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.

Outdoor Air:

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

AC Unit:

- 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.

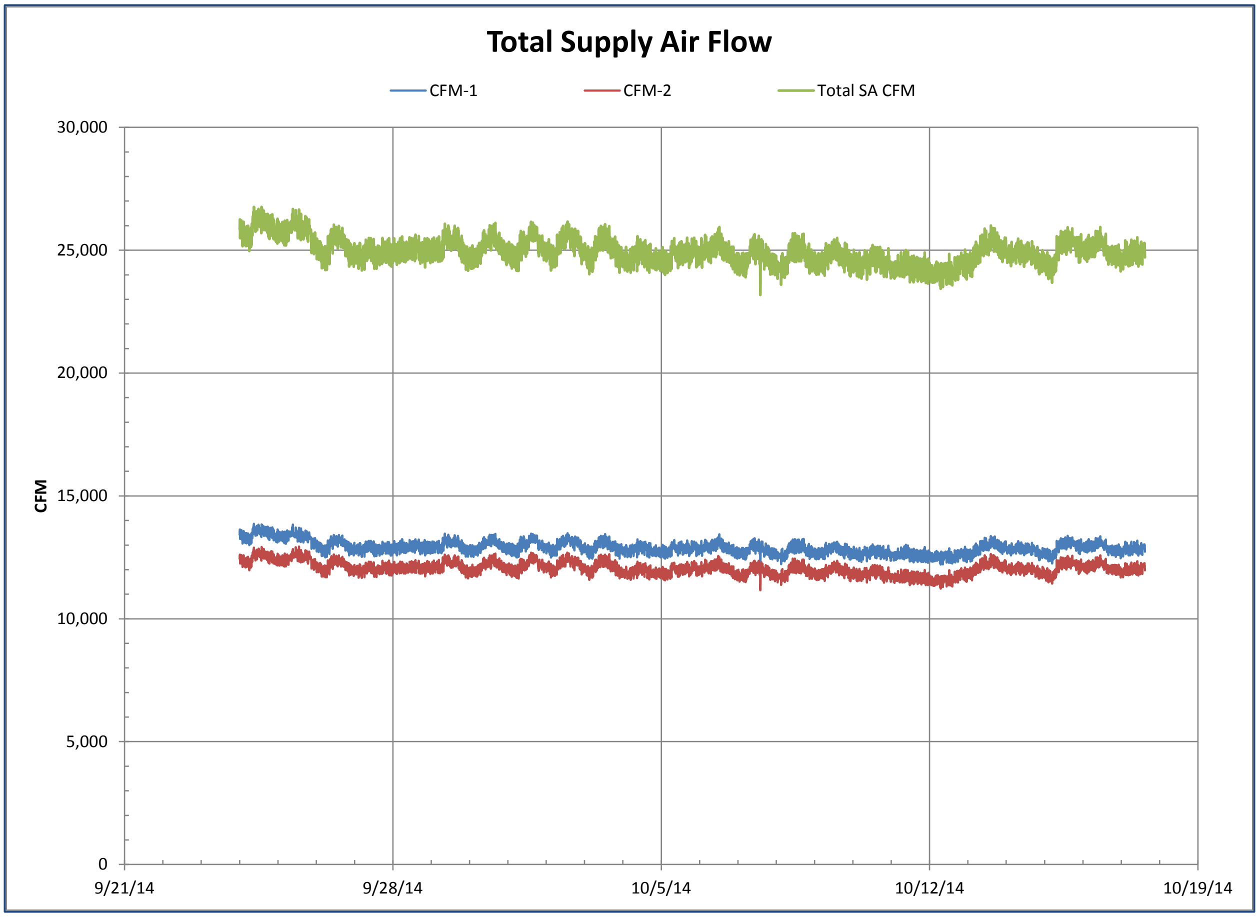


Figure 1. Trended Supply Air Flows (CFM)

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.

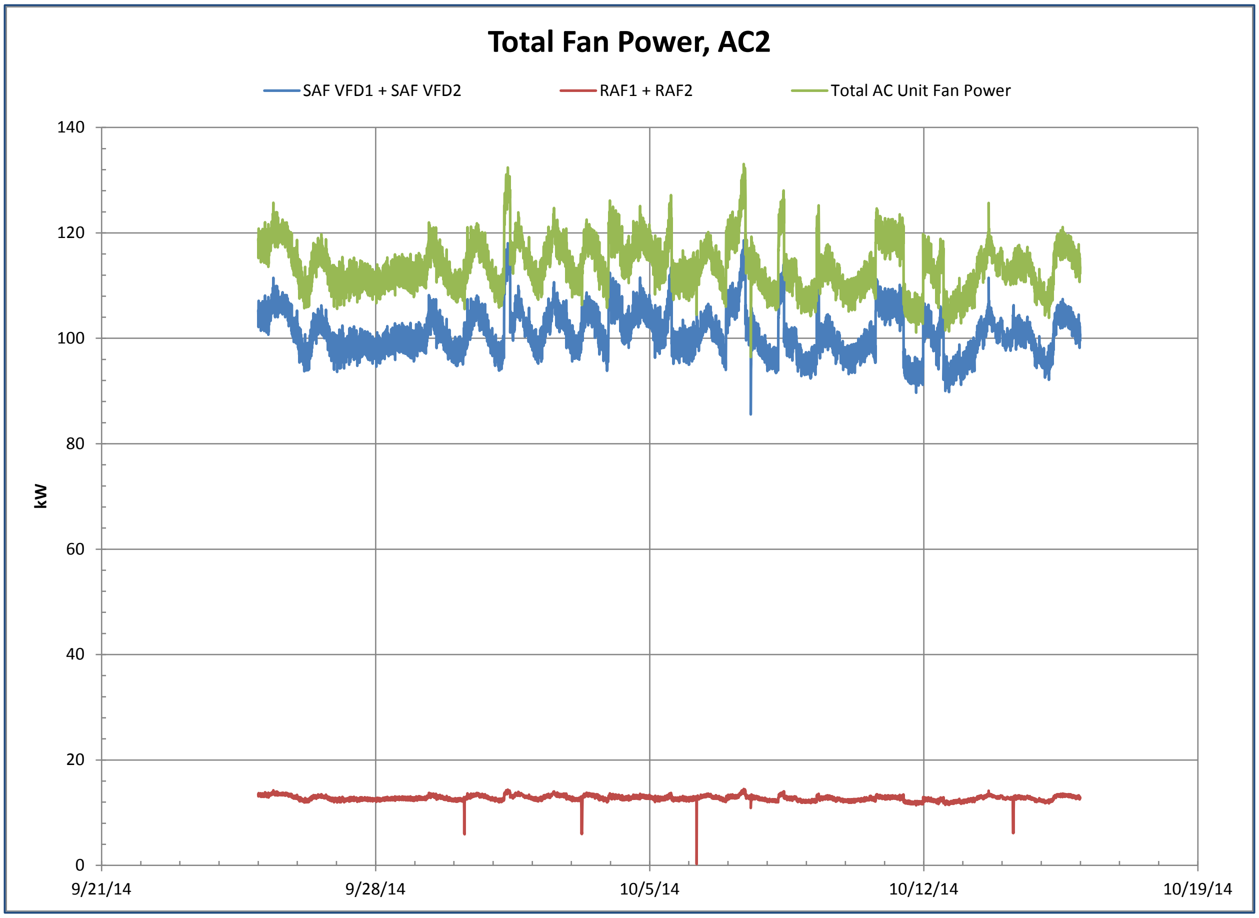


Figure 2. Measured Fan Powers (kW)

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.

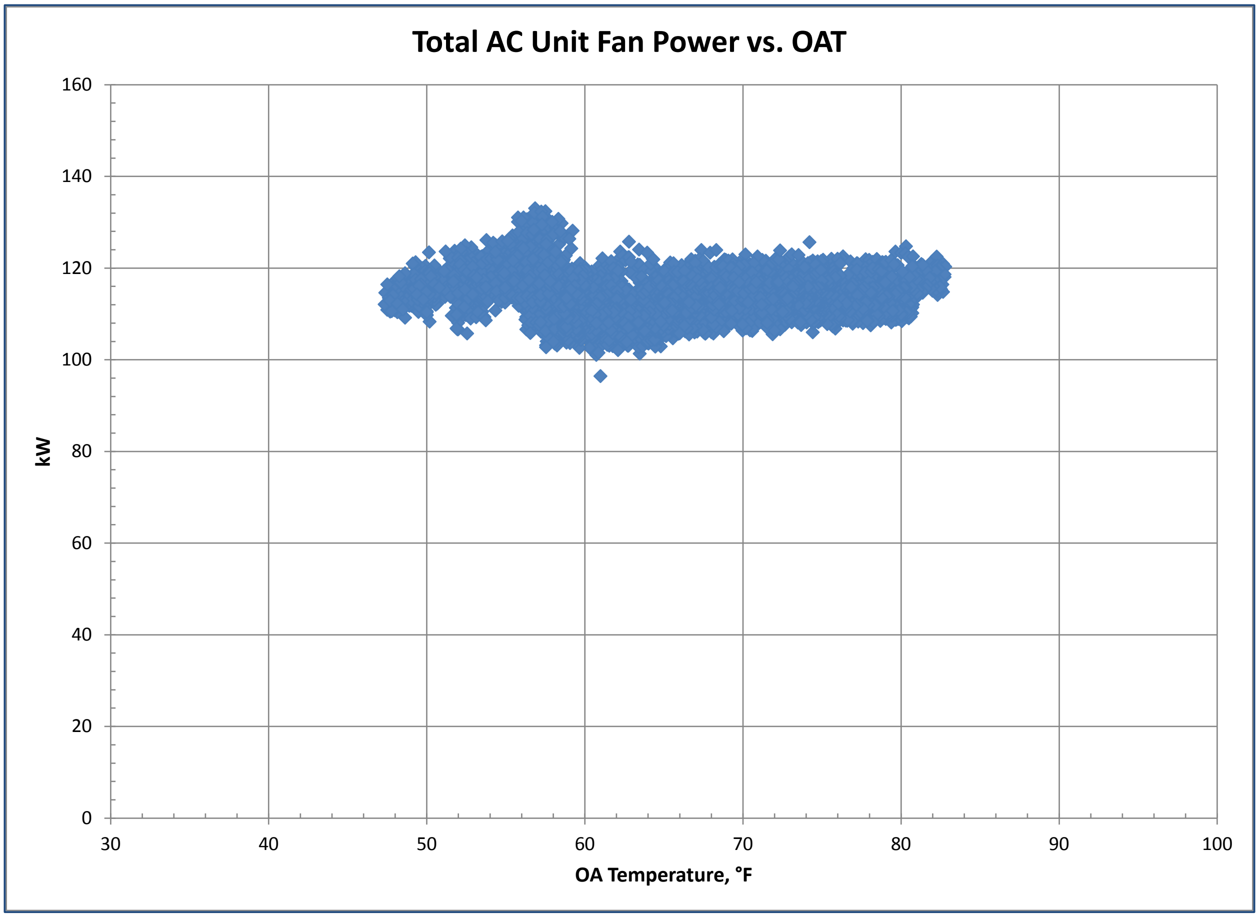


Figure 3. Fan Power vs. Outside Air Temperature

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.

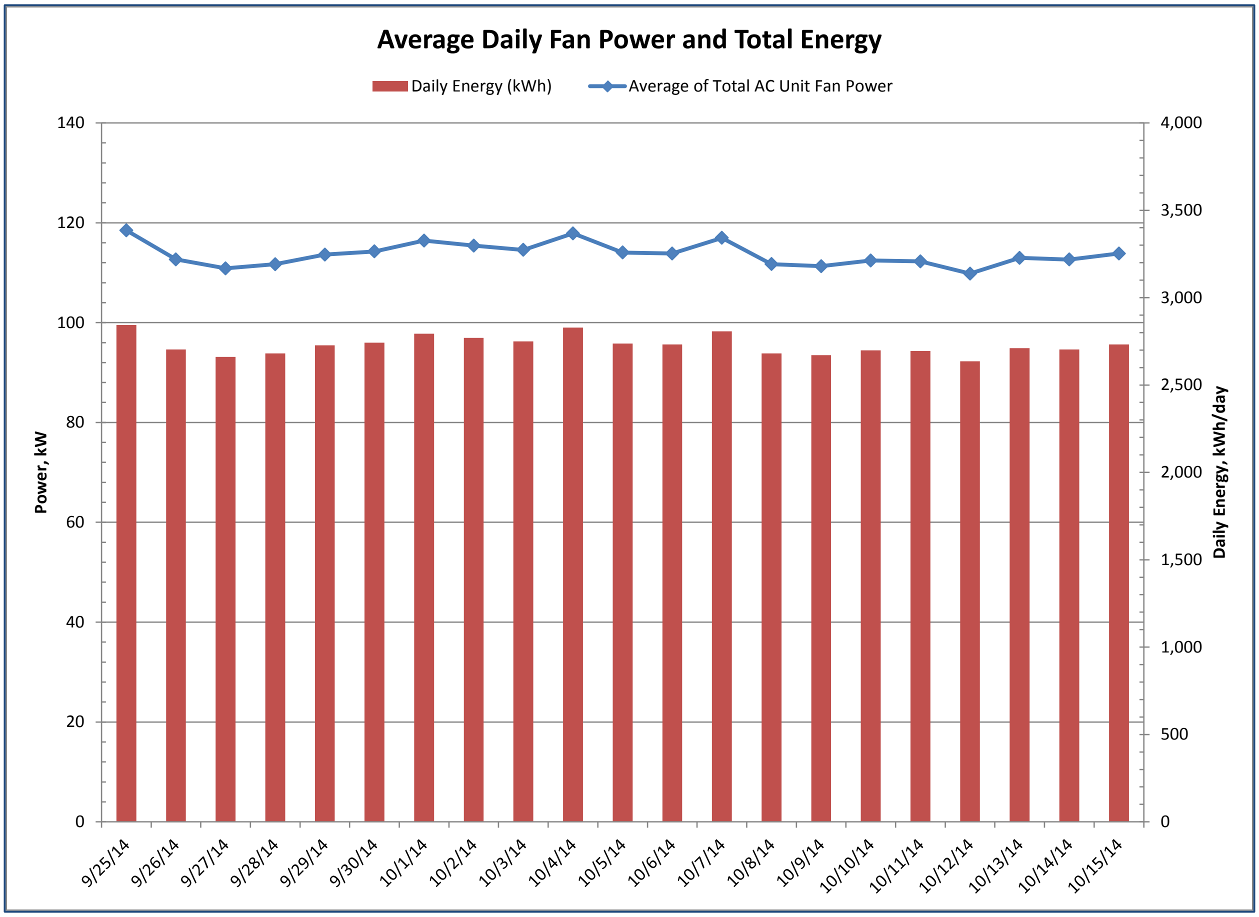


Figure 4. Daily Average Power and Total Energy Consumption

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.

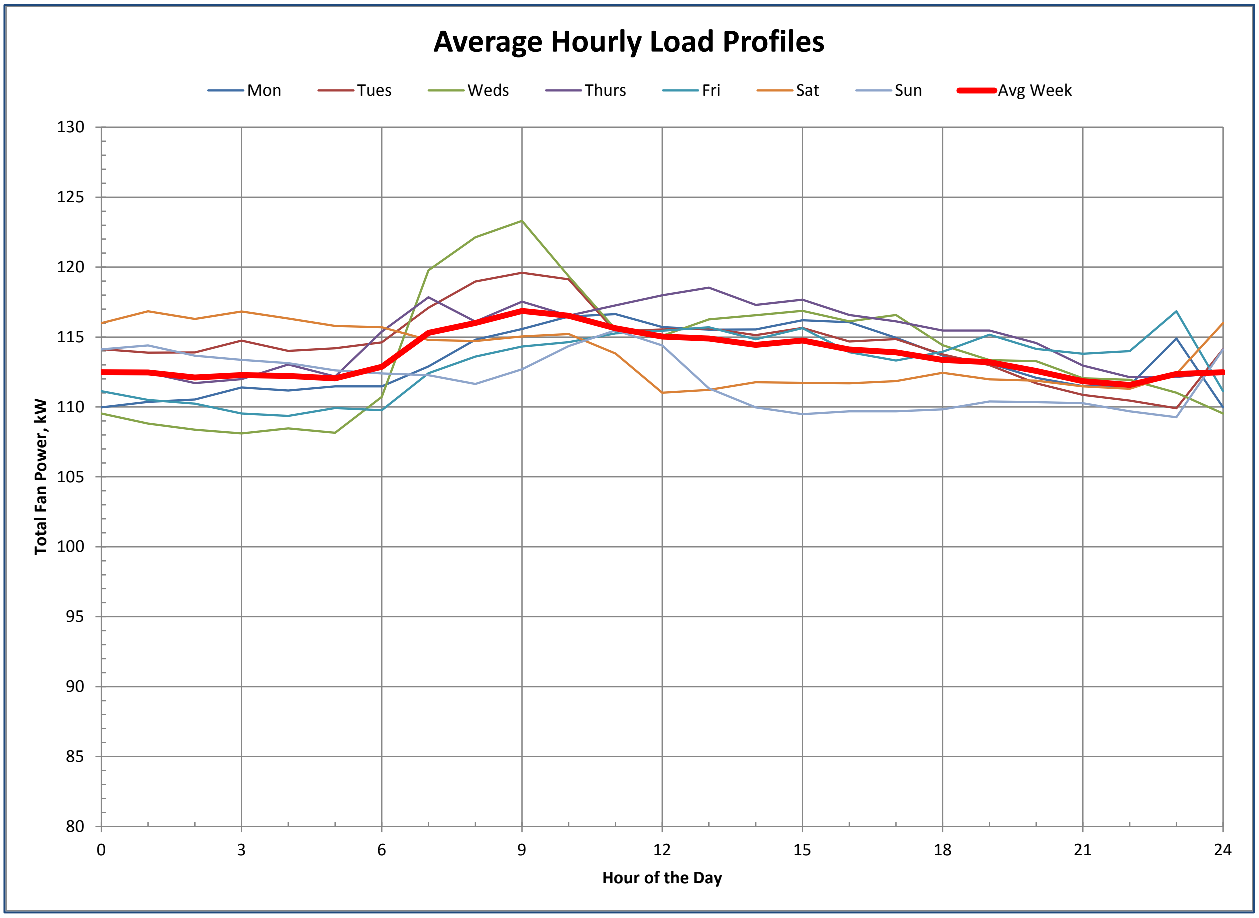


Figure 5. Average Load Profiles (Fan kW)

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.

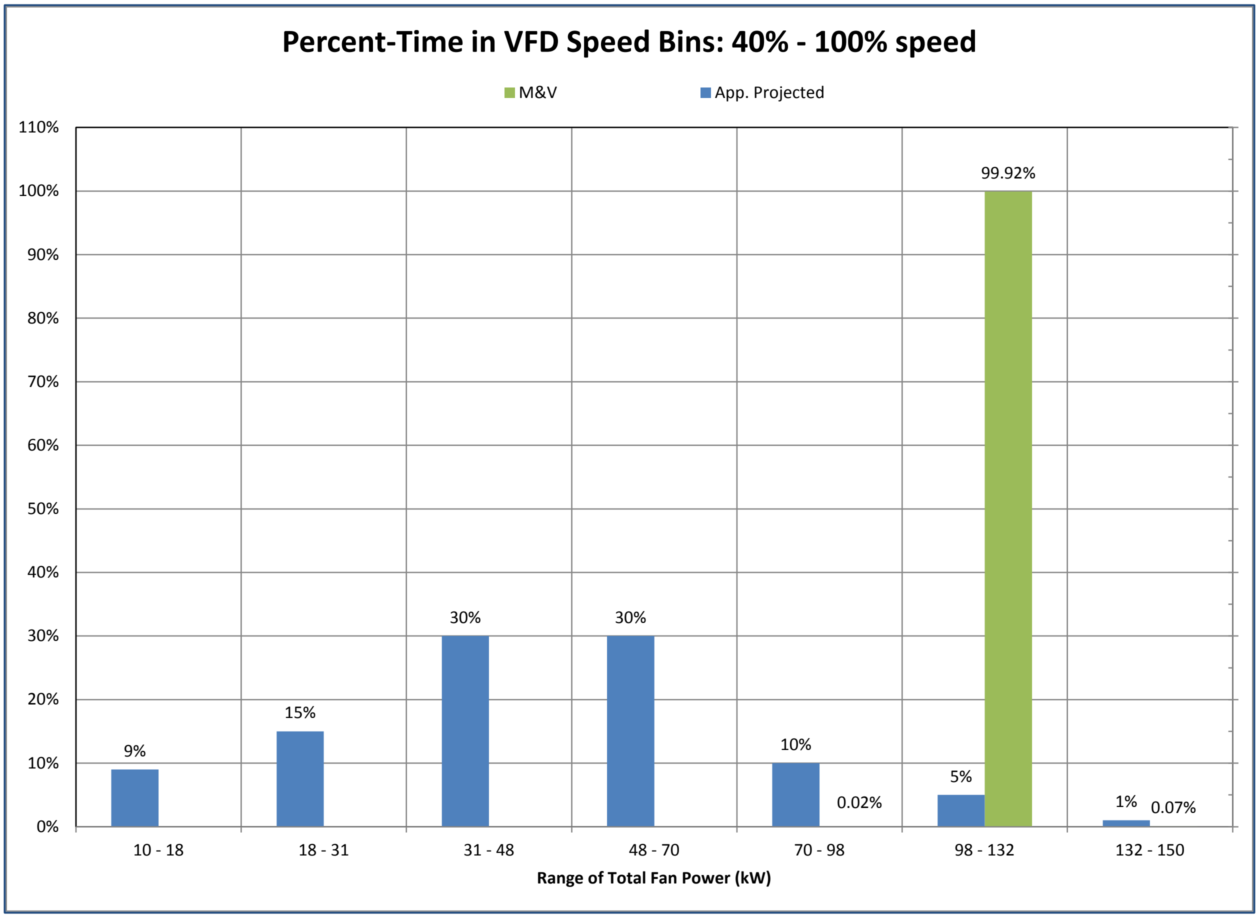


Figure 6. Compare Estimated and Actual Fan Speed Distribution

[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].

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:

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

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

[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].

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

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.

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).

<u>General points:</u>

- Outdoor air temperature and relative humidity.

<u>Air Handling Units</u>

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.

<u>Lighting.</u>

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.

Model:

- 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.*

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:

- *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.*

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:

- *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.

<u>*Model:*</u>

- *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.

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.

<u>Model:</u>

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

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

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.

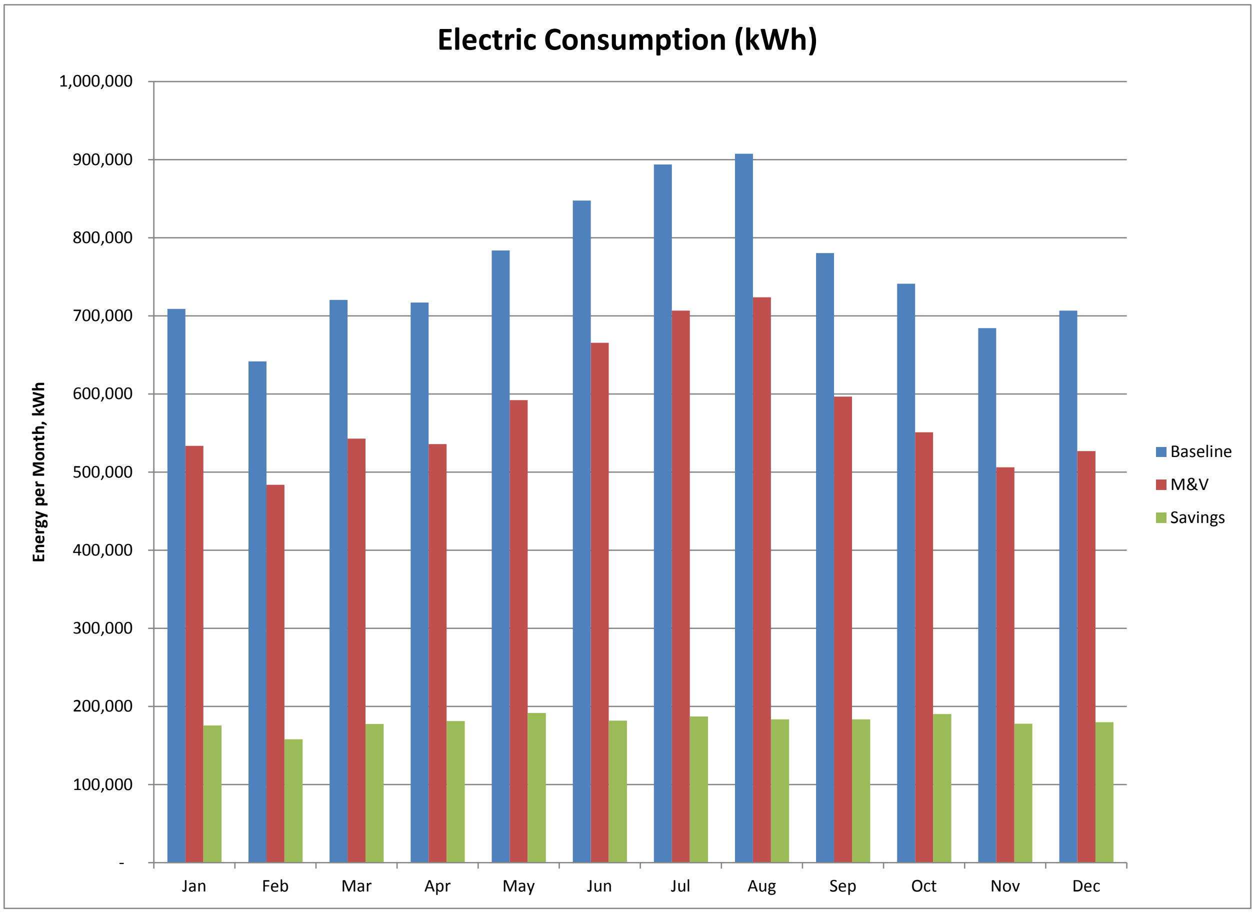
A new parametric analysis was added to activate the new schedules. This step increases the energy savings.

