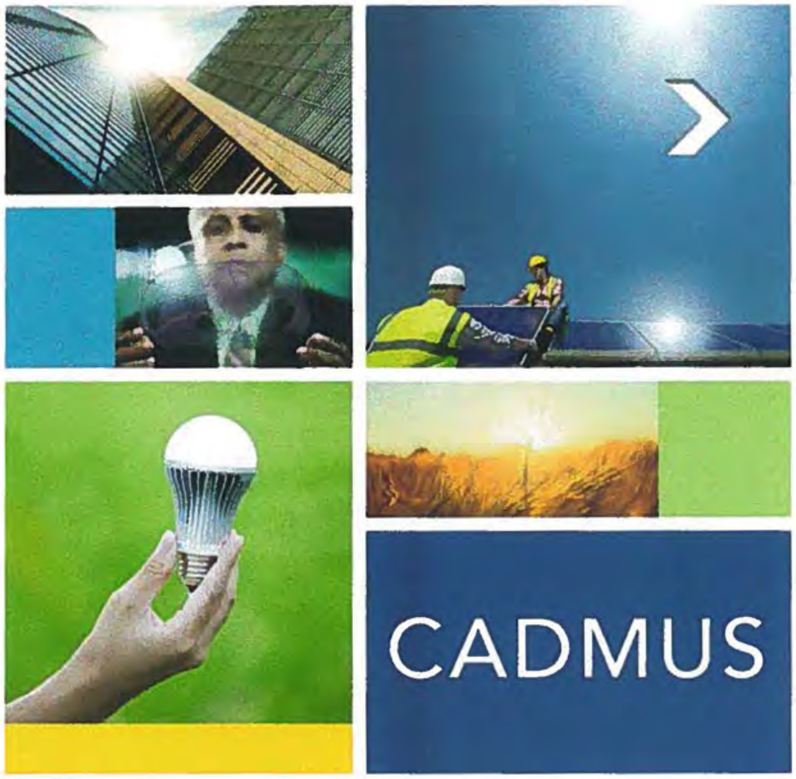


Evaluation of the Smart $aver Nonresidential Custom Incentive Program in Kentucky

March 11, 2016

Evaluation, Measurement, & Verification for Duke Energy Kentucky

The Cadmus Group, Inc.

An Employee-Owned Company • www.cadmusgroup.com

This page left blank.

CADMUS

Prepared by:

Cadmus
NORESCO
BuildingMetrics

This page left blank.

CADMUS

Table of Contents

Executive Summary

Duke Energy Kentucky (DEK) engaged Cadmus, along with NORESCO and BuildingMetrics as subcontractors (evaluation team) to perform an impact evaluation of the Smart $aver® Custom Incentive Program.

The evaluation results below are based on an impact evaluation conducted in Ohio. Realization rates (RR) by end use were used to extrapolate findings to the population of Kentucky projects. TecMarket Works (along with NORESCO and BuildingMetrics as subcontractors) completed site visits and prepared Measurement & Verification (M&V) reports for 33 participants in Ohio and 1 participant in Kentucky. In March 2015, the evaluation contract was transferred to Cadmus, with NORESCO and BuildingMetrics as subcontractors. Cadmus completed this report describing the results of the evaluation.

The DEK evaluation period includes 55 Kentucky projects completed by July 2015, with application received dates from May 2012 through March 2014. TecMarket Works performed verification site visits in two phases during fall of 2013 and winter of 2014.

Key Findings and Recommendations

Based on the evaluation of the sampled projects, the evaluation team identified the following key findings and recommendations.

Engineering Impact Estimates: Key Findings and Recommendations

- The program achieved an overall kWh RR across all projects of 95%. The majority of projects (29 out of 34) had a realization rate between 49% and 189%.
- Lighting and HVAC projects performed very close to program estimates (kWh RR of 97% and 109%, respectively), while process projects underperformed relative to program estimates (kWh RR of 77%).
- Seven percent (7%) of the evaluated program savings are associated with freeriders, based on participants' responses to the program participation application survey. Therefore, the program "net of freeridership" ratio is 93%.
- There were no HVAC projects completed in Kentucky during the evaluation period. The RR values presented here are based on Ohio projects.
- Variable frequency drive (VFD) projects had more operating hours at higher loads than assumed by program calculations; VFD loads were less variable than assumed by program calculations. As a result, the RR values were low (77%). The evaluation team recommends reviewing VFD project load history assumptions during project screening.
- In new construction or major retrofit projects where building performance models were developed to estimate expected savings, the incorrect application of the ASHRAE 90.1-2007 Energy Standard baseline caused large variations in RRs. The evaluation team recommends more careful screening of new construction or renovation projects using ASHRAE 90.1 as the baseline.

- Lighting produced 94% of total program evaluated savings. Program calculations for lighting projects generally excluded consideration of HVAC interactive effects. The evaluation team suggests all lighting projects include interactive effects using multipliers available in the Ohio Technical Reference Manual (TRM).

Table 1 shows the program's *expected* (claimed, prior to the application of the RR from the previous Evaluation, Measurement, and Verification (EM&V) study), evaluated gross, and net energy savings by measure type.

Table 1. Program *Expected*, Evaluated Gross, and Net Energy Savings by Measure Type

Measure Type	Population Size	*Expected* Population kWh Impact	Realization Rate	Gross Evaluated Population kWh Impact	NTG Ratio	Net Evaluated Population kWh Impact
Lighting	44	6,281,480	97%	6,095,383		5,668,706
HVAC*	-	-	109%	-	93%	-
Process	11	375,542	77%	290,581		270,240
Total	55	6,657,022	95%	6,385,964	93%	5,938,946
* The realization rate for HVAC projects was calculated based on the Ohio sample.						

Table 2 and

CADMUS

Table 3 show the *expected*, evaluated gross, net summer coincident peak (CP), and non-coincident peak (NCP) demand savings for the program. Table 4 shows the net energy and demand savings per unit and total for the M&V sampled projects.

Table 2. Program *Expected,* Evaluated Gross, and Net CP Demand Savings by Measure Type

Measure Type	Population Size	Expected Population CP kW Impact	Realization Rate	Gross Evaluated Population CP kW Impact	NTG Ratio	Net Evaluated Population CP kW Impact
Lighting	44	818	124%	1,012	93%	942
HVAC*	-	-	213%	-		-
Process	11	43	93%	40		37
Total	**55**	**861**	**138%**	**1,053**	**93%**	**979**
* The realization rate for HVAC projects was calculated based on the Ohio sample.						

Table 3. Program *Expected,* Evaluated Gross, and Net NCP Demand Savings by Measure Type

Measure Type	Population Size	Expected Population NCP kW Impact	Realization Rate	Gross Evaluated Population NCP kW Impact	NTG Ratio	Net Evaluated Population NCP kW Impact
Lighting	44	898	168%	1,511	93%	1,405
HVAC*	-	-	121%	-		-
Process	11	51	75%	38		35
Total	**55**	**949**	**129%**	**1,549**	**93%**	**1,440**
* The realization rate for HVAC projects was calculated based on the Ohio sample.						

Table 4. Net Energy and Demand Savings per Unit and Total for Sampled Projects

Measure Type	Number of Sampled Units	Evaluated Net Per Unit kWh	Evaluated Net Per Unit NCP kW	Evaluated Net Per unit CP kW	Evaluated Net Sample Total kWh	Evaluated Net Sample Total NCP kW	Evaluated Net Sample Total CP kW
Lighting	10	58,889	12	7	588,892	120	73
HVAC	16	1,062,813	218	184	17,005,002	3,490	2,939
Process	8	207,315	17	15	1,658,520	133	118

Evaluation Parameters

Table 5 lists the parameters reviewed in this evaluation, which consisted of gross savings realization rate for energy, CP, and NCP demand. Table 6 lists the start and end dates for sampling and review activities conducted for the impact evaluation.

Table 5. Evaluated Parameters with Value and Achieved Precision and Confidence

Gross Savings	Value	Confidence/Precision
Energy RR	95%	90%/±8%
NCP demand RR	129%	90%/±10%
CP demand RR	138%	90%/±9%

Table 6. Sample Period Start and End Dates and Dates Evaluation Activities Conducted

Evaluation Component	Sample Period*	Dates Conducted	Total Conducted
Site visits	January 2010 – March 2014	Fall 2013 and Winter 2014	34
*Sample period is identified based on the application received dates.			

Introduction and Purpose of Study

Description of the Program

The Duke Energy Custom Program intends to supplement the Smart $aver Nonresidential Prescriptive Incentive Program, which provides prescriptive rebates for preselected measures. Customers wishing to install measures not included in the Smart $aver Nonresidential Prescriptive Incentive Program list may apply for a rebate through the Custom Program. Table 7 lists the number of projects completed during the evaluation period.

Table 7. DEK Smart $aver Custom Program Participation Count[1]

Program	Completed Projects
Smart $aver Nonresidential Custom Incentive Program	55

Evaluation Objectives

The evaluation team performed an impact analysis using an M&V plan developed by NORESCO. The M&V plan followed the International Performance Measurement and Verification Protocol (IPMVP), separating projects into lighting, HVAC, and process categories and drawing size-stratified samples from each category. The impact analysis sought to estimate a savings RR for each category that could be projected into the full program participant population in the evaluation period.

Due to the relatively small number of DEK Smart $aver program participants, the sample was pulled from the list of customers that submitted an application for participation in the program in Ohio. DEO received the first application in January of 2010 and paid the first incentive in January of 2012. DEK received the first application in May of 2012 and paid the first incentive in June 2012. Two series of samples were pulled in May 2013 (21 projects) and June 2014 (15 projects) from the program opportunity tracking database (two later dropped out of the verification site visit sample). The sites were visited during fall of 2013 and winter 2014.

Researchable Issues

In completing this study, the evaluation team performed the following activities:

- Estimated kWh, non-coincident peak (NCP) kW, and coincident peak (CP) kW savings for each project in the sample;
- Calculated kW and kWh RRs for each project overall and by end use;
- Calculated confidence intervals around the RRs; and
- Identified causes for differences between evaluated savings and *ex ante* savings estimates.

[1] The evaluation team is basing the program participation count on the number of applications received during the evaluation period that resulted in complete projects by June 2015.

CADMUS

Methodology

Overview of the Evaluation Approach

This impact analysis sought to estimate a savings RR for each category (lighting, HVAC, and process) that could be prospectively projected onto the full program participant population.

Study Methodology

The impact methodology consisted of an engineering analysis following the IPMVP.[2] Field staff conducted site surveys and installed metering equipment to gather data according to the M&V plan, taking pre- and post-installation measurements whenever possible. The team developed energy and demand savings estimates for each sampled project.

Data Collection Methods, Sample Sizes, and Sampling Methodology

The evaluation team chose a sample of 34 projects (33 in Ohio and one in Kentucky) to meet a sampling error of ±10% at 90% confidence. The team stratified the participant population by project type and size to achieve an efficient sample. In particular, the evaluation included three very large HVAC projects in a "certainty" stratum to improve overall sample precision.

Number of Completes and Sample Disposition for Each Data Collection Effort

Table 8 lists the sample disposition for the impact study.

Table 8. Status of Sample with Application Received Dates January 2010 – March 2014

Group	Stratum	Sample Size	Completed	Notes
Lighting	1	7	10	Oversampled lighting in year 1
HVAC	1	3	3	Sample completed
	2	7	7	Sample completed
	3	7	6	One site dropped from the study
Process	1	9	8	One site dropped from the study
Total		**33**	**34**	

Expected and Achieved Precision

The evaluation team expected the sample design to return a sampling error of ±10% at 90% confidence. Based on the final sample disposition and observed sample variability, the evaluation achieved a precision of ±8%, ±10%, and ±9% for energy, NCP, and CP demand savings, respectively, at 90% confidence.

2 International Performance Measurement and Verification Protocol. *Concepts and Options for Determining Energy and Water Savings. Volume 1*. Prepared by Efficiency Valuation Organization. www.evo-world.org. September, 2010. EVO 10000–1:2010.

Description of Baseline Assumptions, Methods, and Data Sources

For most projects included in the M&V sample, the evaluation team used existing equipment as the baseline assumption. Renovation and new construction projects used ASHRAE 90.1 as the baseline.

Description of Measures and Selection of Methods by Measures or Markets

The custom program encompasses a wide selection of measures. Current applications include a variety of lighting, HVAC, and industrial process projects.

Use of TRM Values and Explanations if TRM Values not Used

The evaluation team used primary data collection, engineering algorithms, building energy simulation modeling, and statistical regression modeling to conduct this study. As this is a custom program, TRM algorithms and values generally do not apply. TRM algorithms for lighting measures and HVAC interactive effects were used, as applicable.

Validity Threats, Bias Sources of Bias, and Methods for Addressed These

When feasible, the study utilized a pre- and post-M&V protocol. Due to the project's timing, the evaluation team took post-only measurements for most projects. Use of post-only measurements for these projects was not expected to bias the results significantly. The team assigned applications to a measure category (e.g., lighting, HVAC, process) and then stratified the applications by kWh savings. The team selected sites at random within each stratum. Two projects in the sample did not complete before the end of the study, and one site experienced a data logger failure that required the team to perform a desk review on the project, an action not expected to bias the results. The team employed state-of-the-art engineering modeling techniques to reduce engineering bias.

Snapback and Persistence

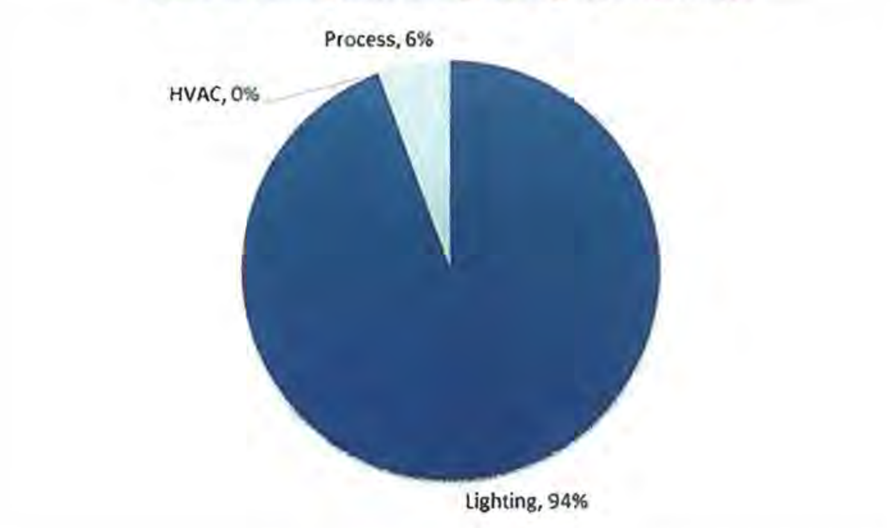
The team did not estimate snapback or persistence as these topics were not in the scope of this evaluation.

Impact Evaluation Findings

Engineering-Based Impact Analysis

The impact evaluation included the following elements: a tracking system review, sample design and selection, an engineering review of the custom program applications, field M&V of selected projects, data analysis, and reporting. For the sample plans for on-site logging, the evaluation team obtained tracking data from Duke Energy for pre-approved projects with applications that were in various stages of completion, received from January 2010 through March 2014. Figure 1 shows the breakdown of *expected* energy savings by measure

Figure 1. DEK *Expected* Energy Savings by Project Type



Sample Design

Program staff enter project leads into the Sales Force system and track them as they progress in the system. Projects that are at the Proposal to Customer stage are put in a list of potential candidates. Once the project proceeds to Contract Approval, it is eligible for sampling. The intention is to capture as many projects in the contract approval phase, before construction begins, to obtain pre-installation data. Note, once a project is closed out and paid, the final record is entered into Duke's data warehouse, which is a database that houses participation records, the list of custom measures, and the impacts associated with each measure. The impacts claimed by the program team for each custom project are modeled in DSMore software to determine cost effectiveness.

The sampling plan incorporates a stratified random sample approach, where projects are stratified according to size and technology type (i.e., lighting, HVAC, or process) and are sampled randomly within each stratum. The evaluation team separated Lighting and Process projects into three, size-based strata.

The team calculated the total sample size using the following equation:[3]

$$n = \frac{\left(\sum_k (kWh_k \times cv_k)\right)^2}{\left(\frac{P \times kWh}{Z}\right)^2 + \sum_k \frac{(kWh_k \times cv_k)^2}{N_k}}$$

Where:

- n = total sample size required
- kWh_k = estimated savings from group k
- cv_k = assumed coefficient of variation for group k
- P = desired precision
- KWh = total kWh savings
- Z = z statistic (1.645 at 90% confidence)
- N_k = population size of group k

The team allocated samples to each group using the following equation:

$$n_k = n \times \frac{kWh_k \times cv_k}{\sum_k (kWh_k \times cv_k)}$$

Table 9 summarizes total program savings by sample stratum, expected variations in the project RRs, the number of projects in each stratum, and sample sizes required to meet the design's relative precision at the program level. This table represents a projection of the final program population at the time of sample selection. This projection assumed all customers in the Contract Approval stage would complete construction on their projects and would receive incentives in this evaluation cycle. The team used coefficients of variation by project type from the 2011 DEO Custom program impact evaluation to design the sample. The evaluation team could not complete the sample as designed, given oversampled lighting projects early in the evaluation, and two HVAC projects dropped from the study.

[3] Bonneville Power Administration (BPA). *Sampling Reference Guide*. Research Supporting an Update of BPA's Measurement and Verification Protocols. August 2010.

Table 9. Sample Design Based on DEO Projected Population

Group	kWh	CV	Total Projects	Sample Size	Completed
Lighting 1	13,883,797	0.42	88	7	10
HVAC 1	8,429,798	0.54	3	3	3
HVAC 2	9,751,467	0.54	10	7	7
HVAC 3	10,594,666	0.54	43	7	6
Process 1	13,526,905	0.5	31	8	8
Total*			175	32	34

Table 10 lists the key characteristics of sampled projects.

Table 10. Summary of *Expected* Savings for Sampled Projects

	Customer	Group	Project Type	*Expected* kWh	*Expected* NCP kW	*Expected* CP kW
1	[Redacted]	Lighting	High bay fixture retrofit	29,052	6	6
2	[Redacted]	HVAC	Whole building retrofit	887,484	146	122
3	[Redacted]	HVAC	VAV conversion	789,375	73	44
4	[Redacted]	HVAC	Window replacement	1,032	26	25
5	[Redacted]	HVAC	Lighting and HVAC upgrades	2,420,314	307	247
6	[Redacted]	HVAC	DDC upgrade	2,192,110	291	38
7	[Redacted]	HVAC	Chiller replacement	220,000	4	4
8	[Redacted]	Lighting	Lighting upgrade	47,429	10	4
9	[Redacted]	Process	Dry cooler	649,824	0	0
10	[Redacted]	Process	Air compressor upgrade	612,650	70	70
11	[Redacted]	HVAC	Controls upgrade	889,566	408	142
12	[Redacted]	Lighting	Exterior lighting retrofits at three schools	193,412	7	0
13	[Redacted]	Lighting	Interior lighting retrofit	27,078	7	7
14	[Redacted]	Process	Refrigeration compressor upgrade	437,515	50	(7)
15	[Redacted]	Process	VFD retrofit	15,879	4	6
16	[Redacted]	HVAC	Chiller upgrade	346,708	18	18
17	[Redacted]	Lighting	LED retrofit at three stores	12,611	2	2
18	[Redacted]	Lighting	Refrigerated case lighting at 17 stores	130,021	12	10
19	[Redacted]	Process	Heat sealer	360,060	41	41
20	[Redacted]	Lighting	Interior lighting retrofit	138,545	17	16
21	[Redacted]	Process	VFD air compressor	98,972	11	11
22	[Redacted]	Lighting	LED retrofit at two stores	35,615	7	8
23	[Redacted]	HVAC	Add VFD to existing chiller	532,027	79	39
24	[Redacted]	Lighting	LED retrofit at one store	3,766	1	1
25	[Redacted]	HVAC	New chilled water plant	730,151	142	(49)
26	[Redacted]	HVAC	Upgrades to 6 schools	3,448,380	633	217
27	[Redacted]	HVAC	New construction	806,200	310	79
28	[Redacted]	HVAC	Lab fume hood VAV conversion	1,957,873	415	349

	Customer	Group	Project Type	Expected kWh	Expected NCP kW	Expected CP kW
29	[Redacted]	Process	Vending machine controllers	93,447	11	11
30	[Redacted]	HVAC	Chiller replacement	580,966	225	193
31	[Redacted]	HVAC	Energy management system	694,307	0	0
32	[Redacted]	Lighting	Metal halide fixture replacement	35,021	8	8
33	[Redacted]	Process	Air compressor replacement	36,433	4	4
34	[Redacted]	HVAC	Energy management system	244,110	26	19

Application Review

Duke Energy provided the evaluation team with a customer application for each site, along with any supporting documentation. The team reviewed each application to better understand the measures included and expected savings. The Duke Energy Business Relations Manager associated with each sampled site contacted customers to secure participation in the evaluation. Once contact was established with the customer, the team followed up with the customer via phone calls and e-mails to gain additional information about the facility, measures, and construction schedule.

M&V Plan Development

For each sampled site, NORESCO developed an M&V plan that covered the following topic areas:

- ***Introduction:*** a description of the project and the measures installed, including the following: sufficient detail to understand the M&V project scope and methodology; savings by measure and a list of priorities for measures within the project; and baseline assumptions.
- ***Goals and Objectives:*** a list of overall goals and objectives of M&V activity.
- ***Building Characteristics:*** an overview of the building, with a summary table of relevant building characteristics, such as building size (square footage), number of stories, building envelope, lighting system, and HVAC system.
- ***Data Products and Project Output:*** specific end products, such as kWh savings, coincident and noncoincident kW savings, therm savings, and a list of raw and processed data to be supplied at the study's conclusion.
- ***M&V Option:*** a description of the M&V Option, according to the IPMVP.
- ***Data Analysis:*** a list of engineering methods and/or equations used to generate the data products identified above and a list of data sources, either measurements or stipulated values from secondary data sources.
- ***Field Data Points:*** a list of specific field data points collected through the M&V plan. Field data were composed of survey data, one-time measurements, and time series data, collected from data loggers installed for the project, or trend data, collected from a site's energy management system (EMS).
- ***Data Accuracy:*** a list of meter and sensor accuracy for each field measurement point.

- ***Verification and Quality Control:*** a list of steps taken to validate the accuracy and completeness of raw field data.
- ***Recording and Data Exchange Format:*** a list of formats of raw and processed data files used in the analysis and supplied as data products.

Appendix B contains the M&V plans, along with the processed data summary and project results. Table 11 summarizes M&V plans for each sampled site.

CADMUS

Table 11. M&V Plan Summary

Customer Number	Customer	Project Type	IPMVP Option	Baseline Assumption	M&V Plan Summary
1	[Redacted]	Lighting	A	Existing equipment	Post-installation current logging of a sample of lighting circuits
2	[Redacted]	HVAC	D	ASHRAE 90.1	Post-renovation logging of apartments and common areas to establish occupancy patterns and plug loads
3	[Redacted]	HVAC	A	Existing equipment	Post-installation monitoring of installed measures
4	[Redacted]	HVAC	D	ASHRAE 90.1	On-site survey to verify installation of measures and develop data for simulation model inputs
5	[Redacted]	HVAC	D	Existing equipment	On-site survey and short-term trend logging of affected systems to update eQuest model
6	[Redacted]	HVAC	D	Existing equipment	Post-installation, on-site survey and monitoring of installed measures to update eQuest model
7	[Redacted]	HVAC	A	Existing equipment	On-site survey and monitoring of installed measures
8	[Redacted]	Lighting	A	Existing equipment	
9	[Redacted]	Process	A	Existing equipment	
10	[Redacted]	Process	B	Existing equipment	Pre/post-monitoring
11	[Redacted]	HVAC	A	Existing equipment	On-site survey and monitoring of installed measures
12	[Redacted]	Lighting	A	Existing equipment	
13	[Redacted]	Lighting	A	Existing equipment	
14	[Redacted]	Process	A	Existing equipment	
15	[Redacted]	Process	A	Existing equipment	
16	[Redacted]	HVAC	A	Existing equipment	
17	[Redacted]	Lighting	A	Existing equipment	
18	[Redacted]	Lighting	A	Existing equipment	
19	[Redacted]	Process	A	Existing equipment	On-site survey and monitoring of installed measures
20	[Redacted]	Lighting	A	Existing equipment	
21	[Redacted]	Process	A	Existing equipment	On-site survey and desk review
22	[Redacted]	Lighting	A	Existing equipment	On-site survey and monitoring of installed measures
23	[Redacted]	HVAC	A	Existing equipment	
24	[Redacted]	Lighting	A	Existing equipment	
25	[Redacted]	HVAC	A	ASHRAE 90.1	
26	[Redacted]	HVAC	C	Existing equipment	Pre/post billing analysis at two schools, comprising 90% of project savings
27	[Redacted]	HVAC	D	ASHRAE 90.1	Short-term monitoring of lighting circuits to establish eQuest model lighting schedules
28	[Redacted]	HVAC	A	Existing equipment	On-site survey and monitoring of installed measures
29	[Redacted]	Process	A	Existing equipment	
30	[Redacted]	HVAC	A	Existing equipment	

Customer Number	Customer	Project Type	IPMVP Option	Baseline Assumption	M&V Plan Summary
31	[Redacted]	HVAC	D	Existing equipment	Short-term monitoring of affected systems to update eQuest model
32	[Redacted]	Lighting	A	Existing equipment	On-site survey and monitoring of installed measures
33	[Redacted]	Process	A	Existing equipment	
34	[Redacted]	HVAC	D	Existing equipment	On-site survey and short-term monitoring of affected systems to update eQuest model

Measurement and Verification

TecMarket Works subcontractors collected field data according to the M&V plan, with personnel from NORESCO training the contractors. Metering equipment included a combination of the following: portable data acquisition equipment (capable of measuring temperature, relative humidity, and electric current); true electric power meters; and trend logs from facility control systems. Appendix B describes specific instrumentation used at each site (also summarized in Table 12). The evaluation team also obtained survey data and spot measurements during meter installation. The team configured metering equipment and/or trend logs to collect data for a period of three to four weeks. One process site had instrumentation installed over two separate, four-week periods to capture winter and summer operations.

Table 12. M&V Approach Summary

Site Number	Customer	Project Type	Measurements Taken	Monitoring Duration
1	[Redacted]	Lighting	Spot true electric power and time-series lighting circuit current measurements	3 weeks
2	[Redacted]	HVAC	Residential unit feeder circuit current, common area circuit current	3 weeks
3	[Redacted]	HVAC	Trend logging of AC unit flow, VFD speed, and static pressure setpoint. Logging of VFD input power and outdoor temperature and humidity	3 weeks
4	[Redacted]	HVAC	On-site survey to develop simulation model inputs. No monitoring done	N/A
5	[Redacted]	HVAC	Trend logging of fan speed, static pressure, and supply air, return air, mixed air and outdoor air temperatures at a sample of air handlers; outdoor temperature and humidity	4 weeks
6	[Redacted]	HVAC	Trend logging of chilled and hot water temperatures at central plant, supply temperatures, static pressure and VFD speeds at a sample of air handlers, outdoor temperatures and humidity	2 weeks

Site Number	Customer	Project Type	Measurements Taken	Monitoring Duration
7	[Redacted]	HVAC	Power logging of lead and lag chillers, current logging of chilled water pumps, outdoor temperature and humidity	3 weeks
8	[Redacted]	Lighting	Spot true electric power and time series current measurements of a sample of lighting circuits	3 weeks
9	[Redacted]	Process	Power logging of chillers and dry cooler; current logging of chilled water and dry cooler pumps; and sump heater, outdoor temperatures, and humidity	3 weeks during summer and 3 weeks during winter
10	[Redacted]	Process	Power logging of new and replaced air compressor	5 days pre; 3 weeks post
11	[Redacted]	HVAC	Trend logging of: supply, return, and mixed air temperatures; fan powers and speeds; static pressure and outdoor air at a sample of air handlers; outdoor temperatures and humidity	3 weeks
12	[Redacted]	Lighting	Spot power and post-installation current monitoring of a sample of lighting circuits	3 weeks
13	[Redacted]	Lighting	Spot power and post-installation current monitoring of a sample of lighting circuits	3 weeks
14	[Redacted]	Process	Spot power and post-installation kW monitoring of a new refrigeration compressor	5 weeks
15	[Redacted]	Process	Spot power and post-installation kW monitoring of a new VFD	3 weeks
16	[Redacted]	HVAC	Spot power and post-installation kW monitoring of all chillers in chilled water plant; trend logs of chilled and condenser water supply and return temperatures and flow rates; logging outdoor temperatures and humidity	3 weeks
17	[Redacted]	Lighting	Spot power and post-installation current monitoring of a sample of lighting circuits	3 weeks
18	[Redacted]	Lighting	Spot power and post-installation current monitoring of a sample of refrigerated case lighting circuits	3 weeks
19	[Redacted]	Process	Post-installation power monitoring of a sample of heat sealers across 7 stores; spot measurement of baseline heat sealer power	3 weeks per sealer
20	[Redacted]	Lighting	Post-installation light logging of a sample of fixtures	3 weeks
21	[Redacted]	Process	Spot measurement of compressor power	1 week pre; logger failed, no post time series data available
22	[Redacted]	Lighting	Spot power and post-installation current monitoring of a sample of lighting circuits	4 weeks

Site Number	Customer	Project Type	Measurements Taken	Monitoring Duration
23	[Redacted]	HVAC	Power logging of chiller kW; trend logging of chilled and condenser water supplies and return temperatures; outdoor temperatures and humidity	3 weeks
24	[Redacted]	Lighting	Spot power and post-installation current monitoring of a sample of lighting circuits	3 weeks
25	[Redacted]	HVAC	Power logging of chiller and tower kW; trend logging of chilled and condenser water supply and return temperatures; chilled water flow rate	3 weeks
26	[Redacted]	HVAC	On-site survey to confirm installation and to identify non-routine baseline adjustments; cooling and heating degree days corresponding to billing data	12 months pre and 12 months post
27	[Redacted]	HVAC	Spot power and current monitoring of a sample of lighting circuits representing major usage areas	3 weeks
28	[Redacted]	HVAC	Trend logging of air-handlers' air flow, fan speeds, supply air temperature and static pressures, and outdoor temperatures and humidity; power and current logging of AHU fan power	3 weeks
29	[Redacted]	Process	Post-installation power monitoring of a sample of vending machines	3 weeks
30	[Redacted]	HVAC	Post-installation kW logging of new chiller, chilled water, and condenser water pumps; trend logging of chilled and condenser water supply and return temperatures, flow rates, and VFD speeds; cooling tower fan VFD speeds and outdoor temperatures	5 weeks
31	[Redacted]	HVAC	Fan kW measurements at a sample of AHUs; outdoor temperatures and humidity	3 weeks
32	[Redacted]	Lighting	Spot kW and post-installation current monitoring of affected lighting circuits	3 weeks
33	[Redacted]	Process	Pre-/post- installation kW logging of a new air compressor	1 week pre, 3 weeks post
34	[Redacted]	HVAC	Trend logging of AHU supply, return and mixed air temperatures, static pressure and OA damper position; space temperatures and terminal discharge temperatures at a sample of VAV boxes	3 weeks

Calculations and Reporting

TecMarket Works subcontractors collected pre- and post-installation data and forwarded them to NORESCO for analysis. The evaluation team analyzed the data according to the M&V plan developed for each project. Data analysis consisted of pre- and post-comparisons of monitored data, extrapolated to annual consumption and demand using simple engineering models or linear regression techniques described in the M&V plan. The team then developed a site report for each completed project (included in Appendix B). Table 13 summarizes calculations and analysis techniques used.

