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.

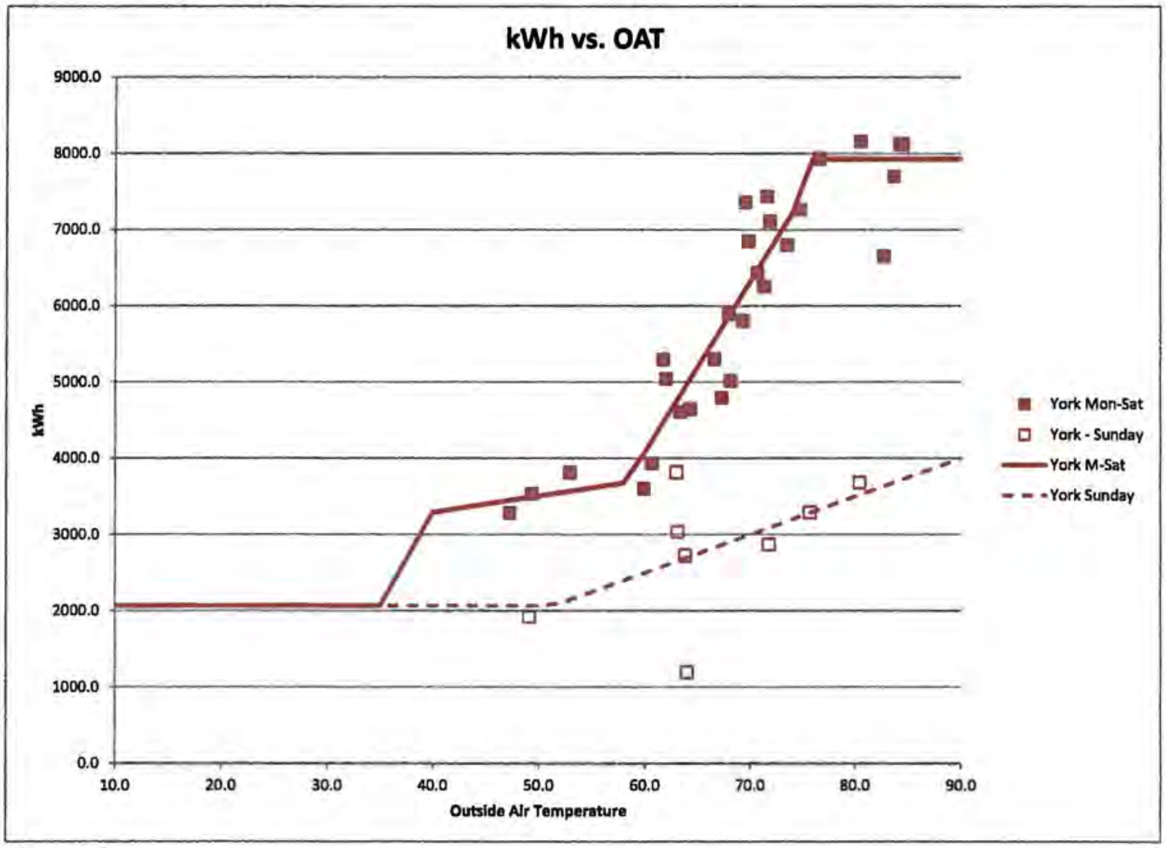


Figure 2

Error! Reference source not found. 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.

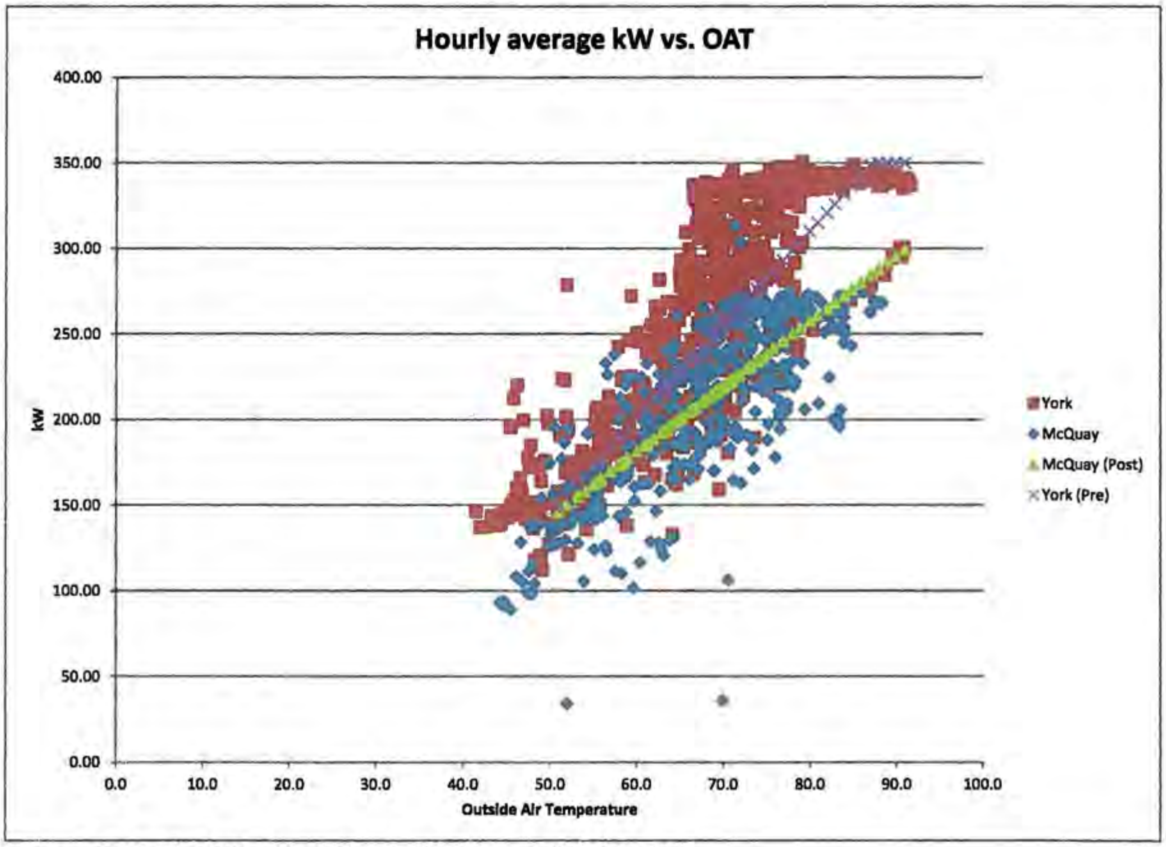


Figure 3. Peak kW values for both Pre and Post ECM

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.

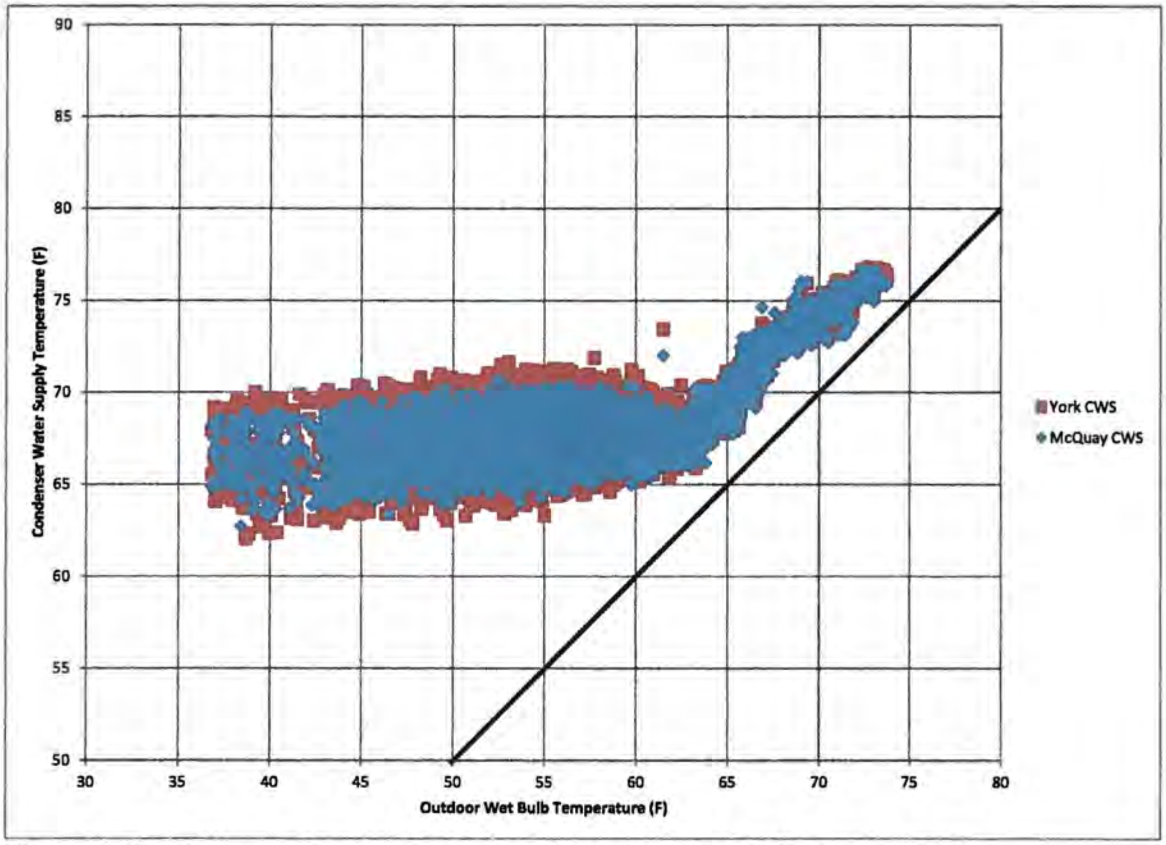


Figure 4. Condenser water supply temperature versus wet bulb temperature

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.

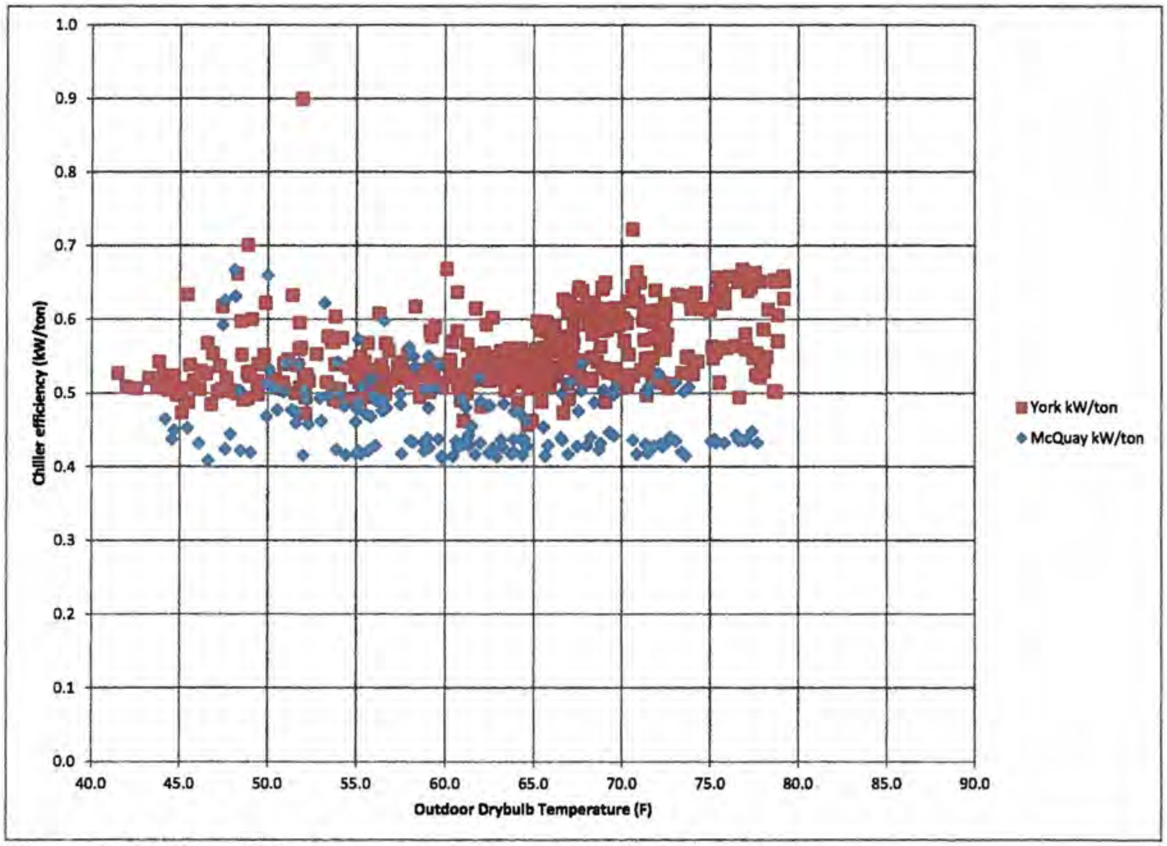


Figure 5. Chiller efficiency versus outdoor drybulb temperature

[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:

Katie Gustafson
Architectural Energy Corporation

Stuart Waterbury
Architectural Energy Corporation

2540 Frontier Avenue, Suite 100
Boulder CO
80301

(303) 444-4149

ARCHITECTURAL ENERGY CORPORATION

TABLE OF CONTENTS

ARCHITECTURAL ENERGY CORPORATION

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

ARCHITECTURAL ENERGY
CORPORATION

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**

ARCHITECTURAL ENERGY CORPORATION

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.

$$LF(t) = \frac{\sum_{i=1}^{N_{Logged}} (Current_{ControlPoint_i} * ScaleFactor_i)}{\sum_{i=1}^{N_{Logged}} kWControlPoint_i}$$

$$kW_{Lighting}(t) = LF(t) * \sum_{i=1}^{N_{ControlPoints}} kWControlPoint_i$$

Where

LF(t) = Lighting Load factor at time = t
$kWControlPoint_i$ = connected load of control point i
$CurrentControlPoint_i$ = logged current at control point i from time series data
$ScaleFactor_i$ = 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.

ARCHITECTURAL ENERGY
CORPORATION

- 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

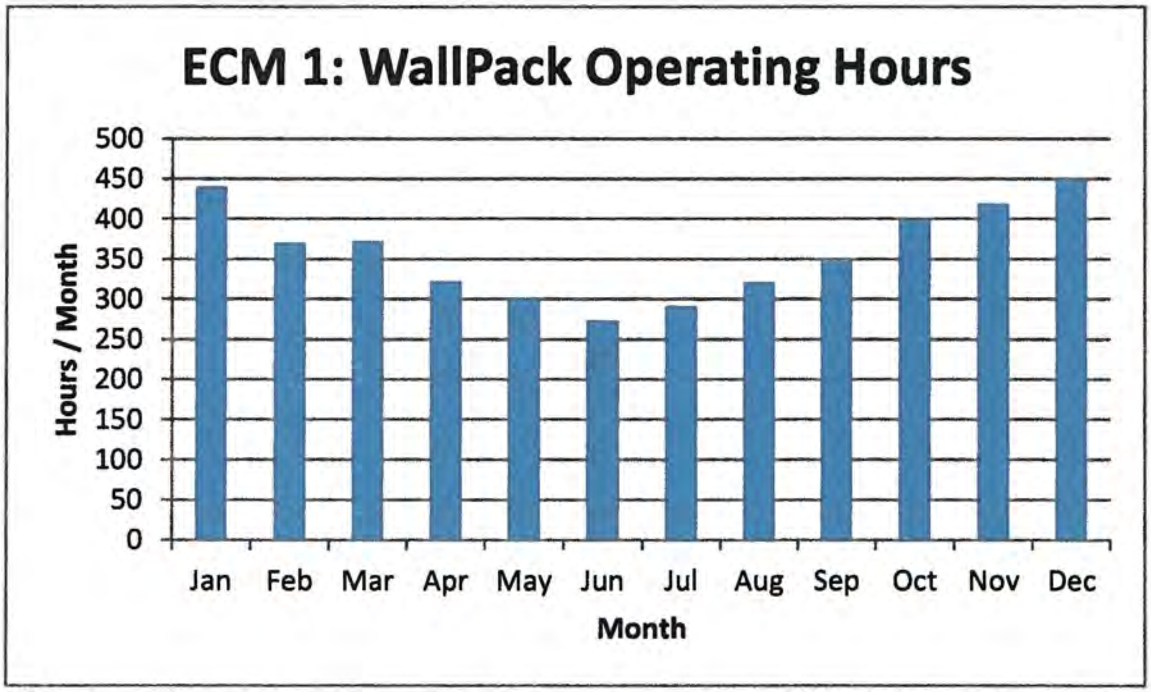
Base kW	EE kW	HOURS	CF	Lighting Only			With HVAC Interactions WHFe= 0.0 WHFd= 0.0		
				kWh savings	NCP kW	CP kW	kWh savings	NCP kW	CP kW
28.6	13.4	4734.1	0.65	71,718	15.1	9.8	71,718	15.1	9.8

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.