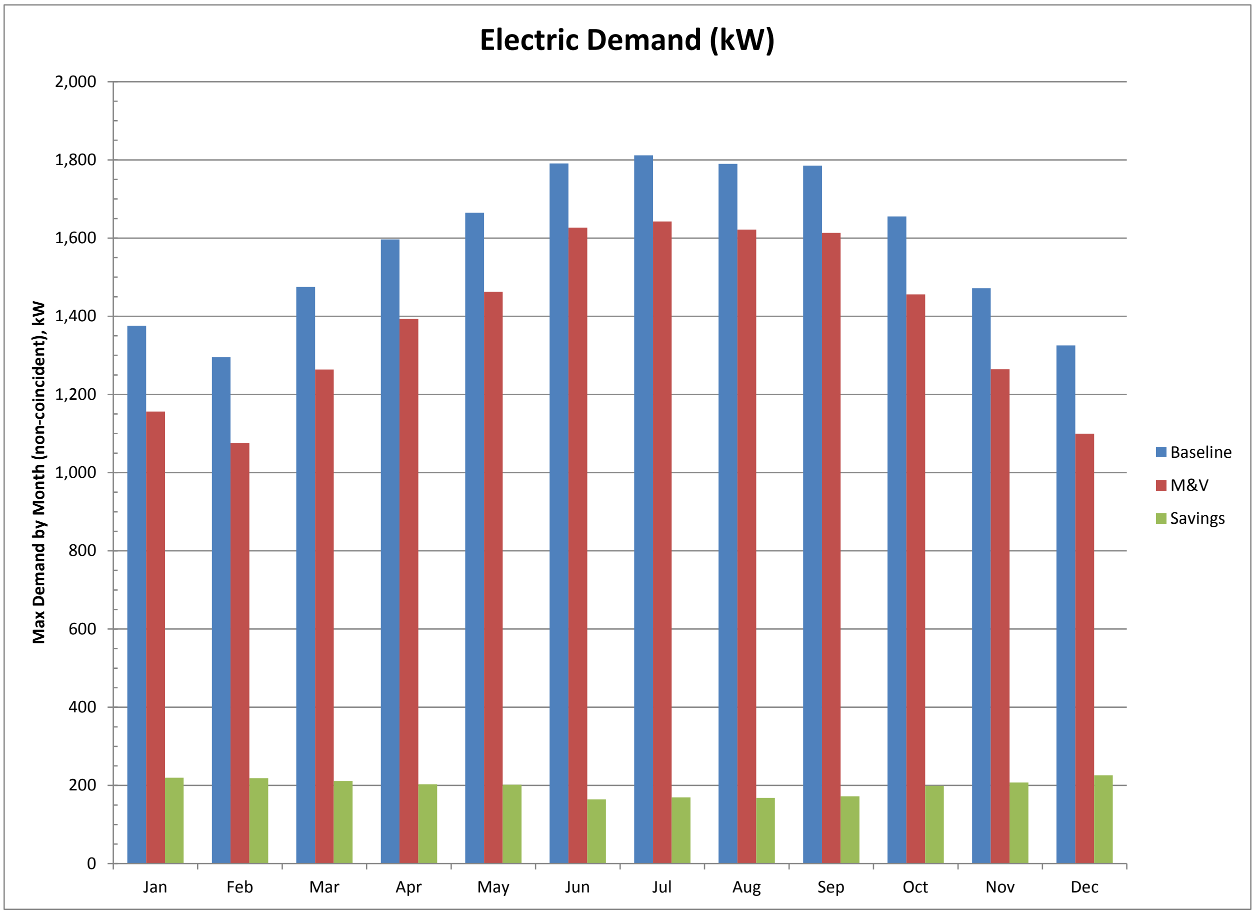
Results Summary

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

Referenced Figures

Figure 1:Static Pressure Data for AC-4

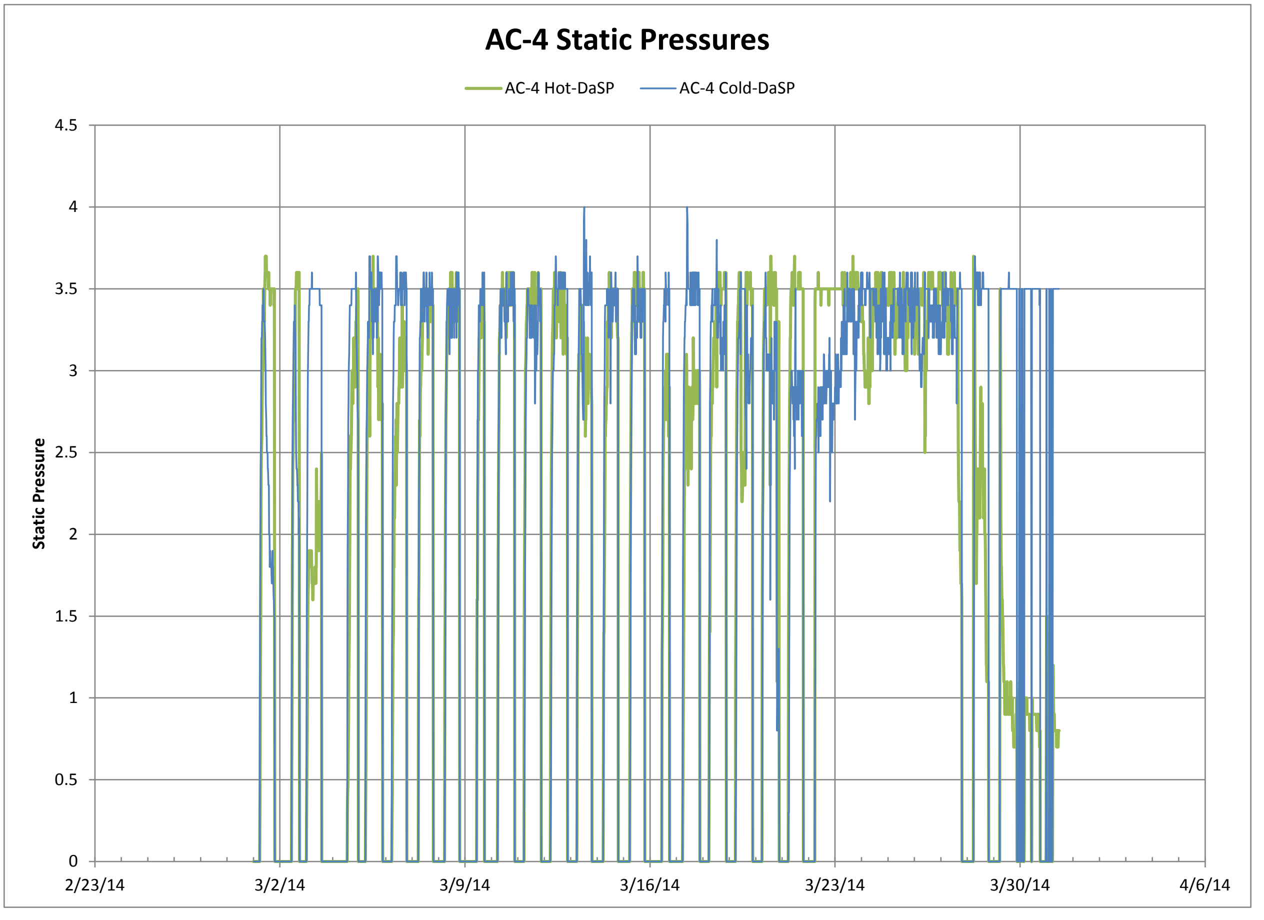


Figure 2:Return Air Temperatures for AC-4

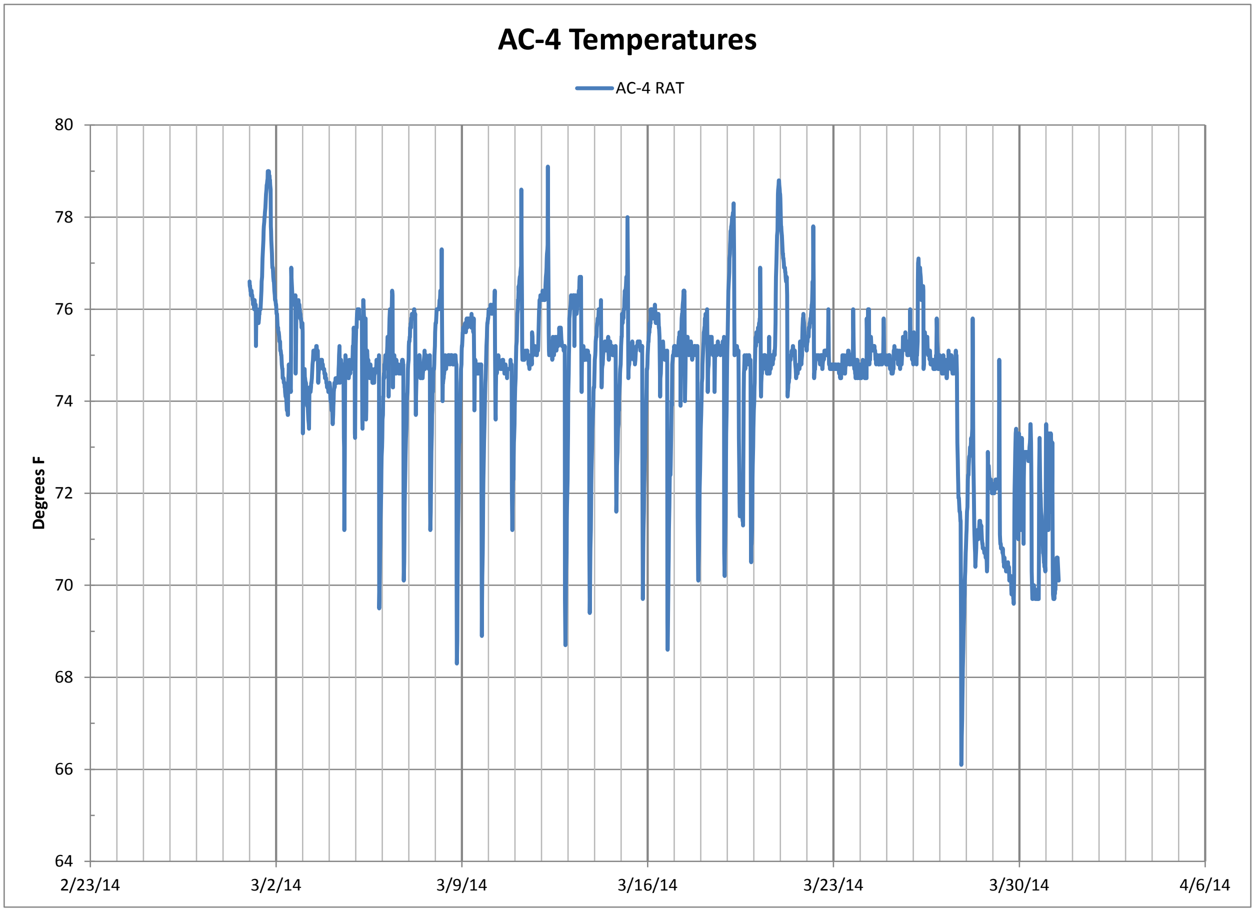


Figure 3:Static Pressure and VFD Speed Data for AC-1

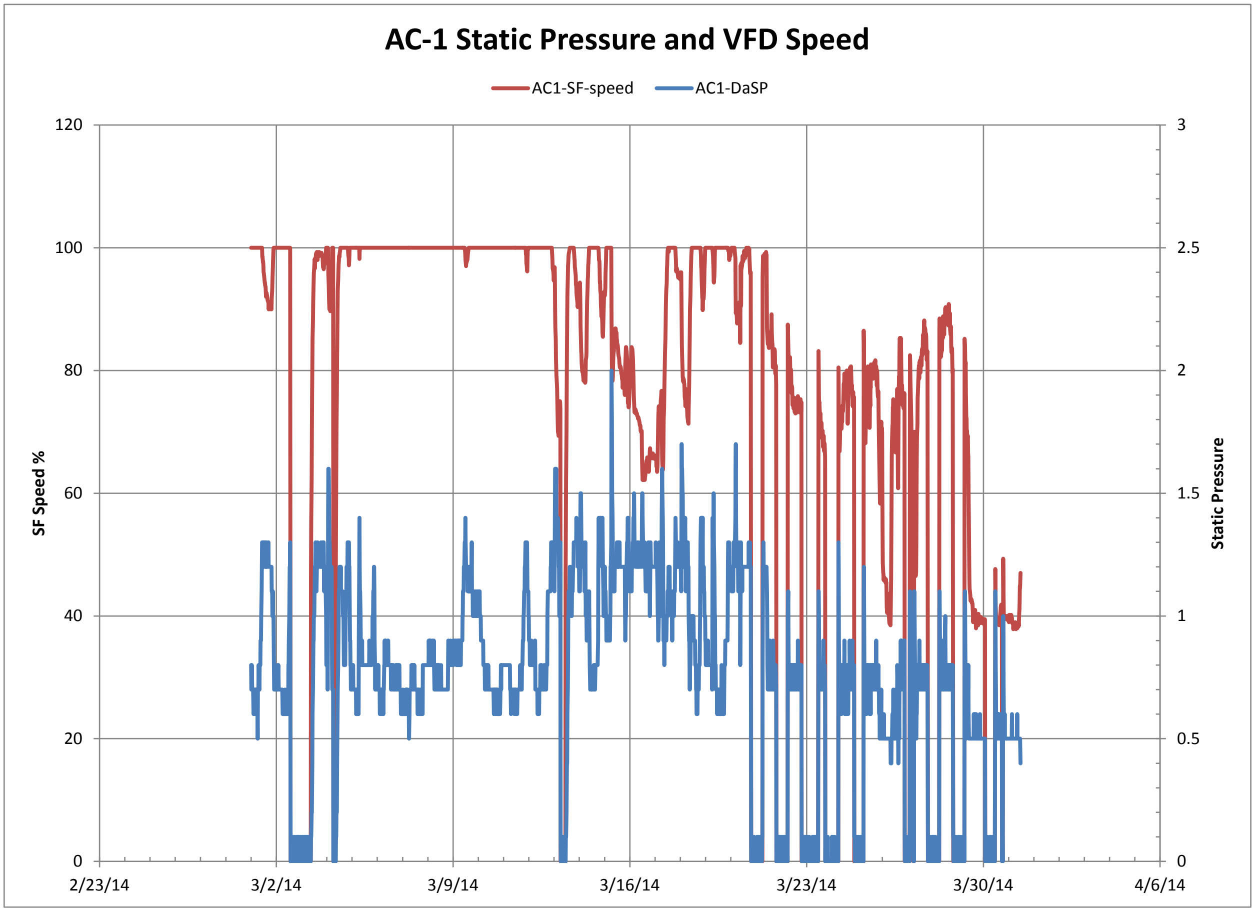
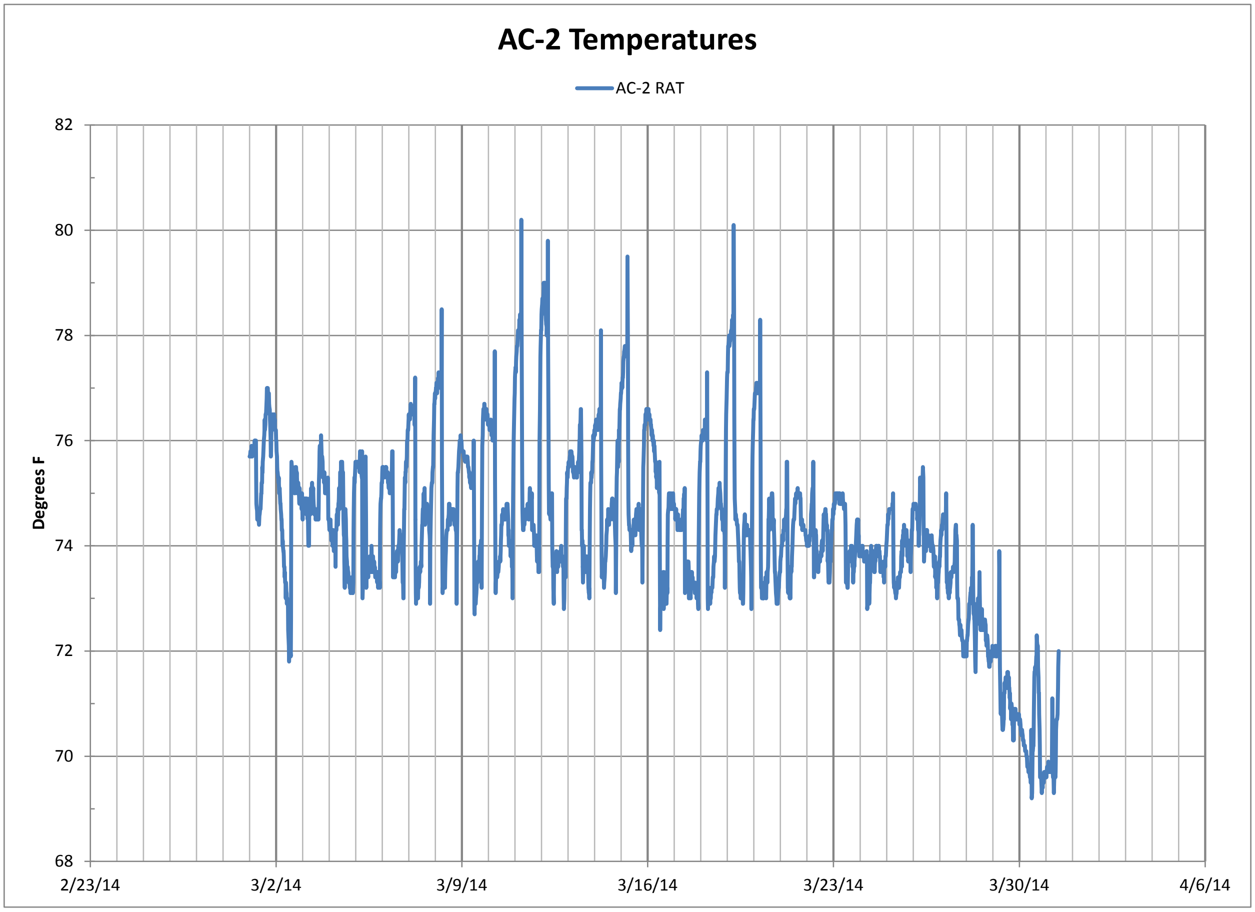


Figure 4: Return Air Temperatures for AC-2



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 82Addition_H3.2)				●	●		50		59.00	Steam humidifier on intlet 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

Spot-Watt form

DATE: 2/28/2014 **SITE NAME:** [redacted]
Location: Penthouse and Level C 11:15pm

Logger#: Fluke Multimeter
VFD inf. **Subject** AC-4 **Logger Reading** 61.5% SP **(Units)** 6.1 Vdc
~~Channel#~~ 36.5 HZ 28.9 A

The CT is mounted on:

			Amps	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 Mutimeter 11:45am
VFD inf **Subject** AC-5 **Logger Reading** 72% SP **Temp** 7.2 Vdc
~~Channel#~~ 43.5 Hz 54.6 A

The CT is mounted on:

			Amps	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 Multimeter 12:15pm
VFD inf **Subject** AC-1 **Logger Reading** 55.1% SP **Temp** 5.5 Vdc
~~Channel#~~ 33.5 Hz 19.0 A

The CT is mounted on:

			Amps	Volts	Watts	PF	KVA	KVAR
O A CB#		Phase A	9.5	274.9	1.87 kw	.75	2.42	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 Multimeter 12:30pm
VFD inf **Subject** AC-2 **Logger Reading** 69.5% SP **Temp** 7.0 Vdc
~~Channel#~~ 41.9 HZ 47.6 A

The CT is mounted on:

			Amps	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

ECM Confirmation Data Forms

ECM Confirmation Data Forms

ECM# and Title	1 - Light_W_ph1n <Part 1>
Description	In 265 spaces (Area 1), change Lighting LPD to 0.84 W/sqft
Info determined from Model	Many of these spaces are in [redacted] Most of [redacted] received this reduced LPD.
Action in Field	*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 (see table below)
Other Notes	Original LPD's are: 1.00 and 1.30 W/sqft.
For Analysis	*From total fixture W and total A, determine average W/sqft to update model.*

Action in Field:

#	Space ID	Fixt. Type	* Fixt. W	No. of Fixts.	Room L	W	Area
1	3rd Floor bay	2 - 4' Fluor	50	33	32	48	1536
2							
3	D Stack	1 - 4' Fluor	25	8			
4	(manual switches	1 - 2' Fluor	17	1	32	4.5	144
5	on each stack row)						
6	50% on						
7							
8							
9							
10							
11							
12							
13							
14							
15							

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.*

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 they 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.*

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.*

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.*

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.

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.*

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

	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	5:30 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°

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.*

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																								

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.*

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.*

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). AC-1 AC-2 AC-3 Yes/No No No No
	Confirm the fan on-off schedules for the above AC units. M / Tu / W / Th / F / Sat / Sun AC-1 Fan ON: 7:00 am / 7:00 am / 7:00 am / 7:00 am / 7:00 am / 7:00 am / 11:30 am AC-1 Fan OFF: 9:30 pm / 9:30 pm / 9:30 pm / 7:00 pm / 7:00 pm / 7:00 pm / 5:30 pm AC-2 Fan ON: Same as above AC-2 Fan OFF: AC-3 Fan ON: Same as above AC-3 Fan OFF:
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.* AC-1 AC-2 AC-3 Yes/No Y Y 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°

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 ——→
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.*

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:

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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)
- CO_2 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.

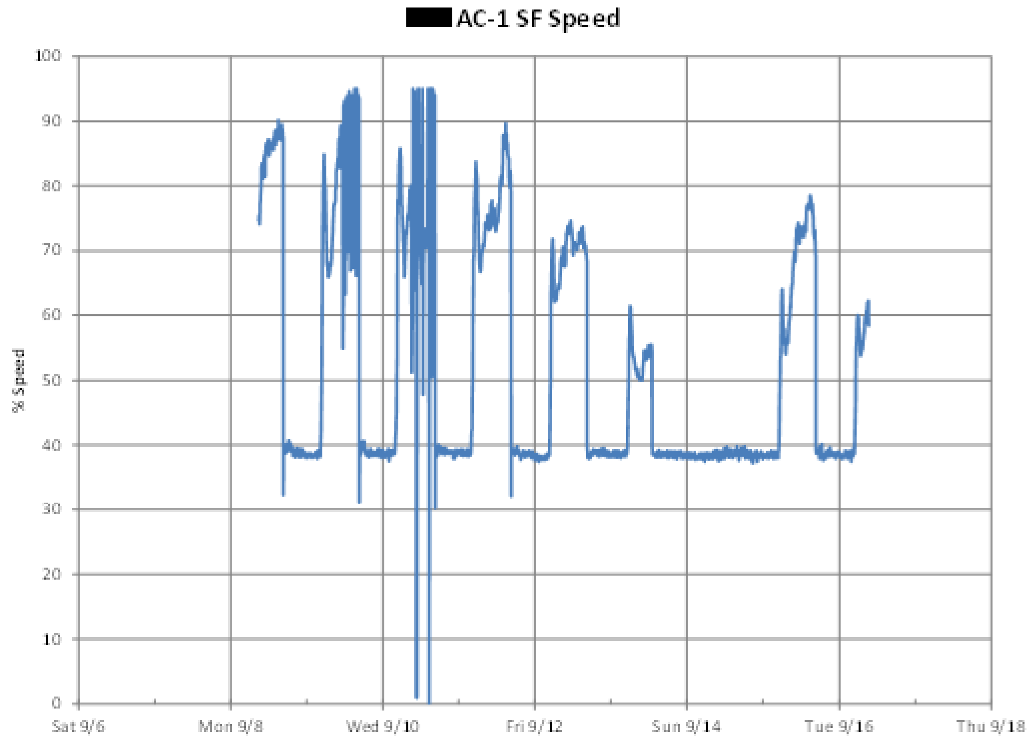

Figure 1: VFD Speed – AC-1.

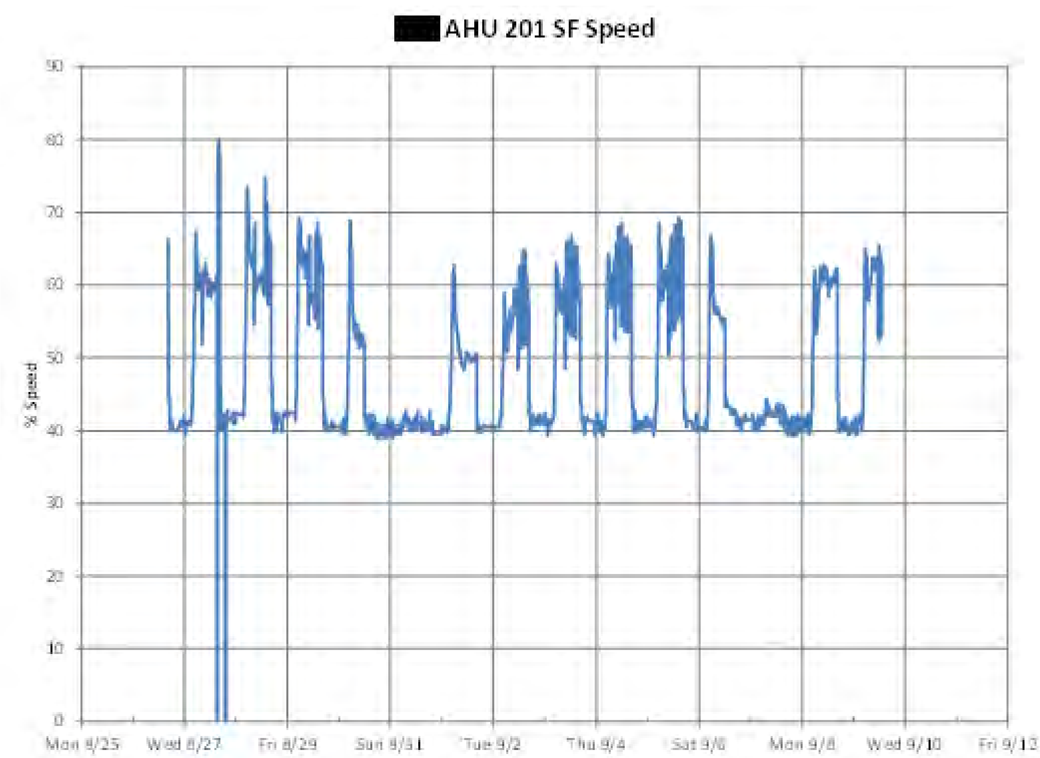

Figure 2: VFD Speed – AHU-201.

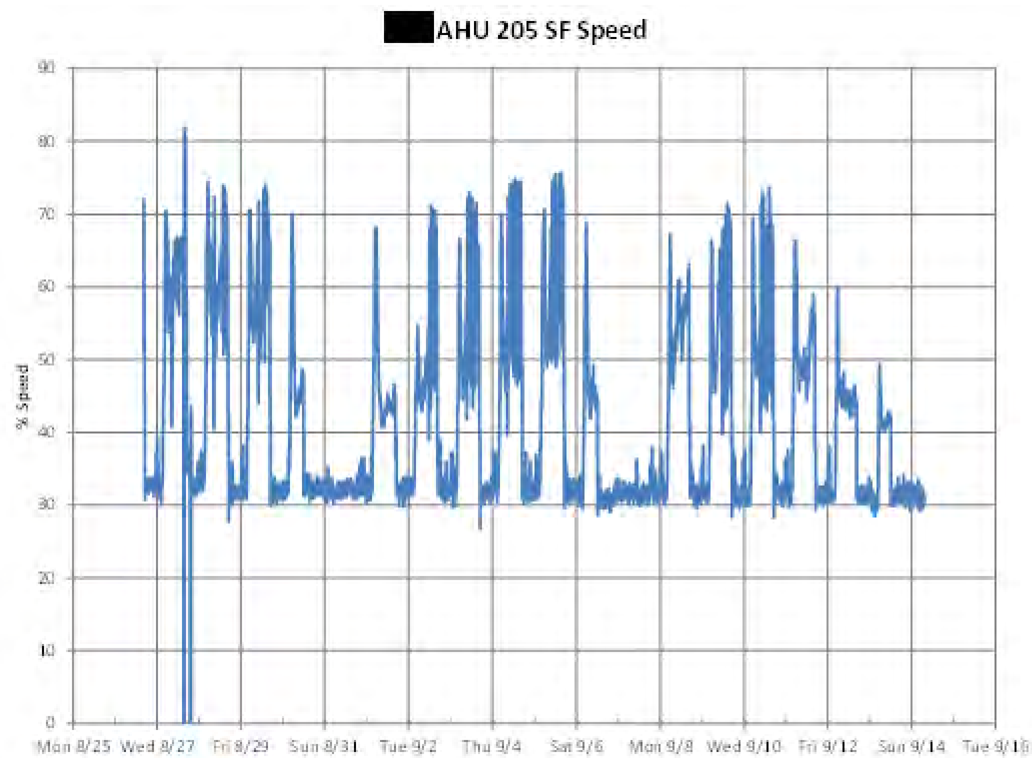

Figure 3: VFD Speed – A HU-205.

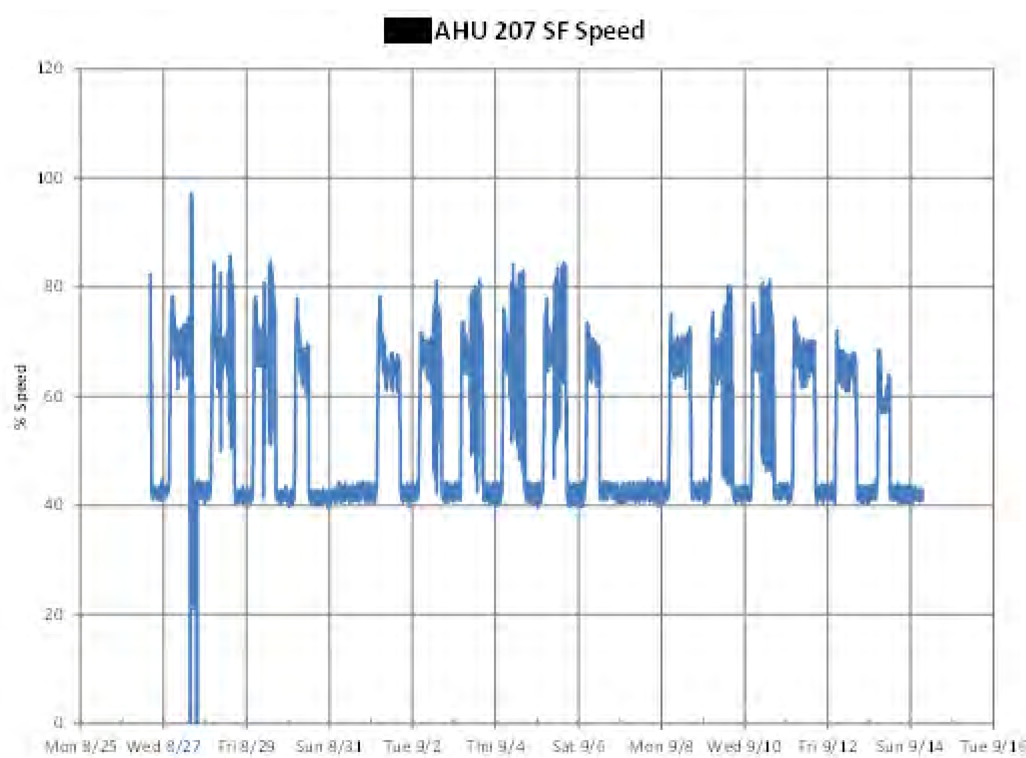

Figure 4: VFD Speed – A HU-207.

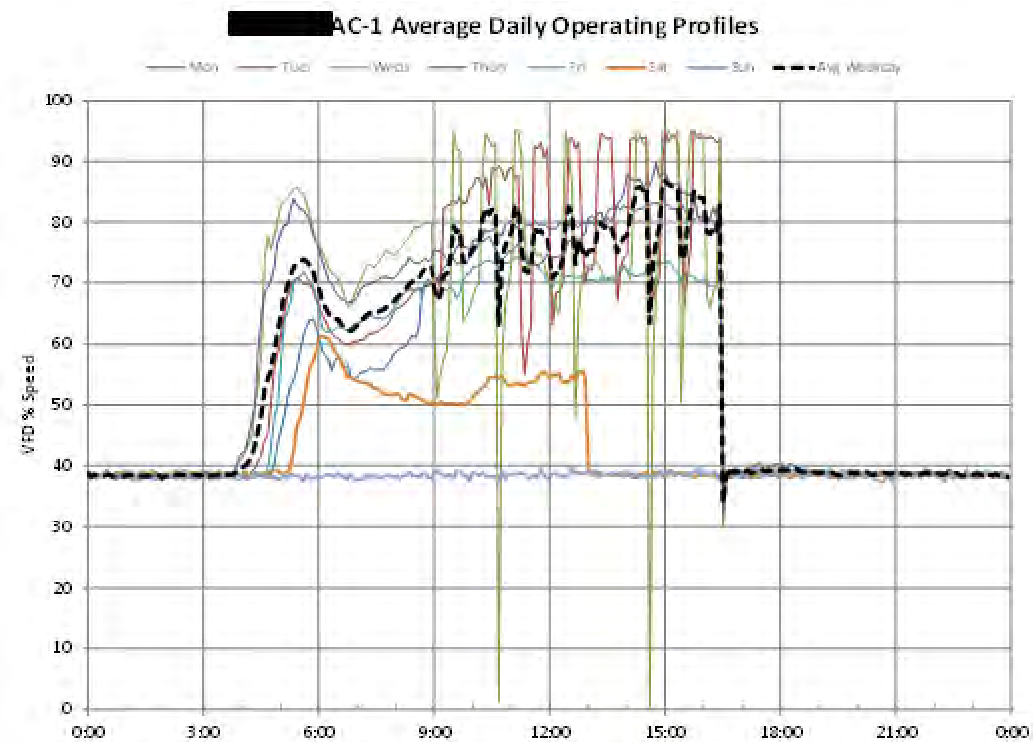

Figure 5: Average Daily Profiles – AC-1.

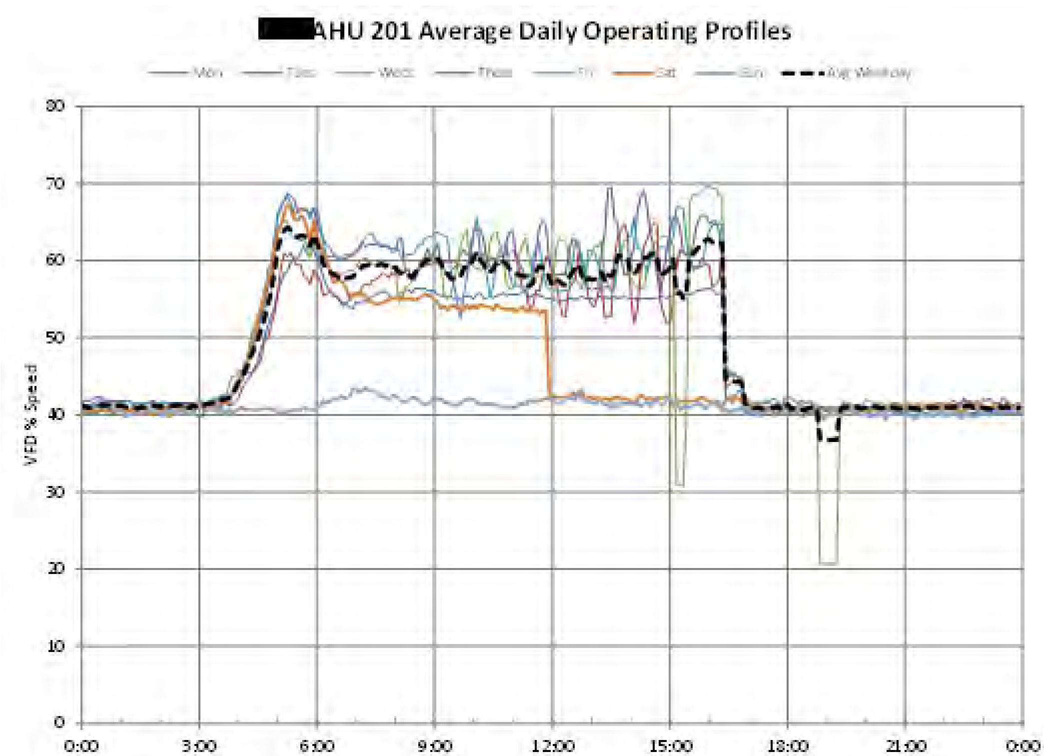

Figure 6: Average Daily Profiles – AHU-201.