Table 13. Calculation Approach Summary

Site	Customer	Type	Calculations
1	[Redacted]	Lighting	Engineering equations with parameters from metered data
2	[Redacted]	HVAC	eQuest model, revised based on on-site survey and monitored data
3	[Redacted]	HVAC	Developed average daily pre/post load profiles from monitored data and engineering calculations
4	[Redacted]	HVAC	Developed eQuest model from drawings and on-site survey
5	[Redacted]	HVAC	eQuest model revised based on on-site survey and monitored data
6	[Redacted]	HVAC	eQuest model revised based on on-site survey and monitored data
7	[Redacted]	HVAC	Post-installation regression model of new chiller plant, engineering equations to establish existing equipment baseline
8	[Redacted]	Lighting	Engineering equations with parameters from metered data
9	[Redacted]	Process	Post-installation regression model of chiller plant and drycooler; engineering equations to establish an existing equipment baseline
10	[Redacted]	Process	Developed average daily pre/post-load profiles from monitored data
11	[Redacted]	HVAC	Engineering equations with parameters from metered data
12	[Redacted]	Lighting	Engineering equations with parameters from metered data
13	[Redacted]	Lighting	Engineering equations with parameters from metered data
14	[Redacted]	Process	Developed average daily pre/post-load profiles from monitored data
15	[Redacted]	Process	Developed average daily pre/post-load profiles from monitored data and engineering calculations
16	[Redacted]	HVAC	Post-installation regression model of new chiller plant; engineering equations to establish an existing equipment baseline
17	[Redacted]	Lighting	Engineering equations using parameters from metered data
18	[Redacted]	Lighting	Engineering equations using parameters from metered data
19	[Redacted]	Process	Developed average daily pre/post-consumption from monitored data and engineering calculations
20	[Redacted]	Lighting	Engineering equations with parameters from on-site survey and logger data
21	[Redacted]	Process	Engineering desk review based on pre-installation data
22	[Redacted]	Lighting	Engineering equations with parameters from on-site survey and logger data
23	[Redacted]	HVAC	Post-installation regression model of chiller with VFD; engineering equations to establish a baseline
24	[Redacted]	Lighting	Engineering equations with parameters from on-site survey and logger data

Site	Customer	Type	Calculations
25	[Redacted]	HVAC	Post-installation regression model of chiller plant; engineering equations to establish a baseline
26	[Redacted]	HVAC	Weather-adjusted, pre/post-billing analysis
27	[Redacted]	HVAC	eQuest model, revised based on on-site survey and monitored data
28	[Redacted]	HVAC	Developed average daily AHU pre/post-load profiles from monitored data and engineering calculations; bin analysis conducted to estimate chiller savings
29	[Redacted]	Process	Developed average daily pre/post-load profiles from monitored data and engineering calculations
30	[Redacted]	HVAC	Post-installation regression model of new chiller plant, engineering equations to establish an existing equipment baseline
31	[Redacted]	HVAC	eQuest model updated with results of AHU monitoring
32	[Redacted]	Lighting	Engineering equations with parameters from on-site survey and logger data
33	[Redacted]	Process	Developed average daily pre/post- load profiles from monitored data and engineering calculations
34	[Redacted]	HVAC	eQuest model updated with trend data and calibrated to billing data

Freeridership Calculations

[Redacted]

Table 14 shows the evaluated savings weighted results of the 55 projects with the original scoring. The projects exhibited 7% freeridership, and therefore the program receives a net of freeridership ratio of 0.93.

Table 14. Net of Freeridership Ratio Development in Kentucky

Number of Applicants	Energy Savings Weighted Freeridership Score	Net of Freeridership Ratio
55	7%	0.93

Results

This section reports evaluation results, including annual savings for kWh and kW as well as RRs for each project. The report summarizes this data by project type. The section also includes independent assessments of project life.

Annual Savings

Table 15, Table 16, and Table 17 list the estimated sampling precision in RRs by kWh, NCP kW, and CP kW. Note that sampling precision has been calculated for the combined Ohio and Kentucky population, which were 164 and 55 projects, respectively. Table 18 summarizes annual savings from each project, and Table 19 lists average annual RRs by project types.

CADMUS

Table 15. kWh Realization Rate and Achieved Sampling Precision

Stratum	Population Size	Sample Size	Actual Sample Error Ratio	Relative Precision
Lighting	130	10	0.08	4%
HVAC 1	3	3	0.00	0%
HVAC 2	13	7	0.49	31%
HVAC 3	33	6	0.53	36%
Process	40	8	0.39	23%
Total	**219**	**34**		**8%**

Table 16. NCP kW Realization Rate and Achieved Sampling Precision

Stratum	Population Size	Sample Size	Actual Sample Error Ratio	Relative Precision
Lighting	130	10	0.25	13%
HVAC 1	3	3	0.00	0%
HVAC 2	13	7	0.76	47%
HVAC 3	33	6	0.25	17%
Process	40	8	0.91	53%
Total	**219**	**34**		**10%**

Table 17. CP kW Realization Rate and Achieved Sampling Precision

Stratum	Population Size	Sample Size	Actual Sample Error Ratio	Relative Precision
Lighting	130	10	0.08	4%
HVAC 1	3	3	0.00	0%
HVAC 2	13	7	0.81	50%
HVAC 3	33	6	0.53	36%
Process	40	8	0.52	30%
Total	**219**	**34**		**9%**

CADMUS

Table 18. Annual Gross Realization Rate Results by Project

Customer	kWh Savings			NCP kW Savings			CP kW Savings		
	Eval	Exp	RR	Eval	Exp	RR	Eval	Exp	RR
[Redacted]	33,163	29,052	1.1	6.5	5.7	1.15	6.8	5.7	1.18
[Redacted]	472,937	887,484	0.5	5.4	146.5	0.04	3.4	122.1	0.03
[Redacted]	289,424	789,375	0.37	13.7	73.2	0.19	24.8	44.3	0.56
[Redacted]	9,941	1,032	9.63	0.6	26.0	0.02	4.6	25.2	0.18
[Redacted]	2,168,811	2,420,314	0.90	225.8	307.2	0.74	185.0	247.5	0.75
[Redacted]	1,564,549	2,192,110	0.71	95.8	290.9	0.33	212.9	37.9	5.62
[Redacted]	109,283	220,000	0.50	25.3	3.9	6.57	25.3	3.9	6.57
[Redacted]	71,718	47,429	1.51	15.1	9.8	1.53	9.8	4.2	2.31
[Redacted]	556,075	649,824	0.86	-	-		-	-	
[Redacted]	301,013	612,650	0.49	6.2	69.9	0.09	29.1	69.9	0.42
[Redacted]	390,832	889,566	0.44	36.5	408.3	0.09	36.2	141.6	0.26
[Redacted]	192,361	193,412	0.99	44.4	6.7	6.64	-	-	
[Redacted]	28,140	27,078	1.04	9.0	7.1	1.27	9.0	7.3	1.23
[Redacted]	265,983	437,515	0.61	-2.9	50.3	-0.06	6.4	-6.9	-0.92
[Redacted]	29,818	15,879	1.88	22.6	4.0	5.71	6.0	5.8	1.04
[Redacted]	219,938	346,708	0.63	37.8	17.9	2.11	-15.2	17.9	-0.85
[Redacted]	14,365	12,611	1.14	3.2	2.5	1.30	3.2	2.5	1.30
[Redacted]	99,312	130,021	0.76	12.7	11.6	1.09	12.4	10.5	1.18
[Redacted]	223,750	360,060	0.62	51.0	41.1	1.24	32.2	41.1	0.78
[Redacted]	113,142	138,545	0.82	16.9	17.1	0.99	16.0	16.3	0.98
[Redacted]	216,227	98,972	2.18	27.2	11.3	2.41	21.6	11.3	1.91
[Redacted]	47,252	35,615	1.33	12.4	7.4	1.68	11.9	7.6	1.57
[Redacted]	366,940	532,027	0.69	83.0	79.0	1.05	81.1	38.8	2.09
[Redacted]	3,534	3,766	0.94	0.9	0.8	1.23	0.9	0.8	1.21
[Redacted]	2,088,267	730,151	2.86	127.4	142.0	0.90	141.5	-48.9	-2.89
[Redacted]	6,466,479	3,448,380	1.88	1,784.0	633.1	2.82	1,616.0	216.8	7.45
[Redacted]	1,242,006	806,200	1.54	502.9	310.0	1.62	122.6	78.9	1.55

[4] Expected values are equal to the claimed value prior to the application of the realization rate from the previous EM&V study.

CADMUS

Customer	kWh Savings			NCP kW Savings			CP kW Savings		
	Eval	Exp	RR	Eval	Exp	RR	Eval	Exp	RR
[Redacted]	1,899,212	1,957,873	0.97	445.0	415.4	1.07	396.0	349.1	1.13
[Redacted]	165,128	93,447	1.77	34.7	10.7	3.25	28.8	10.7	2.70
[Redacted]	461,629	580,966	0.79	353.4	224.5	1.57	311.0	193.4	1.61
[Redacted]	72,558	694,307	0.10	-16.0	-		-14.0	-	
[Redacted]	30,230	35,021	0.86	8.4	8.4	0.99	8.4	8.4	0.99
[Redacted]	36,433	25,361	0.70	4	4	1.01	4	3	0.64
[Redacted]	462,143	244,110	1.89	32.5	25.9	1.25	29.1	18.6	1.56

Table 19. Average Annual Gross Realization Rate by Project Type

Project Type	kWh Savings			NCP kW Savings			CP kW Savings		
	Expected	Evaluated	RR	Expected	Evaluated	RR	Expected	Evaluated	RR
Lighting	652,550	633,217	97%	77	130	168%	63	78	124%
HVAC	16,740,60	18,284,94	109	3,104	3,753	121%	1,487	3,160	213%
Process	2,304,780	1,783,355	77%	191	143	75%	136	127	93%
Overall	**19,697,93**	**20,701,52**	**95%**	**3,372**	**4,026**	**129%**	**1,686**	**3,365**	**138%**

Table 20 summarizes specific findings for each project. Appendix B contains more information on each project sampled.

Table 20. Findings Summary

Customer	Project Type	kWh RR	NCP kW RR	Findings Summary
[Redacted]	Lighting	1.14	1.15	RR close to 1; small difference in the assumed operating hours and fixture watts
[Redacted]	HVAC	0.53	0.04	ASHRAE 90.1-2007 standard incorrectly applied to the baseline model; lighting power density and baseline HVAC system types were revised.
[Redacted]	HVAC	0.37	0.19	Flow modulation assumed in application was not realized
[Redacted]	HVAC	9.63	0.02	Glazing specifications used in the ex-ante model do not match the manufacturer specifications. Normal replacement rather than early replacement baseline used.
[Redacted]	HVAC	0.90	0.74	Verified lighting power density higher than program assumption, small boiler not installed, boiler room upgrades only partially completed, condenser water reset not implemented, static pressure reset not fully implemented, revised thermostat setpoints and economizer settings, some VAV conversions were not done, optimum start not implemented.
[Redacted]	HVAC	0.71	0.33	Controls not implemented as planned; air handler shut down; chilled water reset and supply air reset strategies not implemented
[Redacted]	HVAC	0.50	6.57	New chiller cycled on a biweekly basis with existing chiller; runs for half of the available hours
[Redacted]	Lighting	1.51	1.53	Verified installed fixture watts less than assumed in application; monitored operating hours exceeded assumed values for several lighting systems
[Redacted]	Process	0.86		Increased dry cooler fan and pump operations at low temperatures; more chiller operations at low temperatures than assumed in the application
[Redacted]	Process	0.49	0.09	Existing compressor used less energy, and new compressor used more energy than assumed in the application
[Redacted]	HVAC	0.44	0.09	Excessive minimum outdoor air; lack of economizer operations relative to program assumptions

CADMUS

Customer	Project Type	kWh RR	NCP kW RR	Findings Summary
[Redacted]	Lighting	0.99	6.64	Monitoring showed slight variations in operating hours; apparent error in program NCP kW calculations
[Redacted]	Lighting	1.04	1.27	Program calculations did not include HVAC interactive effects
[Redacted]	Process	0.61	-0.06	Program assumption of part-load operation of baseline compressor was incorrect; monitoring indicated more hours at higher loads, reducing savings
[Redacted]	Process	1.88	5.71	Actual motor speeds were less than program assumptions; baseline drive losses were not included in program calculations
[Redacted]	HVAC	0.63	2.11	Verified chiller plant sequencing differed from program assumptions; program calculations did not include process chilled water loads
[Redacted]	Lighting	1.14	1.30	Fixture watt savings slightly higher than program assumptions; program calculations did not include HVAC interactions
[Redacted]	Lighting	0.76	1.09	Operating hours longer than assumed in program calculations; interactive effects with refrigeration plant not included in program calculations
[Redacted]	Process	0.62	1.24	Program calculations overestimated baseline heat sealer watts and operating hours
[Redacted]	Lighting	0.82	0.99	Fixture watt savings slightly lower than program assumptions; program calculations did not include HVAC interactions
[Redacted]	Process	2.18	2.41	More hours at part load; higher savings from new compressor.
[Redacted]	Lighting	1.33	1.68	Fixture-watt savings exceeded program assumptions; HVAC interactions not included in program calculations
[Redacted]	HVAC	0.69	1.05	Chiller full-load hours were less than program assumptions
[Redacted]	Lighting	0.94	1.23	Lighting operating hours were less than program assumptions; HVAC interactions were not included in program calculations
[Redacted]	HVAC	2.86	0.90	Monitoring indicates more hours at low loads than in program assumptions
[Redacted]	HVAC	1.88	2.82	Project exceeds program expectations, based on billing analysis
[Redacted]	HVAC	1.54	1.62	Verified a lighting power density lower than program assumptions; window overhangs and side fins were removed from the baseline model, to be consistent with the ASHRAE 90.1-2007 standard
[Redacted]	HVAC	0.97	1.07	Lower air flow observed in monitored data increased AHU savings and decreased chiller savings relative to program calculations
[Redacted]	Process	1.77	3.25	Energy and demand savings exceeded program expectations; HVAC interactive effects not included in program calculations

Customer	Project Type	kWh RR	NCP kW RR	Findings Summary
[Redacted]	HVAC	0.79	1.57	Verified chiller plant full load hours were lower than program assumptions
[Redacted]	HVAC	0.10		AHU scheduling was not implemented
[Redacted]	Lighting	0.86	0.99	Monitoring indicated lower operating hours than assumed in program applications
[Redacted]	Process	0.70	1.01	Revisions to flow/power relationships reduced savings at lower flowrates
[Redacted]	HVAC	1.89	1.25	Calibrated model predicted greater savings than program expectations

Project Life

The evaluation team conducted an independent assessment of the project life, comparing project life estimates to those claimed by the program. Program project life estimates were used to set incentive levels and to calculate lifecycle savings and benefits of each project. Table 21 lists project life estimates for each project.

Table 21. Program Claimed Project Life Estimates

Customer	Project Type	Program Project Life (years)
[Redacted]	Lighting	10.0
[Redacted]	HVAC	18.0
[Redacted]	HVAC	15.0
[Redacted]	HVAC	20.0
[Redacted]	HVAC	14.0
[Redacted]	HVAC	10.0
[Redacted]	HVAC	20.0
[Redacted]	Lighting	10.9
[Redacted]	Process	20.0
[Redacted]	Process	15.0
[Redacted]	HVAC	8.0
[Redacted]	Lighting	10.0
[Redacted]	Lighting	10.0
[Redacted]	Process	15.0
[Redacted]	Process	15.0
[Redacted]	HVAC	20.0
[Redacted]	Lighting	8.0
[Redacted]	Lighting	12
[Redacted]	Process	7.0
[Redacted]	Lighting	8.0
[Redacted]	Process	15.0
[Redacted]	Lighting	12.0
[Redacted]	HVAC	15.0
[Redacted]	Lighting	8.0

CADMUS

Customer	Project Type	Program Project Life (years)
[Redacted]	HVAC	20.0
[Redacted]	HVAC	13.9
[Redacted]	HVAC	15.0
[Redacted]	HVAC	10.0
[Redacted]	Process	10.0
[Redacted]	HVAC	20.0
[Redacted]	HVAC	10.0
[Redacted]	Lighting	8.0
[Redacted]	Process	15.0
[Redacted]	HVAC	7.0

The evaluation team conducted an independent assessment of project life, examining measures making up each project and assigning an effective useful life (EUL) to each measure. EUL estimates were obtained from the Ohio TRM, the California Database for Energy Efficiency Resources (DEER) EUL table, or program claims for measures not yet addressed by these data sources. Table 22 shows the assessment results.

Table 22. Evaluated Project Life Estimates

Customer	Project Type	Measures	EUL	Source	Source Measure
[Redacted]	Lighting	High bay fixture retrofit	15	OH TRM	High Bay lighting
[Redacted]	HVAC	Whole building retrofit	15	OH TRM, DEER	Interior lighting, heat pump, cooling tower, VFD, EMS
[Redacted]	HVAC	VAV conversion	15	DEER	VAV box and VFD fan
[Redacted]	HVAC	Window Replacement	20	DEER	Low Solar Heat Gain Coefficient Windows
[Redacted]	HVAC	Lighting and HVAC upgrades	15	OH TRM	Interior Lighting, HVAC
[Redacted]	HVAC	DDC Upgrade	15	DEER	Energy Management System (EMS)
[Redacted]	HVAC	Chiller Replacement	20	OH TRM	Chiller replacement
[Redacted]	Lighting	Lighting upgrade	15	OH TRM	High efficiency linear fluorescent
[Redacted]	Process	Dry cooler	20	Application	Not applicable
[Redacted]	Process	Air compressor upgrade	15	OH TRM	High efficiency air compressor
[Redacted]	HVAC	Controls upgrade	15	DEER	Energy Management System (EMS)
[Redacted]	Lighting	Exterior lighting retrofits at three schools	15	OH TRM	High Bay lighting
[Redacted]	Lighting	Interior lighting retrofit	15	OH TRM	High efficiency linear fluorescent
[Redacted]	Process	Refrigeration compressor upgrade	15	DEER	Refrigeration Plant Upgrade
[Redacted]	Process	VFD Retrofit	15	OH TRM	Variable Frequency Drives
[Redacted]	HVAC	Chiller upgrade	20	OH TRM	Chiller replacement
[Redacted]	Lighting	LED retrofit at three stores	20	IN Framework	LED lighting
[Redacted]	Lighting	Refrigerated case lighting at 17 stores	8.1	OH TRM	Refrigerated Case Lighting
[Redacted]	Process	Heat Sealer	7	Application	Not applicable
[Redacted]	Lighting	Interior lighting retrofit	15	OH TRM	High efficiency linear fluorescent
[Redacted]	Process	VFD Air Compressor	15	OH TRM	High efficiency air compressor
[Redacted]	Lighting	LED retrofit at two stores	20	IN Framework	LED lighting
[Redacted]	HVAC	Add VFD to existing chiller	15	OH TRM	Variable Frequency Drives
[Redacted]	Lighting	LED retrofit at one store	20	IN Framework	LED lighting
[Redacted]	HVAC	New chilled water plant	20	OH TRM	Chiller replacement

Customer	Project Type	Measures	EUL	Source	Source Measure
[Redacted]	HVAC	Upgrades to 6 schools	15	OH TRM, DEER	VFD, VAV box, RTU, EMS
[Redacted]	HVAC	New construction	16.3	OH TRM	Lighting - new construction, lighting controls, high performance glazing
[Redacted]	HVAC	Lab fume hood VAV conversion	15	DEER	VAV box and VFD fan
[Redacted]	Process	Vending machine controllers	5	OH TRM	Vending Machine Occupancy Sensors
[Redacted]	HVAC	Chiller Replacement	20	OH TRM	Chiller replacement
[Redacted]	HVAC	Energy Management System	15	DEER	Energy Management System (EMS)
[Redacted]	Lighting	Metal halide fixture replacement	7.5	OH TRM	PS Metal Halide
[Redacted]	Process	Air compressor replacement	15	OH TRM	High efficiency air compressor
[Redacted]	HVAC	EMS	15	DEER	Energy Management System (EMS)

The program estimated the project life, and independent project life estimates were weighted by expected kWh savings and evaluated kWh savings, respectively, with a weighted average project life calculated for each project type. Table 23 shows the results.

Table 23. Summary of Project Life Estimates by Project Type

Project Type	Program Project Life	Evaluated EUL
Lighting	10.0	14.1
HVAC	13.4	15.9
Process	15.0	14.6

Appendix A. Summary Form

Smart $aver Nonresidential Custom Incentive Program

Duke Energy Kentucky
Completed EMV Fact Sheet
2014 Evaluation – Cadmus

Program Description

The Duke Energy Smart $aver Nonresidential Custom Incentive Program supplements the Smart $aver Nonresidential Prescriptive Incentive Program, which provides prescriptive rebates for preselected measures. Customers wishing to install measures not included in the Smart $aver Nonresidential 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 17, 2016
Region(s)	KY
Evaluation Period	Applications Received from May 2012 through March 2014
Gross Energy Savings (kWh)	6,385,964
Net Coincident kW Impact (Summer)	979
Measure life	Various
Net Energy Savings (kWh)	5,938,946
Process Evaluation	Yes, reported separately.
Previous Evaluation(s)	Yes

Evaluation Methodology

The evaluation team conducted the impact evaluation based on measurement and verification of a sample of 33 participants in Ohio and one participant in Kentucky. The evaluation team estimated a savings realization rate for each project category (lighting, HVAC, and process) that was projected onto the full program participant population.

Impact Evaluation Details

- The program achieved an overall kWh RR across all projects of 95%. The majority of projects (29 out of 34) had a realization rate between 49% and 189%.
- Lighting and HVAC projects performed very close to program estimates (kWh RR of 97% and 109% respectively), while process projects underperformed relative to program estimates (kWh RR of 77%).
- Seven percent (7%) of the evaluated program savings are associated with freeriders. Therefore, the program "net of freeridership" ratio is 93%.
- Unrealized savings were due to incorrect application of the ASHRAE 90.1-2007 standard baseline, differences in assumed verus actual operation, differences between program application stated measure efficiency and those installed, and partial project implementation.
- Lighting produced 94% of total program evaluated savings.

CADMUS

Appendix B. Required Savings Tables

Measure Name	Gross kWh RR	NCP kW RR	CP kW RR	EUL	Net of Freeridership Ratio
Custom	95%	129%	138%	Custom	93%

CADMUS

Appendix C. Freeridership Survey

[Redacted]

CADMUS

Appendix D. Site M&V Reports—Full Customer Detail

ARCHITECTURAL ENERGY CORPORATION

[Redacted] (12-112)

- Lighting Retrofit -

M&V Report

PREPARED FOR:
Duke Energy
Ohio

PREPARED BY:
Architectural Energy Corporation
2540 Frontier Avenue, Suite 100
Boulder, Colorado 80301

PREPARED IN:
August 2012
V1.2

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]

ARCHITECTURAL ENERGY
CORPORATION

INTRODUCTION

This report addresses M&V activities for the [redacted] custom program application. The application covers a lighting retrofit at one location in Cincinnati, Ohio. This M&V report is for post-retrofit monitoring only. The measures include:

ECM-1 – High bay fixture retrofit with motion sensors

- This project involves the removal of 36 existing T-12 high output strip fixtures, to be replaced by 11 new 6-lamp T-5 fluorescent high bay fixtures with motion sensors. This will result in an overall power reduction of 5,742W.

GOALS AND OBJECTIVES

A post-retrofit survey of the lighting usage was conducted to determine the power reduction from the lighting upgrade.

The projected savings goals identified in the application are:

Facility	Application Proposed Annual kWh savings	Application Proposed Summer Peak kW savings	Duke Proposed Annual kWh savings	Duke Proposed Summer Peak kW savings
[Redacted]	29,560	6	29,052	6
Total	**29,560**	**6**	**29,052**	**6**

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

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

PROJECT CONTACTS

Duke Energy M&V Coordinator	Frankie Diersing	513-287-4096
Duke Energy BRM		
Customer Contact	[Redacted]	[Redacted]
Architectural Energy Corporation Contact	Todd Hintz	p: 303-459-7476 thintz@archenergy.com

SITE LOCATIONS/ECM'S

Site	Address	Sq. Footage	ECM's Implemented

ARCHITECTURAL ENERGY CORPORATION

[Redacted]	[Redacted]	8,000	# 1

Data Products and Project Output

- Average pre/post load shapes by daytype for controlled equipment
- Verify fixture counts (post-retrofit), and that all fixtures have been upgraded
- Summer peak demand savings
- Annual Energy Savings

M&V Option

IPMVP Option A

M&V Implementation Schedule

- Conducted the post-retrofit survey after the customer performed the lighting retrofit.
  - Deployed post-retrofit loggers.
  - Spot measured the lighting load connected to the circuit by measuring the kW load and current draw of the circuit.
- Since the customer has already performed the lighting retrofit, pre-retrofit operating hours were used and pre- fixture information was taken from the application. Pre-retrofit fixture specifications and quantities removed from the project were verified in the field to match the application.
- Collected data during normal operating hours (avoided holidays or atypical operating hours).

Data Accuracy

Measurement	Sensor	Accuracy	Notes
Current	Magnelab CT	±1%	> 10% of rating

Field Data Points

Post-Installation

Survey data

- Determined fixture count and Wattage
- Verified that all new fixture specifications and quantities were consistent with the application
- Determined how lighting is controlled post-retrofit and recorded controller settings
- Determined how lighting was controlled pre-retrofit
- 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

One-time measurements taken (to establish ratio of kW/amp and simultaneous logger amp readings)

- Lighting circuit power when lights are on

The following procedure was used to gather time series data on controlled equipment:

- Typical lighting load shape
  - Deployed two current measurement CT loggers to measure current at the panelboard.
  - Loggers were configured for 5 minute instantaneous readings and operated for three weeks.
- Spot measure the lighting load connected to each circuit by measuring the kW load and current draw of the circuit during the post-retrofit survey. The lighting load circuits had only one fixture type on the circuit.

LOGGER TABLE

The following table summarizes all logging equipment that was used to accurately measure the above noted ECM's (PER STORE):

ECM	Hobo U-12	20A CT
1	2	2
Total	**2**	**2**

DATA ANALYSIS

- **ECM-1**

1. Converted time series data on logged equipment into pre/post average load shapes by day type (ex. weekday, weekend, holiday).
2. Load shapes were used to determine the daily Equivalent Full Load Hours (ELFH) for each day type.
3. The Pre annual kWh was calculated using the following equations:

$$\frac{kWh}{year}_{pre} = \left[\sum_{i=1}^{N_{daytypes}} EFLH_i * N_{days/yr_i} \right] * ConnectedLoad_{pre}$$

4. The Post annual kWh was calculated using the following equations:

$$\frac{kWh}{year}_{post} = \left[\sum_{i=1}^{N_{daytypes}} EFLH_i * N_{days/yr_i} \right] * ConnectedLoad_{post}$$

5. The annual kWh ***saved*** was calculated using the previous data in the following equation:

$$\frac{kWh}{year}_{Savings} = \frac{kWh}{year}_{Pre} - \frac{kWh}{year}_{Post}$$

6. Estimated peak demand savings by subtracting pre/post time series data.
7. Calculated coincident peak savings by subtracting pre/post kW values at the grid peak.

Verification and Quality Control

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

Recording and Data Exchange Format

1. Pre-installation Lighting Survey Form and Notes.
2. Post-installation Lighting Survey Form and Notes.
3. Hobo/Elite Pro logger binary files
4. Excel spreadsheets

Field Staff

☐ Verifiable Results
☐ AEC
■ **Other**

Contracting type

■**T&M**
☐ Per logger

ARCHITECTURAL ENERGY
CORPORATION

ARCHITECTURAL ENERGY
CORPORATION

RESULTS SUMMARY

The following results account for benefits of the lighting replacement and occupancy sensor installation at [Redacted].

A summary of the estimated annual savings is shown in Table 1.

TABLE 1. ESTIMATED ANNUAL ENERGY SAVINGS

[Redacted] Results	
Actual Post Total (kWh/year)	14250
Estimated Pre Total (kWh/year)	47413
Lighting Savings (kWh/year)	33163
Application Savings (kWh/year)	29052
Realization Rate (kWh/Year)	**114%**
Actual Post Total (Non-Coincident Peak kW)	3.5
Actual Post Total (Coincident Peak kW)	3.2
Estimated Pre Total (Peak kW)	9.7
Lighting Savings (Non-Coincident Peak kW)	6.2
Lighting Savings (Coincident Peak kW)	6.5
Application Savings (Peak kW)	5.7
Realization Rate (Coincident Peak kW)	**118%**
Realization Rate (Non-Coincident Peak kW)	**115%**

The lighting was initially estimated to run 5148 hours/year with motion control on all of the fixtures. The estimated pre-retrofit run hours were determined to be 4898 hours/year. The pre-retrofit run hours were estimated by assuming that the lighting was on at 100% in the pre-retrofit case whenever the lights were on at any level greater than 5% in the post retrofit case. The increased kWh/year realization rate could possibly be explained by the decrease in actual run hours from the original estimation.

Graphs of actual logger data are shown in Figures 1-2. Evidence of the installed motion detectors can be seen in both figures.

FIGURE 1.

ARCHITECTURAL ENERGY
CORPORATION

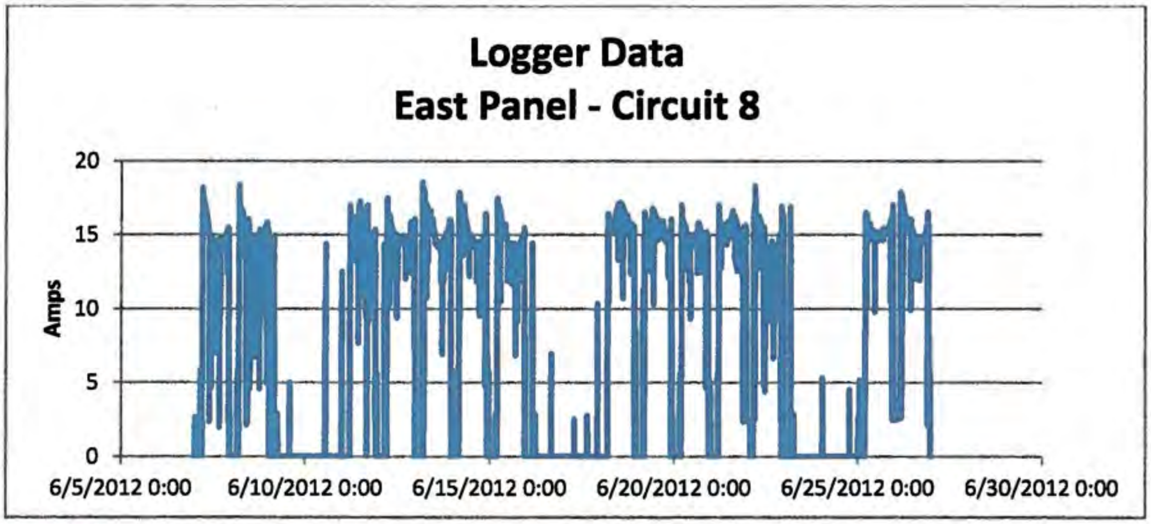
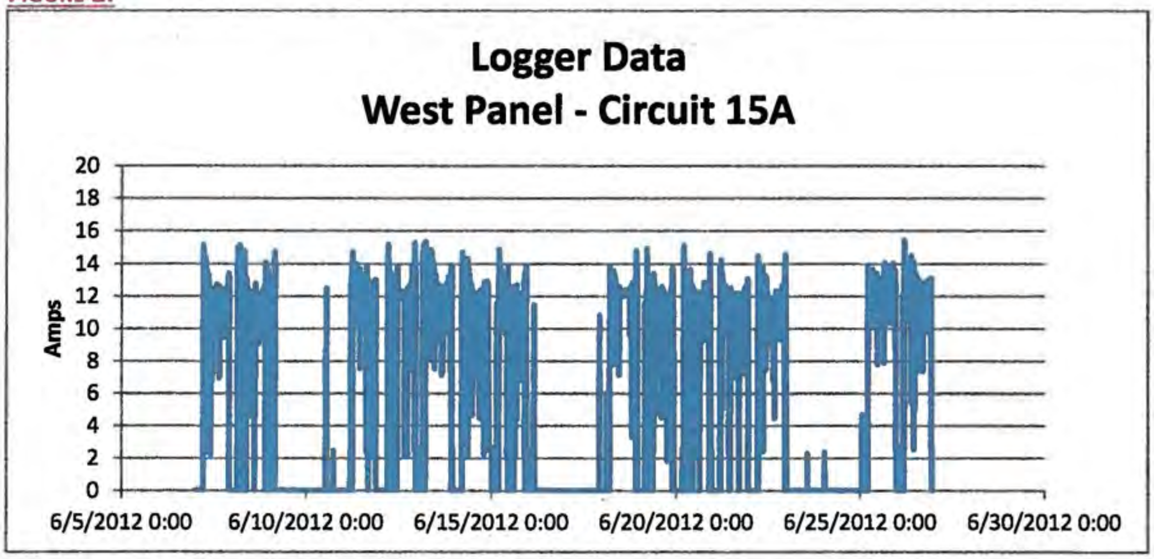


FIGURE 2.



[Redacted]
Whole Building Renovation
M&V Report

Prepared for
Duke Energy Ohio

March 2015, Version 1.0

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:

Mike Johnston
NORESCO LLC

Stuart Waterbury
NORESCO LLC

2540 Frontier Avenue, Suite 100
Boulder CO
80301

(303) 444-4149

NORESCO
United Technologies

Introduction

This report addresses M&V activities for the [Redacted] custom program application. The application covers a whole-building energy retrofit at one location in Cincinnati, Ohio. The measure includes:

ECM-1 – Whole Building Retrofit

The [redacted] in downtown Cincinnati was purchased by [Redacted] and was renovated to include retail and apartment space. The 15 story building was mixed use retail and office space at the time of purchase. After retrofits, the basement and first 3 floors of the building remain retail/office space, while floors 4 through 15 have been converted into 87 apartment units.