[redacted] Ground
Average Load Shapes

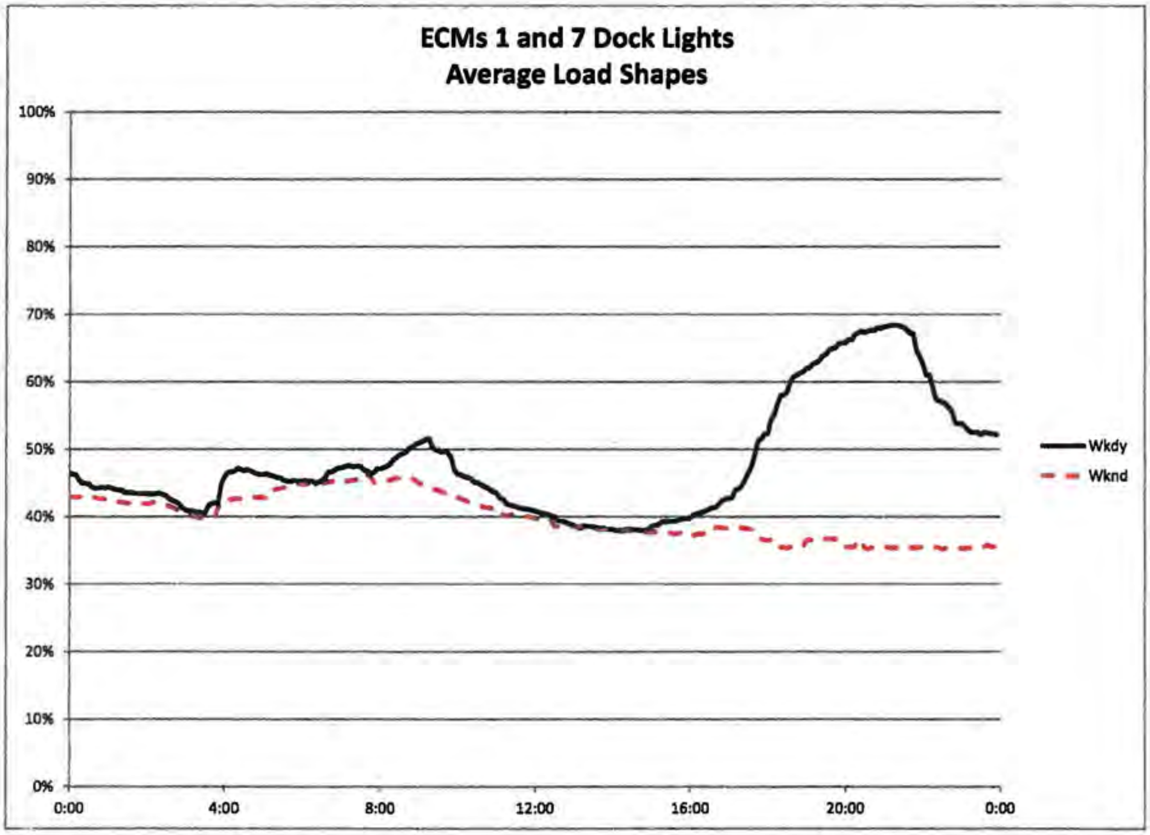
To calculate the total savings for the ECMs at [Redacted] we separately analyzed the savings for like fixtures. We then added the savings from each analysis together to determine the total project savings and realization rate. We calculated the savings separately because there were three different control 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.



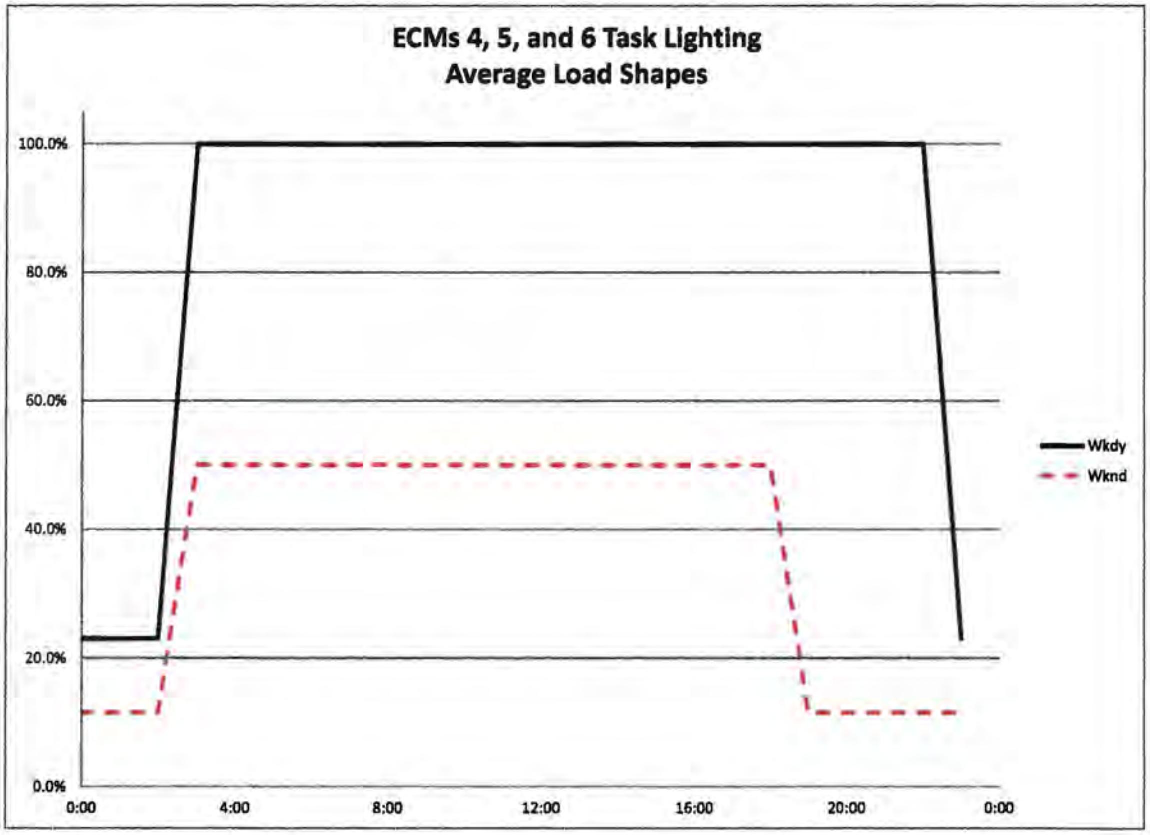
Because the operating hours of the outdoor lighting fixtures that are controlled by photocells varies throughout the year, monthly operating hours are shown in lieu of a daily load shape.

ARCHITECTURAL ENERGY
CORPORATION



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.

ARCHITECTURAL ENERGY
CORPORATION



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.

ARCHITECTURAL ENERGY
CORPORATION

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.

Submitted by:

Stuart Waterbury
Architectural Energy Corporation

2540 Frontier Avenue, Suite 100
Boulder CO
80301

(303) 444-4149

ARCHITECTURAL ENERGY CORPORATION

TABLE OF CONTENTS

Introduction

This report addresses 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

Duke Energy M&V Coordinator	Frankie Diersing	513-287-4096
Duke Energy BRM	Wes Needham	513-247-4061 [Redacted]-usa.com
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.
  - Chiller 1 power (155-ton chiller)
  - Chiller 2 power (110-ton chiller
  - Chiller 3 power (250-ton chiller, installed in June of 2013)
  - Chilled water pump
  - Dry cooler fan power
  - Dry cooler circulation pump power
  - 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:**

  - 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:**
  - 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:**
  - Compare the pre- and post-retrofit kWh and kW to determine savings.
  - 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.

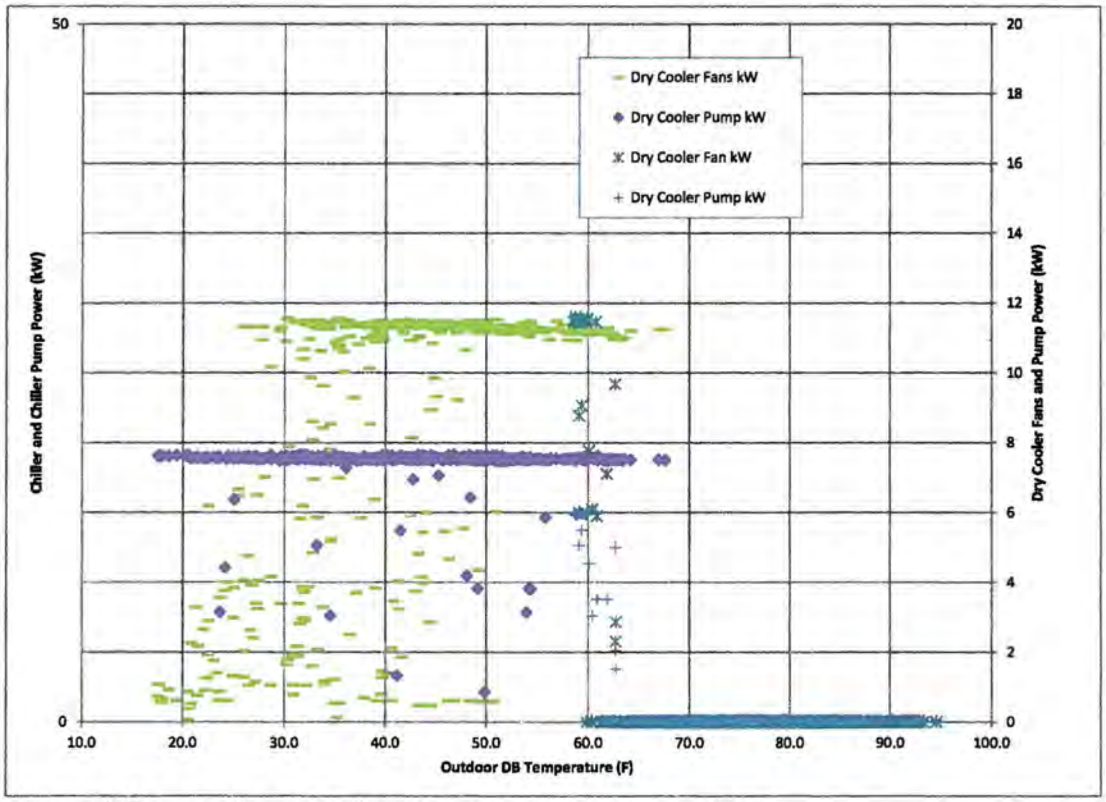


Figure 1. Dry cooler operation versus outdoor temperature

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.

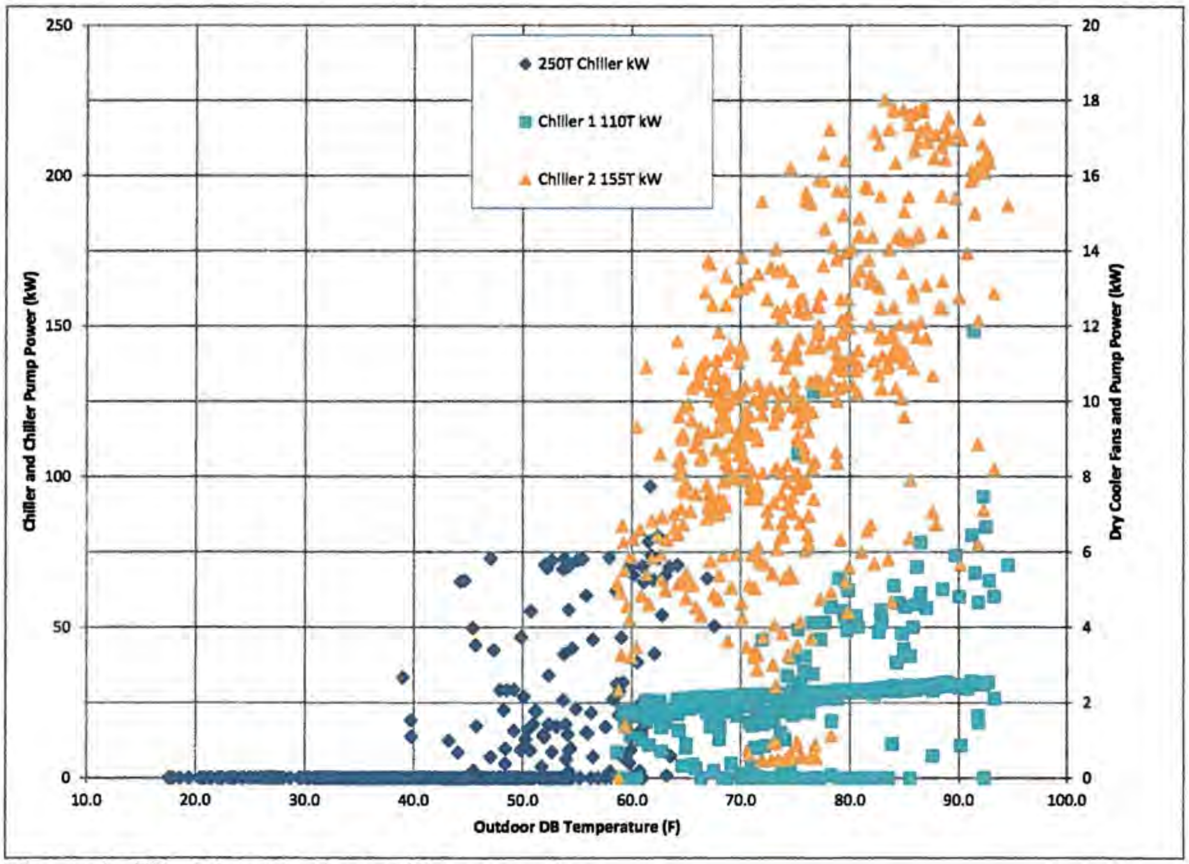


Figure 2. Weekday daytime chiller operation

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.

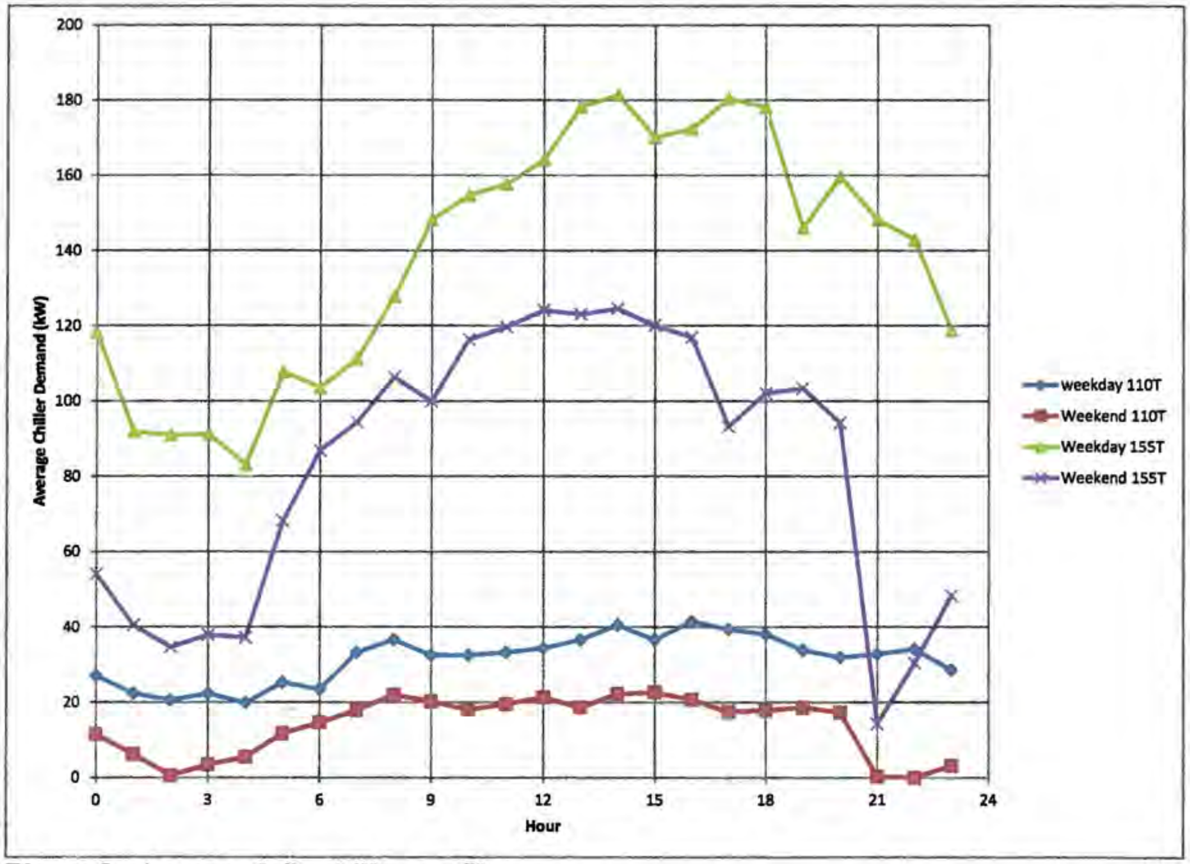


Figure 3. Average daily chiller profiles

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.