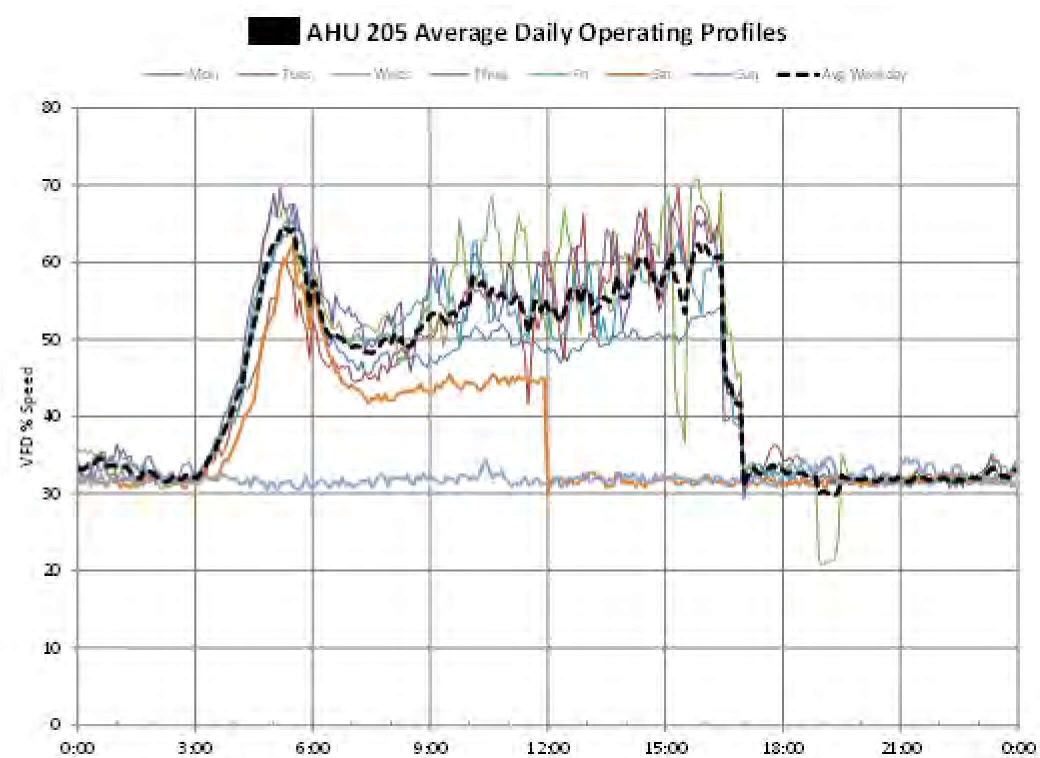

Figure 7: Average Daily Profiles – AHU-205.

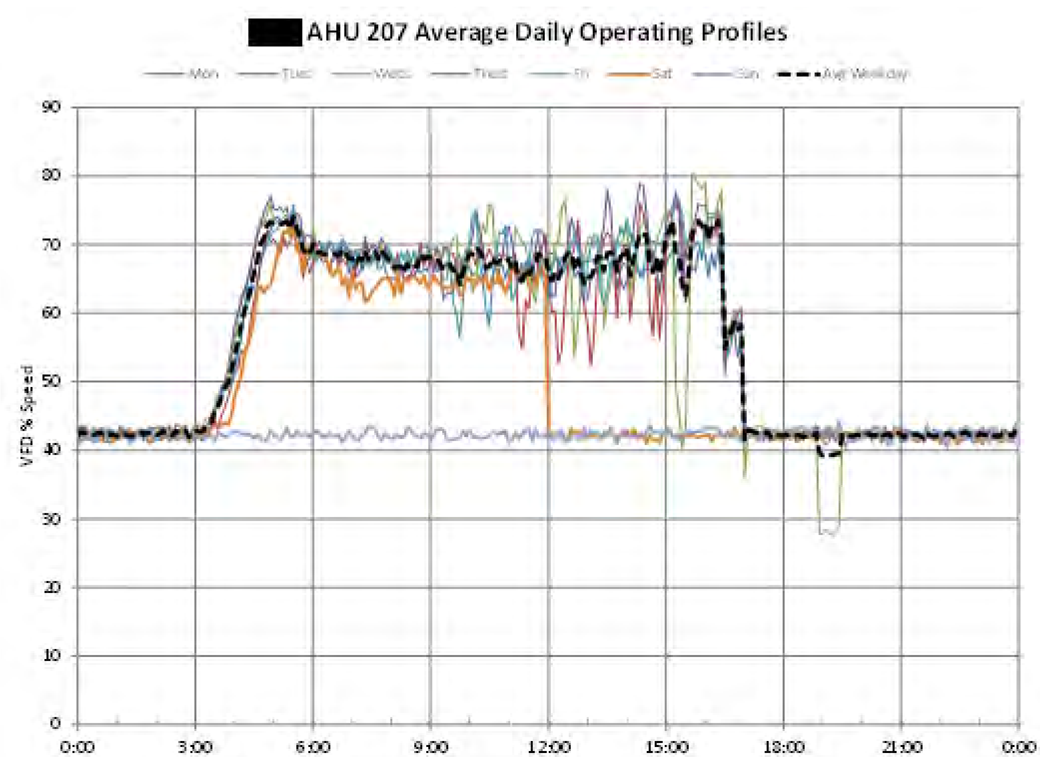

Figure 8: Average Daily Profiles – AHU-207.

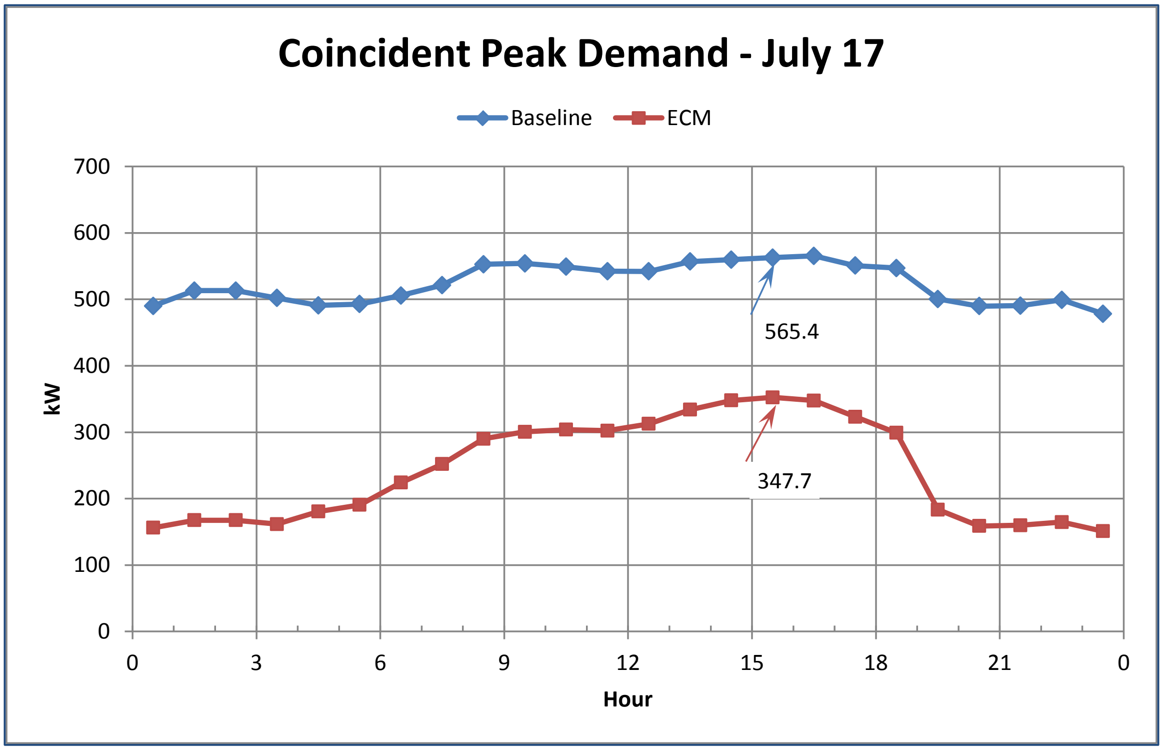

Figure 9: Coincident Peak Demand Day.

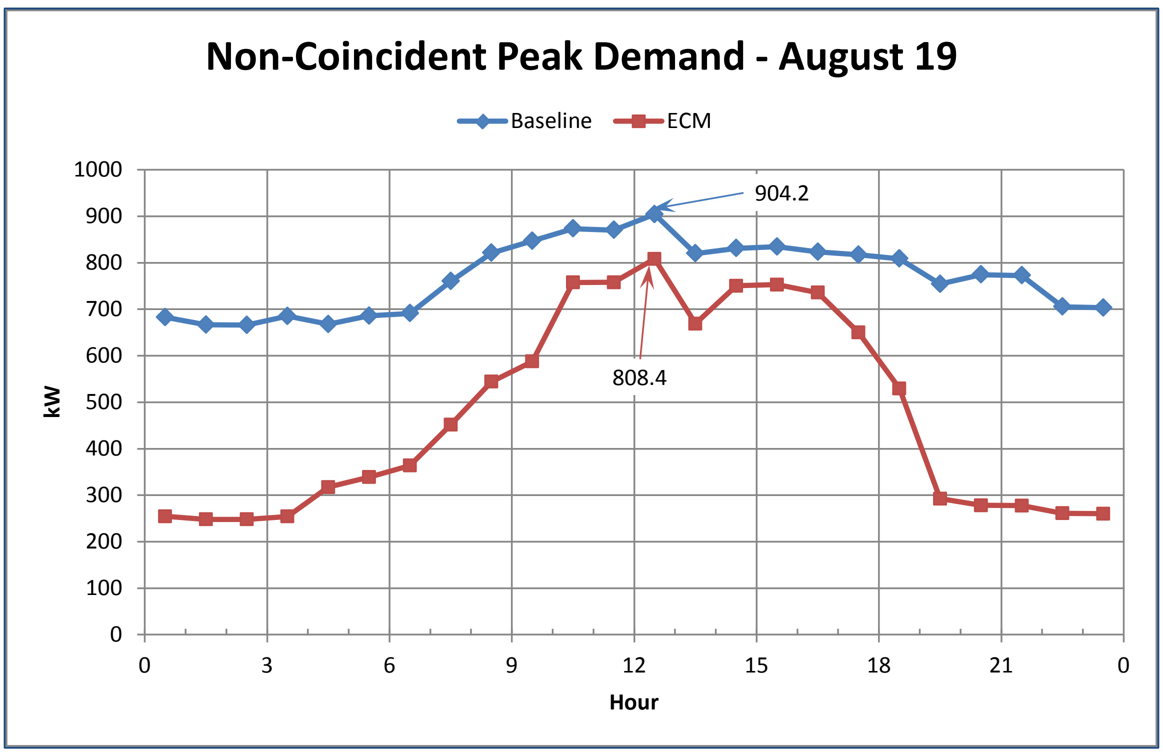

Figure 10: Non-Coincident Peak Demand Day.

[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:

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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.

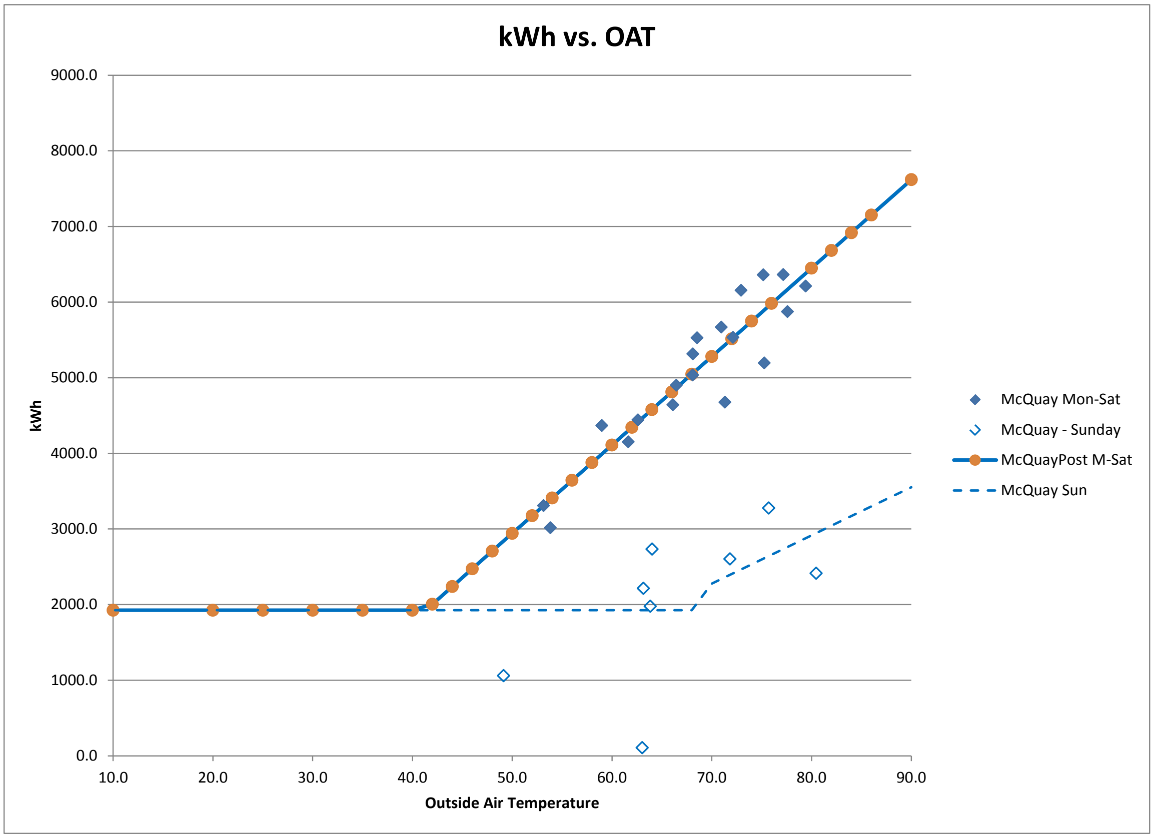

Figure 1

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.

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

40% under 40 OAT (DB) as a constant load to cool the printing presses. Above 40 degrees, the chillers were assumed to follow the linear regressions noted above. A change-point model can be seen in Figure 2 for the York chiller and was modeled that way for the yearly extrapolation.

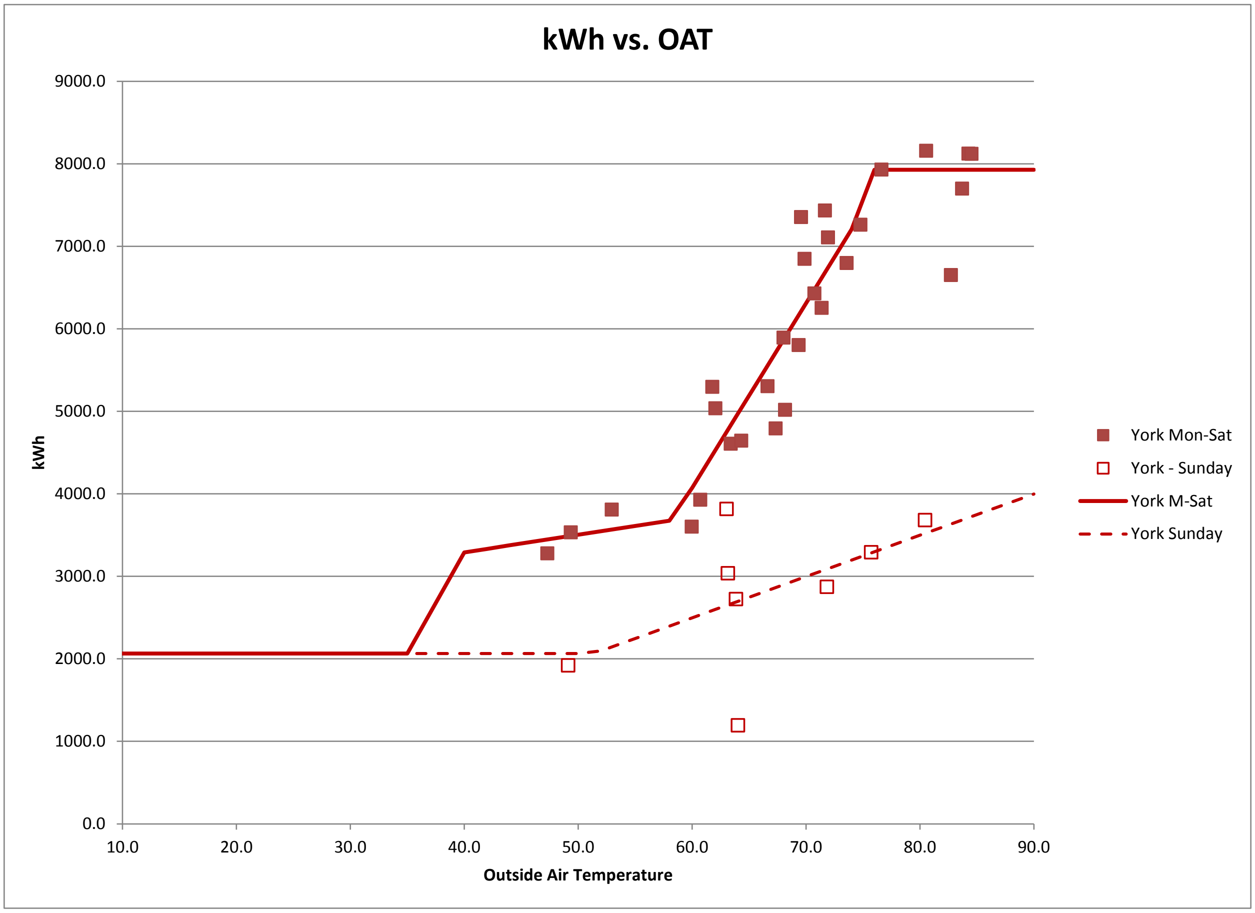

Figure 2

Figure 3 depicts peak kW values for both Pre and Post ECM. Similar to the kWh/day extrapolation, Peak kW/day were extrapolated for the year by substituting TMY3 outside air temperatures (DB) into the hourly linear regression equations. The maximum value of these extrapolations was assumed to be the peak demand.

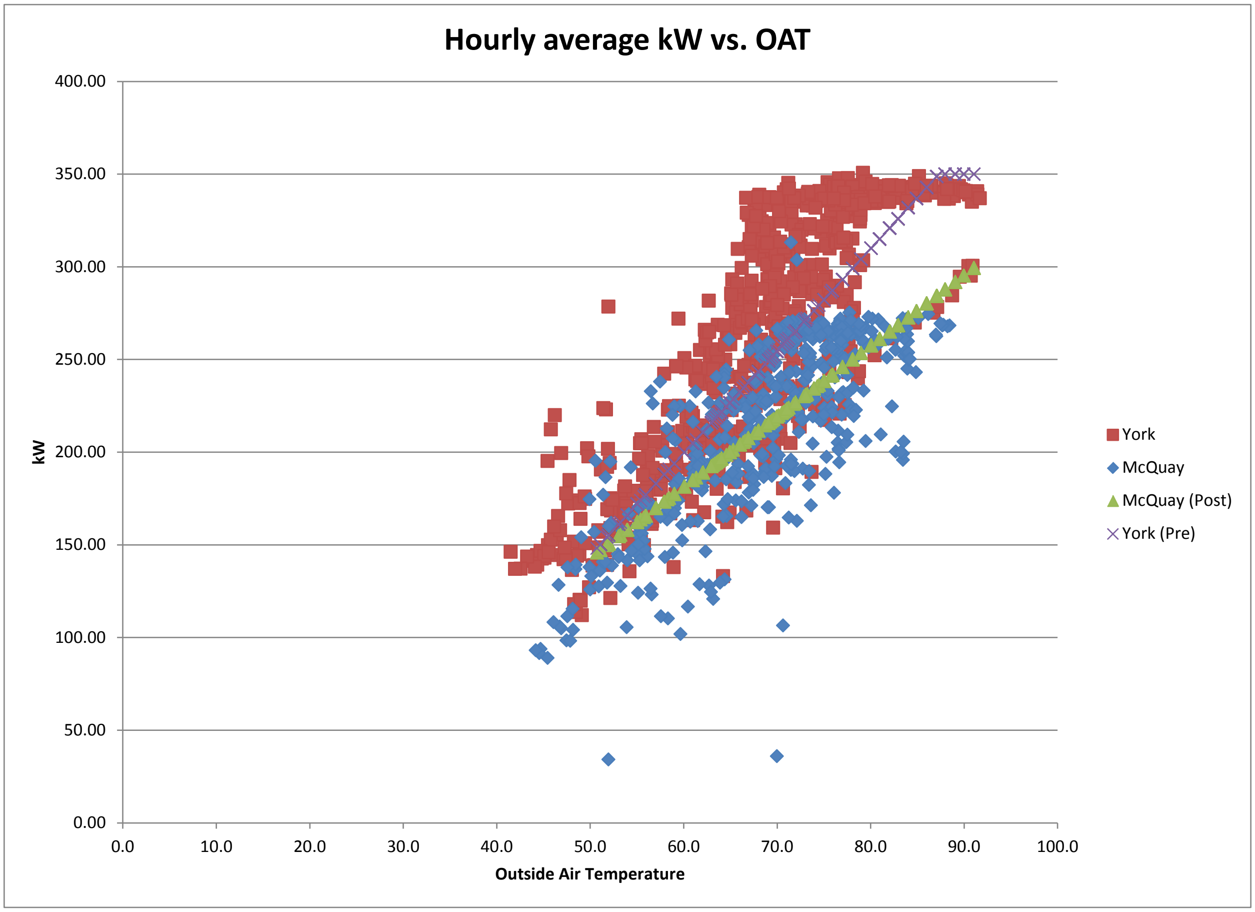

Figure 3. Peak kW values for both Pre and Post ECM

There is very little savings observed between the pre and post chiller demand at low temperatures. Since both the old York and the new McQuay chillers have VFDs, they could benefit from lower condenser water supply temperatures. However, Figure 4 shows that the condenser water temperature setpoint is between 65 and 70F whenever the outdoor wetbulb temperature is below about 62F. Above 62F wetbulb, the condenser water supply temperature is maintained about 5F above the wetbulb temperature.

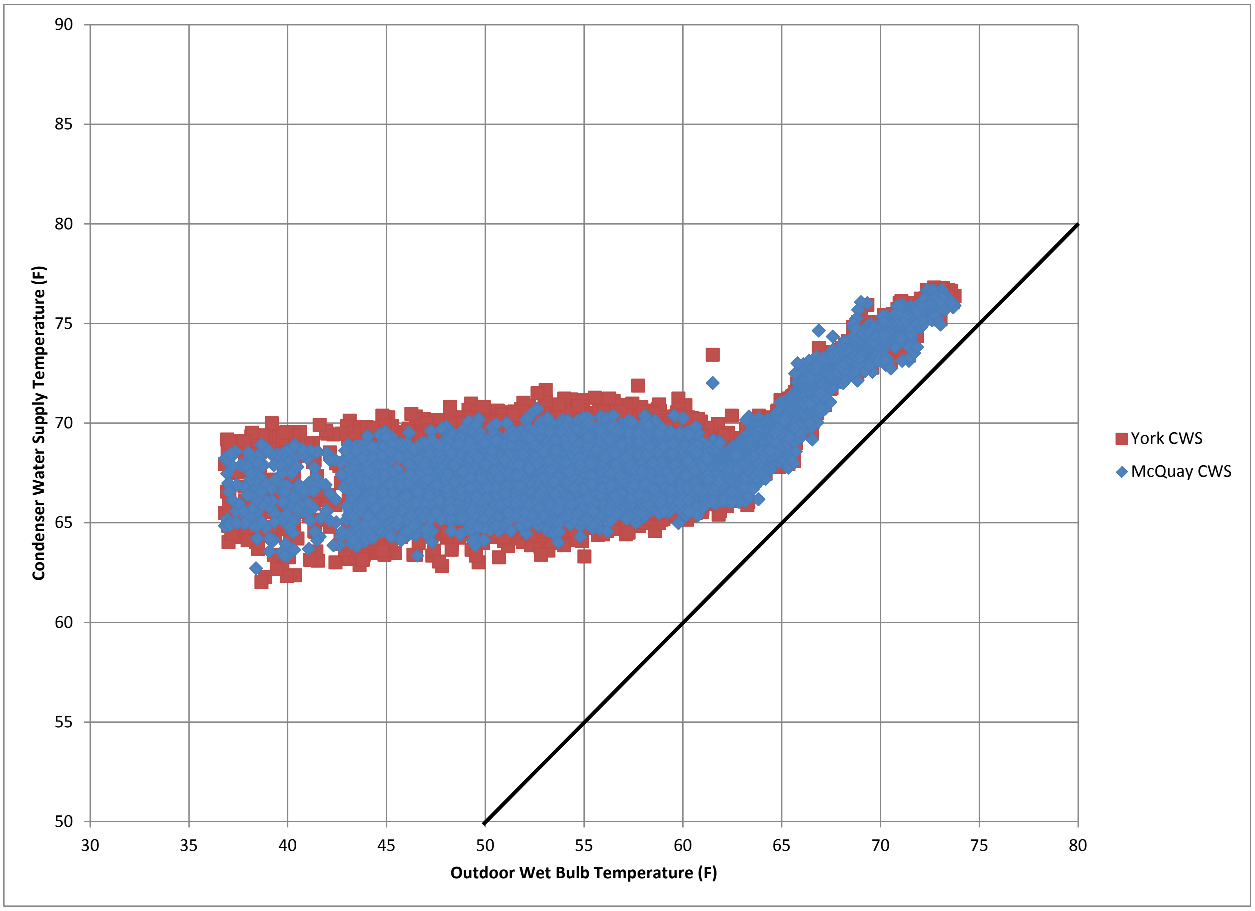

Figure 4. Condenser water supply temperature versus wet bulb temperature

Figure 5 shows the efficiency for both the York and McQuay chillers. At higher outdoor temperatures when the load is generally higher, the McQuay is more efficient. At lower temperatures, however, when the load is lower, the measured efficiency of the McQuay decreases (increase in kW/ton), and is more scattered. On average, the measured efficiency of the McQuay is about 8 percent better than the York at lower temperatures.

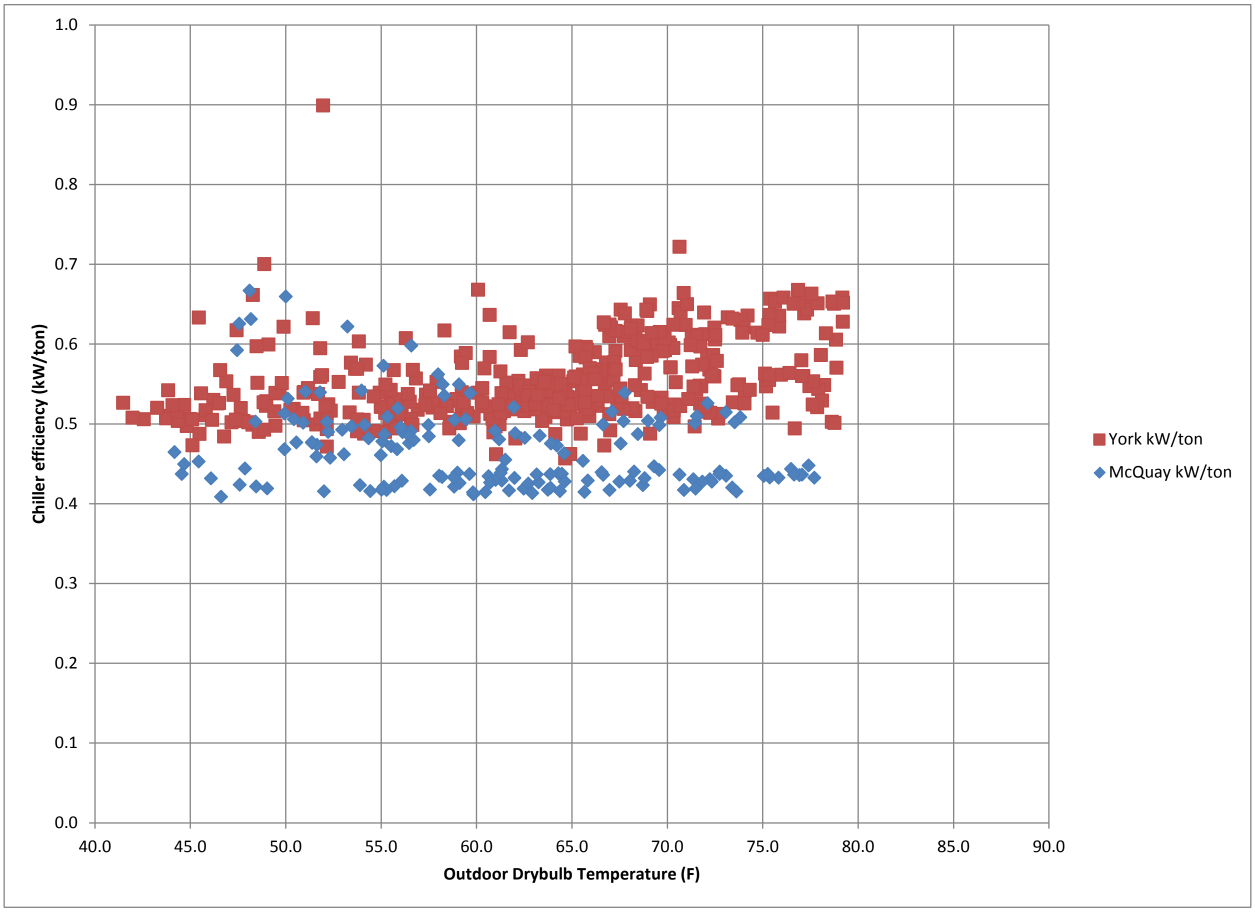

Figure 5. Chiller efficiency versus outdoor drybulb temperature

[Redacted]
Lighting Replacement
M&V Report

Prepared for
Duke Energy Ohio

March 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 the program participants.