All energy components (HVAC, lighting, appliances) were removed in the retrofit and replaced with new, high-efficiency components. Many existing components were original to the building (1920's era). The original building was mainly lit by T12 lamps, with an overall building lighting power density of approximately 1.1 W/ft^2. In the new design, water source heat pumps are utilized throughout the building, and the lighting power density has been reduced to 0.83 W/ft^2. Other components include high-efficiency boilers, cooling towers, pump VFDs, individually programmable thermostats throughout the building, and a DDC control system.

Goals and Objectives

The projected savings goals identified in the application are:

Facility	Proposed Annual kWh savings	Proposed kW Savings	Duke Projected Annual kWh savings	Duke Projected NCP kW savings	Duke Projected CP kW savings
[Redacted]	541,200	0	887,484	146.5	122.1
Total	**541,200**	**0**	**887,484**	**146.5**	**122.1**

It should be noted that NORESCO was provided eQuest energy model files dated February 2013 that showed an annual electric savings of 850,353 kWh. Per the customer, proposed savings from the application was based on much earlier modeling performed in 2010 using a different energy simulation software program. Between then and final design, numerous design changes were made which the customer thought resulted in greater savings over the ASHRAE Baseline.

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	Mike Johnston	c: 303-459-7433 mjohnston@noresco.com
Customer Contact	[Redacted]	[Redacted]

Site Locations/ECMs

Address
[Redacted]

Data Products and Project Output

- Average pre/post load shapes by daytype for the whole facility
- 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 performed the energy retrofits.
  - Collected data during normal operating hours (avoid holidays or atypical operating hours).
  - Obtained and verified the post-retrofit HVAC system configuration, parameters, and selected equipment..
  - Performed spot-measurements on selected controlled equipment.

  - Deployed post-retrofit loggers to record temperature and power measurements on selected circuits.
- Confirmed and updated the provided eQUEST energy model to reflect as-built conditions (NORESCO's responsibility).
- Evaluated the energy and demand savings of the retrofit measure.

Field Survey Points

Pre – installation

- No pre-installation field survey was performed, as this was a complete renovation, and the Baseline was based on ASHRAE 90.1-2007, rather than existing conditions.

Post – installation

- Visual verification of information listed in attached "Energy Model Input Summary".

Spot measurements

- V/A/kW/PF for residential circuits.

Time series data on controlled equipment

- Current on feeders for a group of residential apartments
- SAT and RAT for a heat pump in a common area
- OAT and RH
- Lighting circuit current for sampled circuits for common residential areas

Set up loggers for 5-minute instantaneous readings. Deploy for 3 weeks.

Data Accuracy

Measurement	Sensor	Accuracy	Notes
Current	Magnelab CT	±1%	Recorded load must be < 130% and >10% of CT rating
Power	ElitePro	±1%	
Temperature	Onset Temp/RH	±0.36°F	

Field Data Logging

- Installed data loggers to collect data on a sample of residential apartments (feeders serving 14th floor. Sample a heat pump in the commercial area for SAT and RAT Logged outdoor air temperature and relative humidity. Logged for 3 weeks with a 5-minute interval.

- For lighting circuits, monitored circuit current for three different residential common areas in order to determine lighting schedules. Logged for 3 weeks with a 5-minute interval.

Logger Table

The following table summarizes the logging equipment that was used for the above noted items:

Item	Hobo Loggers	CT-V Current Transducers	Hobo Temperature Probes	Weather Station
Residential Feeders	1	4 (CTV-C, 100A)		
OA, SA, RA	1		2	1
Lighting	1	3 (CTV-A, 20A)		
Total	**3**	**7**	**2**	**1**

Data Analysis

- Used the data collected in the operator interview to verify equipment specifications, schedules, setpoints and sequence of operation data for the eQUEST energy model.

- Confirmed that ASHRAE 90.1-2007 Baseline building is properly represented in the model.

- Compared trend data on schedules and setpoints to the post-retrofit eQUEST model and update with as-built conditions. Confirmed that the post-retrofit building envelope, lighting, and HVAC systems are properly represented in the model.

- Confirmed all other data in the "Energy Model Input Summary" (attached).

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 post-retrofit equipment specifications and quantities are consistent with the application. If they were not consistent, recorded discrepancies.

Recording and Data Exchange Format

1. Energy Model Input Summary 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

BASELINE ENERGY MODEL PARAMETERS

The following items were observed based on evaluation of the Baseline energy modeling inputs:

- A weather file was not included in the model submittal, therefore, a TMY3 weather file for Cincinnati, OH was used from the DOE2.2/eQuest website to perform the simulation.
- The Baseline model had the same concrete envelope as the proposed model. This correctly follows protocol of Table G3.1 of ASHRAE 90.1-2007 for existing building envelopes, where the Baseline building design reflects existing conditions prior to any revisions that are part of the scope of work being evaluated. The information provided in the Energy Model Input Summary for the Baseline envelope is incorrect in that it indicated R-13 + R-7.5 Continuous Insulation was modeled (metal frame construction). Additionally, for the Proposed model, exterior walls were modeled as 12 inch concrete, with an R-10 layer. Per conversations with the customer, no insulation was added to the existing, uninsulated walls in the renovation. Therefore, this R-10 layer was removed in both models.
- The Baseline model had glazing specified based on ASHRAE 90.1 requirements for climate zone 4A, with the Proposed model having glazing specifications for the existing glass. Because the windows were not replaced in the renovation, the Baseline model glazing should represent the existing glazing, such that no differences in glazing performance is modeled. Glazing specifications in the Proposed model (SC = 0.63 and a conductance of 0.69) was transferred to the Baseline model.
- The Baseline model incorrectly specified the system for residential floors as Packaged Multizone. This should have been modeled as packaged terminal air conditioners (PTAC)

with hot water fossil fuel boiler heating type per ASHRAE 90.1-2007 Appendix G Tables G3.1.1A and G3.1.1B.

- The Baseline model specified residential floor lighting power densities of 1.1 W/ft^2. It appears this was arrived at using the space-by-space method of calculating interior lighting power allowance (9.6.1 of ASHRAE 90.1-2007). This method is to be used when spaces are separated by space type in the model, depicting other power allowances of other spaces, such as corridors, electrical/mechanical, stairs, storage, restrooms, lobby, etc. Because these spaces are not represented in the model, the Building Area Method of Calculating Interior Lighting Power Allowance (9.5.1 of ASHRAE 90.1-2007) should be used. This results in a 0.7 W/ft^2 LPD allowance for the Multifamily floors and a 1.0 W/ft2 for the Office area, 1.5 W/ft^2 for the financial/bank area, using Retail as a proxy, per 9.5.1a: "For building area types not listed, selection of a reasonably equivalent type shall be permitted."

PROPOSED DESIGN ENERGY MODEL PARAMETERS

Where possible, the inputs to the Proposed Design model were verified with project design and bid documents that were submitted with the application. These included:

- Glazing in the Proposed Design was modeled with a Solar Heat Gain Coefficient (SHGC) of 0.59 (SC = 0.63) and a conductance of 0.69 (excluding exterior film coefficient). No documentation was provided on existing glazing performance.
- Exterior walls were modeled as 12 inch concrete, with an R-10 layer. Per conversations with the customer, no insulation was added to the existing, uninsulated walls in the renovation. Therefore, this R-10 layer was removed.
- Lighting plans and fixture schedules were used to verify installed lighting power densities. No information was provided for commercial floors, presumably because no savings were claimed for these floors. Residential floors appeared nearly identical in fixture count for each floor based on lighting plans submitted. A representative lighting power take-off for a residential floor was performed to determine installed LPD as follows.

Table 1: Residential Floor Lighting Power Density Calculation.

Fixture Code	Fixture Wattage	Fixture Count	Total Wattage
A1	19	104	1976
Ceiling Fan (lighting only)	28	13	364
P1 (assumed Wattage)	15	13	195
B1	34	13	442
C2	32	15	480
S3 (Existing fixture- assumed Wattage)	64	9	576
		Total Watts:	4033
		Gross Floor Area (ft^2):	7047

Installed LPD (W/ft²):	**0.57**

This compares to a 0.83 W/ft^2 in the proposed model. It may have been that net floor area was used by the customer for calculation, rather than gross area. ASHRAE 90.1 guidelines dictate that gross floor area be used for calculation of lighting power density.

- Mechanical schedules and equipment specifications to verify water source heat pump heating and cooling efficiencies. Based on design documents, average nominal cooling efficiency for the heat pumps is 13.5 EER and average nominal heating efficiency is 4.6 COP. This agreed with inputs to the model, though it did not agree with the modeling input summary provided (14 EER, 4.1 COP).
- Mechanical schedules and equipment specifications to verify boiler efficiencies. Based on design documents, boilers are condensing, with 93.5% full fire efficiency. This agreed with inputs to the model, though it did not agree with the modeling input summary provided (98% efficiency).
- Mechanical schedules and equipment specifications to verify pumping power. Modeling inputs for pumping gpm, head, and pump and motor efficiencies were verified, and modeling inputs were confirmed to be in agreement with design documents.

DATA REVIEW

Current transducers were installed on feeders to nine apartments totaling 10,239 square feet, as shown in Table 2. Note the 14th floor has larger apartments than other floors because additional lofts exist, extended into the 15th level. Data was logged at 5 minute intervals for a period of three weeks, from September 6th – Sept 30th, 2014.

Table 2: Apartments on Monitored Circuit.

Apartment #	Area (sf)
[redacted]	710
[redacted]	653
[redacted]	1,517
[redacted]	1,111
[redacted]	1,138
[redacted]	1,140
[redacted]	1,046
[redacted]	814
[redacted]	2,110
Total:	**10,239**

A power calculation was made from the current measured in amps by assuming 120 V supply voltage phase-to neutral and a 0.85 power factor, summing the current for each of two conductors of one phase. Power was then normalized by square footage and typical weekday and weekend hourly profiles were developed by averaging hourly data. This is shown in Figure 1.

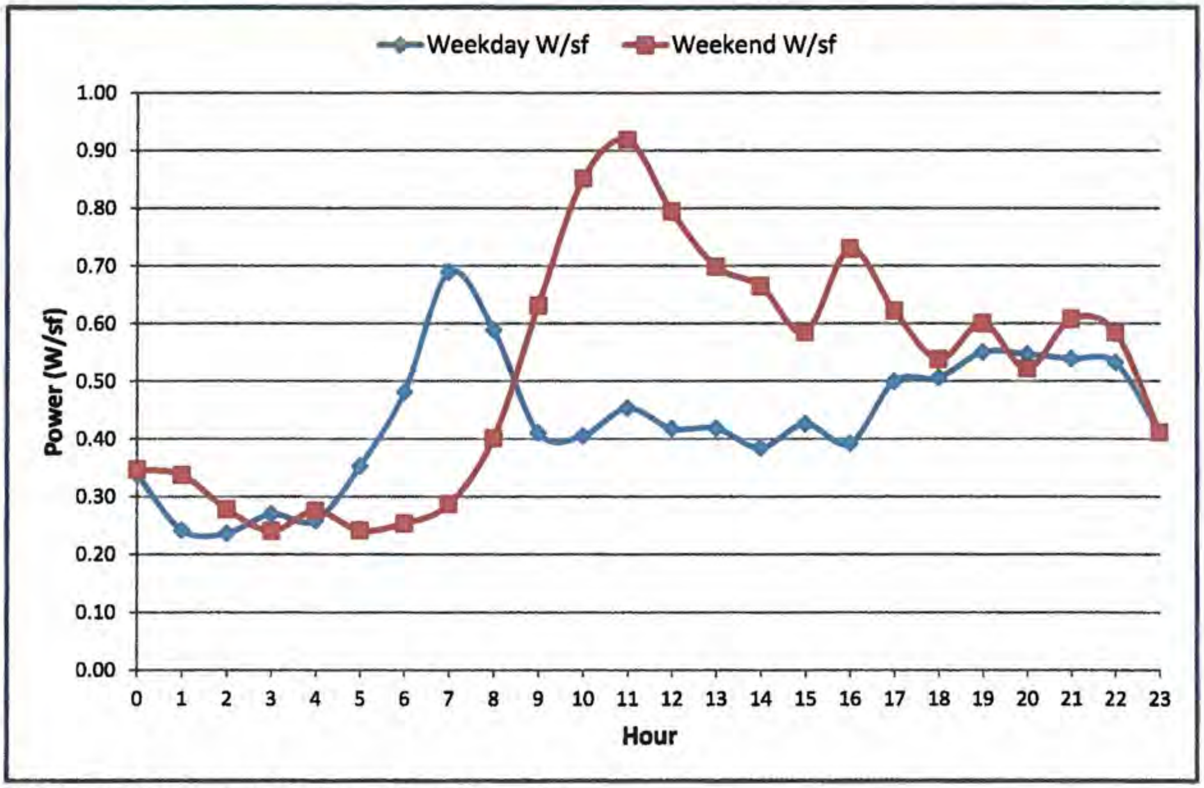


Figure 1: Average Apartment Load Profile.

It was noted that no OAT correlation could be discerned between normalized apartment power and outdoor air temperature. This is because there are too many end-uses mixed into the total measurement. This lack of correlation is shown in Figure 2.

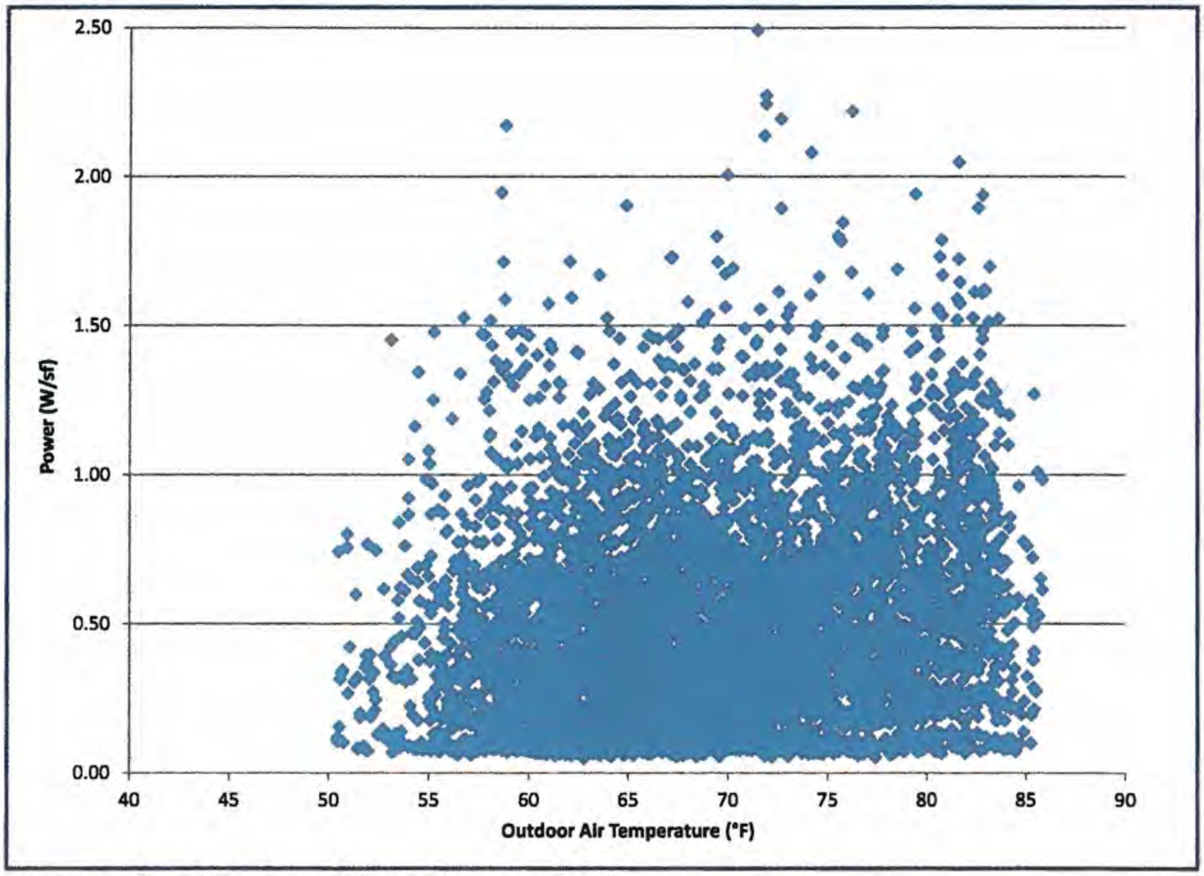


Figure 2: Apartment Load Correlation to OAT.

Also collected were several common area loads via current transducers, including the fitness room, corridor, and entertainment room, with results shown in Figure 3. Unfortunately, none of these spaces were explicitly built in the model (which involved highly simplified 5-zone core/perimeter modeling), nor did any of the spaces represent primary scheduling for the commercial space. For this reason, schedules in the commercial space were not adjusted from scheduling assumed in the original model.

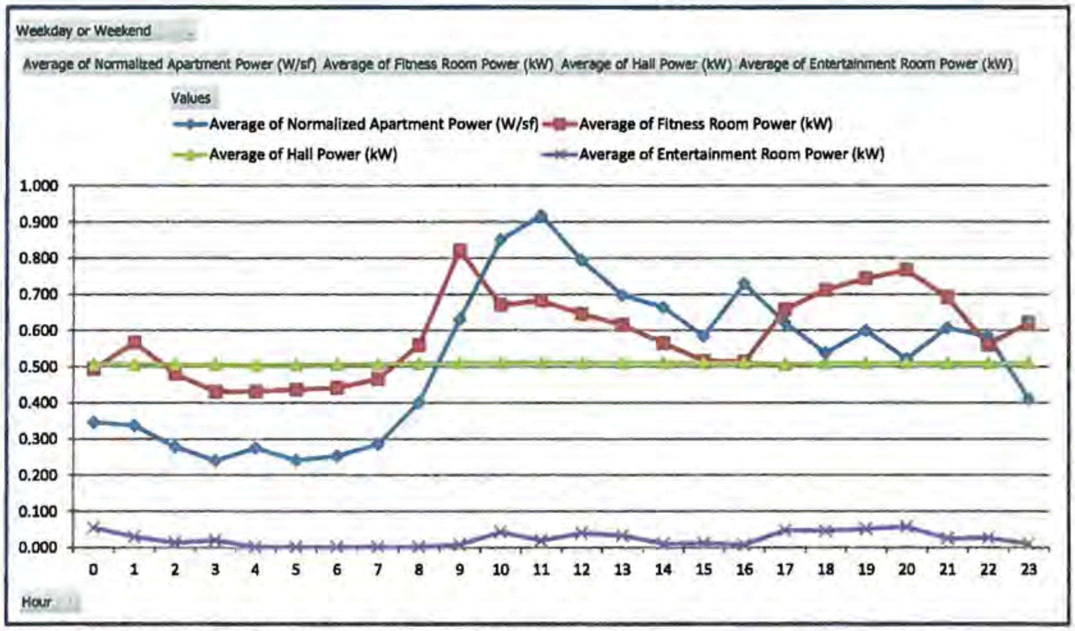


Figure 3: Monitored Residential Common Space Power.

MODEL ADJUSTMENTS

First, the Baseline and Proposed models inputs were adjusted based on parameters evaluated in the previous sections.

Because there are more than 80 apartments that are individually metered in the renovated building, not all of which are occupied, it was not practical to collect utility data for model calibration. However, logger data were used for adjustment of schedules to reflect observed operating conditions with the following methodology.

Because end-uses in apartments were not individually measured or logged, and in order to develop operating schedules for use in the energy model as multipliers on installed lighting power density and equipment power, it was assumed that 90% of the installed lighting power was operating at the peak hour (11 am on weekends). From there, a percent usage profile schedule was developed from the normalized power profiles. This is illustrated in Figure 4. It was assumed that plug loads also tracked this profile, so the schedule was also applied to equipment power densities in the residences. Since schedules are to be identical between the Baseline and the Proposed per ASHRAE 90.1 modeling, the same adjusted schedules for residential lighting and plug loads were input into the Baseline model.

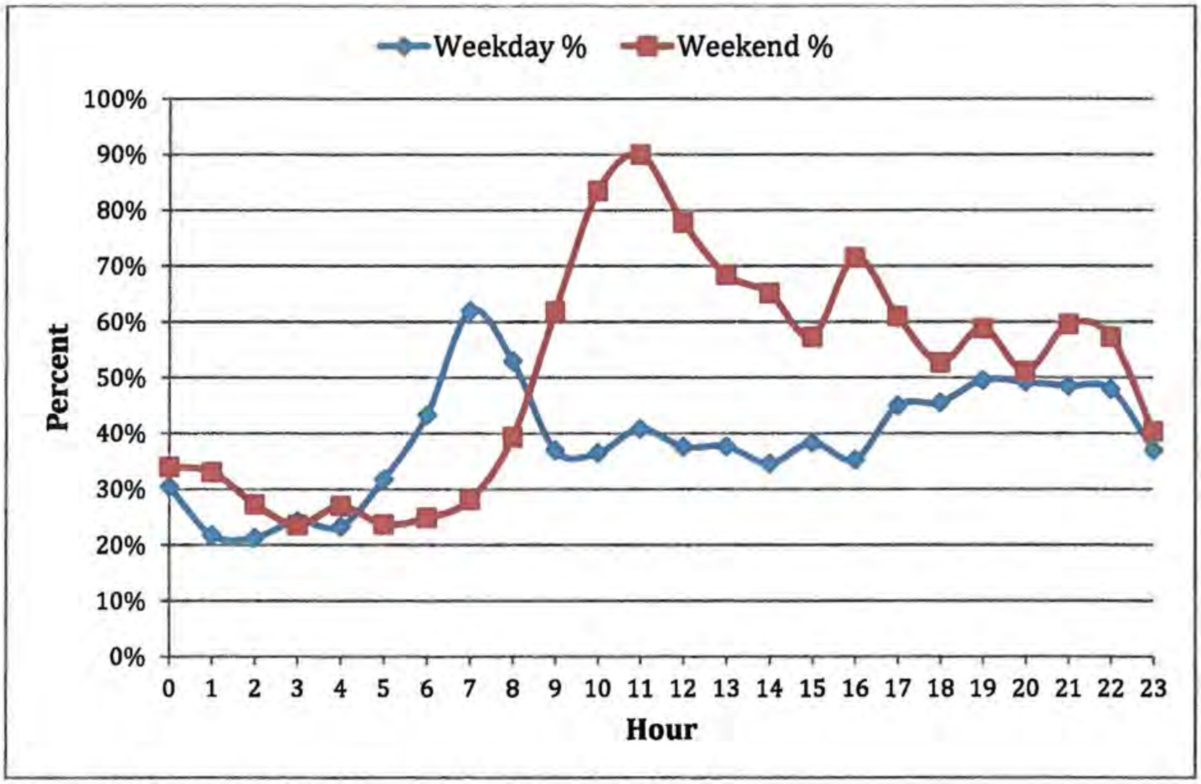


Figure 4: Apartment Lighting and Equipment Schedules.

ENERGY SAVINGS

The revised models were then run to calculate the annual post-retrofit demand and energy consumption of the Adjusted Proposed model compared to an average of four 90 degree rotations of the Adjusted Baseline model per ASHRAE 90.1 modeling protocol. Table 3 presents Adjusted modeling results.

Table 3: Adjusted Model Results.

Rotation	kWh	Coincident Peak Demand	Peak Demand	Therms
0° Baseline	2,620,320	565.1	675.1	41,846
90° Baseline	2,628,350	555.2	684.6	41,052
180° Baseline	2,635,541	568.5	685.3	39,782
270° Baseline	2,637,110	580.9	689.6	40,971
Average Baseline	**2,630,330**	**567.4**	**683.7**	**40,913**
Proposed Design	**2,157,393**	**564.0**	**678.3**	**14,427**
Savings	**472,937**	**3.4**	**5.4**	**26,486**

Table 4 presents the final energy and demand savings and realization rates for the [Redacted] Custom Incentive Program project. For Ohio in 2013, the coincident peak demand is evaluated on July 17 (Monday), for the hour between 4-5 PM.

Table 4: Comparison of Results to Projected Savings.

Facility	[Redacted]		
	Annual Energy Usage (kWh)	Summer Coincident Peak Demand (kW)	Summer Peak Demand (kW)
Duke Projected Savings	887,484	122.1	146.5
Model Savings	472,937	3.4	5.4
Realization Rate	53%	3%	4%

There are two primary reasons for the lower realization rates on this project:

1. The lighting power density for the Multifamily floors of the ASHRAE 90.1-2007 Baseline was incorrectly modeled as 1.1 W/ft^2 using the 90.1 Building Area Method. This should have been modeled as 0.7 W/ft^2.

2. The Baseline model incorrectly specified the system for residential floors as Packaged Multizone. This should have been modeled as packaged terminal air conditioners (PTAC) with hot water fossil fuel boiler heating type per ASHRAE 90.1-2007 Appendix G Tables G3.1.1A and G3.1.1B.

Attachments

1. Energy Model Input Summary

ENERGY MODEL INPUT SUMMARY (as received and as modified) (page 1 of 2)

Baseline Energy Analysis Input Summary According to ASHRAE 90.1-2007

1. Building Envelope
    1.1. Roof: R-20 Insulation
    1.2. Exterior walls: R-13 + R-7.5 Continuous Insulation Adjusted to be same as existing building per 90.1 modeling guidelines. 12 inch on most levels. Model submitted showed an R-10 layer, which was removed for the model adjustment.
    1.3. Slab: 6" Slab
    1.4. Floors: Metal frame with R-30 Insulation
2. Vertical Fenestrations
    2.1. Windows: U-Value of 0.55 and Shading Coefficient of 0.40 Adjusted to be same as existing building per 90.1 modeling guidelines.
    2.2. Doors: Metal door no insulation
3. Daylighting control
    3.1. Not Modeled
4. Operational Schedule
    4.1. Subbasement – 3rd Floor: office/financial occupancy 8AM-5PM no weekend or holidays
    4.2. 4-15 Floors: Residential Occupancy, mainly 5PM-7AM
5. Lighting Power Density
    5.1. 1.1 W/sq.ft. all floors Adjusted to 1.0 W/sf for office, 1.5 W/sf for financial, and 0.7 W/sf for residential floors.
6. Domestic Water Heating
    6.1. 50 gallons electric storage tanks in each apartment.
7. HVAC System
    7.1. DX Cooling units with 9.8 EER. Submitted model showed Packaged Multizone. Changed to packaged terminal air conditioners (PTAC) with hot water fossil fuel boiler heating type per ASHRAE 90.1-2007 Appendix G Tables G3.1.1A and G3.1.1B.
    7.2. Hot water fossil fuel boiler, 80% efficiency.

ENERGY MODEL INPUT SUMMARY (page 2 of 2)

Proposed Energy Analysis Input Summary

1. Building Envelope
   1.1. Roof: R-20 Insulation
   1.2. Exterior walls: 24" Concrete Walls no insulation 12 inch on most levels. Model submitted showed an R-10 layer, which was removed for the model adjustment.
   1.3. Slab: Concrete slab
   1.4. Floors: concrete floors
2. Vertical Fenestrations
   2.1. Windows: Perimeter windows are double pane ½" air gap and tinted
   2.2. Light-well and first floor are single pane 1/8" clear
   2.3. Doors: as in baseline
3. Daylighting control
   3.1. Not Modeled
4. Operational Schedule
   4.1. Sub basement-3 Floor: office occupancy 8AM-5PM no weekend or holidays
   4.2. 4-15 Floor Apartments: residential occupancy 5PM-7AM Lighting and equipment schedules adjusted based on analysis of monitored data.
5. Lighting Power Density
   5.1. Sub-3 Floor Office: estimated at 1.1 W/sqft Adjusted to 1.0 W/sf for office and 1.5 for financial to be same as ASHRAE Baseline.
   5.2. 4-15 Floor Apartments: 0.83 W/sqft Adjusted to 0.57 W/sf based on takeoffs.
6. Domestic Water Heating
   6.1. 50 gallons electric storage tanks in each apartment.
7. HVAC System
   7.1. Cooling: WSHP with efficiency of EER 14. Model submitted and equipment installed averaged 13.5.
   7.2. Heating: WSHP with efficiency of COP 4.1. Model submitted and equipment installed averaged 4.6.
   7.3. Cooling plant: high efficiency cooling tower with VFD
   7.4. Heating plant: High efficiency boiler with 98% efficiency. Model submitted and equipment installed was 93.5%

[Redacted] AC2 West Upgrade M&V Report

Prepared for Duke Energy Ohio

February 2015, Version 1.1

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

Introduction

This report addresses measurement and verification (M&V) activities for [redacted] custom program application. The application covers upgrading the HVAC unit AC 2 West. The measure includes:

ECM-1 – Air Valve Modifications to Reduce Building Air Flow

- Replacing the existing supply fan in a constant volume, dual duct air handler with a new Huntair FANWALL 12-fan array system. Two new VFD's allow full modulation and also provide redundancy.
- Two new VFDs were also installed on the two existing return fans to allow variable speed operation.
- Old DDC controls were entirely replaced. This effort including adding static pressure sensors in the three duct mains served by this unit. The unit previously maintained 6.5 inches of static pressure at the discharge. The new maximum pressure setpoint was to be 4.0 in-WG at the fan discharge, and the new fans would modulate downward from that pressure as VAV boxes in the space close off. (Approximately 40% of the existing terminal boxes had already been converted to single duct, variable volume, although the main system still operated at constant volume.)
- A power (kW) meter was to be installed on the return fan to verify savings.
- The application considered fan energy savings only, although additional energy savings in cooling are expected.

The installation was completed in September, 2013, so the M&V activities were for post-retrofit only.

Goals and Objectives

Pre-and post-retrofit energy calculations for the building HVAC systems were previously created by the applicant's engineering firm. These calculations are included in the application.

The projected savings goals identified for this project are:

Facility	APPLICATION		DUKE PROJECTIONS		
	Propose d Annual kWh Savings	Propose d Peak kW Savings	Proposed Annual kWh Savings	Proposed Non-Coincident Peak kW Savings	Proposed Coincident Summer Peak kW Savings
[Redacted] HVAC Unit AC 2 West	792,201	-5	789,375	73.2	44.3

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

- Annual electric energy (kWh) savings
- Building 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]	[Redacted]	[Redacted]

Site Locations/ECM's

Site	Address	Sq. Footage	ECMs Implemented
[Redacted]	[Redacted]	1,400,000	1

Data Products and Project Output

- Energy consumption pre- and post-retrofit for the controlled equipment
- Annual energy savings
- Peak demand savings
- Coincident peak demand savings

M&V Option

IPMVP Option A

M&V Implementation Schedule

This survey and data collection was for post-retrofit only.

- Post-retrofit data was collected for a thorough evaluation.
- The monitoring period included both normal workdays and weekends. No holidays occurred during the monitoring period.

Field Survey

Customer Interview

Interviewed the building contact.

- Determined the normal occupancy schedules
- Determined the number of holidays observed per year
- Obtained a copy of the final air test and balance measurements.
- Confirmed the configurations of the AHU:

System:	AC2 West	
	Supply Fans	Return Fans
Total # available	12	2
HP each	15	15
# Running when Occupied	12	2
# Running when Unocc'd	12	2
# VFD's Installed	2	2

- Obtained pre-retrofit and post-retrofit sequences of operation for the HVAC unit.
- Determined if any sequence changed between the pre- and post-retrofit.
- Determined additional information as requested in the M&V Plan.

Spot-Measurements

For the subject AC Unit:

- Measured supply fan volts, amps, watts and power factor before each VFD.
- Recorded the number of supply fans controlled by each VFD in the above measurement.
- Measured return fan volts, amps, watts and power factor upstream of each VFD.
- Verified that each return fan VFD controls a single return fan.

Field Data Logging

Time series data on controlled equipment

Trend logs were established in the EMS to monitor certain points defined below. Otherwise, data loggers were deployed as noted.

<u>Outdoor Air:</u>

- Installed a weather logging station data logger to record outside air temperature and relative humidity in 5-minute intervals.

<u>AC Unit:</u>

- Trended the following points in the EMS:
  - Supply fans' VFD speed
  - Supply air flows (CFM)
  - Supply air static pressure setpoint
  - Return fans' VFD speed

The following points were not trended:
  - Actual supply air static pressure
  - Return fans' air flow (CFM)
  - No new power meters for supply or return fans were installed by the customer, so data loggers were installed to measure these powers.