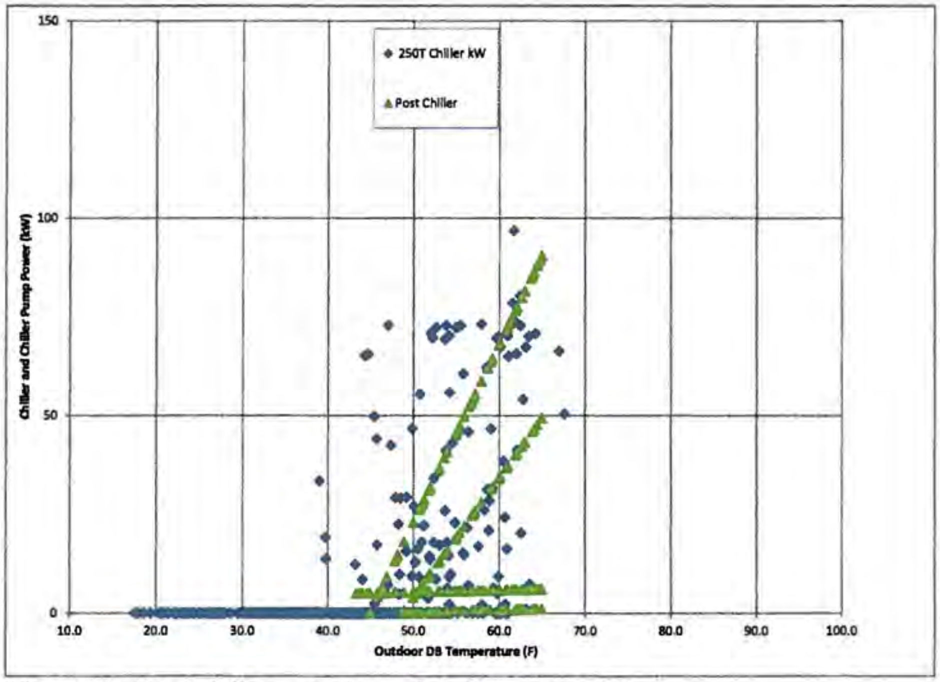


Figure 4. Post chiller monitored data and model

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.

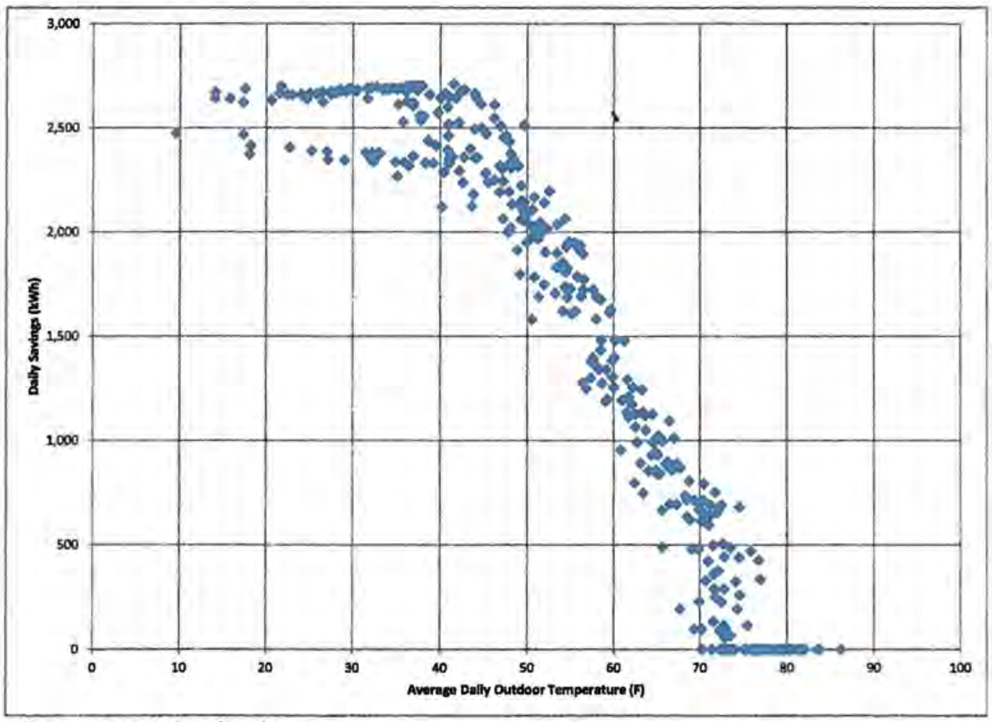


Figure 5. Daily Savings

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].

Submitted by:

Doug Dougherty
NORESCO, Inc.

Stuart Waterbury
NORESCO, Inc.

2540 Frontier Avenue, Suite 100
Boulder CO
80301

(303) 444-4149

NORESCO
United Technologies

Introduction

This report addresses 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

AEC Contact	Todd Hintz Doug Dougherty	thintz@noresco.com ddougherty@noresco.com	o: 303-459-7476 c: 303-261-5378 o: 303-459-7416
Customer Contact	[Redacted]	[Redacted]	[Redacted]
Duke Energy M&V Coordinator	Frankie Diersing	Frankie.Diersing@duke-energy.com	o: 513-287-4096 c: 513-673-0573

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. <u>*Not available.*</u>
- 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:

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

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

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

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.

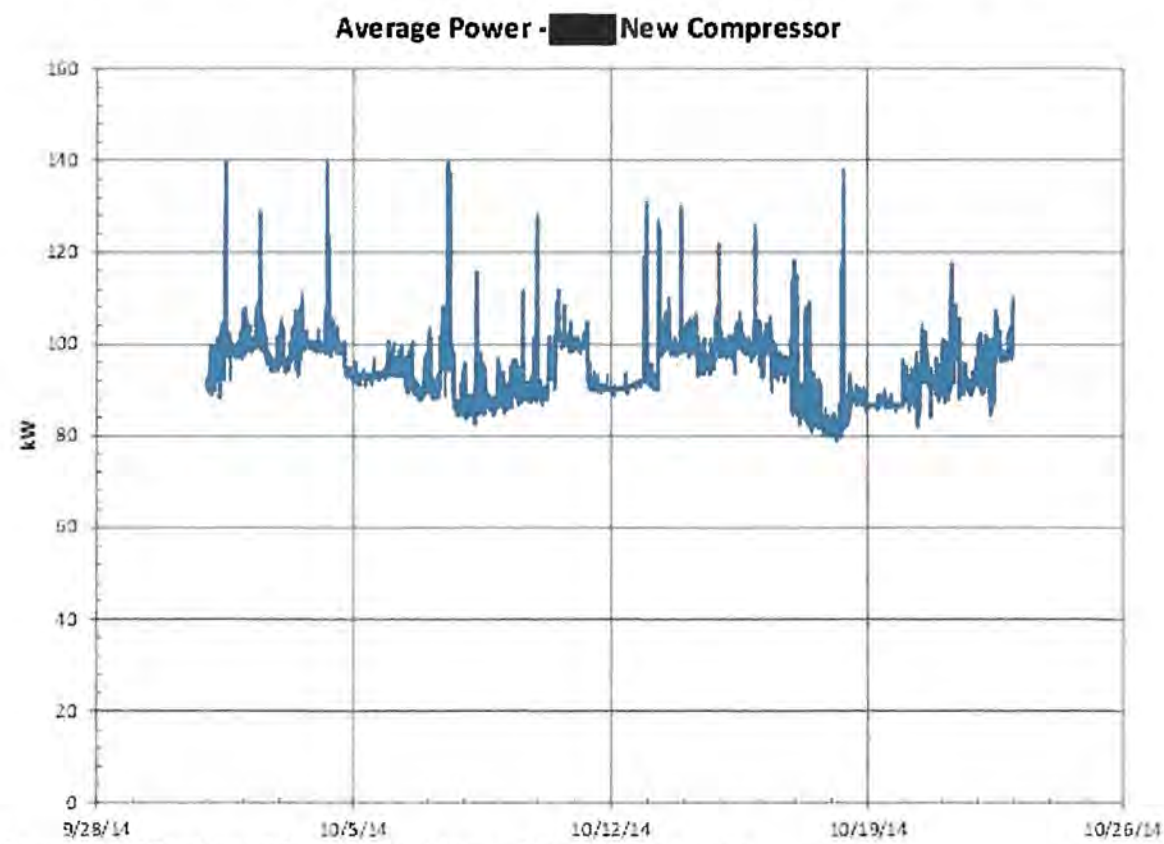


Figure 1: Monitored Power Readings – New Compressor

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.

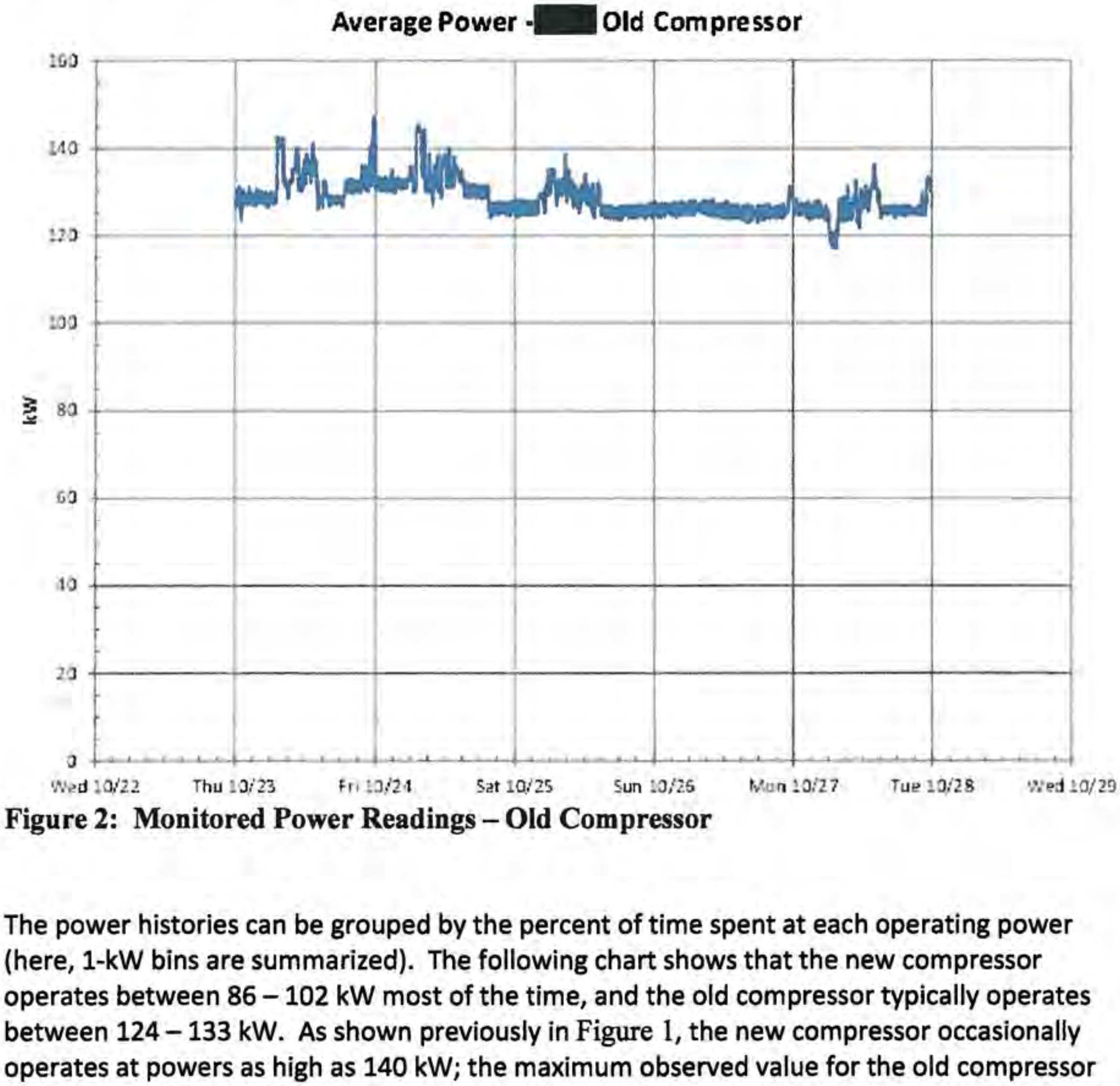


Figure 2: Monitored Power Readings – Old Compressor

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.

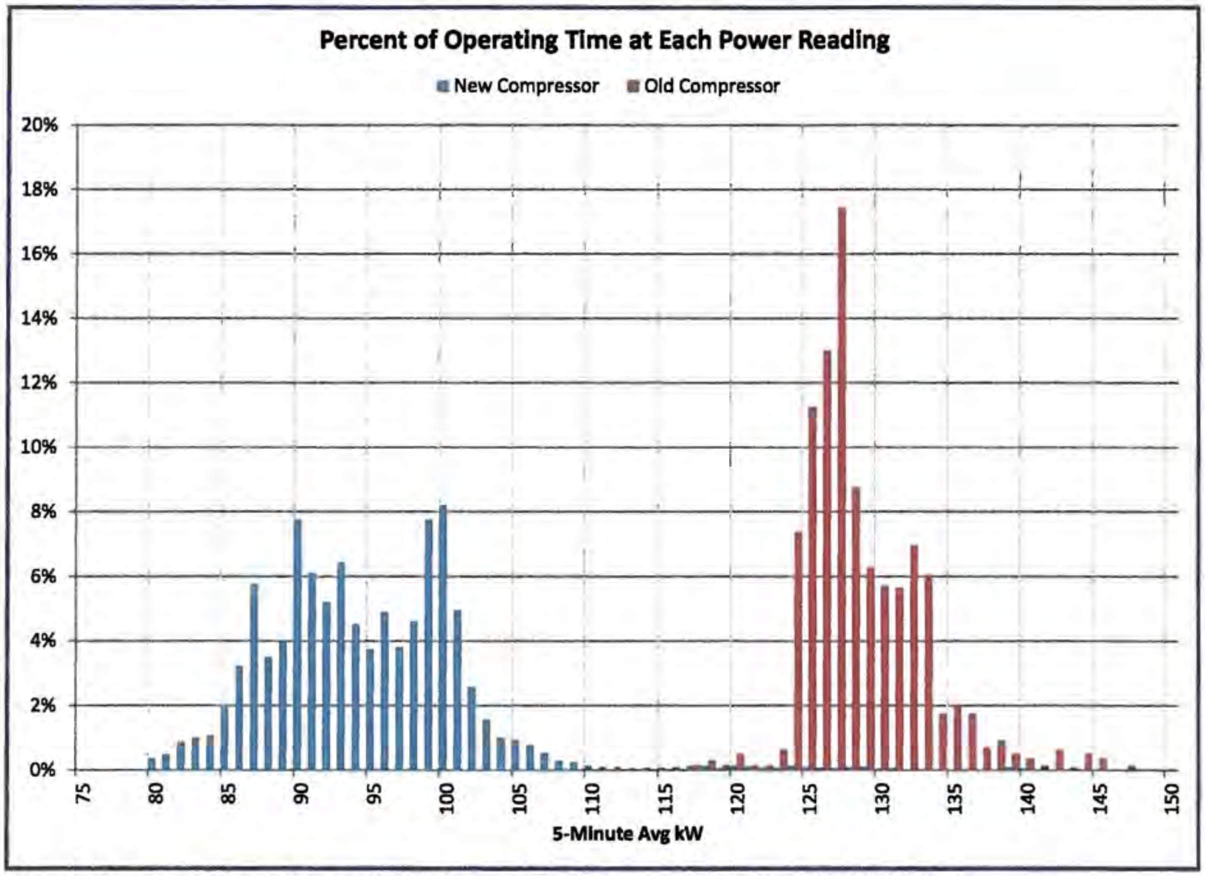


Figure 3: Percent of Operating Time at Each Power Reading (1-kW bins)

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.)