Submitted by:

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Introduction

This document addresses M&V activities for the lighting retrofit at [Redacted] that was rebated under Duke Energy's Smart $aver Custom Lighting Incentive program. This facility also participated in the Duke Energy's Smart $aver Prescriptive Lighting Incentive program at the same time as they participated in the custom program. This report only discusses the fixtures that were rebated through the custom program.

Custom Program Lighting						
ECM	**QTY**	**Baseline**	**New**	**Location**	**Description**	**Control**
1	10	150W HPS	42W CFL Wallpack	Outdoor Canopy	Building Mounted	Manual
2	36	175W MH	21W LED Dock lighting	Warehouse Dock Lights	Indoor	Manual
3	1	1L 3' T12	4' 1L T8	Office	Indoor [Redacted] Sign	Manual
4	138	2L 8' T12	4' 4LT8	Warehouse Task lighting	Indoor	Manual
5	3	2L 8' T12	4' 4LT8	Warehouse Task lighting	Indoor	Manual
6	1	2L 8' T8	4' 4LT8	Warehouse Task lighting	Indoor	Manual
7	3	500W Halogen	21W LED Dock lighting	Warehouse Dock Lights	Indoor	Manual

Goals and Objectives

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

The projected savings goals are:

Application Proposed Annual savings (kWh)	Application Proposed Peak Savings (kW)	Duke Projected Savings (kWh)	Duke Projected Peak Savings (kW)
47,185	13	47,429	9.8

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

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

Project Contacts

Duke Energy M&V Admin.	Frankie Diersing	513-287-4096	
Site Contact	[Redacted]	[Redacted]	[Redacted]
AEC Contact	Katie Gustafson	303-459-7430	kgustafson@archenergy.com

Site Locations/ECM's

Address	ECM's Implemented
[Redacted]	1-7

Data Products and Project Output

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

M&V Option

IPMVP Option A

M&V Implementation Schedule

- Post data was collected for a thorough evaluation.
- Survey data was collected during normal operating hours (not during holidays).

Field Data Logging

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

ECM	Hobo (U12)	CTV-A 20A
2 and 7	2	3
4, 5, and 6	2	4
Total	**4**	**7**

Data Accuracy

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

Data Analysis

ECMs Two through Seven Methodology

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

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

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

Where

LF(t) = Lighting Load factor at time = t
$\mathrm{kWControlPoint}_i$ = connected load of control point i
$\mathrm{CurrentControlPoint}_i$ = logged current at control point i from time series data
$\mathrm{ScaleFactor}_i$ = Convert logged current to kW
NLogged = population of logged control points
NControlPoints = population of all control points

- Created separate schedules for weekdays and weekends using LF(t).
- Tabulated average equivalent full load operating hours by day type (e.g. weekday and weekend). Equivalent full load operating hours for each day type were calculated from the time-series LF by averaging the daily average load factor for each day type (0 to 100 percent), and then converting that to an equivalent number of daily operating hours (0-24 hours).
- Extrapolated annual operating hours from the recorded hours of use by day type.

- Generated the load shape by plotting surveyed fixture kW against the actual schedule of post operation for each day type.
- Calculated the energy savings and compared to project application:

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

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

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

Where:

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

ECM 1 Methodology

During the installation site visit the field tech was unable to locate the circuit for the ECM 1 (outdoor canopy) fixtures. In order to determine the savings for this measure we used the following equation.

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

where:

$N_{Fixtures}$	= number of fixtures installed or replaced
$kW_{Fixture}$	= connected load per fixture
HOURS	= Used hours between sunset and sunrise for Cincinnati, OH from the United States Naval Observatory.
NCP $kW_{savings}$	= non-coincident peak savings
CP $kW_{savings}$	= coincident peak savings
CF	= coincidence factor

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 were consistent with the application.

3. Verified that pre-retrofit lighting fixtures were removed from the project
4. Verified electrical voltage of pre and post lighting circuits.

Recording and Data Exchange Format

1. Post-installation Lighting Survey Form and Notes.
2. Hobo logger binary files
3. Excel spreadsheets

Results Summary

The following tables summarize the total estimated savings for the Lifetime Fitness lighting retrofit.

Table 1. Energy Savings and Realization Rates

	Duke Savings	Realized Savings	Realization Rate
		Lighting Only	**Lighting Only**
Energy (kWh)	47,429	71,718	151%
Demand (kW)	9.8	15.1	153%
CP Demand (kW)	4.2	9.8	231%

The savings presented in the application for the measures that were rebated were 13 kW NCP demand savings and 47,185 kWh energy savings. These savings did not take into account interactive effects with the HVAC system. The application does not calculate coincident peak demand savings. It is unclear why there is a difference between the Duke and M&V NCP demand savings, since presumably both used the same fixture watts as used in this report. This difference in NCP demand savings, in addition to the increased operating hours discussed below, both contribute to the difference in energy savings, and consequently, an increased energy realization rate.

- This site did not have any HVAC savings associated with the lighting retrofit because this space is heated with gas and not cooled.
- During the field verification it was found that ECM 3 the 4' 1L T8 fixture for an indoor [Redacted] sign was not installed. The site visit tech as well as the site contact verified this sign had been removed and was no longer onsite. The other ECMs were verified to be installed.
- The verified post kW/fixture for ECMs 4, 5, and 6 is 10% less than the wattage listed in the application. This is contributing to the greater than 100% demand realization rate.
- The realized savings energy savings are greater than Duke projected savings because the verified demand savings are greater than the Duke estimated demand savings. Also, the hours of operation for ECMs 1 and 7 were twice as much as indicated in the project application.

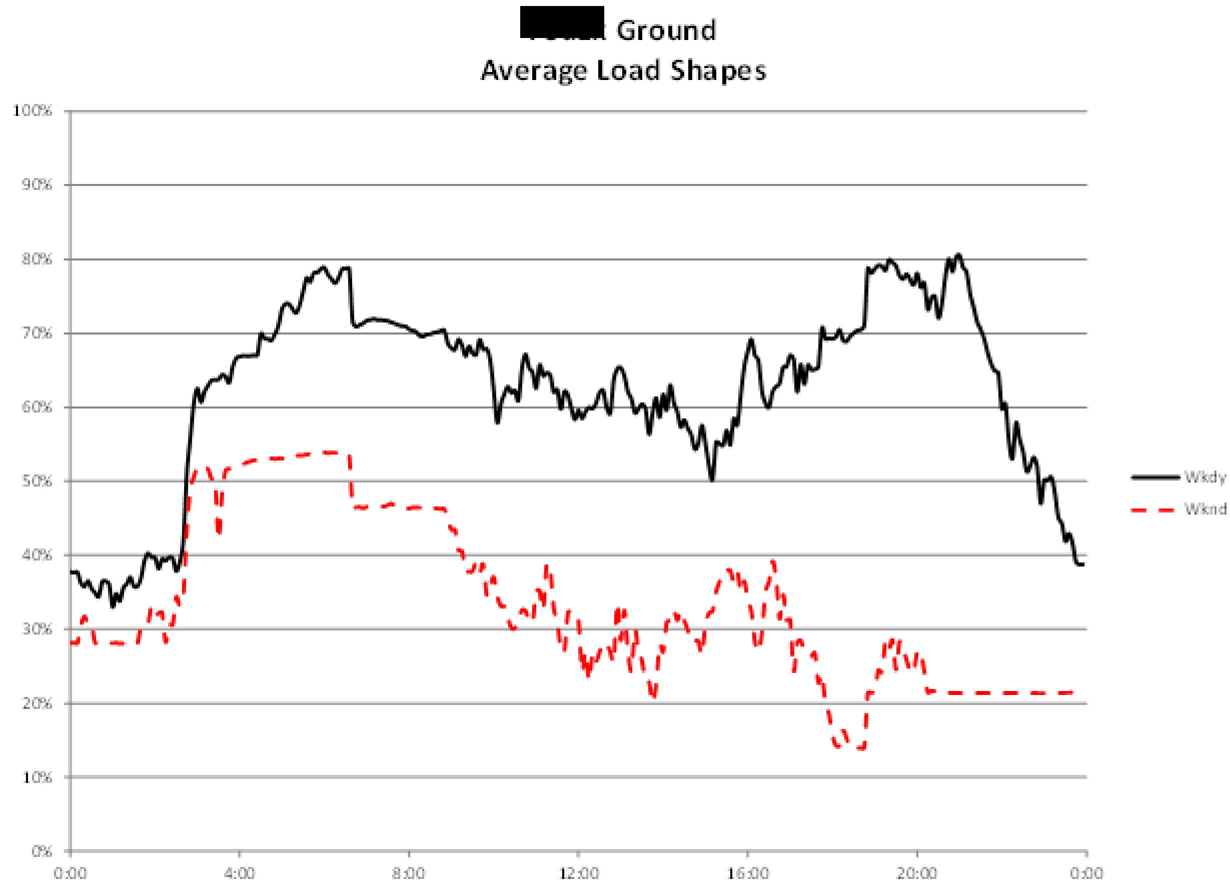
- ECMs 4, 5, and 6 fixture's operating hours are during coincident peak hours which contributes to the greater than 200% coincident peak realization rate.
- The 159 percent realization rate can largely be explained by two factors: operating hours that are 39 percent higher than in the application, and the M&V connected load savings that are about 8 percent greater than in the application.

The energy and demand savings calculation summary is shown in Table 2. Demand savings details are shown in Table 3 and the application fixture wattage are shown in Table 4 at the end of this report.

Table 2. Summary of Energy and Demand Savings Calculations

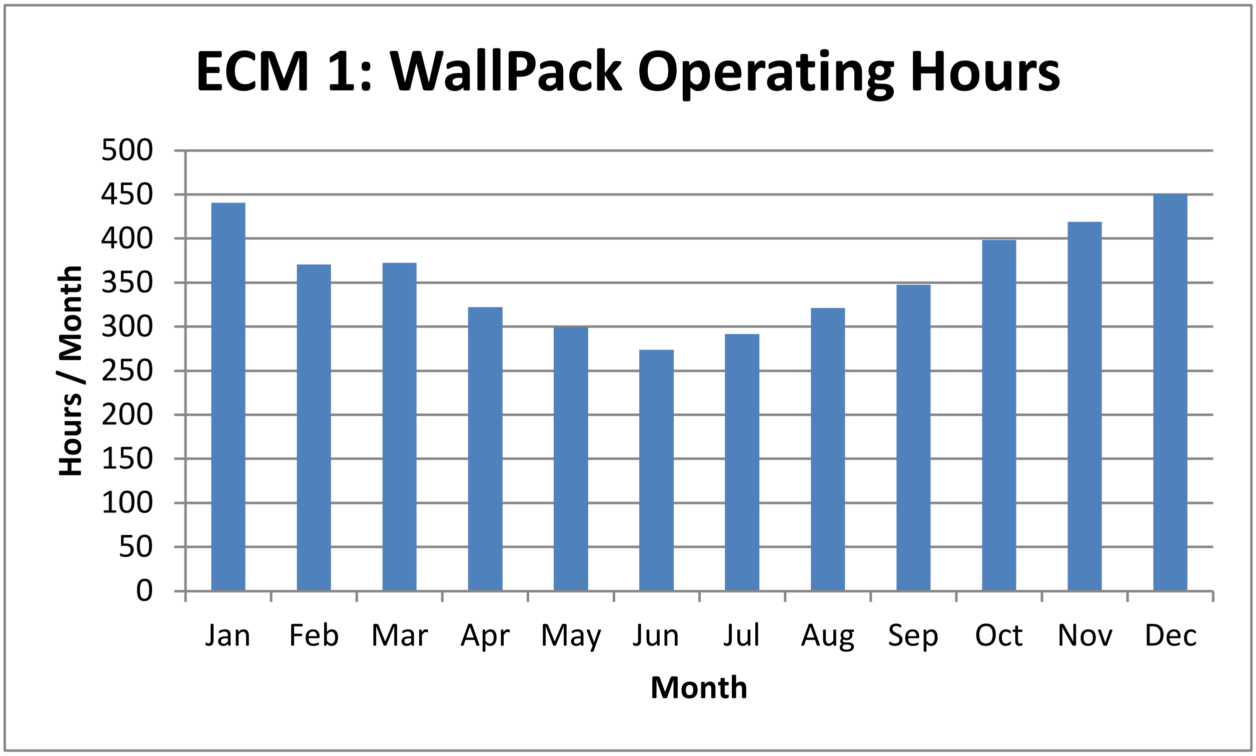
Base kW	EE kW	HOURS	CF	Lighting Only			With HVAC interactions WHFe= 0.0 WHFd= 0.0		
				kWh savings	NCP kW	CP kW	kWh savings	NCP kW	CP kW
28.6	13.4	4734.1	0.65	71,718	15.1	9.8	71,718	15.1	9.8

The following figure shows the average daily load shape. When extrapolated to the year, the annual operating hours are 4,734.1, which are 39 percent greater than the hours stated in the application, which contributes to a realization rate greater than 100 percent.

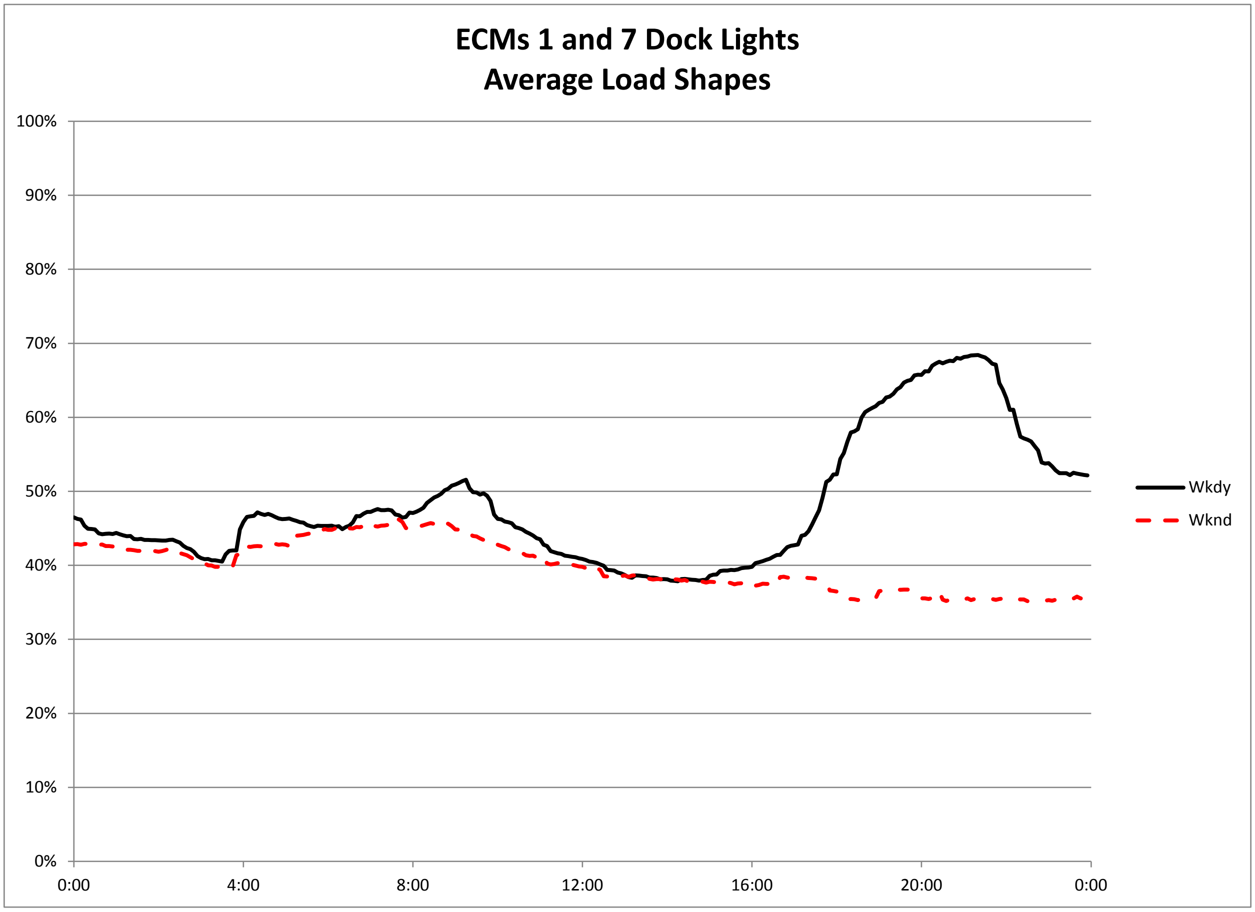


To calculate the total savings for the ECMs at [Redacted] we separately analyzed the savings for like fixtures. We then added the savings from each analysis together to determine the total project savings and realization rate. We calculated the savings separately because there were three different control types for the new fixtures. ECM1 consists of outdoor lighting wallpacks that are controlled with a photocell, ECMs 2 and 3 are LED loading dock lights controlled with manual switches, and ECMs 4, 5, and 6 are controlled with occupancy sensors. Since the occupancy sensors were not rebated under the custom program, a pre-occupancy sensor load shape was developed based on the monitored data and the expected operation of these fixtures without occupancy sensors. To develop the average load shape for the custom retrofit fixtures, we took a weighted average of the load shapes for each analysis.

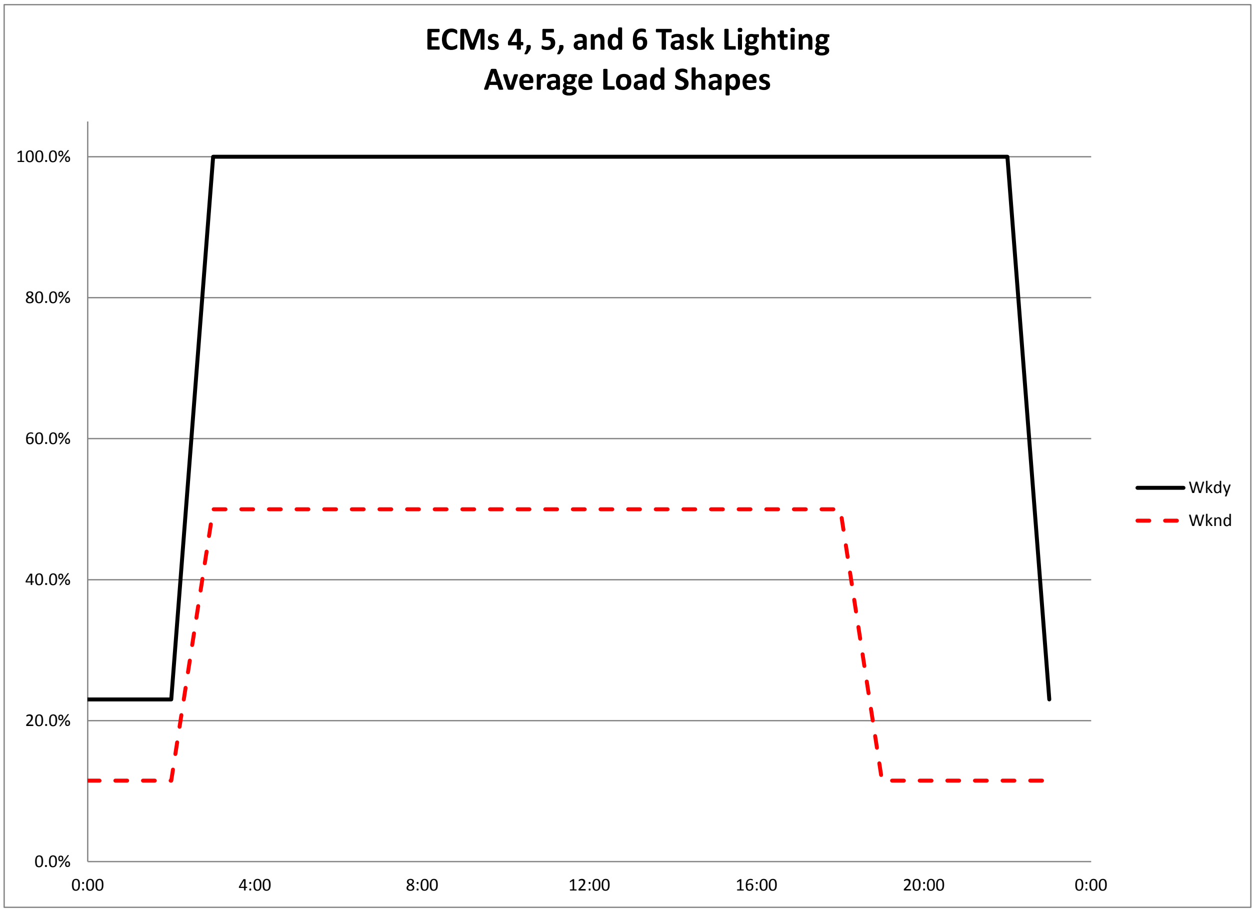
The following figures show the load shapes for each fixture type.



Because the operating hours of the outdoor lighting fixtures that are controlled by photocells varies throughout the year, monthly operating hours are shown in lieu of a daily load shape.



The dock lights are switched on and off by truck drivers as they are needed. The lights are not visible from the inside and it appears from the monitored data that the fixtures are unintentionally left on for extended periods of time.



When the task lighting was retrofitted, occupancy sensors were installed to control the new fixtures. The occupancy sensors were rebated through Duke Energy's Smart $aver Prescriptive Lighting Incentive program. To determine the savings from the lighting retrofit, excluding the savings associated with the occupancy sensors, we developed the above load shapes based off of the operating schedule determined from the monitored data.

Table 3. Demand Savings Detail

ECM	EE Technology					Base Technology				
	Quantity	EE Fixture Type	W/ Fixture	Source	Connected kW	Quantity	Base Fixture Type	W/ Fixture	Source	Connected kW
1	10	42W CFL Wallpack	42	Cut sheet	0.4	10	150W HPS	188	SPC Apdx B	1.9
2	36	21W LED Dock lighting	21	Cut sheet	0.8	36	175W MH	208	SPC Apdx B	7.5
4	138	4' 4LT8	85.8	Spot Measure	11.8	138	2L 8' T12 Mag	123	OH TRM	17.0
5	3	4' 4LT8	85.8	Spot Measure	0.3	3	2L 8' T12 HO	207	SPC Apdx B	0.6
6	1	4' 4LT8	85.8	Spot Measure	0.1	1	2L 8' T8	109	OH TRM	0.1
7	3	21W LED Dock lighting	21	Cut sheet	0.1	3	500W Halogen	500	SPC Apdx B	1.5
Total					13.4					28.6

Notes

1. OH TRM - State of Ohio Energy Efficiency Technical Reference Manual. See http://amppartners.org/pdf/TRM_Appendix_E_2011.pdf
2. SPC Apdx B – Appendix B 2013-14 Table of Standard Fixture Wattages. See http://www.aesc-inc.com/download/spc/2013SPCDocs/PGE/App%20B%20Standard%20Fixture%20Watts.pdf

Table 4. Application Fixture Wattages

ECM1	Application EE Fixture Watts	Application Base Fixture Watts
1	46	188
2	21	215
4	95	123
5	95	207
6	95	109
7	21	500

[Redacted][Redacted] Dry Cooler Retrofit 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 program participant.

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Introduction

This report addresses the evaluation results for the [Redacted] custom program application. The application covers the implementation of a dry cooler for purposes of eliminating chiller operation during outdoor temperatures less than nominally 50F.

Note: The measure already has been installed and implemented. Field logging was post install only.

The measure includes:

ECM-1 – Dry Cooler

- Install dry cooler that will be the first stage of process cooling. The dry cooler is sized so that any time the ambient temperatures are below 50F, chiller operation is eliminated.

Goals and Objectives

The projected savings goals identified in the application are:

ECM	Application Proposed Annual savings (kWh)	Application Proposed Target Impact (kW)	Duke Projected savings (kWh)	Duke Projected Target Impact (kW)
Dry Cooler	**519,095**	**0**	**649,824**	**0**

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

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

Project Contacts

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Customer Contact	[Redacted]	[Redacted]
Architectural Energy Corporation Contact	Stuart Waterbury	p: 303-459-7417 swaterbury@archenergy.com

Site Locations/ECM's

Site	Address	ECM's Implemented
[Redacted]	[Redacted]	1

Data Products and Project Output

- Average pre-/post- demand / consumption models for the chiller and dry cooler
- Pre- and post-energy consumption for the chiller and dry cooler
- Annual Energy Savings
- Peak Demand Savings
- Coincident Peak Demand Savings

M&V Option

IPMVP Option A

M&V Implementation Schedule

Note: Since the baseline chillers were supplemented by a new chiller in June of 2013, data collection occurred during two trips. The first trip collected chiller power data and survey information. The second trip was primarily intended to collect dry cooler data since it was not operating to a great extent during the first trip, due to the high outdoor temperatures.

- Obtain pre-retrofit (prior to dry cooler installation) sequence of operations for the process chillers.
- Obtain and verify the post-retrofit sequence of operations documentation for the chiller and dry cooler.
- Evaluate the configuration of the chilled water pumps that circulate through the chiller(s) and dry cooler. Determine if the pumping configuration with and without the dry cooler will affect the chilled water pump power draw.
- Verify that all equipment affected by the measure is working properly.
- Confirm the installation schedule and sequence of operations for the new 250-ton chiller, to be installed in June of 2013. Note that the 250-ton chiller installation is not part of this evaluation.
- Monitoring trip 1 (June 2013): Performed logging as specified in Field Data Logging section below.
- Monitoring trip 2 (November 2013): Perform logging as specified in Field Data Logging section below. The 155-ton chiller was still onsite during this logging period, but did not operate. The 250-ton chiller was installed and was the primary chiller.
- Evaluate the energy impacts of the dry cooler retrofit.

Field Survey Points

Post-Installation

Survey data

- Dry cooler and chiller nameplate data.
- Chiller and dry cooler operating schedule, including weekdays, weekends, and holidays.
- Chiller and dry cooler sequence of operations.

- Production schedule. Also, surveyed plant operators to determine if there are any variations in output that would increase or decrease production cooling load.
- One-time power measurements of the equipment listed below.
    - o Chiller 1 power (155-ton chiller)
    - o Chiller 2 power (110-ton chiller
    - o Chiller 3 power (250-ton chiller, installed in June of 2013)
    - o Chilled water pump
    - o Dry cooler fan power
    - o Dry cooler circulation pump power
    - o Dry cooler sump heater

Data Accuracy

Measurement	Sensor	Accuracy	Notes
Temperature	Hobo thermistor	±0.5F°	
Current	Magnelab CT	±1%	> 10% of rating
True electric power	ElitePro	±1%	

Field Data Logging

The field data logging occurred during two periods. The purposes of each logging period were as follows:

- **Logging period 1 (June 6 – June 25, 2013):**
  Monitored the baseline 110-ton and 155-ton chillers to determine their performance before they were replaced / supplemented by the new 250-ton chiller that is not part of this incentive. The dry cooler was also monitored during this period, according to the table below. During this period, confirmed the replacement schedule for the new chiller, and the intended sequence of operation for the new chiller.

  Deployed loggers to measure the following:
    - Outdoor air temperature and relative humidity.
    - Chiller kW on chiller 1 and chiller 2.
    - Chilled water pump current.
    - Dry cooler fan kW (40 hp). (Application info: runs between 40 and 50F)
    - Dry cooler pump current. (5 hp) (Application info: runs between 35 and 50F)

- **Logging period 2: (November 6 – November 25, 2013)**
  Late Fall logging provided more information on the dry cooler performance, during the lower outdoor temperatures. The dry cooler, pumps, and chillers were monitored as listed below.
    - Outdoor air temperature and relative humidity.
    - Chiller kW on new 250-ton chiller, and 110-ton and 155-ton chillers that were logged during Logging Period 1.
    - Chilled water pump current.

- Dry cooler fan kW (40 hp). (Application info: runs between 40 and 50F)
- Dry cooler pump current. (5 hp) (Application info: runs between 35 and 50F)
- Sump heater current.

For both logging periods, the Elite Pro loggers were set up to record the following information:

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

Logger Table

The following table summarizes all logging equipment that was used to measure the above noted ECMs:

ECM	Elite-Pro	500 amp CT	100 amp CT	Hobo	20-amp Hobo CTs	Weather Station
Chiller 1 kW	1	3				
Chiller 2 kW	1	3				
New Chiller (250T)	1	3				
Chilled water pump				1	1	
Dry cooler fan	1		3			
Dry cooler pump				1	1	
Outdoor TDB, RH						1
Totals	**4**	**9**	**3**	**2**	**2**	**1**

Data Analysis

- Originally, based on the sequence of operation listed in the application and the survey information gathered during site visits, the analysis was going to be restricted to outdoor temperatures below 50F, since the dry cooler was supposed to operate only at temperatures below 50F. Above 50F, the plant was to operate with chillers only. However, the data indicate that the dry cooler does operate, on average, up to 65F. Therefore, the analysis will be restricted to temperatures below 65F. The dry cooler will have no impact on load whenever the outdoor temperature is nominally above 65F.

- Process load: The application notes state that the processing cooling load is constant throughout the year.
  The data indicate that the load does vary from weekdays to weekends, and that the load is lower during some of the night-time hours.

- **Pre-retrofit condition:**

  - o Based on the initial logging period with the original chiller plant, determined the chiller demand, with special attention to periods when the dry cooler was not operating and the outdoor temperature is relatively low (around 65F). Using DOE2 chiller curves, developed a regression for the 110T and 155T chillers for low outdoor temperature chiller performance.

- **Post-retrofit conditions:**
  - o From the logged data, confirmed the sequence of operation for the dry cooler fan, pump, and sump heater. At no time during the monitoring period did the sump heater operate, even though outdoor temperatures were as low as 17F.

- **Savings calculations:**
  - o Compare the pre- and post-retrofit kWh and kW to determine savings.
  - o Using TMY3 data, calculate the hourly demand for the pre and post-retrofit conditions, restricting the savings calculations to hourly outdoor temperatures below 65F.

Verification and Quality Control

1. Visually inspect logger data for consistent operation. Sort by day type and remove invalid data. Look for data out of range and data combinations that are physically impossible.
2. Verify post retrofit equipment specifications are consistent with the application. If they are not consistent, record discrepancies.
3. Verify electrical voltage of equipment circuits.

Recording and Data Exchange Format

1. Post-installation Survey Form and Notes.
2. Hobo/Elite Pro logger binary files (post)
3. Excel spreadsheets

Results Summary

This section expands on the discussion in the data analysis section by presenting the monitored data, models where comparable to the monitored data, and the final savings results.

The dry cooler sequence of operation outlined in the application, is listed below in Table 1. The observed sequence of operation is shown later in Table 2.

Table 1. Application and Survey sequence of operations

OAT	Chiller operation	Dry cooler fan	Dry cooler circulation pump
Below 35	Off	Off	Off
35-40	Off	Off	On
40-50	Off	On	On
50-80	On	On	On
Above 80	On	Off	Off

The dry cooler fan and pump operate whenever the outdoor temperature is below about 65F, as shown in Figure 1. This is in contrast to the expected sequence of operation listed above. The fan modulates somewhat as the outdoor temperature decreases, but the pump never shuts off when the dry cooler is in operation, regardless of the outdoor temperature.