- For each VFD, configured Elite Pro data loggers to record the following information:
  - Voltage
  - Current (amps)
  - Power factor
  - Power (kW)

- Set up loggers (or trend logs) for 5-minute average readings (not instantaneous) and allowed operation for a minimum of three weeks.
- Collected data during normal operating hours (avoided atypical operating situations such as maintenance shutdowns).

Logger Table

The following table summarizes the logging equipment used to accurately measure the above noted ECM's.

Function	Hobo Weather Station	ElitePro Energy Logger	Magnelab CT's*
OAT/RH	1		
AHU Supply Fans (two VFD's)		2	(6) 150A
AHU Return Fans (two VFD's)		2	(6) 20A
Total	**1**	**4**	**12**

*CT sizes were based on 460-volt, 3-phase 3-wire delta electrical service and the following fan motor horsepowers:

System	Quantity per VFD	HP per Motor	Total VFD Connected HP
AC2 West Supply Fans	6	15	90
AC2 West Return Fans	1	15	15

Data Accuracy

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

Data Analysis

NOTE: The analysis approach is presented below.

1. Converted time series data on logged equipment into post-retrofit average load shapes by day-type.

2. Developed post -retrofit regression model of total daily fan energy (kWh) as a function of daily average outdoor dry-bulb temperature and humidity. *[There is no correlation of fan energy to OA conditions.]*
3. If warranted by a correlation of total daily kWh to daily average outdoor air temperature, generate post -retrofit bin analysis using local weather data. Using the correlated fan power values, calculate the fan energy consumed from the binned weather hours at each daily average OAT. *[N/A]*
4. Since there is no discernable correlation of total daily fan energy to outdoor air temperature, generated post -retrofit analysis using average day-type load shapes.
5. Totaled the fan energy by day-type to determine the total annual fan energy consumption.
6. From the time-series data, determined the non-coincident peak demand and the coincident peak demand. For 2014, the coincident peak hour for Ohio is on July 17th from 4-5 p.m. Since this date and time was not captured in the monitored data, the coincident peak demand was be estimated as the maximum demand observed in the 4-5 PM hour on any weekday of the monitoring period.
7. Since there was no opportunity to evaluate the fan energy usage of the HVAC unit prior to the retrofit, and since there is no correlation of total daily fan energy to outdoor air temperature, we used the measured total unit fan power found in the attachment to the application as the basis for determining energy savings. This value (137.3 kW) is about 90% of the rated power of the original constant-volume fan.
8. Compared the revised post-retrofit model output with the pre-retrofit output to determine the annual energy savings.

Verification and Quality Control

- Visually inspected trend and logger data for consistent operation. Looked for data out of range and data combinations that are physically impossible. Removed invalid data.
- Verified pre-retrofit and post retrofit equipment specifications, quantities, and schedules are consistent with the application.

Recording and Data Exchange Format

1. Applicable field notes
2. EMS data files and data logger files
3. Excel spreadsheets.

Results

The M&V efforts determined the following:

- The original constant volume supply fan in the dual duct air handler was replaced with a new FANWALL 12-fan array system as planned. The two new VFD's were installed.
- Two new VFDs were also installed on the two existing return fans.
- The new static pressure setpoint was 2.5 +/- 0.1 in-WG during the monitoring period. This value is measured in the ductwork on the ninth floor.
- Approximately 40% of the existing terminal boxes had been converted to single duct, variable volume terminals at the time of the application. This figure is now 100%.
- The planned power (kW) meter that was to be installed on the return fan to verify savings was not installed.
- Since the facility is a hospital, it is occupied and operated continuously, with no shutdowns for holidays.
- Monitoring was conducted for 23 days.

During the monitoring period, the supply air flows (CFM per main duct), supply and return fan VFD speeds and the supply air static pressure were all trended in the facility's EMS. However, the return fan air flow was not provided, and the VFD speeds and the static pressure data were only recorded for the last 24 hours.

All four VFD's receive the same speed command signal. Although there is only 24 hours of data to directly support this statement, the trended CFM and measured power data are all consistently similar in their variation. The SF CFM's vary only +/- 7% over the monitoring period. The VFD speed varies only from 82-90%, averaging 85.2%. A chart of the trended CFM is shown below.

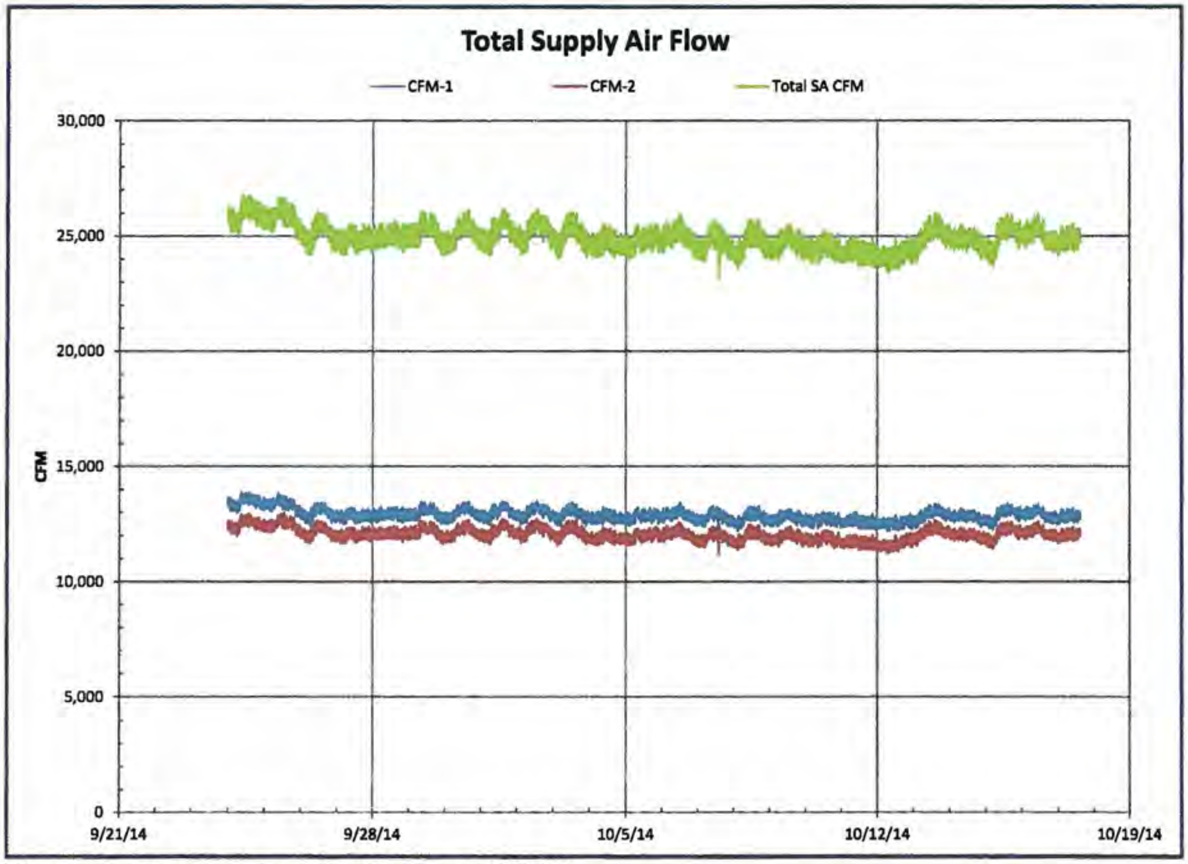


Figure 1. Trended Supply Air Flows (CFM)

A chart of the measured power history is shown below in Figure 2. The average supply fan power was 100.95 kW and the average return fan power was 12.75 kW, for a total of 113.7 kW. The total power value varies only +/- 15% over the course of the monitoring period. The maximum total power observed was 133.1 kW.

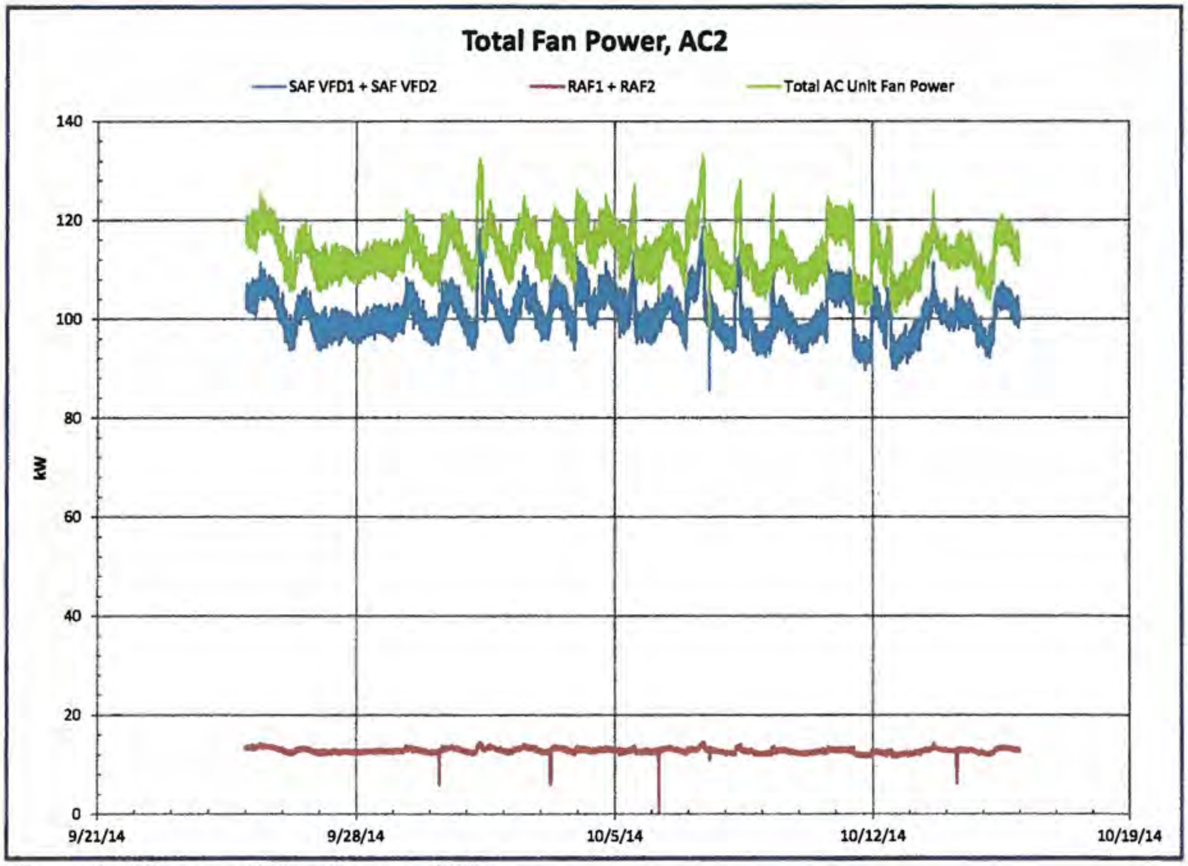


Figure 2. Measured Fan Powers (kW)

Outside air temperature was also measured, but, as shown in the following chart, there is no significant correlation of fan power to the OA temperature, on either a timed interval or daily basis.

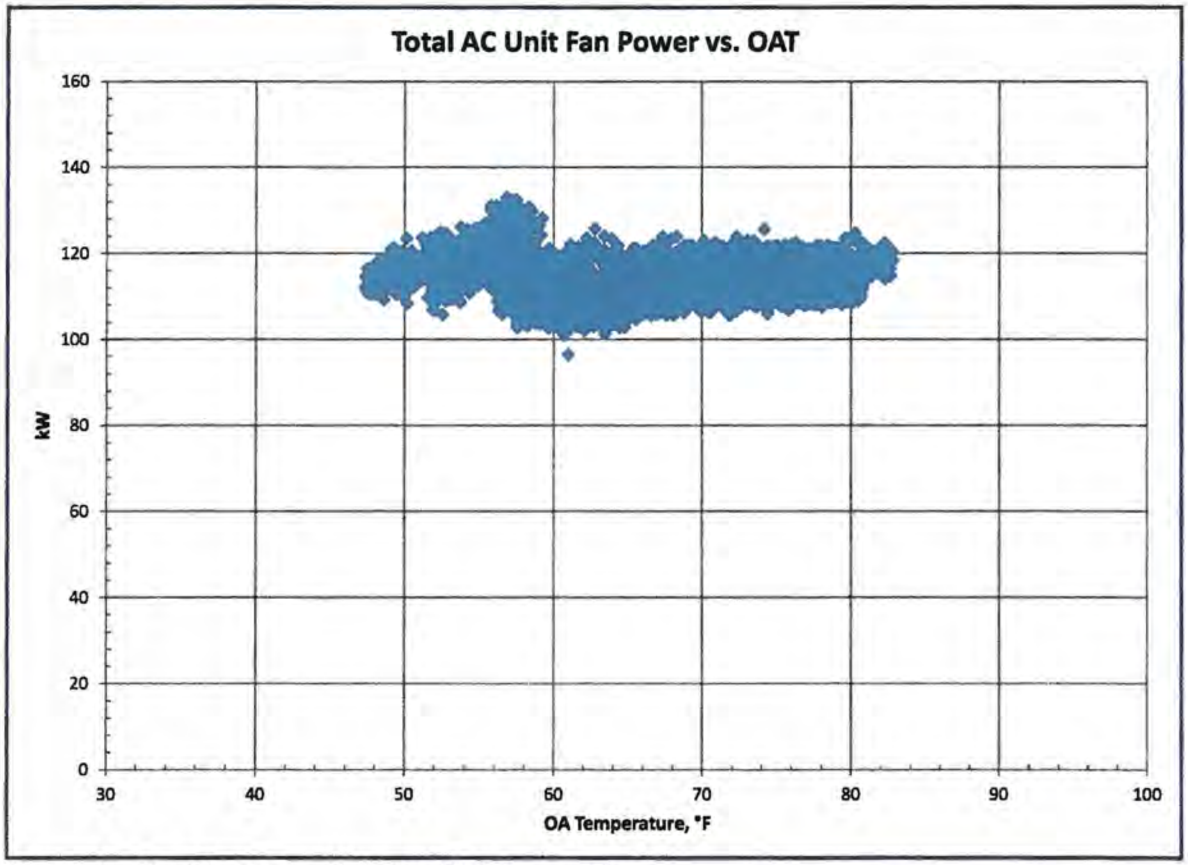


Figure 3. Fan Power vs. Outside Air Temperature

The chart below shows the average daily fan power (supply plus return, kW) and daily total energy consumption over the monitoring period. As previously mentioned, the average power is fairly uniform across all days and temperatures, and the average total fan power is 113.7 kW. The average daily total energy consumption is 2,729 kWh/day. Multiplied by 365 days per year, the total annual energy consumption is 996,003 kWh/year.

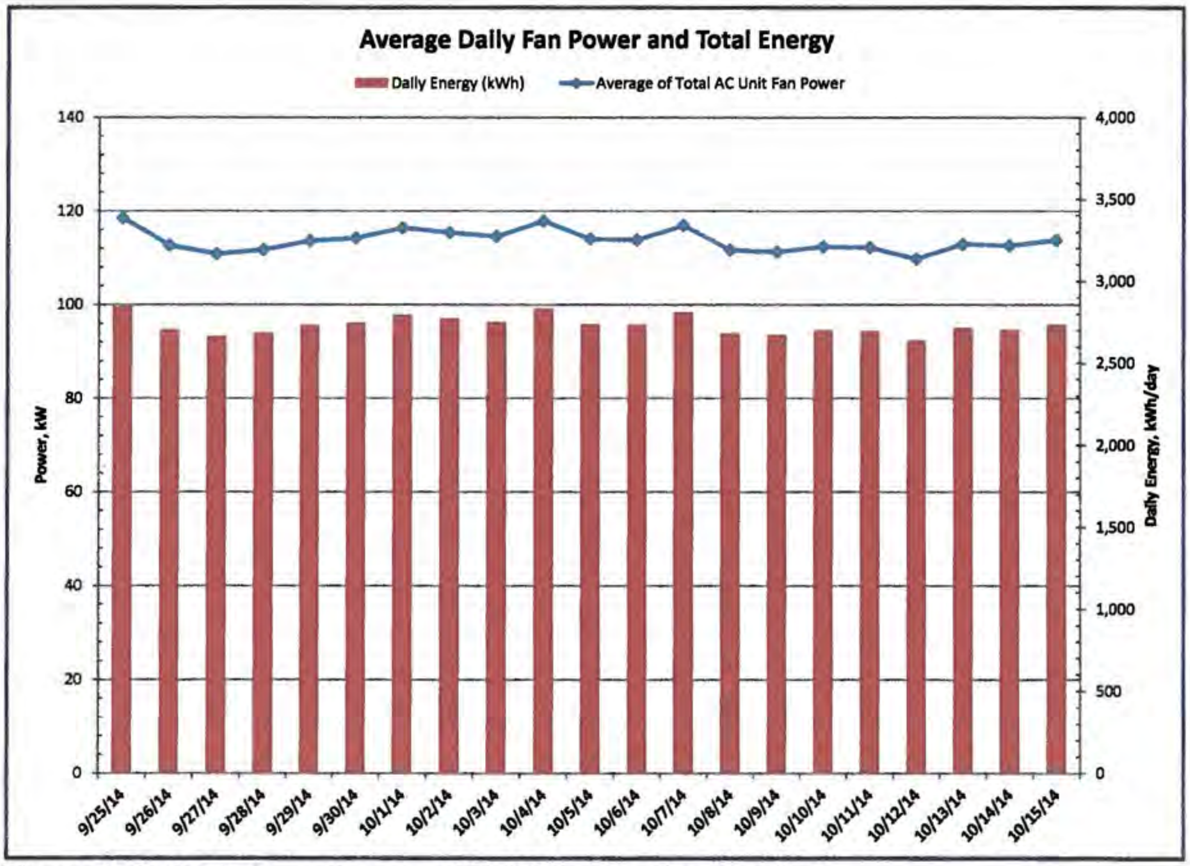


Figure 4. Daily Average Power and Total Energy Consumption

As noted previously, the maximum power observed during the monitoring period was 133.1 kW. Developing average hourly load profiles from the measured power data shows that the fan power is generally slightly higher in the late mornings than it is in the afternoons (see the following chart). For Ohio in 2014, the coincident peak demand hour is on July 17, for the hour between 4-5 PM. Monitoring was not in progress on that date for this project; therefore, the available monitored data was used to determine the peak power expended during the 4-5 PM time period on any weekday, which was 121.9 kW.

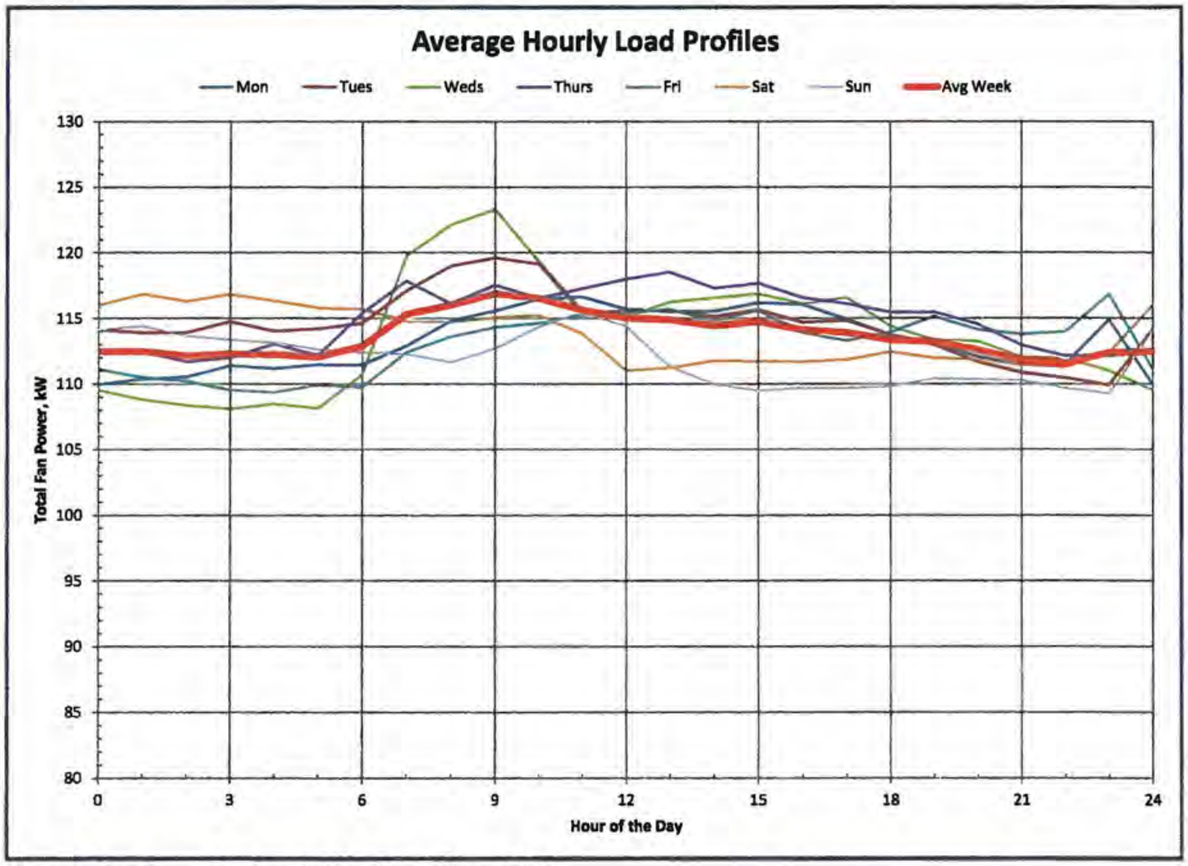


Figure 5. Average Load Profiles (Fan kW)

For the baseline (pre-retrofit) peak power and annual energy consumption, and since the average load is very steady, we used the measured total unit fan power found in the attachment to the application as the basis for determining energy savings. There was no opportunity to measure the fan powers independently before the retrofit occurred. Also, since there is no variation of fan power or air flow with the OA temperature, there is no need to adjust the measured value for such variations. Therefore, from the application, the pre-retrofit power and energy consumption are as shown in the table below:

Table 1. Baseline (Pre-Retrofit) Power and Annual Energy Consumption

	Fan BHP	Fan KW	Hours of Operation / Year	Operating Load Percentage	Annual Energy (kWh)
Supply Fan	184	137.264	8760	100%	1,202,433
Return Fans (total of 2)	12.7	9.474	8760	100%	82,994
Totals		**146.7**			**1,285,427**

The pre- and post-retrofit values described above lead to the energy and demand savings shown in the following table.

Table 2. Annual Energy and Demand Savings - [Redacted] AC 2 West

Facility: [Redacted] HVAC Unit AC 2 West			
	Annual Energy (kWh)	Non-Coincident Peak Demand (kW)	Coincident Summer Peak Demand (kW)
Pre-Retrofit	1,285,427	146.7	146.7
Post-Retrofit - M&V	996,003	133.1	121.9
Savings	289,424	13.7	24.8
Duke Projections	789,375	73.2	44.3
Realization Rates	37%	19%	56%

The realization rates are poor, and far below expectations. The main reason for this performance is that the anticipated variations in supply air delivery and fan power, to be achieved by installing the VFD's on the new Fanwall array and the return fans, are not present. The chart in Figure 6 compares the measured fan power values for all the monitored time intervals to the distribution used in the application (the power values on the horizontal axis correspond to average VFD speed bins of 40%, 50%, 60% ... 100%, as used in the application). The application calculation does not state how the anticipated distribution of %-speed hours was generated.

The savings that have been achieved are most likely due to the reduction in supply fan discharge pressure, which was one of the goals of the ECM. The original supply fan and the new Fanwall system were supposed to have the same peak full-load power. Our field technician's notes state that the duct pressure is now controlled to a setpoint of 2 in WC on the ninth floor (the data records 2.5 in WC as the actual value). The original pressure at the supply fan discharge was 6.5 in WC. The designer's hope was to reduce the discharge pressure from 6.5 to 4.0 in WC, a drop to 61% of the original value. Allowing for a couple of more inches of pressure drop on the inlet side of the fan, the reduction from 6.5 to 4.0 at the fan outlet is probably a drop to about 70% of the original total pressure value. The actual reduction in average supply fan power is to 73%, so the reduction in pressure does seem to explain the observed savings.

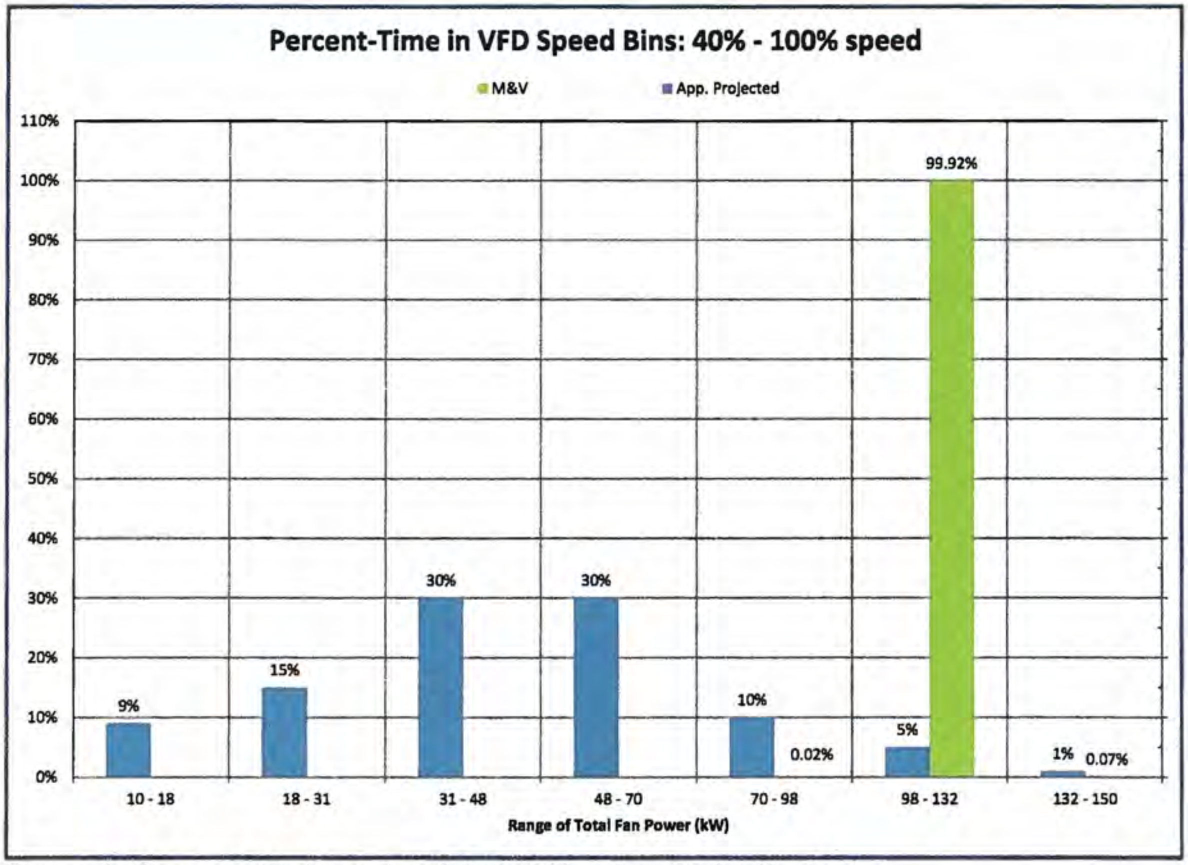


Figure 6. Compare Estimated and Actual Fan Speed Distribution

ARCHITECTURAL ENERGY CORPORATION

[Redacted]

- Window Replacement -

M&V Summary Report

PREPARED FOR:
Duke Energy
Ohio

PREPARED BY:
Architectural Energy Corporation
2540 Frontier Avenue, Suite 100
Boulder, Colorado 80301

PREPARED IN:
December 2012

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

The M&V activities described here were 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].

ARCHITECTURAL ENERGY CORPORATION

INTRODUCTION

This report addresses M&V activities completed for the [Redacted] custom program application. The measures include:

ECM-1: Window Replacement

- The [Redacted] windows were original to the building, single-pane casement windows that were drafty, poorly-insulated and generally very inefficient. The majority of the [redacted]'s windows have been replaced with new double pane, low-e, clear windows with a U-value of 0.36 and shading coefficient of 0.65.

  In addition, the current system utilizes approximately 20 window air conditioners to serve particular perimeter spaces. The new glazing will allow these spaces to be completely served by the central cooling system, saving cooling energy in the process.

Note: ECMs have already been installed for this application. Survey data will be for Post-install only.

GOALS AND OBJECTIVES

The projected savings goals identified in the application are:

Application Proposed Annual savings (kWh)	*Application Proposed Peak Savings (kW)*	*Duke Projected savings (kWh)*	*Duke Projected Peak savings (kW)*
1,033	26	1,032	26.0

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

- Annual gross kWh savings
- Summer peak kW savings
- Utility Coincident peak demand savings
- kWh & kW Realization Rates

PROJECT CONTACTS

Duke Energy M&V Coordinator	Frankie Diersing	513-287-4096
Duke Energy BRM	Cory Gordon	
Customer Contact	[Redacted]	[Redacted]
Architectural Energy Corporation Contact	Peter Fox	p: 303-459-7477 pfox@archenergy.com

SITE LOCATION

Address	*Square Footage*	*Facility Age*
[Redacted]	~30,000	50+ years

Data Products and Project Output

- Model predicting annual pre/post kWh
- Summer peak demand savings [kW]
- Coincident peak demand savings [kW]
- Annual Energy Savings

Recording and Data Exchange Format

1. Pre-installation utility data.
2. Post-installation Survey Form and Notes.
3. Excel spreadsheets.
4. eQUEST and DOE-2 energy model data files.

M&V Option

IPMVP Option D: Calibrated Simulation

Field Survey Points

Following window installation, all information was recorded in the AEC Survey-It data form. This form includes detailed information about all building systems, including:

- Building wall, window, and floor area.
- Space types and uses.
- HVAC zoning.
- Occupancy schedules and operations (daily, weekly, annually, holidays).
- Lighting loads and schedules.
- Equipment loads and schedules.
- Temperature setpoints, Energy Management Systems.
- HVAC system controls.
- Shading and blinds.
- Air handlers and water heating.
- Building envelope, including windows, walls, areas, and construction types.

Data Analysis

1. Verify Proposed Measures Were Implemented:

   Verified that all windows were replaced. In addition, nameplate data was collected for all HVAC equipment to ensure that it was accurately represented in the computer energy model.

2. Calculation Methodology:

   A computer energy simulation of the building was created using DOE-2 software with an eQUEST front end. This model was used to calculate the building energy performance and a host of other information. From these outputs, the necessary annual energy use in kWh was compared to determine the savings attributed to the building envelope upgrade.

In the creation of the Baseline building model, inputs such as equipment schedules were modified to accurately reflect the conditions of the pre-retrofit building.

3. Energy Model Calibration:

Due to limited utility data specific to this building of the school campus, it was not possible to calibrate the model to billing data. It is believed that the model accurately reflects the building characteristics and there are no parameter changes that can be made while maintaining an accurate simulation of the facility.

4. Savings Verification and Realization Rate:

The annual energy results of the Baseline and Existing building models have been compared to determine the amount of annual energy savings resultant from the retrofits. Once the savings are calculated, the realization rate is summarized by the following formula:

$$\text{Realization Rate for kWh} = kWh_{actual} / kWh_{application}$$
$$\text{Realization Rate for kW} = kW_{actual} / kW_{application}$$

Verification and Quality Control

1. Verified that pre-retrofit and post-retrofit window specifications and quantities are consistent with the application. If they are not consistent, record discrepancies.

Results Summary

Verify Proposed Measures Were Implemented:

Exterior Window Retrofit:

The windows were installed in the areas specified from a drawing set provided by the contractor to AEC. The school website also verifies the progress of construction through a sampling of renovation photos.

Results:

The values listed in the Goals & Objectives section above were provided as the submitted savings estimates to Duke Energy, and are repeated here for comparison.

Application Proposed Annual savings (kWh)	Application Proposed Peak Savings (kW)	Duke Projected savings (kWh)	Duke Projected Peak savings (kW)
1,033	26	1,032	26.0

These values were obtained through iterations of a Trace 700 energy model performed by Heapy Engineering in conjunction with this project. The Duke values are used for Savings Realization Rate calculations in this report.