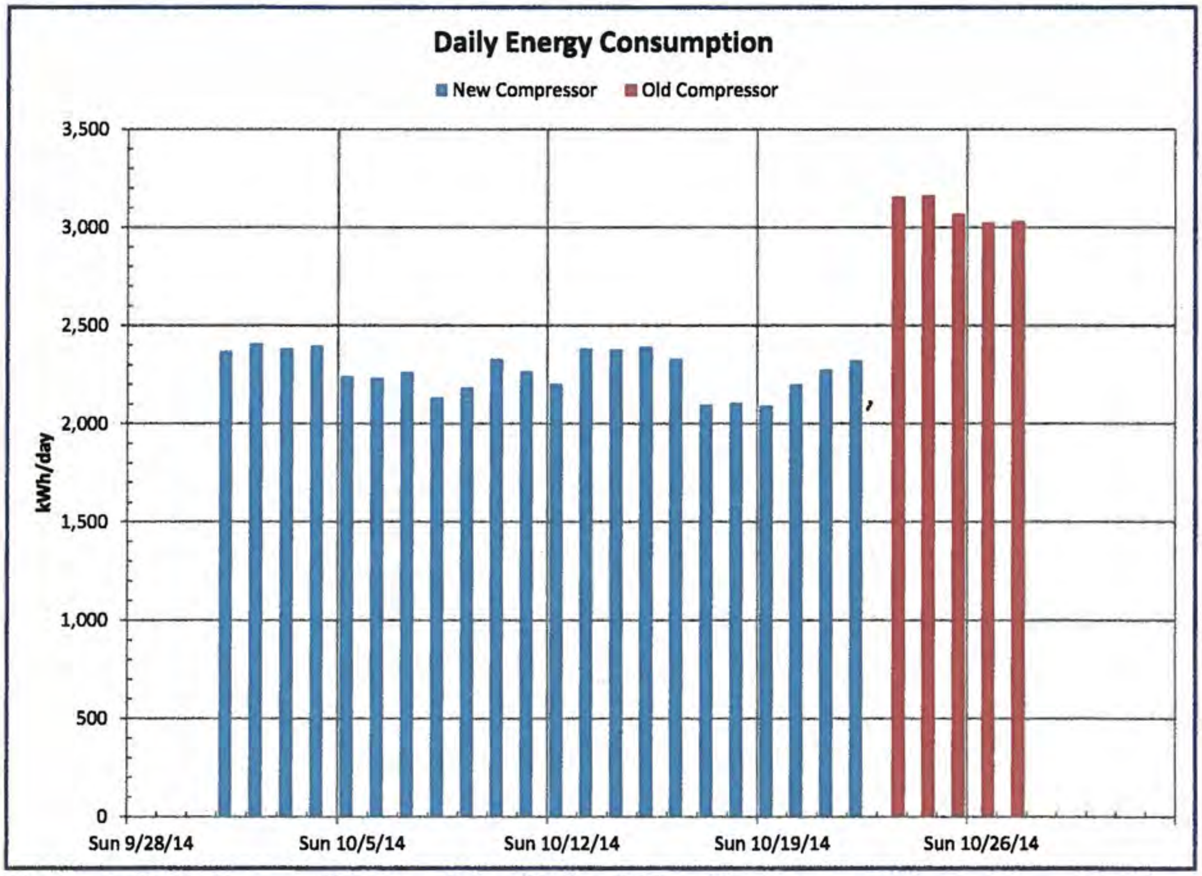


Figure 4: Daily Energy Consumption – Old and New Compressors

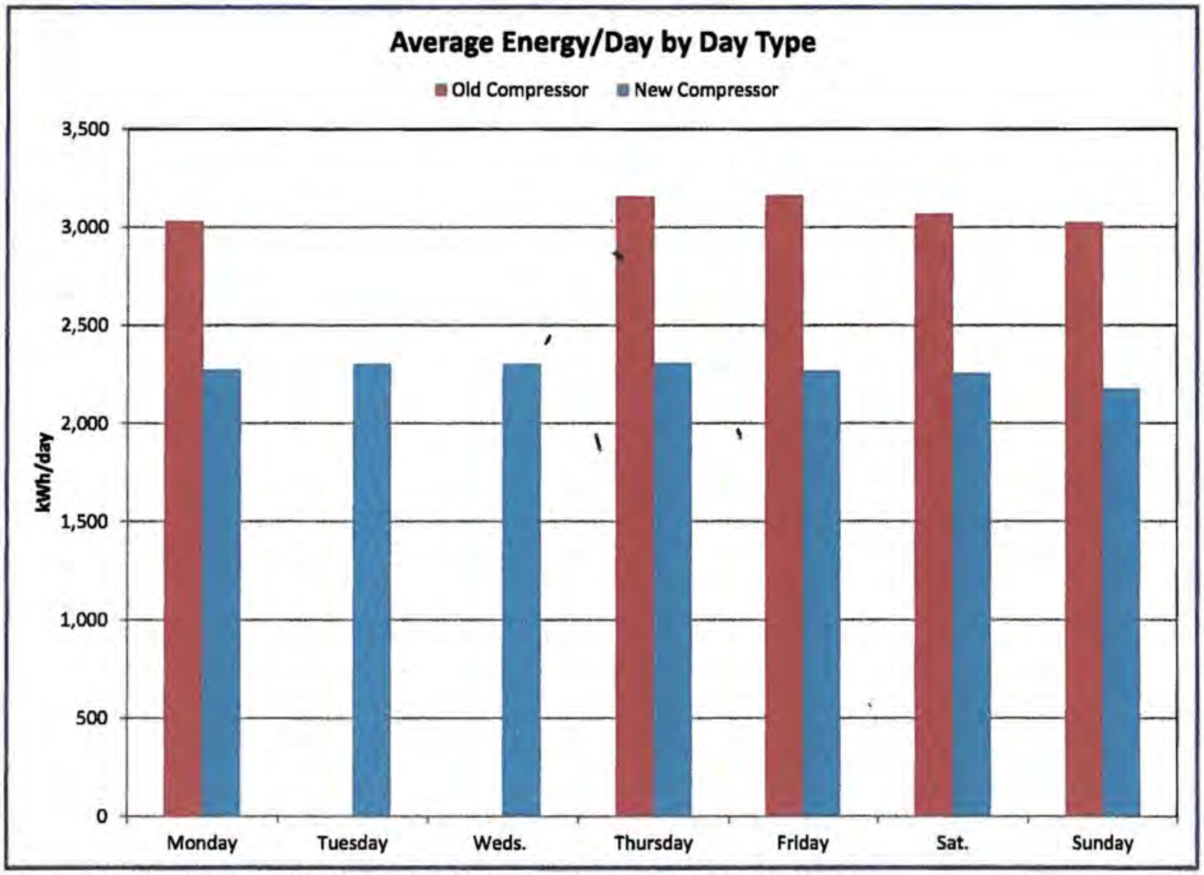


Figure 5: Average Daily Energy Consumption by Day of the Week

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

10% Bins (*Power*)	Power Range (kW)		Old Compressor		New Compressor	
	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].

Submitted by:

Todd Hintz
NORESCO, Inc.

Jerry Moechnig
NORESCO, Inc.

2540 Frontier Avenue, Suite 100
Boulder CO
80301

(303) 444-4149

NORESCO
United Technologies

Introduction

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

NORESCO Contact	Todd Hintz	thintz@noresco.com O: 303-459-7476
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
$\eta_{fanstatic}$ = Fan Efficiency
η_{motor} = 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

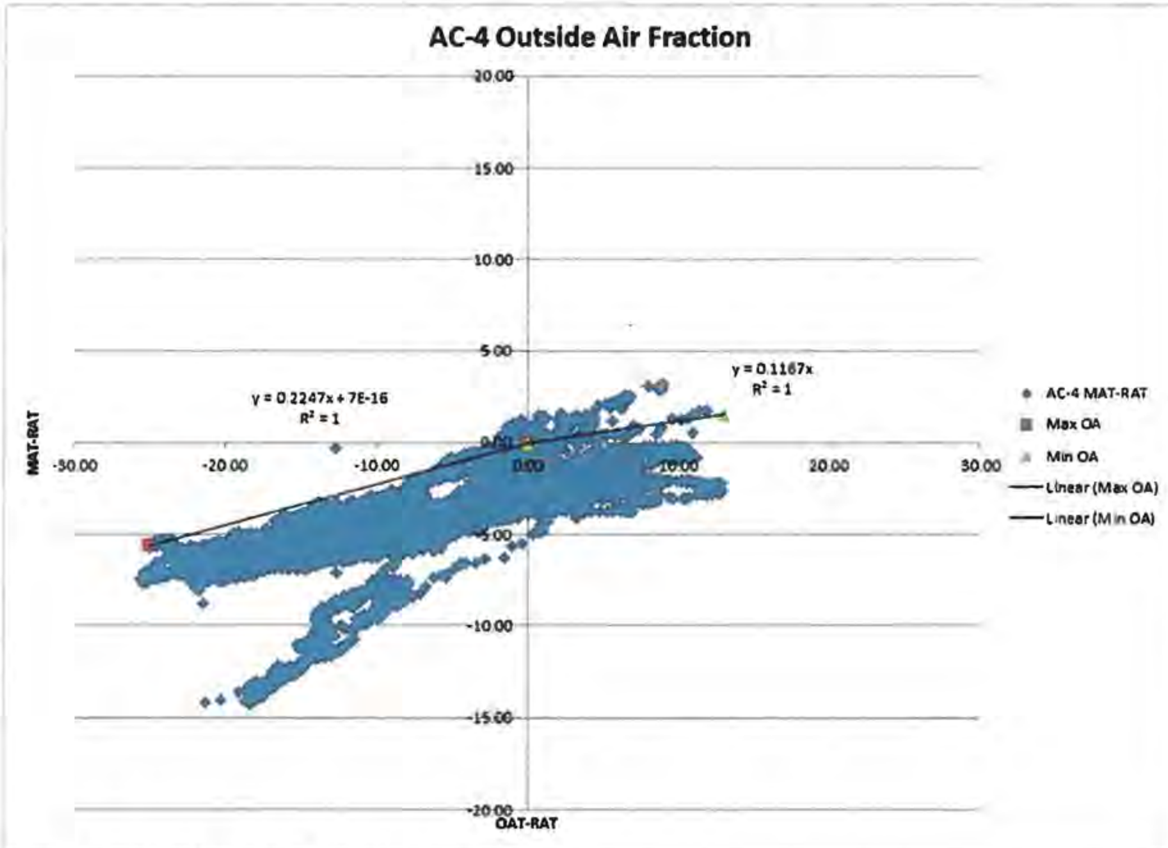


Figure 1. AC-4 Outside air fraction

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.

