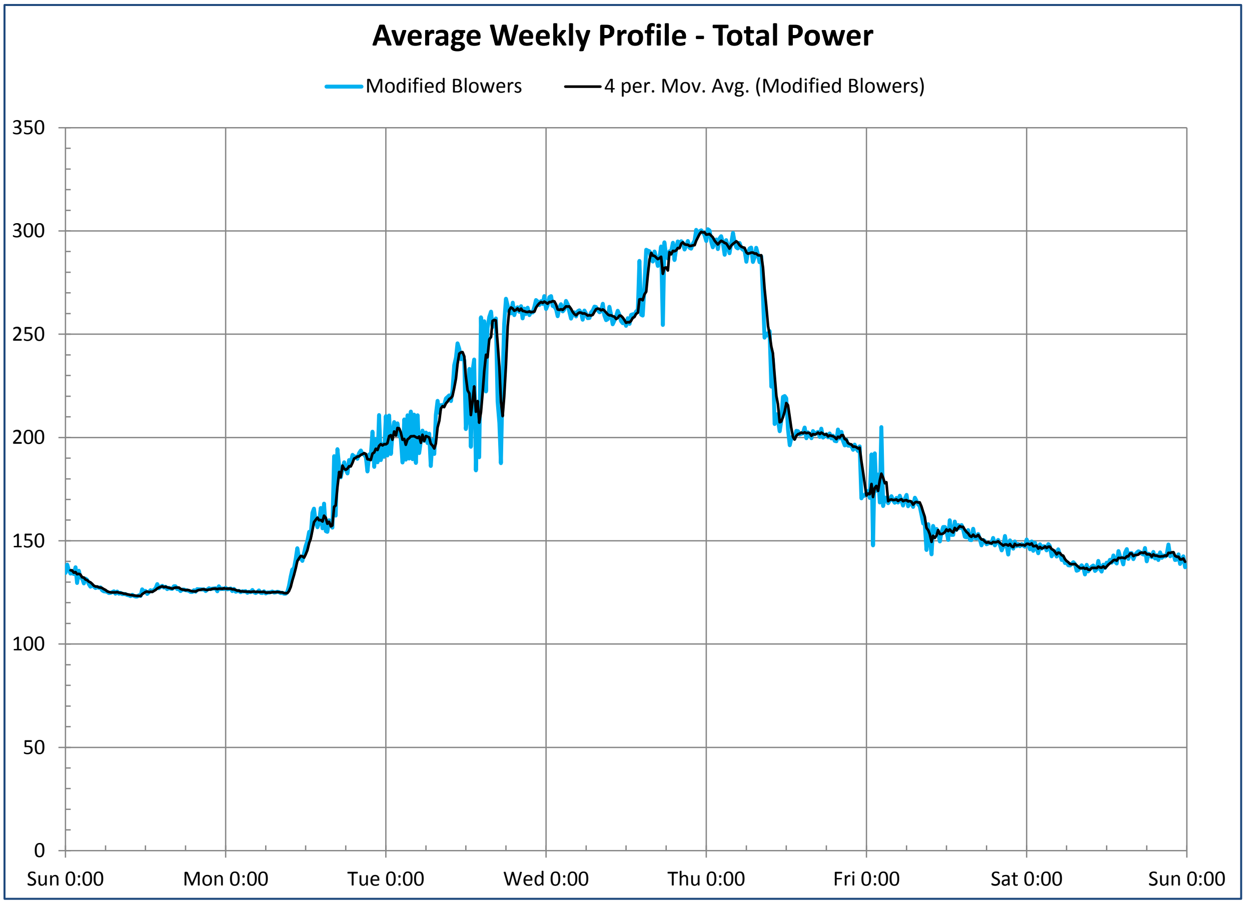


Figure 6: Average Weekly Power Profile, Post-Retrofit.

As previously mentioned, the pre-retrofit situation required two blowers to operate on average, and four blowers for peak loads. For all four blowers running, the application documents estimate the pre-retrofit peak power to be 986 kW; for two blowers running, the average pre-retrofit power is half that number, or 493 kW. Since there was no opportunity to evaluate the blower energy usage independently prior to the retrofit, we used these values as the basis for determining energy savings.

Correlating the pre-retrofit peak power to the peak power observed during the monitoring effort, and the average pre-retrofit power to the average observed, enables us to estimate what the pre-retrofit history would have been for the loads observed in this study. A graph of that estimated history is shown below, followed by a corresponding weekly profile. Using the average pre-retrofit power value, the average energy consumption is 82,824 kWh/week, or about 4,318,700 kWh per year.

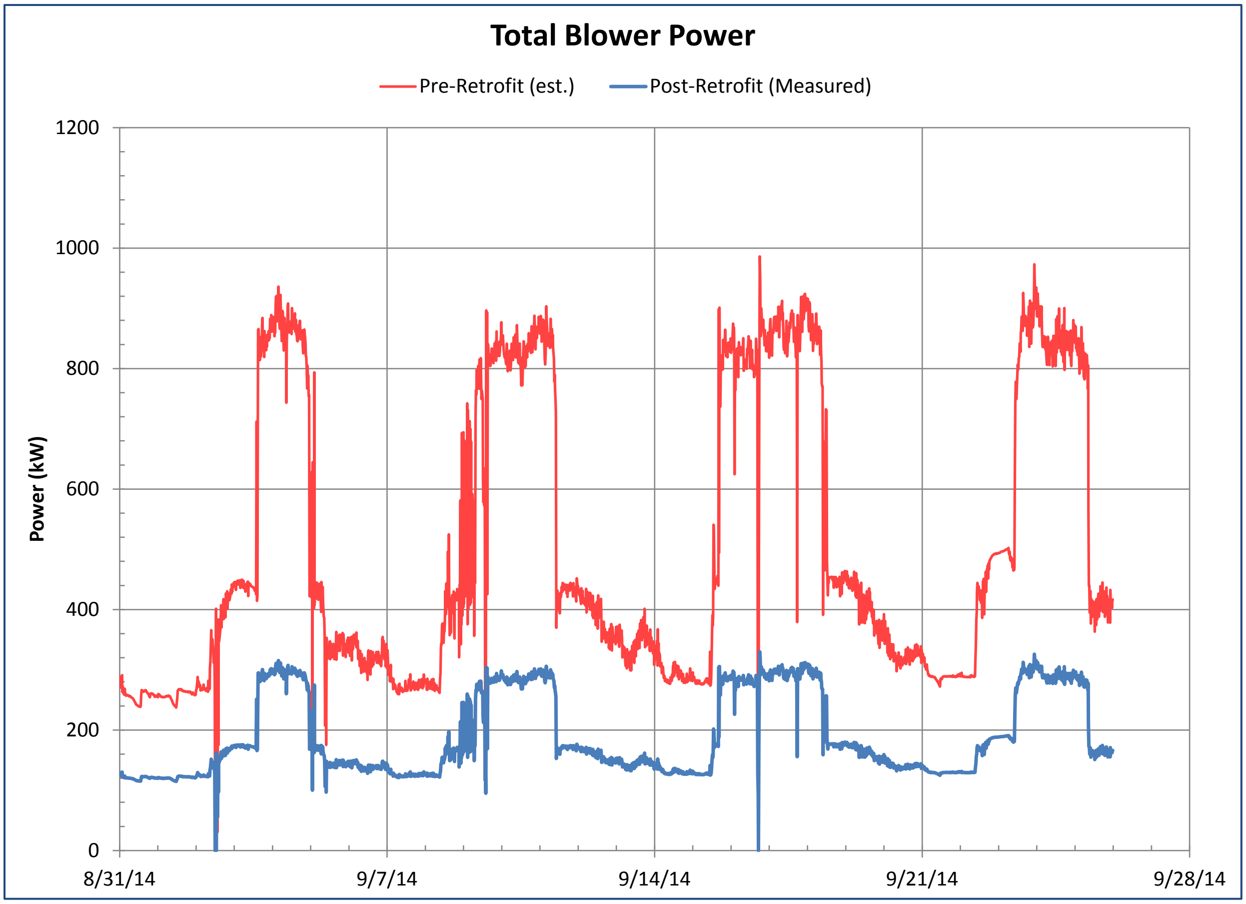


Figure 7: Total Blower Motor Power including Estimated Pre-Retrofit System.

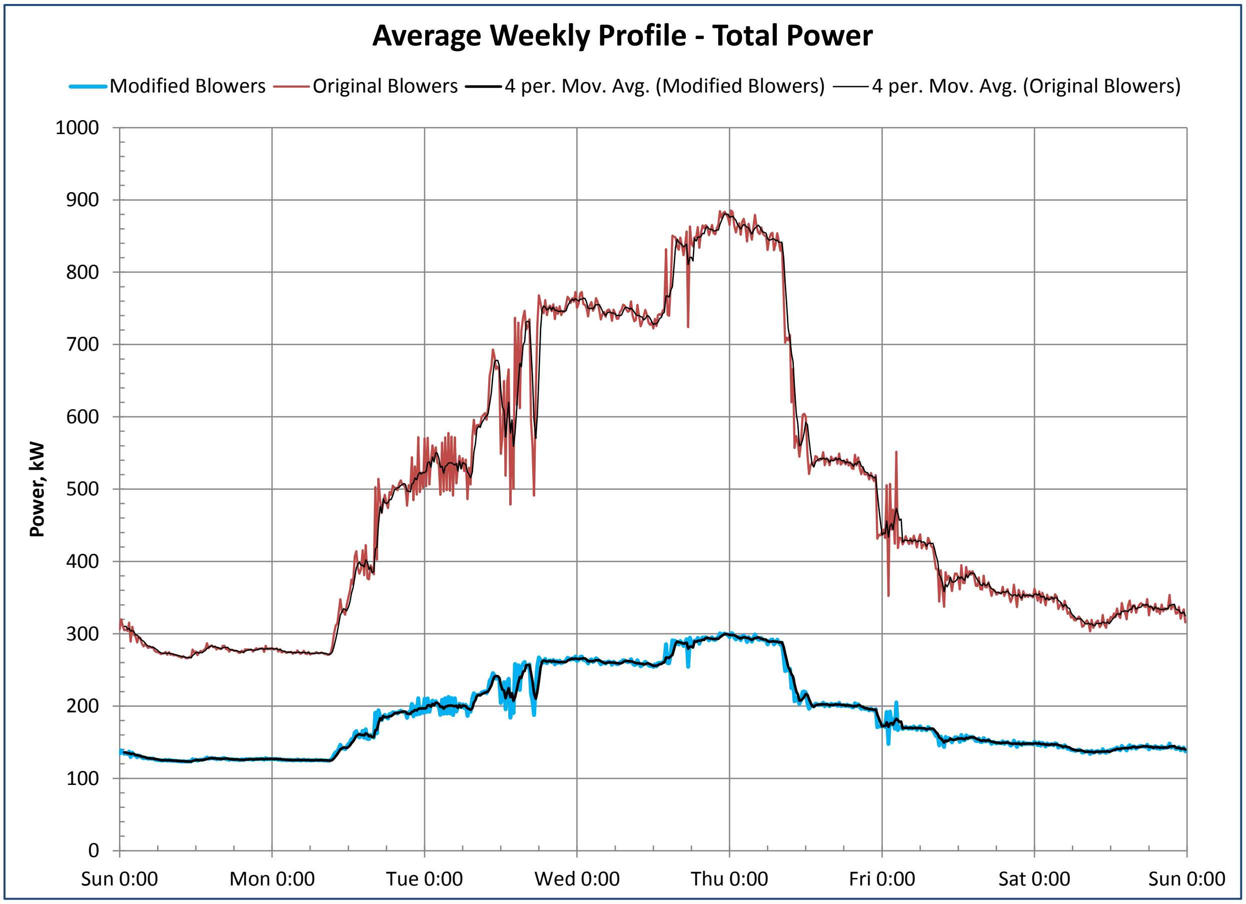


Figure 8: Average Weekly Power Profile including Estimated Pre-Retrofit System.

Summarizing the above findings and comparing the M&V energy and demand savings to the Duke projected values gives the following results:

Table 1: M&V Savings Summary and Realization Rates

	Annual Energy (kWh)	Annual Coincident Peak Demand (kW)	Annual Non-Coincident Peak Demand (kW)
Pre-Retrofit Baseline	4,318,680	986.0	986.0
Post-Retrofit M&V Results	1,648,482	312.4	329.7
M&V Savings	2,670,198	673.6	656.3
Duke Projected Savings	2,885,315.24	329.4	329.22
Realization Rates	93%	204%	199%

The realized energy savings were close to those expected, and the realized demand savings were close to those proposed in the program participation application (but more than the savings expected by Duke Energy).

Application ID 13-1458788
Compressed Air
M&V Report

August 5, 2016

Duke Energy Carolina
139 East Fourth Street
Cincinnati, OH 45201

The Cadmus Group, Inc.

An Employee-Owned Company • www.cadmusgroup.com

CADMUS

Prepared by:
Dave Korn
Christie Amero

Cadmus

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Introduction

This report addresses M&V activities for one retrofit energy conservation measure (ECM) conducted as part of the [redacted] Smart $aver custom incentive program application; specifically, this addressed the replacement of controls for three air compressors at one location in [redacted], NC.

Cadmus based the following facility and equipment descriptions on the original project documentation.

Facility Description: This plant manufactures plywood products and operates five shifts per day. Descriptions follow of the site's compressed air equipment:

- One Sullair, 25-200L, single-stage, 200-hp, 1,000 ACFM* with inlet modulation with blowdown control
- One Sullair, 25-200H, single-stage, 200-hp, 900 ACFM* with inlet modulation with blowdown control
- One Sullair, LS25S-250L, single-stage, 250-hp, 1,218 ACFM* with variable displacement control

*ACFM is the rated actual volumetric flow rate in cubic feet per minute, in the pipework after the compressor.

ECM-1—Load Shifting from Less-Efficient Compressors to More Efficient Compressors

Pre-Retrofit: In the pre-retrofit case, the two inlet modulation compressors (i.e., Compressor 1 and Compressor 3) and the variable displacement compressor (Compressor 2) equally shared the compressed air load.

Installed: In the installed case, the load shifted primarily to the 250-hp variable displacement compressor, with the 200-hp compressors turning on as needed. Variable displacement controls were also added to the existing 200-hp compressors. This configuration was expected to save energy by reducing part load and unloaded operation on all three compressors. Table 1 (below) summarizes this load shift.

The measure included a pressure flow controller, which allowed plant pressure to reduce plant air pressure by 10 psi to 95 psi, further increasing efficiency.

Variable displacement compressors operate more efficiently than inlet modulation compressors, but not quite as efficiently as variable speed compressors. Variable displacement compressors rely on multiple control systems (i.e., variable capacity valve, inlet valve, pressure switch) that function simultaneously. A variable speed compressor adjusts the operating speed of the compressor to match demand.

Table 1. Comparison of Pre- and Post-Installation Load Division

Comp #	Pre-Retrofit					Installed				
	Shift 1	Shift 2	Shift 3	Shift 4	Shift 5	Shift 1	Shift 2	Shift 3	Shift 4	Shift 5
Comp-1	31%	36%	45%	50%	59%	0%	0%	0%	0%	0%
Comp-3	31%	36%	45%	50%	59%	0%	0%	13%	27%	58%
Comp-2	31%	36%	45%	50%	59%	74%	87%	100%	100%	100%

Table 2 shows expected annual operating hours per shift and compares the total compressed air flow demand per shift in the pre- and post-installation cases.

Table 2. Annual Operating Hours and Total Required Flow Rate per Shift

Shift #	Annual Hours	Pre Required Flow, CFM	Post Required Flow, CFM	Pre Required Flow, million CF	Post Required Flow, million CF
1	961	960	902	55.4	52.0
2	626	1,125	1,057	42	40
3	4,816	1,418	1,333	410	385
4	2,250	1,557	1,463	210	198
5	84	1,850	1,739	9	9
Total	**8,737**	**-**	**-**	**727**	**683**

The shift total airflow in the post-installation case is ~100 CFM less than in the pre-retrofit case—a reduction of about 6%.

Goals and Objectives

Table 3 shows the projected savings goals identified in the project application.

Table 3. Project Goals

Applicant		Duke Energy			
Annual kWh Savings	Avg. Demand Reduction, kW	Projected Annual kWh Savings*	Claimed Annual kWh Savings	Claimed Coincident Peak kW Reduction	Claimed Non-CP kW Reduction
1,342,200	87	1,240,013	1,239,992	141.6	141.5

* Source: DSMore input spreadsheet.

The M&V project sought to verify the actual numbers for the following:

- Facility peak demand reduction (kW)
- Summer utility coincident peak demand reduction (kW)
- Annual energy savings (kWh)
- Annual realization rates (kW and kWh)

Project Contacts

The Duke Energy contact listed in Table 4 granted approval to plan and schedule the site visit for this M&V effort.

Table 4. Project Contacts

Organization	Contact	Contact Information
Duke Energy	Frankie Diersing	p: 513-287-4096 Frankie.diersing@duke-energy.com
Cadmus	Christie Amero	p: 303-389-2509 christie.amero@cadmusgroup.com
Customer	redacted	

Site Location

The location this measure was installed is shown in Table 5.

Table 5. Project Location

Address	ECM
redacted	1

M&V Option

To assess this project, Cadmus utilized IPMVP Option A.

Implementation

Cadmus reached out to the site contact provided by Duke Energy, seeking to review the evaluation plan and schedule the site visit. The site contact confirmed the equipment was served by 480 V and used flexible regarding scheduling. On January 5, 2016, Tom Davis of Cadmus performed the site visit.

Field Notes

During the site visit, Cadmus met with the site contact to review the metering plan and to collect general operating information. The facility operates 24/7, year-round, and the compressed air discharge pressure is maintained at 110 psi. The contact did not note any changes in production schedules since the new controls were installed. Currently, the site does not have trends set up on the compressed air system.

Field Data

Cadmus collected the data shown in Table 6 for all installed equipment included in the application.

Table 6. Installed Equipment Nameplate Data

Equipment ID	Make	Model #	Serial Number	hp	Control Strategy
Comp-1	Sullair	LS25-200L AC	003-119610	200	Single-Stage
Comp-2	Sullair	LS25S-250L AC	N/A	250	Variable Displacement
Comp-3	Sullair	LS25S-200H AC	N/A	200	Single-Stage

During the site visit, Cadmus photographed the compressors and associated nameplates: Figure 1 shows Sullair Compressor #2; Figure 2 shows the electrical panel for Sullair Compressor #1; and Figure 3 shows the nameplate for Compressor #1.

Figure 1. Sullair Compressor #2

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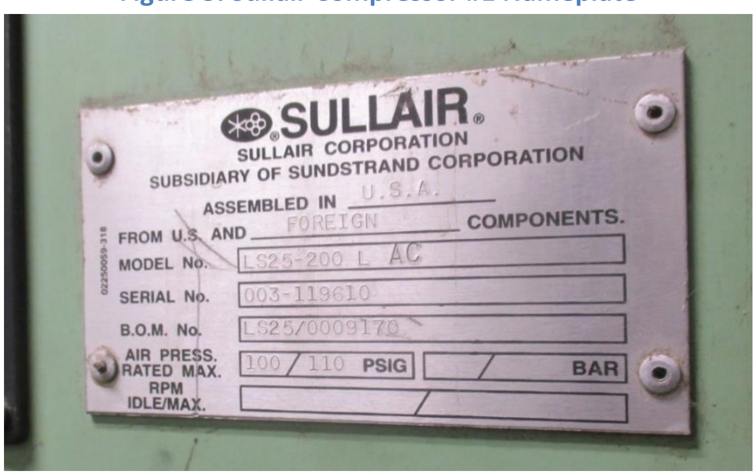
Figure 2. Sullair Compressor #1 Panel

Figure 3. Sullair Compressor #1 Nameplate



Cadmus installed three-phase electric power meters in all three air compressors. These collected data for two weeks at one-minute intervals. Table 7 summarizes the installed metering equipment.

Table 7. Summary of Installed Metering Equipment

Equipment ID	RX3000	WattNode 3D-480	Current Transducers (Qty/Size)
Comp-1	1	1	3 / 400 A
Comp-2	1	1	3 / 1200 A
Comp-3		1	3 / 400 A
Total	**3**	**3**	**9**

Figure 4, Figure 5, and Figure 6 summarize the metered demand data for compressor #1, #2, and #3, respectively, during the metering period.

Figure 4. Sullair Compressor #1 Power Metered Data

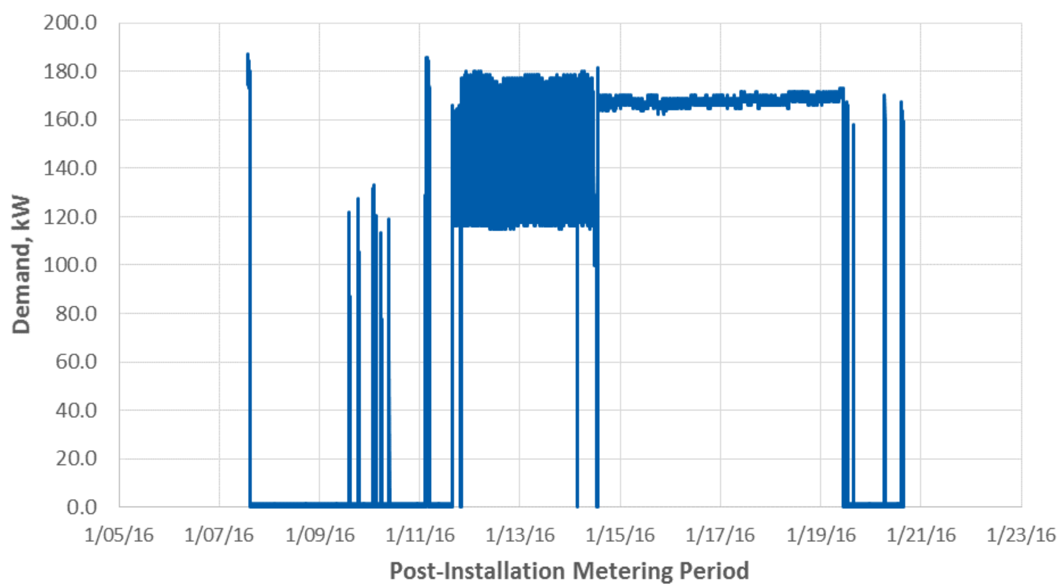


Figure 5. Sullair Compressor #2 Power Metered Data

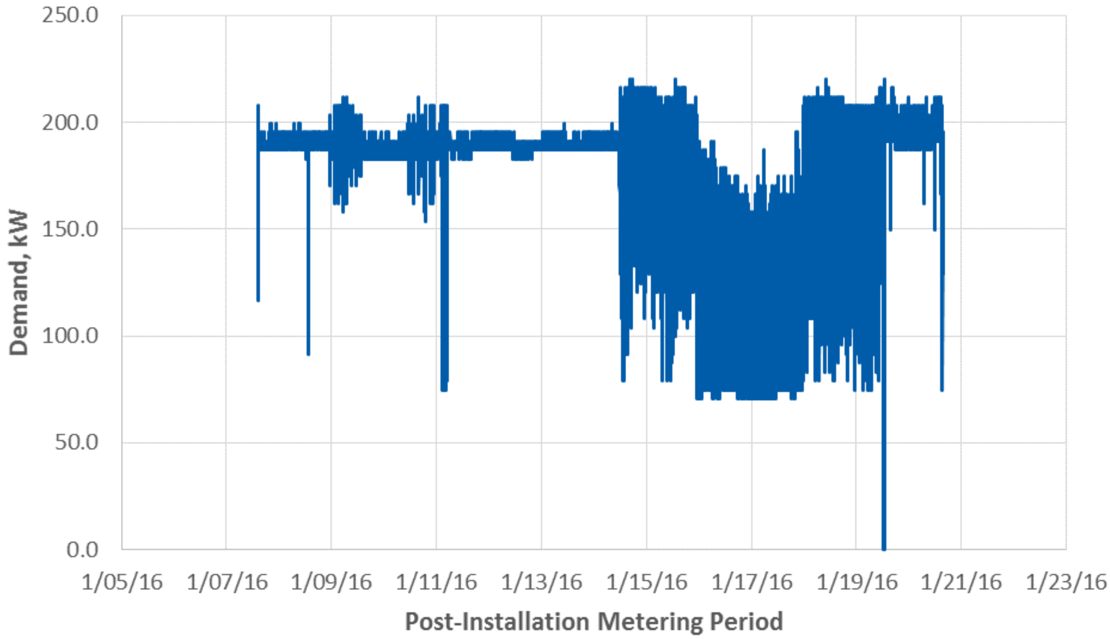
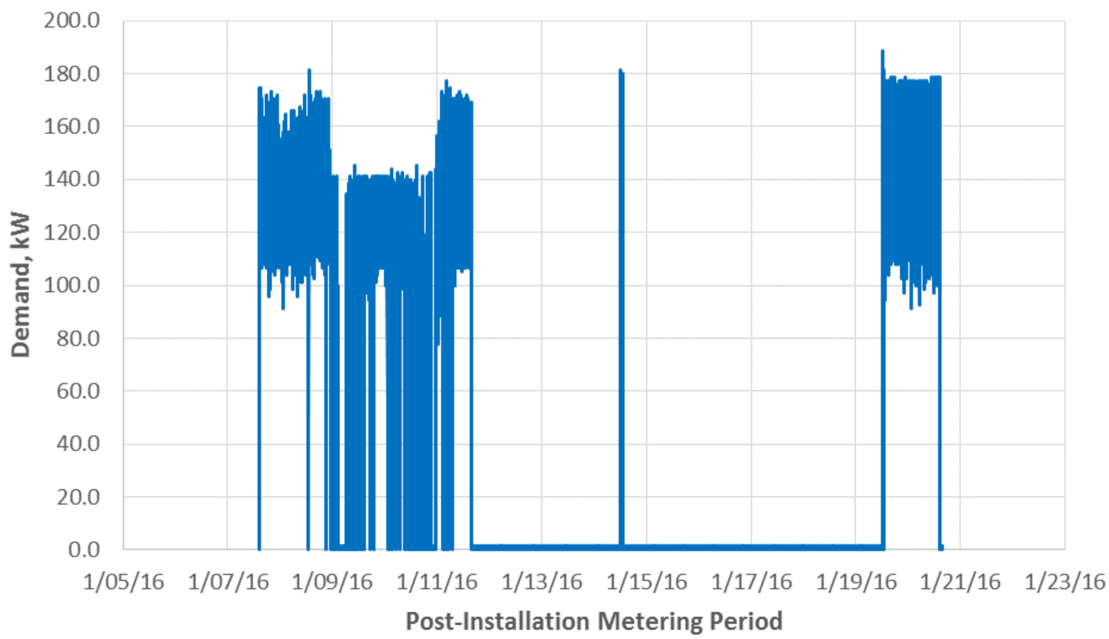