Establish the Baseline Energy Use:

The baseline building electricity consumption resulting from M&V activities was determined through a model of the school created in eQuest version 3.64. A site visit was conducted to help assess the space characteristics, mechanical systems, operation, etc. so that the model would accurately represent the facility as much as possible. This information was collected from the SurveyIt form provided by AEC, bid drawings, Trace 700 model outputs, utility data, and the school website. The following are the main assumptions applied to both building models in addition to glass types:

- Operation schedule: 7am-10pm, Monday-Saturday.
- Holidays and breaks are based on 2013 school calendar.
- Occupied Heating and Cooling setpoints: 68°F and 74°F respectively.
- Thermal storage charging enabled from 9pm-6am, 3 tanks totaling 360 Tons capacity.
- (1) 60 Ton chiller for cooling and thermal storage charging, operates at ~9 EER.
    - Air-cooled operation based on model number.
- (2) 1,262,000 Btuh Lochinvar boilers for space heating.
- Unit Ventilators serve exterior spaces, with OA connection and dampers.
    - Fans cycle overnight without OA, zone temperature control, HW CHW connection.
- Drawings supplied dimensions, zoning, and window-wall areas

Establish the Post-ECM Energy Use:

The post-retrofit building use was determined through adjustments to the baseline building, constructed as described above. This ensured that schedules, equipment, and geometry would remain the same and only window properties could be adjusted. The values given to the two window types were as stated in the *Duke Energy Custom Application* and *Energy Analysis* provided from Heapy Engineering.

	U-Value	*Shading Coefficient*
Existing Window	1.57	0.90
New Windows	0.36	0.65

Savings Verification and Realization Rate:

It is believed that the model accurately reflects the building characteristics and there are no additional parameter changes that can be made while maintaining an accurate simulation of the facility. Due to limited utility data specific to this building of the school campus, calibration of the model to utility bill data was not possible.

Baseline and Post-retrofit savings data can now be compared to determine the savings actually realized as a result of this project. The realization rate is determined by the following formula:

$$Realization\ Rate = \frac{kWh_{actual}}{kWh_{application}}$$

The modeled energy use, savings totals, and realization rates for [redacted] are listed in the following Table.

	kWh	Non-coincident Peak kW	Coincident Peak kW
Duke Estimated Savings	1,032	26.0	25.2
Evaluated Savings	9,941	0.6	4.6
Realization Rate	9.63	0.02	0.18

ARCHITECTURAL ENERGY
CORPORATION

[Redacted]

- Integrated Energy Design for Electric Efficiency -

M&V Report

PREPARED FOR:
Duke Energy
Ohio

PREPARED BY:
Architectural Energy Corporation
2540 Frontier Avenue, Suite 100
Boulder, Colorado 80301

PREPARED IN:
June 2014
Version 1.0

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].

ARCHITECTURAL ENERGY CORPORATION

INTRODUCTION

This report addresses M&V activities for the [redacted] custom program application.

The [redacted] facility in downtown Cincinnati is composed of three buildings [redacted]. An engineering and re-commissioning study of the [redacted] was conducted in mid-2011 to January 2012. The resulting "SmartBuilding Advantage Engineering Study" report details a number of recommendations for lighting, mechanical and controls improvements in a three-phase renovation project.

The *Custom Incentive Program* application that is the subject of this M&V effort covers HVAC systems and controls upgrades in the 1982 building. The building is served by nine air handlers having several different system types and capacities. The table below summarizes the air handling units by level served and system type.

1982 Building air handling units

Level	Served By	System Type(s)
3 (public)	AC-2, AC-4, AC-5[1]	Dual duct
D (non-public)	AC-3	Constant volume
C (non-public)	AC-3	Constant volume
2 (public)	AC-2, AC-4, AC-5[1]	Dual duct
1 (public)	AC-2, AC-4, AC-5[1]	Dual duct
B (non-public)	AC-1, AC-6, AC-7, AC-8, AC-9, HV-1	VAV and constant volume, plus a multi-zone heat recovery unit.

Note:

1. AC-2 serves the core of levels 1, 2, and 3, while AC-4 and AC-5 each serve half of the perimeter of levels 1, 2, and 3.

The above AC units, except for HV-1, were to be upgraded in the second phase of the three-phase project, as outlined in the engineering study. An eQUEST energy model was previously developed as part of that assessment to estimate the energy savings attributable to each phase.

Phase 1 consisted of the Energy Conservation Measures (ECM's) listed below. The conditions of the [redacted] at the completion of Phase 1 constitute the baseline conditions for Phase 2.

ECM#	Description
Phase 1: Recommissioning and Lighting Retrofit	
1	Lighting retrofits
2	Lighting controls – occupancy
3	Lighting controls – daylighting
52-1	Repair steam condensate system
52-2	Eliminate summer boiler plant operation
52-3	Re-commissioning

ARCHITECTURAL ENERGY CORPORATION

82-1	Re-commissioning (limited)
95-1	Re-commissioning

Phase 2 was divided into two sub-phases, Phase 2A and 2B, for scheduling purposes. The Phase 2 ECMs consist of the following:

ECM#	Description
Phase 2A:	[Redacted] Major Mechanical and Controls
82-2A	Replace/retrofit AC-4 and AC-5
4A	[Redacted] BAS and controls upgrade/retrofit
Phase 2B:	[Redacted] Major Mechanical and Controls
82-2B	Replace/retrofit AC-1 and AC-2
82-3	Controls upgrade/retrofit for AC-3
82-4	Controls upgrade/retrofit for AC-6, 7, 8, 9

The Phase 2 ECM's are described in more detail below.

- **EMC 82-2A: Replace/retrofit AC-4 and AC-5**
  These units were to be replaced with VAV air handling units. The existing dual-duct mixing boxes throughout the building were either converted to standard VAV boxes, or replaced with fan-powered VAV boxes with heating coils.

- **ECM 82-2B: Replace/retrofit AC-1 and AC-2**
  This measure completes the replacement of the major air handling units serving the 82 Building. These units were to be replaced with VAV air handling units, and, as for AC-4 and AC-5, the existing mixing boxes throughout the building were either converted to VAV boxes, or replaced with fan-powered VAV boxes with heating coils.

- **ECM 82-3: AC-3 controls retrofit**
  AC-3 was recently mechanically overhauled, and only requires a controls retrofit. This unit serves the Level C and D stacks, which are areas of low occupancy. Therefore, air flow can be varied based on heating, cooling and ventilation demand.

- **ECM 82-4: AC-6, 7, 8, and 9 controls upgrade/retrofit**
  Since these units are relatively new, only a controls upgrade/ retrofit was to be implemented. Some of these units also already have VFDs. It was also recommended that these units be re-commissioned to optimize operation.

- **ECM-4A: BAS and controls upgrade/retrofit for [Redacted]**
  This ECM consisted of new building controllers, programmable I/O controllers, enterprise server and software, sub-meters and integrating existing meters.

Note that all ECMs recommending equipment replacement or retrofit include complete replacement of existing controls with new digital controls. All AC units received air balancing and commissioning.

Goals and Objectives

The projected savings goals identified in the application are presented in the following table.

Projected Savings Comparisons

	Annual Energy Savings (kWh)	Peak Demand Savings (kW)
Application Proposed - Phase 2A	1,332,814	152.1
Application Proposed - Phase 2B	971,498	110.9
Application Total	2,304,311	263.0
Duke Projections	2,420,314	307.2

The objectives of this M&V project are to verify the actual:

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

Project Contacts

Duke Energy M&V Coordinator	Frankie Diersing	513-287-4096	Frankie.Diersing@duke-energy.com
E$ Energy Consultant	Michelle Kolb		
Customer Contacts	[Redacted] [Redacted]	[Redacted]	
AEC Contact	Doug Dougherty	(w) 303-459-7416 (c) 303-819-8888	ddougherty@archenergy.com

Site Location

Site	Address
[Redacted]	[Redacted]

Data Products and Project Output

- AEC survey data forms
- Model predicting pre-renovation baseline and post- renovation (as-built) electric energy consumption in kWh and electric coincident demand in kW
- Annual energy savings
- Summer building peak demand savings
- Coincident peak demand savings.

M&V Option

IPMVP Option D – Calibrated Simulation

M&V Implementation Schedule

The renovation was completed in October, 2013; only post-installation data is available.

- Prior to arrival on-site, requested the electronic files for the eQuest building energy model that was previously developed. *[This model was received by AEC.]*
- Prior to arrival on-site, contacted the building site contact to determine whether the required survey data can be collected by trending in the site's BAS.
- During the site visit, verified that the HVAC systems described in the model were installed and/or upgraded (refer to forms).
- Filled out the attached data collection forms.
- Established trend logs to monitor operation of supply fans, economizer air temperatures, and outdoor air temperature and relative humidity.
- All lighting is on a fixed schedule, therefore deployment of data loggers to monitor lighting circuits for schedules was not required.
- Trended EMS data for four weeks (the month of March, 2014).
- Updated the building energy model as required reflecting the actual installed conditions with respect to the modeled ECM's.
- Evaluated the energy impacts of the as-built building improvements in the energy model.

ARCHITECTURAL ENERGY
CORPORATION

Field Survey Points

Personnel Interview / BAS Review:

- With the assistance of the on-site contact, reviewed the BAS programming to determine information requested in the attached survey forms.

Survey Data for New and Retrofitted Equipment:

- HVAC Equipment Operating Data. Recorded systems operating information on the attached data collection forms. These forms include detailed information about the HVAC systems for and affecting [Redacted], including:
    - New small boiler
    - Modifications to the existing steam heating plant
    - Existing chillers
    - Existing condenser (cooling tower) loop controls
    - [Redacted] air handling units AC-1 through AC-9.
- Lighting.
    - Verified the lighting retrofit for [Redacted] has been completed.
    - Spot-checked the lighting power density (LPD) of [Redacted] as instructed in the survey forms.
    - Verified that occupancy sensors are installed in restrooms, as instructed in the survey forms.

Spot-Measurements

- For air handling units **AC-1, AC-2, AC-4 and AC-5**, measured the total unit electrical parameters including power (volts, amps, power factor and kW).
    - *Recorded the fan VFD frequency at the time of the measurement.*

BAS Trending / Field Datalogging

Time-series data

- Set up trend logs for 15 minute instantaneous readings.
- Collected data during normal operating periods (avoiding atypical operating situations such as maintenance shutdowns).

ARCHITECTURAL ENERGY CORPORATION

General points:

- Outdoor air temperature and relative humidity.

Air Handling Units

For the air handling units **AC-1, AC-2, AC-4 and AC-5**, gathered trended data from the BAS as described below.

- Supply fan VFD output signal (percent of full frequency or Hertz).
- Supply duct static pressure
- Supply duct air flow (CFM) *[Was not available.]*
- Supply air temperature
- Outside air temperature
- Mixed air temperature
- Return temperature.

Lighting.

Occupants **do not** have control of lighting. All lighting is scheduled through the lighting control system.

- Determined from the lighting control system programming the lighting on-off schedules for typical areas in [Redacted]. No BAS trending or data logging was required.

Logger Table

Not applicable.

Data Accuracy

Not applicable.

Data Analysis

1. Determined the lighting schedule from the lighting control system.

2. Determined the AHU fan operating schedules from the BAS programming. Confirmed with trended AHU fan operating data by unit and by day-type.
3. Plot the trended / logged economizer data vs. outdoor air temperature to verify economizer enable temperatures. *[Because of cold weather, economizers were not in use.]*
4. Compared the lighting schedules, fan schedules, etc., as determined from the preceding steps, to the schedules found in the existing eQUEST energy model.
5. From the survey forms, noted any differences between the existing model and the as-found Phase 1 parametric run inputs.
6. Made required revisions to the Phase 1 parametrics and re-ran the Phase 1 model. This model performance at the end of Phase 1 is the baseline, or "pre-retrofit" case, for this analysis.
7. Determined the pre-retrofit (baseline) annual energy usage and peak/coincident kW demand during the on-peak period.
8. From the survey forms, noted any differences between the existing model and the as-found Phase 2 parametric run inputs.
9. Made required revisions to the Phase 2 parametrics and re-ran the Phase 2 model. This model is the "proposed building," or "post-retrofit" case, for this analysis.

   Note: Since the building revisions were completed within just five months of the M&V data collection effort, the post-retrofit model cannot be calibrated to the actual building utility performance. Such calibration requires that a year's worth of monthly utility bills be available.
10. Determined the post-retrofit annual energy usage and average peak/coincident kW demand during the on-peak period.
11. Compared the post-retrofit model output with the pre-retrofit output to determine the annual energy and demand savings.
12. Determined the energy savings Realization Rate by dividing the annual energy savings found in the step above to the savings estimated by Duke Energy.
13. Determined the demand savings Realization Rate by dividing the peak coincident savings found in the step above to the savings estimated by Duke Energy.

Verification and Quality Control

1. Visually inspected trend data for consistent values.
2. Verified equipment specifications and performance parameters are consistent with the application, recorded discrepancies.

Recording and Data Exchange Format

- ECM Confirmation Data Forms and other field notes.
- Energy Management System data files, if collected
- Data logger files *[None]*
- DOE-2/eQUEST energy model data files
- Excel spreadsheets

Results

Listed here are the results of the field investigation and the trend data analysis. These results are presented in order of the parametric runs included with the "eQUEST" energy model, so that the impact of the M&V findings on the model inputs may be explained.

An inconsistency in the model is that the 1982 building is sometimes referred to as the "1983" building. For consistency in this report, all references to "1983" have been changed to "1982." This mainly affects the ECM headings.

The completed ECM Confirmation Data Forms may be found at the end of this report.

PHASE 1

ECM 1: Light_W_ph1n <Part 1>

In 265 spaces, the lighting power density (LPD) was reduced to 0.84 W/ft2.

The field survey found that the lighting is typically two 32W lamps per fixture. A typical surveyed area had 33 fixtures in a 32-ft by 48-ft area.

From the spare parts inventory ballast, the ballast factor is 0.71, typical of a "low-output" ballast. We did not open a fixture to find out if this ballast is actually what is installed. Assuming it is, the LPD for the above fixture spacing is 0.976 W/ft2.

<u>*Model*</u>:

- In this ECM, change the LPD from 0.84 to 0.976.

ECM 1: Light_W_ph1n <Part 2>

In 17 spaces (Area 2), change Lighting LPD to 0.40 W/sqft. All of the spaces receiving this reduced LPD appear to be in the 1955 Building. No effect on [Redacted].

- *Assume implemented and run ECM as programmed.*

ARCHITECTURAL ENERGY CORPORATION

ECM 2: Boiler_eff_ph1n

This ECM was to install a small 90% efficient hot-water boiler (100,000 Btu/hr) in [Redacted]to serve the summer reheat loads so that the large boilers could be shut off.

The small boiler was not installed. Instead, a new main gas-fired HW boiler was installed. Manufacturer's literature says the new boiler's rated output is 2790 MBH and its rated input is 3000 MBH (efficiency = 93.0%), and the unit has a turn-down ratio of 15.

In the PB model, the small boiler was set up to be baseloaded; i.e., it would provide the first 100,000 Btu of heating load no matter what the season.

Model:

- *Redefine the "small boiler" as the "new HW boiler" having:*
    - *2790 MBH output capacity*
    - *HIR = 1.07527 , equivalent to an efficiency of 93%.*
    - *A minimum load fraction = 0.06667, equivalent to a turn-down ratio of 15 to 1.*

ECM 3: AHU_Sch_ph1n

[Redacted]AHU controls changes - No effect on [Redacted].

Model:

- *Assume implemented and run ECM as programmed.*

ECM 4: OccSensor_ph1n

Occupancy Sensors

Forty-six spaces were to receive occupancy sensors for lighting control. Of the 46 spaces, only four are in [Redacted] and these are installed in restrooms.

Field investigation verified that the restrooms do have occupancy sensors. However, there is a lot of traffic through the restrooms all day long, so the lights probably aren't off very often. The lights are scheduled to be off at night in both the baseline and proposed-building models.

A review of the model shows that this ECM was not activated for the parametric runs, and thus no energy savings for occupancy sensors were included in the final results.

Model:

ARCHITECTURAL ENERGY CORPORATION

- *Leave the measure as not activated.*

ECM 5: heatLeak_ph1n

The original boiler plant was in poor condition. A large, uninsulated condensate tank, leaking boiler steam traps, and an uninsulated boiler exhaust vent all emitted a great deal of heat into the boiler room, the surrounding walls and spaces. Since all the spaces use the steam plant, the heat leaks were charged to all spaces equally. Heat gains to spaces from inefficiencies of old steam boilers were modeled as 150 Btuh / space. This heat gain offsets some heating energy provided through the HVAC systems when heating is called for (offsetting mainly gas), but also increases the cooling loads when cooling is called for, increasing the electrical load.

The ECM was to:

- Insulate steam condensate receiver tank
- Vent condensate discharge outside of building
- Survey and repair steam traps.

If all measures had been done, the heat gains to the spaces were to be reduced to zero.

The field investigation found that the steam condensate receiver tank was NOT insulated, and the condensate discharge was NOT vented outside the building. The steam traps have been repaired.

Since only one of the three measures in this ECM was implemented, credit is only given for one-third of the heat gain reduction. Thus the heat gain is reduced to 100 Btuh/space instead of zero. However, based on the output of the model, the new HW boiler provides approximately 43% of the total load on the boiler plant, which also displaces heat gains to the building from the remaining steam boilers. Thus, the new value of the heat gain to each space is 100 Btuh x 57% = 57 Btuh.

Model:

- *For the post-retrofit building, use a heat gain to each space of 57 Btu/hr instead of zero.*

ECM 6: Economizerall_ph1n

Economizer control changes for [Redacted]AHU's. No effect on [Redacted].

Model:

- *Assume implemented and run ECM as programmed.*

ARCHITECTURAL ENERGY CORPORATION

ECM 7: StaticReset_ph1n

Static pressure control changes for [Redacted] AHU's. No effect on [Redacted].

Model:

- *Assume implemented and run ECM as programmed.*

ECM 8: 95AHU_VFD_ph1n

Change HVAC System type to VAV for [Redacted] AHU's. No effect on [Redacted].

Model:

- *Assume implemented and run ECM as programmed.*

ECM 9: Chiller_eff_ph1n

Baseline chiller EIR was = 0.199, or kW/ton = 0.700

The chillers were rebuilt in 2011 and appear to be working properly. While the plant seemed functional, controls re-commissioning was recommended to achieve some additional energy savings. This ECM modeled the outcome of the re-commissioning as an improvement in the EIR to 0.1950, or kW/ton = 0.686, for both Chiller 1A and Chiller 1B.

Model:

- *Assume implemented and run ECM as programmed.*

ECM 10: Tower_reset_ph1n

Originally, the Baseline condenser water (CW) loop temperature was fixed. It had been recommended to implement Condenser water reset control. This measure would have allowed the loop temperature to float with the cooling load.

Field investigation found that this measure was attempted but there were too many problems, so the system was put back to a fixed CW loop temperature. The loop temperature setpoint is 74°F.

Model:

- *Do NOT implement this ECM.*

- *The fixed CW loop temperature setpoint is 74F.*

The preceding measures mark the completion of Phase 1, which constitutes the Baseline Building (BL) for this analysis.

Completion of the following Phase 2 measures constitutes the Proposed Building (PB) for this analysis.

ECM 11: 82_AHU_4-5_ph2

In [Redacted], dual duct air conditioning units AC-4 and AC-5 were to be replaced with VAV units, or retrofit with VAV capability. The first ECM modeled as part of the replacement/repair of these units is "Static pressure control."

The field investigation found:

- AC-4 and AC-5 were changed to VAV systems.
- VAV boxes were installed at the zones.
- The static pressure setting for the AC units is 3.5 in-WC.
- Static pressure reset was NOT implemented.

AC-4 and AC-5 are dual-duct systems. Trend data for these units' hot and cold decks' static pressures show that the pressure is very close to the setpoint of 3.5 in-WC in one of the decks whenever the fan is running. The pressure in the other duct does drop below 3.5, but this is believed to be an indication that the duct pressure was not being controlled when the service of the first duct was being called for. For example, if the system is calling primarily for heating, the pressure in the hot deck will be 3.5 in-WC and the pressure in the cold deck will drift to a lower value (typically still above 2.5 in-WC). See Figure 1.

There are some times when both the hot and cold decks' static pressures are reduced, but these appear to have been times when the fans were ramping up or down and steady state operation was not established.

The original model had some relatively high values inserted for supply fan power per CFM, which imply high static pressures. Although static pressure control is not implemented, converting the systems to VAV and setting the static pressures as determined from the field investigation still saves a significant amount of energy.

In the model, this ECM included AC-8. AC-8 was not converted to VAV. Therefore, it was removed from this parametric run.

Model:

ARCHITECTURAL ENERGY
CORPORATION

- *For AC-4 and AC-5,*
    - *Accept the new VAV system types*
    - *Set the maximum static pressure = 3.5 in-WC*
    - *Do NOT implement static pressure reset.*
- *For AC-8*
    - *Eliminate AC-8 from this measure.*

ECM 12: 82AHU_4-5_ph2 <Part 1>

AC units AC-4 and AC-5 were supposed to get optimum start programming in the summer (i.e., the BAS decides when to start the units up in the mornings, before actual occupied hours, in order to reach comfort conditions by the beginning of occupied hours). Rather than starting the units at a fixed time of 4 AM, start-up could be delayed to as late as 6 AM, if the control system decides comfort conditions would be met by the beginning of occupancy.

The actual ECM included AC units AC-6, AC-7 and AC-8 in this measure.

The field investigation found that none of the units were programmed for optimum start control. *However, examining the model parametric programming shows that optimum start had not been activated for these units anyway.*

The field investigation found that the fixed schedule for all five units is:

Monday through Wednesday:	On at 7:00 AM	Off at 9:30 PM.
Thursday through Saturday:	On at 7:00 AM	Off at 7:30 PM.
Sunday:	On at 11:30 AM	Off at 5:30 PM.

However, for both AC-4 and AC-5, the trend data does show a regular schedule for the week or so that the system was not running continuously. The schedule is slightly different from that provided from the field survey.

Monday through Wednesday:	On at 5:30 AM	Off at 9:30 PM.
Thursday through Saturday:	On at 5:30 AM	Off at 7:00 PM.
Sunday:	On at 10:30 AM	Off at 5:30 PM.

This schedule is used in the model. Because of model limitations, half-hour times are rounded to the whole hour, keeping the number of operating hours the same where possible.

Model:

- *Do NOT implement this ECM (no change to model).*

- *Adjust the units' BL operating schedule to match the times above.*

ECM 12: 82AHU_4-5_ph2 <Part 2>

This control measure enables the units to come on at night if any zone goes out of its setback temperature range.

The actual ECM included AC units AC-4, AC-5, AC-6, AC-7 and AC-8.

The field investigation found that all of the units do have this programming. In the last two days of the monitoring period, the trend data for AC-4 does show some night-time operation.

Model:

- *Run this ECM as programmed.*

ECM 12: 82AHU_4-5_ph2 <Part 3>

This control measure enables AC units to bring in outside air at night if needed for space pre-cooling before occupied hours (night flushing).

The actual ECM included AC units AC-4, AC-5, AC-6, AC-7 and AC-8.

The field investigation found that all of the units do have this programming. Due to the winter conditions, the trend data for AC-4 and AC-5 did not capture any night pre-cooling operation.

Model:

- *Run this ECM as programmed.*

ECM 12: 82AHU_4-5_ph2 <Part 4>

This control measure "set back" the heating space temperature setpoint and "set up" the cooling temperature setpoint during unoccupied hours for 124 zones. Most of the zones are served by AC-4 and AC-5; although a few zones are served by AC-6 through AC-9.

In the model, the ECM included the following temperature setpoints:

- Setback Cool Sch = 76°F from 6 AM- 9 PM, 82°F from 9 PM – 6 AM.
- Setback Heat Sch – Summer = 70°F from 6 AM- 9 PM, 64°F from 9 PM – 6 AM.
- Setback Heat Sch – Winter = 70°F from 4 AM- 9 PM, 64°F from 9 PM – 4 AM.

The field investigation found that all of the units do have set-back programming, but that the setpoints are slightly different for heating:

- Setback Cool Sch = 76°F during occupied hours, 82°F unoccupied (same temperatures as above).
- Setback Heat Sch – Summer = 70°F occupied, 68°F unoccupied.
- Setback Heat Sch – Winter = 70°F occupied, 69°F unoccupied.

For AC-4, trend data shows that, for the monitoring period, occupied space return air temperatures were typically between 74 and 76°F, and at night the temperatures drifted between 72 and 78°F. The daily temperature spread is typically 1-1/2 degrees when the supply fan is on. During the cold weather the average return air temperature was 75°F; this average was starting to fall to approximately 71°F in the last two days of the monitoring period. See Figure 2.

For AC-5, trend data shows that, for the monitoring period, occupied space return air temperatures were typically between 73 and 76°F. The daily temperature spread is typically two degrees when the supply fan is on. During the cold weather the average return air temperature was 75°F; this average was approximately 70°F when the fan returned to its normal schedule.

Model:

- *Adjust the units' setback setpoints to match the temperatures above, as necessary.*

ECM 12: 82AHU_4-5_ph2 <Part 5>

An additional 31 spaces, mostly located in [Redacted] and the penthouses, also had setback control implemented. This measure is considered not applicable to [Redacted].

Model:

- *Assume implemented and run ECM as programmed.*

ECM 13: Economizerall_2-4-5_ph2 <Part 1>, and ECM 15: economizerall_1-3_ph2

All AC units AC-1 through AC-8 were to get economizer capability, enabling the units to bring in up to 100% outside air when the outside air temperature (OAT) is closer to the desired supply air temperature for cooling than the return air temperature. The Economizer High Limit was to be 65°F, and the Economizer Low Limit was to be 45°F. When the OAT is above the high limit, the system returns to minimum OA to avoid excessive cooling energy. When the OAT is below the low limit, the system returns to minimum OA to avoid having to heat outside air, and to avoid potentially freezing water coils.

ARCHITECTURAL ENERGY CORPORATION

The field investigation found the following conditions programmed for the eight AC units:

Unit	*Economizer control enabled?*	*High limit = 65?*	*Low limit = 45?*
AC-1	Yes	80	Yes
AC-2	Yes	80	Yes
AC-3	Yes	80	Yes
AC-4	Yes	80	Yes
AC-5	Yes	80	Yes
AC-6	Yes	80	40
AC-7	Yes	90	40
AC-8	No – AC-8 is 100% Outside Air		

Model:

- *For AC-1 through AC-7,*
  - *Run the ECM'S with economizers enabled, as programmed.*
  - *Adjust the units' high and low limit setpoints to match the temperatures above, as necessary.*
- *For AC-8,*
  - *Do not implement this ECM, as the unit is 100% outside air.*

ECM 13: Economizerall_2-4-5_ph2 <Part 2>

For AC-8, the Minimum OA ratio was to be changed to 0.0010 (essentially, unit was to be changed from a 100% Outside Air unit to a recirculating unit).

The field investigation found that AC-8 is still a 100% OA unit.

Model:

- *Do NOT implement this ECM.*

ECM 14: 83_AHU_1-2-3_ph2 <Part 1>

Units AC-1 and AC-2 were to be replaced with VAV units, or retrofit with VAV capability, and AC-3 was to receive a controls upgrade. The first ECM modeled as part of the replacement/repair of these units is "Static Pressure Control."

The field investigation found:

- AC-1 and AC-2 were changed to VAV systems, but AC-3 was not.
- VAV boxes were installed at the zones for AC-1 and AC-2 only.
- The static pressure setting for AC-1 is 1.2 in-WC.
- The static pressure setting for AC-2 is 3.5 in-WC.
- The static pressure setting for AC-3 was not determined.
- Static pressure reset was NOT implemented for either AC-1 or AC-2.

However, trend data for AC-1's static pressure shows that it does vary between 0.4 and 1.7 in-WC. However, there is not a clear-cut relationship between the static pressure and VFD speed. See Figure 3.

AC-2 is a dual-duct system. Trend data for AC-2's hot deck's static pressure shows that it did vary around a setpoint of 3.5 in-WC for the first 2-1/2 weeks of monitoring, and then was either at 3.5 or zero for the following week. The unit did not go off for the first 2-1/2 weeks; it was reported that the system ran continuously because of extended cold winter weather during that period.

Trend data for AC-2's cold deck's static pressure shows that it did vary widely (from 1.0 to 4.0 in-WC) during the 3-1/2 weeks; however, this is believed to be an indication that the duct pressure was not being controlled when the service of the heating duct was being called for.

We conclude that AC-1behaves as if it has static pressure control, and therefore this ECM will be modeled for this unit. However, the measure does not appear to be implemented for AC-2.

As with AC-4 and AC-5, the original model had some relatively high values inserted for supply fan power per CFM, which imply high static pressures. Although static pressure control is not implemented, converting the systems to VAV and setting the static pressures as determined from the field investigation still saves a significant amount of energy.

In the model, this ECM included AC-3. AC-3 is a constant volume unit and was not converted to VAV. Therefore, it was removed from this parametric run.

Model:

- *For AC-1,*
    - *Accept the new VAV system types*
    - *Assume static pressure control is implemented and run the ECM as programmed.*
    - *Set the maximum static pressure for AC-1 = 1.6 in-WC.*

- *For AC-2,*
    - *Accept the new VAV system types*
    - *Set the maximum static pressure = 3.5 in-WC*
    - *Do NOT implement static pressure reset.*

- *For AC-3 ,*
  - *Do NOT change the system type to VAV*
  - *Keep the static pressure settings as currently modeled*
  - *Do NOT implement Static pressure reset.*

ECM 14: 83_AHU_1-2-3_ph2 <Part 2>

Unit AC-3 was to be changed to a VAV System, and was to activate when any zone exceeds its cooling setpoint.

The field investigation found that AC-3 was not changed to a VAV system (as noted in part 1 of this ECM above).

Model:

Do NOT implement this ECM.

ECM 16: 82AHU-Sch_1-2-3_ph2 <Part 1>

AC units AC-1, AC-2 and AC-3 were supposed to get optimum start programming in the summer. Rather than starting the units at a fixed time of 4 AM, start-up could be delayed to as late as 6 AM if the control system decides comfort conditions would be met by the beginning of occupancy.

The field investigation found that none of these units were programmed for optimum start control. The fixed schedule for all three units is:

Monday through Wednesday:	On at 7:00 AM	Off at 9:30 PM.
Thursday through Saturday:	On at 7:00 AM	Off at 7:30 PM.
Sunday:	On at 11:30 AM	Off at 5:30 PM.

For AC-1, the trend data does not show regular start or stop times for any day of the week, due to unusual operation resulting from the cold weather. Therefore the fixed schedules provided above from the field survey are used in the model.

For AC-2, the trend data does show a regular schedule for the week or so that the system was not running continuously. The schedule is slightly different from that provided from the field survey.

Monday through Wednesday:	On at 5:30 AM	Off at 9:30 PM.
Thursday through Saturday:	On at 5:30 AM	Off at 7:00 PM.
Sunday:	On at 10:30 AM	Off at 5:30 PM.

This schedule is used in the model. As before, half-hour times are rounded to the whole hour, keeping the number of operating hours the same where possible.

Model:

- *For AC-1 and AC-3,*
    - *Adjust the Baseline units' operating schedules to match the fixed times above.*
    - *Do NOT implement this ECM.*

- *For AC-2,*
    - *Adjust the Baseline unit's operating schedule to match the fixed times given above for this unit.*
    - *Do NOT implement this ECM.*

ECM 16: 82AHU-Sch_1-2-3_ph2 <Part 2>

This control measure enables the units AC-1, AC-2 and AC-3 to come on at night if any zone goes out of its setback temperature range.

The field investigation found that all of the units do have this programming. After the cold-weather period, the trend data for AC-1 does show some night-time operation.

Model:

- *Run this ECM as programmed.*

ECM 16: 82AHU-Sch_1-2-3_ph2 <Part 3>

This control measure enables units AC-1, AC-2 and AC-3 to bring in outside air at night if needed for space pre-cooling before occupied hours (night flushing).

The field investigation found that all of these units do have this programming, but only for winter.

Model:

- *Enable this ECM only during the winter season for these units.*

ECM 16: 82AHU-Sch_1-2-3_ph2 <Part 4>

This control measure set back the heating space temperature setpoint and set up the cooling temperature setpoint during unoccupied hours for 113 zones. All of the zones are served by AC-1, AC-2 and AC-3.

In the model, the ECM included the following temperature setpoints:

- Setback Cool Sch = 76°F from 6 AM- 9 PM, 82°F from 9 PM – 6 AM.
- Setback Heat Sch – Summer = 70°F from 6 AM- 9 PM, 64°F from 9 PM – 6 AM.
- Setback Heat Sch – Winter = 70°F from 4 AM- 9 PM, 64°F from 9 PM – 4 AM.