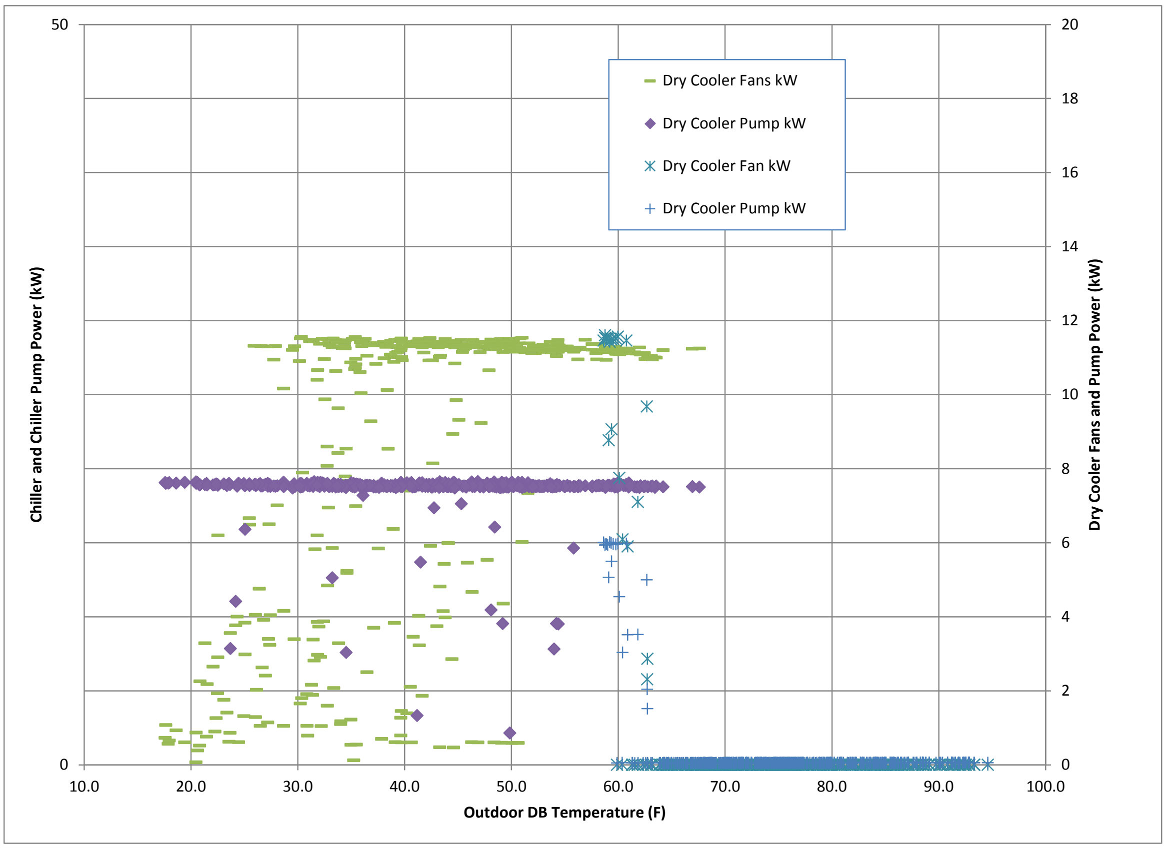

Figure 1. Dry cooler operation versus outdoor temperature

The observed sequence of operation is shown below.

Table 2. Observed sequence of operations

OAT	Chiller operation	Dry cooler fan	Dry cooler circulation pump
15-65F	On at 45F and above	On	On
Above 65F	On	Off	Off

There are a few significant differences between the expected and actual sequence of operation: First, the dry cooler circulation pump is operating whenever the dry cooler fan is on. Also, the dry cooler fans do not shut down at lower outdoor temperatures. Finally, there is some chiller operation observed as low as 45F, as shown in Figure 2. Figure 2 shows both the June and November monitoring periods: the 250-ton chiller operates during the November period, and the 110-ton and 155-ton chillers operate during the June monitoring period.

All of these differences between the expected and actual sequence of operation will increase the post-retrofit consumption, and consequently reduce the savings.

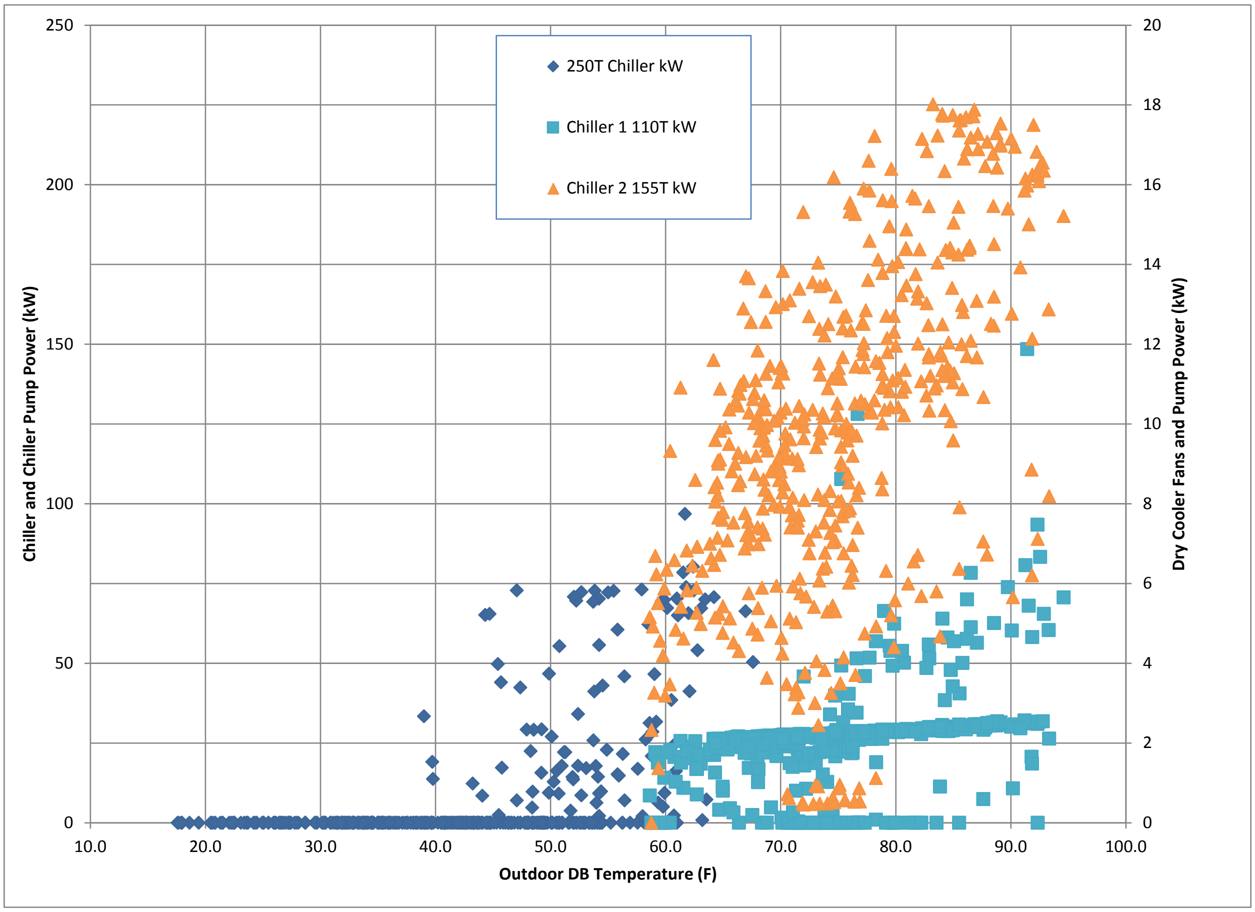

Figure 2. Weekday daytime chiller operation

As stated earlier, in contrast to what was stated in the application and recorded during the survey interview, the load has some variation between day and night, and weekdays and weekends. Figure 3 shows average daily profiles for the pre-retrofit chillers. Although these profiles are somewhat smoothed by averaging multiple days, the important observation is a distinct difference between weekdays and weekends, and a relatively sharp drop in demand during the night time hours.

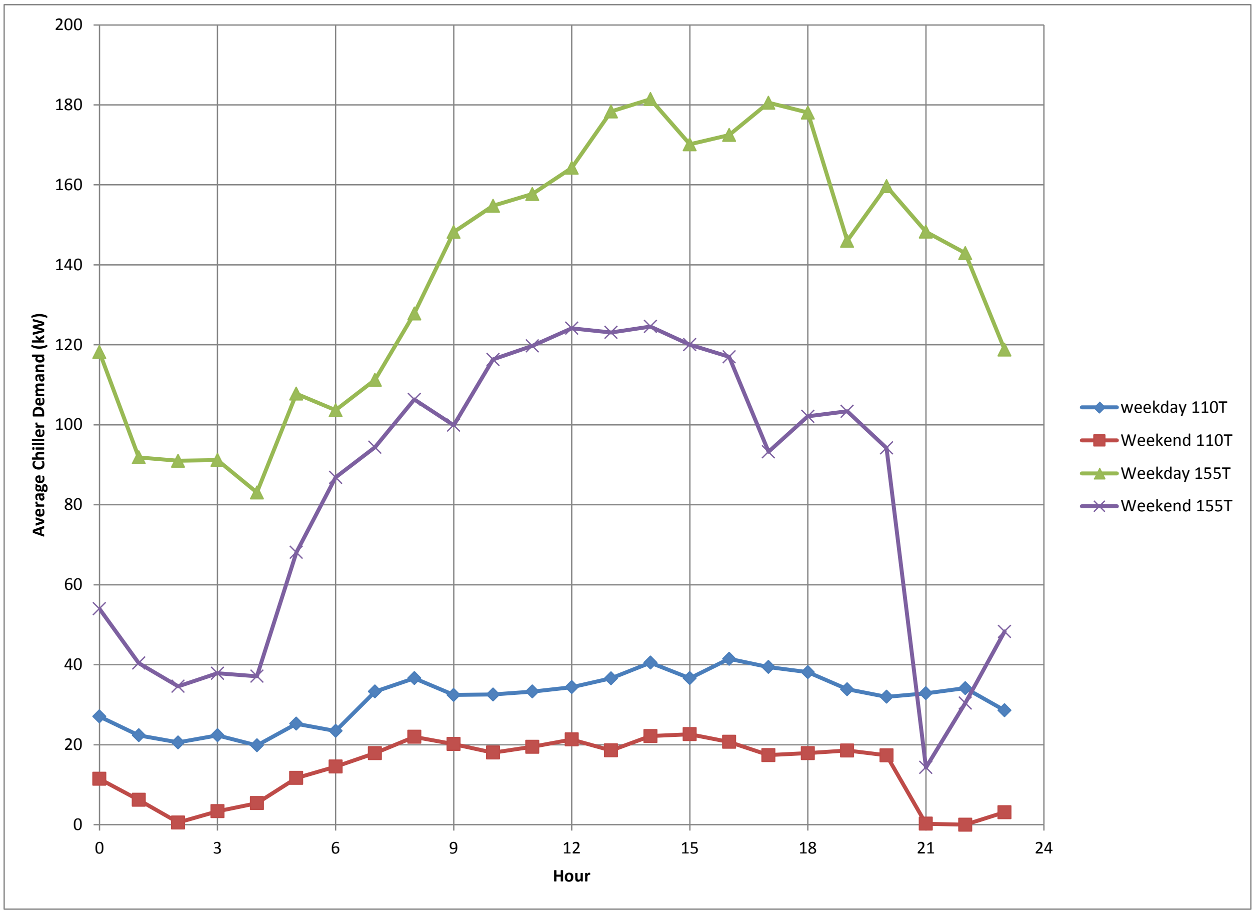

Figure 3. Average daily chiller profiles

All of the above results were used to create multiple regressions for each chiller for different day types and different day periods (day and night). The post-retrofit results of these regressions are shown in Figure 4, which show the monitored and modeled post-retrofit chiller performance. During the post-retrofit case, the 155-ton chiller did not operate. Instead, the new, more efficient 250-ton chiller, which is not part of this ECM, provided all of the chiller cooling. Since it is somewhat more efficient than the combination of the 110-ton reciprocating chiller and the 155-ton rotary chiller, the modeled data draws more power, on average, than the measured data from the more efficient chiller. The multiple groups of modeled data are the result of the different day types and day periods.

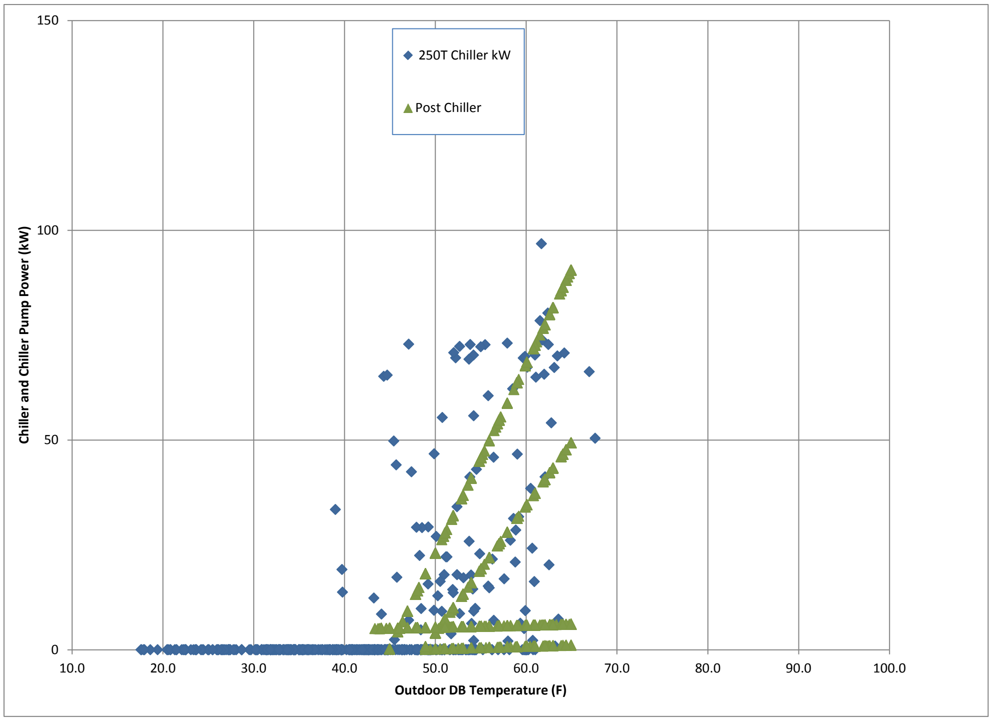

Figure 4. Post chiller monitored data and model

A summary of the savings are shown below in Table 3, and in Figure 5. The last column in the table indicates the percent of time in each month that the outdoor temperature was below 65F, when the dry cooler could operate. Since there is no difference between the pre and post cases above 65F, they are not included in the analysis.

Table 3. Savings Summary

Month	Avg OAT (F)	Post Dry Cooler Fan (kWh)	Dry cooler pump (kWh)	Post Chiller (kWh)	Post Chiller Pump (kWh)	Pre Chiller (kWh)	Pre Chiller Pump (kWh)	Savings (kWh)	Percent of month suitable for dry cooler operation
1	31.6	5,744	5,453	649	9,687	91,811	9,687	79,965	100%
2	32.1	5,131	4,710	2,723	8,736	82,528	8,736	69,964	100%
3	42.7	6,361	5,430	7,483	9,466	90,178	9,466	70,904	98%
4	56.4	5,911	4,335	15,139	7,526	72,533	7,526	47,149	80%
5	63.2	4,424	3,090	12,399	5,364	51,618	5,364	31,706	55%
6	68.1	2,992	2,055	7,142	3,567	32,828	3,567	20,639	38%
7	77.3	611	413	1,132	716	6,100	716	3,944	7%
8	73.9	1,465	990	3,165	1,719	15,050	1,719	9,430	18%
9	65.1	3,393	2,423	8,895	4,205	40,784	4,205	26,074	45%
10	53.7	6,432	4,710	11,270	8,177	79,267	8,177	56,854	84%
11	47.9	6,436	5,078	11,630	8,815	85,152	8,815	62,009	94%
12	36.3	6,294	5,483	3,322	9,687	92,536	9,687	77,437	100%

Total								**556,075**	

Figure 5 shows the temperature dependence of the savings. As expected, the savings are greatest at low temperatures when the chiller is completely off. As the outdoor temperature increases, the daily savings decrease. Some daily savings are shown even when the average daily outdoor temperature is above 65F because of the diurnal variation in hourly temperatures, i.e., some hours had outdoor temperatures below 65F even though the daily average could be above 65F.

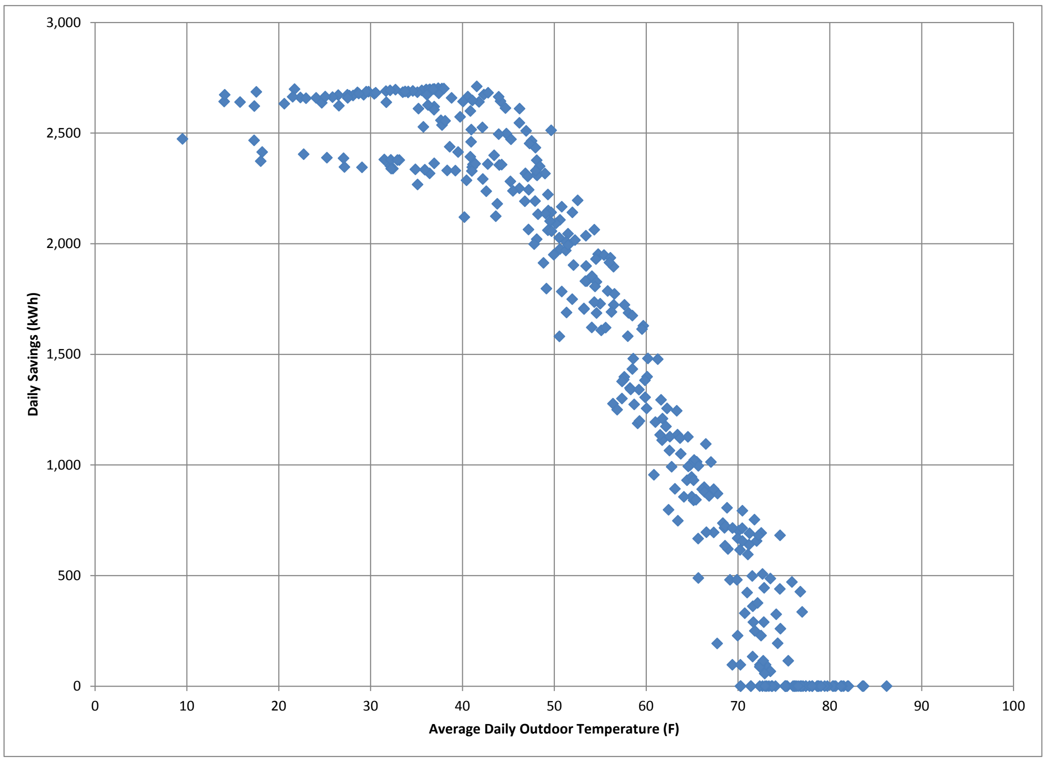

Figure 5. Daily Savings

Since this ECM only provides savings during cold weather, coincident peak demand savings weren't expected, nor were they observed. However, there are winter non-coincident peak demand savings of 123 kW.

The realization rate for this ECM 79 percent, as shown below in Table 4. The realization rate is are somewhat lower than expected, but this is likely due to the increased dry cooler fan and pump operation at low temperatures, and more chiller operation at low temperatures in the post-retrofit case.

Table 4. Realization rate

M&V Energy Savings	556,075
Duke Projected Savings	**649,824**

Energy Realization Rate	**86%**

[Redacted]
Air Compressor Upgrade
M&V Report

Prepared for
Duke Energy Ohio

March 2015, v1.0

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].

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Introduction

This report addresses M&V activities for the [REDACTED] Compressor custom program application. The application covers a new compressor upgrade in Cincinnati, Ohio. The measure includes the following:

ECM-1: Air Compressor Replacement

- Replace an existing 200 HP air compressor that is towards the end of its useful life (5 years remaining) with a new 150 HP variable speed compressor.
- Existing compressor will become a backup unit.

Note: The ECM has already been implemented. However, after the new compressor was monitored, the site agreed to operate the old compressor temporarily to help us establish a baseline. Thus, both pre- and post-retrofit measurements were taken.

Goals and Objectives

The projected savings goals identified in the application are:

Application Annual Savings (kWh)	Application Annual Savings (kW)	Duke Projected Annual Savings (kWh)	Duke Projected Non-Coincident Peak Savings (kW)	Duke Projected Coincident Peak Savings (kW)
612,610	0	612,650	69.9	69.9

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

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

Project Contacts

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Site Locations/ECM's

Address
[Redacted]

Data Products and Project Output

- Average pre-replacement and post- replacement load shapes by day-type for controlled equipment
- Peak demand savings
- Coincident peak demand savings
- Annual energy savings

M&V Option

IPMVP Option B

M&V Implementation Schedule

- Surveyed site personnel to obtain information on system operations.
    - Obtained the pre-retrofit sequence of operations and/or operating schedule for the compressed air system.
    - Obtained and verified the post-retrofit sequence of operations and/or operating schedule for the new compressed air system.
    - NOTED any differences between pre- and post-retrofit operations resulting from changes in production or operating schedules.

    - Obtained the facility's holiday schedule.
- Deployed a data logger to record electrical parameters on the new compressor. This data was used to determine the post-retrofit load shape and energy consumption.
    - Collected data during normal operating hours (avoided atypical operating situations such as maintenance shutdowns).
- Evaluated the energy savings of the compressor replacement.

Data Accuracy

Measurement	Sensor	Accuracy	Notes
Current	DENT Split-Core CT	±1%	Recorded load must be < 130% and >10% of CT rating
kW	Dent ElitePro	±1%	

Field Data Points

Post – installation

Survey data (for the new compressor)

- Compressor make/model
- Photographs of compressors.

Time series data on the both the old and new compressors.

- Compressor volts, amps, kW, kVA, kVAR, and power factor.

Field Data Logging

Post – installation

ECM-1

- Spot measured all controlled compressors voltage, amps, power factor and power.
- If available from plant instrumentation, record compressed air delivered flow (CFM) and pressure coinciding with the above electrical measurements. *Not available.*
- Installed one ElitePro power/energy data logger on the existing compressor.

- Set up the logger to monitor voltage, amps, power factor and compressor power (kW, kVA & kVAR) on each leg, and to totalize same (on Channel 5).
- If power trending is available from plant instrumentation, record kW for each compressor in place of installing ElitePro loggers. *Not available.*
- Set up logger for 5 minute readings. Deployed for 3 weeks.
- Following the data collection for the new compressor, the data logger was re-installed on the old compressor and that compressor was operated for five days to establish a baseline.

Logger Table

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

Compressor	ElitePro Energy Logger	Magnelab 500A CT*
150 HP	1	3
200 HP	1	3
Total	**2**	**6**

Data Analysis

1. Converted post-retrofit time series data on the new compressor into average kWh-based load shapes by day type to establish post-retrofit energy consumption. The following equations show how the post-retrofit annual energy consumption (kWh) was determined:

   First:

   $$kWh_{interval} = kW_{interval} * (5 \text{ min/interval}) / (60 \text{ min/hour})$$

   Then:

   $$\frac{kWh}{year_{weekdays}} = \sum_i kWh_i \times \frac{weekdays\_per\_year}{weekdays\_monitored}$$

   $$\frac{kWh}{year_{weekend-days}} = \sum_i kWh_i \times \frac{weekend-days\_per\_year}{weekend-days\_monitored}$$

$$\frac{kWh}{year} = \frac{kWh}{year}_{weekdays} + \frac{kWh}{year}_{weekend-days}$$

2. Determined the new compressor's maximum power (kW), and the maximum coincident power (kW), in the measured data.

3. Using additional time series data for the old compressor and the method described in Step 1, estimated the annual energy consumption of the old compressor.

4. Review application baseline calculations for errors that could affect originally-predicted baseline and proposed energy usage and energy savings. This review will help explain any differences between predicted and monitored/verified energy savings.

5. Determined the annual baseline energy consumption (kWh), maximum power (kW), and the maximum coincident power (kW) for the old compressor.

6. It was not necessary to normalize the pre-retrofit energy consumption value for changes in production or year-to-year operation, or for changes in system pressure. The conditions are the same in the post-retrofit operation.

7. Calculated the annual energy savings. The annual energy saved (kWh) is the difference in the calculated pre- and post-retrofit energy consumptions described above.

8. Estimated coincident peak demand savings. 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 estimated as the maximum demand observed in the 4-5 PM hour on any weekday of the monitoring period.

9. Estimated peak demand savings. For this application, both kW_{post} and kW_{pre} were determined from monitored data. The demand savings is then calculated by:

$$kW_{saved} = kW_{pre} - kW_{post}$$

10. Compared the calculated energy and coincident demand savings to Duke-projected savings and calculated the realization rates.

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 pre-retrofit and post retrofit equipment specifications and quantities are consistent with the application.

3. Verified electrical voltage of equipment circuits.

Recording and Data Exchange Format

1. Elite Pro data logger files
2. Excel spreadsheets.

Results

The operating power of the new air compressor was monitored with a data logger for over three weeks. The following chart shows the logged total power value of the compressor. The data shows that the VFD is doing a good job of reducing the power required to operate the system, with minimum power levels reduced by as much as 43% from the peak value.

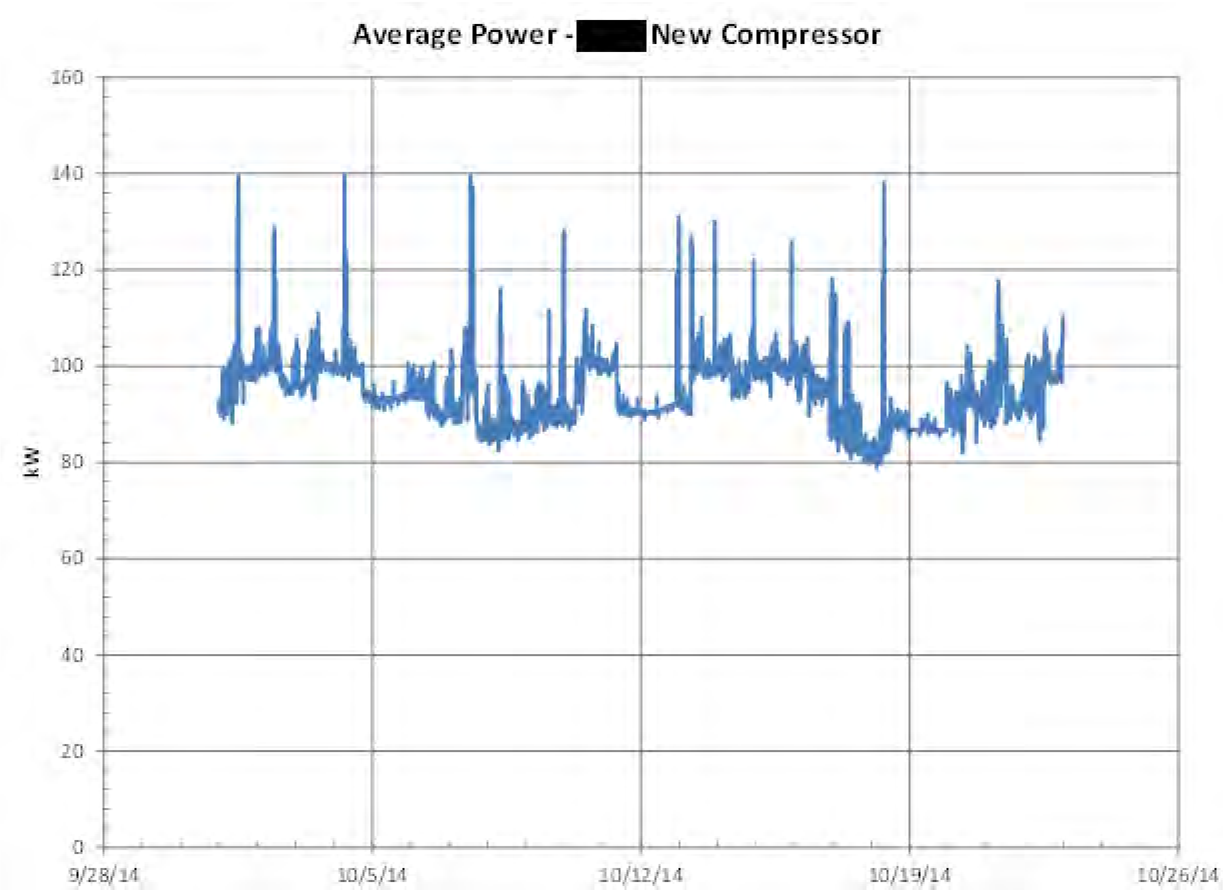

Figure 1: Monitored Power Readings – New Compressor

The old compressor was still on site and was monitored for five days after the new compressor was monitored. The site agreed to operate the old compressor temporarily to help us establish a baseline. Its power history is shown in the following figure. The data shows that the compressor operated at a slightly higher power level at its peak, and generally operated much closer to its peak value overall, than the new compressor.