Figure 6. Sullair Compressor #3 Power Metered Data



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Data Accuracy

Table 8. Metering Equipment Accuracy

Measurement	Sensor	Accuracy	Notes
Power, kW	WattNode Power Meter	±1%	-
Current, amps	Magnelab CT	±1%	Recorded load must be < 130% and > 10% of CT rating

Data Analysis

The results of the first analysis indicated much higher installed energy use than was originally expected. After reviewing the data and discussing the results with Duke Energy, Cadmus contacted the site to confirm whether there had been any changes in equipment operation or increases in production that may have caused the increased compressed air demand. The site contact confirmed that there had not been any increases in production, but that there had been an issue with the equipment during the metering period. Much of the site's piping is located outside and the valve on the regenerative dryer serving the air compressors had frozen on January 14th, a week into the metering period. The site was able to bypass the dryer, but this caused the air compressors to work harder than usual to meet the same compressed air load. The site installed a new refrigerated air dryer in February and has not experienced any freezing issues since.

The plots of the metered data for the three compressors confirm a change in operation around January 14th. Based on the this and the site contact's information, Cadmus used the first week of post-installation metered data to verify the controlled equipment's power demand and operating hours. Table 9 summarizes average daily operating demand and percent operating for each compressor from the power metered data collection.

Table 9. Summary of Power Metered Data

Weekday	Compressor #1		Compressor #2		Compressor #3	
	% Operating	Avg. kW	% Operating	Avg. kW	% Operating	Avg. kW
Monday	48%	120.0	100%	187.7	64%	121.4
Tuesday	100%	142.1	100%	189.7	10%	1.4
Wednesday	100%	143.7	100%	190.6	10%	1.4
Thursday	65%	133.3	100%	187.3	48%	122.1
Friday	10%	1.4	100%	190.6	97%	132.7
Saturday	12%	13.7	100%	190.7	66%	106.6
Sunday	15%	23.4	100%	189.5	65%	105.7
Average	**50%**	**82.51**	**100%**	**189.45**	**51%**	**84.46**

As expected, Compressor #2 operated as the lead compressor, running during a majority of the metering period; Compressor #1 and #3 have reduced operating hours.

The evaluated installed case annual energy use was 2,394,523 kWh. The coincident peak demand was 287.9 kW, and the average annual demand was 273.3 kW.

As trend data were unavailable from the site, and the project involved an airflow demand reduction, Cadmus used the pre-retrofit average daily shift airflow demand provided in the original documentation (shown in Table 2). Average daily airflow demand was 1,387 CFM, and the load evenly divided over the three compressors in the pre-retrofit case (462 CFM each). The part-load curves shown below were used to estimate the average compressor demand.

Figure 7 shows the part-load curve for a variable displacement compressor (Compressor 2). Figure 8 shows the part-load curve for a single-stage compressor (Compressor 1 and 3).

Figure 7. Variable Displacement Compressor Part-Load Curve (% kW vs. % Capacity)

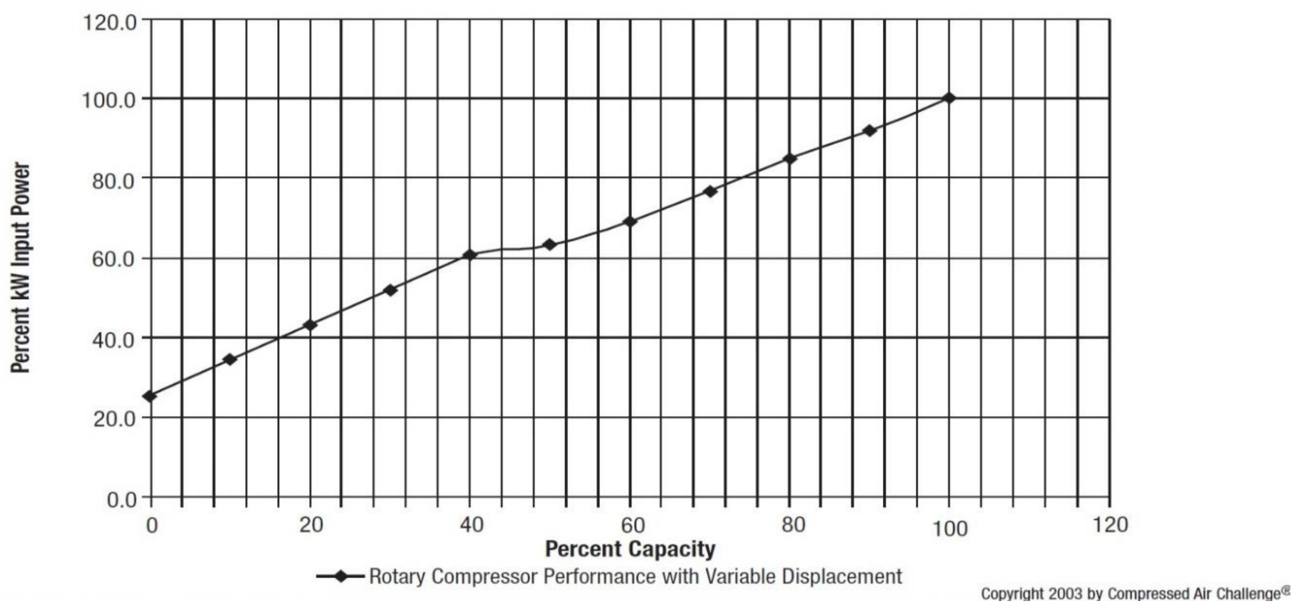
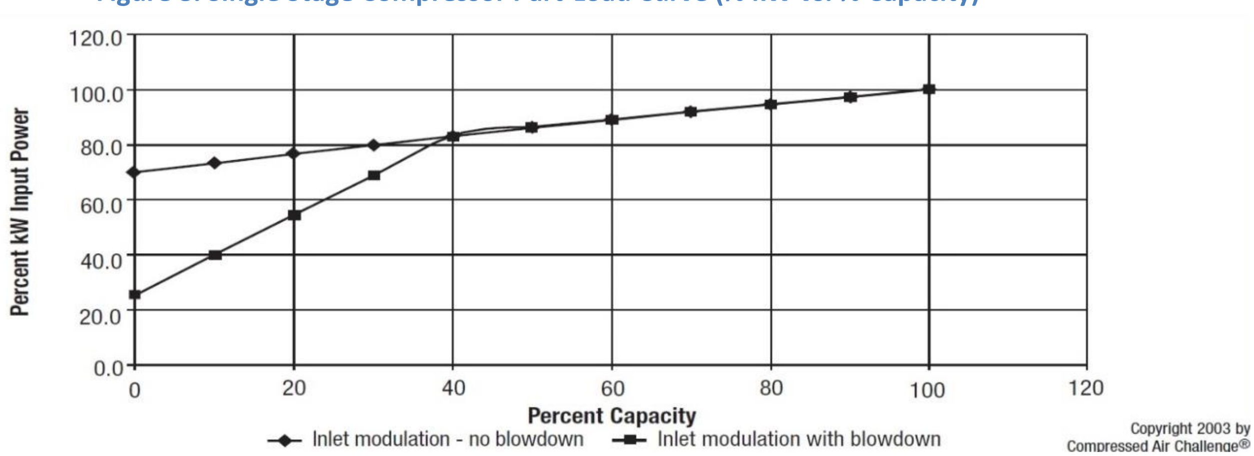


Figure 8. Single Stage Compressor Part-Load Curve (% kW vs. % Capacity)



Cadmus assumed pre-retrofit operating hours equaled the installed case. Table 10 summarizes the pre-retrofit calculations.

Table 10. Summary of Pre-Retrofit Energy Use Calculations

Parameter	Compressor #1 (Single-Stage)	Compressor #2 (Variable Displacement)	Compressor #3 (Single-Stage)
Nameplate hp	200	250	200
Rated ACFM	1,000	1,218	900
Avg. % Capacity	46%	38%	51%
Avg. % kW (from curves)	84%	60%	88%
Full Load Demand, kW	157.0	196.3	157.0
Avg. Operating Demand, kW	131.9	117.8	138.2
Total Avg. Weekly Demand, kW			**387.9**

Evaluated pre-retrofit annual energy use was 3,388,869 kWh; coincident peak demand was 386.9 kW; and average annual demand was 386.9 kW.

Total evaluated energy savings were 994,346 kWh. The evaluated total summer coincident peak demand reduction (July, Monday–Friday, 4:00–5:00 p.m.) was 99.0 kW, and the average, or non-coincident, peak demand reduction was 113.5 kW.

Conclusion

Cadmus found the compressor control system installed as expected. The overall energy savings realization rate was 80%, compared to the Duke Energy claimed savings. The summer peak demand realization rate was calculated as 70%. The average (or non-coincident) peak demand reduction realization rate was 81%.

The main impact on the reduced evaluated energy savings and demand reduction was that the average weekly metered demand for the installed compressed air controls was 10% higher than that expected in the original study.

Table 11 compares the applicant, Duke Energy claimed, and evaluation energy savings and demand reduction. Table 12 provides realization rates compared to the energy savings and demand reductions claimed by Duke Energy.

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Table 11. Comparison of Applicant, Duke Energy Claimed, and Evaluation Energy Savings and Demand Reduction

Applicant		Duke Energy Claimed			Evaluation		
Annual kWh Savings	Avg. kW Reduction	Annual kWh Savings	Coincident Peak kW Reduction	Non-CP kW Reduction	Annual kWh Savings	Coincident Peak kW Reduction	Non-CP kW Reduction
1,342,200	87	1,239,992	141.6	141.5	994,346	99.0	113.5

Table 12. Energy Savings and Demand Reduction Realization Rates

Annual kWh Savings	Coincident Peak kW Reduction	Non-CP kW Reduction
80%	70%	80%

Application ID 13-1492004
HVAC
M&V Report

January 24, 2017

Duke Energy
139 East Fourth Street
Cincinnati, OH 45201

The Cadmus Group, Inc.

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CADMUS

Prepared by:
Dave Korn
Christie Amero

Cadmus

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Introduction

This report outlines Cadmus' measurement and verification (M&V) activities for one retrofit energy conservation measure (ECM) included as part of the [redacted], Smart $aver custom incentive program application—specifically for optimizing the site's chilled water plants. Energy savings were expected to result from improved chiller performance and reduced pump and fan demand. A description of the measure as submitted in the original application documentation is provided below.

ECM-1: Chilled Water Plant Optimization

The approximately 1,000,000 square-foot [redacted] provides urgent care, general medicine, trauma, and rehabilitation services, operating 24 hours per day, year-round. The annual electric energy use is approximately 39,500,000 kWh, based on 2012 and 2013 utility data; [redacted]'s design day chilled water load is 4,800 tons.

Pre-Retrofit: [Redacted] was previously served by two chiller plants, referred to as CEP-1 and CEP-2. CEP-1 used standard, constant-speed equipment while CEP-2 used new, high-performance, variable-speed equipment. A summary of the pre-retrofit chilled water plant equipment follows.

Chilled Water Plant 1 (CEP-1)

- Four constant-speed chillers
- Four constant-speed condenser water pumps
- Four constant-speed primary water pumps
- Four variable-speed cooling towers
- Four variable-speed secondary water pumps

Chilled Water Plant 2 (CEP-2)

- Two variable-speed chillers
- Two constant-speed condenser water pumps
- Two constant-speed primary water pumps
- Two variable-speed cooling towers
- Two variable-speed secondary water pumps

In the original analysis, the pre-retrofit average annual total plant performance (including chillers, pumps, cooling towers, and other equipment) was assumed to be 0.68 kW/ton.

Installed: For this project, [redacted] installed additional, high-performance, variable-speed equipment and a Hartman Loop chiller plant optimization control system for CEP-2, and it decommissioned CEP-1. A summary of the upgraded chilled water plant equipment (CEP-2) follows.

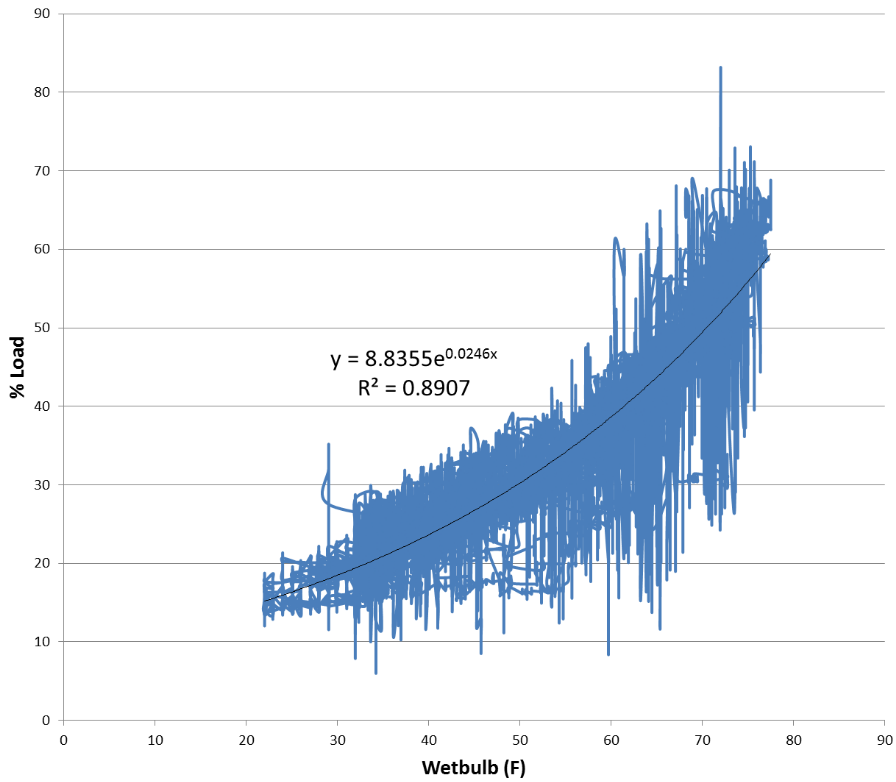
Upgraded Chilled Water Plant (CEP-2)

- Five variable-speed chillers (two existing 1,200-ton units; three new 1,300-ton units)
- Five 75-hp variable-speed condenser water pumps (installed drives on two existing pumps and added three new pumps with drives)
- Five 40-hp variable-speed primary water pumps (installed drives on two existing pumps and added three new pumps with drives)
- Five variable-speed cooling towers, each with two 30-hp fan motors (two existing, added three new with drives)
- Four 250-hp variable-speed secondary water pumps (two existing, added two new with drives)

The new variable-speed equipment and the Hartman Loop control system allow the facility to optimize the plant operating parameters (chilled water supply temperature, chiller variable frequency drive (VFD) speed and flow rate, pump and fan speeds) in real-time, based on outside air conditions and loads. The installed average annual plant performance was expected to be 0.49 kW/ton.

Energy savings in the original application were calculated using an 8,760 hour model, with typical meteorological year (TMY) data for [redacted], North Carolina. Monthly load profiles, determined using actual data from April and May, were used to create a regression for the 8,760 hour model (shown in Figure 1). The calculated annual load (14,466,596 ton-hours) was assumed equal for the pre-retrofit and installed cases. Based on the plant's performance improvement, annual energy savings were estimated as 2,618,060 kWh in the original analysis, or 7% of the total facility energy use.

Figure 1. Load Profile: Regression Analysis



Goals and Objectives

Table 1 shows the projected savings goals identified in the project application.

Table 1. Project Goals

Application		Duke Energy			
Annual kWh Savings	Average kW Reduction	Projected Annual kWh Savings*	Claimed Annual kWh Savings	Claimed Coincident Peak kW Reduction	Claimed Non-CP kW Reduction
3,050,292	N/A	2,618,060	2,618,060	416.96	511.51

* Source: DSMore input spreadsheet.

Cadmus' objective for this M&V project was to verify the following actual data:

- Facility peak demand reduction (kW)
- Summer utility coincident peak demand reduction (kW)
- Annual energy savings (kWh)
- Annual realization ratios (kW and kWh)

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Project Contacts

Table 2 lists the Duke Energy contact who granted Cadmus approval to plan and schedule the site visit for this M&V effort, along with the Cadmus contact and the customer contact.

Table 2. Project Contacts

Organization	Contact	Contact Information
Duke Energy	Monica Redman, Senior DSM & Retail Programs Analyst	monica.redman@duke-energy.com
Cadmus	Christie Amero, Senior Analyst	office: 303-389-2509 christie.amero@cadmusgroup.com
Customer	redacted	

Site Location

The site location is listed in Table 3.

Table 3. Site Location

Address	ECM
redacted	1

M&V Option

To assess this site, Cadmus followed IPMVP Option A.

Implementation

Cadmus reached out to the site contact provided by Duke Energy, seeking to review the evaluation plan and schedule the site visit. During the initial discussion, Cadmus was informed that the energy management system for the updated chilled water plant records data for the power and energy use of all controlled equipment, so additional on-site power metering was not necessary. Cadmus held a conference call with the site contact and controls representative two weeks before the site visit to select the number of trend points to collect from the system, and sent a list of points to the controls representative ahead of the site visit. Christie Amero of Cadmus performed the site visit on June 23, 2016, to physically verify the installed equipment and collect the trend data.

Field Survey

During the site visit, Cadmus met with the facility manager and controls representative to review the general sequence of operation and collect trend data for the chilled water plant. Since the site is a [redacted], the chilled water plant runs year round, but the lead equipment is rotated throughout the year to maintain equal runtime. According to the site contact, [redacted] has added approximately 200,000 square feet of [redacted] offices and [redacted] rooms since the project was completed and the cooling load has increased.

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Prior to the retrofit, the controls sequence would base load the constant speed system (CEP-1) during the summer months when the cooling load was highest and operate the variable speed system (CEP-2) as a trim system. During the winter months when the cooling load was reduced, CEP-2 was used as the primary system and operated up to capacity before energizing CEP-1.

The post-retrofit chilled water system uses Armstrong's OPTI-VISOR™ controls software to optimize setpoints; the number of chillers, cooling towers, pumps, and fans operating; and VFD speed on a real-time basis. For example, the controls reset the chilled water supply temperature based on outside air temperature (where a lower outside air temperature leads to a higher chilled water supply temperature). The primary chilled water pump drive speed is varied based on the required chilled water flow rate and the number of chillers operating. The secondary chilled water pump speeds are controlled based on differential pressure. The controls typically operate more cooling towers and condenser water pumps than chillers to provide more surface area for heat transfer. The equipment and controls were fully commissioned by a third-party commissioning agent.

Overall, the site contact is very pleased with the outcome of the project and has noticed a significant decrease in the electric utility bill, even with the additional cooling load.

Field Data

ECM-1: Chilled Water Plant Optimization

Cadmus collected the data shown in Table 4 for all installed equipment included in the application.

Table 4. Installed Equipment Nameplate Data

Equipment	Unit ID	Make	Model Number	Serial Number	Capacity	VFD
Chillers	CH-1	York	YKQRQQK1-DAGS	N/A	1,200 tons	Yes
	CH-2	York	YKQRQQK1-DAGS	SLWM-729650	1,200 tons	Yes
	CH-3	Trane	CVHF 1300	L14C01582	1,300 tons	Yes
	CH-4	Trane	CVHF 1300	L14C01575	1,300 tons	Yes
	CH-5	Trane	CVHF 1300	L14C01576	1,300 tons	Yes
Cooling Towers	CT-1	Evapco	N/A	N/A	(2) @ 30-hp	Yes
	CT-2	Evapco	N/A	N/A	(2) @ 30-hp	Yes
	CT-3	Evapco	USS 212-436	10-382799	(2) @ 30-hp	Yes
	CT-4	Evapco	USS 212-436	N/A	(2) @ 30-hp	Yes
	CT-5	Evapco	USS 212-436	N/A	(2) @ 30-hp	Yes
Primary Chilled Water Pumps (Pump and Motor)	PCHWP-1	Bell & Gossett	10X12X12M	C112400-02	40-hp	Yes
		Marathon	JVJ364TTFS6086BT	WAA063639		
	PCHWP-2	Bell & Gossett	10X12X12M	C112400-01	40-hp	Yes
		Marathon	JVH364TTFS6086BT	WAA063173		
	PCHWP-3	Bell & Gossett	10X12X12M	QFF363-01	40-hp	Yes
		Marathon	NVB364TTFCA6086	75331688-1		
	PCHWP-4	Bell & Gossett	10X12X12M	QFF362-02	40-hp	Yes
		Marathon	NVB364TTFCA6086	75331688-1		

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Equipment	Unit ID	Make	Model Number	Serial Number	Capacity	VFD
	PCHWP-5	Bell & Gossett	10X12X12M	N/A	40-hp	Yes
		Marathon	NVB364TTFCA6086	75332446-1		
Secondary Chilled Water Pumps (Pump and Motor)	SCHWP-1	Bell & Gossett	10X12X14	OFD256-01	250-hp	Yes
		Marathon	JVJ449THFS14037A A	WAA063829		
	SCHWP-2	Bell & Gossett	10X12X14	QFD256-02	250-hp	Yes
		Marathon	JVK449THFS14037A A	WAA063864		
	SCHWP-3	Bell & Gossett	10X12X14	QFF393-02	250-hp	Yes
		Marathon	NVD449TSHFS16032	WAA091026		
	SCHWP-4	Bell & Gossett	10X12X14	QFF393-01	250-hp	Yes
		Marathon	NVD449TSHFS16032	WAA091027		
Condenser Water Pumps	CWP-1	Bell & Gossett	10X12X14	C112399-01	75-hp	Yes
		Marathon	JVJ405TTFS6086AT	WAA063612		
	CWP-2	Bell & Gossett	10X12X14	C112399-02	75-hp	Yes
		Marathon	JVJ405TTFS6086AT	WAA063611		
	CWP-3	Bell & Gossett	10X12X14	QFF363-02	75-hp	Yes
		Marathon	NVD405TTFS6086AT	70029385-01		
	CWP-4	Bell & Gossett	10X12X14	QFF363-03	75-hp	Yes
		Marathon	NVD405TTFS6086AT	70029385-02		
	CWP-5	Bell & Gossett	10X12X14	QFF363-01	75-hp	Yes
		Marathon	NVD405TTFS6086AT	70029385-03		

During the site visit, Cadmus also photographed the chilled water plant equipment and nameplates: Figure 2 shows the nameplate for a pre-retrofit York chiller on the left and for a new installed Trane chiller on the right, and Figure 3 shows a controls panel for one of the new installed Trane chillers.