The field investigation found that all of the units do have set-back programming, but that the setpoints are slightly different for heating:

- Setback Cool Sch = 76°F during occupied hours, 82°F unoccupied (same temperatures as above).
- Setback Heat Sch – Summer = 70°F occupied, 68°F unoccupied.
- Setback Heat Sch – Winter = 70°F occupied, 69°F unoccupied.

For AC-1, trend data shows that, for the monitoring period, occupied space return air temperatures were typically between 73 and 77°F, and at night the temperatures drifted between 70 and 80°F. The daily temperature spread is typically 1 – 2 degrees when the supply fan is on. During the cold weather the average return air temperature was 75°F; this average was starting to fall to approximately 70°F when the fan returned to its normal schedule.

For AC-2, trend data shows that, for the monitoring period, occupied space return air temperatures were typically between 73 and 76°F, and at night the temperatures drifted between 74 and 78°F. The daily temperature spread is typically 1 – 3 degrees when the supply fan is on. During the cold weather the average return air temperature was 75°F; this average was starting to fall to approximately 70°F when the fan returned to its normal schedule. See Figure 4.

Although the trend data showed temperatures somewhat higher than the reported winter heating setpoints, this was due to atypical operation during the extreme cold weather. Since about two days of "normal" operation was captured at the end of the monitoring period, the setback schedules reported from the field investigation are implemented in the model.

The occupied and unoccupied hours are slightly different from those provided in the model; see ECM 16, part 1.

Model:

Adjust the units' BL setback setpoints to match the temperatures above.

ECM 17: New – Enable Occupied-Unoccupied HVAC Systems Scheduling

ARCHITECTURAL ENERGY CORPORATION

Most of the fan systems originally operated continuously. The controls upgrades installed as part of the retrofit enabled systems to be scheduled off when the building is unoccupied, and this has been done. Although the new daily and weekly schedules were built into the model, the final step of activating the new schedules had not been performed in the parametric runs.

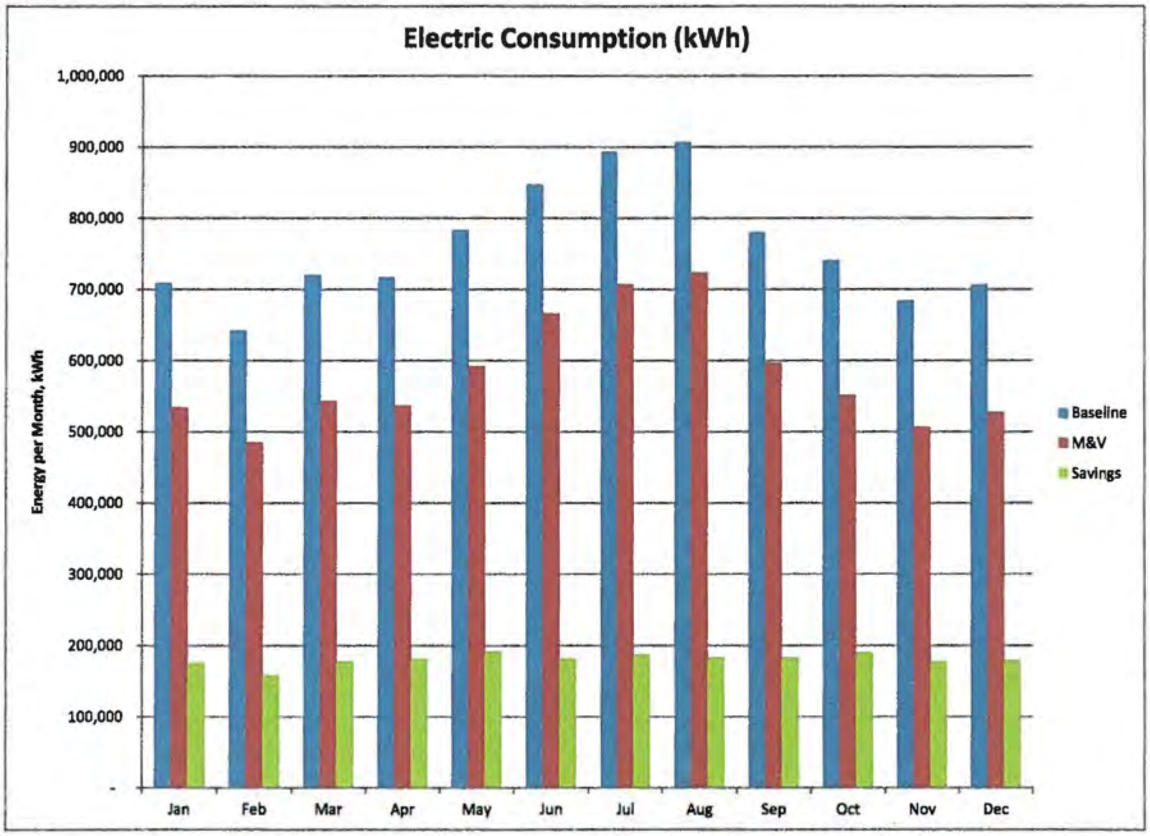
A new parametric analysis was added to activate the new schedules. This step increases the energy savings.

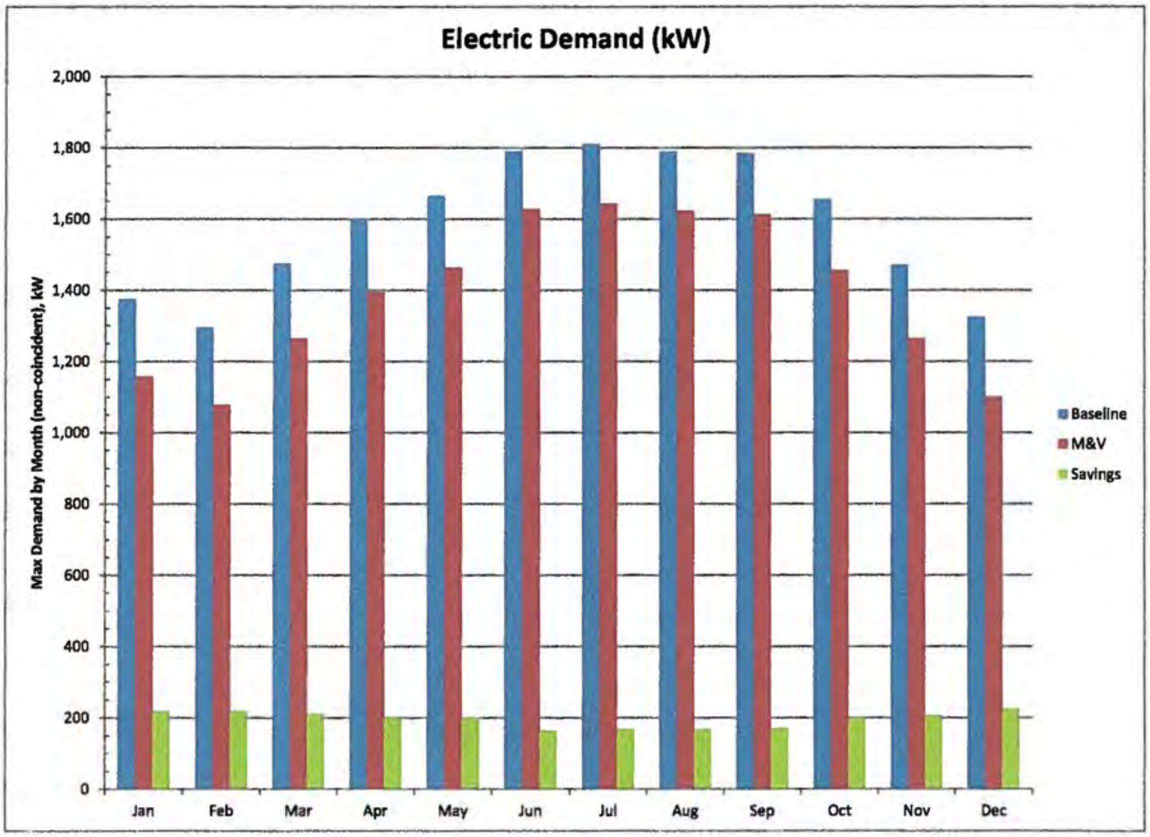
Results Summary

The modified energy analysis results in the energy and demand savings presented in the following table. For Ohio in 2013, the coincident peak demand hour is on July 17, for the hour between 4-5 PM. A comparison to the projected savings goals is also presented. Charts of the energy consumption and maximum demand each month follow the table.

Projected Savings Comparisons

	Annual Energy Savings (kWh)	Non-Coincident Peak Demand Savings (kW)	Coincident Peak Demand Savings (kW)
Duke Projections	2,420,314	307.2	247.5
M&V Projections	2,168,811	225.8	185.0
Realization Rates	90%	74%	75%%


Electric Consumption (kWh)
Energy per Month, kWh
1,000,000
900,000
800,000
700,000
600,000
500,000
400,000
300,000
200,000
100,000
-
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Baseline
M&V
Savings



ATTACHMENTS

1. Referenced Figures
2. Spot-Watt form
3. ECM Confirmation survey forms

ARCHITECTURAL ENERGY
CORPORATION

Referenced Figures

Figure 1:Static Pressure Data for AC-4

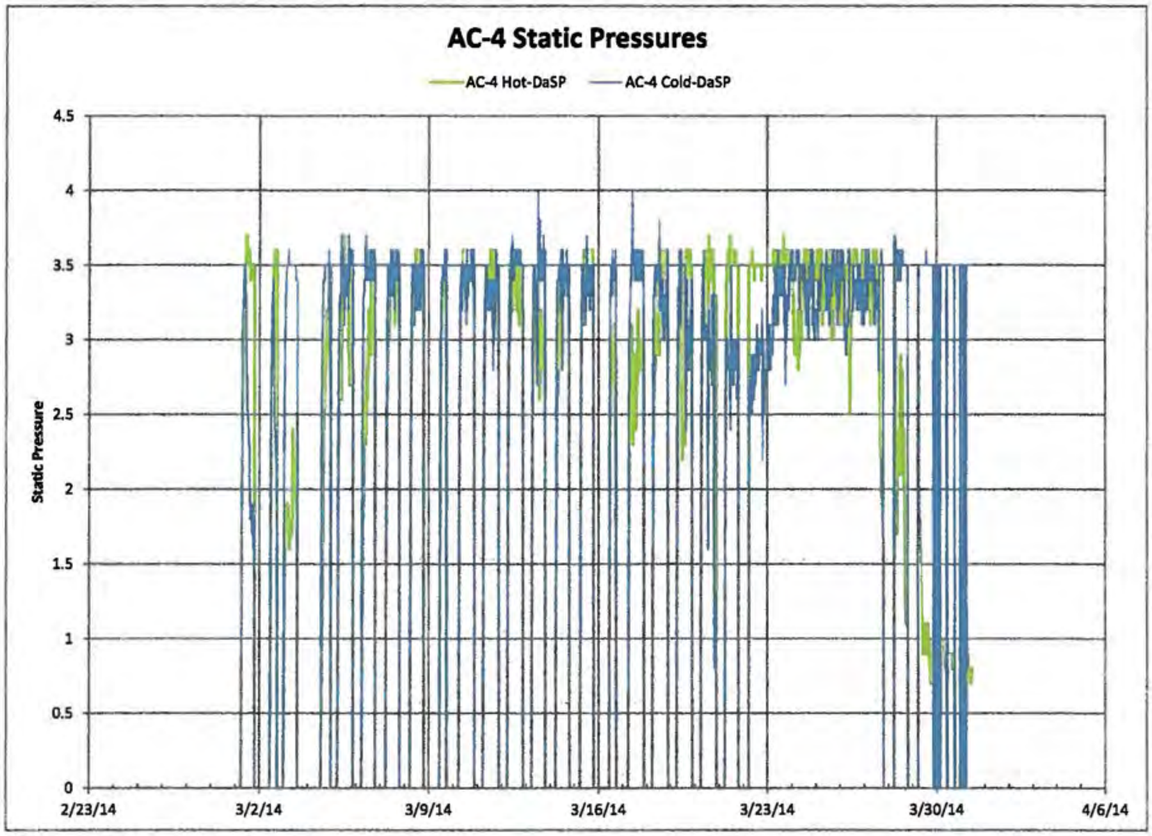


Figure 2:Return Air Temperatures for AC-4

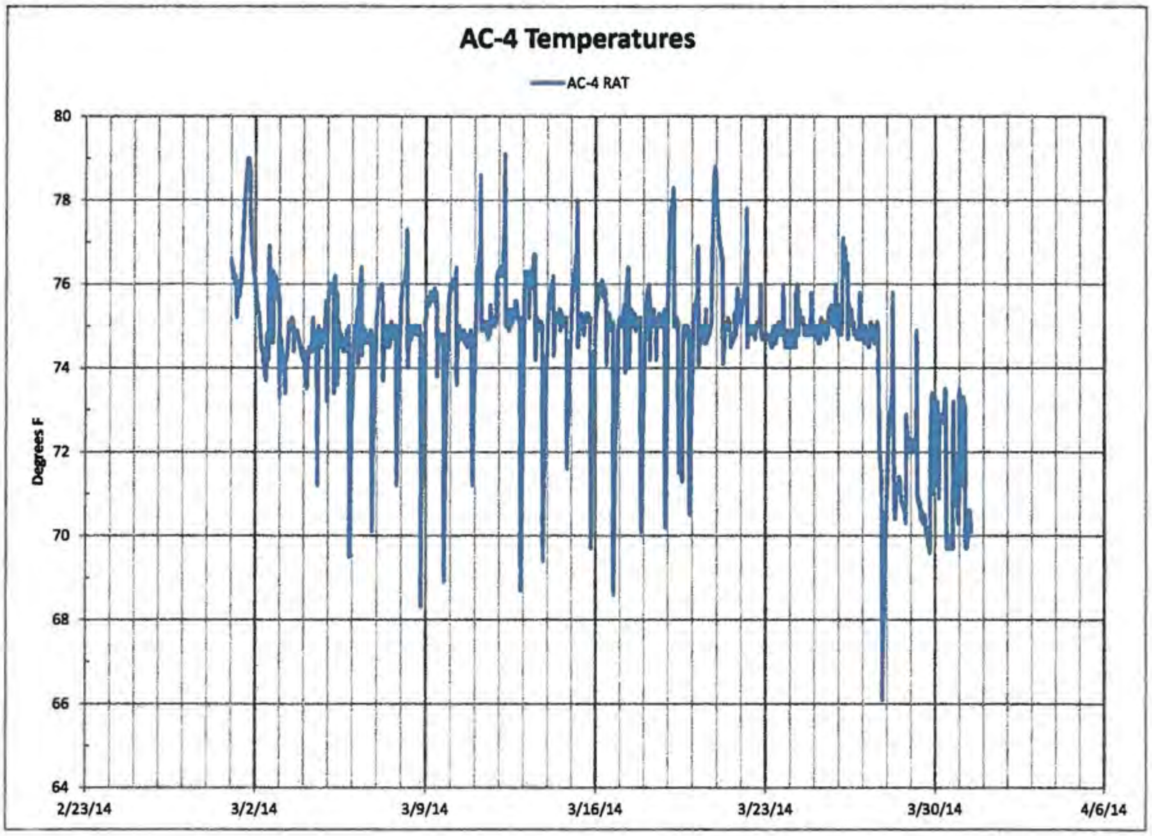


Figure 3:Static Pressure and VFD Speed Data for AC-1

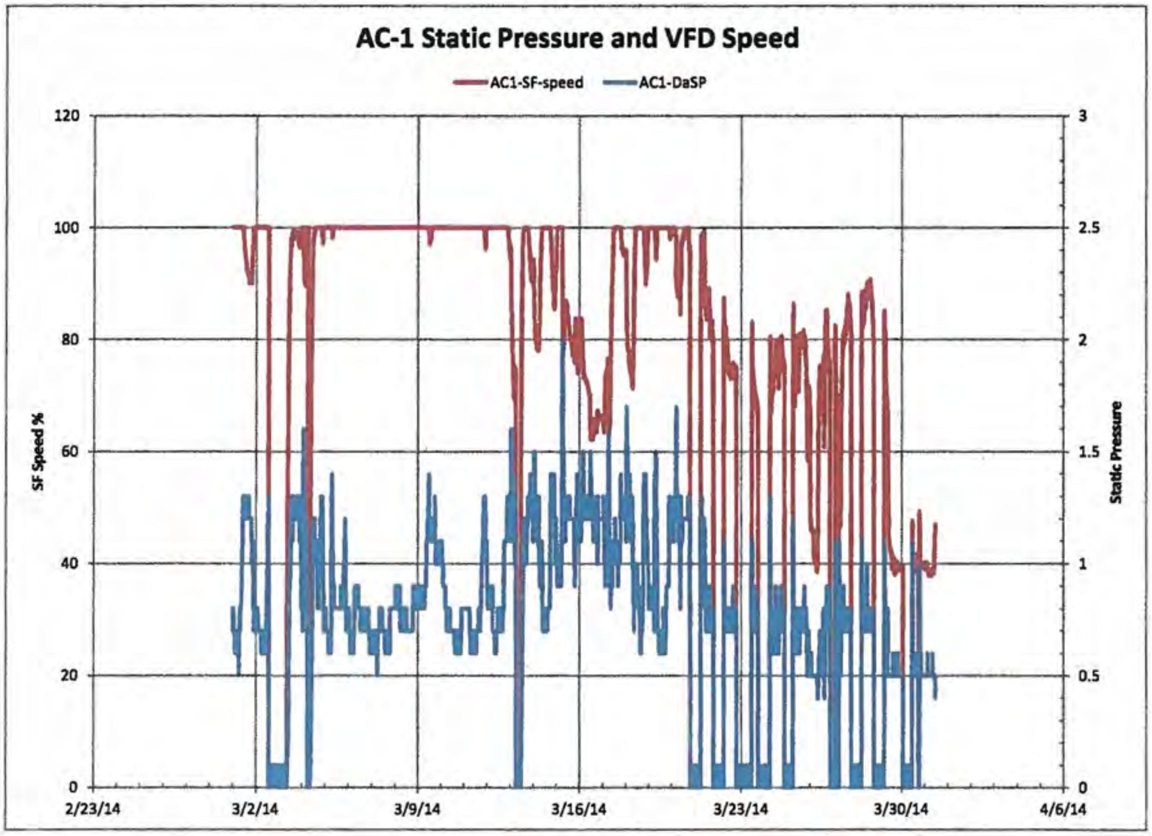
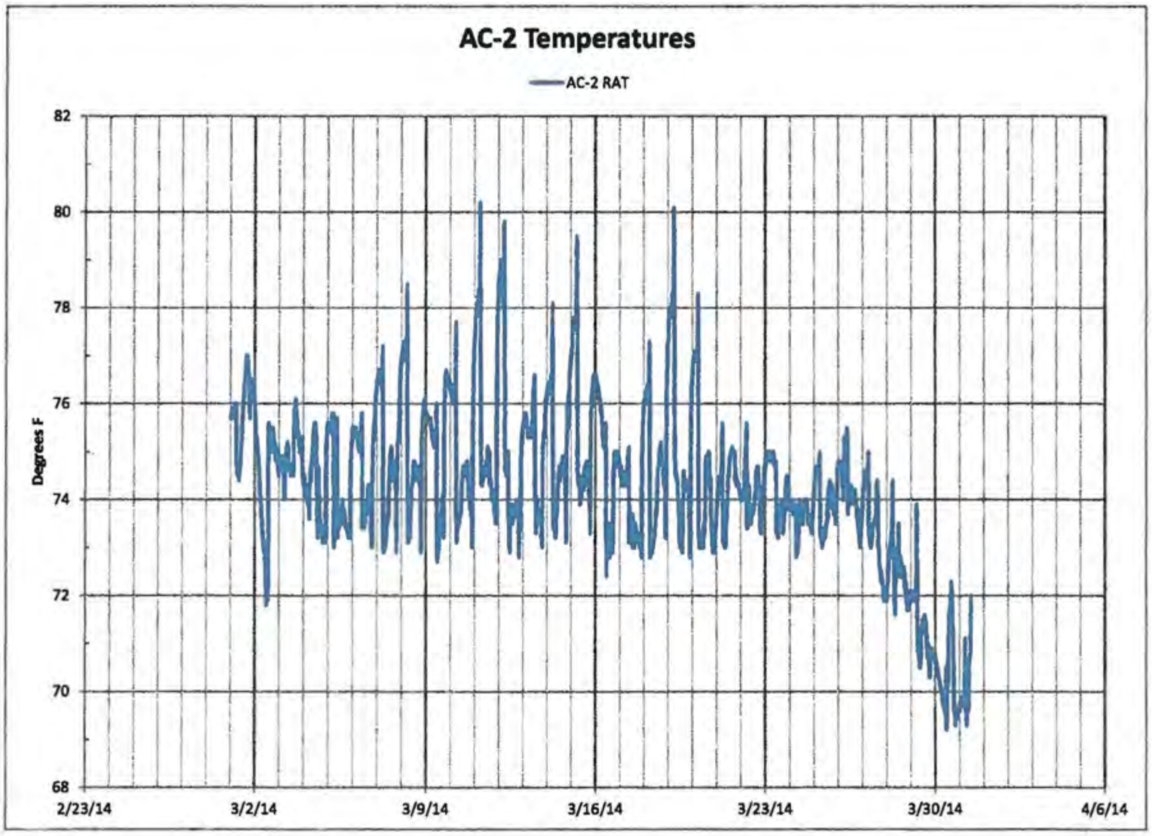


Figure 4: Return Air Temperatures for AC-2



ARCHITECTURAL ENERGY
C O R P O R A T I O N

REFERENCE (FROM SBA REPORT)

Table 17: [redacted] air handling units and fans

#	Location	Area/Zone	Configuration: CV	Dual Duct	MZ	VAV	IGV	VFD	Fan (Motor Power) (hp)	(kW)	Observed Current (A)	Notes
AC-1	C stack Mech Rm	Serves B level, northeast section, acquisitions and technical services (see B2Addition_H3.2)				●	●		50		59.00	Steam humidifier on inlet to cooling coil, before stm coil, no OA, IGV
REF-1	C stack Mech Rm	Return for AC-1							15		20.00	
AC-2	C stack Mech Rm	Serves levels 1, 2, 3, core		●					100		120.00	Dual-duct (hot deck valved off for summer), OA & RA dampers not coordinated, air leaking at discharge access door, stm humidifier, condensate leaking/pond
REF-2	C stack Mech Rm	Return for AC-2							20		24.00	
AC-3	C stack Mech Rm	Serves C and D stack							25		29.50	Return fan overpowering, cooling only, no OA
REF-3	C stack Mech Rm	Return for AC-3							8			
AC-4	Penthouse	Serves levels 1, 2, 3, perimeter		●					75		88.00	Dual-duct
REF-4	Penthouse	Return for AC-4							15		21.00	
AC-5	Penthouse	Serves levels 1, 2, 3, perimeter		●					100		120.00	Dual-duct, OA damper not sealing
REF-5	Penthouse	Return for AC-5							20		27.00	
AC-6	B level mezzanine, (catwalk in ceiling)	Serves B stack, catalog services, mezzanine				●		●	15		18.90	2 VFDs, ex fan not running, simultaneous h/c
EF-6	B level mezzanine ceiling above catalog	Return for AC-6						●	5			
AC-7	AC-7 mech room, (dock)	Hallway, break rooms						●	3			
AC-8	Facilities Office (dock), (ceiling)	Serves offices in dock area							1		2.30	
HV-1	Hv-1 mech room (dock)	Heat recovery unit							15		20.00	Multi-zone (5 zones), heat wheel not working
VF - 1 (EF - 1)	Hv-1 mech room (dock)	Return/exhaust for heat recovery unit							20		25.00	
VF-2	Oil Pump Mech Rm, (dock)								1		1.85	
GEF-1	Penthouse											
TEF-1	Penthouse											
EF -2	C stack Mech room exhaust fan								3		2.60	
EF-3	Penthouse exaust fan								4			
AC-9	Dock Booth (ceiling)											

Notes:

1) All units: 460V, 3 phase current

ARCHITECTURAL ENERGY CORPORATION

Spot-Watt form

DATE: 2/28/2014 **SITE NAME:** [redacted]

Location: Penthouse and Level C 11:15am

Logger#: Fluke Mult. meter

VFD inf. Channel#__	**Subject** AC-4		**Logger Reading**		**(Units)**		
	36.5 HZ 28.9A		61.5% SP		6.1 Vdc		
The CT is mounted on		**Amps**	**Meter Readings** Volts	**Watts**	**PF**	KVA	KVAR
O A CB#	**Phase A**	18.53	274.1	3.9 kw	.75	5.01	3.26
O B CB#	Phase B	16.01	272.7	3.18 kw	.74	4.30	2.89
O C CB#	Phase C	18.02	272.7	3.54 kw	.72	4.94	3.43

Logger#: Fluke Mult. meter 11:45am

VFD inf Channel#__	**Subject** AC-5		**Logger Reading**		**Temp**		
	43.5 Hz 54.6A		72% SP.		7.2 Vdc		
The CT is mounted on		**Amps**	**Meter Readings** Volts	**Watts**	**PF**	KVA	KVAR
O A CB#	**Phase A**	43.2	274.1	10.1 kw	.86	11.8	6.1
O B CB#	Phase B	37.0	272.8	8.3 kw	.81	10.2	6.0
O C CB#	Phase C	43.4	272.8	9.5 kw	.81	11.8	6.9

Logger#: Fluke Multi meter 12:15pm

VFD inf Channel#__	**Subject** AC-1		**Logger Reading**		**Temp**		
	33.5 Hz 19.0A		55.1% SP		5.5 Vdc		
The CT is mounted on		**Amps**	**Meter Readings** Volts	**Watts**	**PF**	KVA	KVAR
O A CB#	**Phase A**	9.5	274.9	1.87 kw	.75	2.12	1.71
O B CB#	Phase B	7.90	273.7	1.50 kw	.73	2.10	1.45
O C CB#	Phase C	8.9	273.9	1.75 kw	.70	2.57	1.79

Logger#: Fluke Multi meter 12:30pm

VFD inf Channel#__	**Subject** AC-2		**Logger Reading**		**Temp**		
	41.9 HZ 42.6A		69.5% SP		7.0 Vdc		
The CT is mounted on		**Amps**	**Meter Readings** Volts	**Watts**	**PF**	KVA	KVAR
O A CB#	**Phase A**	29.4	274.4	6.5 kw	.83	7.06	4.39
O B CB#	Phase B	25.6	274.0	5.6 kw	.87	7.00	4.30
O C CB#	Phase C	30.8	273.0	6.1 kw	.78	8.12	5.19

ARCHITECTURAL ENERGY CORPORATION

ECM Confirmation Data Forms

ECM Confirmation Data Forms

<table>
<tr><td>ECM# and Title</td><td>1 - Light_W_ph1n <Part 1></td></tr>
<tr><td>Description</td><td>In 265 spaces (Area 1), change Lighting LPD to 0.84 W/sqft</td></tr>
<tr><td>Info determined from Model</td><td>Many of these spaces are in [redacted] Most of [redacted] received this reduced LPD.</td></tr>
<tr><td>Action in Field</td><td>Spot-check 15 of these spaces for fixture type, fixture Watts, number of fixtures and area of room to determine actual W/sqft.
* Not including ballast
<table>
<tr><th>#</th><th>Space ID</th><th>Fixt. Type</th><th>* Fixt. W</th><th>No. of Fixts.</th><th>Room L</th><th>W</th><th>Area</th></tr>
<tr><td>1</td><td>3rd Floor bay</td><td>2 - 4' Fluor</td><td>50</td><td>33</td><td>32</td><td>48</td><td>1536</td></tr>
<tr><td>2</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>3</td><td>D Stack</td><td>1 - 4' Fluor</td><td>25</td><td>8</td><td></td><td></td><td></td></tr>
<tr><td>4</td><td>(manual switches</td><td>1 - 2' Fluor</td><td>17</td><td>1</td><td>32</td><td>4.5</td><td>144</td></tr>
<tr><td>5</td><td>on each stack row)</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>6</td><td>50% on</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>7</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>8</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>9</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>10</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>11</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>12</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>13</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>14</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>15</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
</table></td></tr>
<tr><td>Other Notes</td><td>Original LPD's are: 1.00 and 1.30 W/sqft.</td></tr>
<tr><td>For Analysis</td><td>From total fixture W and total A, determine average W/sqft to update model.</td></tr>
</table>

ARCHITECTURAL ENERGY
CORPORATION

ECM# and Title	1 - Light_W_ph1n <Part 2>
Description	In 17 spaces (Area 2), change Lighting LPD to 0.40 W/sqft
Info determined from Model	All of the spaces receiving this reduced LPD appear to be in the 1955 Building. No effect on [redacted].
Action in Field	*None.*
Other Notes	
For Analysis	*Assume implemented and run model as programmed.*

ECM# and Title	2 - Boiler_eff_ph1n
Description	Change Small Boiler capacity to 0.1000 Mbtu/hr Change Load Range 1 to Small Boiler Change Boiler Order to 1.000
Info determined from SBA Report	During the cooling season, one or more large steam boilers (4 million Btu/hr each) were run to provide reheat capability, primarily in [redacted]. Running the large boiler creates a tremendous heat input (cooling load) in [redacted] This ECM installed a small hot-water boiler (100,000 Btu/hr) in [redacted] to serve the summer reheat loads so that the large boilers may be shut off.
Action in Field	*Verify the small boiler was installed and is operable.* 3000 MBH New Boiler in operation *Verify the large boilers are now shut down entirely during the summer.* old boiler on standby - emergency only *Collect nameplate data for the small boiler.* Aerco Benchmark 3000 Max. Water Temp 210°F Model BMK 3000 160 PSIG Ser No. 6-12-0996 3000 MBH input 2012 2900 MBH output
Other Notes	Small boiler is supposed to be 90% efficient.
For Analysis	*If implemented, update the small boiler capacity and efficiency as necessary.*

ARCHITECTURAL ENERGY
CORPORATION

ECM# and Title	3 - AHU_Sch_ph1n
Description	For [redacted] AHU's and three ACU's (total of 15 units), change the AHU controls: Fan control – Change Cooling Fan Sched to OptStartFanSch Change Night Cycle Control to Cycle on Any OA – change Min Air Sched to MinFlowSch In 128 spaces, set Cool Temp Sched to Setback Cool Sch, ... and set Heat Temp Sched to a Setback Heat Sch.
Info determined from Model	No effect on [redacted].
Action in Field	*None.*
Other Notes	
For Analysis	*Assume implemented and run model as programmed.*

ECM# and Title	4 - OccSensor_ph1n
Description	In 17 spaces, change Lighting Sched 2 to OccLight In 29 spaces, change Lighting Sched 1 to OccLight
Info determined from SBA Report	The 17 spaces are in [redacted] - N/A to this application. Of the 29 spaces, some are restrooms in all three buildings and the rest are in [redacted]. Only four are in [redacted]
Action in Field	*Spot-check the four restrooms in [redacted], Levels B, 1 and 2, to verify they have Occupancy Sensors installed.* *Restroom Location* — *OS installed (Yes/No)* B 35 — Yes 3 — Yes 2 — Yes 1 — Yes
Other Notes	Maintenance / Janitor who cleans restrooms verified the all where off at night
For Analysis	*Update the [redacted] model if required if OS's are not installed. Assume the Bldg [redacted] occupancy sensors are installed.*

ARCHITECTURAL ENERGY
CORPORATION

ECM# and Title	5 - heatLeak_ph1n
Description	In EVERY space, change Internal Energy Source Input Power to 0.0000 Btu/h.
Info determined from SBA Report	The existing boiler plant was in poor condition: A large, uninsulated condensate tank, leaking boiler steam traps, and an uninsulated boiler exhaust vent all emitted a great deal of heat into the boiler room, the surrounding walls and spaces. The 1952 and 1982 buildings use steam for their air handlers and humidification purposes. The 1995 building has hot water converters for both domestic hot water and re-heat at the VAV boxes. Since all the spaces use the steam plant, the heat leaks were charged to all spaces equally. Spot-checking, the baseline IESIP was = 150 Btu/h in every space. If the issues have been repaired, this heat gain to the spaces can be eliminated.
Action in Field	*Verify the following actions were accomplished:* · *Insulated steam condensate receiver tank* No · *Vented condensate discharge outside of building* No · *Surveyed and repaired steam traps.* Yes
Other Notes	
For Analysis	*If all of the above actions were accomplished, run ECM as is.*

ECM# and Title	6 - Economizerall_ph1n
Description	For all 9 [redacted] AHU's, Change OA control to OA Temperature, Change Drybulb High Limit to 65°F, Change Economizer Low Limit to 45°F.
Info determined from Model	No effect on [redacted]
Action in Field	*None.*
Other Notes	Drybulb High Limit was 56°F.
For Analysis	*Assume implemented and run model as programmed.*

ARCHITECTURAL ENERGY
CORPORATION

ECM# and Title	7 - StaticReset_ph1n
Description	For all 9 [redacted] AHU's, Change Cooling Fan EIR to 0.5SPfanCurve
Info determined from Model	No effect on [redacted].
Action in Field	*None.*
Other Notes	Fan EIR was 1.5SPfanCurve
For Analysis	*Assume implemented and run model as programmed.*

ECM# and Title	8 - 95AHU_VFD_ph1n
Description	For 4 [redacted] AHU's, Change HVAC System type to VAV, Change Cooling Fan Control to Fan EIR FPLR, Change Cooling Fan EIR to 0.5SPfanCurve, Change Cool Control to Warmest, Change Hot Deck Max Lvg Temp to 95°F, Change Heat Control to Coldest.
Info determined from Model	No effect on [redacted].
Action in Field	*None.*
Other Notes	Systems were SZRH.
For Analysis	*Assume implemented and run model as programmed.*

ECM# and Title	9 - Chiller_eff_ph1n
Description	For both chillers (1a and 1b), Change EIR to 0.1950
Action in Field	*Verify manufacturer name & model number of chillers (loc'd in [redacted]?)* No new chillers - 2 existing chillers *Other pertinent nameplate data:*
Other Notes	kW/ton = EIR * 12000/3413 = EIR * 3.516, so kW/ton = 0.686 Baseline chiller EIR was = 0.199, or kW/ton = 0.700
For Analysis	*Look up kW/ton from mfr's model #. Adjust model inputs as required.*

19

ARCHITECTURAL ENERGY
CORPORATION

ECM# and Title	10 - Tower_reset_ph1n
Description	For condenser water loop, Change Cool Setpoint Control to Load Reset
Action in Field	*Verify CW loop temp setpoints, and that the loop temperature is allowed to float.* Set point - 74° Loop temperature not allowed to float Tried to float but too many problems
Other Notes	Baseline CW loop temp was fixed.
For Analysis	*Update ECM with new setpoints if necessary.*

--- End of Phase 1 ---

--- Begin PHASE 2 ---

ECM# and Title	11 – 83_AHU_4-5_ph2
Description	For 83-AC-4, AC-5 and AC-8, Change Cooling Fan Control to Fan EIR FPLR Change Cooling Fan EIR to 0.5SPfanCurve
Info determined from SBA Report	Units AC-4 and AC-5 were to be replaced with VAV units, or retrofit with VAV capability. The first ECM modeled as part of the replacement/repair of these units is "Static pressure control."
Action in Field	*FOR:* *AC-4* / *AC-5* / *AC-8* *Determine if these units were replaced or retrofitted.* Y / Y / Y BAS only *Verify these units are now VAV systems.* Y / Y / Not VAV *Verify that VAV boxes were installed at the zones.* Y / Y / Not VAV *Verify the static pressure settings of the AC units.* 3.5 in WC / 3.5 in WC / ___ *Verify whether the SP setting resets, and if so, what the controlling variable is (most-demanding VAV box, time of day, etc.).* No Reset / No Reset / ___
Other Notes	Baseline Fan EIR was 1.5SPfanCurve. Implication is that the baseline SP is 1.5 in-WG, and that the SP is now allowed to reset as low as 0.5 in-WG.