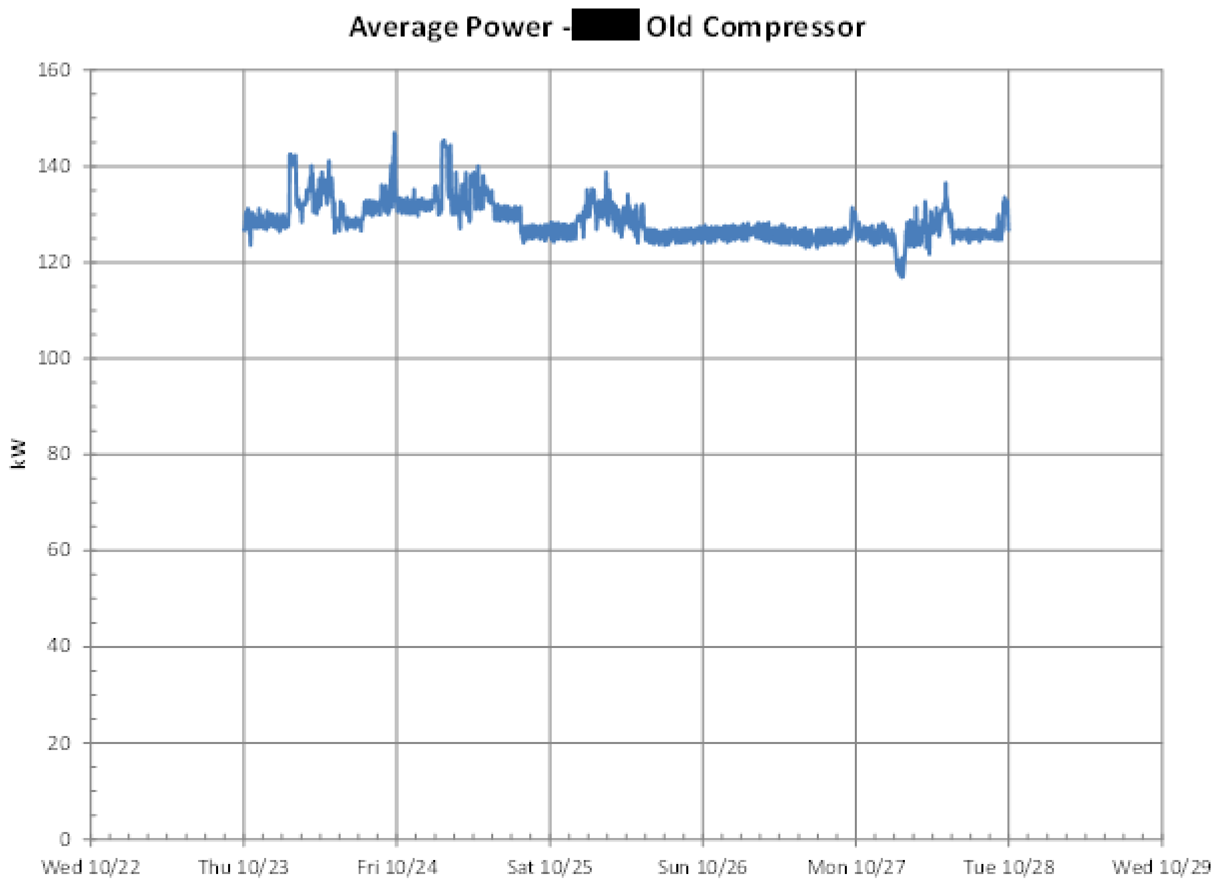

Figure 2: Monitored Power Readings – Old Compressor

The power histories can be grouped by the percent of time spent at each operating power (here, 1-kW bins are summarized). The following chart shows that the new compressor operates between 86 – 102 kW most of the time, and the old compressor typically operates between 124 – 133 kW. As shown previously in Figure 1, the new compressor occasionally operates at powers as high as 140 kW; the maximum observed value for the old compressor was 147 kW during the five days of monitoring (5-minute average values). The average power levels are 129 kW for the old compressor and 94.6 kW for the new compressor. Note: this chart covers the logged data only but is assumed to be representative of annual performance.

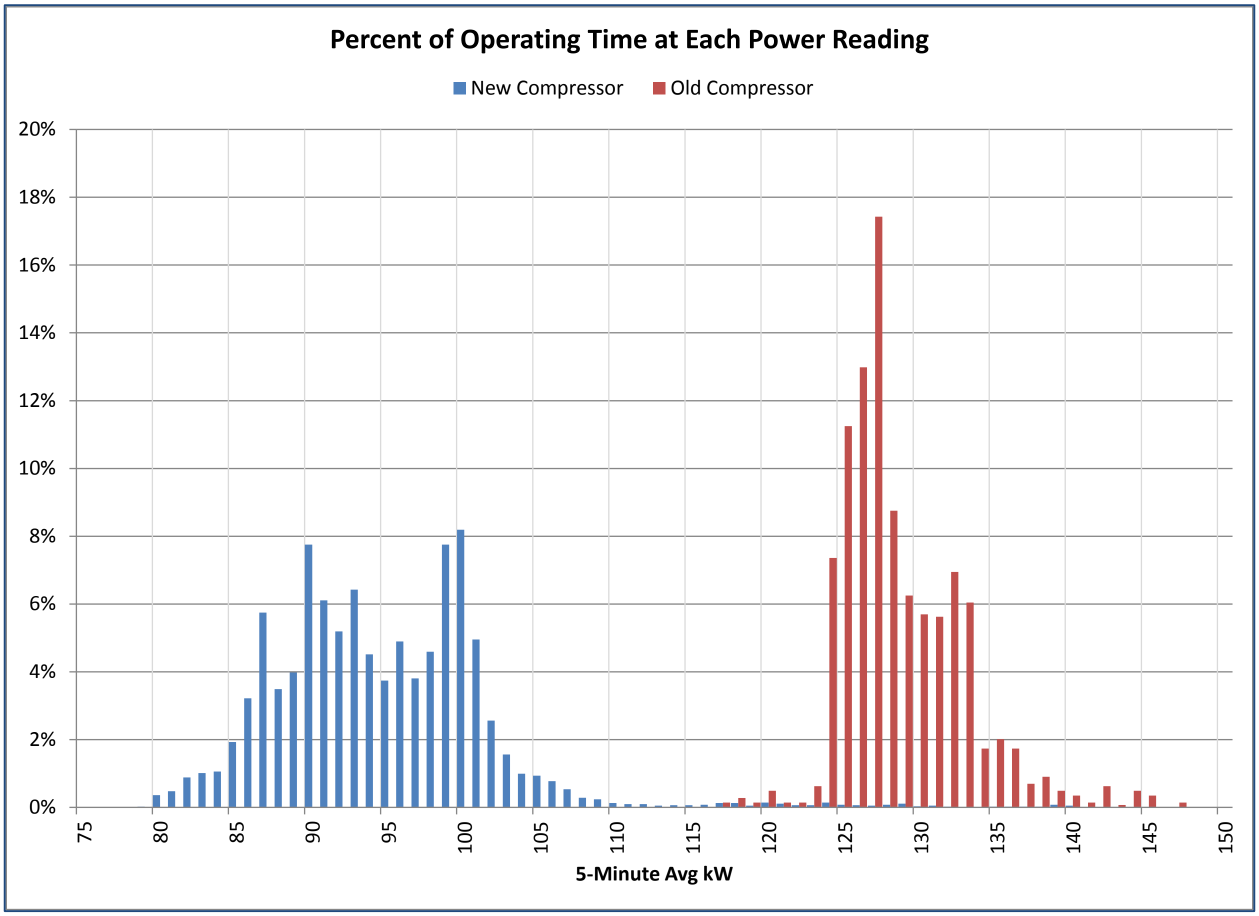

Figure 3: Percent of Operating Time at Each Power Reading (1-kW bins)

The daily energy consumption is graphed in the following figure. Again, the higher energy usage of the old compressor is evident. In the subsequent figure (Figure 5), the average daily energy is plotted by day of the week (there is no data for the old compressor on Tuesday or Wednesday since it was operated for less than a week). The average energy consumption is 3,095 kWh/day for the old compressor and 2,270 kW for the new compressor, a savings of about 27%. (Since there are less than seven days of data for the old compressor, its average energy consumption value is calculated as the weighted value of 5/7 of the average weekday value plus 2/7 of the average weekend value.)

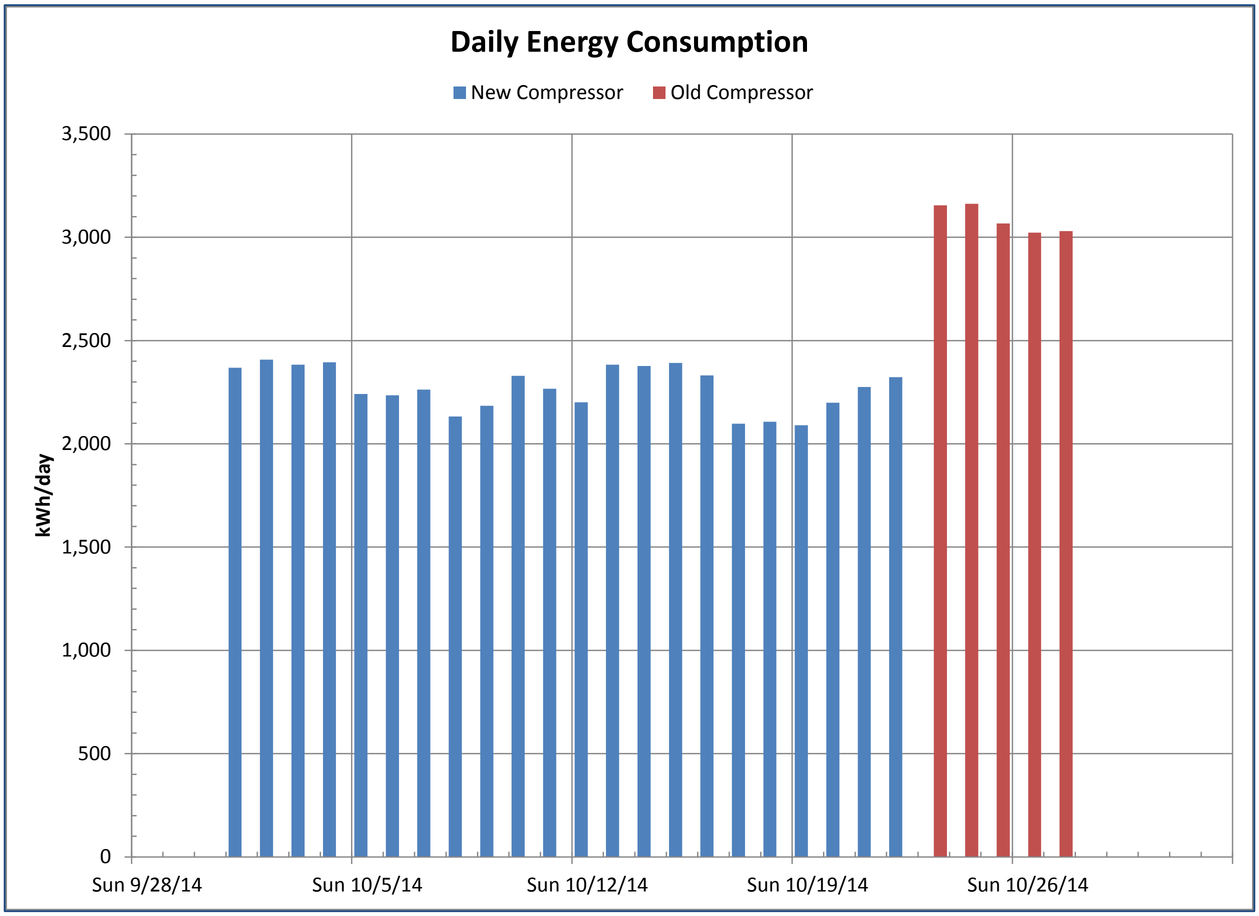

Figure 4: Daily Energy Consumption – Old and New Compressors

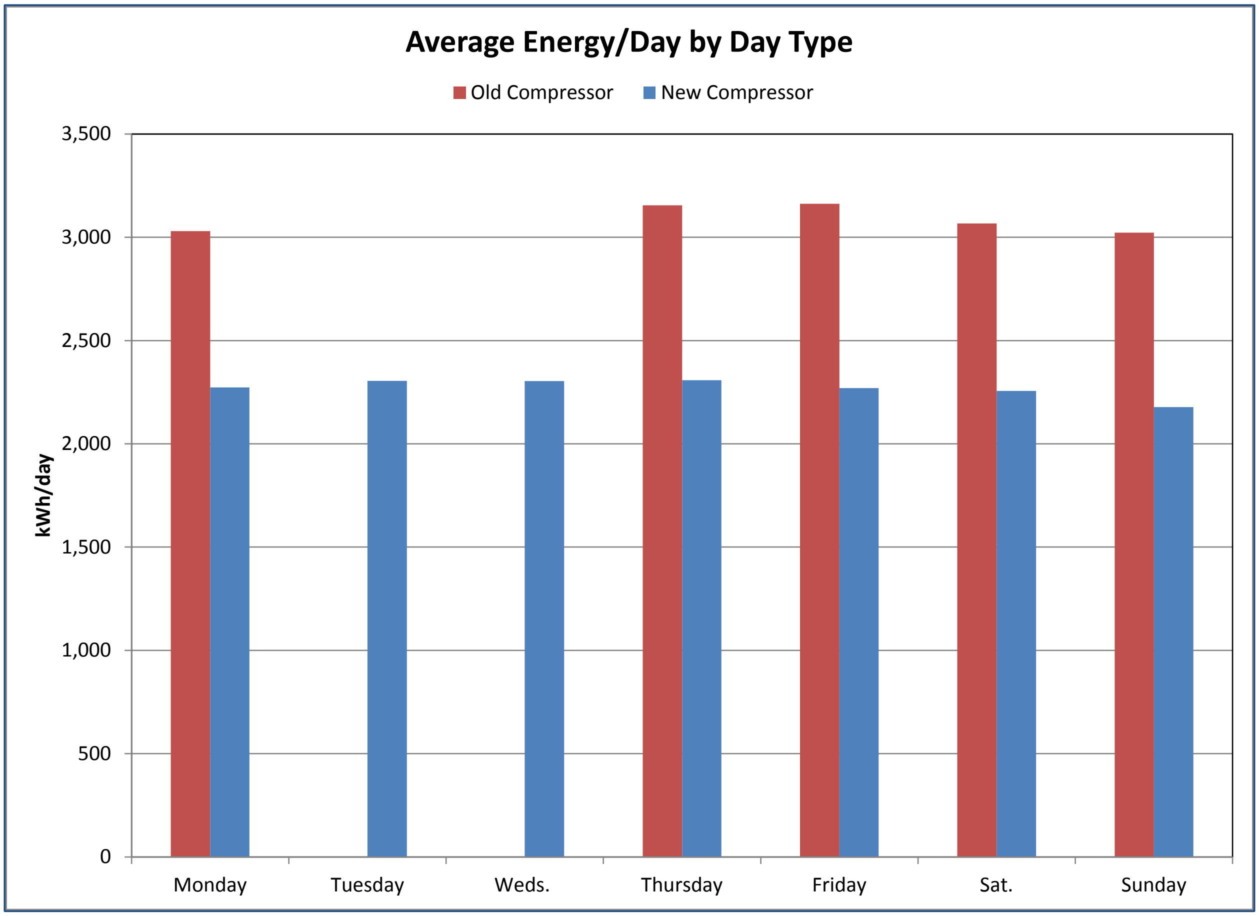

Figure 5: Average Daily Energy Consumption by Day of the Week

From the average daily power and energy consumption values, the annual energy usage can be calculated for both the old and new compressors; the results are presented in the following table. Also presented are the peak electrical demands, both coincident and non-coincident. 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 estimated as the maximum demand observed in the 4-5 PM hour on any weekday of the monitoring period.

Table 1: Summary of Results – [Redacted] Compressor Replacement

	Annual Average Power (kW)	Average Daily Energy (kWh/day)	Annual Energy (kWh)	Annual Coincident Peak Demand (kW)*	Annual Non-Coincident Peak Demand (kW)*
Pre-Retrofit Baseline	129.0	3,095	1,129,675	130.7	145.0
Post-Retrofit M&V Results	94.6	2,270	828,662	101.7	138.8
M&V Savings		825	301,013	29.1	6.2
Savings %			26.6%	22.2%	4.3%
Duke Projected Savings			612,650	69.9	69.9
Realization Rates			49%	42%	9%

*15-minute average values.

To explain the less-than-expected energy savings and the low realization rate, consider the following information from the application documents:

Table 2: Information from Application Documents

Application Data						Derived from Application Data				
Air Flow Rate Demand (SCFM)		% Time	Hours	Listed Energy Consumption (kWh)		Percent of Max SCFM			Average Power (kW)	
From	To			Baseline	New	From	To	Approx. Top of Bin (*SCFM*)	Baseline	New
334	370	18%	1577	240,620	128,910	62.4%	69.2%	70%	152.6	81.7
371	407	81%	7096	1,119,360	620,410*	69.3%	76.1%	76%	157.7	87.4
408	535	1%	88	6,000	4,050	76.3%	100.0 %	100%	68.2**	46.0**
Annual Total Energy (kWh):			8,761	1,365,980	753,370	Annual Average Power (kW):			155.9	86.0

*Corrected from 62,014.
**The application documents do not explain why the power level at the highest air demand range is much lower than the power at lesser air flows; however, the effect of this possible error is low because so few hours were estimated for this bin.

Contrast the above with the following results obtained through the analysis of the monitoring data:

Table 3: Results from Monitored Data Analysis

	Power Range (kW)		Old Compressor		New Compressor	
10% Bins (_Power_)	From	To	Estimated Operating Hours/Year	Avg. Power (kW)	Estimated Operating Hours/Year	Avg. Power (kW)
10%	0	15	0	0	0	0
20%	15	30	0	0	0	0
30%	30	45	0	0	0	0
40%	45	60	0	0	0	0
50%	60	75	0	0	0	0
60%	75	90	0	0.0	2,707	87.4
70%	90	105	0	0.0	5,714	96.8
80%	105	120	91	119.0	243	110.1
90%	120	135	8,146	128.1	80	125.7
100%	135	150	523	139.1	16	138.6
Total Hours			8,760		8,760	
Annual Average Power (kW)				129.0		94.6

Note that Table 2 is binned on air flow range, whereas Table 3 is binned on monitored power range. However, what is important is that the average powers for the bins in which the compressor spends most of its time (highlighted cells), as well as the overall annual average powers, were higher in the application data than in the monitored data for the baseline (old) compressor, and lower in the application data than in the monitored data for the new compressor. These conditions mean that the old compressor used less energy than was originally estimated, and the new compressor uses more energy, both of which decrease the predicted savings.

[Redacted]
HVAC Controls Retrofit
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].

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Introduction

This report addresses M&V activities for the [Redacted]custom program application. The application covers the retrofit of HVAC controls at the [Redacted] in Cincinnati, Ohio. The installation was completed as of June 2013, so this report is post-retrofit M&V only.

This retrofit project involved the implementation of several controls and control strategies for selected AHUs that serve the facility. The affected AHUs for all of the measures are: AC-18, AC-19, AC-25, AC-26, AC-4, and AC-6.

ECM-1 – Economizer Controls
This measure involves deploying economizer to better use free cooling below 65F OAT. Current operation has the OAT flow fixed at 25% at these temperatures.

ECM-2 – Excess Outside Air Reduction
This measure involved the implementation of controls allowing for the reduction of excess outside air (OSA). Savings occur as a result of a reduction plant load due to a lower mixed air temperature and lower temperature drop across cooling coils.

ECM-3 – Static Pressure Reduction
This measure involves a static pressure reset on supply fans at lower outdoor air temperatures.

Goals and Objectives

The projected savings goals identified in the application are:

	APPLICATION		**DUKE PROJECTIONS**	
Facility	**Proposed Annual kWh savings**	**Proposed Summer Peak kW savings**	**Proposed Annual kWh savings**	**Proposed Summer Peak kW savings**
[Redacted]	1,683,386	168	889,566	141.6

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

- Annual gross kWh savings
- Building peak demand savings
- Coincident peak demand savings
- KWh, kW and coincident kW Realization Rate

Project Contacts

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Duke Energy M&V Admin.	Frankie Diersing	O: 513-287-4096
Customer Contact	[Redacted]	[Redacted]

Site Locations/ECM's

Site	Address	Sq. Footage	ECMs Implemented
[Redacted]	[Redacted]	1,259,510	1, 2, 3

Data Products and Project Output

- Average pre- and post-retrofit load shapes by day-type for controlled equipment
- Energy consumption pre- and post-retrofit for controlled equipment
- Annual Energy Savings
- Peak demand savings
- Coincident peak demand savings

M&V Option

IPMVP Option A

M&V Implementation Schedule

- Obtained pre-retrofit and post-retrofit sequences of operation for all controlled equipment.
- Verified proper operation of the equipment on the new control sequences.
- Established trend logs to monitor operation of the AHUs and outdoor air conditions.
- Trended EMS data for three weeks.
- Evaluated the energy impacts of the controls retrofit.

Field Data Points

Survey data

- Pre-retrofit and post-retrofit sequences of operation for all controlled equipment. Pay particular attention to outside air damper settings, pressure settings and operating sequences.

The following time-series data was collected on controlled equipment

General points:

- Outdoor air temperature (both dry bulb and wet bulb or relative humidity)

For each of the controlled AHUs (qty = 6):

- Established trend logs on each of the 6 units to measure SAT, MAT, RAT, OAT (dry bulb and wet bulb), supply fan power, supply fan VFD speed, supply fan static pressure, return fan power, OA CFM and OA damper position.

Field Data Logging

- Set up trend logs for 5 minute instantaneous readings and collected data for three weeks.
- Collected data during normal operating hours (avoided atypical operating situations such as maintenance shutdowns).

Data Analysis

ECM-1

There were no changes to damper control above 65F. Between 55F and 65F, the ECM description states that the outside air damper is set to 100% OA, and below 55F the damper modulates to meet the user setpoint.

OAT, RAT and MAT shall be used to verify proper OA damper operation, using the equation:

Equation 1

- $OA\% = \frac{(T_{mixed} - T_{return})}{(T_{OutsideAir} - T_{return})}$

Since it is difficult to calculate OA percentage using equation 1 when the temperature differences are small, it is more effective to plot the numerator versus the denominator, (Tmixed-Treturn) vs. (ToutsideAir-Treturn), and determine the slope of the line.

ECM-2

Ton-hours of cooling for both the pre- and post-retrofit cases were determined using TMY data temperature bins and the following equations:

Equation 2

- $MATcalc = m(OAT) + (1 - m) * RAT$

Equation 3

- $MAh = m(OAh) + (1 - m) * RAh$

Equation 4

- $CoolingTons = 4.5 * CFM * (MAh - SAh)/12000$

Equation 5

- $kWcooling = CoolingTons * 0.92\ kW/ton$

Hours in the specified enthalpy ranges shall be calculated using TMY3 data. Cooling efficiency is assumed to be 0.92 kW/ton, as provided by Good Samaritan Building Engineer.

ECM-3

Fan power savings due to the static pressure reset can be calculated using the following equation:

Equation 6

- $kW = \left[\frac{CFM * \Delta P}{6356 * \eta_{fanstatic} * \eta_{motor}}\right] * .746$

Where:

kW = Kilowatts
CFM = Cubic Feet per Minute
ΔP = Differential Pressure
ηfanstatic = Fan Efficiency
ηmotor = Motor Efficiency
.746 = Conversion factor from Horsepower to kW

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 are physically impossible.
- Verified pre-retrofit and post retrofit equipment specifications, quantities, and schedules are consistent with the application.

Recording and Data Exchange Format

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

Results

The following results show the benefit of the three ECM's implemented at the [Redacted] in Cincinnati, OH.

ECM-1&2

Both ECM-1 (Economizer Controls) and ECM-2 (Excess Outside Air Reduction) were calculated together because the savings were discovered by using TMY3 data. ECM-1 occurs when the outside air temperature (OAT) is less than 65°F and ECM-2 occurs when the OAT is greater than 70°F.

Outside air fractions were discovered by using Equation 1. Graphical representations of outside air fractions can be found in Figure 1, Figure 2, Figure 3, Figure 4, Figure 5, and Figure 6.

The slope of the line represents the outside air fraction. There are offsets in the data which may be related to sensor inaccuracy, offsets, sensor placement, etc. Since the offset is not used to develop the outside air fraction, it can be ignored. To accurately determine the slope (outside air fraction), the following trend lines were set to intersect the graph origin. The trend line left of the vertical axis established was used as the OA percentage when the unit is economizing and the line to the right of the vertical axis was used when OA conditions were not acceptable for economizing.

Figure 1

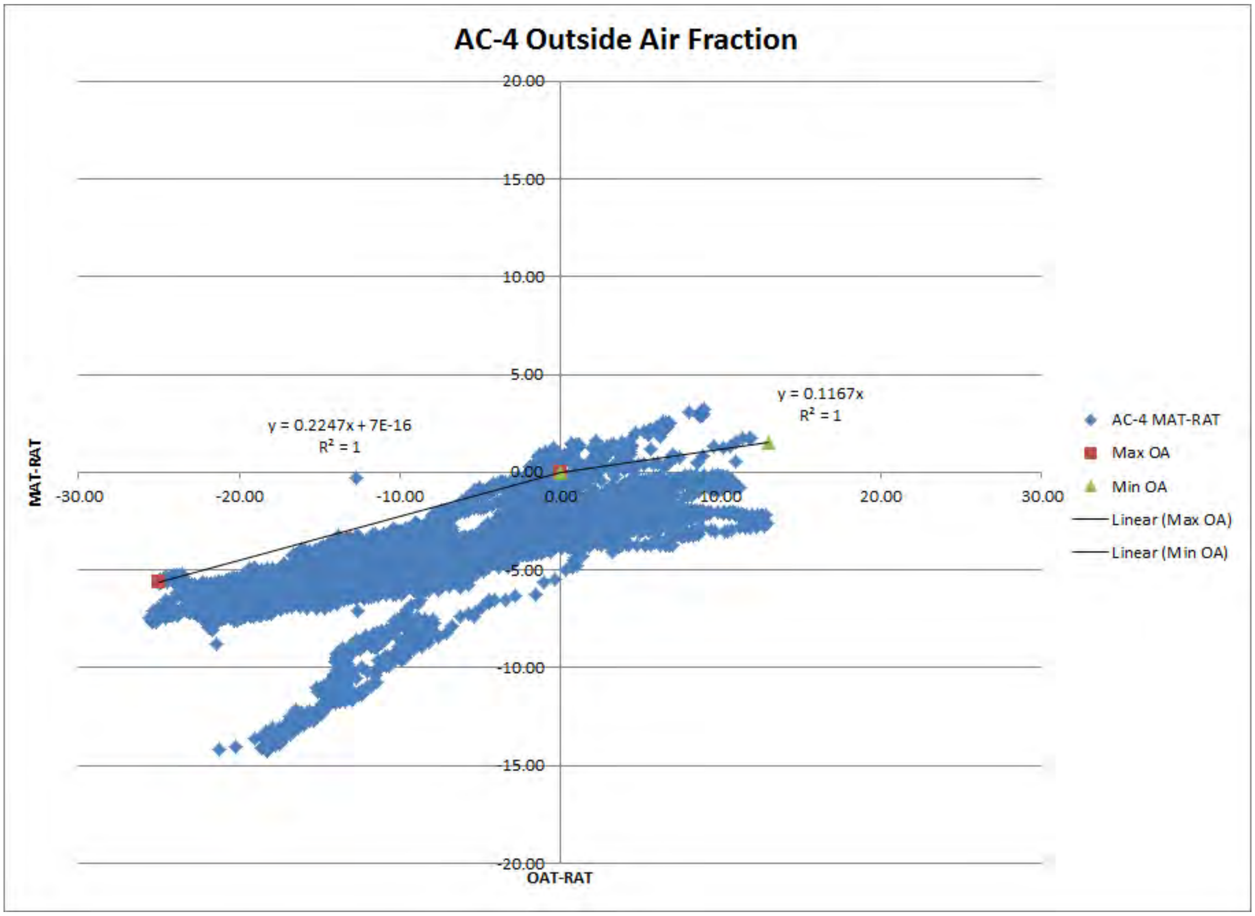

Figure 1. AC-4 Outside air fraction

As can be seen in Figure 2, there appears to be a constant OA fraction. This was confirmed by trend data analysis of the OA damper for this unit and mixed air temperatures. During the logging period, this unit was bringing in a large percentage (57%) of OA even when outside air conditions were not ideal for economizing. This would make the compressors work harder to cool the outside air down to the units discharge air temperature setpoint, and resulted in a very low amount of savings. See Figure 8 and Table 1.

The "ideal" economizer outside air fraction curve would look very similar to that shown in Figure 3, for AC-18. The data to the left of the vertical axis shows periods when the outdoor temperature is lower enough for effective economizer operation. The slope to the left of the axis is about 62%, representing an outside air fraction of 62% (ideally this would be 100%, but the data show that less than 100% outside air is introduced into the air handler). To the right of the axis, the data flattens out completely, representing an outside air fraction close to zero percent.