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Figure 2. Pre-Retrofit (left) and Installed (right) Chiller Nameplates

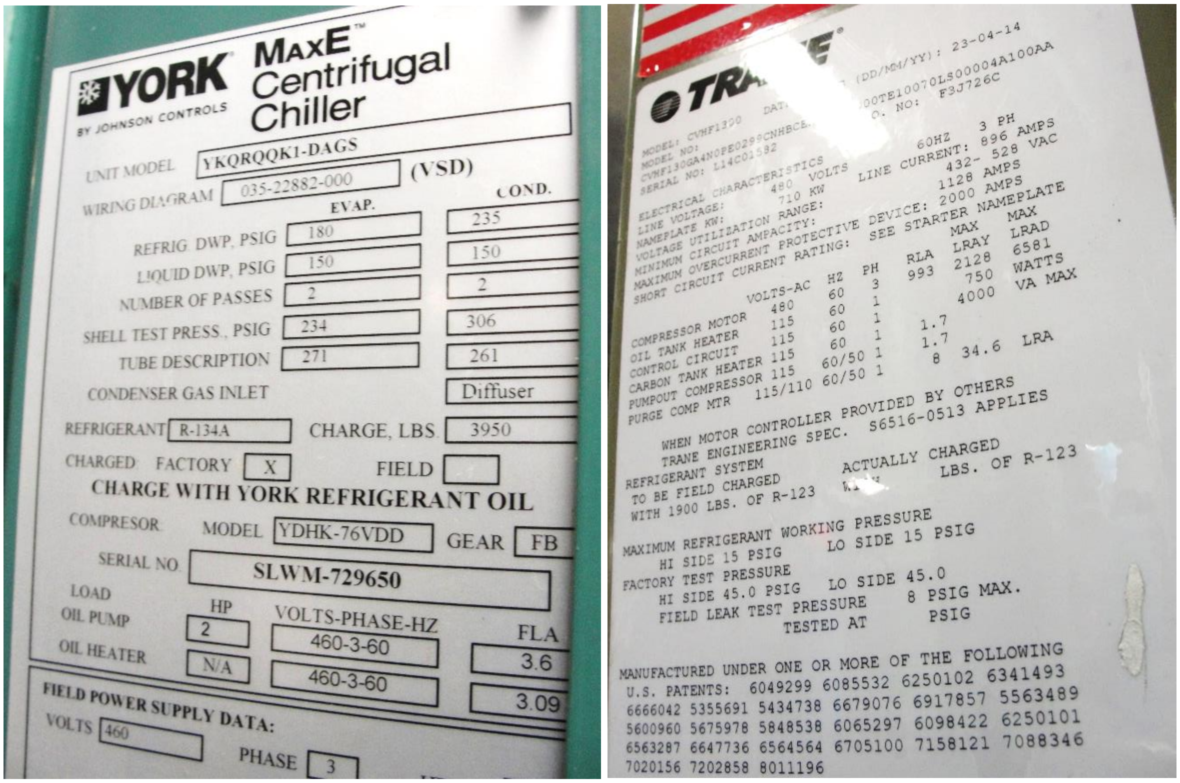

Figure 3. Installed Trane Chiller Control Panel

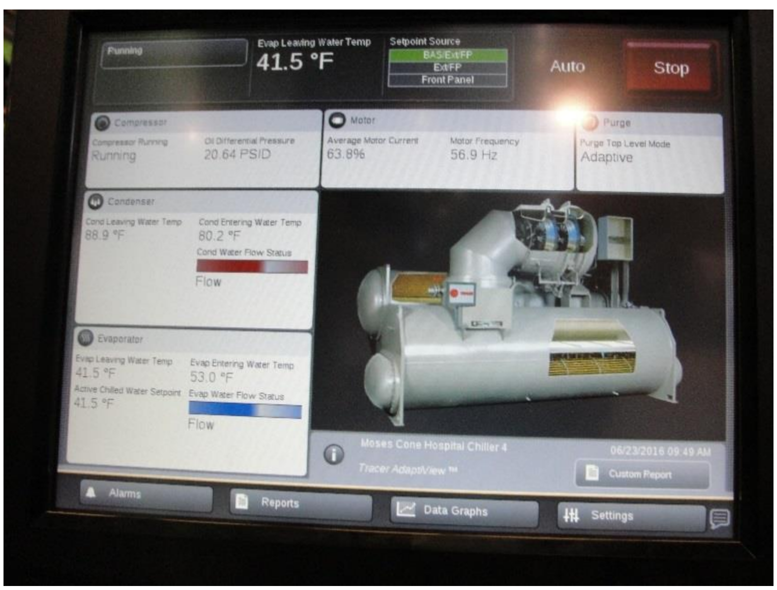

Figure 4 shows some of the VFDs controlling cooling tower fans, and Figure 5 shows the nameplate for one of the new installed cooling towers and the row of towers on the roof of the hospital.

Figure 4. Cooling Tower Fan Variable Frequency Drives

Figure 5. Cooling Tower Array and Nameplate for New Installed Tower

Figure 6 shows two of the drives controlling primary chilled water pumps, and Figure 7 shows the motor and pump nameplates for one of the installed primary chilled water pumps.

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Figure 6. Primary Chilled Water Pump Variable Frequency Drives

Figure 7. Primary Chilled Water Pump – Motor Nameplate (left) and Pump Nameplate (right)

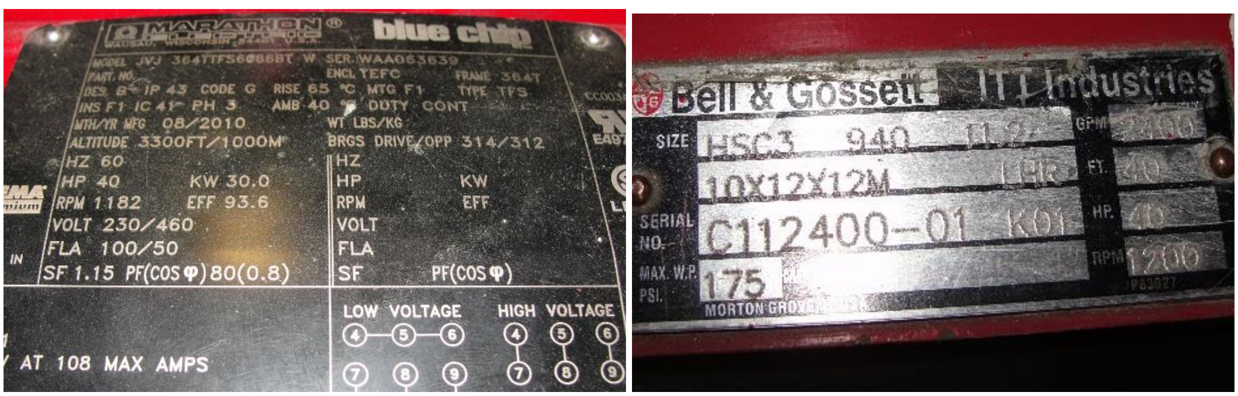

Figure 8 shows two of the drives controlling secondary chilled water pumps, and Figure 9 shows the motor and pump nameplate for one of the secondary chilled water pumps.

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Figure 8. Secondary Chilled Water Pump Variable Frequency Drives

Figure 9. Secondary Chilled Water Pump – Motor Nameplate (left) and Pump Nameplate (right)

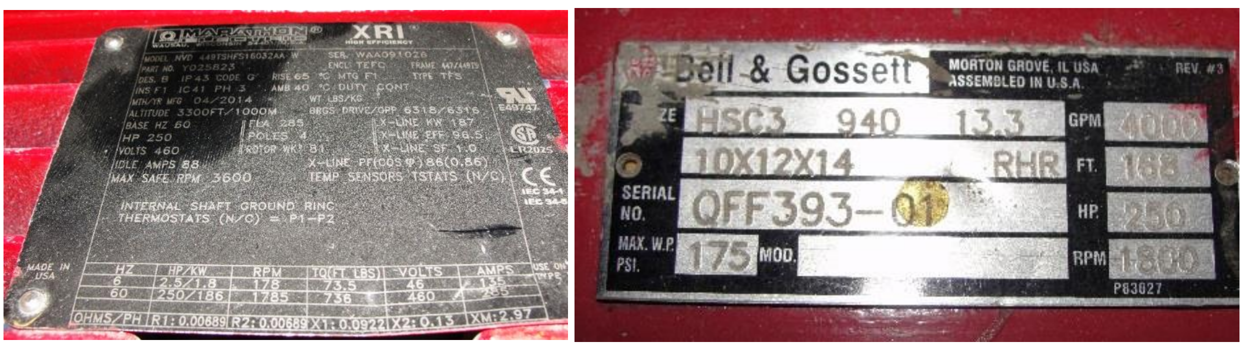

Figure 10 shows one of the drives controlling a condenser water pump, and Figure 11 shows the motor and pump nameplate for one of the condenser water pumps.

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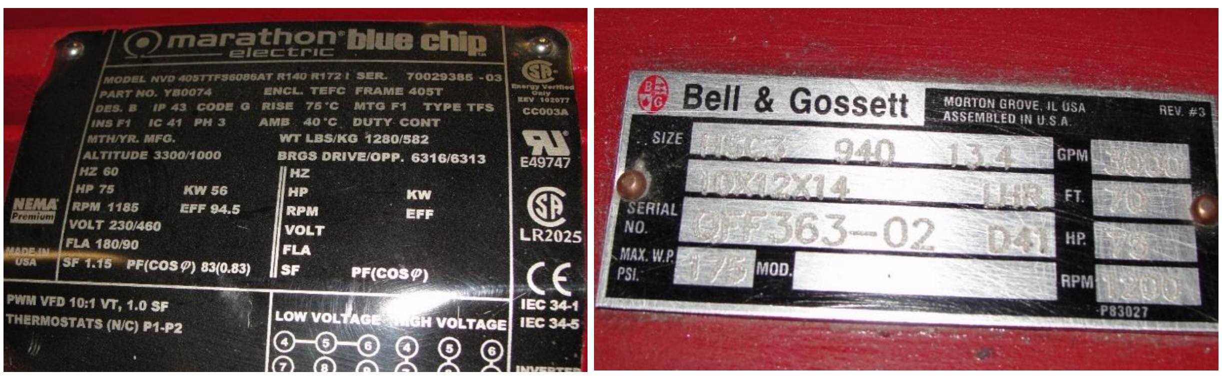
Figure 10. Condenser Water Pump Variable Frequency Drive

Figure 11. Condenser Water Pump – Motor Nameplate (left) and Pump Nameplate (right)



Cadmus also collected one year of site-trended power demand data for all equipment submitted in the application, along with three months (April through June 2016) of flow rates, supply and return temperatures, and outside air conditions. Pump and fan demand was measured by the ABB VFDs for the motors and chiller demand was measured by the internal controls. Table 5 summarizes the trend points that were provided by the site contact.

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Table 5. Trend Points Collected from Site

Equipment ID	Trend Point	Data Interval	Duration
Chillers (CH-1, 2, 3, 4, & 5)	Flow rate (GPM)	5 minutes	3 months
	CHW supply temperature, °F	5 minutes	3 months
	CHW return temperature, °F	5 minutes	3 months
	Input kW	5 minutes	1 year
Condenser Water Pumps (CWP-1, 2, 3, 4, & 5)	Input kW	5 minutes	1 year
Chilled Water Pumps (CHWP-1, 2, 3, 4, & 5)	Input kW	5 minutes	1 year
Cooling Towers (CT-1, 2, & 3)	Entering water temperature, °F	5 minutes	3 months
	Leaving water temperature, °F	5 minutes	3 months
	Fan input kW	5 minute	1 year
Outside Air Conditions	Dry bulb/wet bulb, °F	1 minute	1 year

Data Analysis

ECM-1: Chilled Water Plant Optimization

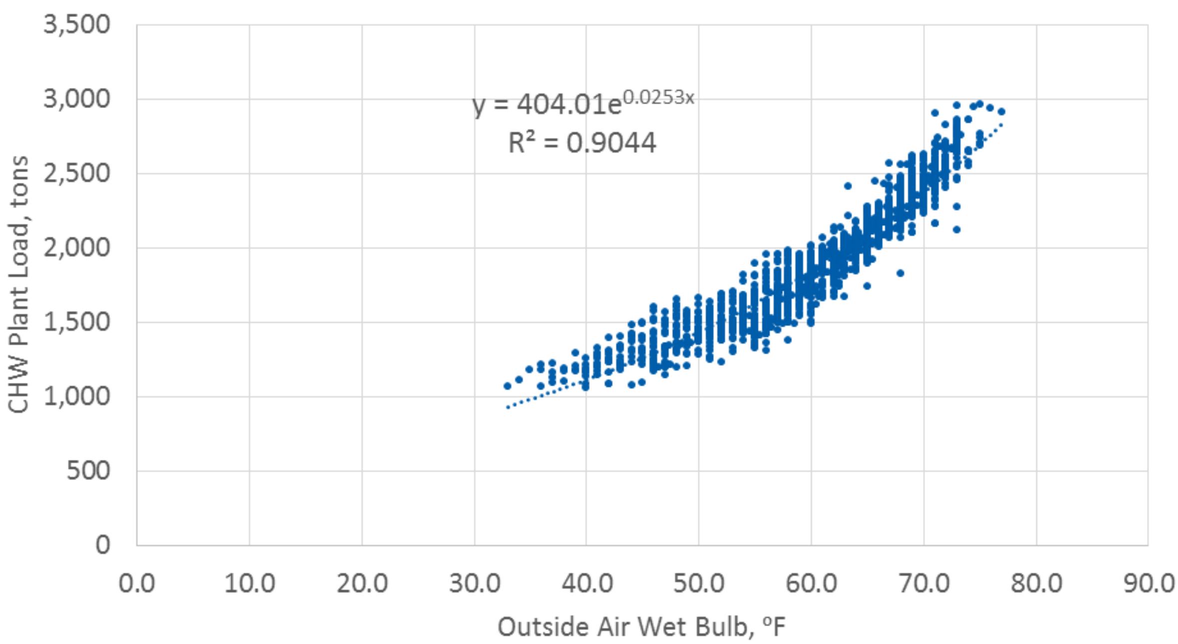
Cadmus used the trend data for the installed equipment to verify the chilled water plant equipment demand and operating hours. Table 6 summarizes the average monthly outside air dry bulb temperature and individual chiller demand from the trend data collection. The installed average monthly chiller demand was used in the 8,760 hour model.

Table 6. Summary of Installed Average Monthly Chiller Demand and Outside Air Temperature

Month	Outside Air Dry Bulb, °F	Average Chiller Demand, kW					
		CH-1	CH-2	CH-3	CH-4	CH-5	Total
January	32.6	6.4	12.5	95.4	69.0	161.6	344.8
February	41.0	8.6	2.5	140.3	54.2	65.3	270.8
March	52.5	2.1	2.1	30.2	79.3	282.9	396.6
April	58.4	47.9	37.8	148.1	239.8	290.0	763.5
May	66.2	16.3	258.1	237.3	257.1	141.4	910.2
June	74.5	164.8	308.0	266.7	275.2	218.1	1,232.7
July	77.8	358.1	2.0	332.6	240.1	267.5	1,200.3
August	76.6	293.1	68.2	284.5	244.3	331.4	1,221.5
September	68.2	61.5	277.8	206.6	204.2	270.9	1,021.0
October	55.6	2.0	206.9	173.4	129.1	134.2	645.7
November	51.5	32.9	140.9	82.4	102.5	154.0	512.7
December	39.6	58.7	119.1	56.3	107.6	196.2	537.9

Cadmus created an 8,760 hour model with TMY data for [redacted], North Carolina. We plotted the trended chilled water plant load against actual outside air wet bulb temperature (see Figure 12), then used the exponential trend fit from this plot to extrapolate the chilled water load to the 8,760 hour model. The total evaluated chilled water annual load was 14,308,149 ton-hours, or approximately 99% of that expected in the original application analysis. For this analysis, we assumed the load was equal in the pre-retrofit and installed cases.

Figure 12. Trended Chilled Water Plant Load vs. Outside Air Wet Bulb Temperature



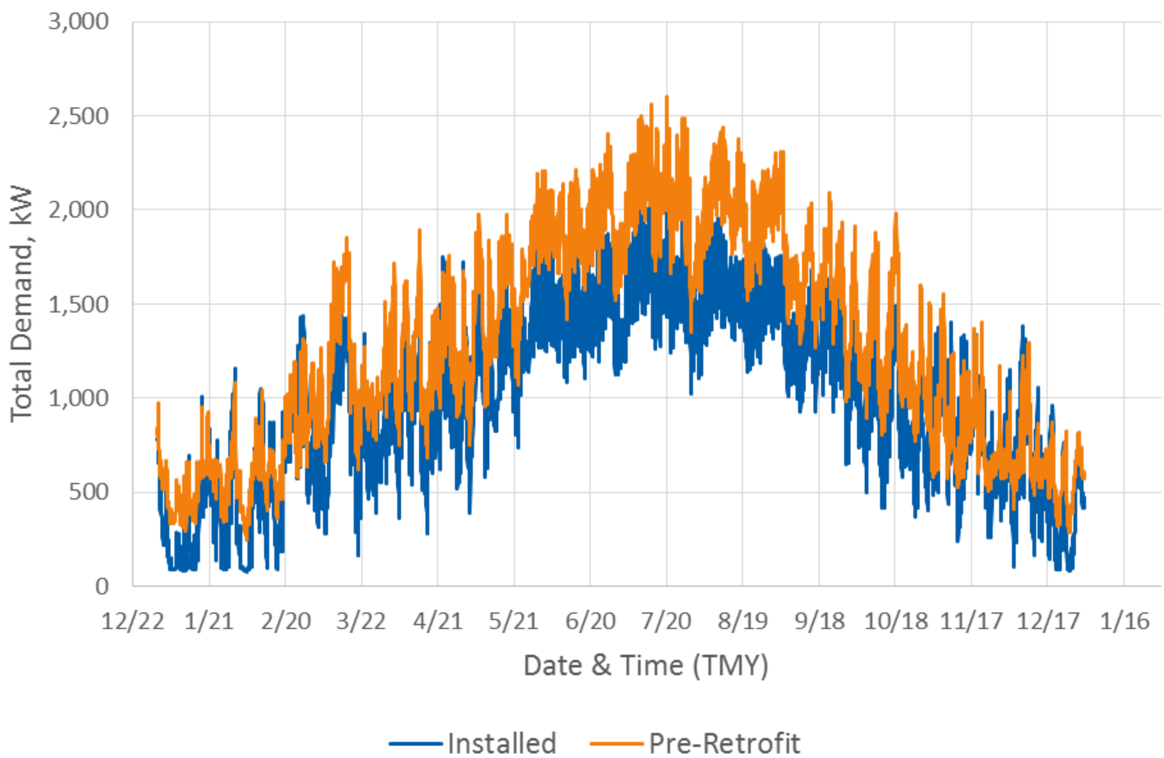
Cadmus created similar curves for chilled water plant load and total primary and secondary chilled water pump demand, total condenser water pump demand, and total cooling tower fan demand. We used these curves to extrapolate the equipment component demand to the 8,760 hour model. The evaluated installed case annual energy use was 8,846,907 kWh. The coincident peak demand was 1,721.6 kW, and the average annual demand was 1,009.9 kW.

Cadmus used the site contact's description of the pre-retrofit system sequence of operation to determine when CEP-1 or CEP-2 would have operated. Cadmus assumed that CEP-1 would have been the primary system from March 1 to November 1. Based on this assumption, CEP-1 operated 5,880 hours per year and CEP-2 operated 2,880 hours per year. We based the full load and part load performance for the standard efficiency, constant-speed CEP-1 chillers on the International Energy Conservation Code 2009 baseline performance for water-cooled chillers, de-rating by 10% for age. The primary chilled water pumps and condenser water pumps in both CEP-1 and CEP-2 were constant speed. The secondary chilled water pumps and cooling tower fans were controlled by VFDs in both CEP-1 and CEP-2. Cadmus assumed that one pump and one cooling tower were dedicated to one chiller in each plant (CEP-1 and CEP-2) in the pre-retrofit case.

The evaluated pre-retrofit annual energy use was 11,291,063 kWh; coincident peak demand was 2,135.8 kW; and average annual demand was 1,288.9 kW.

Total evaluated energy savings were 2,444,156 kWh (22% savings). The evaluated total summer coincident peak demand reduction (for the month of July, Monday through Friday from 4:00 p.m. to 5:00 p.m.) was 414.3 kW, and the average, or non-coincident, peak demand reduction was 279.0 kW. Figure 13 compares the evaluated total system demand for the pre-retrofit and installed cases.

Figure 13. Comparison of Evaluated Pre-Retrofit and Installed Case Total System Demand



Conclusion

While on the site, Cadmus found the equipment and controls installed as expected. The overall energy savings realization rate was 93%, compared to the Duke Energy claimed savings. The summer peak demand realization rate was calculated as 99%. The average (or non-coincident) peak demand reduction realization rate was 55%.

The greatest impact on the evaluated energy savings and demand reduction was that the installed cooling tower fans use 166% more energy than the pre-retrofit cooling tower fans based on the trend data collected. The installed case operates more cooling towers than chillers to provide more surface area for heat transfer, which reduces the cooling load on the chillers. The overall average installed plant performance is 25% higher than expected in the original study, mainly due to the additional fan demand.

Table 7 shows a comparison of the applicant, Duke Energy claimed, and Cadmus evaluated energy savings and demand reduction. Table 8 provides realization rates comparing the energy savings and demand reductions claimed by Duke Energy to those calculated by Cadmus.

Table 7. Comparison of Applicant, Duke Energy Claimed, and Evaluation Energy Savings and Demand Reduction

Applicant		Duke Energy Claimed			Evaluation		
Annual kWh Savings	Average kW Reduction	Annual kWh Savings	Coincident Peak kW Reduction	Non-CP kW Reduction	Annual kWh Savings	Coincident Peak kW Reduction	Non-CP kW Reduction
3,050,292	N/A	2,618,060	416.96	511.51	2,444,156	414.3	279.0

Table 8. Energy Savings and Demand Reduction Realization Rates

Annual kWh Savings	Coincident Peak kW Reduction	Non-CP kW Reduction
93%	99%	55%

Application ID 13-1532263
Lighting Retrofit
M&V Report

Prepared for
Duke Energy Carolinas

January 2015, Version 1.0
(Revised August 22, 2016)

Note: This project has been randomly selected from the list of applications for which incentive agreements have been authorized under Duke Energy's Smart $aver® Custom Incentive Program.