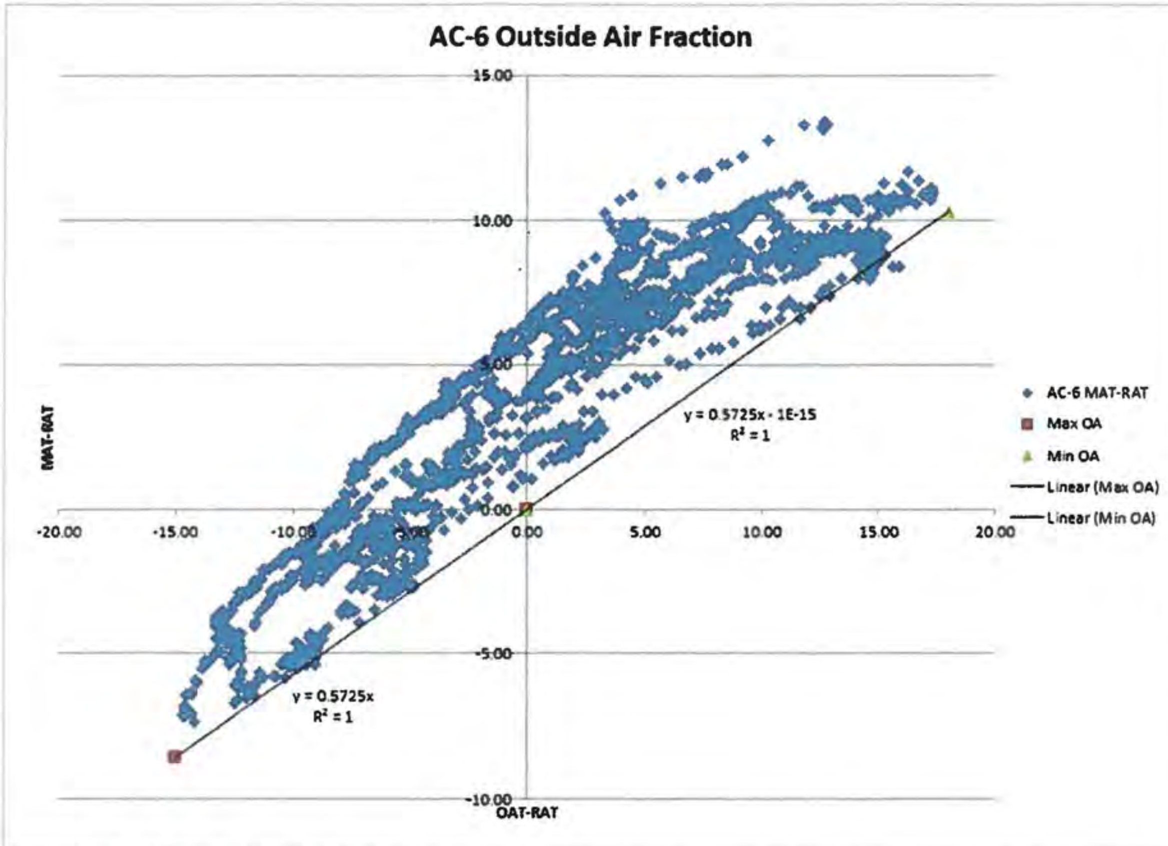


Figure 2. AC-6 Outside air fraction

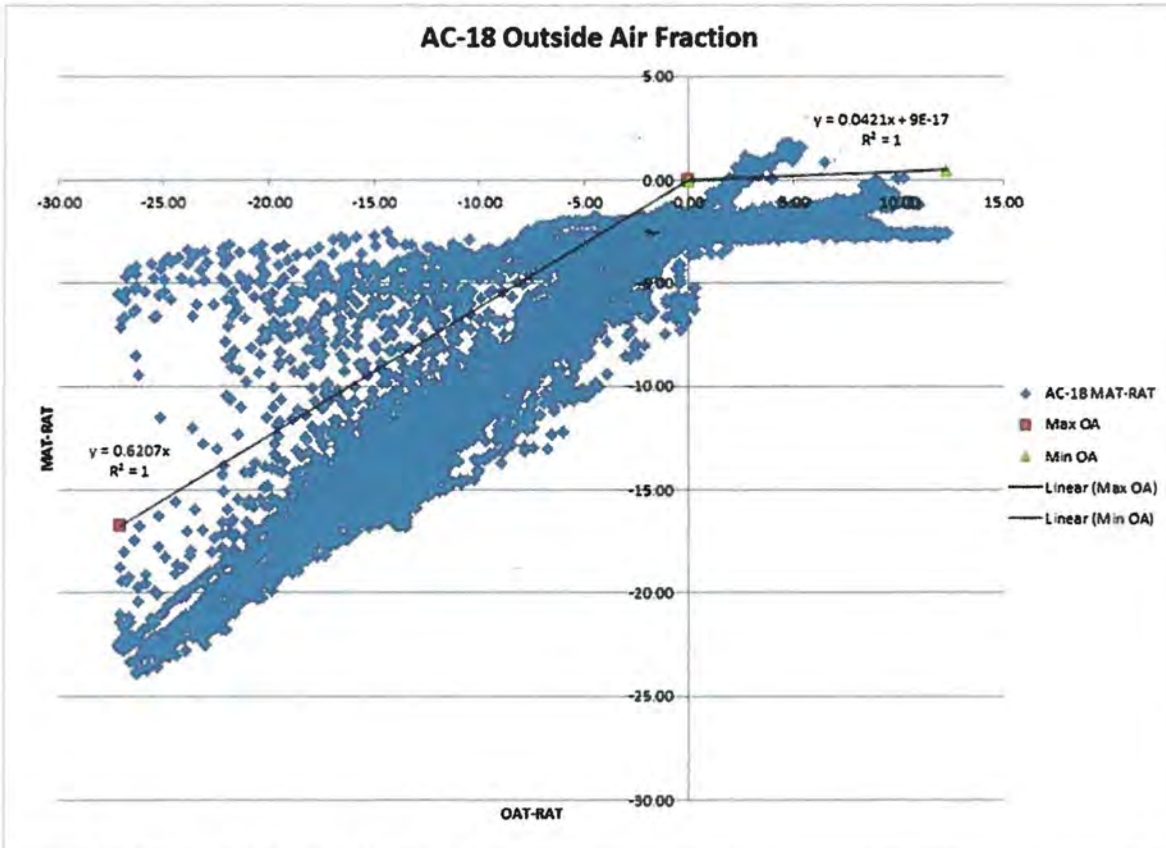


Figure 3. AC-18 Outside air fraction

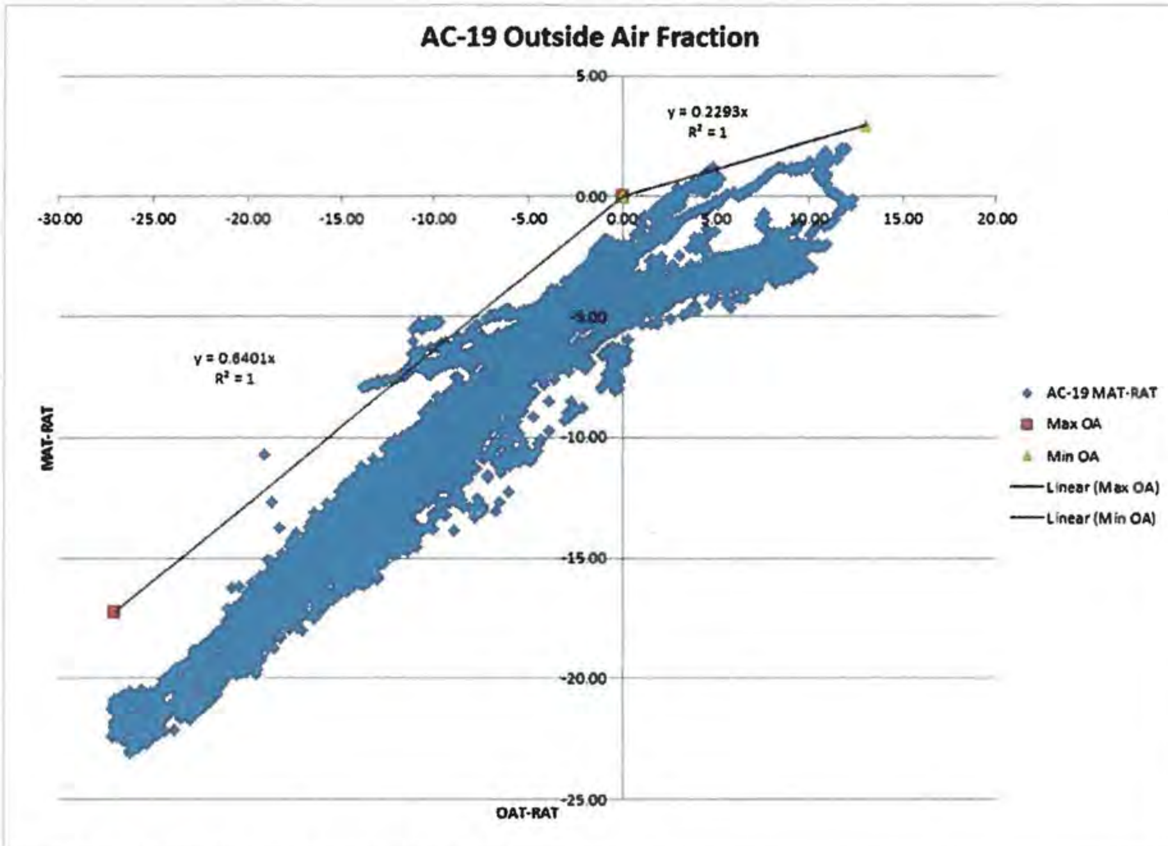


Figure 4. AC-19 Outside air fraction

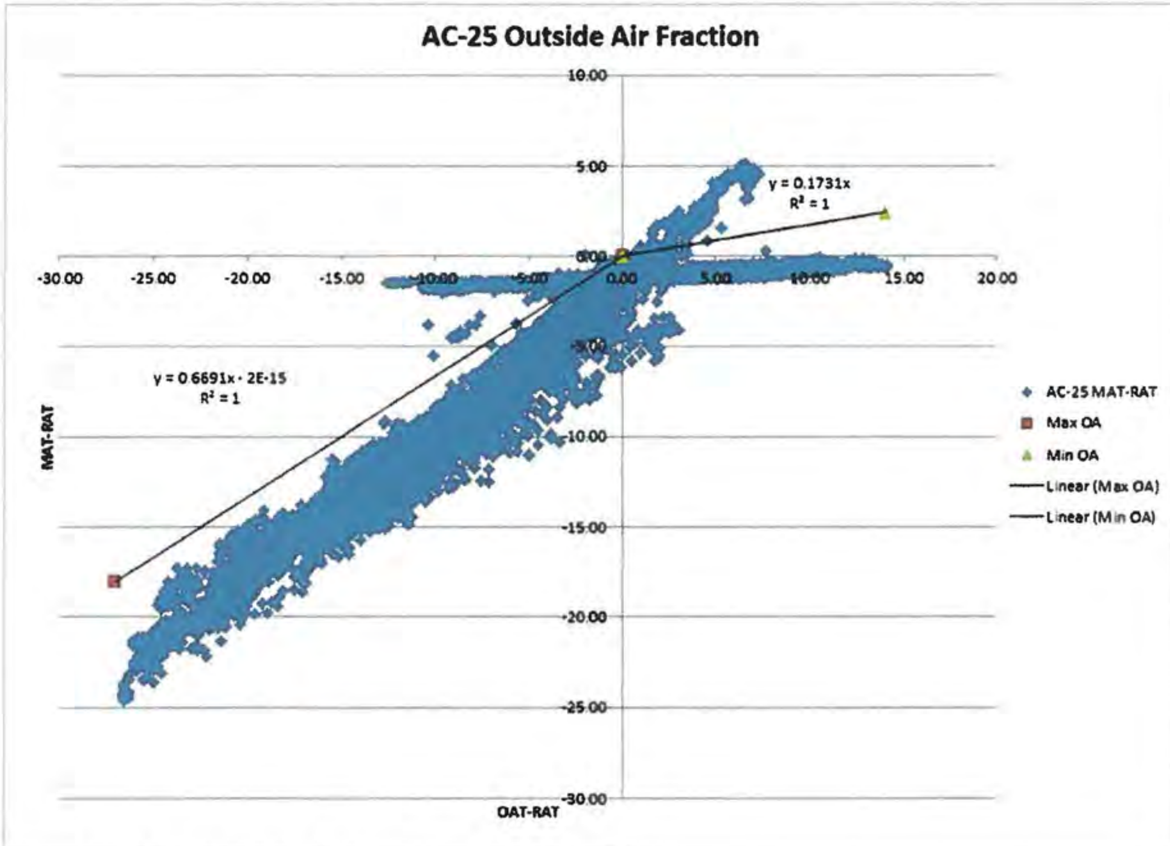


Figure 5. AC-25 Outside air fraction

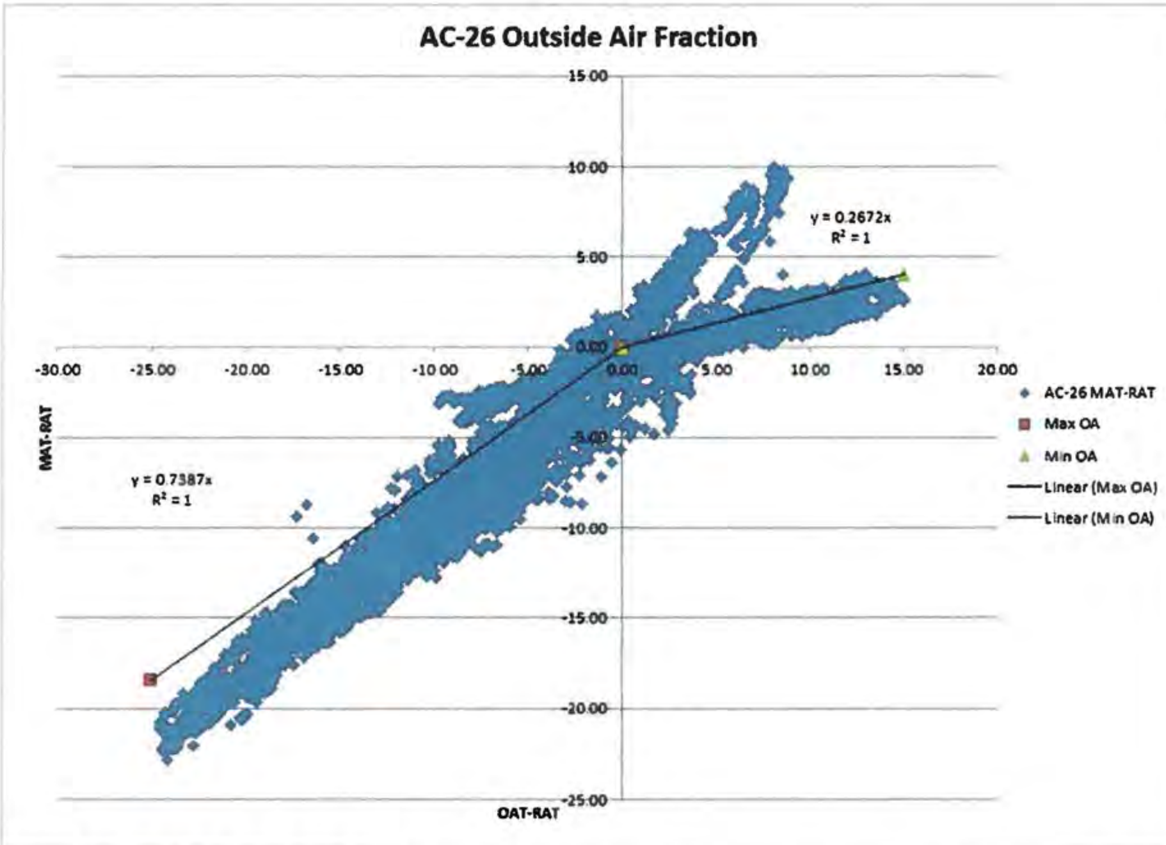


Figure 6. AC-26 Outside air fraction

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.