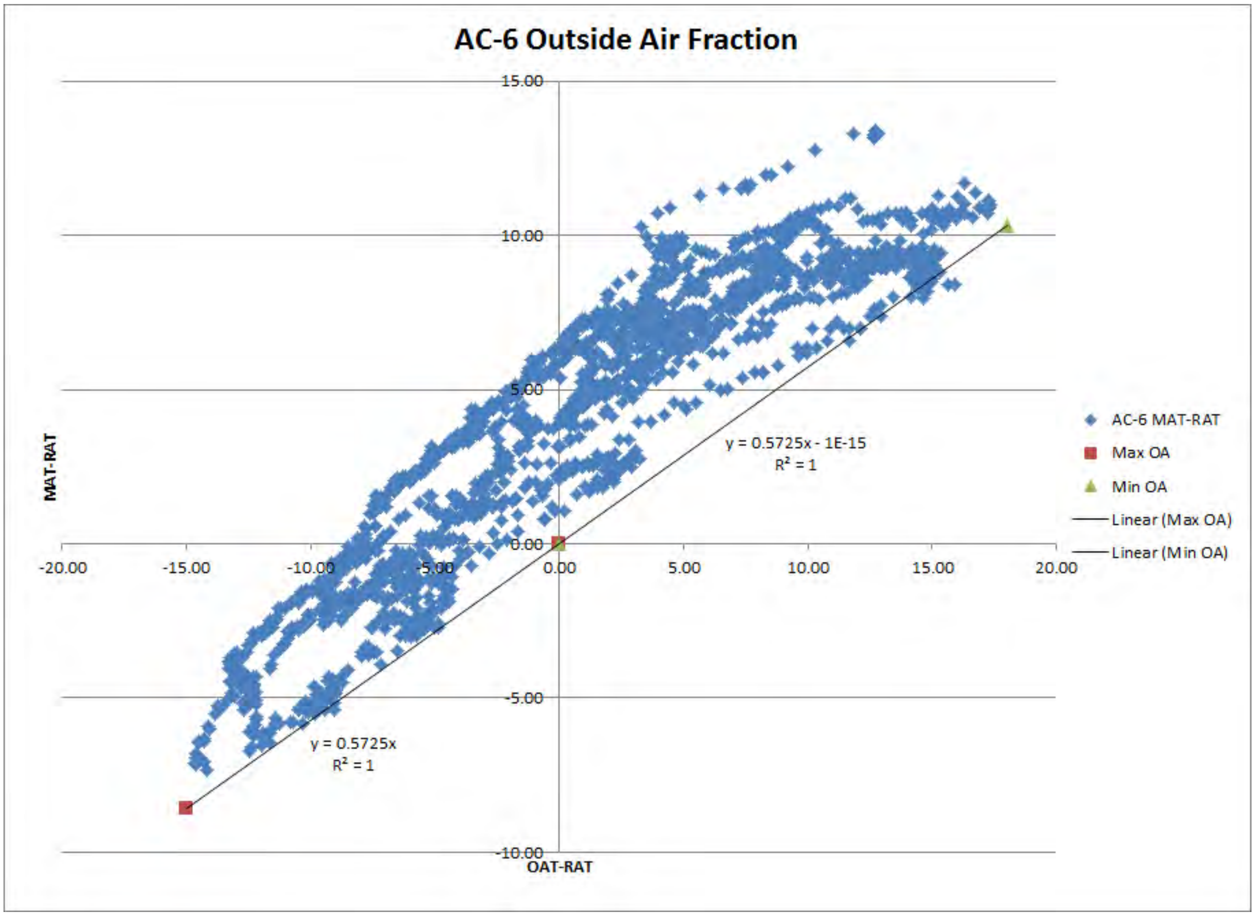

Figure 2. AC-6 Outside air fraction

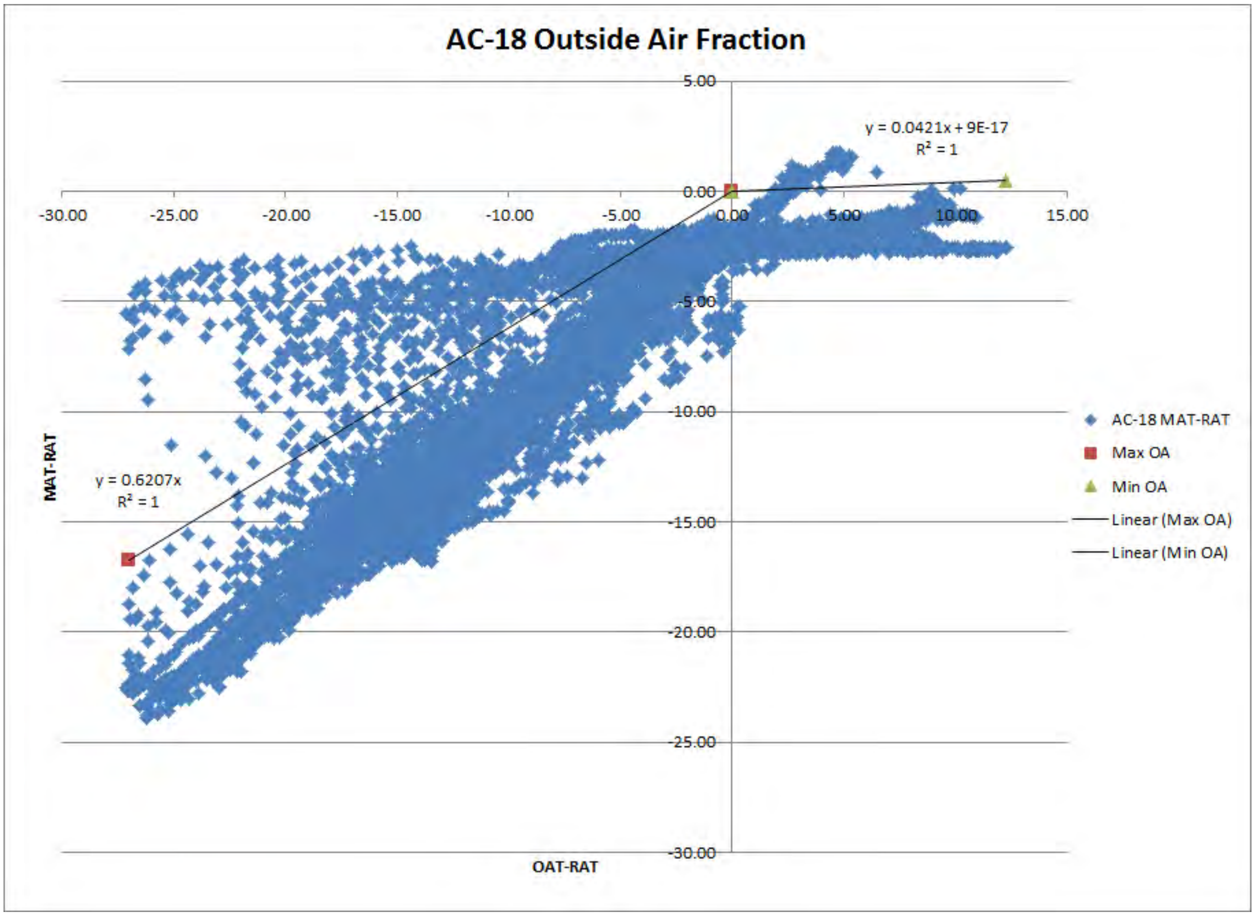

Figure 3. AC-18 Outside air fraction

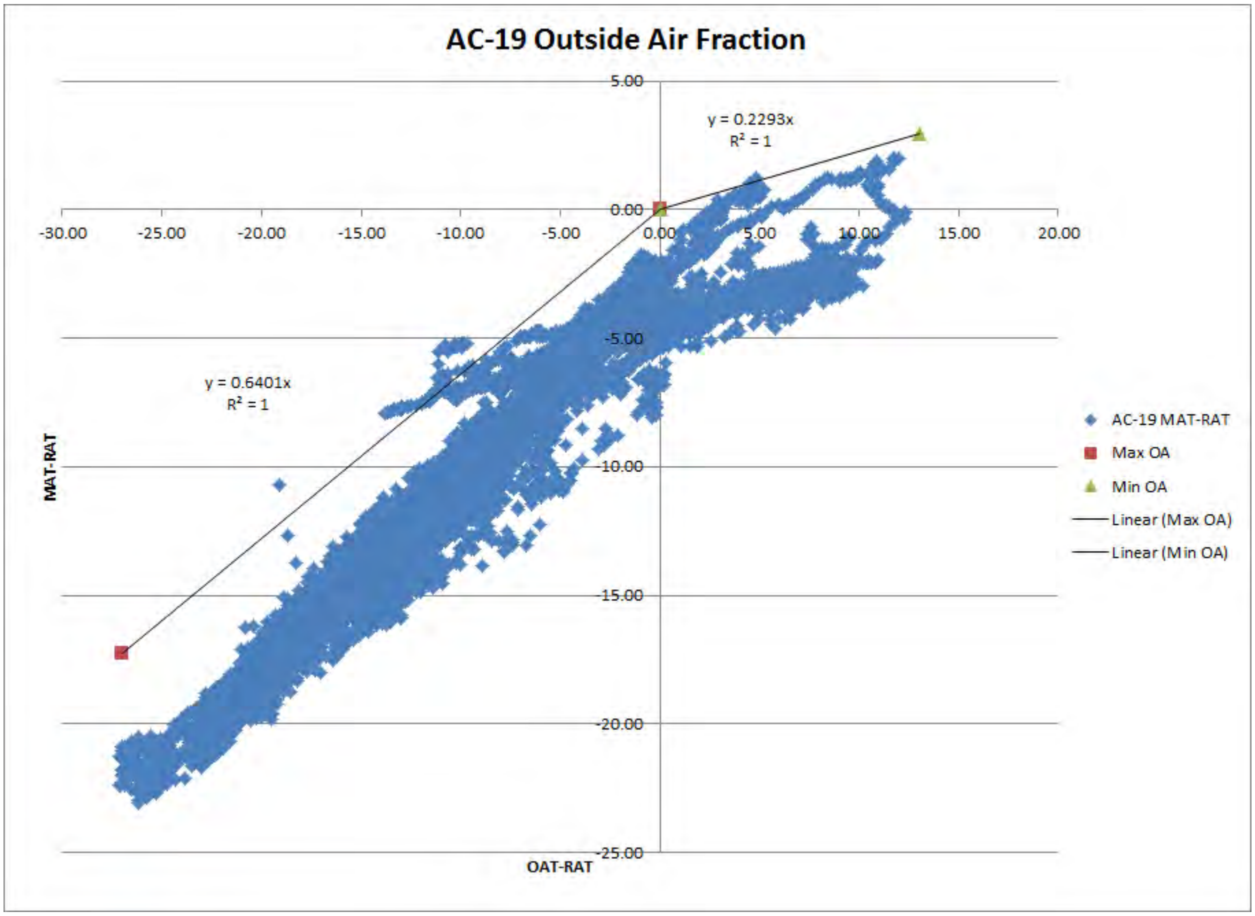

Figure 4. AC-19 Outside air fraction

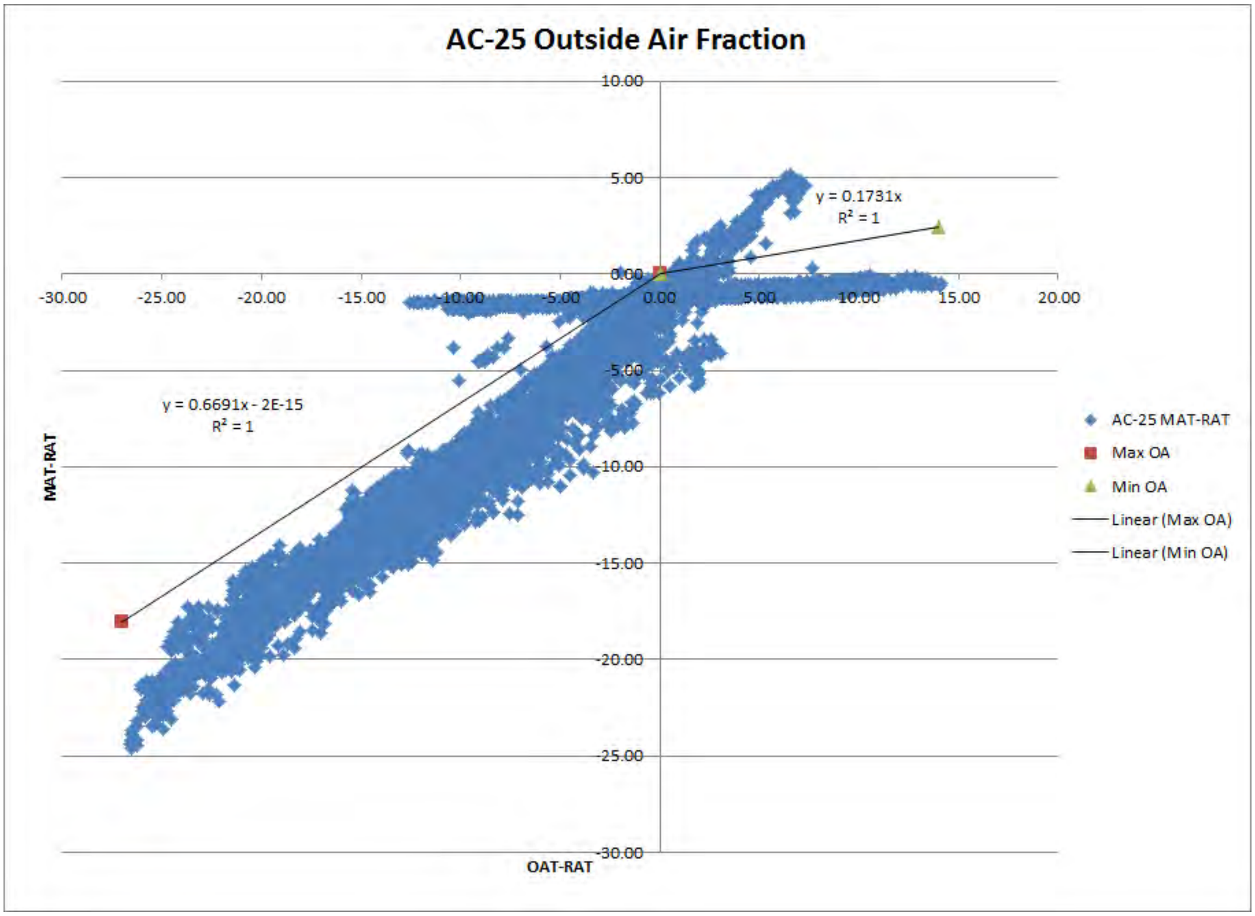

Figure 5. AC-25 Outside air fraction

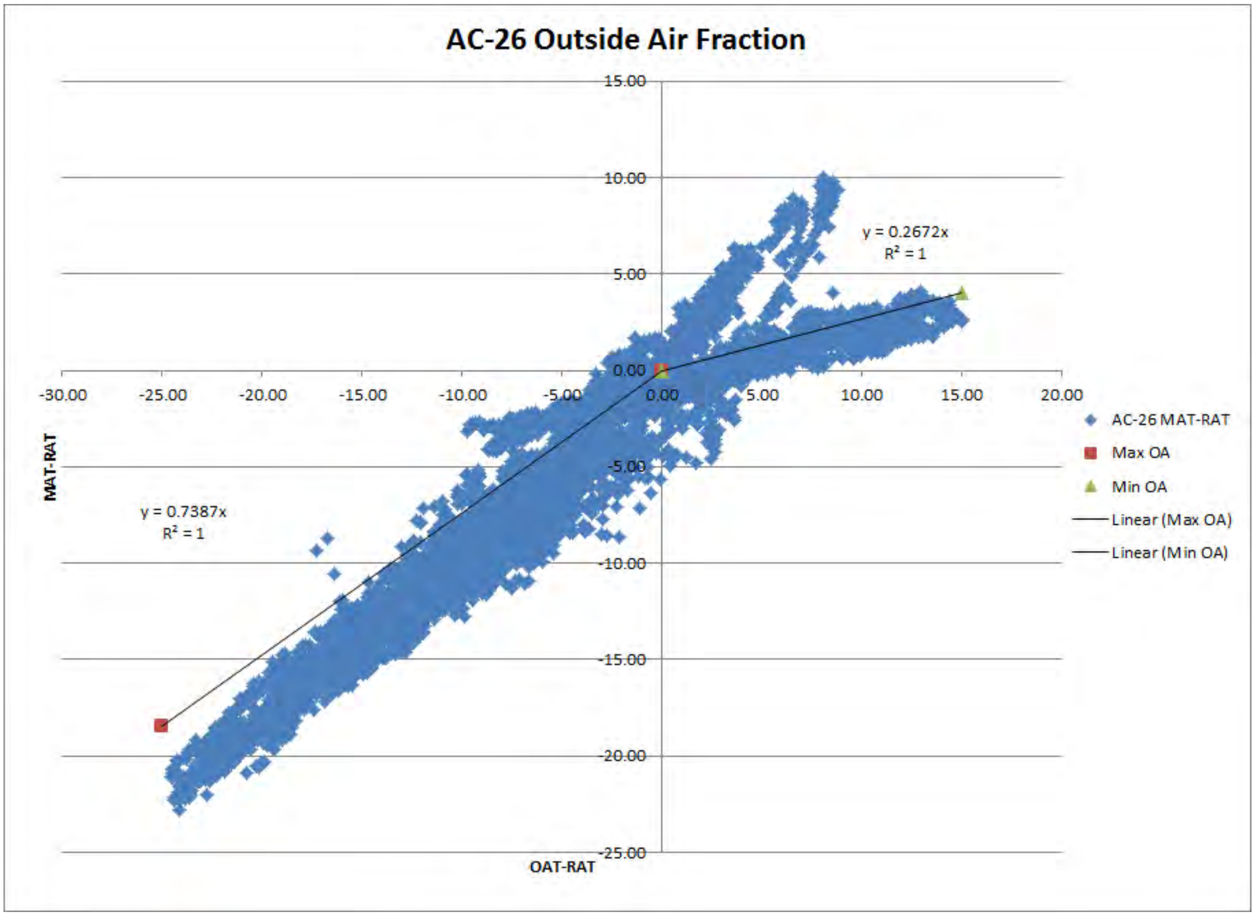

Figure 6. AC-26 Outside air fraction

Equation 2, Equation 3, Equation 4, and Equation 5 were used to determine kW associated with economizer cooling (or lack of) for each unit in both the Pre and Post cases.