The M&V activities described here are undertaken by an independent third-party evaluator of the Smart $aver® Custom Incentive Program.

Findings and conclusions of these activities shall have absolutely no impact on the agreed upon incentive between Duke Energy and [redacted].

Submitted by:

Katie Gustafson
NORESCO, Inc.

Stuart Waterbury
NORESCO, Inc.

2540 Frontier Avenue, Suite 100
Boulder CO
80301

(303) 444-4149

On August 22, 2016 the Duke Energy projected savings in this report were corrected by Cadmus to correspond to Duke Energy expected savings as found in the Duke Energy program tracking database.

Introduction

This document addresses the M&V activities for the lighting retrofit at [redacted]'s [redacted], North Carolina location. This lighting retrofit was rebated through Duke Energy's Smart $aver Custom Lighting Incentive program.

- **ECM-1 –** Retrofitted (246) 1000 W Metal Halide fixtures with 575 W Pulse Start Metal Halide fixtures.
- **ECM-2 –** Retrofitted (369) 400 W Metal Halide fixtures with 250 W Pulse Start Metal Halide fixtures.
- **ECM-3 –** Retrofitted (26) 250 W Metal Halide Fixtures with 150 W Pulse Start Metal Halide fixtures.
- **ECM-4 –** Retrofitted (60) 400 W Metal Halide Fixtures with 5L T5HO fixtures.

Goals and Objectives

Post-retrofit surveys of the lighting usage were conducted to determine the power reduction from the lighting upgrade.

The projected savings goals are:

Facility	Proposed Annual kWh savings	Proposed kW Savings	Duke Expected Annual kWh savings	Duke Expected kW savings
redacted	1,696,067	194	1,625,074	185
Total	**1,696,067**	**194**	**1,625,074**	**185**

The objective of this M&V project will be to verify the actual:

- Annual gross kWh savings
- Summer peak kW savings
- Coincidence Peak kW savings
- kWh & kW Realization Rates

Project Contacts

Duke Energy M&V Coordinator	Frankie Diersing	p: 513-287-4096

NORESCO Engineer	Katie Gustafson	p: 303-459-7430 kgustafson@noresco.com
Customer Contact	redacted	

Site Locations/ECM's

Address	ECMs Implemented
redacted	1-4

Data Products and Project Output

- Post retrofit survey of lighting fixtures.
- Average post-retrofit lighting fixture load shapes.
- Equivalent Full Load Hours (HOURS) by day type (weekday/weekend).
- Summer peak demand savings.
- Summer utility coincident peak demand savings.
- Annual Energy Savings.

M&V Option

IPMVP Option A

Field Data Points

Post-Installation

Survey data

- Fixture count and Wattage.
- Verified that all fixture specifications and quantities were consistent with the application.
- Determined how the lighting is controlled and recorded controller settings.
- Verified that all pre (existing) fixtures were removed.
- Determined what holidays the building observes over the year.
- Determined if the lighting zones are disabled during the holidays.

Data Accuracy

Measurement	Sensor	Accuracy
Current	CTV-A 20A	±4.5%

Field Data Logging

The following table summarizes the quantities and locations of lighting loggers that were deployed to meter the retrofitted fixtures.

ECM	Hobo (U12)	CTV-A 20A
1	4	13
2	2	8
3	1	2
4	1	4
Total	**8**	**27**

Data Analysis

- Used the standard calculation template for estimating pre and post demand and energy consumption that incorporates the methodology described below.
- From survey data calculated the actual pre and post fixture kW.
- Weighted the time-series data according to connected load per control point. Methodology included in analysis worksheet.
- From time-series data determined the actual schedule of post operation.

$$\mathrm{LF(t)} = \frac{\sum_{i=1}^{N_{Logged}} \left(\mathrm{Current}_{\mathrm{ControlPoint}_i} * \mathrm{ScaleFactor}_i\right)}{\sum_{i=1}^{N_{Logged}} \mathrm{kWControlPoint}_i}$$

$$\mathrm{kW}_{\mathrm{Lighting}}(t) = \mathrm{LF(t)} * \sum_{i=1}^{N_{ControlPoints}} \mathrm{kWControlPoint}_i$$

Where

LF(t) = Lighting Load factor at time = t

$\mathrm{kWControlPoint}_i$ = connected load of control point i

$\mathrm{CurrentControlPoint}_i$ = logged current at control point i from time series data

$\mathrm{ScaleFactor}_i$ = Convert logged current to kW

NLogged = population of logged control points

NControlPoints = population of all control points

- Created separate schedules for weekdays and weekends using LF(t).
- Tabulated average operating hours by daytype (e.g. weekday and weekend).
- Extrapolated annual operating hours from the recorded hours of use by daytype.
- Generated the post load shape by plotting surveyed fixture kW against the actual schedule of post operation for each daytype.
- Calculated pre annual operating hours using the post-retrofit schedules by daytype and extrapolating to the full year.
- Calculated energy savings and compare to project application:

$$kWh_{savings} = (N_{Fixtures} * kW_{Fixture} * Hours)_{PRE} - (N_{Fixtures} * kW_{Fixture} * Hours)_{Post}$$

$$NCP\ kW_{savings} = (N_{Fixtures} * kW_{Fixture})_{PRE} - (N_{Fixtures} * kW_{Fixture})_{Post}$$

$$CP\ kW_{savings} = NCP\ kW_{savings}\ x\ CF$$

where:

$N_{Fixtures}$	= number of fixtures installed or replaced
$kW_{Fixture}$	= connected load per fixture
HOURS	= equivalent full load hours per fixture
NCP $kW_{savings}$	= non-coincident peak savings
CP $kW_{savings}$	= coincident peak savings
CF	= coincidence factor

- The savings with HVAC interactions are calculated from:

$$kWh_{savings\ with\ HVAC} = kWh_{savings}\ x\ (1 + WHFe)$$
$$kW_{savings\ with\ HVAC} = kW_{savings}\ x\ (1 + WHFd)$$

where:

WHFe	= waste heat factor for energy
WHFd	= waste heat factor for demand

Verification and Quality Control

1. Visually inspected lighting logger data for consistent operation. Sorted by day type and removed invalid data.
2. Verified the post retrofit lighting fixture specifications and quantities were consistent with the application.
3. Verified that pre-retrofit lighting fixtures were removed from the project. Inspected storeroom for replacement lamps or fixtures.

Recording and Data Exchange Format

1. Hobo logger binary files
2. Excel spreadsheets

Results Summary

The following tables summarize the total estimated savings for the [redacted] lighting retrofit.

Table 1. Energy Savings and Realization Rates.

	Duke Savings	Realized Savings		Realization Rate	
		Lighting Only	Lighting and HVAC	Lighting Only	Lighting and HVAC
Energy (kWh)	1,625,074	1,762,545	2,056,890	108%	127%
Peak Demand (kW)	185	209	248	113%	134%
CP Demand (kW)	185	205	243	111%	131%

The energy and demand savings calculation summary is shown in **Error! Reference source not found.**. Demand savings details are shown in **Error! Reference source not found.** at the end of this report.

Table 2. Summary of Energy and Demand Savings Calculations.

Base kW	EE kW	HOURS	CF	Lighting Only			With HVAC interactions WHFe= 0.167 WHFd= 0.188		
				kWh savings	NCP kW	CP kW	kWh savings	NCP kW	CP kW
469.8	261.2	8450	0.996	1,762,545	208.6	204.7	2,056,890	247.8	243.1

- Used 0.167 for the energy and 0.188 for the demand waste heat interaction factors. These were based on a DOE2 model for a refrigerated warehouse cooled with an ammonia chiller.
- Pre wattages are based on Appendix B.

Figure 1 shows the average daily load shape. When extrapolated to the year, the M&V annual operating hours are 8450, which are four percent less than the 8760 hours, stated in the application. There were a few periods where some lighting was off, which resulted in the lower than the full 8760 operating hours.

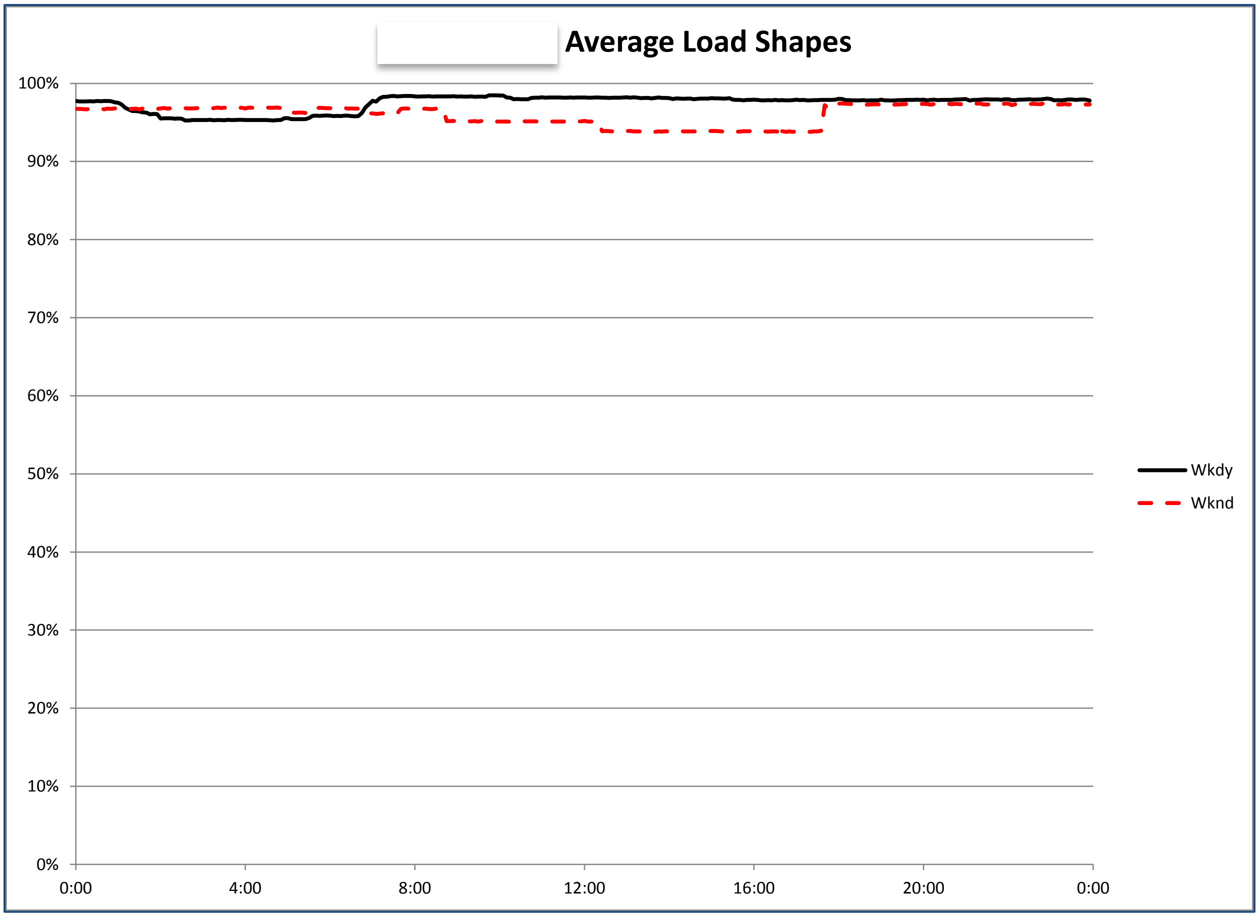


Figure 1: Average load shapes.

Table 3. Demand Savings Detail.

ECM	EE Technology						Base Technology				
	Quantity	EE Fixture Type	W/ Fixture	Source	Cut Sheet W/Fixture	Connected kW	Quantity	Base Fixture Type	W/ Fixture	Source	Connected kW
1	246	575 W PSMH	563	Spot Measurement	640	138.6	246	1000 W MH	1080	Appendix B	265.68
2	369	250 W PSMH	283	Spot Measurement	284	104.6	369	400 W MH	458	Appendix B	169.002
3	26	150 W PSMH	176	Spot Measurement	187	4.6	26	250 W MH	295	Appendix B	7.67
4	60	5L T5HO	225	Spot Measurement	287	13.5	60	400 WMH	458	Appendix B	27.48

Notes:

- SPC Apdx B – Appendix B 2013-14 Table of Standard Fixture Wattages. See http://www.aesc-inc.com/download/spc/2013SPCDocs/PGE/App%20B%20Standard%20Fixture%20Watts.pdf

Application ID 13-1544634 Injection Molding Machine M&V Report

August 5, 2016

Duke Energy Carolinas

139 East Fourth Street

Cincinnati, OH 45201

The Cadmus Group, Inc.

An Employee-Owned Company • www.cadmusgroup.com

CADMUS

Prepared by:
Dave Korn
Christie Amero

Cadmus

CADMUS

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CADMUS

Introduction

This report addresses M&V activities for one retrofit energy conservation measure (ECM) as part of the [redacted] Smart $aver custom incentive program application; specifically, the replacement of one injection molding machine.

ECM-1—Injection Molding Machine Replacement

The customer manufactures injection molding products. Injection molding machines—also known as presses—mold polypropylene resin into various exterior building products. Press sizes range from 44 tons to 3,000 tons.

This retrofit project targeted a 1996 Van Dorn, 500-ton hydraulic press, replaced with a Sumitomo Systec 420, 506-ton hybrid press, which operates more energy efficiently and is intended to increase productivity.

Goals and Objectives

Table 1 shows projected savings goals identified in the project application.

Table 1. Project Goals

Applicant		Duke Energy		
Annual kWh Savings*	Avg. kW Reduction	Claimed Annual kWh Savings	Claimed Coincident Peak kW Reduction	Claimed Non-CP kW Reduction
48,427	9	135,308	22	22

* The application energy saving estimates provided to Cadmus appear to have been incomplete, since they are significantly lower than those ultimately claimed by Duke Energy for program tracking.

The M&V project sought to verify actual numbers for the following:

- Facility peak demand reduction (kW)
- Summer utility coincident peak demand reduction (kW)
- Annual energy savings (kWh)
- Annual realization rates (kW and kWh)

Project Contacts

The Duke Energy contact listed in Table 2 granted approval to plan and schedule the site visit for this M&V effort.

Table 2. Project Contacts

Organization	Contact	Contact Information
Duke Energy	Frankie Diersing	p: 513-287-4096 Frankie.diersing@duke-energy.com
Cadmus	Christie Amero	p: 303-389-2509 christie.amero@cadmusgroup.com
Customer	redacted	

Site Location/ECM Location

The location where this measure was installed is shown in Table 4.

Table 3. Project Location

Address	ECM
redacted	1

M&V Option

To assess this project, Cadmus utilized IPMVP Option A.

Implementation

Cadmus reached out to the site contact provided by Duke Energy to review the evaluation plan and to schedule the site visit. The site contact confirmed that the equipment was served by 480V and the meter installation could be performed de-energized. Christie Amero and Tom Davis of Cadmus performed the site visit on January 8, 2016.

Field Notes

During the site visit, Cadmus met with the site contact to review the metering plan and to collect general operating information.

The site produces various plastic parts for building construction (e.g., basement vent grills, drains, tool box organizers). Production typically slows in December and January due to fewer construction projects during those months.

The facility—typically operating 24 hours per day, Monday through Friday—runs four days per week (Monday–Thursday) during December and January. Operation ramps up from May to October, and the site operates six days per week (Monday–Saturday) 75% of the time during those months.

The 13 injection molding machines on site range from ~100 tons to 500 tons, with most of the smaller machines all-electric.

The new, 500-ton hybrid press, which can make up to 100 different parts over the course of the year and utilizes ~20 different materials (e.g., polypropylene, polystyrene). Recently, the machine produced a ~2-pound basement vent grill and a ~5-pound tool box organizer.

The new machine currently has no trend points in place.

Field Data

Table 4 shows product data that Cadmus collected for the installed injection molding machine included in the application.

Table 4. Installed Equipment Nameplate Data

Equipment ID	Make	Model #	Serial Number	Capacity, tons
500-ton Hybrid IMM	Sumitomo DEMAG	SYSTEC 460/820-3300	8073-0099	500

During the site visit, Cadmus photographed the injection molding machine and associated nameplate: Figure 1 shows the installed, 500-ton, injection molding machine; Figure 2 shows the nameplate.

Figure 1. Installed 500-ton Injection Molding Machine

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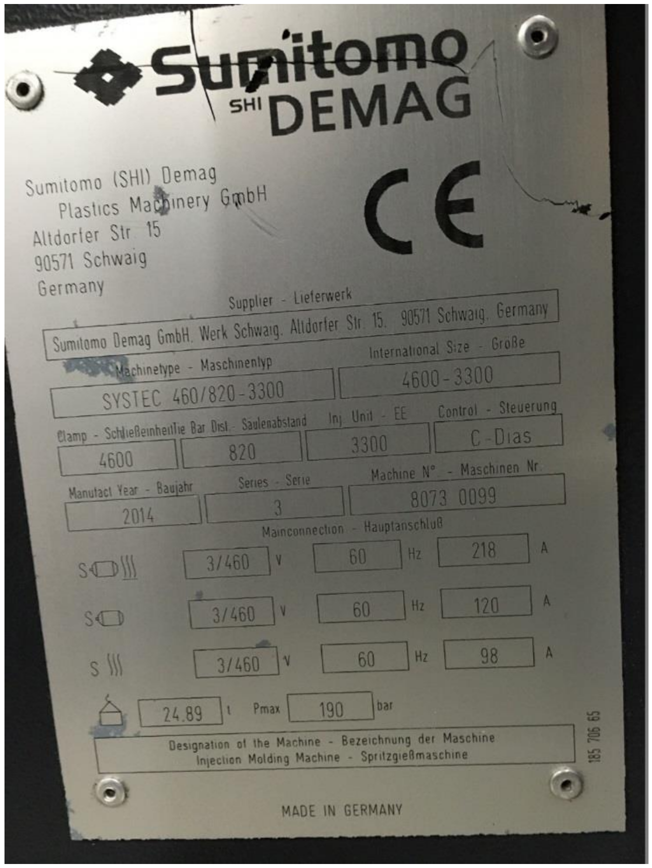
Figure 2. Injection Molding Machine Nameplate



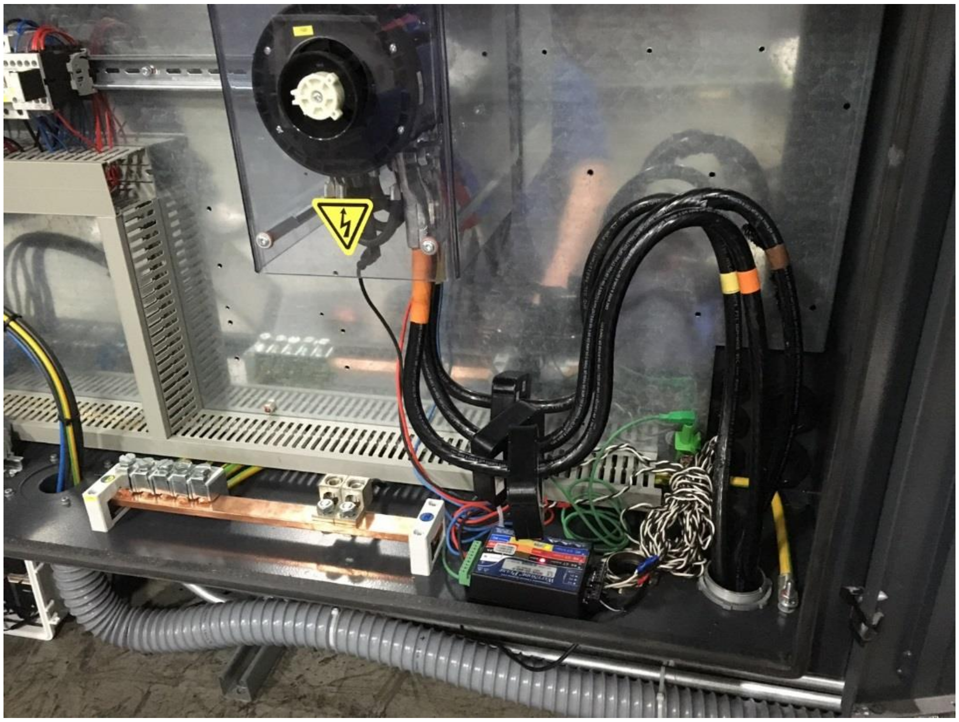
The site contact described parts the machine currently produces and stated the site would run one part through the machine during the metering period; hence, the weight and cycle time of this part would be representative of the average part the machine would make during the year.

Cadmus installed one, three-phase, electric power meter on the injection molding machine, collecting data for two weeks at one-minute intervals. Table 5 summarizes the installed metering equipment, and Figure 3 shows the power meter installation in the injection molding machine.

Table 5. Summary of Installed Metering Equipment

Equipment ID	RX3000	WattNode 3D-480	Current Transducers (Qty/Size)
500-ton IMM	1	1	3 / 400 A

Figure 3. Injection Molding Machine Power Meter Installation



During the meter removal, the site contact provided a summary of part data and machine throughput during the metering period. The mold that the machine ran during the metering period produced two grills and two slides per shot for a foundation vent. The slide was assembled into the grill, so two complete parts were made per shot. The material used was 20% talc-filled polypropylene. The shot weight of 1.168 kW included the weight of the runner, a narrow channel in the mold that moves the plastic from the center point to various areas of the part. Completed parts weigh 0.53 kg.

Table 6 summarizes machine operations and production parameters.

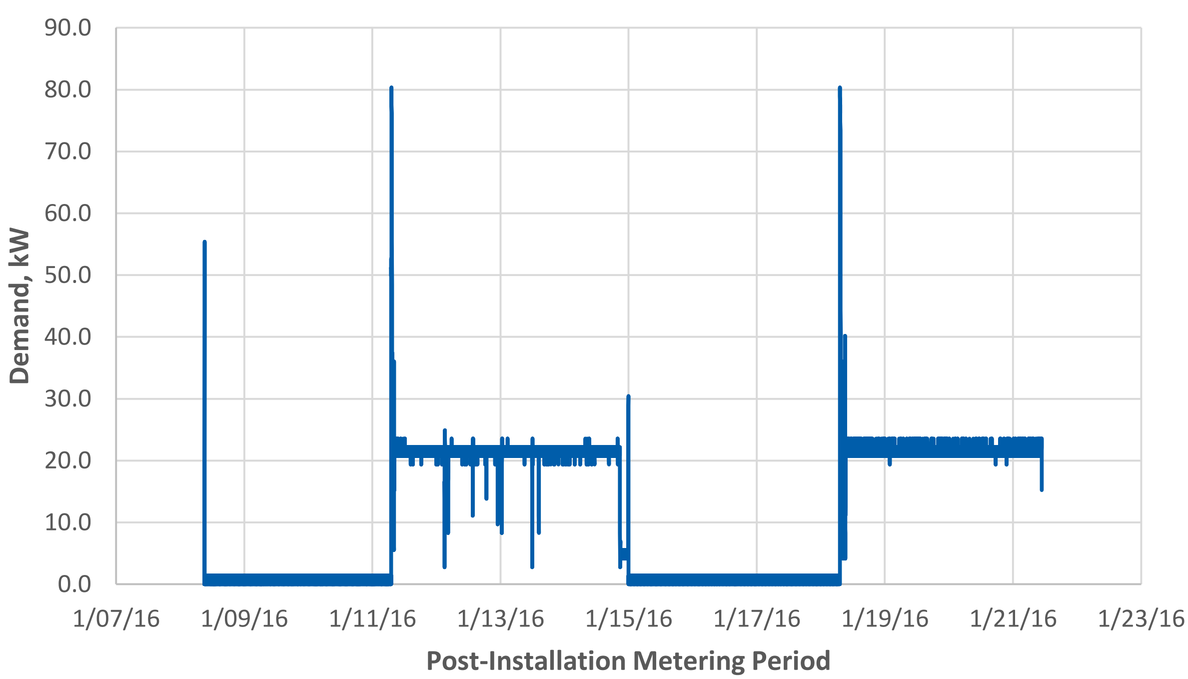
Table 6. Summary of Machine Operation and Production Parameters

Parameter	Value
Run Hours	158 hours, 4 minutes
Material	20% Tac-Filled Polypropylene
Cycles Completed	9,748
Cycle Time, s	58.4
Material Used, kg	11,393.45
Shot Weight, kg (includes runner)	1.169
Cavities per Mold	4 (2 2-piece parts per mold)
Part Weight, kg	0.53

Figure 4 shows the machine's control panel output, including the material type, number of cycles, part shot weight, and number of cavities per mold. Figure 5 summarizes metered demand data during the metering period.