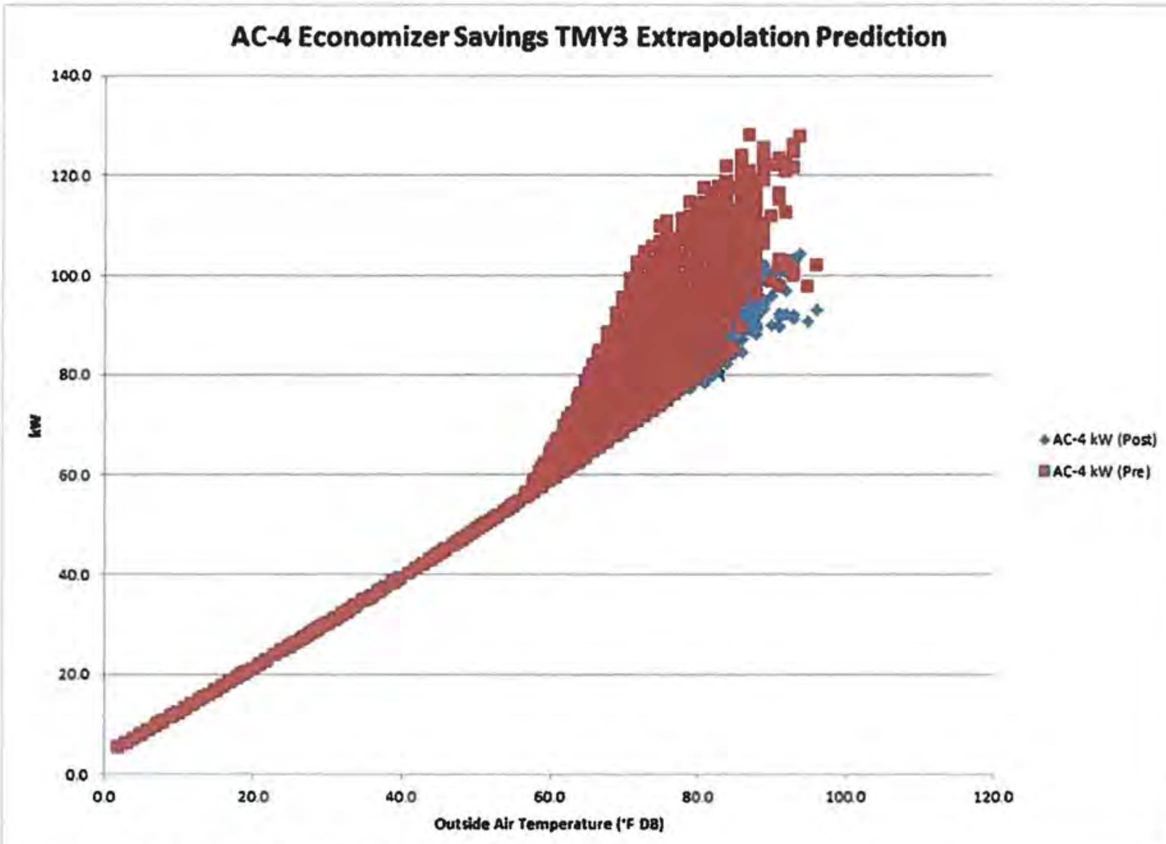


Figure 7. AC-4 Pre and post-retrofit demand

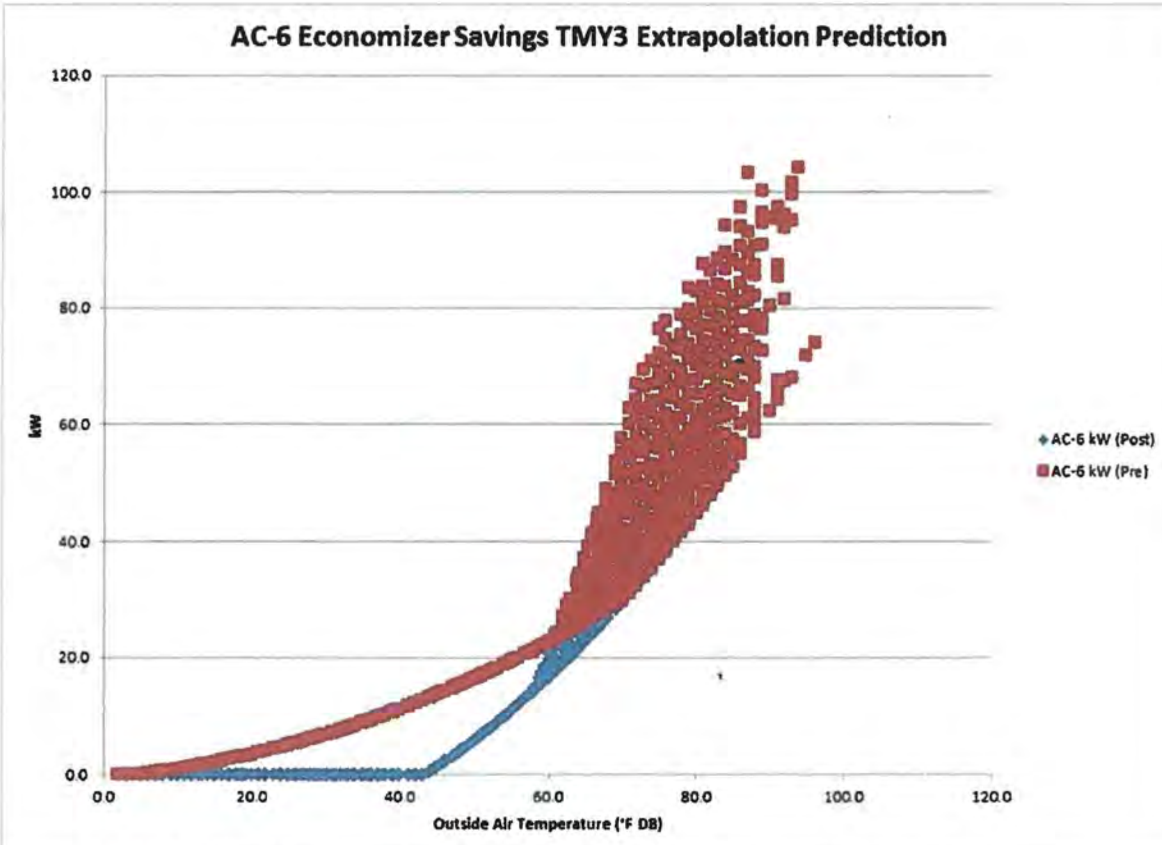


Figure 8. AC-6 Pre and post-retrofit demand

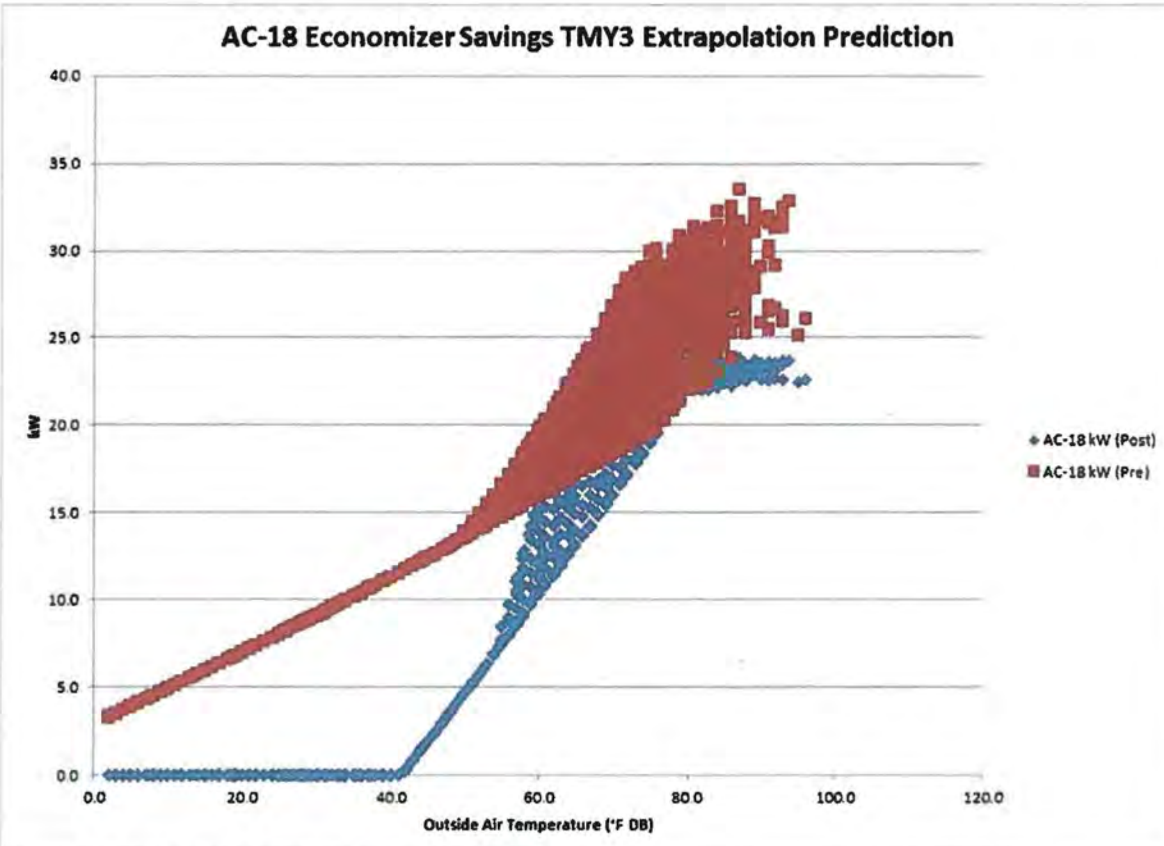


Figure 9. AC-18 Pre and post-retrofit demand

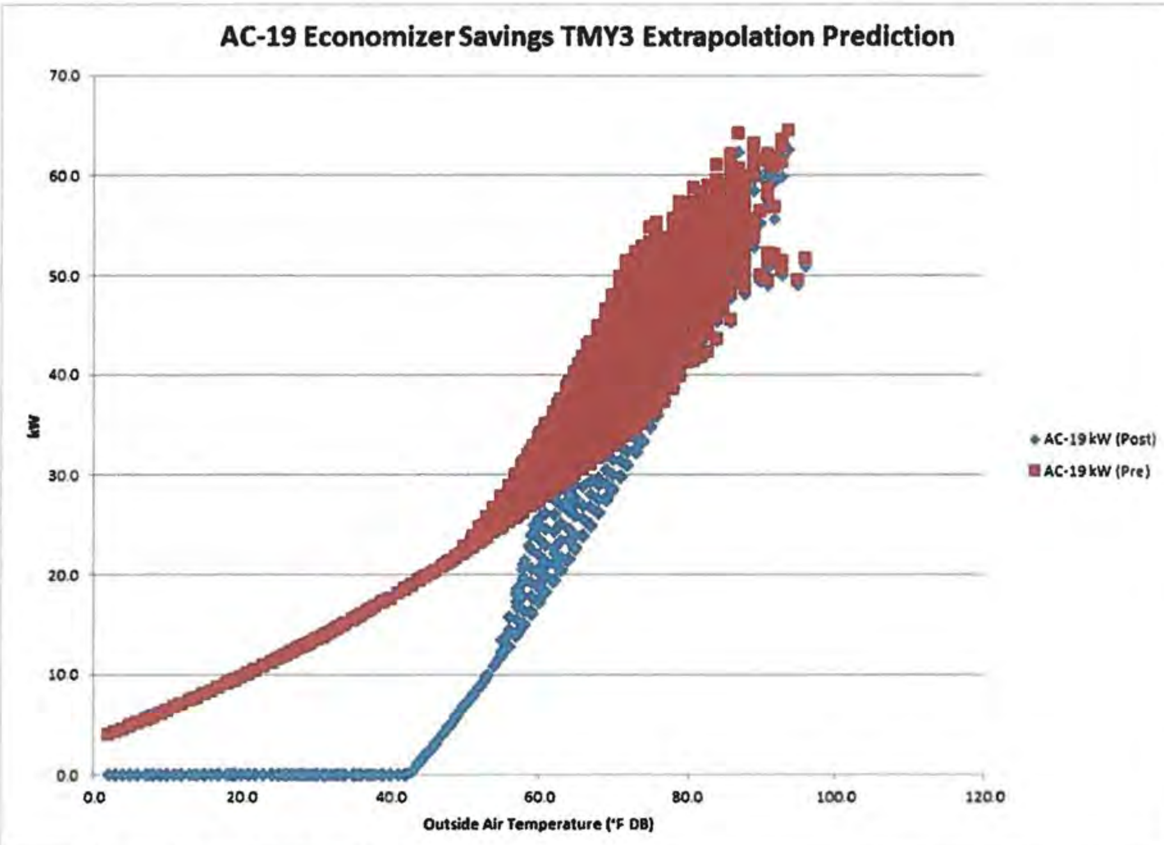


Figure 10. AC-19 Pre and post-retrofit demand

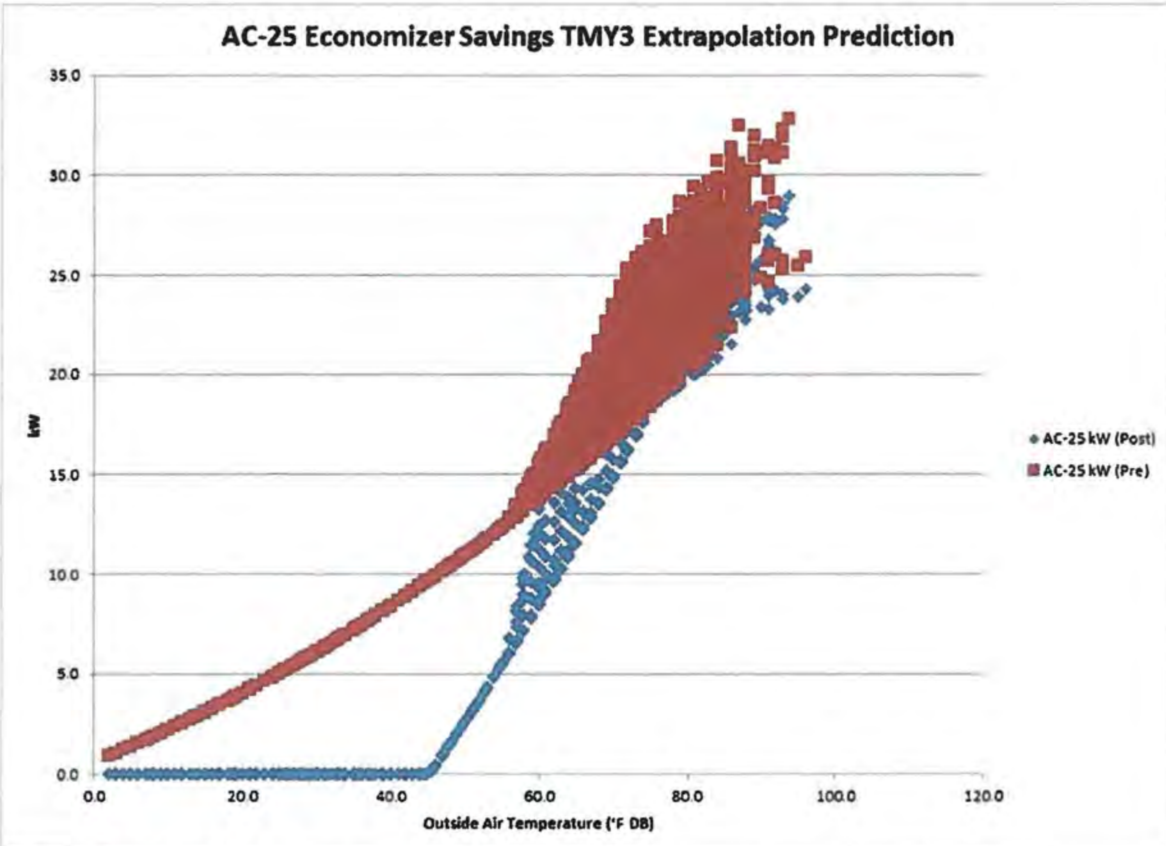


Figure 11. AC-25 Pre and post-retrofit demand

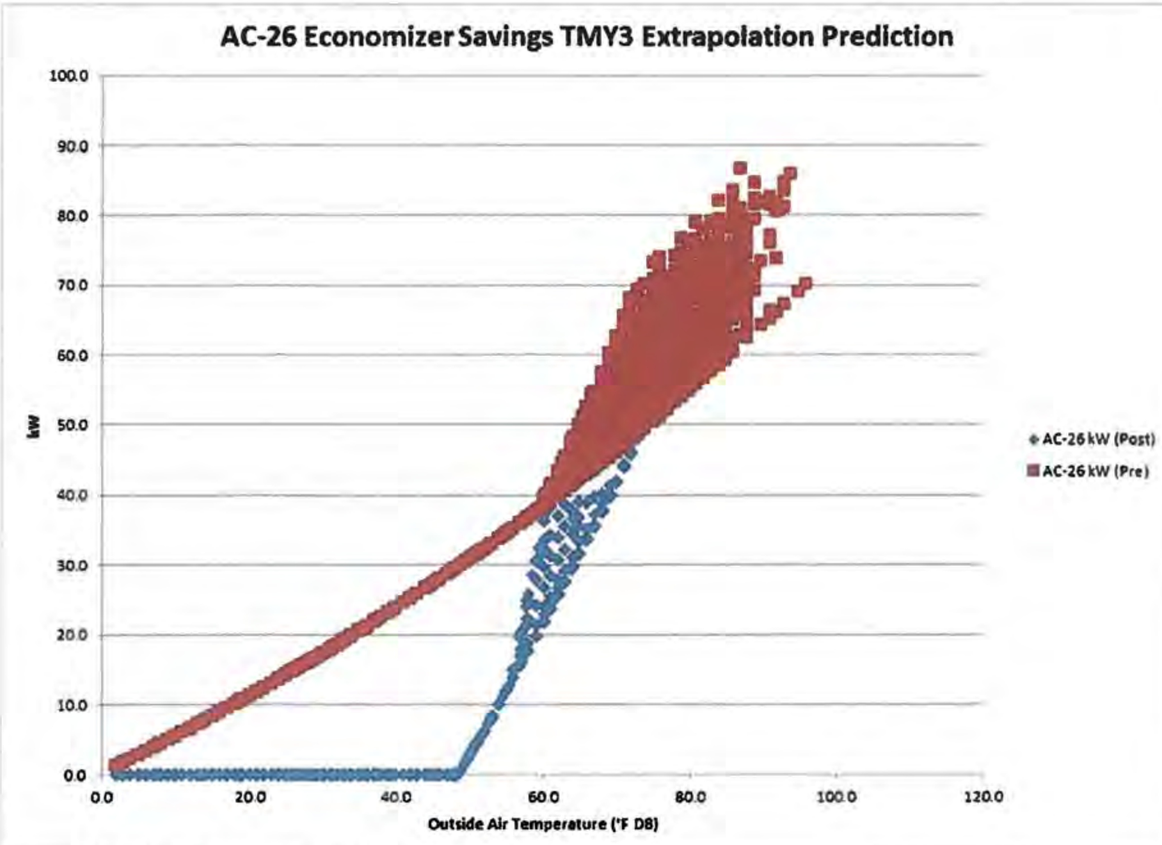


Figure 12. AC-26 Pre and post-retrofit demand

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
Architectural Energy Corporation

Stuart Waterbury
Architectural Energy Corporation

2540 Frontier Avenue, Suite 100
Boulder CO
80301

(303) 444-4149

ARCHITECTURAL ENERGY
CORPORATION

TABLE OF CONTENTS

Introduction

This report addresses M&V activities for the 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 **Error! Reference source not found.** 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 **Error! Reference source not found.** 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.

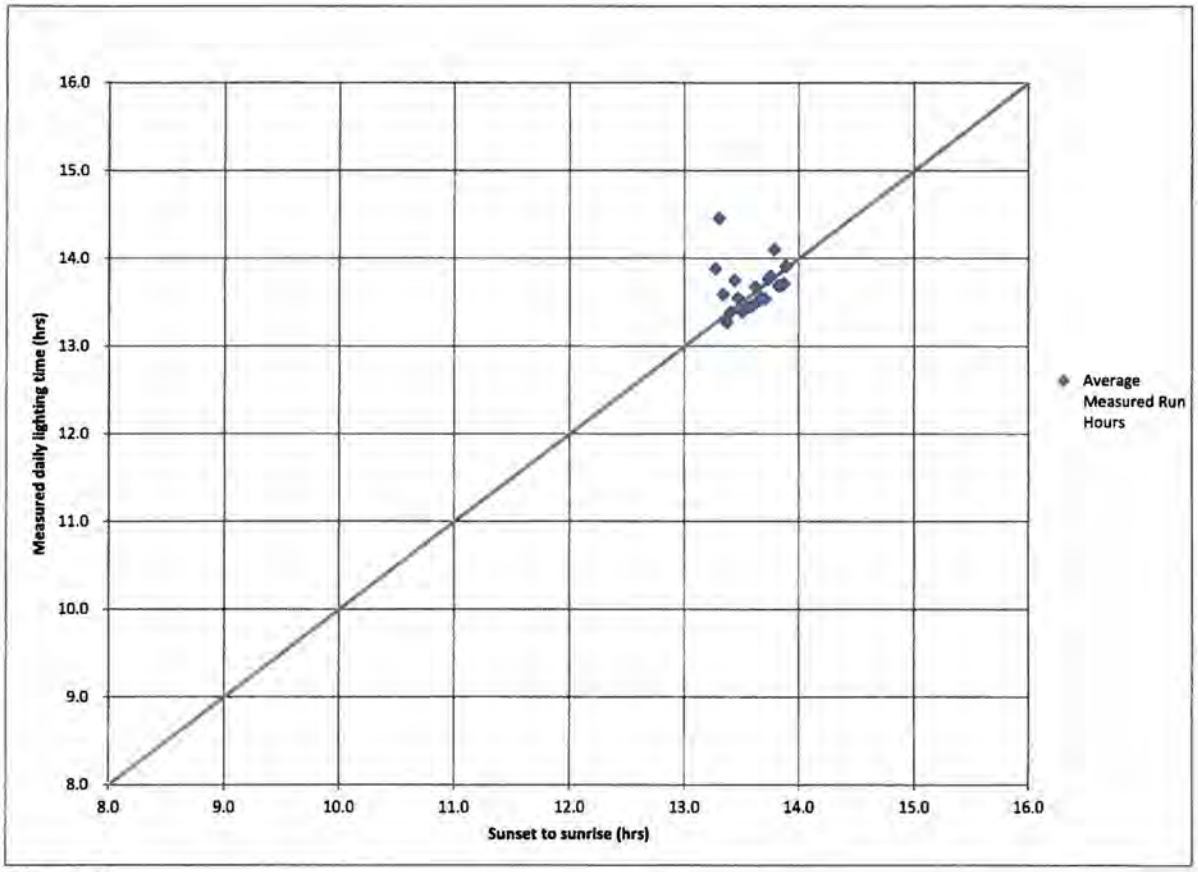


Figure 1

A summary of the estimated annual savings is shown in Table 1**Error! Reference source not found.**.

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 **Error! Reference source not found.**, as the date approaches the winter solstice, the lighting circuits are energized for longer periods of time, with some variability due to weather, etc.

[redacted]