ARCHITECTURAL ENERGY CORPORATION

ECM# and Title	12 – 82AHU_4-5_ph2 <Part 1>
Description	For 83-AC-4, AC-5, AC-6, AC-7 and AC-8, Change Cooling Fan Sched to OptStartFanSch
Action in Field	*Determine what the beginning and end dates are for "Summer."* Not at this time *Start:* ______ *End:* ______
	Confirm the AC units have optimum start programming in the summer (i.e., the BAS decides when to start them up in the mornings in order to reach comfort conditions by a certain later time).
	Confirm the fan on-off schedules for the above AC units.
Other Notes	OptStartFanSch – Summer = 1 from 6 AM- 9 PM, 0 from 9 PM – 4 AM, and -999 from 4 AM – 6 AM. OptStartFanSch – Winter = 1 from 4 AM- 9 PM, 0 from 9 PM – 4 AM.
For Analysis	*Incorporate field schedule differences, if any, in the model.*

Optimum start programming:

	AC-4	AC-5	AC-6	AC-7	AC-8
Yes/No	No	No	No	No	No

Fan on-off schedules:

	M	Tu	W	Th	F	Sat	Sun
AC-4 Fan ON:	7:00 am	7:00 am	7:00 am	7:00 am	7:00 am	7:00 am	11:30 am
AC-4 Fan OFF:	9:30 pm	9:30 pm	9:30 pm	7:00 pm	7:00 pm	7:00 pm	6:30 pm
AC-5 Fan ON:			Same as above				
AC-5 Fan OFF:							
AC-6 Fan ON:			Same as above				
AC-6 Fan OFF:							
AC-7 Fan ON:			Same as above				
AC-7 Fan OFF:							
AC-8 Fan ON:			Same as above				
AC-8 Fan OFF:							

ECM# and Title	12 – 82AHU_4-5_ph2 <Part 2>
Description	For 83-AC-4, AC-5, AC-6, AC-7 and AC-8, Change Night Cycle Control to Cycle on Any
Action in Field	*Confirm the units are programmed to come on at night if any zone goes out of its setback temperature range.*

	AC-4	AC-5	AC-6	AC-7	AC-8
Yes/No	Y	Y	Y	Y	Y

All units programed to operate during unoccupied times during winter when outside temp @ 62° or higher and summer temp less than 82°

23

ARCHITECTURAL ENERGY
CORPORATION

ECM# and Title	12 – 82AHU_4-5_ph2 <Part 3>
Description	For 83-AC-4, AC-5, AC-6, AC-7 and AC-8, OA – change Min Air Sched to MinFlowSch
Action in Field	*Confirm the units have economizers and that they are operable (not fixed or locked in one position either by BAS programming or physically).* Yes/No — AC-4: Y; AC-5: Y; AC-6: lock-temp; AC-7: Y; AC-8: 100% O.A.
	Confirm these units are allowed to bring in OA at night (i.e., between 6 AM and 9 AM; verify these times) if needed for space pre-cooling before occupied hours (night flushing). Yes/No — AC-4: Y; AC-5: Y; AC-6: Y; AC-7: Y; AC-8: Y
Other Notes	MinFlowSch = -999 from 6 AM- 9 PM, 0.0010 (enables economizer) from 9 PM – 6 AM.
For Analysis	*Update ECM with new economizer operation, if necessary.*

ARCHITECTURAL ENERGY
CORPORATION

ECM# and Title	12 – 82AHU_4-5_ph2 <Part 4>
Description	For 124 spaces, Change Cool Temp Sched to Setback Cool Sch Change Heat Temp Sched to Setback Heat Sch
Info determined from Model	The 124 zones are located in Bldg 82 and are mostly served by AC-4 and AC-5; eleven zones are served by AC-6 through AC-9.
Other Notes	Setback Cool Sch = 76°F from 6 AM- 9 PM, 82°F from 9 PM – 6 AM. Setback Heat Sch – Summer = 70°F from 6 AM- 9 PM, 64°F from 9 PM – 6 AM, Setback Heat Sch – Winter = 70°F from 4 AM- 9 PM, 64°F from 9 PM – 4 AM.
Action in Field	*In the BAS programming, spot-check **15** zones in Bldg 82 served by AC-4 thru AC-9 to verify they have the "Setback" heating and cooling temperature setpoint schedules listed above.* *Insert "Y" or "N" in the blanks. For any "N" answer, fill in a table like the one below with the actual temperature schedule. Use extra sheets if necessary.*
For Analysis	*Update ECM with new space temperature schedules, if necessary.*

#	Space ID	Cooling Sched	Heat Sched-Summer	Heat Sched-Winter
1	AC-4 → AC-9	76/82	70/68	70/69
2	See page 29 for occupied / unoccupied times			
3				
4	At the present time all units on 24/7			
5	due to extreme winter weather conditions			
6				
7				
8				
9				
10				
11				
12				
13				
14				
15				

Space ID																								
Hour:	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Cooling Schedule																								
Heat Sch – Summer																								
Heat Sch – Winter																								

ARCHITECTURAL ENERGY
CORPORATION

ECM# and Title	12 – 82AHU_4-5_ph2 <Part 5>
Description	For 31 spaces, Change Heat Temp Sched to Setback Heat Sch
Info determined from Model	The 31 zones are mostly located in Bldg 95 and the penthouses, although some are mechanical spaces scattered throughout the three buildings. Consider N/A to Bldg 82.
Action in Field	*None.*
For Analysis	*Assume implemented and run model as programmed.*

ECM# and Title	13 – Economizerall_2-4-5_ph2 <Part 1> For 83-AC-2, AC-4, AC-5, AC-6, AC-7 and AC-8, ...
And ...	15 – economizerall_1-3_ph2 For 83-AC-1 and AC-3, ...
Description	Change OA control to OA Temperature, Change Drybulb Economizer High Limit to 65°F, Change Economizer Low Limit to 45°F.
Action in Field	*Confirm these AC units have the economizer high- and low-limit setpoints listed above. In the blanks, insert "Y" if yes, or the actual temperature setting if No.* *High limit = 65?* / *Low limit = 45?* AC-1: 80 / Y AC-2: 80 / Y AC-3: 80 / Y AC-4: 80 / Y AC-5: 80 / Y AC-6: 80 / 40 AC-7: 90 / 40 AC-8: No Economizer / 100% O.A.
For Analysis	*Update ECM with new economizer controls, if necessary.*

ECM# and Title	13 – Economizerall_2-4-5_ph2 <Part 2>
Description	For 83-AC-8, change Minimum OA to 0.0010 ratio
Action in Field	*None – already confirmed whether unit AC-8 has an enabled economizer in ECM 12 part 3.*
For Analysis	*If the above unit has an economizer, run ECM as is.*

ARCHITECTURAL ENERGY CORPORATION

ECM# and Title	14 – 83_AHU_1-2-3_ph2 <Part 1>
Description	For 83-AC-1, AC-2 and AC-3, Change Cooling Fan Control to Fan EIR FPLR Change Cooling Fan EIR to 0.5SPfanCurve
Info determined from SBA Report	Units AC-1 and AC-2 were to be replaced with VAV units, or retrofit with VAV capability, and AC-3 was to receive a controls upgrade. The first ECM modeled as part of the replacement/repair of these units is "Static pressure control."
Action in Field	*FOR:* *AC-1* *AC-2* *AC-3* *Determine if these units were replaced or retrofitted.* Y Y N *Verify these units are now VAV systems.* Y Y N *Verify that VAV boxes were installed at the zones.* Y Y ____ *Verify the static pressure settings of the AC units.* 1.2 in wc 3.5 in wc NA *Verify whether the SP setting resets, and if so, what the controlling variable is (most-demanding VAV box, time of day, etc.).* No Reset No Reset ____
Other Notes	Baseline Fan EIR was 1.5SPfanCurve. Implication is that the baseline SP is 1.5 in-WG, and that the SP is now allowed to reset as low as 0.5 in-WG.
For Analysis	*Update ECM with new information if necessary.*

ECM# and Title	14 – 83_AHU_1-2-3_ph2 <Part 2>
Description	For 83-AC-3, Change HVAC System type to VAV, Change Cool Control to Warmest
Action in Field	*Already confirmed whether the above AC unit is a VAV system in ECM 14 part 1.* *Confirm the unit will activate when any zone exceeds its cooling setpoint.* Not changed
For Analysis	*Update ECM with new information if necessary.*

ARCHITECTURAL ENERGY
C O R P O R A T I O N

ECM# and Title	16 – 82AHU-Sch_1-2-3_ph2 <Part 1>
Description	For 83-AC-1, AC-2 and AC-3, Change Cooling Fan Sched to OptStartFanSch
Action in Field	*Determine what the beginning and end dates are for "Summer."* Not at this time *Start:* ________ *End:* ________ *Confirm the AC units have optimum start programming in the summer (i.e., the BAS decides when to start them up in the mornings in order to reach comfort conditions by a certain later time).* Yes/No: AC-1 No, AC-2 No, AC-3 No *Confirm the fan on-off schedules for the above AC units.* AC-1 Fan ON: M 7:00am, Tu 7:00am, W 7:00am, Th 7:00am, F 7:00am, Sat 7:00am, Sun 10:30am AC-1 Fan OFF: M 9:30pm, Tu 9:30pm, W 9:30pm, Th 7:00pm, F 7:00pm, Sat 7:00pm, Sun 5:30pm AC-2 Fan ON / OFF: Same as above AC-3 Fan ON / OFF: Same as above
Other Notes	OptStartFanSch – Summer = 1 from 6 AM- 9 PM, 0 from 9 PM – 4 AM, and -999 from 4 AM – 6 AM. OptStartFanSch – Winter = 1 from 4 AM- 9 PM, 0 from 9 PM – 4 AM.
For Analysis	*Incorporate field schedule differences, if any, in the model.*

ECM# and Title	16 – 82AHU-Sch_1-2-3_ph2 <Part 2>
Description	For 83-AC-1, AC-2 and AC-3, Change Night Cycle Control to Cycle on Any
Action in Field	*Confirm the units are programmed to come on at night if any zone goes out of its setback temperature range.* Yes/No: AC-1 Y, AC-2 Y, AC-3 Y
For Analysis	*Update ECM with new night operating schedule, if necessary.*

All units programed to operate during unoccupied times during Winter outside temp 62° or higher and Summer temp less than 82°

ARCHITECTURAL ENERGY
CORPORATION

ECM# and Title	16 – 82AHU-Sch_1-2-3_ph2 <Part 3>
Description	For 83- AC-1, AC-2 and AC-3, OA – change Min Air Sched to MinFlowSch
Action in Field	*Confirm the units have economizers and that they are operable (not fixed or locked in one position either by BAS programming or physically).* AC-1 AC-2 AC-3 Yes/No Y Y N
	Confirm these units are allowed to bring in OA at night (i.e., between 6 AM and 9 AM; verify these times) if needed for space pre-cooling before occupied hours (night flushing). AC-1 AC-2 AC-3 Yes/No winter only — — Y
Other Notes	MinFlowSch = -999 from 6 AM- 9 PM, 0.0010 (enables economizer) from 9 PM – 6 AM.
For Analysis	*Update ECM with new economizer operation, if necessary.*

ARCHITECTURAL ENERGY CORPORATION

ECM# and Title	16 – 82AHU-Sch_1-2-3_ph2 <Part 4>
Description	For 113 spaces, Change Cool Temp Sched to Setback Cool Sch Change Heat Temp Sched to Setback Heat Sch
Info determined from Model	The 113 zones are all located in Bldg 82 and are served by AC-1, AC-2 and AC-3.
Other Notes	Setback Cool Sch = 76°F from 6 AM- 9 PM, 82°F from 9 PM – 6 AM. Setback Heat Sch – Summer = 70°F from 6 AM- 9 PM, 64°F from 9 PM – 6 AM, Setback Heat Sch – Winter = 70°F from 4 AM- 9 PM, 64°F from 9 PM – 4 AM.
Action in Field	*In the BAS programming, spot-check **15** zones in Bldg 82 served by AC-1 thru AC-3 to verify they have the "Setback" heating and cooling temperature setpoint schedules listed above.* *Insert "Y" or "N" in the blanks. For any "N" answer, fill in a table like the one below with the actual temperature schedule. Use extra sheets if necessary.*
For Analysis	*Update ECM with new space temperature schedules, if necessary.*

#	Space ID	Cooling Sched	Heat Sched-Summer	Heat Sched-Winter
1	AC-1	76/82	70/68	70/69
2	AC-2	Same as above		
3	AC-3	Same as above		
4	See page 29	for occupied/unoccupied times		
5				
6				
7				
8				
9				
10				
11				
12				
13				
14				
15				

Space ID																								
Hour:	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Cooling Schedule																								
Heat Sch – Summer																								

[Redacted]
Custom DDC Upgrade
M&V Report

Prepared for
Duke Energy Ohio

March 2015, Version 1.0

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

Introduction

This report addresses measurement and verification (M&V) activities for the [Redacted] custom program application. The application covers upgrading the existing Direct Digital Control (DDC) system at [Redacted] facility in Fairfield, Ohio. The installation was completed in December 2013, so this report is for post-retrofit M&V activities only. The measure includes:

ECM-1 – New Energy Management System Installation

The [Redacted] building consists of two nine-story office towers. Tower 1 is 388,100 square feet and Tower 2 is 418,860 square feet. The original controls for Tower #1 (south) consisted of pneumatically controlled VAV boxes with no energy management features or feedback to the central HVAC AHU's or central plant. The original controls for Tower #2 (north) consisted of digitally controlled VAV boxes, again with few energy management features or feedback to the central HVAC AHU's or central plant. These controllers are no longer manufactured and a memory upgrade was not available.

The original controls on the main AHU's were an early version of ALC DDC installed approximately 15 years ago. These controllers required a memory upgrade to implement the latest energy savings software.

In the past, the air handlers ran continuously and the central plant was always available for both heating and cooling needs.

Based on the age of the controllers and the energy savings potential, an upgrade to a new Automated Logic DDC for the terminal units and a memory upgrade for the AHU controllers with the ALC energy suite programming was recommended.

The control measures that were to be implemented for this ECM were:

- Time-of-day control scheduling for each zone
- Local override button for timed override operation
- Demand run for AHU's and central plant equipment based on actual space occupancy
- Outside air reset of heating & cooling setpoints
- Outside air lockout of heating and cooling modes
- VAV demand reset of discharge air setpoint
- VAV demand reset of static setpoint
- Central setpoint control to prevent simultaneous heating/cooling
- Night setback
- Optimum start/stop
- Demand limiting (programming included, electric pulse required)
- CO2 Ventilation Control.

Goals and Objectives

Pre-and post-retrofit energy models of the building were previously created by the applicant's EMS vendor. These models were obtained from Duke Energy, and were used to determine the energy and power reduction achieved by the control system upgrade. Any modifications necessary as a result of the M&V investigation were incorporated.

The projected savings goals identified in the application were:

	APPLICATION		DUKE PROJECTIONS		
Facility	Proposed Annual kWh savings	Proposed Summer Peak kW savings	Proposed Annual kWh savings	Proposed Summer Peak (Non-coincident) kW savings	Proposed Coincident Peak kW savings
[REDACTED]	2,970,180	405	2,192,110	290.9	37.9

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

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

Project Contacts

Noresco Contact	Doug Dougherty	ddougherty@noresco.com Office: 303-459-7416
Duke Energy M&V Admin.	Frankie Diersing	513-287-4096
Customer Contact	[Redacted]	[Redacted]

Site Locations/ECM's

Site	Address	Sq. Footage	ECMs Implemented
[Redacted]	[Redacted]	Tower 1: 388,100 Tower 2: 418,860	1

Data Products and Project Output

- Energy consumption pre- and post-retrofit for the entire facility

- Annual energy savings
- Peak demand savings
- Coincident peak demand savings

M&V Option

IPMVP Option D

M&V Implementation Schedule

This survey and data collection was for post-retrofit only.

- Obtained copies of the existing computer energy models (pre- and post-upgrade).
- Compared the pre- and post-upgrade models to determine what changes were made in the post-upgrade model to improve the building's energy performance.
- Ran the existing energy models to verify the reported energy and demand savings are obtained.
- Conducted an interview with the building contact. Determined if all the model changes were accomplished by the DDC upgrade.
- Verified that the equipment on the new control system is operational.
- Established trend logs to monitor operation of equipment and outdoor air conditions, as detailed in the "Field Data Points" section below.
- Trended EMS data as needed for a minimum of two weeks.
- Revised the building energy models as required based on the findings of the M&V investigation.
- Ran the revised energy models to obtain updated energy and demand savings values.
- Compared the updated savings values to the original reported values and calculated the energy and demand savings realization rates.

Field Data Points

Prior to Site Visit

- Obtained copies of the existing computer energy models (pre- and post-upgrade).
- Compared the pre- and post-upgrade models to determine what changes were made in the post-upgrade model to improve the building's energy performance.

Survey data

- Interviewed the building contact to get an overview of:
    - Building layout
    - Space usages
    - Normal occupancy schedules
    - Number of holidays observed per year
    - Mechanical systems types
- Pre-retrofit and post-retrofit sequences of operation for all controlled equipment.
- Capacities of affected HVAC equipment.
- Through interview with the building contact and examination of the DDC programming, verified whether the following DDC capabilities were installed with the upgrade and are operational:

1. Time-of-day control scheduling for zones
2. Local override button(s) for timed override operation
3. Demand run for AHU's and central plant equipment based on actual space occupancy
4. Outside air reset of heating & cooling setpoints
5. Outside air lockout of heating and cooling modes
6. VAV demand reset of discharge air [temperature] setpoint
7. VAV demand reset of static pressure setpoint
8. Central setpoint control
9. Night setback
10. Optimum start/stop
11. Demand limiting (programming included, electric pulse required)
12. CO2 Ventilation Control

Time series data on controlled equipment

Established trend logs in the DDC to monitor the points defined below.

General points:

Trended the following:

- Outdoor air temperature and relative humidity.

For central plant equipment:

Trended the following points

- Chilled Water supply temperature setpoint
- Hot Water supply temperature setpoint.

For a random sample of the AHUs:

Trended the following points

- Supply air temperature setpoint
- Supply air static pressure setpoint
- Supply fan VFD speed

Set up trend logs for five-minute readings and allowed operation for a minimum of two weeks. Collected data during normal operating hours.

Measurement	Sensor	Accuracy	Notes
VFD Speed	DDC Trends	Unknown	
Temperature / RH	DDC Trends	Unknown	

Data Analysis

Ran the existing energy models to verify the reported energy and demand savings are obtained.

Determined from the field survey data and customer contact interview if all of the control measures for the post-upgrade model have been implemented.

Revised the post-retrofit model with any changes required. See the Results section for specifics.

Ran the revised post-retrofit model to determine annual post-retrofit energy consumption.

Compared the revised post-retrofit model output with the pre-retrofit output to determine the annual energy savings.

Verification and Quality Control

- Visually inspected trend data for consistent operation. Sorted by day type and removed invalid data. Looked for data out of range and data combinations that were physically impossible.

Recording and Data Exchange Format

1. Applicable field notes
2. Building Automation System data files and data logger files
3. Excel spreadsheets
4. eQUEST energy model data files

Results

Field investigation and trending through the facility's DDC lead to the following findings regarding the DDC capabilities.

The various figures referred to in the text below are consolidated at the end of the report.

- Time-of-day control scheduling for each zone

A total of seventeen air handling units (AHUs) serve the two towers. Six units were trended through the site's DDC system. The eQuest models as received implemented operating schedules that shut the HVAC systems down at night. Trend data indicated that the AHUs still run continuously and reach a minimum speed at night, but they do not shut off. Examples are shown in Figures 1 – 4. The schedule was modified to reflect continuous fan operation.

- Local override button for timed override operation

The local override buttons are installed, but no obvious overrides are apparent in the trend data. The models were left as is.

- Demand run for AHU's and central plant equipment based on actual space occupancy

This appears to have been implemented in the ECM model by allowing VAV boxes to close all the way down during unoccupied periods. The eQuest models as received model this control scheme by eliminating VAV box minimum flow setpoints. Allowing VAV boxes to close rather than maintain a higher minimum airflow should allow the AHU fans to run at lower speeds, move less air and reduce chiller and boiler loads as a consequence.

This ECM is responsible for the large majority of the energy savings in the building. Although the fans never entirely shut off, as described earlier, the models were left as is with VAV terminals being allowed to close during unoccupied times.

- Outside air reset of heating & cooling setpoints

It was reported during the customer interview that the chilled water supply temperature does not reset. A data center in the building uses plant chilled water year-round and the CHW supply temperature is fixed at 44°F. The eQuest models as received did implement an outside air reset control for chilled water. The model was edited to remove this control scheme and to use a constant water temperature.

- Outside air lockout of heating and cooling modes

Cooling is never locked out because the CHW system serves a data center that requires continuous cooling, as previously mentioned. The CHWS setpoint was a constant 43°F during the monitoring period. However, a water-side economizer has been installed to provide free cooling when the outside air temperature (OAT) is less than 45°F. Thus although cooling is always available, the chillers are not needed below this OAT.

The heating equipment is supposed to be shut off when the OAT is warmer than 55°F. However, although the OAT reached 101°F during the monitoring period, the HWS setpoint was always a constant 165°F, but this may just be the setpoint value in the EMS.

The eQuest model as received did not explicitly include lockout controls; the equipment merely responds to the imposed loads. The models were left as is.

- VAV demand reset of discharge air setpoint

The models as received allowed discharge air temperatures (DAT) in the range of 55°F – 63°F. The M&V effort determined that this reset control is only partially implemented. In general, the DAT setpoints are constant at 55°F, except for AHU-205, for which the DAT setpoint is constant at 57°F with one 25-minute period at 55°F, and for AC-1, for which the DAT setpoint is set at 55°F each night at midnight, then up to 58°F during the day at a time that varies from 9:00 AM to 8:45 PM. The temperature stays up until the next midnight, and the temperature is 58°F all day Saturday.

As a compromise to partially implement DAT setpoint reset in the ECM model, the model was edited to simulate a more restricted reset range of 55°F-57°F.

- VAV demand reset of static setpoint

Static pressure reset is reportedly implemented, but according to the trend data the static setpoints do not reset. The constant setpoints are set between 1.0 and 1.5 in-WC. However, the ECM model as received did not include static pressure reset. Therefore the models were left as is.

- Central setpoint control to prevent simultaneous heating and cooling

This ECM is somewhat unclear; we would need more specifics about what the controls do that prevents simultaneous heating and cooling. The ECM above, "Demand run for AHU's and central plant equipment based on actual space occupancy," does help to prevent simultaneous heating and cooling by reducing the amount of reheat energy required at the VAV boxes. The models were left as is.

- Night setback

M&V determined that this has been implemented. The AHU fans slow down abruptly at 4:30 or 5:00 every afternoon (except AHU-202), which is an expected response to the cooling setpoints being raised throughout the building at that time. Examples are shown in Figures 5 – 8.

The models as received did model this ECM and were left as is.

- Optimum start/stop

This measure appears to be implemented. The data shows that each fan starts up about the same time each day, but the times range from 3:20 to 5:15 AM from one fan to the next. The speeds ramp up slowly, but generally all the fans reach full speed by 5 to 6 AM. The staggered start time and slowly-building speeds indicate that the controls have decided how to optimally achieve occupied conditions at the desired time. On Sundays the fans are at minimum speed all day (N/A to AHU-202). See Figures 5 – 8.

The models were left as is for this feature.

- Demand limiting (programming included, electric pulse required)

This feature is reportedly implemented; however, the models do not predict the buildings ever reach the kW levels at which the demand limiting would be in effect. The lowest level of demand limiting is 2500 kW; if the demand reaches this value the heating setpoint is lowered by 1.5 F and the cooling setpoint is raised by the same amount. At 2700 kW, the setback/setup increases to 2.5 F, and at 2800 kW it increases to 3.5 F. With this measure in place for the late August to mid-September 2014 billing period, the peak demand was reportedly reduced for the North and South towers plus the garage from 3145 kW in 2013 to 2870 kW.

The eQuest models as received do not model this ECM, and the peak demand reached in the simulations is 904 kW for the baseline model and 808 kW for the ECM model. These values are not high enough to trigger a demand response.

Other loads external to the building models are evidently included in the demand limits. A note in the application document states, "The eQuest modeling does not account for the automatic peak demand reduction ECM, which will allow the owner to program the desired kW peak and the BAS will load shed to prevent exceeding the setpoint." The differences between the application's claimed savings and the provided models' savings are 331 kW in demand savings and 777,950 kWh in energy savings. No documentation was provided to explain how these savings increases were developed.

Since the models do not account for demand limiting, no changes were required.

- CO2 Ventilation Control.

When CO2 monitoring allows the OA intake flow to be reduced below the design minimum, then energy savings can be achieved, but that does not appear to be the case in this building.

Duct-mounted CO2 sensors are installed in the return air ducts on each floor. The allowable CO2 concentrations in the return air are limited to 800 ppm. If the concentrations go above this value, more outside air is brought in through the AHUs to restore indoor air quality. However, the facility is not presently using CO2 monitoring to reduce outside air below design values. As such, this is not an energy saving measure for this building, it only improves IAQ.

The eQuest models as received do not model this control, and were left as is.

Results

Rerunning the models with the changes described above lead to the following results.

Table 1: Annual Energy and Demand Savings - Includes eQuest Model Updates plus Demand Limiting Savings

Facility: [Redacted]

	Annual Energy (kWh)	Non-Coincident Peak Demand (kW)	Coincident Summer Peak Demand (kW)
Application, including Demand Limiting Savings			
Pre-Retrofit	15,000,000	4,125	n/a
Post-Retrofit	12,029,820	3,720	n/a
Savings	2,970,180	405	n/a
Application's eQuest model			
Pre-Retrofit	3,042,800	900	n/a
Post-Retrofit	850,570	826	n/a
Savings	2,192,230	75	n/a
M&V			
Pre-Retrofit	3,044,111	904.2	565.4
Post-Retrofit	1,479,562	808.4	352.5
Savings	1,564,549	95.8	212.9
Results			
Duke Projections	2,192,110	290.9	37.9
Realization Rates	71%	33%	562%

For plots of the electric demand on the coincident and non-coincident peak days, see Figure 9 and Figure 10.

As previously noted, the main M&V findings that result in the low energy realization rate are:

- The eQuest models as received allowed the HVAC systems to shut down at night; data indicates that the AHUs still run continuously and reach a minimum speed at night, but they do not shut off.
- The chilled water supply temperature was supposed to reset to a warmer temperature when the outside air is cold, but it does not reset. A data center in the building uses plant chilled water year-round and the CHW supply temperature is fixed at 44°F.
- The models allowed discharge air temperatures (DAT) for cooling to reset in the range of 55°F – 63°F. In general, with a few exceptions, the DAT setpoints are constant at 55°F. The ECM model was edited to simulate a more restricted reset range of 55°F-57°F.

For the non-coincident peak demand, the M&V model actually predicts slightly higher savings than the application model did. However, the application presented demand savings that included those achieved with demand limiting, which were determined outside of the eQUEST model. The Duke projected non-coincident peak demand savings may include the demand limiting savings (or a portion of them), and so the realization rate with respect to the M&V results is low.

For the coincident peak demand, the M&V model savings are higher than the Duke projection by a factor of five.

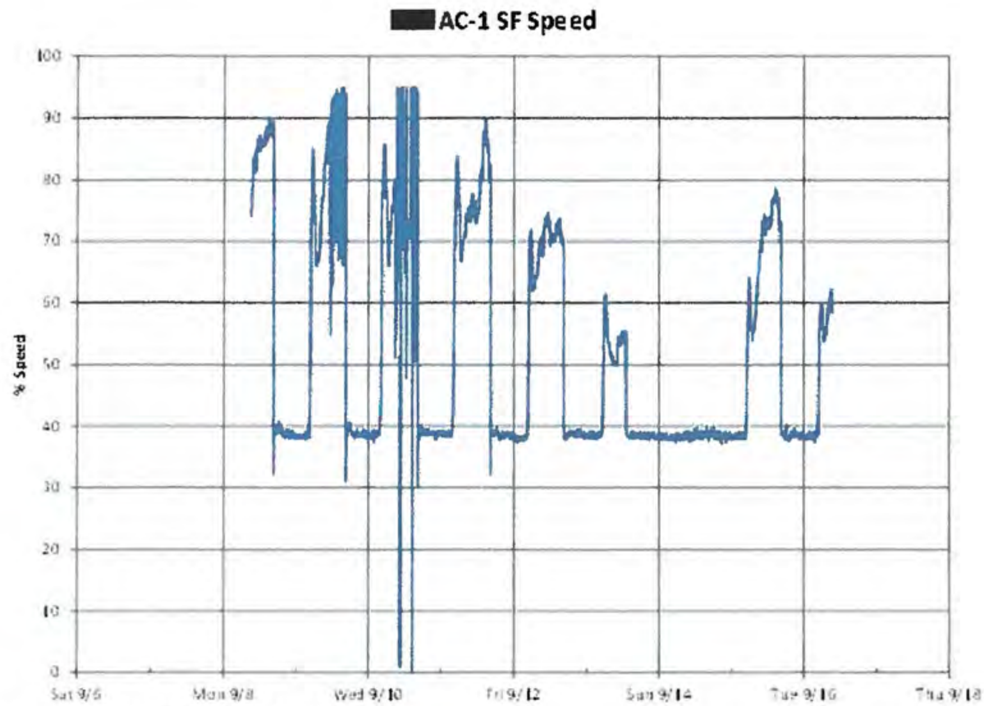


Figure 1: VFD Speed – AC-1.