Figure 4. Injection Molding Machine Power Metered Data

Figure 5. Injection Molding Machine Power Metered Data



Data Accuracy

Table 7. Metering Equipment Accuracy

Measurement	Sensor	Accuracy	Notes
Current, amps	Magnelab CT	±1%	Recorded load must be < 130% and >10% of CT rating
Power, kW	WattNode	±1%	—

Data Analysis

Cadmus used the post-installation metered data to verify the power demand and operating hours of the installed, hybrid, injection molding machine.

Based on the metered data, the machine's power demand averages 20.95 kW when producing parts. When not running (Fridays and weekends during the metering period), the machine has a power draw of ~1.46 kW. The metered energy use rate was 0.31 kWh/kg.

Using the site's monthly operating hour projections, Cadmus calculated installed annual energy use of 139,438 kWh, including energy use during nonproduction hours. Annual demand averaged 15.9 kW; summer coincident peak demand was 21.0 kW.

As a baseline for the measure, Cadmus used a preexisting, 500-ton, hydraulic, injection molding machine. Baseline machine power demand and operating hours had been metered during the original project analysis, and the methodology appeared accurate. Cadmus' evaluation consequently used the hydraulic, machine-metered data. Average operating demand was 41.73 kW. These data did not include power demand for non-operating hours. The metered data can be found in: 'CSN13-1544634 Production Numbers - #8 500T – Sept_Oct_13 (3)' Excel workbook.

Using the same operating hours as the installed case, evaluated baseline annual energy use was 271,196 kWh. Average demand was 31.0 kW, and summer coincident peak demand was 41.7 kW.

The measure produced evaluated annual energy savings of 131,758 kWh, with an average (or non-coincident) peak demand reduction of 15.0 kW and a summer coincident peak demand reduction of 20.8 kW.

Conclusion

Cadmus found the equipment installed as expected. The installed case metered demand data closely matched data collected for the installed machine in the original study.

The measure produced an overall energy savings realization rate of 97%, compared to Duke Energy claimed savings, a summer peak demand realization rate of 94%, and an average (or noncoincident) demand reduction realization rate of 68%. The original analysis assumed the noncoincident demand reduction equaled peak demand reduction and did not account for nonproduction hours.

Table 8 provides a comparison of the applicant, Duke Energy claimed, and evaluation energy savings and demand reduction.

Table 9 provides the realization rates compared to the energy savings and demand reductions claimed by Duke Energy.

Table 8. Comparison of Applicant, Duke Energy Claimed, and Evaluation Energy Savings and Demand Reduction

Applicant		Duke Energy Claimed			Evaluation		
Annual kWh Savings	Avg. kW Reduction	Annual kWh Savings	Coincident Peak kW Reduction	Non-CP kW Reduction	Annual kWh Savings	Coincident Peak kW Reduction	Non-CP kW Reduction
48,427	9.0	135,308	22.1	22.1	131,758	20.8	15.0

Table 9. Energy Savings and Demand Reduction Realization Rates

Annual kWh Savings	Coincident Peak kW	Non-Coincident Peak kW
97%	94%	68%

Application ID 14-1645298
Lighting
M&V Report

August 26, 2016

Duke Energy
139 East Fourth Street
Cincinnati, OH 45201

CADMUS

Prepared by:
Dave Korn
Christie Amero

Cadmus

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CADMUS

Introduction

This report outlines Cadmus' measurement and verification (M&V) activities for one retrofit energy conservation measure (ECM) included as part of the [redacted], Smart $aver custom incentive program application—specifically for replacing halogen parabolic aluminized reflector (PAR) lighting fixtures with LED lighting fixtures. Energy savings were expected to result from the reduced fixture input wattage and reduced fixture quantities. A description of the ECM as submitted in the original application documentation is provided below.

ECM-1: Replace Halogen Lamps with LED Lamps

Pre-Retrofit: [redacted] is a large furniture retail store, located in [redacted], North Carolina. The store is open Mondays through Thursdays from 8:30 a.m. to 5:30 p.m., Fridays from 8:30 a.m. to 8:30 p.m., and Saturdays from 8:30 a.m. to 5:30 p.m. Staff prepare the floor and clean approximately one hour before and one hour after the store closes. The original analysis estimated that interior lighting fixtures remained on 3,588 hours per year. The total annual electricity use for the store is approximately 2,533,000 kWh, based on 2013 utility data.

Installed: This project involved replacing 10,000 60-watt halogen PAR38 lamps with 6,000 19-watt LED lamps. For every five halogen lamps, [redacted] installed three LED track lights. The installed LED lamp is a Philips 19PAR38/F36 2700 DIM AF and is listed on ENERGY STAR's certified LED list.

Goals and Objectives

Table 1 shows the projected savings goals identified in the project application.

Table 1. Project Goals

Application		Duke Energy			
Annual kWh Savings	Average kW Reduction	Projected Annual kWh Savings*	Claimed Annual kWh Savings	Claimed Coincident Peak kW Reduction	Claimed Non-CP kW Reduction
1,743,768	N/A	1,743,768	1,734,359	486.00	106.56

*Source: DSMore input spreadsheet.

For this M&V project, Cadmus sought to verify actual numbers for the following:

- Facility peak demand reduction (kW)
- Summer utility coincident peak demand reduction (kW)
- Annual energy savings (kWh)
- Annual realization ratios (kW and kWh)

Project Contacts

Table 2 lists the Duke Energy contact who granted Cadmus approval to plan and schedule the site visit for this M&V effort, along with the Cadmus contact and the customer contact.

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Table 2. Project Contacts

Organization	Contact	Contact Information
Duke Energy	Monica Redman, Senior DSM & Retail Programs Analyst	monica.redman@duke-energy.com
Cadmus	Christie Amero, Senior Analyst	office: 303-389-2509 christie.amero@cadmusgroup.com
Customer	redacted	

Site Location

The site location is listed in Table 3.

Table 3. Site Location

Address	ECM
redacted	1

M&V Option

To assess this site, Cadmus followed IPMVP Option A.

Implementation

Cadmus reached out to the site contact provided by Duke Energy to review the evaluation plan and to schedule the site visit. Christie Amero of Cadmus performed the site visit on June 22, 2016.

Field Survey

During the site visit, Cadmus met with the facility manager to review the lighting survey and to collect general operating information.

[Redacted] is one of the largest furniture retail stores in the country. The [redacted] location is composed of a campus of buildings containing showroom spaces, a food court, a warehouse, and offices. The main building is four floors and the showroom building is three floors. The main building and showrooms are open during the following periods:

- Mondays through Thursdays, from 8:30 a.m. to 5:30 p.m.
- Fridays, from 8:30 a.m. to 8:30 p.m.
- Saturdays, from 8:30 a.m. to 5:30 p.m.

The site closes only on Thanksgiving Day and Christmas Day.

The spaces where the new LEDs were installed are mainly showrooms for furniture products and do not have occupancy sensors, since dark areas may be an issue for sales. The lighting fixtures are typically turned on and off by facility staff approximately 30 minutes before the store opens and 30 minutes after the store closes. This is contrary to the original application, which stated that the lights are turned on an hour before the store opens and an hour after it closes.

The facility manager stated that the staff have seen a noticeable improvement in the quality of lighting for the retail spaces with the LED PAR38s, which is very important when selling furniture. The pre-retrofit 60-watt halogen lamps only lasted one or two years before they needed to be replaced.

Cooling for the facility is provided by water-cooled chillers of mixed age. There are electric perimeter heating coils, but they are only used a couple of days per year due to the high heat output from the lighting fixtures.

Field Data

ECM-1: Replace Halogen Lamps with LED Lamps

After completing the lighting survey, Cadmus performed a walkthrough of the facility to verify the installed lighting fixture types and to install light loggers. Figure 1 shows the installed PAR38 LEDs in one of the main showrooms. This design is typical throughout the facility. Figure 2 shows the make and model number of the installed PAR38 LED lamp.

Figure 1. Installed PAR38 LED Lamps in Showroom

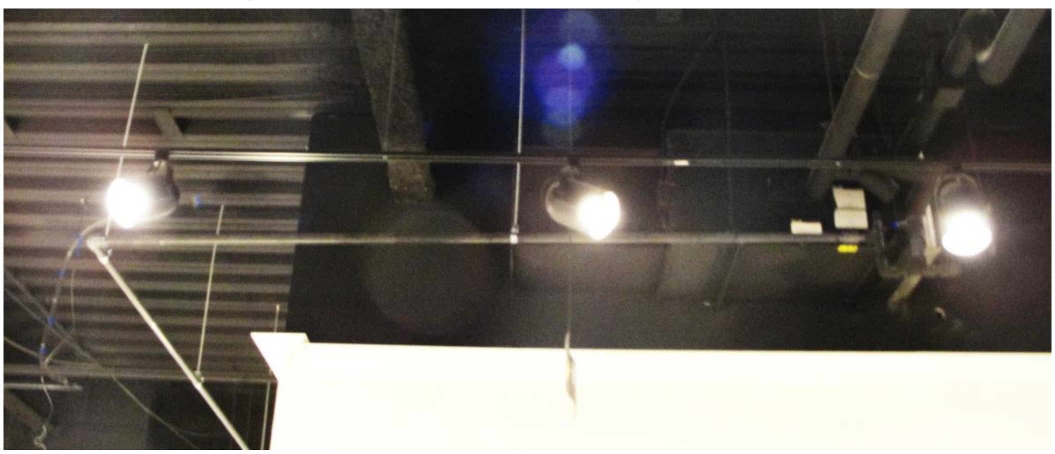
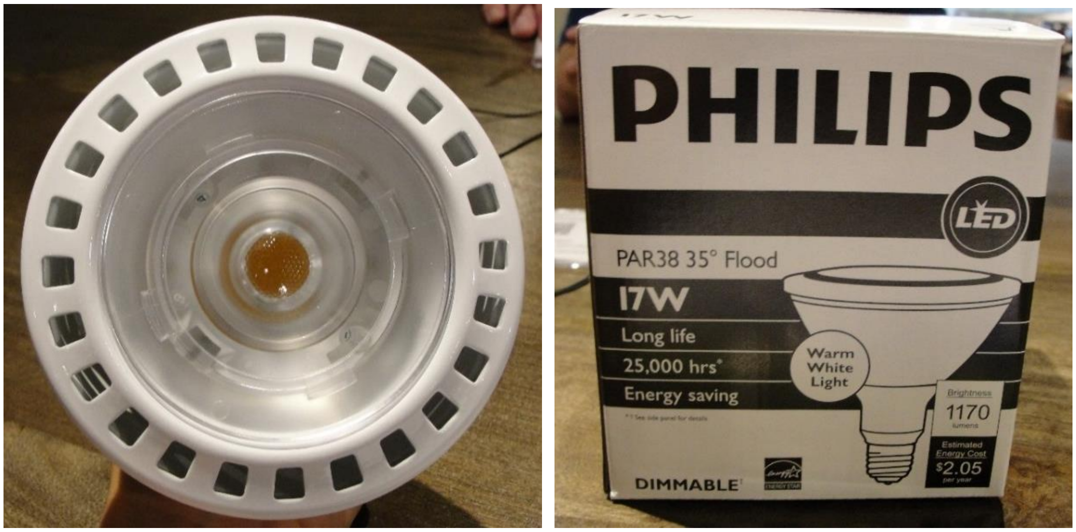


Figure 2. Make and Model of Installed LED Lamps



Cadmus installed six light loggers in a variety of spaces in the main building and showroom to collect fixture operating hours for a three-week period. Table 4 summarizes the locations of installed light loggers and monitored fixture type.

Table 4. Summary of Fixture Counts and Installed Light Loggers

#	Building	Location	Fixture Description	Light Logger Serial Number
1	Main	1st Floor, Section K06	PAR38 LED	10237836
2	Main	2nd Floor, Section M07	PAR38 LED	10168462
3	Main	3rd Floor, Section E10	PAR38 LED	10261680
4	Main	4th Floor, Section J10	PAR38 LED	10171991
5	Showroom	2nd Floor, Section C04	PAR38 LED	10326628
6	Showroom	1st Floor, Section D05	PAR38 LED	10268317

Data Analysis

ECM-1: Replace Halogen Lamps with LED Lamps

Cadmus used the survey and light logger data to verify demand and operating hours for the installed lighting fixtures. Table 5 summarizes light logger data.

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Table 5. Summary of Meter Data

#	Building	Total Hours Metered	Total Operating Hours	Percentage Operating	Average Time On	Average Time Off	Peak Coincidence Factor
1	Main	455.1	207.7	46%	7:08 a.m.	8:10 p.m.	100%
2	Main	455.1	210.0	46%	7:02 a.m.	7:27 p.m.	100%
3	Main	455.1	218.3	48%	6:58 a.m.	7:51 p.m.	100%
4	Main	455.3	158.5	35%	6:31 a.m.	8:56 p.m.	100%
5	Showroom	455.0	227.6	50%	6:40 a.m.	8:58 p.m.	100%
6	Showroom	455.2	226.0	50%	6:31 a.m.	8:42 p.m.	100%
Average		**455.1**	**208.0**	**46%**	**6:48 a.m.**	**8:21 p.m.**	**100%**

The six light loggers produced a mean projected runtime of 4,004 hours. During the three-week metering period, the site produced a mean peak coincidence factor of 100%.

The installed PAR38 LED lamp has an input of 17 watts, versus 19 watts as submitted in the original application. Cadmus could not verify the power usage of the pre-retrofit PAR38 halogen lamps, so we used their specific power of 60 watts for our calculations, based on a discussion with the site contact.

The energy savings and peak demand reduction without HVAC interactive effects are 1,993,949 kWh and 498.0 kW, respectively.

Cadmus also calculated energy savings and demand reductions with HVAC interactive effects, based on the heating and cooling system type collected on site. Cadmus used the waste heat factors listed in TechMarket Works' Process and Impact Evaluation of the Non-Residential Smart $aver® Prescriptive Program in the Carolina System: Lighting and Occupancy Sensors report submitted in April 2013. The energy waste heat factor for a big-box store near Greensboro, North Carolina with air conditioner cooling, electric heating, and no economizer is -0.149, and the demand factor is 0.218. The following equation is used to calculate savings with HVAC interactions:

$$kWh_{savings\ with\ HVAC} = kWh_{savings}\ x\ (1 + WHFe)$$

$$kW_{savings\ with\ HVAC} = kW_{savings}\ x\ (1 + WHFd)$$

Where:

WHFe = Waste heat factor for energy (= -0.149)

WHFd = Waste heat factor for demand (= 0.218)

Total evaluated energy savings were 1,696,851 kWh. The evaluated total summer coincident peak demand reduction (for the month of July, Monday through Friday from 4:00 p.m. to 5:00 p.m.) was 606.6 kW, and the average, or non-coincident, peak demand reduction was 193.7 kW.

Conclusion

While on the site, Cadmus found the equipment installed as expected. The overall energy savings realization rate was 98%, compared to Duke Energy claimed savings. The summer peak demand realization rate was calculated as 125%. The average (or non-coincident) peak demand reduction realization rate was 182%.

The greatest impact to the evaluated energy savings and demand reduction was that the original application did not account for HVAC interactive effects. The evaluated annual operating hours were also slightly higher than expected in the original application and the installed LED fixture wattage was slightly lower than expected.

Table 6 provides a comparison of the applicant, Duke Energy claimed, and Cadmus evaluated energy savings and demand reduction. Table 7 provides realization rates comparing energy savings and demand reductions claimed by Duke Energy to those calculated by Cadmus.

Table 6. Comparison of Applicant, Duke Energy Claimed, and Evaluation Energy Savings and Demand Reduction

Applicant		Duke Energy Claimed			Evaluation		
Annual kWh Savings	Average kW Reduction	Annual kWh Savings	Coincident Peak kW Reduction	Non-CP kW Reduction	Annual kWh Savings	Coincident Peak kW Reduction	Non-CP kW Reduction
1,743,768	N/A	1,734,359	486.00	106.56	1,696,851	606.6	193.7

Table 7. Energy Savings and Demand Reduction Realization Rates

Annual kWh Savings	Coincident Peak kW Reduction	Non-CP kW Reduction
98%	125%	182%

Application ID 13-1589525 Lighting Replacement: M&V Report

August 5, 2016

Duke Energy Carolinas
139 East Fourth Street
Cincinnati, OH 45201

CADMUS

Prepared by:
Dave Korn
Christie Amero
Ari Jackson

Cadmus

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CADMUS

Introduction

This report addresses M&V activities for a lighting retrofit energy conservation measure (ECM) as part of the [redacted] Smart $aver custom incentive program application; specifically, the replacement of 934 lighting fixtures at one location in [redacted], NC.

ECM-1—Replace Metal Halide Fixtures with Fluorescent Fixtures

The plant replaced 869 400-Watt metal halide lighting fixtures with: 12, six-lamp T5-HO; 120, four-lamp T8; and 32, two-lamp, reduced wattage T8 fluorescent fixtures. The ECM included the removal of 589 fixtures.

ECM-2—Replace Fluorescent T12 Fixtures with T8 Fixtures

The plant replaced 65, two-lamp, 8' T12 fixtures with 40, four-lamp, reduced wattage T8 fixtures. The ECM included the removal of 25 fixtures.

Goals and Objectives

Table 1 summarizes the projected savings goals identified in the project application.

Table 1. Project Goals

ECM	Applicant		Duke Energy		
	Annual kWh Savings	Avg. kW Reduction	Claimed Annual kWh Savings*	Claimed Coincident Peak kW Reduction	Claimed Non-CP kW Reduction*
1	1,862,649	398	NA	306	NA
2	41,980	9	NA	4	NA
Total	**1,904,629**	**407**	**1,412,989**	**310.4**	**98.6**

* The program application documentation included claimed non-coincident peak demand and energy savings for the entire application and not for individual ECMs.

The M&V project sought to verify actual numbers for the following:

- Facility peak demand reduction (kW)
- Summer utility coincident peak demand reduction (kW)
- Annual energy savings (kWh)
- Annual realization rates (kWh and kW)

Project Contacts

The Duke Energy contact listed in Table 2 granted approval to plan and to schedule the site visit for the M&V effort.

CADMUS

Table 2. Project Contacts

Organization	Contact	Contact Information
Duke Energy	Frankie Diersing	p: 513-287-4096 Frankie.diersing@duke-energy.com
Cadmus	Christie Amero	office: 303-389-2509 christie.amero@cadmusgroup.com
Customer	redacted	

Site Location

The location where this measure was installed is shown in Table 3.

Table 3. Project Location

Address	ECMs
redacted	1, 2

M&V Option

To assess this project, Cadmus utilized IPMVP Option A.

Implementation

Cadmus reached out to the site contact provided by Duke Energy to review the evaluation plan and to schedule the site visit. Christie Amero of Cadmus performed the site visit on January 7, 2016.

Field Lighting Survey

During the site visit, Cadmus met with the facility manager to review the attached lighting survey and to collect general operating information.

The facility manufactures foam pads for various types of furniture, with its busiest season late spring and early summer. Though heated by a gas-fired, hot water heating system, the warehouse does not employ space cooling. The offices are cooled by a standard DX cooling system (retrofits did not include fixtures in the offices).

The facility operates one shift Monday through Friday, from 6:00 am to 4:30 pm year round, even during the busy season. The site observes eight standard holidays per year. The spaces where new lighting fixtures were installed did not have occupancy sensors, but the site contact stated that lights were turned off at the end of each day.

Field Data

After completing the lighting survey, Cadmus performed a walkthrough of the facility to verify and count new lighting fixtures and to install light loggers. The facility included three main warehouse spaces: a center warehouse space with ~40’ ceilings, and two spaces on either side with ~20’ ceilings. Figure 1 shows lighting fixtures in the main warehouse space.

Figure 1. Main Warehouse Lighting Fixtures

Error! Reference source not found. shows a four-lamp, 2’x4’, fluorescent fixture and a two-lamp, 4’, luorescent fixture.

Figure 2. Installed Four-lamp 2’x4’ and Two-lamp 4’ Fluorescent Fixtures

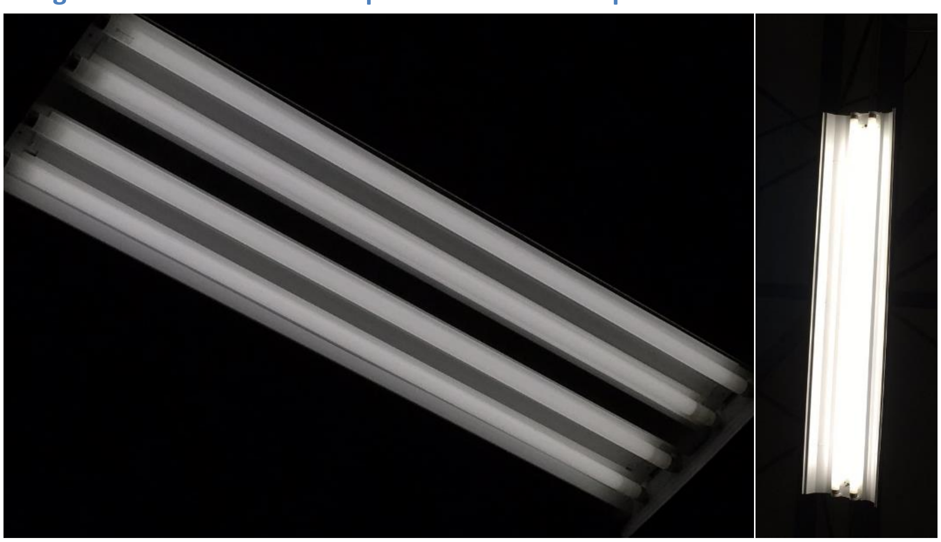
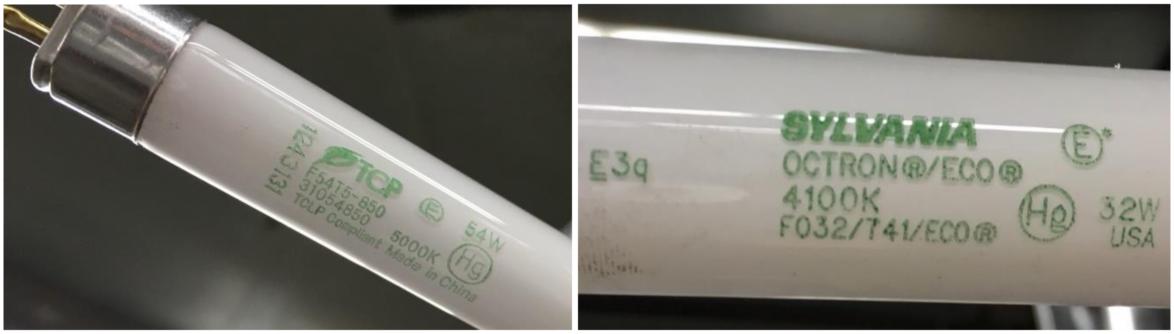


Figure 3. Spare Lamps—54-Watt T5 (left) and 32-Watt T8 (right)



Cadmus installed light loggers throughout the facility to collect fixture operating hours for a two-week period. Table 4 summarizes fixture quantities and locations of installed light loggers.