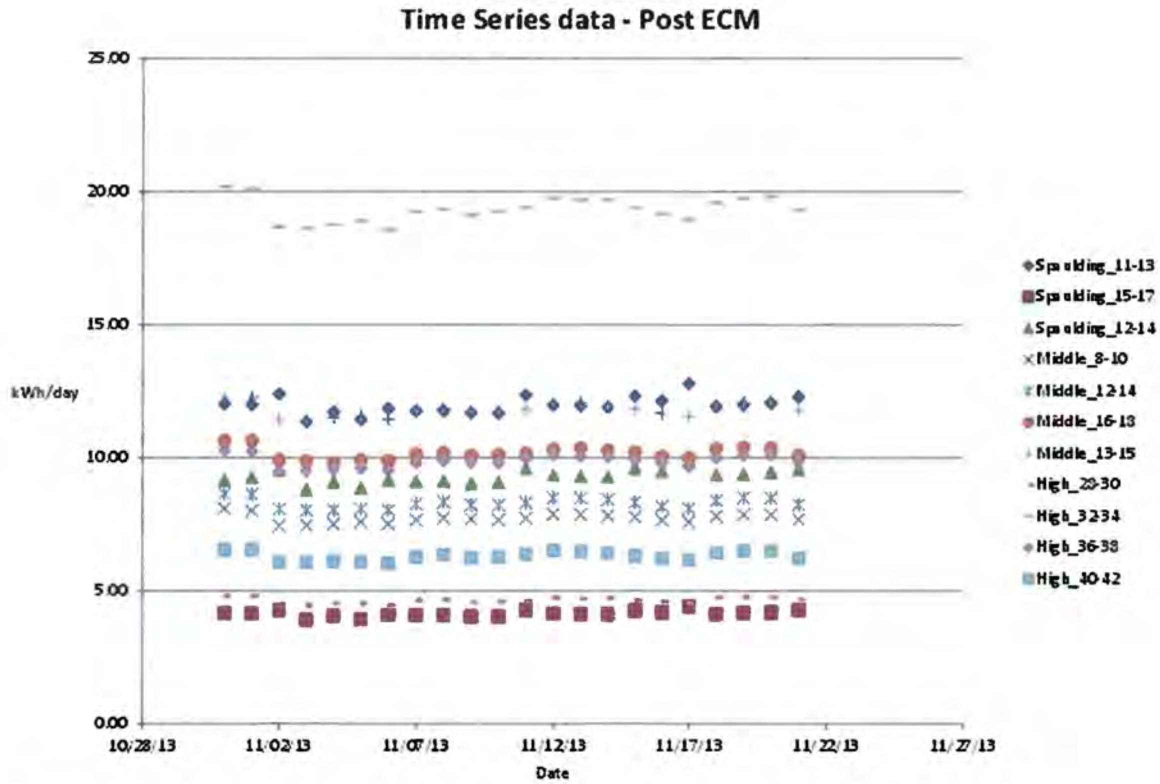


Figure 2

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

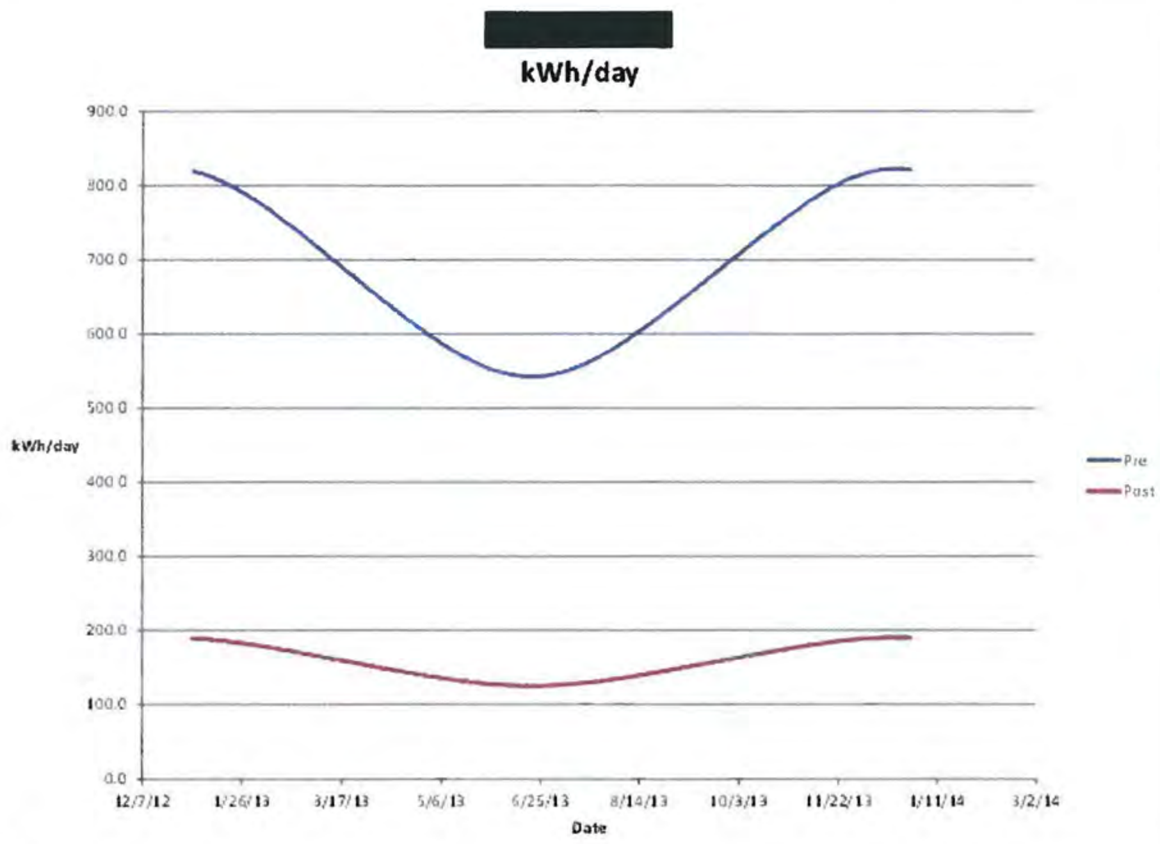

[redacted]
kWh/day
900.0
800.0
700.0
600.0
500.0
kWh/day
400.0
300.0
200.0
100.0
0.0
12/7/12
1/26/13
3/17/13
5/6/13
6/25/13
8/14/13
10/3/13
11/22/13
1/11/14
3/2/14
Date
Pre
Post

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

ARCHITECTURAL ENERGY CORPORATION

[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].

ARCHITECTURAL ENERGY
CORPORATION

Introduction

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

ARCHITECTURAL ENERGY CORPORATION

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.

ARCHITECTURAL ENERGY
CORPORATION

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].

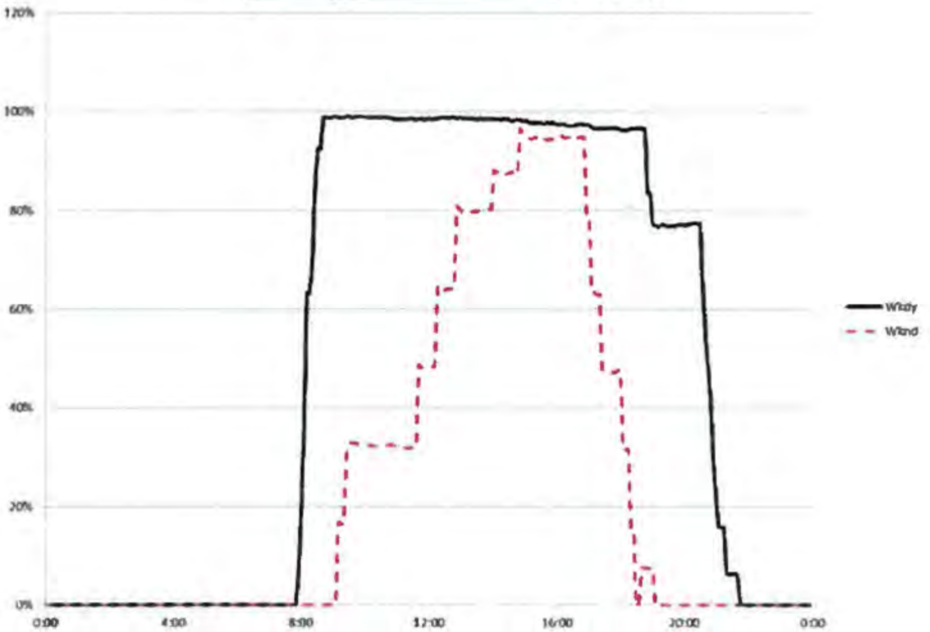
	Lighting	HVAC	Total
Pre kW	11.47		
Post kW	4.62		
Demand Savings	6.85	2.17	**9.02**
Coincident Pk Demand Svgs (kW):	6.81	2.16	**8.97**

		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

ARCHITECTURAL ENERGY
CORPORATION

[redacted] Load Shape



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.

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.

Submitted by:

Doug Dougherty
Architectural Energy Corporation

Stuart Waterbury
Architectural Energy Corporation

2540 Frontier Avenue, Suite 100
Boulder CO 80301
(303) 444-4149

ARCHITECTURAL ENERGY CORPORATION

TABLE OF CONTENTS

Introduction

This plan addresses M&V activities and results for the [Redacted] custom program application. The application covers adding a variable frequency drive (VFD) to a refrigeration compressor in Harrison, Ohio. The measure includes the following:

ECM-1: Refrigeration Compressor VFD

- Purchase and install a new 350-HP ammonia refrigeration compressor with a VFD.
- The compressor is manufactured by the Vilter Manufacturing Company and is a model VSS 2101 single screw compressor.
- The baseline for the compressor's energy consumption and electric demand consists of an input data form that is part of the application, which described the compressor operating at full load for 6,264 hours per year.
- The refrigeration load varies widely, based on the type of product being manufactured. The production schedule is revised on a weekly basis. Production is also heavily influenced by maintenance needs, special orders and inventory – no two weeks are alike.

Goals and Objectives

The projected savings goals identified in the application are:

ECM	Duke Projected Annual Savings (kWh)	Duke Projected Coincident Peak Savings (kW)	Duke Projected Non-Coincident Peak Savings (kW)
1: Refrigeration Compressor VFD	437,515	6.9	50.3

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

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

Project Contacts

AEC Contact	Doug Dougherty	(w) 303-459-7416 (c) 303-819-8888	ddougherty@archenergy.com
DE Acct Executive	Mike Harp	Cell: 513 265-3435	Mike.harp@duke-energy.com
Customer Contact	[Redacted]	[Redacted]	[Redacted]
Duke Energy M&V Coordinator	Frankie Diersing	(w): 513-287-4096 (c): 513-673-0573	Frankie.Diersing@duke-energy.com

Site Locations/ECM's

Site	Address
[Redacted]	[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 A

M&V Implementation Schedule

- Surveyed site personnel to obtain information on pre-retrofit system operations.
  - Obtained the pre-retrofit sequence of operations and/or operating schedule for the refrigeration system.
- Surveyed site personnel to obtain information on post-retrofit system operations.
  - Obtained and verified the post-retrofit sequence of operations and/or operating schedule for the new refrigeration system.
- Deployed dataloggers to record electrical parameters on the new compressor. This data was used to determine post-retrofit load shapes and energy consumption.

- Electrical parameters on the new compressor
- Outdoor air temperature and relative humidity. *(Not required, load is not weather-dependent.)*
- Collected data during normal operating hours.

- Evaluated the energy savings of the compressor replacement.

Data Accuracy

Measurement	Sensor	Accuracy	Notes
Current	DENT Split-Core CT	±1%	Recorded load must be >10% of CT rating
kW	Dent ElitePro	±1%	
Temperature	Hobo Weather Station	0.38°F	
Relative Humidity		2.5% typ./3.5% max	

Field Data Points

Post – installation

Survey data (for all compressors)

- Compressor manufacturer, model number, serial number, etc.
- Condenser nameplate data (if separate from compressor). *(Not required)*
- Photographs of equipment and nameplate(s).

One-time spot measurements for compressor (to check and validate ElitePro data)

- <u>Compressor</u> volts, amps, kW and power factor
- <u>Condenser</u> volts, amps, kW and power factor *(Not required)*
- VFD speed/frequency at the same time as electrical spot-measurements.

Time series data on compressor

- Compressor volts, amps, kW and power factor.

Time series data for outside air

- OA temperature and relative humidity. *(Not required)*

Field Data Logging

Post – installation

ECM-1

- Spot measured compressor voltage, amps, power factor and power using a 3-phase power meter.
- Installed one ElitePro power/energy data logger on the new compressor
- Set up the data logger to monitor voltage, amps, power factor and compressor power (kW) on each leg, and to totalize same (on Channel 5).
- Install one OA weather station. *(Not required)*
- Set up data loggers for 5 minute readings. Deployed for **six** (**6**) weeks to accommodate the highly variable weekly production schedule.

Logger Table

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

ECM	ElitePro Energy Logger	500A CT*	Weather station
Refrigeration Compressor VFD	1	3	1

Data Analysis

1. Converted post-retrofit time series data on logged equipment into average kWh-based load shapes by day type to establish post-retrofit energy consumption. The following equations show post-retrofit annual energy consumption (kWh):

   First:

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

   Then:

   $$\frac{kWh}{year_{workdays}} = \sum_{i} kWh_i \times \frac{workdays\_per\_year}{workdays\_monitored}$$

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

$$\frac{kWh}{year_{post}} = \frac{kWh}{year_{workdays}} + \frac{kWh}{year_{offdays}}$$

- Determined if refrigeration compressor demand is sensitive to outdoor air temperature (OAT) or humidity. If it is, develop pre/post regression models of total daily kWh as a function of average outdoor dry-bulb and/or wet-bulb temperature.
- The above equations may be applied to other day-types separately if necessary (holidays, if Mondays are different from other weekdays, etc.).

2. Determined the maximum power (kW), and the maximum coincident power (kW), in the measured data.
3. Establish a post-retrofit load shape (characterized by refrigeration load vs. time) using collected data on kWh and kW, and manufacturer's information on power vs. load. This load shape will be used in both the pre- and post-retrofit calculations to characterize the energy savings from the VFD retrofit.
4. Given the post-retrofit load shapes, and the kW/load information for the pre-retrofit equipment, estimate the annual energy consumption of the pre-retrofit equipment.

$$\frac{kWh}{year}_{pre} = \sum_i \left[Load_{i,post} \times \left(\frac{kW}{Load} \right)_{pre} \times dt \right]$$

5. Reviewed application baseline calculations for errors that could affect originally-predicted baseline and proposed energy usage and energy savings. This review helps explain any differences between predicted and measured/verified energy savings.
6. Determined the annual baseline energy consumption (kWh), maximum power (kW), and the maximum coincident power (kW).
7. Normalized the pre-retrofit energy consumption value for changes in production or year-to-year operation by using the following equation:

$$\frac{kWh}{year}_{pre-adjusted} = \frac{kWh}{year_{pre}} \times \frac{RunHours_{Pre}}{RunHours_{Post-Extrapolated}}$$

8. Calculated the annual energy savings using the previous data in the following equation:

$$\frac{kWh}{year_{savings}} = \frac{kWh}{year_{pre-adjusted}} - \frac{kWh}{year_{post}}$$

9. Estimated peak demand savings. kW_{post} was determined from monitored data, while $kW_{pre\text{-}adjusted}$ comes from the maximum kW_{pre}, modified by any change from the pre- to post-retrofit CFM load profile. Demand savings is then calculated by:

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

10. Estimated *coincident* peak demand savings. The coincident peak for both pre- and post-retrofit for Ohio in 2013 is the maximum demand experienced between 4:00 and 5:00 PM on July 17. Demand savings is then calculated by:

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

11. Compared 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 logger binary files
2. Excel spreadsheets

Results

DATA REVIEW

The refrigeration compressor power data collected with the ElitePro data logger is shown in the following chart. Data was collected for over five weeks. The VFD is performing very well, allowing the power drawn by the compressor to go from its peak load of almost 274 kW down to as low as 53 kW (when running but not off). The overall average power draw is 208.1 kW when running. Note that the compressor was turned off only for one brief period, on a Saturday night into early Sunday morning, while monitoring was underway. The compressor power is a function of product throughput and not outside air temperature.

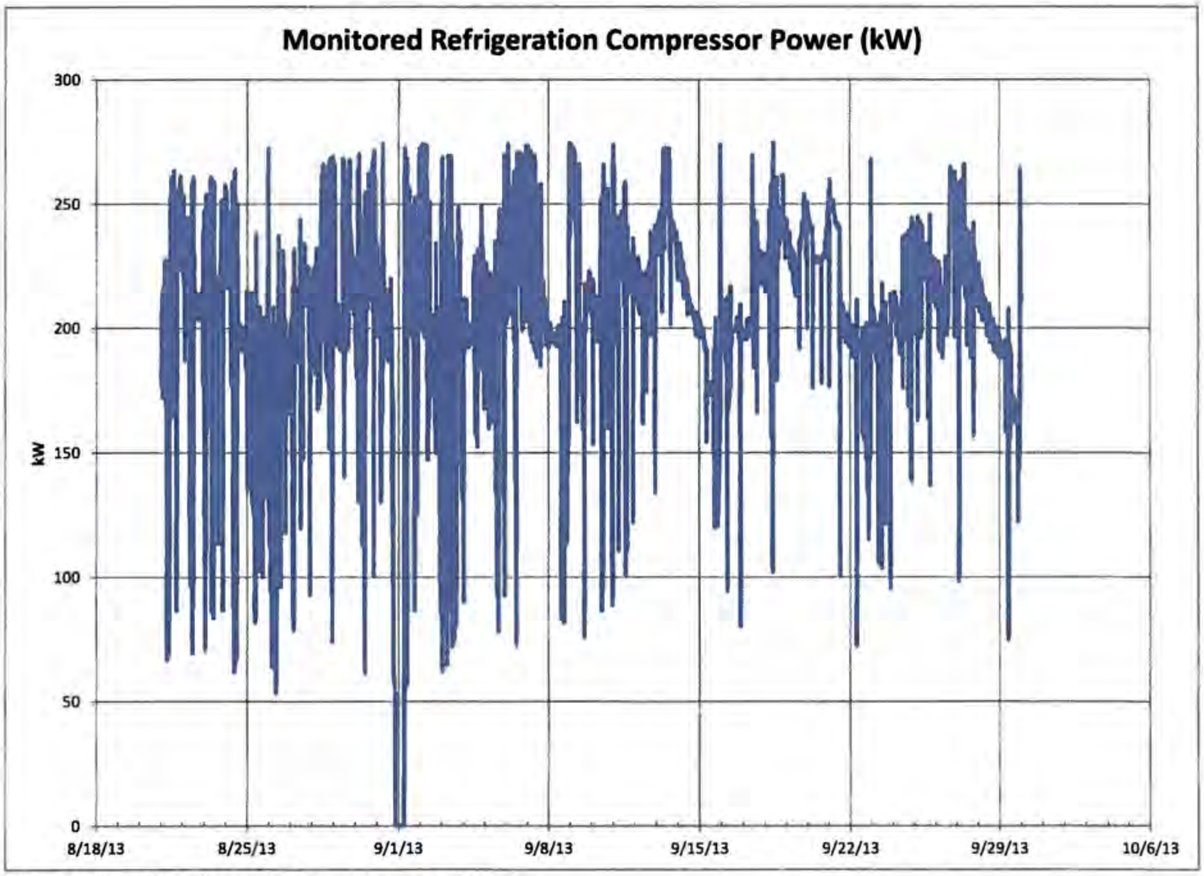


Figure 1. Monitored Compressor Power

The above time-series data can be processed to develop an average weekly demand profile, as shown in the next figure. (Since the data was short one Tuesday and Wednesday of six full weeks of data, only the five full weeks of available monitored data were used to develop this profile and the tables that follow. This technique avoids under-weighting the two missing days.)