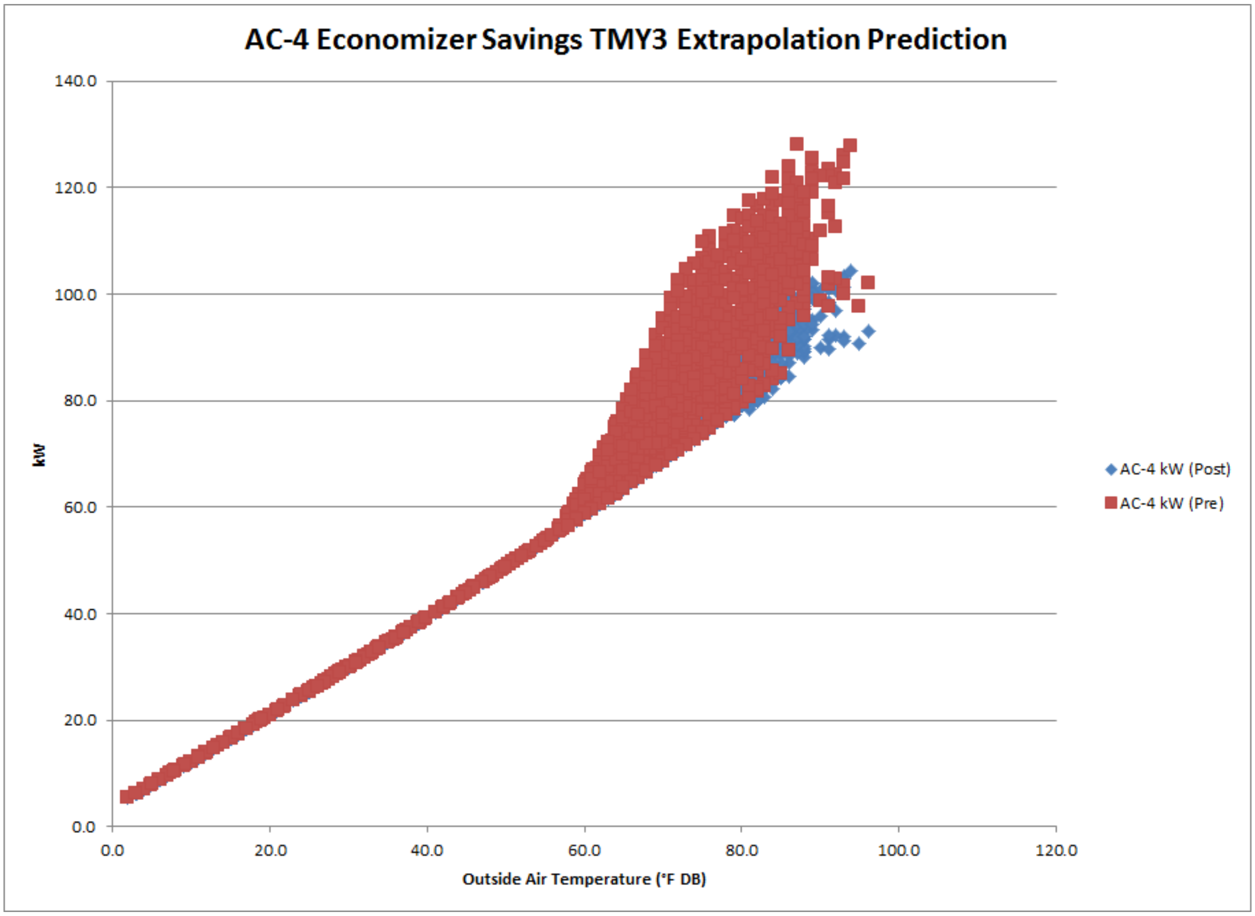

Figure 7. AC-4 Pre and post-retrofit demand

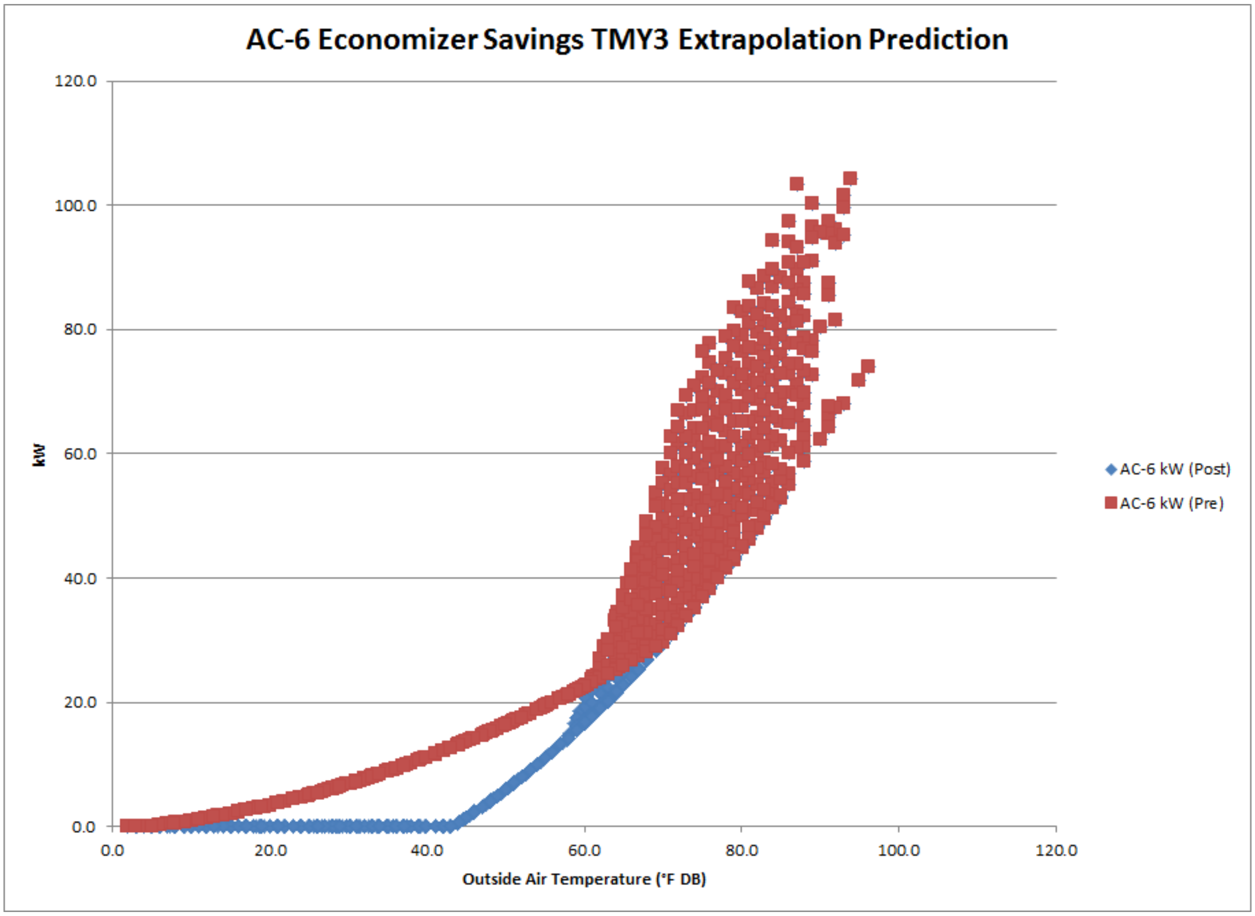

Figure 8. AC-6 Pre and post-retrofit demand

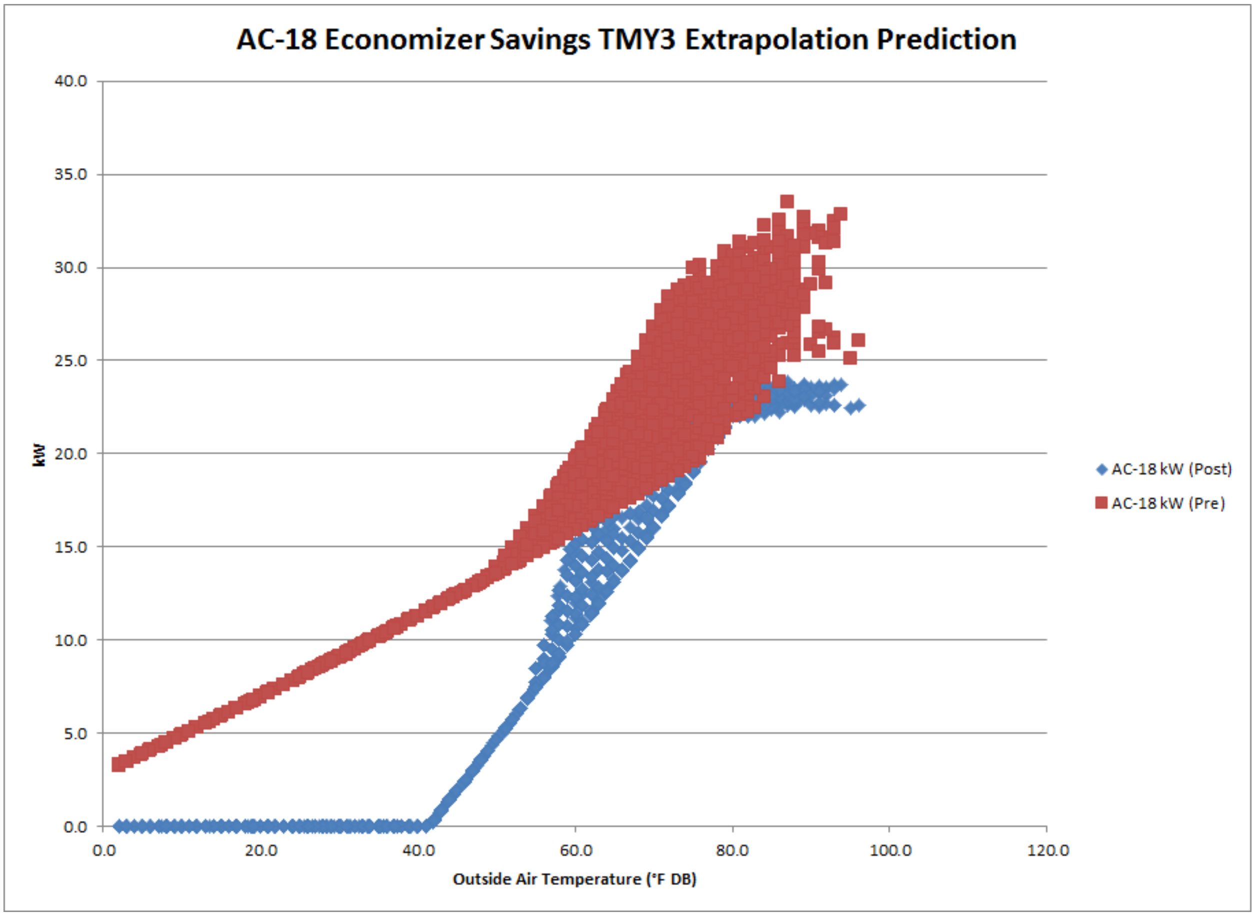

Figure 9. AC-18 Pre and post-retrofit demand

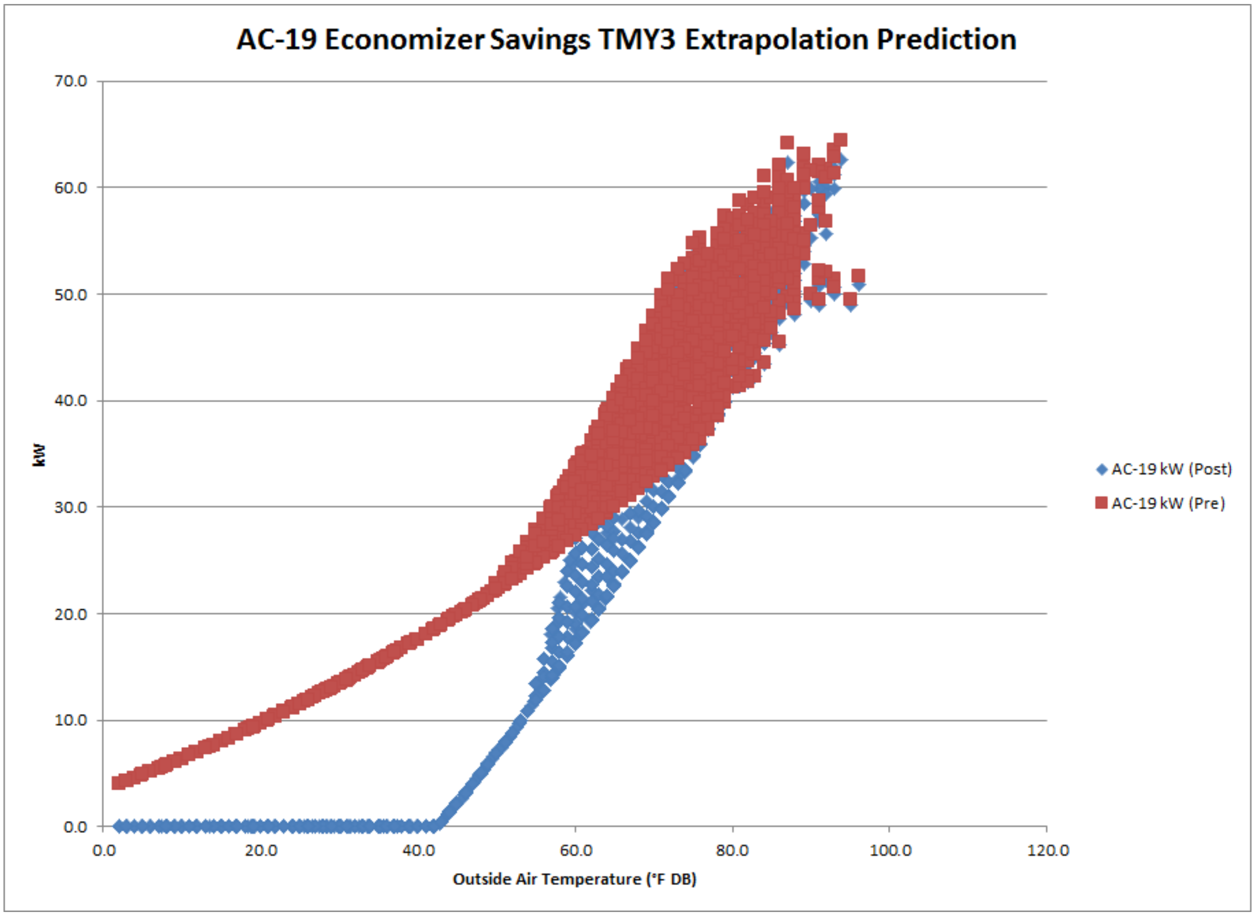

Figure 10. AC-19 Pre and post-retrofit demand

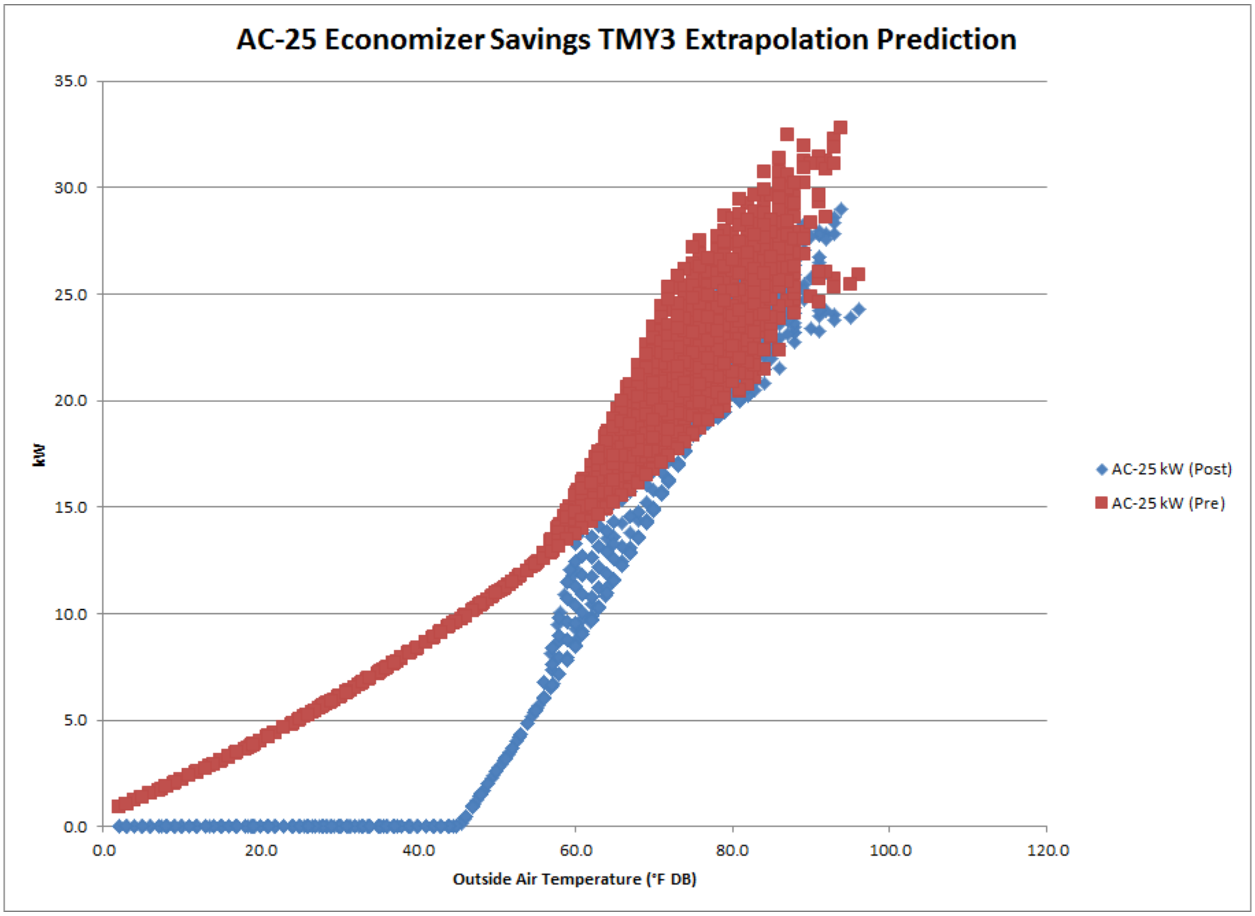

Figure 11. AC-25 Pre and post-retrofit demand

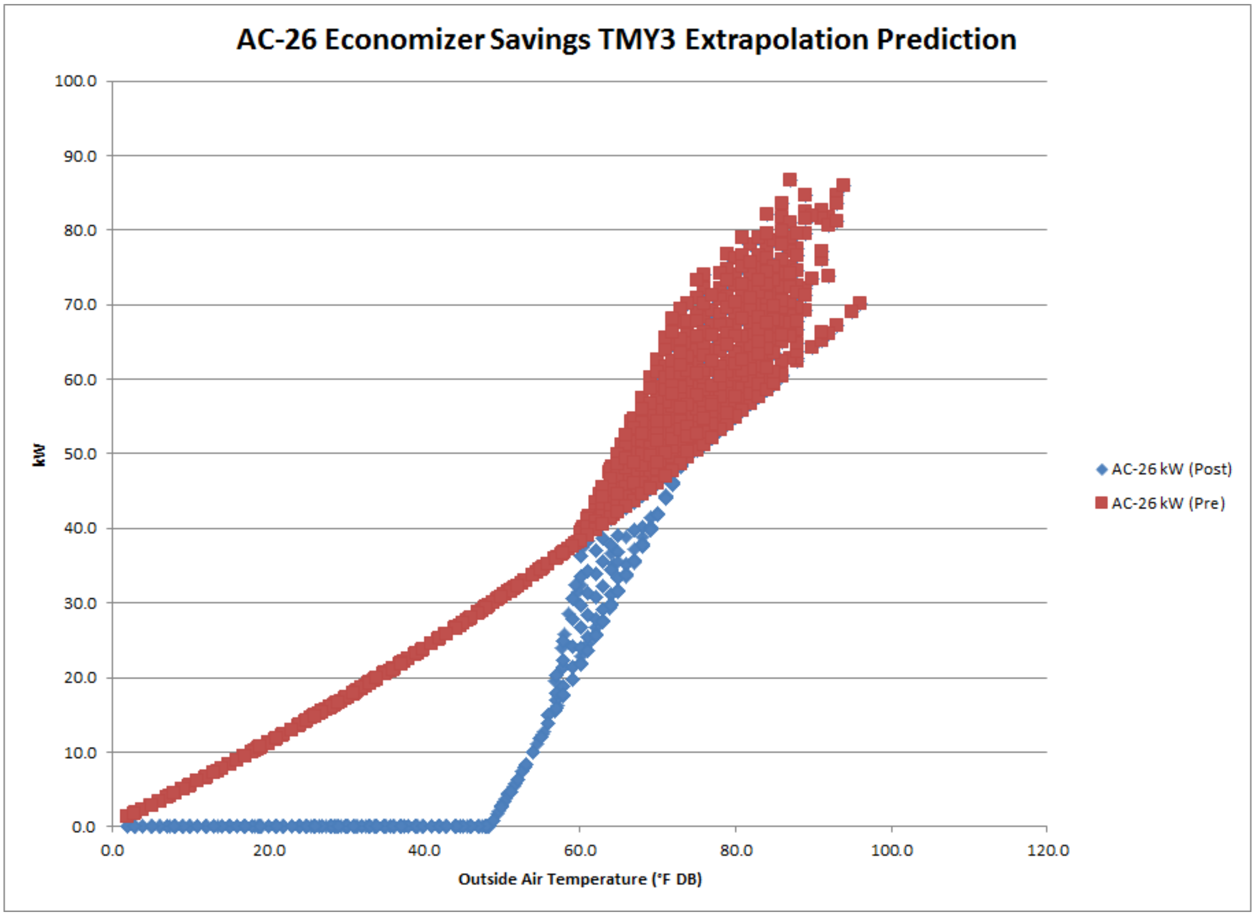

Figure 12. AC-26 Pre and post-retrofit demand

ECM-3

A daily average load-shape of static pressure was created for each air handler for the Post case. The Pre-condition was assumed to be a constant pressure. The maximum measured static pressure for each air handler was used in this case.

These pressures were then substituted into Equation 6.

Tabulated results can be found broken out by ECM in Table 1, Table 2, and Table 3.

Table 1

[Redacted]Energy Reduction Results (kWh)					
ECM	**Pre**	**Post**	**Actual Savings**	**Estimated Savings**	**Duke RR (%)**
AC-4 (ECM 1&2)	510,535.2	490,900.4	19,634.7	-	-
AC-6 (ECM-1&2)	222,976.2	177,730.9	45,245.4	-	-
AC-18 (ECM 1&2)	145,986.8	90,882.2	55,104.6	-	-
AC-19 (ECM 1&2)	250,391.5	169,465.2	80,926.3	-	-
AC-25 (ECM 1&2)	120,132.7	79,362.0	40,770.7	-	-

AC-26 (ECM 1&2)	324,079.9	211,756.4	112,323.5	-	-
AC-4 (ECM 3)	8,083.3	5,353.6	2,729.7	-	-
AC-6 (ECM-3)	18,551.3	13,768.1	4,783.2	-	-
AC-18 (ECM 3)	23,564.5	18,754.8	4,809.7	-	-
AC-19 (ECM 3)	46,683.2	36,877.7	9,805.5	-	-
AC-25 (ECM 3)	23,440.8	15,228.3	8,212.4	-	-
AC-26 (ECM 3)	58,035.6	51,549.4	6,486.2	-	-
Total	**1,752,460.9**	**1,361,628.9**	**390,832.0**	**889,566**	**44%**

Table 2

[Redacted]Coincident Peak Demand Reduction Results (kW)					
ECM	**Pre**	**Post**	**Actual Savings**	**Estimated Savings**	**Duke RR (%)**
AC-4 (ECM 1&2)	124.6	102.7	21.9	-	-
AC-6 (ECM-1&2)	99.5	99.5	0.0	-	-
AC-18 (ECM 1&2)	32.1	23.6	8.5	-	-
AC-19 (ECM 1&2)	62.8	61.2	1.7	-	-
AC-25 (ECM 1&2)	31.9	31.9	0.0	-	-
AC-26 (ECM 1&2)	83.5	83.5	0.0	-	-
AC-4 (ECM 3)	1.0	0.7	0.3	-	-
AC-6 (ECM-3)	3.1	2.9	0.2	-	-
AC-18 (ECM 3)	2.8	2.3	0.6	-	-
AC-19 (ECM 3)	6.6	5.2	1.4	-	-
AC-25 (ECM 3)	3.3	2.4	0.9	-	-
AC-26 (ECM 3)	7.5	6.8	0.8	-	-
Total	**458.8**	**422.6**	**36.2**	**141.6**	**26%**

Table 3

[Redacted]Non-coincident Peak Demand Reduction Results (kW)					
ECM	**Pre**	**Post**	**Actual Savings**	**Estimated Savings**	**Duke RR (%)**
AC-4 (ECM 1&2)	128.0	104.4	23.6	-	-
AC-6 (ECM-1&2)	104.3	104.3	0.0	-	-
AC-18 (ECM 1&2)	33.5	25.0	8.5	-	-
AC-19 (ECM 1&2)	64.4	62.6	1.8	-	-
AC-25 (ECM 1&2)	32.8	32.8	0.0	-	-
AC-26 (ECM 1&2)	86.8	86.8	0.0	-	-
AC-4 (ECM 3)	1.0	0.7	0.3	-	-
AC-6 (ECM-3)	3.2	3.1	0.1	-	-
AC-18 (ECM 3)	2.9	2.8	0.0	-	-
AC-19 (ECM 3)	6.7	5.6	1.1	-	-
AC-25 (ECM 3)	3.3	2.5	0.8	-	-

AC-26 (ECM 3)	7.6	7.2	0.4	-	-
Total	**474.4**	**437.8**	**36.5**	**408.3**	**9%**

[Redacted] Lighting Replacement M&V Report

Prepared for
Duke Energy Ohio

May 2014, v2.0

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 program participants.

Submitted by:

Katie Gustafson
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ARCHITECTURAL ENERGY CORPORATION

TABLE OF CONTENTS

Introduction

This report addresses M&V activities for the new exterior lighting fixtures at the [Redacted].

The measures include:

ECM-1- Retrofit (41) 400 W MH fixtures with 2ft 4L exterior T5 fixtures.
ECM-2- Retrofit (42) 400 W MH fixtures with 2ft 4L exterior T5 fixtures.
ECM-3- Retrofit (42) 400 W MH fixtures with 2ft 4L exterior T5 fixtures.

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 Coincident Peak Savings (kW)	Duke Non-coincident Peak Savings (kW)
192,720	44	193,412	0	6.7

- Verified installed fixture information and operating hours
- Obtained baseline (replaced) fixture information and operating hours
- Verified annual gross kWh savings
- Verified summer peak kW savings
- Determined kWh & kW Realization Rates

Project Contacts

Duke Energy M&V Admin.	Frankie Diersing	513-287-4096	
Site Contact	[Redacted]	[Redacted	[Redacted]
AEC Contact	Katie Gustafson	303-459-7430	kgustafson@archenergy.com

Site Locations/ECM's

Site	Address	ECM

1	[Redacted]	#1
2	[Redacted]	#2
3	[Redacted]	#3

Data Products and Project Output

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

M&V Option

IPMVP Option A

M&V Implementation Schedule

- Post data only was collected.
- Survey data was collected during normal operating hours (not during holidays).

Field Data Points

Post – installation

Field Lighting Survey

- Verified that all pre (existing) fixtures were removed
- Counted the new fixtures.
- Confirmed that the new fixtures, lamps and ballasts correspond to the application.
- Recorded the survey information on the Lighting M&V Survey Form.

Logger Deployment

Hobo current loggers were used.

Select Sample

- Randomly selected four lighting circuits at each [redacted] serving the new lighting.

Data Accuracy

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

Field Data Logging

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

ECM	Hobo (U12)	CTV-A 20A
1	1	4
2	1	4
3	1	4
Total	**3**	**12**

Hobo current loggers

- Prepared to deploy current measurement CT loggers to measure current at the panelboard.
- Installed one CT on each of the randomly selected circuits.
- Spot measured the lighting load connected to the circuit by measuring the kW load and current draw of the circuit during the post-retrofit survey. Recorded the logger current readings in addition to the measurements from the portable power meter to ensure an accurate scale factor.
- Set up loggers for 5 minute instantaneous readings and allowed loggers to operate for a period of three weeks.
- Recorded the survey information on the Lighting M&V Survey Form and have incorporated the information into the body of this report.
- Confirmed that the lighting is controlled with photocells and recorded controller settings.

Data Analysis

- Determined when in relation to the civil twilight the photocells turn the light fixtures on and off.
    - Used the 2013 civil twilight data for Raleigh, NC from http://www.timeanddate.com.
- Calculated the average amount of time before and after the civil twilight that the fixtures were illuminated and turned off.
- Developed a relationship between “night-time hours” and the observed daily hours of operation.

- Applied the calculated average time on before evening civil twilight and average time off after morning civil twilight to each day of 2013.
- Calculated the estimated annual operating hours for each metered location.
- From survey data calculated the actual pre and post fixture kW.

- For each of the metered sites we used the calculated annual operating hours to determine the annual savings.

  1. The Pre and Post annual kWh was calculated using the following equation:

$$kWh = N_{Fixtures} * kW_{Fixture} * Hours$$

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

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

  3. The annual kW saved was calculated using the previous data in the following equation:

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

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

where:

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

Since this was an exterior lighting project, there are no HVAC interactions.

Verification and Quality Control

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

Recording and Data Exchange Format

1. Hobo logger binary files
2. Excel spreadsheets

Results Summary

The following results account for benefits of the lighting replacement. These results are based on the following assumptions:

- The lighting duration is based on the period from sunset to sunrise, according to published sunrise-sunset times for Raleigh, NC, increased by 0.07 hours due to an average difference between the measured lighting duration and the sunset-sunrise duration. See Figure 1 for an illustration of the difference.
- The pre-retrofit demand of each light fixture is 458 watts, from the application and the Ohio TRM.
- The post-retrofit electrical demand of each light fixture used for this analysis is 106 watts, from cut sheets..
- A total of 122 light fixtures were counted plus 4 fixtures located at the tennis courts for a total of 126 fixtures. There is one additional fixture than was listed in the application.

A Comparison of measured daily lighting duration and sunset to sunrise duration during monitoring period can be found in Figure 1 below. This figure illustrates, on average, that the measured daily lighting duration is about 0.07 hours longer than the published sunset-to-sunrise time for Raleigh, NC.

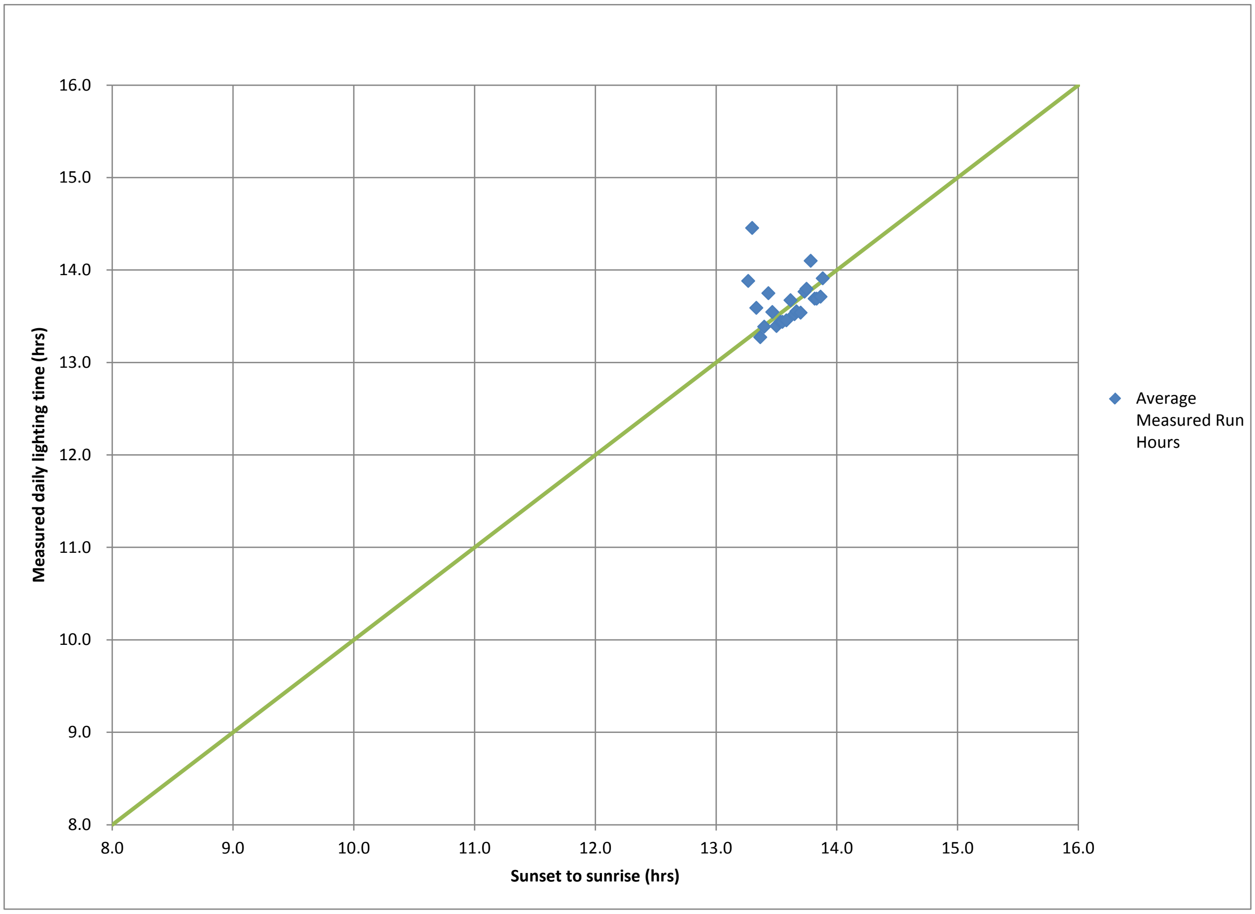

Figure 1

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

Table 1. Energy Savings and Realization Rates

	Duke Savings	Realized Savings	Realization Rate
Energy (kWh)	193,412	192,361	99%
Peak Demand (kW)	6.7	44.4	664%
CP Demand (kW)	0	0	-

Table 2. Summary of Energy and Demand Savings Calculations

Base kW	EE kW	HOURS	CF	Lighting Savings		
				kWh savings	NCP kW	CP kW
57.7	13.4	4337.1	0.00	192,361	44.4	0.0

The energy realization rate is somewhat higher, which can be partially explained by the additional fixture found during the M&V survey, although this is countered by the small differences in HOURS, as shown below.

Analysis	HOURS	Base kW	EE kW
Application	4,380	57.2	13.2
M&V	4,337.1	57.7	13.4

The high RR for NCP demand savings is driven by the very low Duke demand savings expectation. The actual demand savings is at night, and is equal to the full savings of the new fixtures.

Figure 2 depicts a graph of energy consumption for the monitored lights during the monitoring period. In general, as shown previously in Figure 1, as the date approaches the winter solstice, the lighting circuits are energized for longer periods of time, with some variability due to weather, etc.

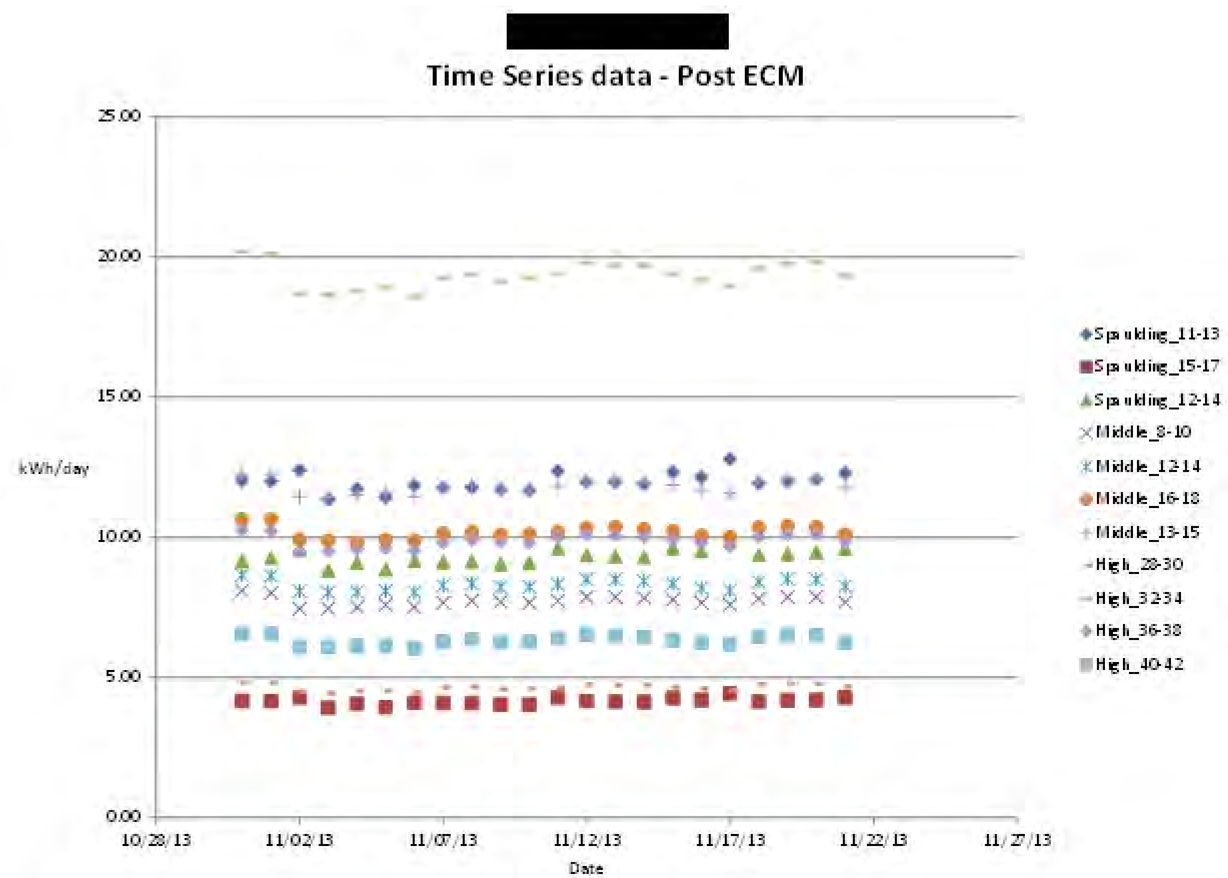

Figure 2

Figure 3 depicts a graph of kWh/day for the population of 126 lights included in the application over the course of 1 year. Daily sunrise/sunset times were used to determine the daily run hours for the fixtures. Extrapolating this for the year yields the annual operating hours of 4,337 hours

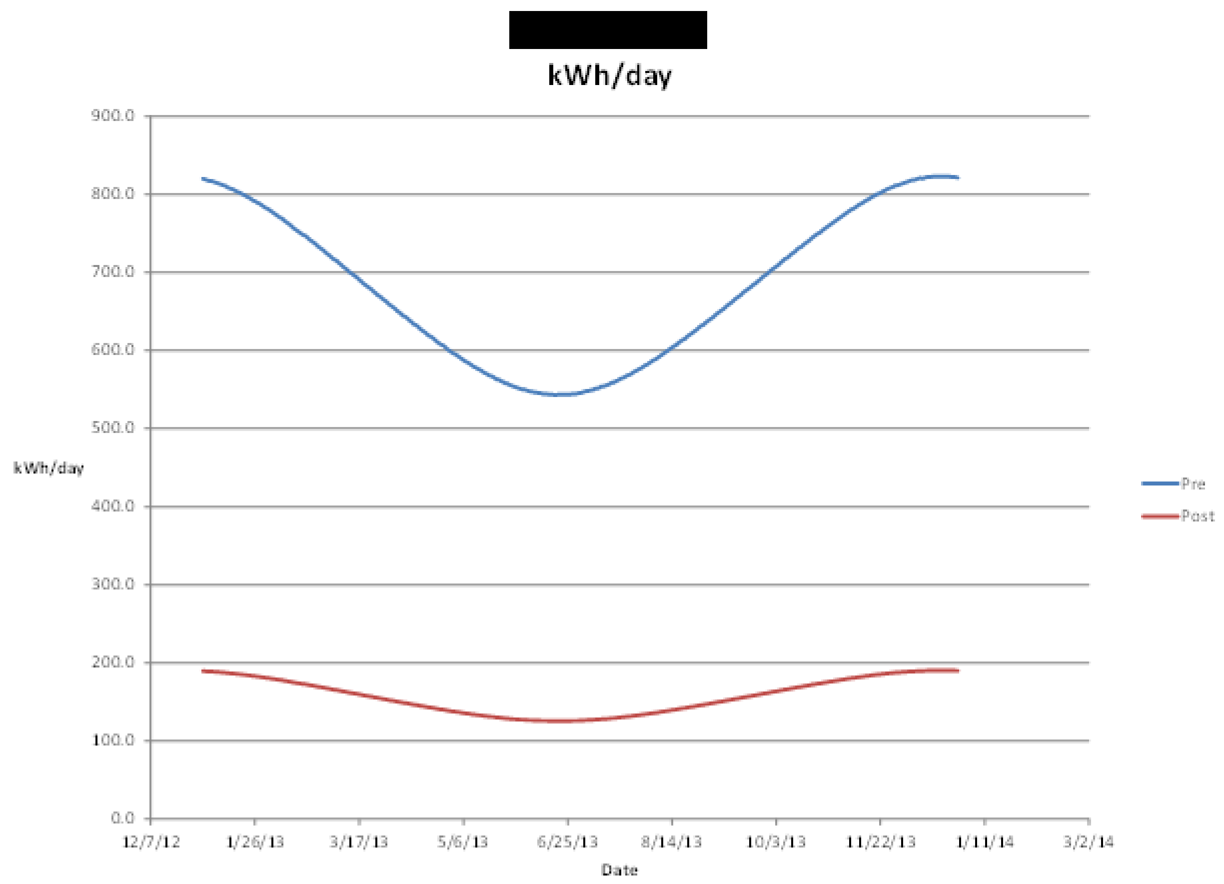

Figure 3

Table 3. Demand Savings Detail

ECM	EE Technology					Base Technology				
	Quantity	**EE Fixture Type**	**W/ Fixture**	**Source**	**Connected kW**	**Quantity**	**Base Fixture Type**	**W/ Fixture**	**Source**	**Connected kW**
1	42	4LT5 (Exterior)	106	Cut sheet and App	4.5	42	400W MH	458	Cut sheet, app, and TRM	19.2
2	42	4LT5 (Exterior)	106	Cut sheet and App	4.5	42	400W MH	458	Cut sheet, app, and TRM	19.2
3	42	4LT5 (Exterior)	106	Cut sheet and App	4.5	42	400W MH	458	Cut sheet, app, and TRM	19.2
Total					13.4					57.7

[Redacted]

- 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:
December 2012

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].

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 measure includes:

ECM-1 – T12 fluorescent fixtures replaced with T8 fixtures

- This project involves the removal of 51 existing 237W T12 fluorescent fixtures, to be replaced by 28 new 171W T8 fixtures. This will result in an overall power reduction of 7,299W. Neither the pre- or post-retrofit scenarios involve lighting controls.

Goals and Objectives

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

The projected savings goals identified in the application are:

Facility	Proposed Annual kWh savings	Proposed Summer Peak kW savings	Duke Estimated Annual kWh savings	Duke Estimated Summer Peak kW savings
Store 564	27,327	7	27,078	7.1
Total	**27,327**	**7**	27,078	7.1

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	Cory Gordon	
Customer Contact	[Redacted]	[Redacted]
Architectural Energy Corporation Contact	Rob Slowinski	p: 303-459-7453 rslowinski@archenergy.com

Site Locations/ECMs

Site	Address	Sq. Footage	ECMs Implemented
[Redacted]	[Redacted]	15,000	# 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

- Conduct the post-retrofit survey after the customer performs the lighting retrofit.
    - Deploy post-retrofit loggers.
    - Spot measure the lighting load connected to the circuit by measuring the kW load and current draw of the circuit.
- Collect logger and spot data during normal operating hours (avoid 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

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

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

- Lighting circuit power when lights are on

Time series data on controlled equipment

- Typical lighting load shape
  - Deployed current measurement CT loggers to measure current at the panelboard on four circuits.
  - Loggers were set up for 5 minute instantaneous readings and collected data for three weeks.
- Spot measured the lighting load connected to the circuit by measuring the kW load and current draw of the circuit during both the post-retrofit survey.

LOGGER TABLE

The following table summarizes all logging equipment used to accurately measure the above noted ECMs:

ECM	Hobo U-12	20A CT
1	4	4
Total	**4**	**4**

DATA ANALYSIS

- **ECM-1**

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

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

6. Estimate peak demand savings by subtracting pre/post time series data.
7. Calculate 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. Sort by day type and remove invalid data.
2. Verified post retrofit lighting fixture specifications and quantities are consistent with the application.
3. Verified pre-retrofit lighting fixtures were removed from the project.
4. Verified electrical voltage of lighting circuits.

Recording and Data Exchange Format

1. Post-installation Lighting Survey Form and Notes.
2. Hobo logger binary files
3. Excel spreadsheets

M&V Results Summary

The following tables show the results of the lighting replacement at [Redacted].

	Lighting	HVAC	Total
Pre kW	11.47		
Post kW	4.62		
Demand Savings	6.85	2.17	**9.02**
Coincident Pk Demand Svgs (kW):	6.81	2.16	**8.97**

		Realized Savings		**Realization Rate**	
	Duke Savings	**Lighting Only**	**Lighting and HVAC**	**Lighting Only**	**Lighting and HVAC**
Energy (kWh)	27,078	25,698	28,140	95%	104%
NCP Demand (kW)	7.1	6.85	9.02	96%	127%
CP Demand (kW)	7.3	6.81	8.97	93%	123%

- (51) pre-existing 2lamp-T12HO-8ft fixtures were replaced with (28) 6lamp high bay T8 fixtures
- 227watts/fixture was assumed for the pre-existing T12 fixtures based on fixture code F82EHL in Appendix B: Table of Standard Fixture Wattages, 2008.
- Power spot measurements were used for post retrofit kW/fixture

FIELD STAFF

☐ Verifiable Results
☐ AEC
■ **Other**

Contracting type

■**T&M**
☐ Per logger

[Redacted]
VFD for New Refrigeration Compressor M&V Report

Prepared for
Duke Energy Ohio

January 2015

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.

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

Submitted by:

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