Table 4. Summary of Fixture Counts and Installed Light Loggers

#	Location	Installed Fixtures Description	Light Loggers	
			Qty	Serial Number
1	Warehouse 1	4-lamp T8	1	10380561
2	Warehouse 1	2-lamp RW-T8	1	10380548
3	Large Warehouse - Row 1	6-lamp T5-HO	1	10380626
4	Large Warehouse - Row 2	6-lamp T5-HO	0	-
5	Large Warehouse - Row 3	6-lamp T5-HO	1	10380574
6	Large Warehouse - Row 4	6-lamp T5-HO	0	-
7	Large Warehouse - Row 5	6-lamp T5-HO	0	-
8	Large Warehouse - Row 6	6-lamp T5-HO	0	-
9	Large Warehouse - Row 7	6-lamp T5-HO	0	-
10	Large Warehouse - Row 8	6-lamp T5-HO	0	-
11	Large Warehouse - Row 9	6-lamp T5-HO	0	-
12	Large Warehouse - Row 10	6-lamp T5-HO	0	-
13	Large Warehouse - Row 11	6-lamp T5-HO	1	10380624
14	Large Warehouse - Row 12	6-lamp T5-HO	1	10380582
15	Warehouse 3	4-lamp T8	1	10380542
16	Warehouse 3	2-lamp T8	1	10380621
17	Shop	2-lamp T8	1	10380581
18	Shop	6-lamp T5HO	0	-
19	Small Room (Under Construction)	2-lamp 4’ T8	0	-
Total	-	-	9	-

Figure 4, Figure 5, and Figure 6 show three locations where Cadmus installed light loggers.

CADMUS

Figure 4. Light Logger #2 Location

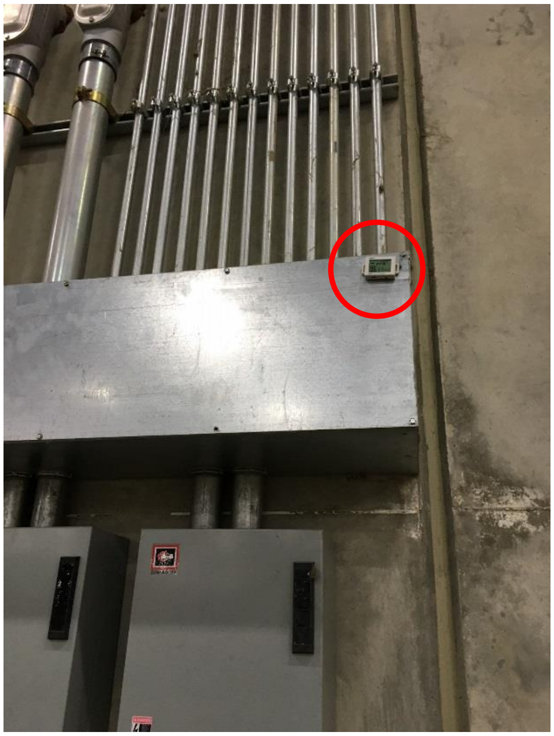


Figure 5. Light Logger #5 Location

Figure 6. Light Logger #7 Location

Data Analysis

Cadmus used the survey and light logger data to verify demand and operating hours for the installed lighting fixtures. The nine loggers produced a mean projected runtime of 2,306 hours. Though less than half of the hours assumed in the original analysis, this remains consistent with the operating schedule confirmed on site. During the two-week metering period, the site produced a mean coincidence factor of 18%. Table 5 summarizes light logger data, and Table 6 summarizes energy-savings calculations.

Table 5. Summary of Meter Data

S/N	Location	Hours Metered	Hours Operating	Percentage Operating	Projected Annual Operating Hours	Coincidence Factor
10380542	Warehouse 3	410	86	21%	1,840	0.13
10380548	Warehouse 1	410	126	31%	2,689	0.15
10380561	Warehouse 1	410	95	23%	2,026	0.1
10380574	Large Warehouse - Row 3	410	304	74%	6,505	0.71
10380581	Shop	410	6	1%	125	0
10380582	Large Warehouse - Row 12	410	44	11%	948	0.09
10380621	Warehouse 3	410	101	25%	2,168	0.13
10380624	Large Warehouse - Row 11	410	102	25%	2,191	0.1
10380626	Large Warehouse - Row 1	410	106	26	2,258	0.17

Table 6. Savings Calculations

Annual Operating Hours	CF	Pre-Retrofit		Post-Retrofit		Energy Savings		
		Qty	kW	Qty	kW	Avg. kW Reduction	Peak Coincident kW Reduction	Annual kWh
2,306	0.18	869	0.5	128	0.4	306.1	55.1	705,807
				136	0.2			
				120	0.1			
				32	0.1			
		65	0.1	40	0.1	4.3	0.8	9,858
Total	**-**	**934**	**-**	**456**	**-**	**310.4**	**55.9**	**715,665**

Conclusion

Cadmus found the equipment installed as expected. The overall energy savings realization ratio was 51%, compared to Duke Energy claimed savings. The summer peak demand realization rate was calculated at 18%. The average (or noncoincident) peak demand reduction realization ratio was 315%.

Energy savings dropped because the initial analysis assumed 18 hours per day of operation, while the site contact claimed 10.5 hours; the meter data showed slightly less than that, on average. Cadmus suspects that the claimed coincident and non-coincident peak demand savings in Duke Energy's program tracking database were erroneously switched.

Table 7 provides a comparison of the applicant, Duke Energy claimed, and evaluation energy savings and demand reduction.

Table 8 provides realization rates compared to energy savings and demand reductions claimed by Duke Energy.

Table 7. Comparison of Applicant, Duke Energy Claimed, and Evaluation Energy Savings and Demand Reduction

ECM	Applicant		Duke Energy Claimed			Evaluation		
	Annual kWh Savings	Avg. kW Reduction	Annual kWh Savings	Coincident Peak kW Reduction	Non-CP kW Reduction	Annual kWh Savings	Coincident Peak kW Reduction	Non-CP kW Reduction
1	1,862,649	398	N/A	306	N/A	705,807	55.1	306.1
2	41,980	9	N/A	4	N/A	9,858	0.8	4.4
Total	**1,904,629**	**407**	**1,412,989**	**310.4**	**98.6**	**715,665**	**55.9**	**310.4**

Table 8. Energy Savings and Demand Reduction Realization Rates

ECM	Annual kWh Savings	Coincident Peak kW	Non-CP kW
1	N/A	18%	N/A
2	N/A	18%	N/A

Total	**51%**	**18%**	**315%**

Application ID 13-1360200
RTU Retrofit, Phase 1
M&V Report

Prepared for
Duke Energy South Carolina

January 2015, Version 4.0
(revised August 22, 2016)

Note: This project has been randomly selected from the list of applications for which incentive agreements have been authorized under Duke Energy's Smart $aver® Custom Incentive Program.

The M&V activities described here are undertaken by an independent third-party evaluator of the Smart $aver® Custom Incentive Program.

Findings and conclusions of these activities shall have absolutely no impact on the agreed upon incentive between Duke Energy and [redacted]

Submitted by:

Rob Slowinski
NORESCO, Inc.

Stuart Waterbury
NORESCO, Inc.

2540 Frontier Avenue, Suite 100
Boulder CO
80301

(303) 444-4149

On August 22, 2016 the Duke Energy projected savings in this report were corrected by Cadmus to correspond to Duke Energy expected savings as found in the Duke Energy program tracking database.

Introduction

This report addresses M&V activities for the [redacted] custom program application. The application covers phase 1 of an RTU retrofit at one location in [redacted], South Carolina. The measure includes:

ECM-1 – DDC Controls
HVAC controls were added to (71) existing RTUs to allow for higher-level energy control strategies, including wintertime free cooling based on active enthalpy measurements. Synchronous (toothed belt) drives were also installed in place of V-belt drives to reduce supply fan energy and eliminate ongoing fan belt replacements. Existing RTUs were also modified to provide enthalpy-controlled economizer functions. In addition, (7) new high-efficiency RTUs were added to the building, although these were not part of the incented activities.

The installed RTUs constitute approximately 4,295 tons.

This project was completed in December 2013, so this M&V report covers post-retrofit monitoring and analysis only.

Goals and Objectives

The projected savings goals identified in the application were:

Facility	Proposed Annual kWh savings	Proposed kW Savings	Duke Expected Annual kWh savings	Duke Expected kW savings
redacted	6,299,169	0	6,299,172	11
Total	**6,299,169**	**0**	**6,299,172**	**11**

The objective of this M&V project was to verify the actual:

- Average pre/post load shapes by daytype for controlled equipment
- Facility peak demand (kW) savings
- Summer utility coincident peak demand (kW) savings
- Annual energy (kWh) savings

Project Contacts

Duke Energy M&V Coordinator	Frankie Diersing	p: 513-287-4096
NORESCO Engineer	Rob Slowinski	p: 303-459-7409 rslowinski@noresco.com
Customer Contact	redacted	

Site Locations/ECMs

Address
redacted

Data Products and Project Output

- Average pre/post load shapes by daytype for controlled equipment
- Facility peak demand (kW) savings
- Summer utility coincident peak demand (kW) savings
- Annual energy (kWh) savings
- kWh & kW Realization Rates

M&V Option

IPMVP Option A

M&V Implementation Schedule

- Conducted the post-retrofit survey after the customer had performed the controls and belt retrofit.
  - Data was collected during normal operating hours (with the Labor Day holiday coming within the middle of the monitoring period).
  - The post-retrofit HVAC schedules of the RTUs and fans were confirmed and duty cycles verified.
  - Spot-measurements were performed on selected controlled equipment.
  - Post-retrofit loggers were deployed to record temperature and power measurements on sampled equipment.
- The energy and demand savings of the retrofit measure were evaluated.

Field Survey Points

Pre – installation

- The pre-retrofit schedules, setpoints and other sequence of operation details for all controlled equipment (both RTUs and motors with new belts) were obtained. The pre-retrofit condition included no economizer operation, with interior cooling setpoints in the range of 68 to 70F.
- Nameplate data was obtained for all equipment.

Post – installation

- The new schedules, setpoints and other sequence of operation details were obtained and verified for all controlled equipment (both RTUs and motors with new belts).

Spot measurements

- V/A/kW/PF were collected for sampled RTUs and sampled motors with newly installed synchronous belts

  The sample included 15 of the 71 units, specifically the following RTUs:

  #4, 14, 17, 22, 25, 31, 36, 41, 49, 65, 71, 88, 101, 139, 141

Field Data Logging

- **ECM-1**

The following points were collected:

- Outdoor air temperature and relative humidity
- SAT, MAT, RAT, supply fan current for sampled RTUs

  The sample included the same 15 of the 71 units, specifically the following RTUs:

  #4, 14, 17, 22, 25, 31, 36, 41, 49, 65, 71, 88, 101, 139, 141

Trends and loggers were setup for 5-minute instantaneous readings and deployed for 3 weeks from August 15th to September 3rd, 2014.

Data Analysis

For the synchronous belt energy savings, the spot readings and trend data confirmed the power draw and operating schedule/duty cycle of the fan motors.

The Belt energy savings were calculated using the following equation:

$$Annual\ kWh\ savings_{Belt} = MonitoredMotorkW \times 8{,}760\frac{Hours}{Year} \times DutyCycle\ \times 0.0306$$

Where:

MonitoredMotorkW is the average non-zero fan motor kW from the trend data

DutyCycle is the percent of time that the fan motor is on

0.0306 is an assumed 3.06% energy savings improvement over standard V-belts, as verified by DOE research[1].

Belt demand savings was calculated using the following equation:

$$kW\ savings_{Belt} = MonitoredMotorkW \times CF \times 0.0306$$

Where:

CF is a coincidence factor, assumed to be 1.0, as all fans appear to be running at all times on weekdays

Economizer cooling energy savings was determined by confirming proper operation of the economizers by plotting mixed air and return air versus outside air, and observing the behavior as OA temperatures dropped. An economizer “lever” plot of MAT-RAT vs. OAT-RAT was also plotted, but due to some inconsistencies in the data, results were difficult to ascertain. Figures 1 and 2 show this relationship for RTUs 49 and 88. Economizing can be observed below about 80F on RTU49, as the slope of MAT is much greater than that of RAT. There is no observable economizing on RTU88.

[1] https://www1.eere.energy.gov/manufacturing/tech_assistance/pdfs/replace_vbelts_motor_systemts5.pdf

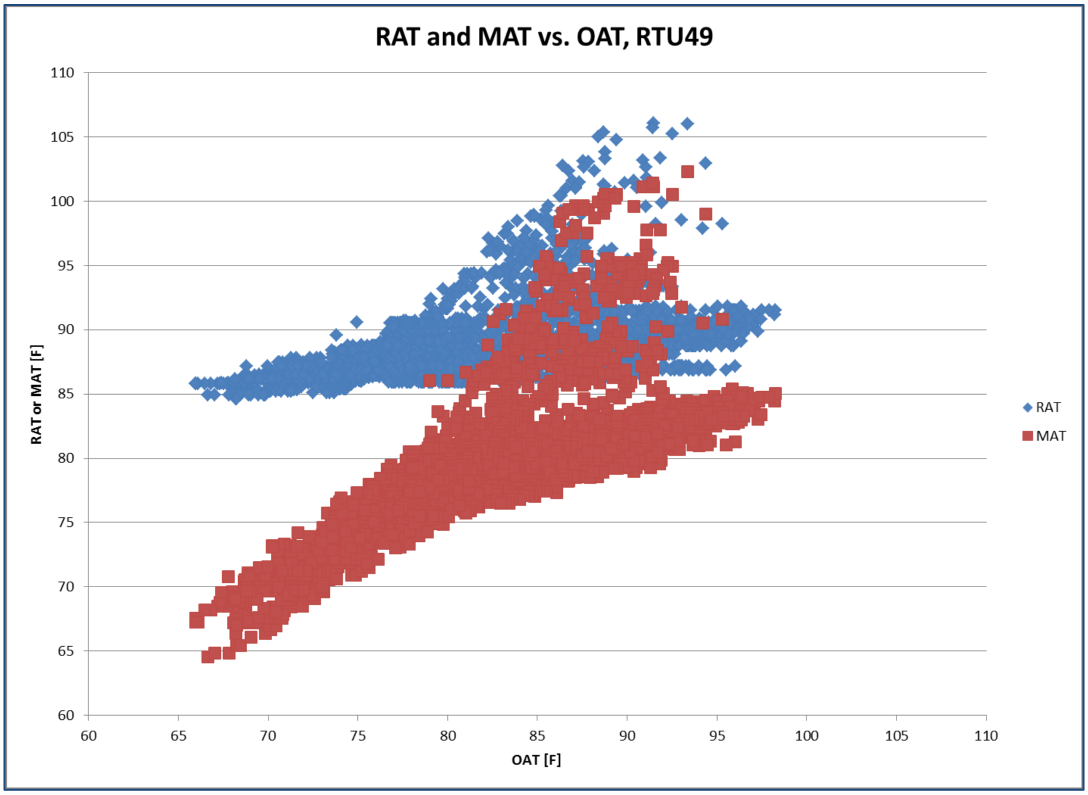


Figure 1: RTU49 Economizer Function.

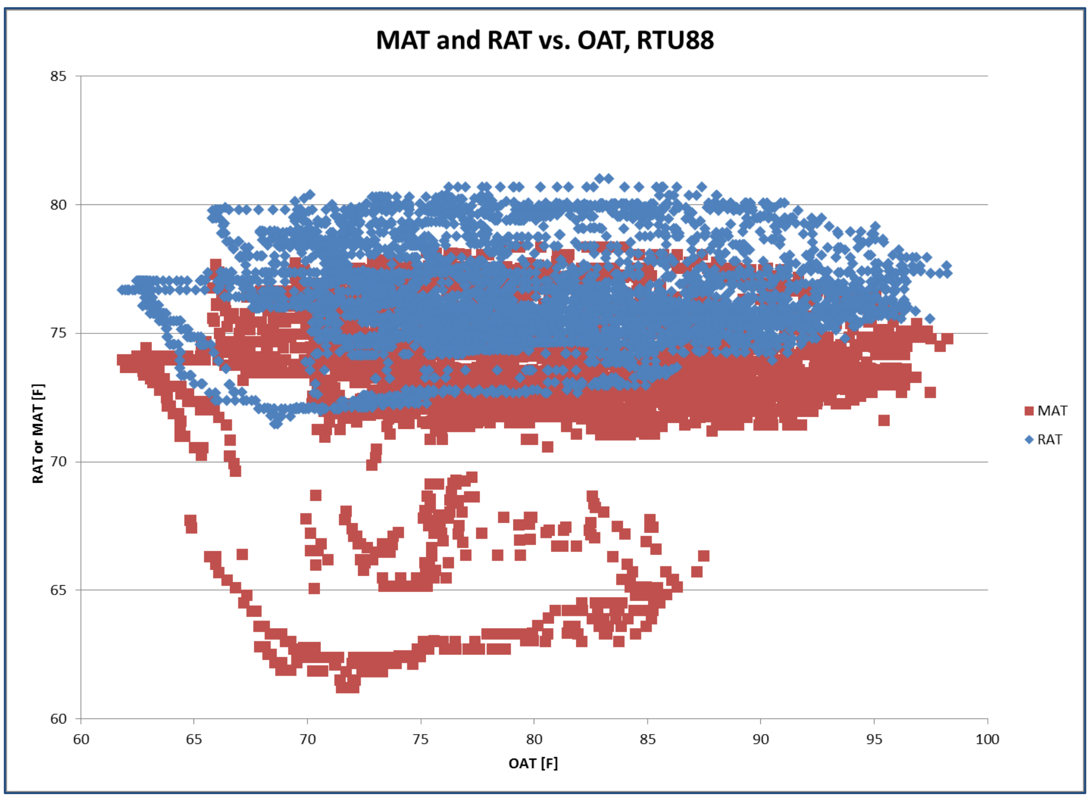


Figure 2: RTU88 Economizer Function.

It should be noted that economizing was not observed on the majority of sampled RTUs. However, because the savings from economizing occurs predominantly at lower outdoor air temperatures and because the 3-week logger data sample rarely included temperatures below 65F, it was assumed that economizing was in fact occurring at these lower temperatures. The site contact indicated that below 60F, all mechanical cooling was locked out. Time series plots—as seen in Figures 3 and 4—also showed brief periods of economizing for many of the RTUs.

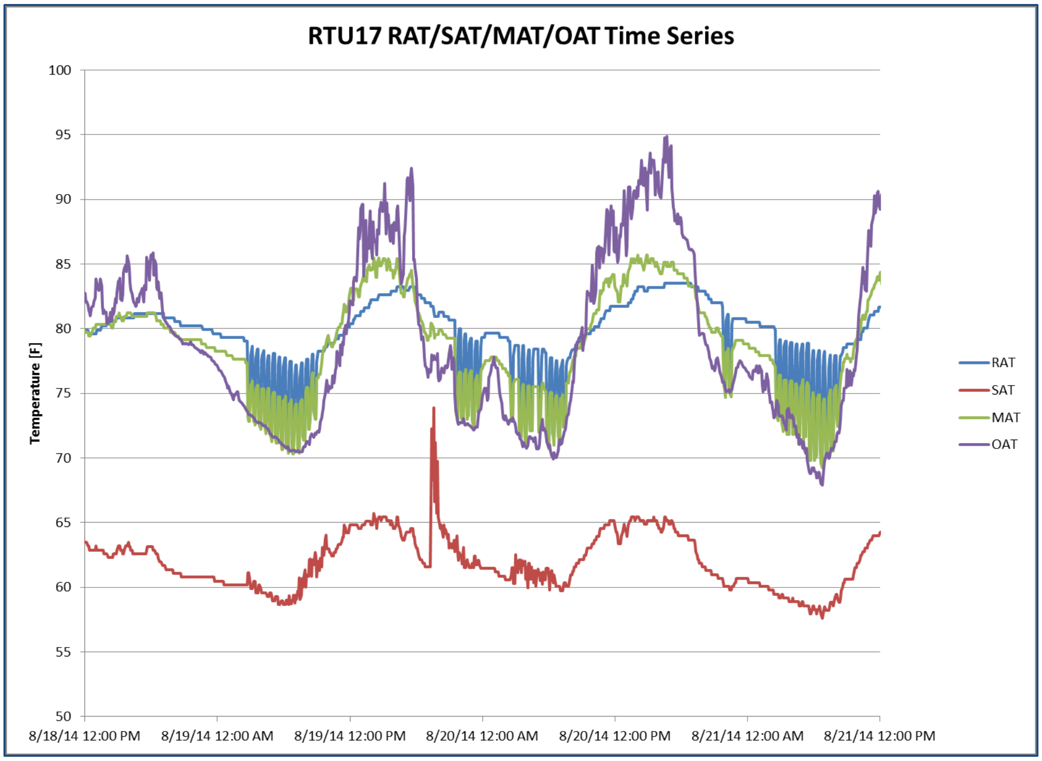


Figure 3: Time series plot of RTU 17 shows some economizing.

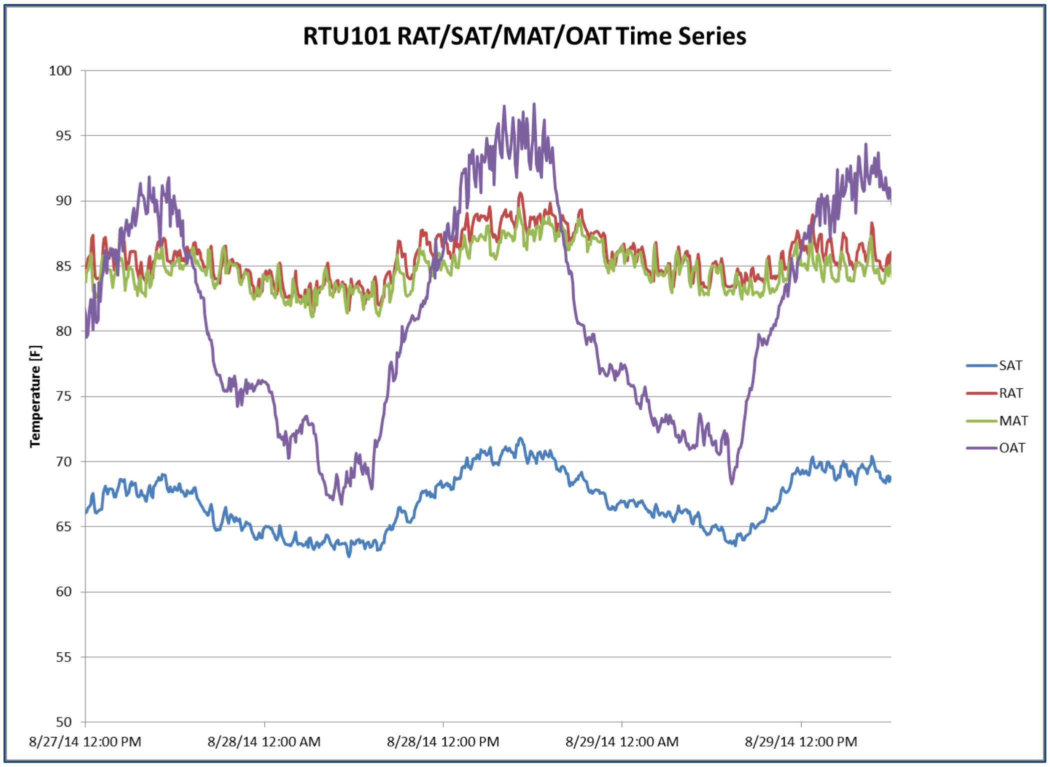


Figure 4: Time series plot of RTU 101 does not show evidence of economizing.

For each RTU, a regression of RAT vs. OAT was created, as seen in Figure 5.