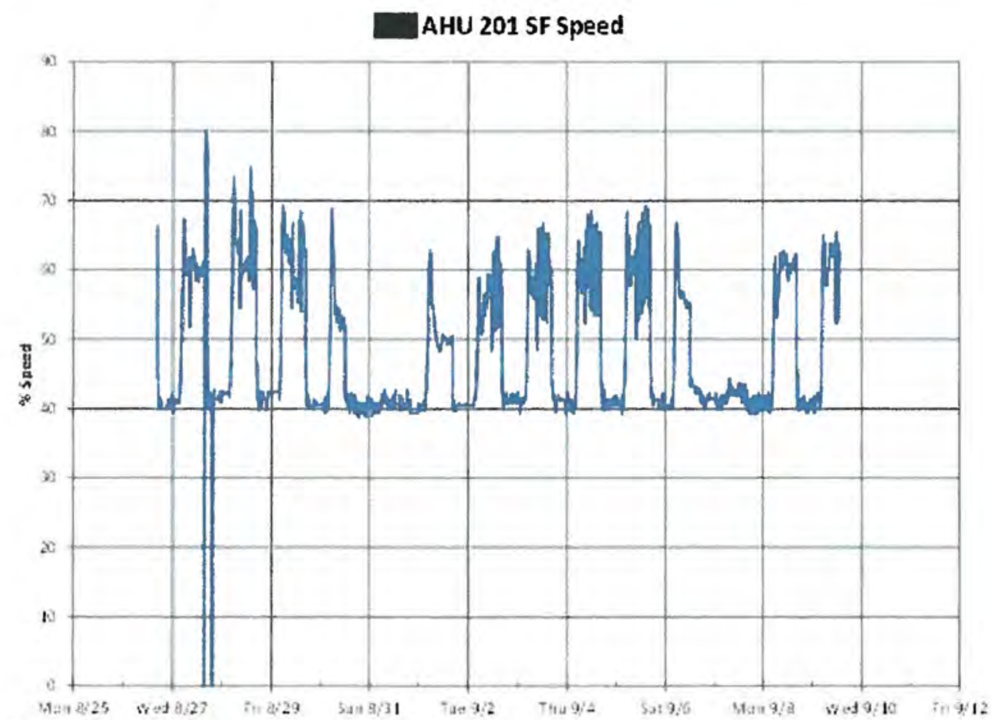


Figure 2: VFD Speed – AHU-201.

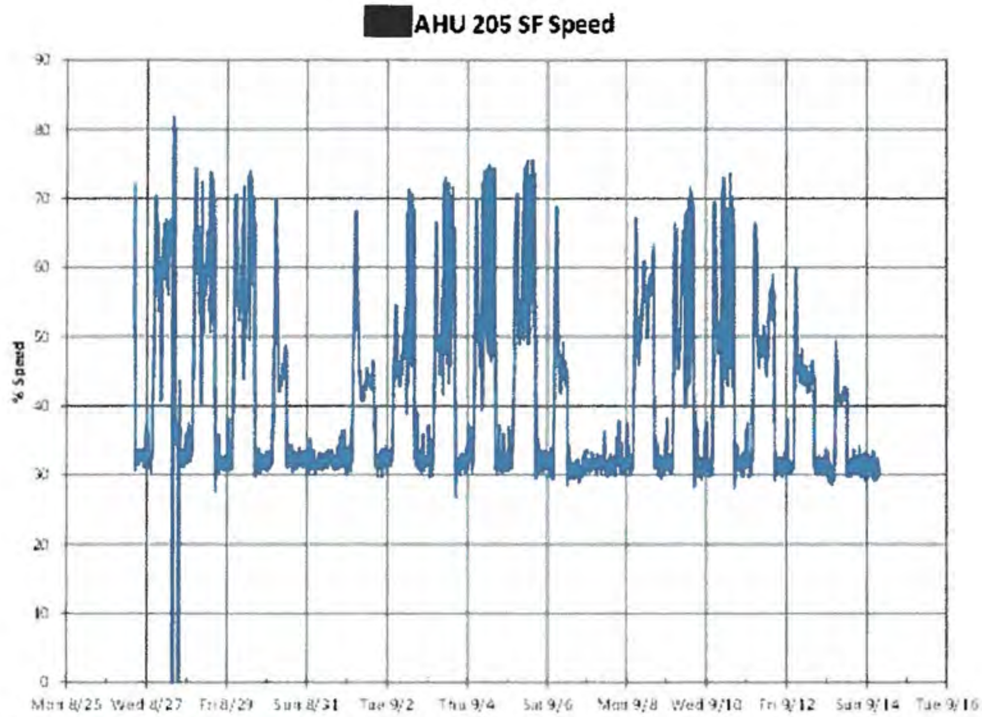


Figure 3: VFD Speed – A HU-205.

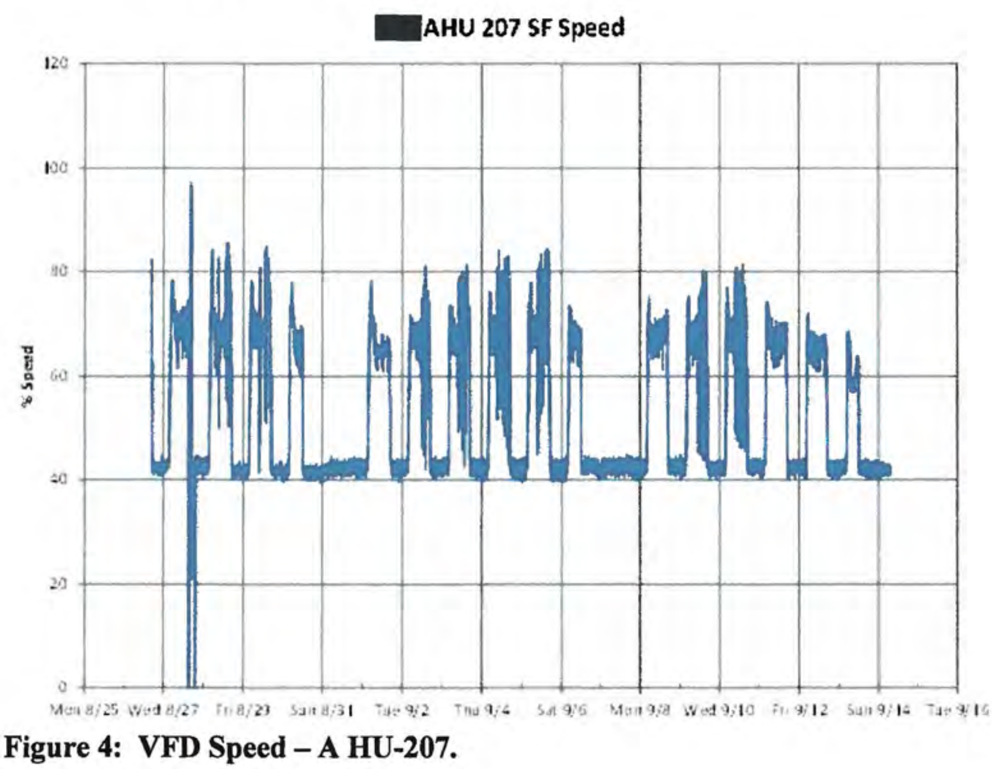


Figure 4: VFD Speed – A HU-207.

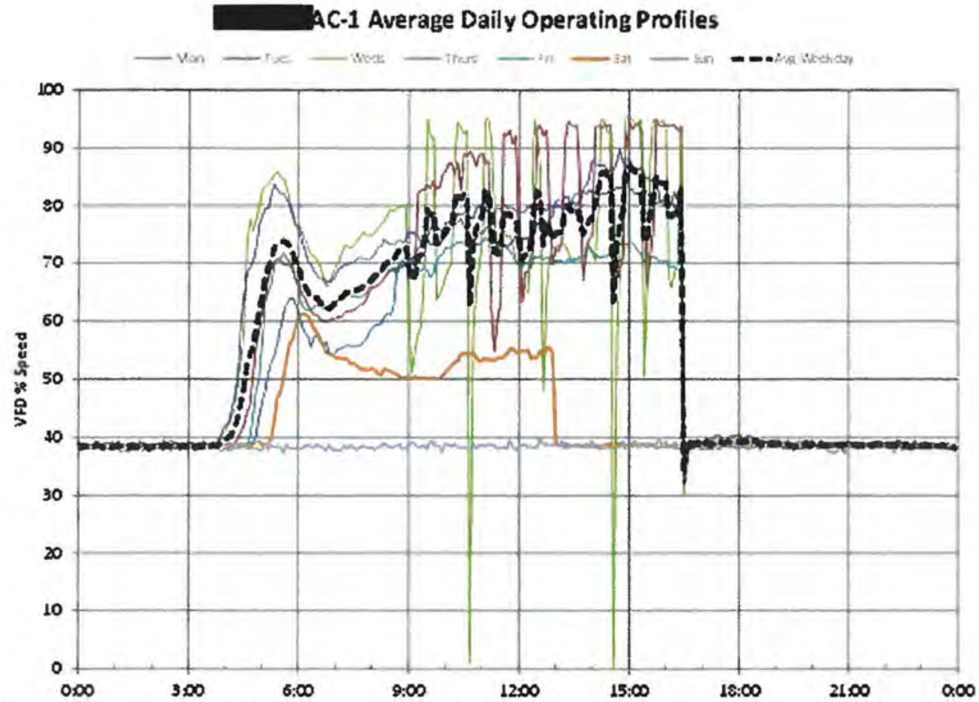


Figure 5: Average Daily Profiles – AC-1.

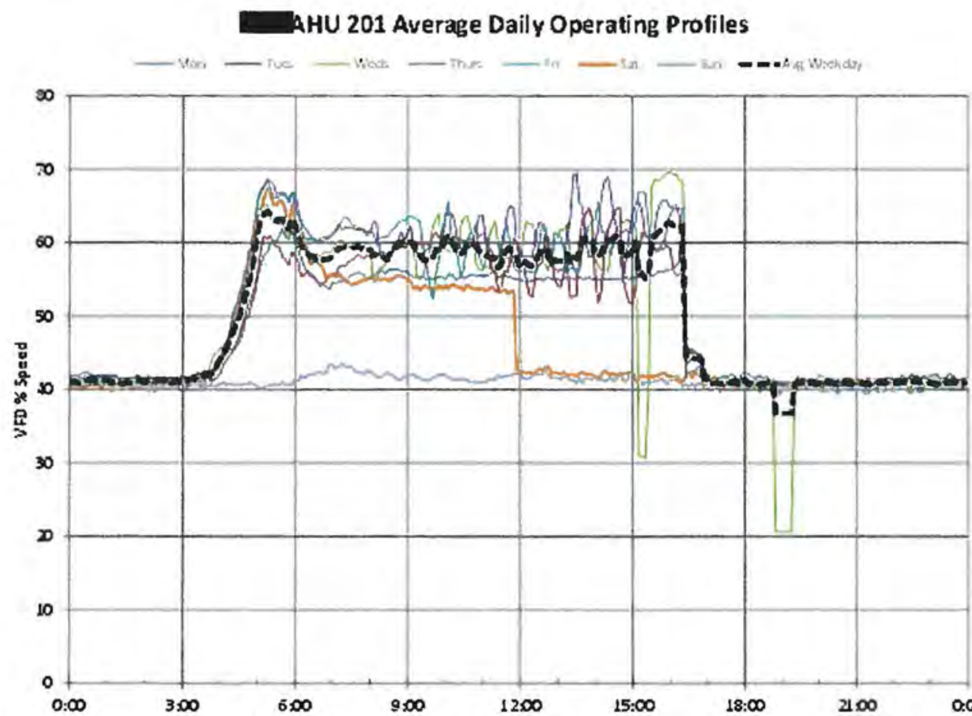


Figure 6: Average Daily Profiles – AHU-201.

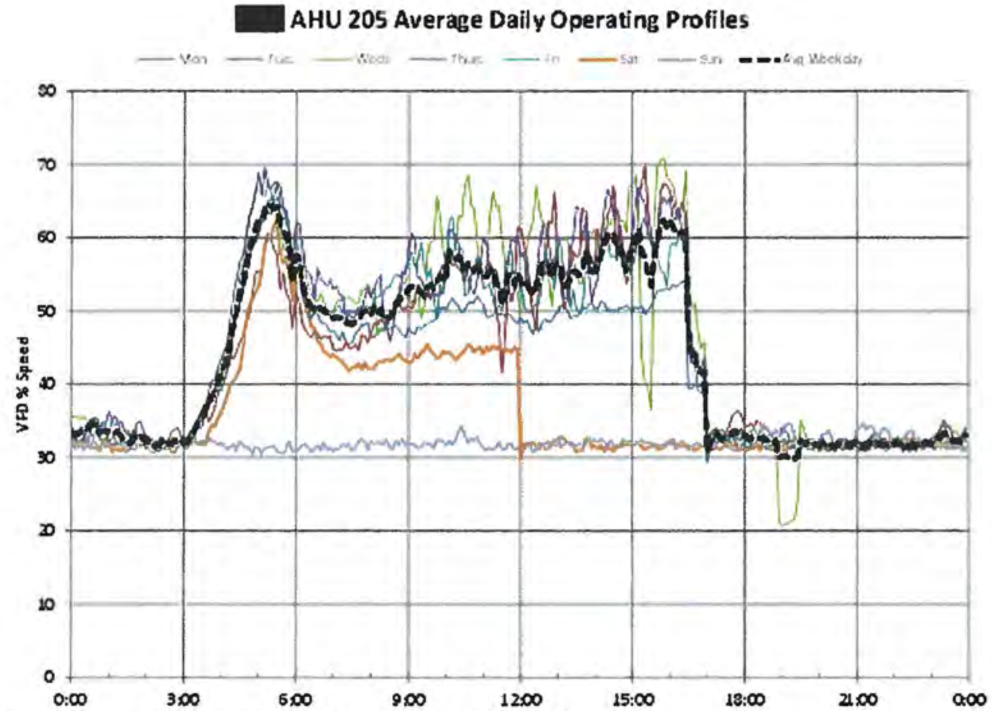


Figure 7: Average Daily Profiles – AHU-205.

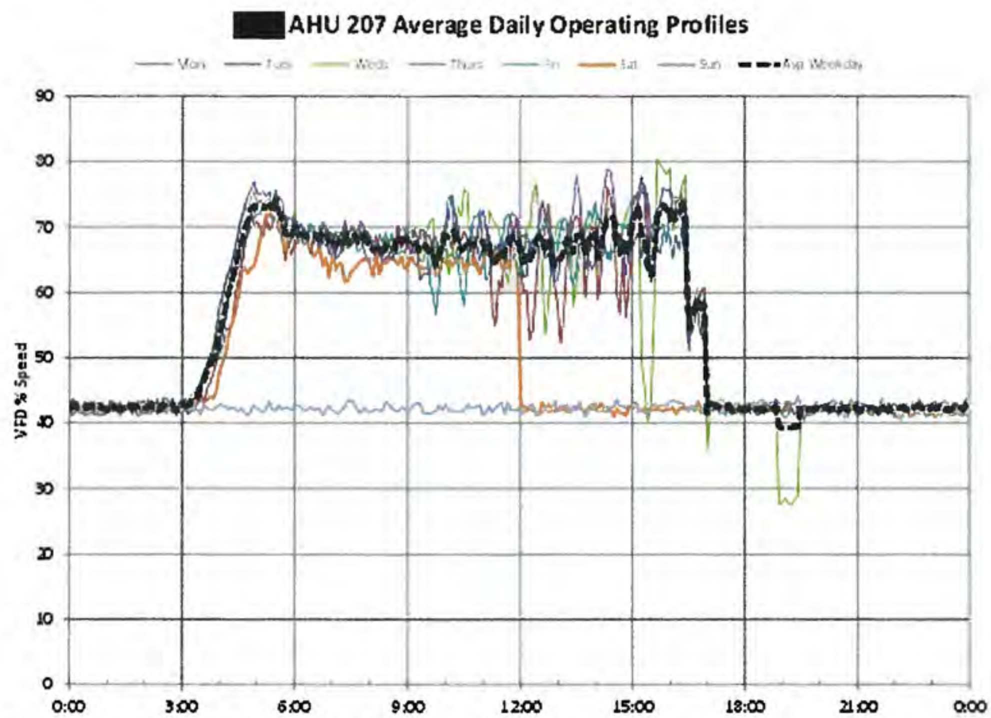


Figure 8: Average Daily Profiles – AHU-207.

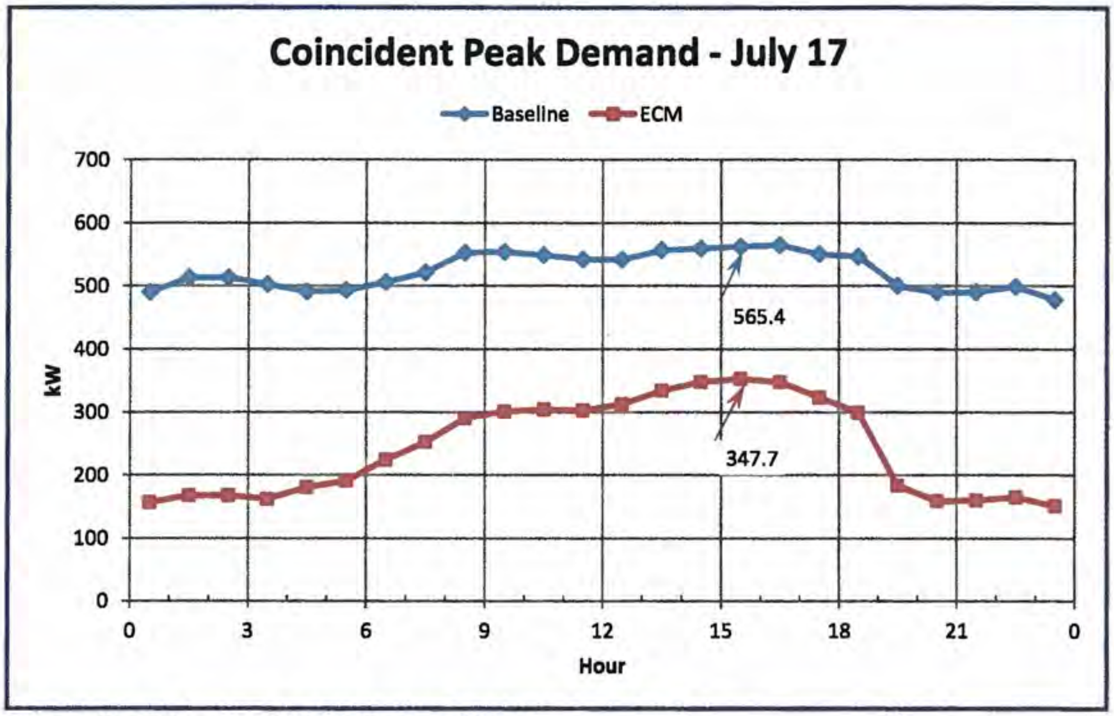


Figure 9: Coincident Peak Demand Day.

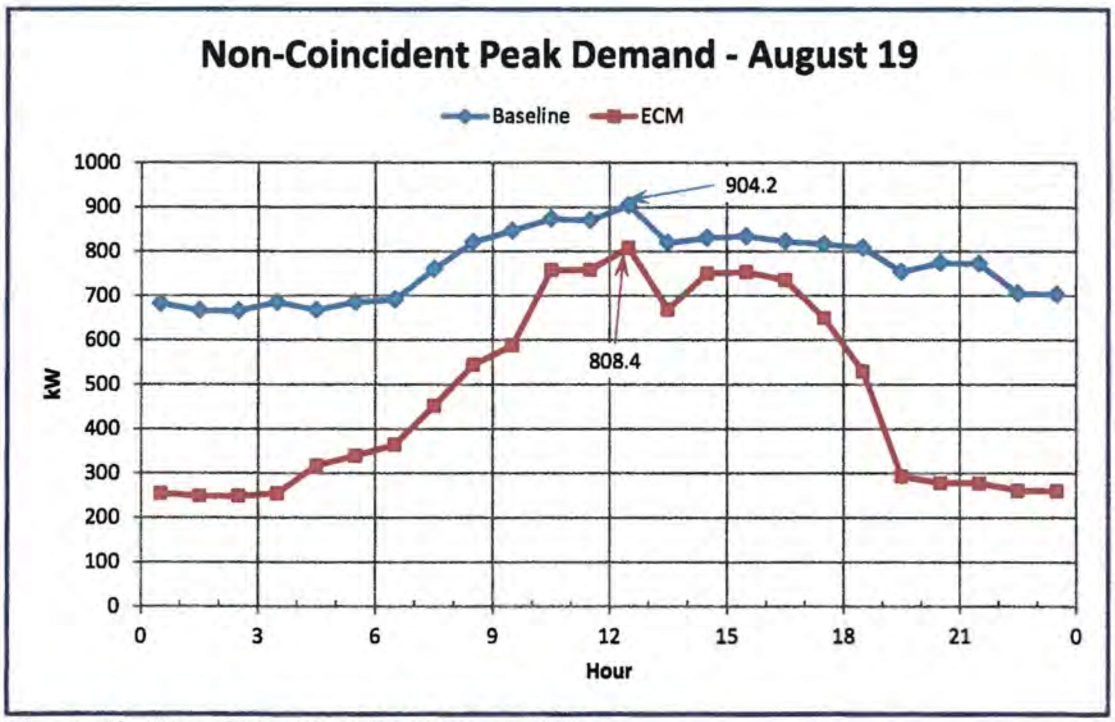


Figure 10: Non-Coincident Peak Demand Day.

[Redacted]
Chiller Replacement
M&V Report

Prepared for
Duke Energy Ohio

May 2014

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:

Todd Hintz
Architectural Energy Corporation

Stuart Waterbury
Architectural Energy Corporation

2540 Frontier Avenue, Suite 100
Boulder CO
80301

(303) 444-4149

ARCHITECTURAL ENERGY CORPORATION

TABLE OF CONTENTS

Introduction

This report addresses M&V activities for the [Redacted] custom program application.

The measures include:

ECM-1

- Replace 13 year old existing 550 Ton York Chiller (0.397 kW/Ton) with a new 550 Ton McQuay Chiller (0.317 kW/Ton). The new chiller has a factory mounted VFD. This chiller serves both the building cooling load as well as the process load to cool the printing presses.

Goals and Objectives

The projected savings goals identified in the application are:

ECM	Application Proposed Annual savings (kWh)	Application Proposed Peak Savings (kW)	Duke Projected savings (kWh)	Duke Projected Peak savings (kW)
1	220,000	0	220,000	4

The objectives of this M&V project were to verify the actual:

- Annual gross kWh savings
- Summer peak kW savings
- Utility Coincident peak demand savings
- kWh & kW Realization Rates

Project Contacts

AEC Contact	Todd Hintz	thintz@archenergy.com	o: 303-459-7476 c: 303-261-5378
Duke Energy M&V Coordinator	Frankie Diersing	Frankie.Diersing@duke-energy.com	o: 513-287-4096 c: 513-673-0573
Customer Contact	[Redacted]	[Redacted]	[Redacted]

Site Locations/ECM's

Address
[Redacted]

Data Products and Project Output

- Average pre/post load shapes by daytype for controlled equipment
- Model predicting pre/post kWh as a function of outdoor temperature
- Summer peak demand savings

- Coincident peak demand savings
- Annual Energy Savings

M&V Option

IPMVP Option A

M&V Implementation Schedule

- This plan was implemented during the summer months (peak cooling season).
- Post data only was collected.
- Monitoring period included both normal workday and weekend periods.

Field Survey Points

Plant/Building Operation

- Obtained chiller sequence of operations for both the pre and post installation cases. Confirmed this sequence for the primary and secondary chillers, cooling towers, and distribution pumps (primary and secondary).
- Obtained production schedule (including days/nights, weekends, and holidays).
- Discovered that the presses are used Wed-Sat only and are cooled during the printing process.
- Discovered that the chillers are cycled on a bi-weekly basis. The chillers are used to cool the building as well as the presses.
- Discovered that approximately 40% of the load goes to the presses while the other 60% cools the building.

The following survey data was collected (for all equipment logged)

- York (550 ton) chiller make/model/serial number (existing chiller)
- York chiller VFD make/model
- York CHW pump capacity (hp)
- York chiller flow rate
- McQuay chiller make/model/serial number (new chiller)
- McQuay chiller VFD make/model
- McQuay CHW pump capacity (hp)
- McQuay chiller flow rate

The following one-time measurements were taken for all equipment logged (to check and validate Elite Pro data)

- York (550 ton) chiller volts, amps, kW and power factor, and VFD speed
- York CHW pump VFD speed (if present), volts, amps, kW, and power factor
- McQuay chiller volts, amps, kW and power factor

- McQuay CHW pump VFD speed (if present), volts, amps, kW, and power factor
- OA Temperature and RH

Data Accuracy

Measurement	Sensor	Accuracy	Notes
Temperature	Hobo thermistor	±0.5°F	
Current	Magnelab CT	±1%	> 10% of rating
True kW	Elite Pro logger	±1%	
RH	±1%	±2.5%	

Field Data Logging

- **ECM-1 – Installed data loggers to log the following data points in 5 minute intervals. Collected data for 3 weeks.**

  - Existing (550 ton) chiller kW (see Elite Pro configure instruction below)
  - Existing CHW pump current
  - Replaced chiller kW (see Elite Pro configure instruction below)
  - Replaced CHW pump current
  - Chilled Water Supply Temperature
  - Chilled Water Return Temperature
  - Condenser Water Supply Temperature
  - Condenser Water Return Temperature

  The Elite Pro loggers were configured to record the following information:

  - Voltage
  - Current
  - Power factor
  - KVA
  - KVAR
  - Power

- **Outdoor Air**
  1. Installed a weather logging station to record outside air temperature and relative humidity in 5 minute intervals. Logged for 3 weeks post-measure installation.

Logger Table

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

ECM	Elite-Pro	Hobo U-12 (4 CH)	Temperature Probe	Dent CT's	Weather Stations

Primary Chiller	1	1	4	(3) 1000 amp	1
Lag Chiller	1	1	4	(3) 1000 amp	-
Primary CHW pump		1		1 (100 amp)	
Secondary CHW pump		1		1 (100 amp)	

Data Analysis

1. Converted time series data on logged equipment into post average load shapes by day-type.
2. Generated pre-retrofit model from performance curves and post retrofit consumption field data.
3. Developed pre/post regression models of total daily kWh as a function of average outdoor drybulb temperature.
4. Estimated peak demand savings by subtracting pre/post time series data during peak ambient temperatures. Calculated coincident peak savings by subtracting pre/post peak kW values at equivalent hot days at the utility coincident peak hour.

- **ECM-1**

5. Regressed data into a temperature dependent load model. Form of the regression equation is:

$$kWh / day = a + b \times T_{avg}$$

where

kWh/day = daily energy consumption
T_{avg} = Daily average drybulb temperature

6. Applied equation above to TMY3 data processed into average drybulb temperature for each day of the year.

Verification and Quality Control

1. Visually inspected time series data for gaps
2. Compared readings to nameplate and spot-watt values; identified out of range data

Recording and Data Exchange Format

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

Results Summary

The following results account for benefits of the chiller replacement.

A summary of the estimated annual savings is shown in Table 1.

Table 1

[Redacted] Energy Reduction Results		
	Pre (kWh)	Post (kWh)
	729237.3	619953.7
Total Savings (kWh)	109,283	
Application Estimated Savings (kWh)	220,000	
Application Realization Rate	50%	
Duke Estimated Savings (kWh)	220,000	
Duke Realization Rate	50%	

Evidence of peak demand reduction is shown in Table 2.

Table 2

[Redacted] Peak Demand Reduction Results		
	Pre (kW)	Post (kW)
	175.	149.7
Total Savings (kW)	25.3	
Application Estimated Savings (kW)	0	
Application Realization Rate	N/A	
Duke Estimated Savings (kW)	3.9	
Duke Realization Rate	657%	

The energy savings, and therefore realization rate, are low. There are several reasons for this energy savings shortfall. The savings calculations that were included in the application assumed that the replaced chiller would run for 5,000 hours per year. During the analysis, it was discovered that the chillers are cycled between the new McQuay chiller and the existing York chiller on a bi-weekly basis, and that there is always one chiller running. Therefore, the savings estimates in this report assume that the new McQuay chiller runs 4,380 hours per year (8,760/2). Since prior to the chiller replacement the chillers were also cycled on a bi-weekly basis, this analysis also assumes that the old chiller operated for 4,380 hours per year. Also, the application savings calculations were not done in respect to weather, i.e., changes in load and efficiency throughout the year. Estimated and actual savings are reflected in Table 1 and Table 2.

Figure 1 and Figure 2 depict graphs of energy consumption and savings for the metered equipment (550 ton McQuay and 550 ton York chillers) during the monitoring period. The new McQuay chiller replaced a 550 ton York chiller identical to the existing chiller. The chillers are cycled on a bi-weekly basis, serve identical loads while running, and do not run at the same time. For this reason, the existing York chiller, which was identical to the pre-retrofit chiller that was replaced by the McQuay, was chosen to represent the "Pre" condition and the McQuay chiller was chosen to represent the "Post" condition.

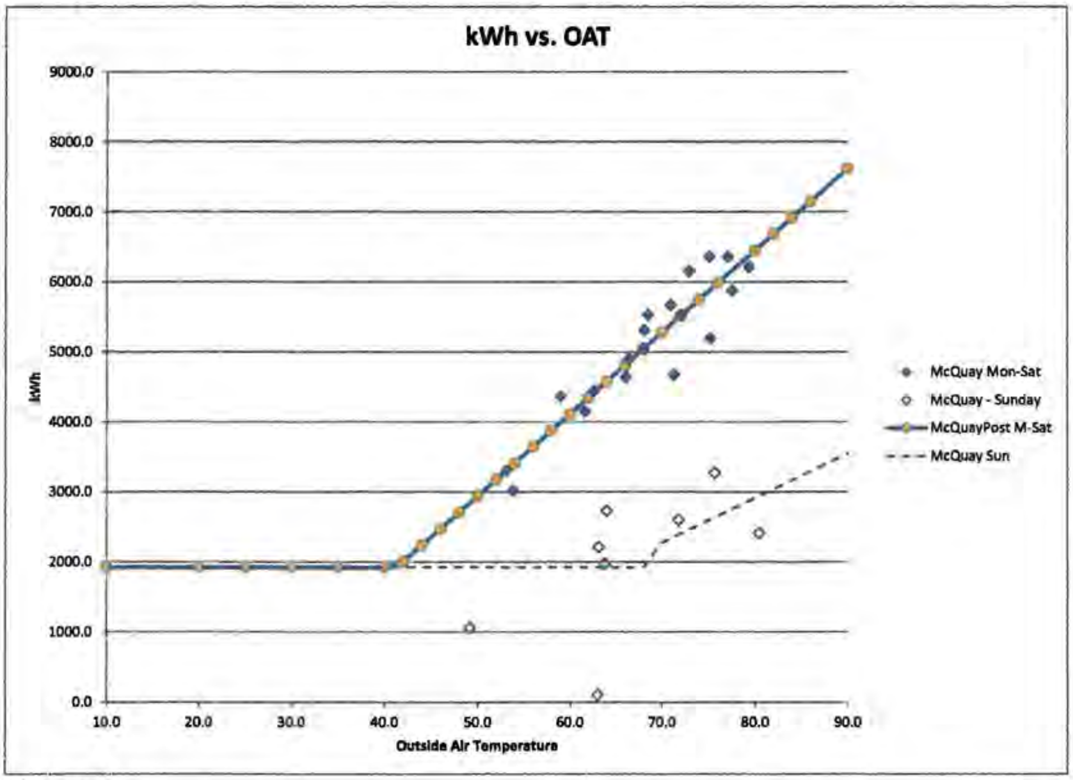


Figure 1

During the analysis, it was noted that there were two distinct operating periods for these chillers. Monday through Saturday, the chiller operation appeared to be much more dependent upon the outside air temperature than did Sunday. For this reason, the two operating periods were regressed separately. Regressions for the Sunday operating period can be found in Figure 1 and Figure 2. Note that although the presses do not run every day, chilled water flows to the presses continuously, and so there is no discernable change in process load regardless of press operation.**Error! Reference source not found.**

Figure 1 and Figure 2 also depict graphs of energy consumption and savings for the metered equipment extrapolated over the course of one year. kWh/day were extrapolated for the year by substituting TMY3 outside air temperatures (dry bulb) into the linear regression equations above for both Pre (York) and Post (McQuay) conditions. The chillers were assumed to run at