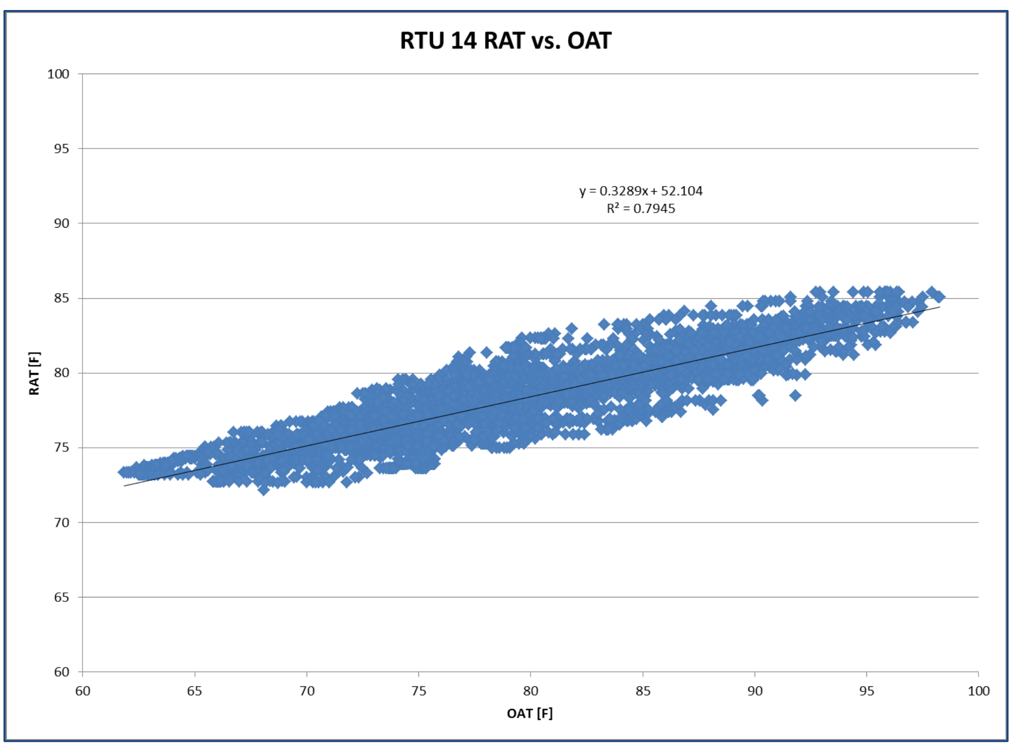


Figure 5: RTU14 RAT vs. OAT.

The RAT regressions were then used in the following equation to determine the cooling energy savings from economizing:

Economizer Energy Savings

Energy consumption from free cooling was determined using an hourly bin data analysis of outside air conditions and the following equations:

$$EnergySavings_{Econ} = \frac{4.5 \times CFM_{obs} \times (OAF_{ECM} - OAF_{base}) \times (h_{RA} - h_{OA})}{12{,}000 \times CoolingkWperTon}$$

$$CFM_{obs} = CFM_{rated} \times (\frac{P_{obs}}{P_{rated}})^{\frac{1}{2.7}}$$

$$OAF_{ECM} = (\frac{MAT - RAT}{OAT - RAT})$$

$$\mathrm{OAF_{base}} = 10\%$$

Where:

- *4.5* is a constant used in total heat equations, incorporating the heat density of dry air and a conversion from hours to minutes
- CFM_{obs} is the average RTU supply fan cubic feet per minute of airflow
- OAF_{ECM} is the outdoor air fraction according to a regression of RAT versus OAT from logged data
- OAF_{base} is the pre-retrofit fixed outdoor air fraction of 10%
- H_{RA} is the enthalpy of return air defined from the RAT versus OAT regression from logged data. This is calculated from the temperature and humidity of the return air
- H_{OA} is the enthalpy of outside air, calculated based on logged temperature and humidity of outside air
- *12,000* is a constant converting BTUs/hr to tons
- *CoolingkWperTon* is the cooling efficiency of the units
- CFM_{rated} is the rated airflow, in CFM, of each RTU supply fan
- P_{obs} is the observed kW from logger data
- P_{rated} is the rated kW of each supply fan
- *2.7* is a fan law constant for VFDs
- *MAT* is the assumed mixed air temperature, controlled to a minimum of 53F during conditions appropriate for economizing, given a discharge air setpoint of 55F and including fan heat

RTU fan schedules were not entirely consistent between the sampled units. Many units were scheduled off for a portion of the day on Saturdays, but some were scheduled for downtime on

Sundays. The length of the downtime was similar, but not completely consistent between the units and on some weekends the downtime appeared to be skipped altogether. In addition, for a couple of the monitored units, the fans appeared to be running at all times. For this reason, the average duty cycle was used to calculate annual energy savings, irrespective of whether a particular unit's downtime occurred on Saturdays, Sundays or not at all. Coincident peak (CP) demand savings was calculated at 3pm on July 17th. The (CP and non-CP) demand calculations for fan belts assumed a coincidence factor of 1.0, as all units appeared to be running at all times during weekdays.

Verification and Quality Control

1. Visually inspected logger data for consistent operation. Sorted by day type and removed invalid data. Looked for data out of range and data combinations that are physically impossible.
2. Verified that pre-retrofit and post retrofit equipment specifications and quantities were consistent with the application.
3. Verified electrical voltage of equipment circuits.

Recording and Data Exchange Format

1. Survey Form and Notes.
2. Building Automation System data files OR data logger files
3. Excel spreadsheets

Results Summary

The following table shows the results of the post-retrofit energy calculations, as compared to pre-retrofit estimates. Energy and demand savings listed in the table include the sum of both the belt retrofit measure and the economizer measure. Itemized belt savings accounted for 34,226 kWh and all of the demand savings (CP and non-CP) in the following energy savings totals:

	Energy Savings [kWh]	NCP Demand Savings [kW]	CP Demand Savings [kW]
Duke Expected	6,299,172	1,340	11
Verified	3,187,362	11.3	11.3
Realization Rate	51%	1%	105%

The verified energy savings results are low (as compared to the pre-retrofit estimates) due to the fact that many of the monitored units showed no signs of economizing during the logging period. It is true that outside air temperatures during the logging period tended to be somewhat high for economizing, but when economizing *was* observed, there seemed to be little observable evidence for *why* it was occurring. Perhaps logging temperatures and operation details during a period of more mild temperatures would show fuller economizer operation, but the data gathered during this project does not fully support that conclusion. There is an apparent clerical error in the reported NCP expected demand savings in the Duke Energy program tracking database as it is much higher than the coincident peak expected savings.

Application ID 13-1570850
HVAC
M&V Report

August 26, 2016

Duke Energy
139 East Fourth Street
Cincinnati, OH 45201

The Cadmus Group, Inc.

An Employee-Owned Company • www.cadmusgroup.com

CADMUS

Prepared by:
Dave Korn
Christie Amero

Cadmus

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Table of Contents

Introduction

This report outlines Cadmus' measurement and verification (M&V) activities for one retrofit energy conservation measure (ECM) included as part of the [redacted], Smart $aver custom incentive program application—specifically for installing economizer controls and synchronous drives on 18 rooftop units (RTUs) at one location in [redacted], South Carolina. Energy savings were expected to result from reduced cooling energy use during shoulder seasons and improved motor efficiency. A description of the measure as submitted in the original application documentation is provided below.

ECM-1: Install Enthalpy Economizer Control and Synchronous Drives on Rooftop Units

Space conditioning for one of [redacted]'s gas turbine manufacturing facilities in South Carolina is provided by packaged RTUs. The 18 RTUs included in this retrofit project serve 117,250 square feet of the facility. The RTUs have direct expansion (DX) cooling coils, with a total cooling capacity of 695 tons and design supply airflow of 450,669 cfm. According to the original study, the facility is occupied 24 hours per day, seven days per week, year-round.

This project was Phase 2 of a two-phase project, where in Phase 1 the facility retrofitted 71 RTUs. The total annual electric energy use for the facility is approximately 158,400,000 kWh, based on 2012 and 2013 utility data.

Pre-Retrofit: In the pre-retrofit case, the 18 RTUs did not have economizers, and the DX cooling coils were required to operate whenever cooling was required. The RTU fans were all driven by standard V-belts, which depend on friction from a pulley; this generates heat and has the potential for slippage, versus tooth and sprocket engagement in a synchronous drive. V-belts also tend to elongate over time, causing belt creep.

Installed: The project involved retrofitting the 18 RTUs with enthalpy controlled economizers and synchronous drive motors. Economizer controls allow units to use outside air for space cooling when ambient conditions allow, reducing the load on DX cooling coils. Synchronous drives have been proven to be more efficient than V-belts because they reduce torque and speed loss. According to the Gates Corporation, switching from a V-belt to a synchronous belt drive system can improve motor efficiency by at least 5%[1].

In the original analysis, energy savings for the economizer controls were calculated using Hourly Analysis Program v4.51 analysis software. The simulation results with and without economizer control were compared. Energy savings for the synchronous drives were calculated using a Gates energy savings calculator. The original analysis assumed that all 18 RTUs had 15-hp fan motors with a full-load motor

[1] "Energy Savings from Synchronous Belts." Gates Corporation. 2014. http://designcenter.gates.com/wp-content/uploads/2015/05/Gates-Energy-Saving-from-Synchronous-Belt-Drives-White-Paper.pdf

efficiency of 86%, operating 8,760 hours per year. The calculator used the Gates Corporation's estimated 5% savings for synchronous belts.

The total annual energy savings submitted in the original application were 1,909,006 kWh, or 1.2% of the total facility annual energy use.

Goals and Objectives

Table 1 shows the projected savings goals identified in the project application.

Table 1. Project Goals

Application		Duke Energy			
Annual kWh Savings	Average kW Reduction	Projected Annual kWh Savings*	Claimed Annual kWh Savings	Claimed Coincident Peak kW Reduction	Claimed Non-CP kW Reduction
1,895,093	N/A	1,909,006	1,909,006	2.45	122.70

* Source: DSMore input spreadsheet.

Cadmus' objective for this M&V project was to verify the following actual data:

- Facility peak demand reduction (kW)
- Summer utility coincident peak demand reduction (kW)
- Annual energy savings (kWh)
- Annual realization ratios (kW and kWh)

Project Contacts

Table 2 lists the Duke Energy contact who granted Cadmus approval to plan and schedule the site visit for this M&V effort, along with the Cadmus contact and the customer contact.

Table 2. Project Contacts

Organization	Contact	Contact Information
Duke Energy	Monica Redman, Senior DSM & Retail Programs Analyst	monica.redman@duke-energy.com
Cadmus	Christie Amero, Senior Analyst	office: 303-389-2509 christie.amero@cadmusgroup.com
Customer	redacted	

Site Location

The site location is listed in Table 3.

Table 3. Site Location

Address	ECM
redacted	1

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M&V Option

To assess this site, Cadmus followed IPMVP Option A.

Implementation

Cadmus reached out to the site contact provided by Duke Energy, seeking to review the evaluation plan and schedule the site visit. During the initial discussion with the site contact, Cadmus was informed that the energy management system (EMS) for the HVAC system currently trends energy use on all of the RTUs submitted in the application, and therefore additional on-site power metering would not be necessary. Christie Amero of Cadmus performed the site visit on June 21, 2016, to meet with the site contact and controls representative, review and set up available trend points, and physically verify the existing RTUs and installed synchronous belts.

Field Survey

During the site visit, Cadmus met with the site contact and controls representatives to review the EMS and collect general operating information. Nine of the 18 RTUs submitted in this application are located on the main manufacturing building and serve the power nozzle repair station (PRS), main distribution center (MDC), and bucket repair areas. The remaining nine RTUs are located on the combustion building.

According to the site contact, the site has increased the cooling load since the project was completed. There are more employees in the two buildings affected by the retrofits and the company added shifts during the weekends. There was also a significant amount of machine waste heat added to the spaces. Site contacts claimed that the interior space temperature at occupied level is maintained between 72°F and 74°F year round. The return air temperature is typically higher than the space temperature because the return air sensors are located in the ductwork in the ceilings (approximately 40’ high).

The site is currently running three shifts, Monday through Friday (24 hours per day) and two shifts on weekends (16 hours per day). The site typically shuts down for two full weeks per year for scheduled maintenance and observes typical federal holidays.

During the site visit, the controls representative relayed that the 18 RTUs had the capability to operate in economizer mode prior to the retrofit project. However, economizer mode had been disabled a few years before the retrofit because the original ductwork and controls dumped cold outside air directly down into the spaces, causing occupant discomfort.

For the retrofit project, the facility changed the space thermostats, improved airflow to the spaces by adding diffusers, and improved economizer change-over controls. The mixed air temperature is now maintained at a minimum of 55°F during the winter months to prevent cold air from being dumped into the spaces.

According to the facility contact, economizer operation is based on outside air dry bulb temperature (not enthalpy, as expected in the original application) and is enabled when the difference between the

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return air temperature and outside air temperature is greater than 5°F. For example, if the return air temperature is 80°F and the outside air temperature is 74°F, the system will go into economizer mode.

Field Data

ECM-1: Install Enthalpy Economizer Control and Synchronous Drives on Rooftop Units

Cadmus collected the trend data shown in Table 4 for all installed equipment included in the application. All 18 RTUs are Trane constant volume packaged units with an average cooling capacity of approximately 36 tons. During the site inspection, Cadmus found that two of the RTU fan motors had V-belt drives (RTU-165 and RTU-166). According to the site contact, synchronous drives were installed in these RTUs during the project, but had to be replaced with V-belts. The RTUs all have constant speed fans (no variable frequency drives), and frequent stopping and starting causes wear and tear on the synchronous belts. The synchronous belts on a few of the remaining retrofitted RTUs were missing some teeth due to this issue.

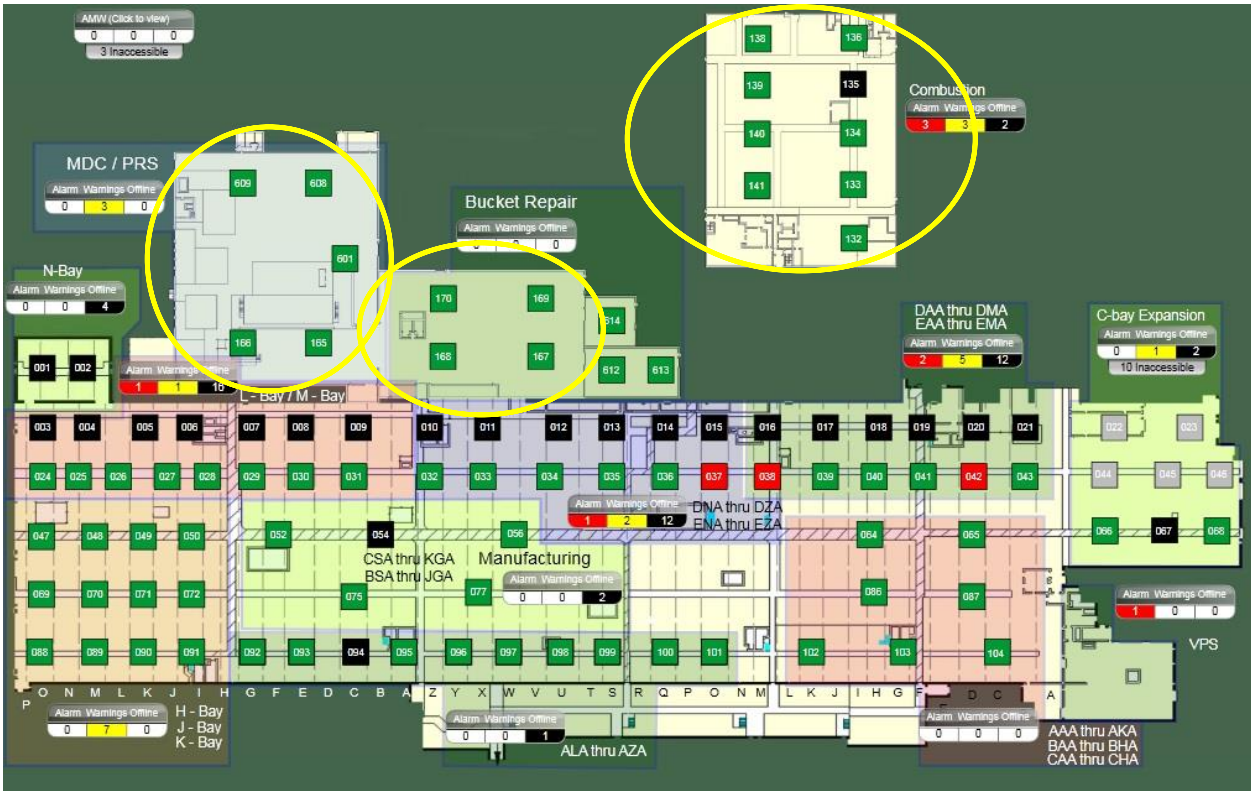
Table 4. Installed Equipment Nameplate Data

Building	Equipment ID	Make	Model #	Cooling Capacity, tons	Fan hp	Belt Type
Combustion	RTU-132	Trane	SFHCC404HTS6	40	15	Synchronous
	RTU-133	Trane	SFHCC404HTS6	40	15	Synchronous
	RTU-134	Trane	SFHCC404HTS6	40	15	Synchronous
	RTU-135	Trane	SFHCC404HTS6	40	15	Synchronous
	RTU-136	Trane	SFHCC404HTS6	40	15	Synchronous
	RTU-138	Trane	SFHCC404HTS6	40	15	Synchronous
	RTU-139	Trane	SFHCC404HTS6	40	15	Synchronous
	RTU-140	Trane	SFHCC404HTS6	40	15	Synchronous
	RTU-141	Trane	SFHCC404HTS6	40	15	Synchronous
MDC/PRS	RTU-165	Trane	50DL44600AA	40	15	V-Belt
	RTU-166	Trane	YCD480A4LF2A3	40	15	V-Belt
	RTU-601	Trane	50DF034620PA	30	15	Synchronous
	RTU-608	Trane	50DF034620PA	30	15	Synchronous
	RTU-609	Trane	50DF034600PA	30	15	Synchronous
Bucket Repair	RTU-167	Trane	SFHFF304HA58	30	15	Synchronous
	RTU-168	Trane	SFHFF304HA58	30	15	Synchronous
	RTU-169	Trane	SFHFF304HA58	30	15	Synchronous
	RTU-170	Trane	SFHFF304HA58	30	15	Synchronous

Figure 1 shows the RTU layout for the main building and combustion building. The RTUs included in this retrofit project are circled in yellow. As stated above, a majority of the RTUs serving the manufacturing area of the main building were retrofitted as part of Phase 1.

Due to the sensitive nature of the products at the site, Cadmus was not able to bring a laptop or camera to take photographs of the installed equipment or controls.

Figure 1. Main and Combustion Building RTU Layout



Cadmus also collected five weeks of energy use (kWh) trend data from the site, for most of the RTUs submitted in the application. The facility provided the cooling command, outside air damper positon, zone temperature, and return and discharge air temperature for the combustion building RTUs only. Table 5 summarizes the points we collected from the system. The site had not saved data from the earlier shoulder season so Cadmus was only able to obtain and analyze July data. This limited the amount of economizing that Cadmus could observe. As explained later we did see some inconsistent controls behavior. Given the lack of data from prime economizing periods we based our analysis on the site successfully economizing during low outside air temperatures.

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Table 5. Provided Trend Points for RTUs

Building	Number of RTUs	Trend Point	Interval	Duration
Combustion (9 RTUs)	9	Energy Use, kWh	1 hour	5 weeks
	7	Zone Temperature, °F	30 minutes	5 weeks
	6	Discharge Air Temperature, °F	30 minutes	5 weeks
	6	Return Air Temperature, °F	30 minutes	5 weeks
	7	Cooling Command, %	30 minutes	5 weeks
	8	Outside Air Damper, %	30 minutes	5 weeks
MDC/PRS* (5 RTUs)	4	Energy Use, kWh	1 hour	5 weeks
	-	Zone Temperature, °F	-	-
	-	Discharge Air Temperature, °F	-	-
	-	Return Air Temperature, °F	-	-
	-	Cooling Command, %	-	-
	-	Outside Air Damper, %	-	-
Bucket Repair (4 RTUs)	4	Energy Use, kWh	1 hour	5 weeks
	4	Zone Temperature, °F	10 minutes	5 weeks
	-	Discharge Air Temperature, °F	-	-
	-	Return Air Temperature, °F	-	-
	-	Cooling Command, %	-	-
	-	Outside Air Damper, %	-	-

* Trend data for RTU-601 on the MDC/PRS building was not provided.

Data Analysis

ECM-1: Install Enthalpy Economizer Control and Synchronous Drives on Rooftop Units

Cadmus used the trend data for the installed equipment to verify the demand and operating hours of the RTUs. Table 6 summarizes the average operating demand for each of the RTUs based on the trend data collected.

Table 6. Summary of Trend Data

Building	RTU ID	Average Operating Demand, kW
Combustion	RTU-132	30.5
	RTU-133	20.8
	RTU-134	8.4
	RTU-135	46.5
	RTU-136	28.0
	RTU-138	27.1
	RTU-139	29.9
	RTU-140	43.00
	RTU-141	27.02
MDC/PRS	RTU-165	41.6
	RTU-166	45.1
	RTU-601*	N/A
	RTU-608	44.6
	RTU-609	48.0
Bucket Repair	RTU-167	23.7
	RTU-168	26.0
	RTU-169	17.3
	RTU-170	31.7

* Data for RTU-601 was not provided. Cadmus assumed the demand for RTU-601 by taking the average demand of RTU-608 and RTU-609.

As a preliminary estimate of the potential energy savings, Cadmus extrapolated the average trended RTU demand to typical annual operation. We calculated fan motor demand using the manufacturers' nameplate horsepower rating with assumed motor load factor of 85.0% and motor efficiency of 86.0%. We estimated the percentage of fan motor demand versus compressor demand by divided the calculated fan demand by the total average trended demand. Cadmus used the average percentage of fan demand for all 18 RTUs (36%) to calculate the total annual fan energy use using the following equation.

$$\text{Total Annual Fan Energy Use, kWh} = \text{Total Trended Average RTU Demand, kW} * \%\ \text{Fan Demand} * 8{,}760\ \text{hours} \quad [1]$$

The estimated total annual fan energy use was 1,834,049 kWh. We calculated the total estimated pre-retrofit cooling energy use assuming cooling was required ten months of the year.

$$\text{Total Annual Cooling Energy Use, kWh} = \text{Total Trended Average RTU Demand, kW} * (1 - \%\ \text{Fan Demand}) * 7{,}300\ \text{hours} \quad [2]$$

The estimated total annual pre-retrofit cooling energy use was 2,745,655 kWh, and total overall pre-retrofit RTU energy use was 4,579,704 kWh. The total cooling-only energy savings submitted in the original application was 1,797,406 kWh, which is 65% of the estimated annual pre-retrofit cooling energy use. Based on this comparison, Cadmus estimated that the cooling energy savings submitted in the original application were too high relative to the pre-retrofit energy use. Table 7 presents the calculations performed for this preliminary estimate.

Table 7. Preliminary Estimate of Pre-Retrofit Energy Use Based on Trended Demand Data

RTU ID	Trended Average Demand, kW	Estimated Fan Demand, kW	Percent Fan Demand	Estimated Annual Pre-Retrofit Energy Use, kWh		
				Fan	Cooling (10 months)	Total
132	30.5	11.1	36%	95,627	143,159	238,786
133	20.8	11.1	53%	65,122	97,491	162,613
134	8.4	11.1	-	26,235	39,275	65,510
135	46.5	11.1	24%	145,556	217,904	363,460
136	28.0	11.1	40%	87,578	131,108	218,686
138	27.1	11.1	41%	85,029	127,293	212,322
139	29.9	11.1	37%	93,673	140,233	233,906
140	43.00	11.1	26%	134,707	201,662	336,368
141	27.02	11.1	41%	84,629	126,694	211,324
165	41.6	11.1	27%	130,280	195,034	325,314
166	45.1	11.1	25%	141,383	211,657	353,040
601*	N/A	11.1	47%	74,390	111,365	185,754
608	44.6	11.1	43%	81,339	121,769	203,108
609	48.0	11.1	64%	54,311	81,305	135,616
167	23.7	11.1	35%	99,165	148,455	247,620
168	26.0	11.1	24%	145,008	217,084	362,092
169	17.3	11.1	25%	139,764	209,233	348,997
170	31.7	11.1	23%	150,252	224,935	375,187
Total	**585.5**	**199.1**	**36%**	**1,834,049**	**2,745,655**	**4,579,704**
Original Application Cooling Energy Savings, kWh						**1,797,406**
Original Application Cooling Energy Savings Compared to Estimated Cooling Energy Use						**65%**

* Data for RTU-601 was not provided. Cadmus assumed the demand for RTU-601 by taking the average demand of RTU-608 and RTU-609.

Our next step in the M&V process was to create an 8,760 hour model with typical meteorological year (TMY) data for [redacted], South Carolina. Since coincident outside air conditions were not available from the site's trend system, we collected coincident weather data from the [redacted] airport weather station. The minimum outside air dry bulb temperature was 68°F during the trend data collection period, which is high for standard economizing. Ideally, we would collect data during a shoulder season to observe the units in typical economizer operation, however the site did not retain data from the earlier shoulder season.

We did not observe economizer operation in a majority of the RTUs, and the units that did economize appeared to do so sporadically. Figure 2 and Figure 3 show plots of the outside air damper position (percent open) and cooling command (on/off) with outside air dry bulb temperature for RTU-136, which is the only unit that consistently operated in economizer mode. In Figure 2, the damper appears to open only when the outside air temperature is below approximately 72°F, but Figure 3 shows the damper opening at 94°F outside air dry bulb temperature on July 11th. This likely increased cooling loads and energy use. We suggest that Duke Energy contact the site about this observation.

Figure 4 shows a similar plot for RTU-134, which did not economizer at all during the trend period, but serves an adjacent building area to RTU-136.

Figure 2. RTU-136 Outside Air Damper Position and Cooling Command (Primary Y-Axis) and Outside Air Dry Bulb Temperature (Secondary Y-Axis) – July 4th through 9th

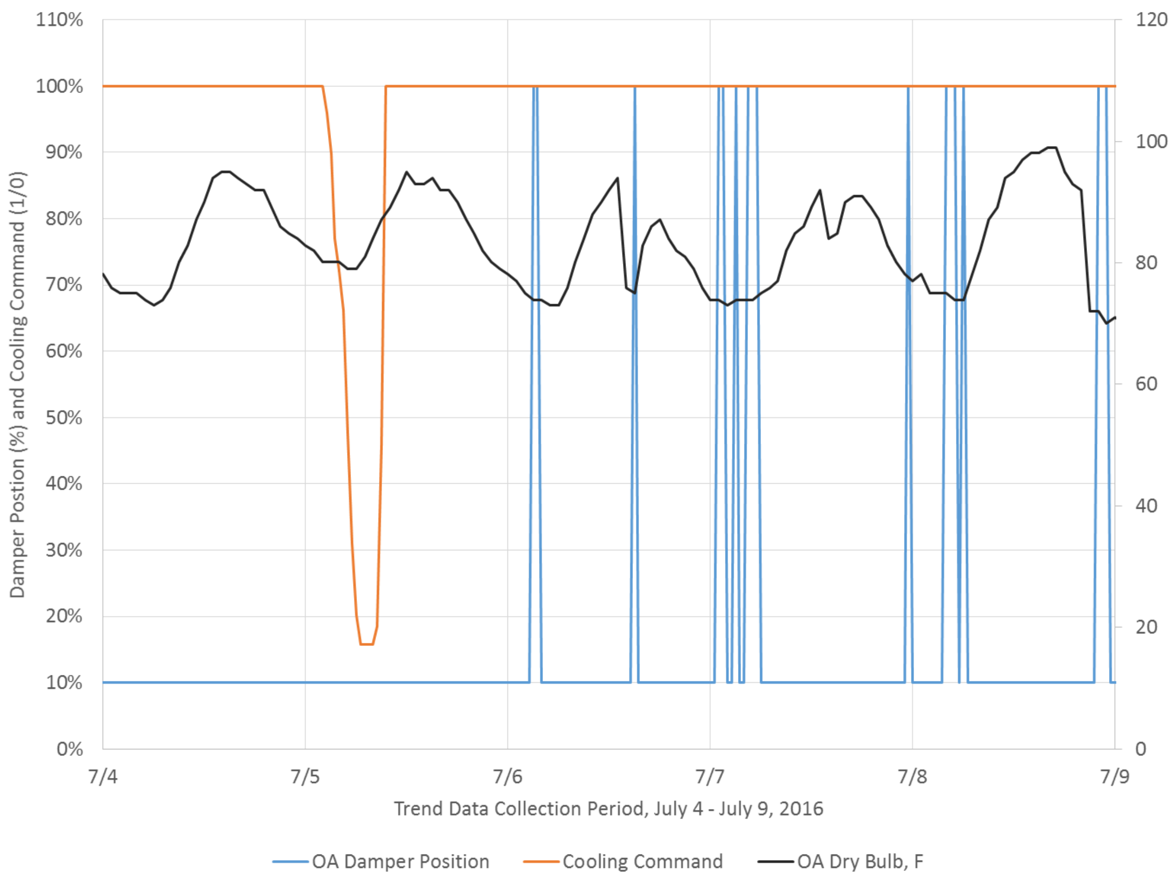

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Figure 3. RTU-136 Outside Air Damper Position and Cooling Command (Primary Y-Axis) and Outside Air Dry Bulb Temperature (Secondary Y-Axis) – July 9th through 14th

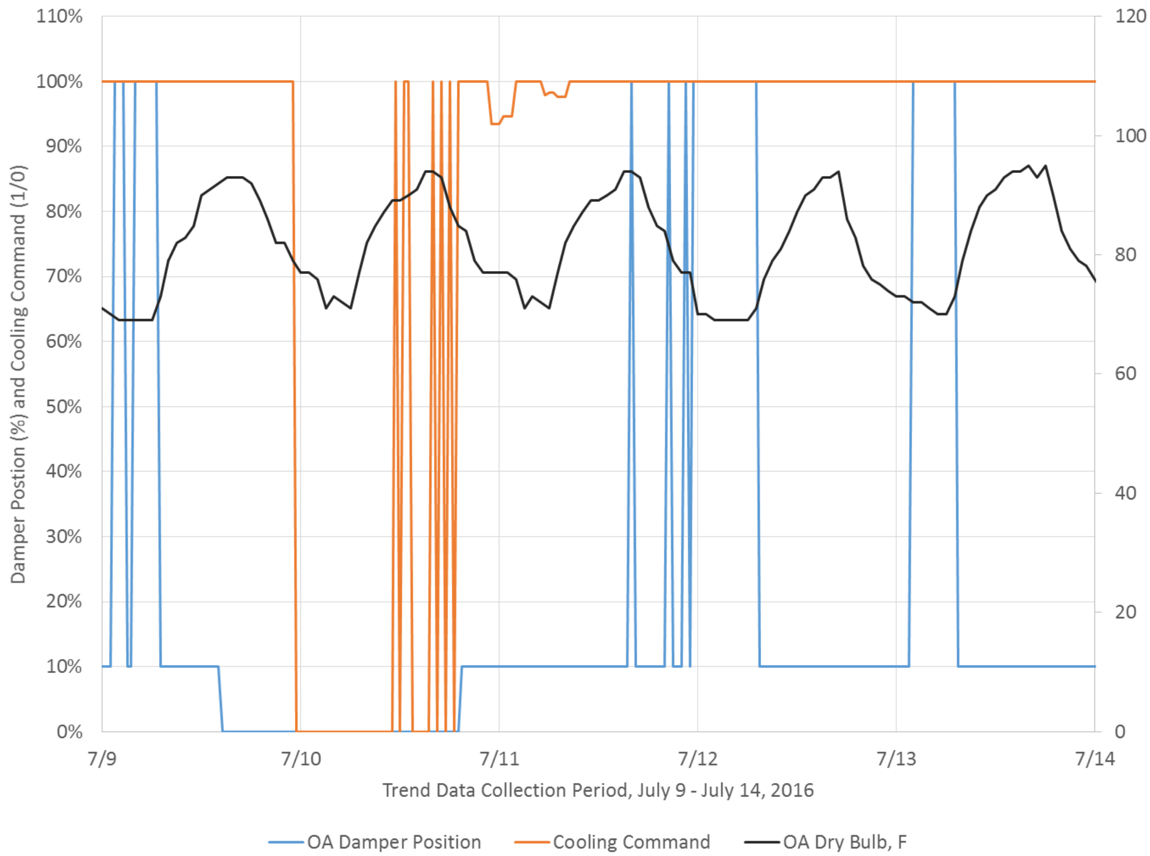
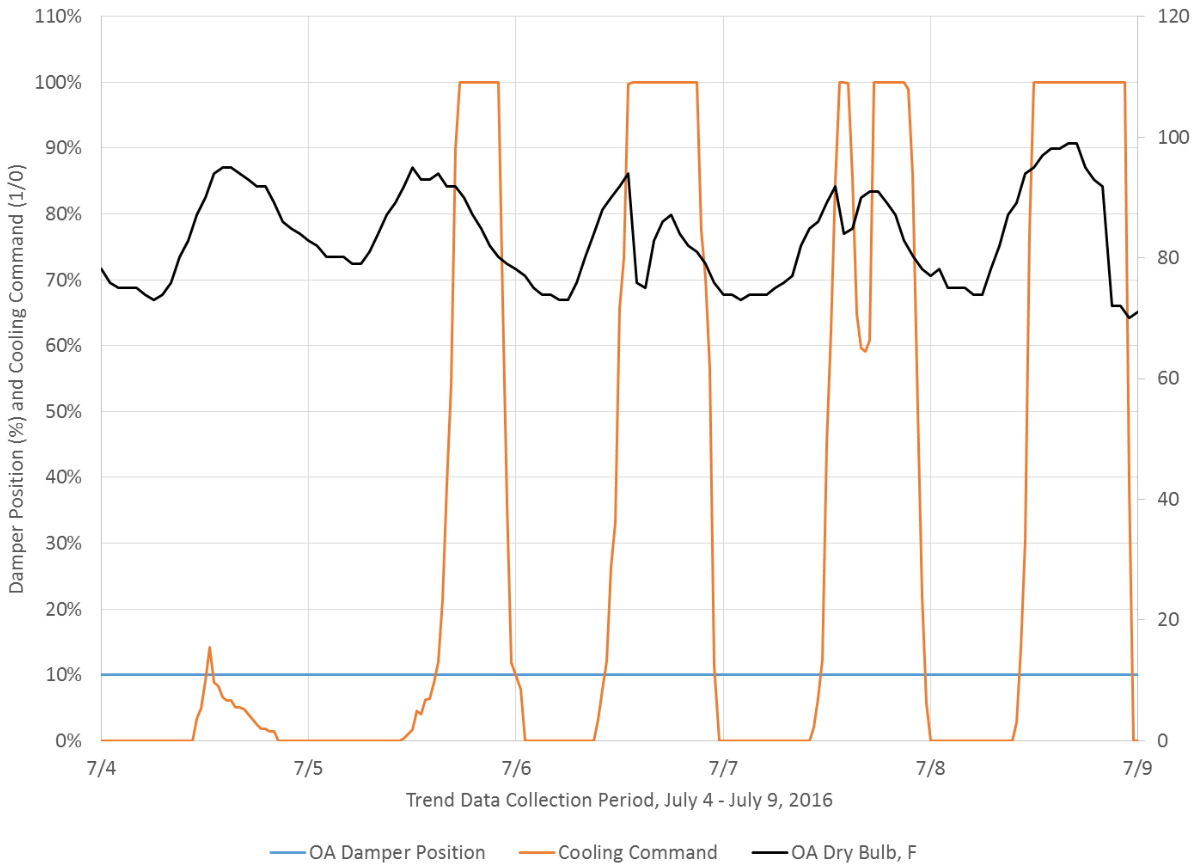


Figure 4. RTU-134 Outside Air Damper Position and Cooling Command (Primary Y-Axis) and Outside Air Dry Bulb Temperature (Secondary Y-Axis) – July 4th through 9th



We could not confirm economizer operation at mild outside air conditions because we did not have trend data for standard economizer conditions. We evaluated the measure based on the site contact's description of economizer operation and the return and discharge air temperatures provided. Cadmus averaged the trended discharge (DAT) and return air temperatures (RAT) provided for six of the 18 RTUs. Figure 5 shows the plot of average RAT versus coincident outside air dry bulb temperature and Figure 6 shows the plot of average DAT versus outside air dry bulb temperature. We used the linear trend fits from these curves to calculate the DAT and RAT for the pre-retrofit and installed system energy use calculations in the hourly model.

Figure 5. Average RAT vs. Outside Air Dry Bulb Temperature

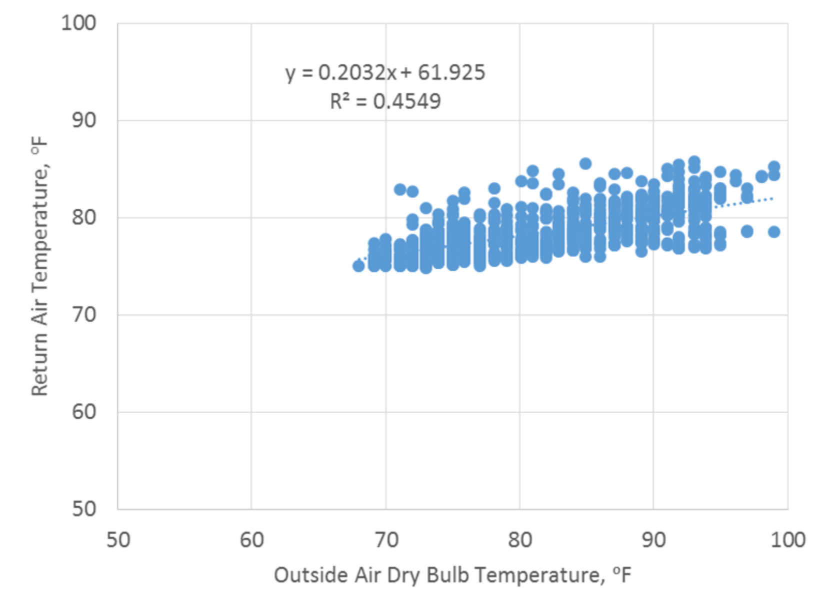
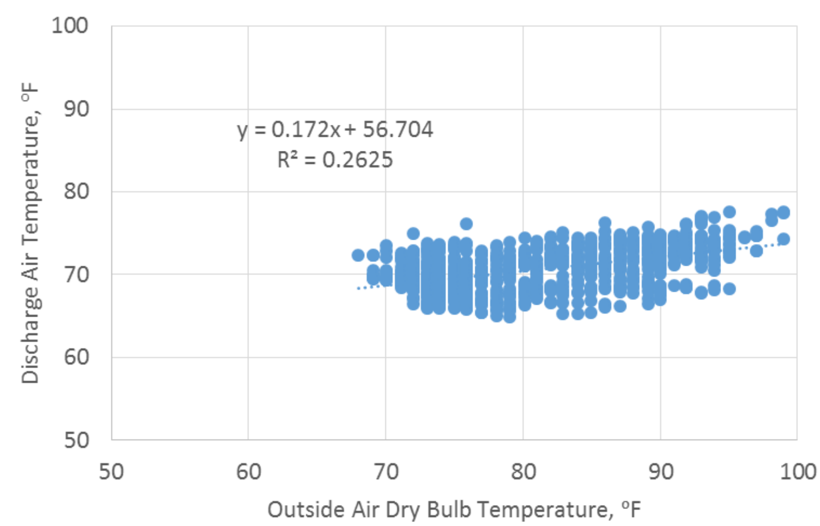


Figure 6. Average DAT vs. Outside Air Dry Bulb Temperature



In the pre-retrofit case, we assumed the minimum outside air flow rate was 10%. We calculated the pre-retrofit mixed air temperature (MAT, temperature of air before the cooling coil) using the following equation:

$$MAT = (\text{Outside Air Dry Bulb, °F} - \text{RAT, °F}) * \text{Percent of outside Air, \%} + \text{RAT, °F} \quad [3]$$

In the pre-retrofit case, the DX cooling coils would have been required to operate whenever the MAT was greater than the DAT, but we applied a cooling cutoff at 40°F outside air temperature, since the site would likely shut lockout the cooling coils at low temperatures to prevent freezing. The total design supply airflow rate for the 18 RTUs is 450,669 cfm based on original application. Cadmus assumed the average supply airflow is 90% of design, or 405,602 cfm. We then calculated the cooling load using the following equation:

Cooling Load, tons = Supply Airflow, cfm * 1.08 * (MAT, °F – DAT, °F) / 12,000 Btu/hr/ton [4]

We used the RTU compressor performance listed on manufacturer's specification sheets to calculate the pre-retrofit RTU cooling demand. The total fan motor demand was calculated using the manufacturers' nameplate horsepower ratings with assumed motor load factor of 85.0% and motor efficiency of 86.0%. We also assumed an average annual fan cycling of 90%. The evaluated pre-retrofit annual energy use was 3,406,597 kWh. The coincident peak demand was 490.9 kW, and average annual demand was 388.9 kW.

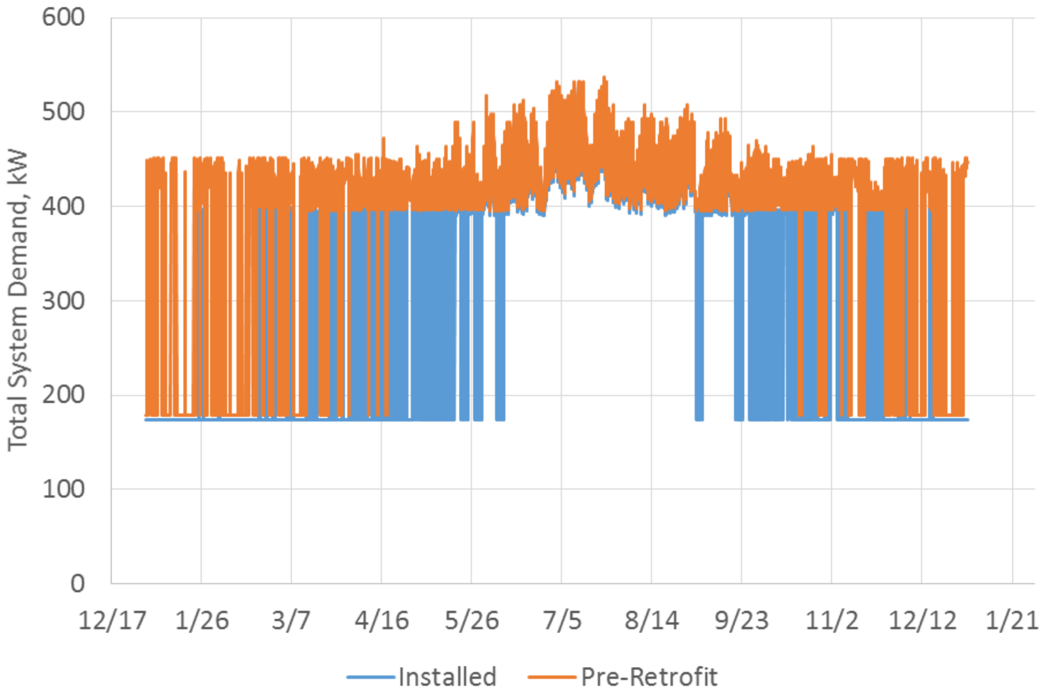
The installed case economizer outside air dry bulb change-over temperature was estimated using psychrometric equations. The average annual return air temperature based on the hourly model is 76.0°F and the interior relative humidity is maintained at approximately 50%, according to the site contact. At these conditions, the enthalpy is 28.7 Btu/lb. Cadmus assumed economizer operation would be beneficial when the outside air enthalpy was 1.0 Btu/lb. below the return air conditions. At outside air conditions of 27.7 Btu/lb. and 100% relative humidity, the dry bulb is 61.9°F. Therefore, Cadmus assumed economizer mode would be enabled when the outside air dry bulb was less than 61.9°F. The minimum MAT is 55°F, based on information from the site contact, so Cadmus calculated the installed system outside air percentage using equation [3] above. We then calculated the installed system cooling load and demand using the same method as the pre-retrofit case.

Cadmus used the U.S. Department of Energy's 3%[2] motor energy savings estimate for synchronous belts for the units that currently have synchronous belts. The evaluated installed annual energy use is 2,594,428 kWh. The coincident peak demand is 486.0 kW, and the average annual demand is 296.2 kW.

The total evaluated energy savings for the 18 RTUs in Phase 2 were 812,169 kWh. The evaluated total summer coincident peak demand reduction (for the month of July, Monday through Friday from 4:00 p.m. to 5:00 p.m.) was 4.87 kW, and the average, or non-coincident, peak demand reduction was 92.71 kW. Figure 7 shows a comparison of the pre-retrofit versus installed evaluated total system demand.

[2] "Replace V-Belts with Notched or Synchronous Belt Drive." U.S. Department of Energy. November 2012. https://www1.eere.energy.gov/manufacturing/tech_assistance/pdfs/replace_vbelts_motor_systemts5.pdf

Figure 7. Comparison of Evaluated Pre-Retrofit versus Installed Total System Demand



Conclusion

Cadmus found the equipment and controls installed as expected, with minor exceptions of the motor belts for two of the RTUs. While the economizer controls were confirmed to be installed, there may be issues with the control strategies since most of the RTUs did not operate in economizer mode as described by the site contacts during the trend data collection period, and three of the nine RTUs we have data for appeared to open their dampers fully during warm periods. The outside air dry bulb temperatures during the trend period were high for economizing, but when the outside air damper positions were observed to be 100% open in a few of the RTUs, there seemed to be little correlation for why it was occurring in some units and not others.

Since the site did not provide supply or return temperature or damper position trends for all of the RTUs, we could not meter internal loads, and the trend data was provided during the month of July, it is difficult for Cadmus to conclude whether the economizer controls are functional at all. The evaluated savings assume the RTUs economize at low outside air conditions, but Cadmus recommends that Duke Energy follow up with the site to discuss these issues and potentially collect another round of trend data during cooler outside air conditions.

The original application also claimed the fan motor energy savings from synchronous drives to be 5% over V-belt drives, but the U.S. D.O.E. supports energy savings of 3%.

The overall energy savings realization rate was 42.5%, compared to the Duke Energy claimed savings. The summer peak demand realization rate was calculated as 198.5%. The average (or non-coincident)

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peak demand reduction realization rate was 75.6%. The realization rate is low because it appears the original application claimed cooling savings of 65% of the estimated pre-retrofit RTU cooling energy. This is a large savings value considering that economizing will typically only take place below 62°F. The original application savings may have arose from an estimated cooling load that was higher than actual.

Table 8 provides a comparison of the applicant, Duke Energy claimed, and Cadmus evaluated energy savings and demand reduction. Table 9 provides realization rates comparing the energy savings and demand reductions claimed by Duke Energy to those calculated by Cadmus.

Table 8. Comparison of Applicant, Duke Energy Claimed, and Evaluation Energy Savings and Demand Reduction

Applicant		Duke Energy Claimed			Evaluation		
Annual kWh Savings	Average kW Reduction	Annual kWh Savings	Coincident Peak kW Reduction	Non-CP kW Reduction	Annual kWh Savings	Coincident Peak kW Reduction	Non-CP kW Reduction
1,895,093	N/A	1,909,006	2.45	122.70	812,169	4.87	92.71

Table 9. Energy Savings and Demand Reduction Realization Rates

Annual kWh Savings	Coincident Peak kW Reduction	Non-CP kW Reduction
42.5%	198.5%	75.6%

Application ID 14-1651242 Lighting Replacement: M&V Report

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Duke Energy Carolina
139 East Fourth Street
Cincinnati, OH 45201

CADMUS

Prepared by:
Dave Korn
Christie Amero

Cadmus