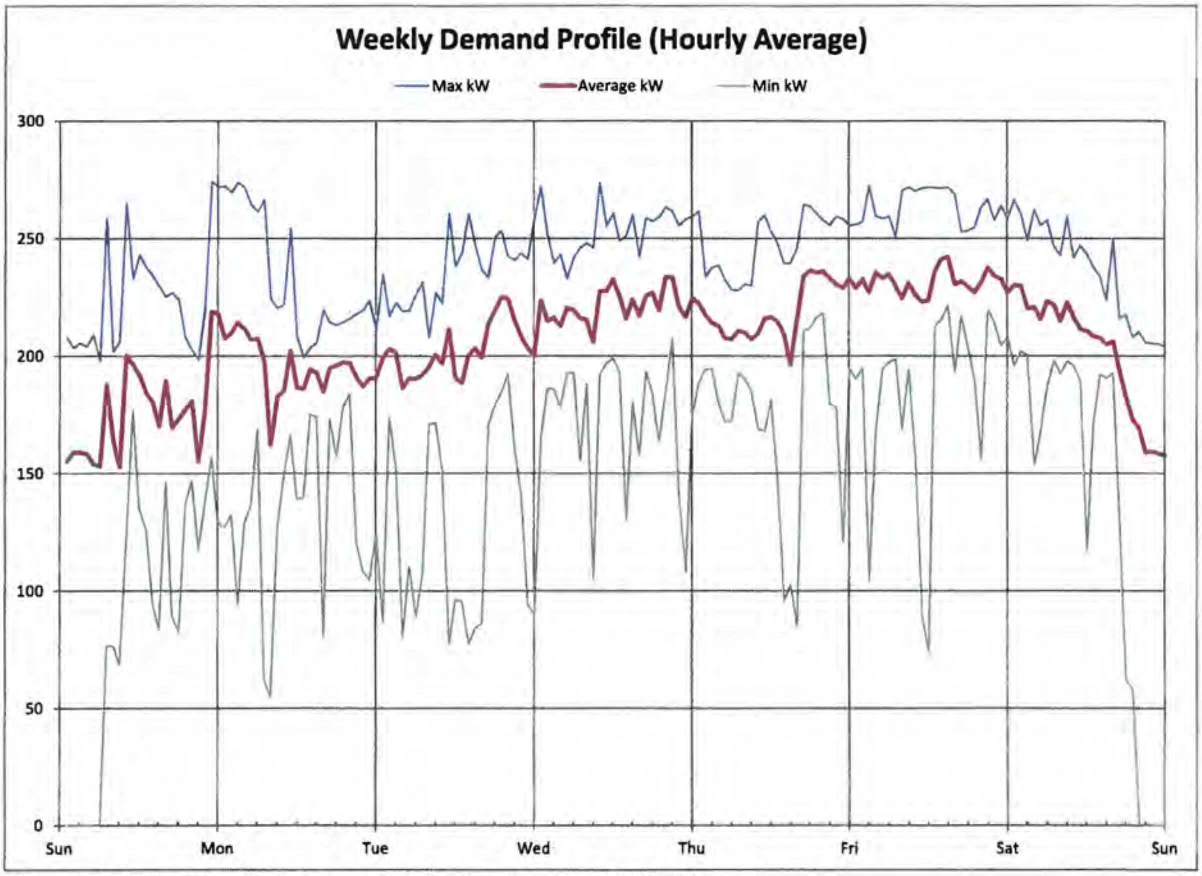


Figure 2. Weekly Compressor Electric Demand Profile

Average values by day of the week were then developed for both power (kW) and energy consumption (kWh), as shown in the following table and accompanying chart. The table also presents the estimated total annual energy usage suggested by the M&V data: about 1,809,600 kWh per year.

Table 1. Average Compressor Load by Day-Type

Day of the Week	Compressor Average Electric Load (kW)	Energy (kWh/day)
Sunday	175.9	4,222
Monday	194.9	4,678
Tuesday	202.4	4,858
Wednesday	221.5	5,316
Thursday	218.9	5,254
Friday	231.3	5,552
Saturday	201.0	4,825
Average week		**34,705**
Weeks/year		52.143
Annual Total		**1,809,621**

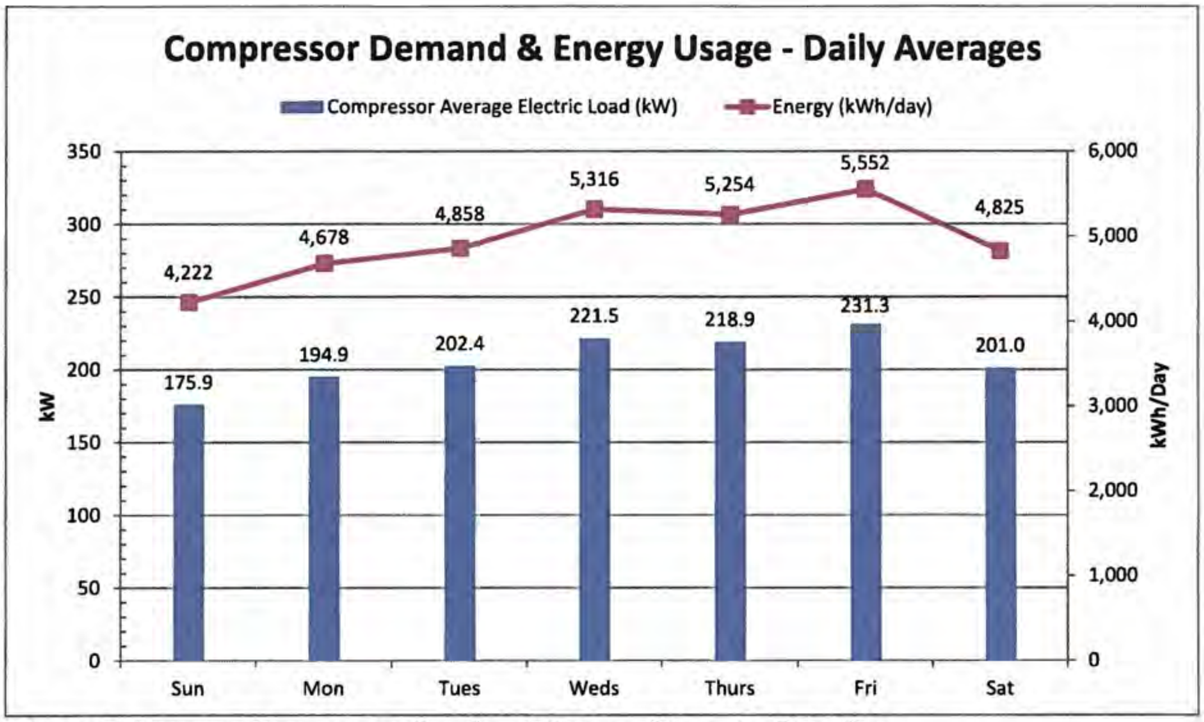


Figure 3. Average Compressor Load and Energy Usage by Day-Type

The original projected savings were determined in the application documents by estimating the amount of time each month that the VFD-equipped compressor would spend in "bins" of 10%-increments of total load. For comparison to those projected results, the monitored data was also binned, and again extrapolated to annual performance. A table of this performance is shown on the following page in Table 2. Compressor Power Profiles (because of the actual distribution of monitored data points, the average power for some of the bins cannot be matched exactly to the 10% power increments).

In addition, part-load performance information was obtained from the manufacturer for the installed compressor model as it would perform without a VFD. Rather than constantly requiring full power, as assumed in the application documents, the compressor does unload and the power decreases as the load is reduced. The power vs. load relationship is shown in **Error! Reference source not found.** after Table 2. Since the compressor maintains constant suction and discharge pressures, the VFD performance is nearly linear with load.

Table 2. Compressor Power Profiles

From Application					Monitored Data				M&V-Projected Baseline			
Compressor Power (kW in 10% steps)	No. of Hours at Indicated Compressor kW		kW Range		Counted Points	Avg. Power (kW)	Equiv. Hours	Annual Equiv. Hours	Counted Points	Avg. Power (kW)	Equiv. Hours	Annual Equiv. Hours
	Baseline	Proposed	Min	Max								
0.00	2496	2496	0.00	10.00	118	0.33	9.83	102.5	119	0.00	9.92	103.4
27.10	0	0	10.00	40.00	1	38.78	0.08	0.9	0	n/a	0.00	0.0
54.20	0	0	40.00	55.00	3	54.23	0.25	2.6	0	n/a	0.00	0.0
81.30	0	430	55.00	98.73	216	81.27	18.00	187.7	0	n/a	0.00	0.0
108.40	0	517	98.73	121.50	102	108.39	8.50	88.6	0	n/a	0.00	0.0
135.49	0	620	121.50	148.20	204	135.47	17.00	177.3	0	n/a	0.00	0.0
162.59	0	723	148.20	172.75	380	162.59	31.67	330.2	0	n/a	0.00	0.0
189.69	0	849	172.75	197.21	1813	189.69	151.08	1,575.6	279	188.29	23.25	242.5
216.79	0	924	197.21	241.81	5922	216.79	493.50	5,146.5	5196	231.88	433.00	4,515.6
243.89	0	1046	241.81	246.73	349	243.89	29.08	303.3	1237	244.30	103.08	1,075.0
270.99	6264	1155	246.73	275.0	972	258.42	81.00	844.7	3249	255.08	270.75	2,823.5
Totals	8,760	8,760			10,080		840	8,760	10,080		840	8,760

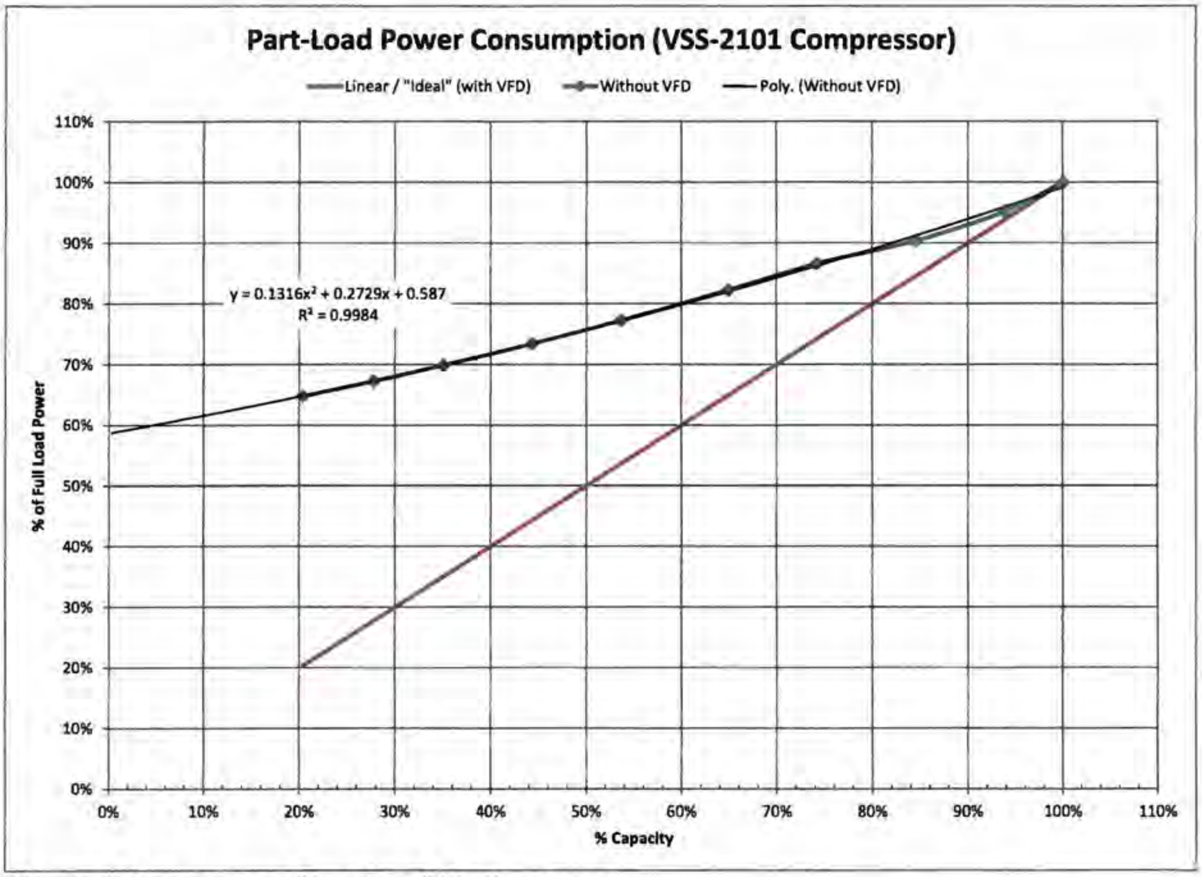


Figure 4. Compressor Part-Load Performance

As was described in the Data Analysis section, the power values at each time interval, as obtained from the monitoring data for the compressor with the VFD, can be converted to refrigeration load values, and then back to the baseline compressor (without a VFD) power values. Once this conversion is done, the baseline compressor's power values can also be binned. The results of this conversion are also presented in Table 2.

The following chart graphically compares the originally proposed post-retrofit performance versus the monitored (extrapolated to a full year) performance. Whereas the original projection estimated that the compressor would be off a good portion of the time, equivalent to two full days per week, the monitored data indicated that the compressor was off for only about ten hours during the five-week period.

In addition, the originally projected post-retrofit performance assumed a gradually increasing number of hours in the 30% to 100% load bins, but the data shows considerably more operation in the 70% and 80% bins instead.

These differences imply a change in the load profile has occurred from that originally estimated, at least for the five weeks during which the compressor was monitored. The result is that more energy is being used by the new compressor than was originally anticipated.

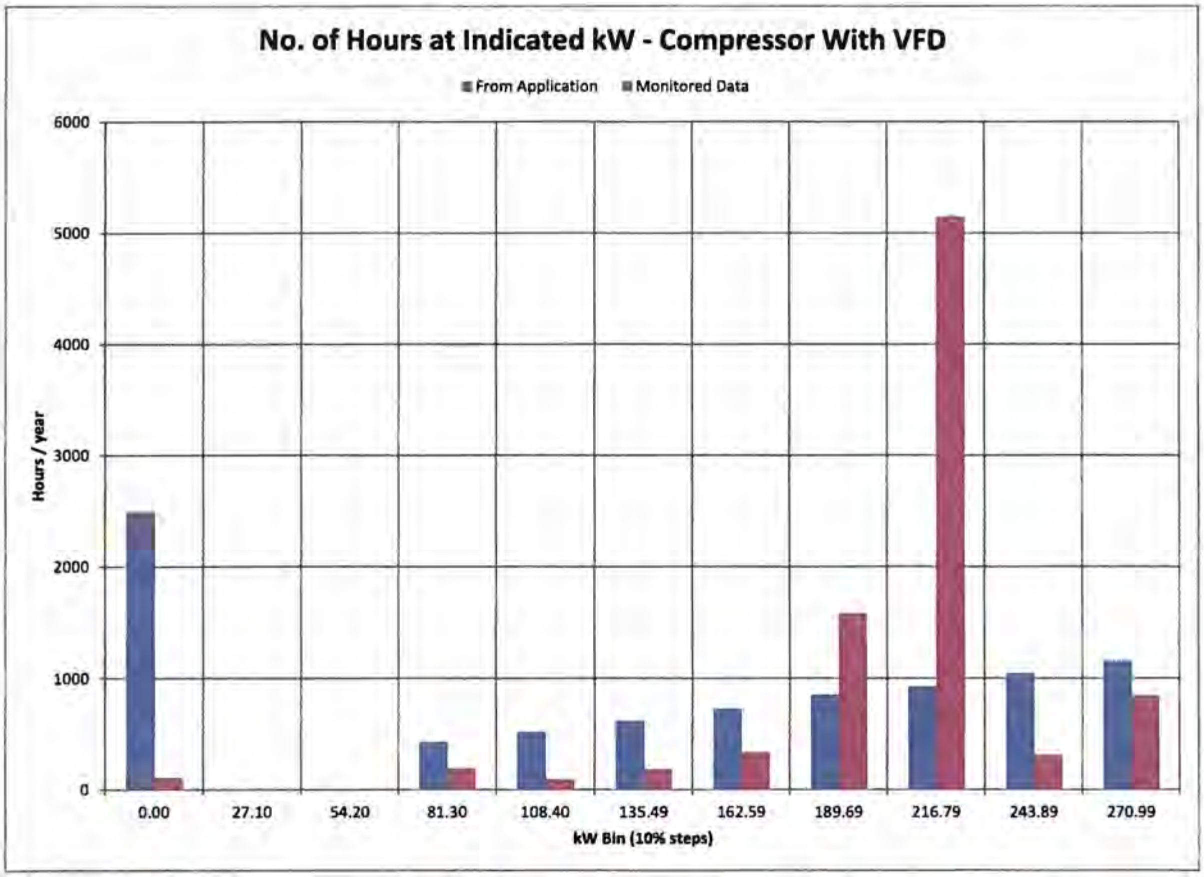


Figure 5. Post-Retrofit Hours of Operation (Original Projection vs. M&V Data)

Similar to the preceding figure, the following chart graphically compares the originally proposed *pre*-retrofit performance versus the performance derived from the post-retrofit load shape and the manufacturer's part-load information (again extrapolated to a full year). Whereas the original projection estimated that the compressor would operate at full load when running, and would be off a good portion of the time, equivalent to two full days per week, the monitored data indicated that the compressor runs more often than this. This finding will increase the baseline energy consumption.

In addition, rather than running at full power whenever operating, the data shows more operation in the 70% and 80% bins instead. This finding will decrease the baseline energy consumption, but combined with the increased operating hours, the net result is that more energy is being used by the new compressor than was originally anticipated.

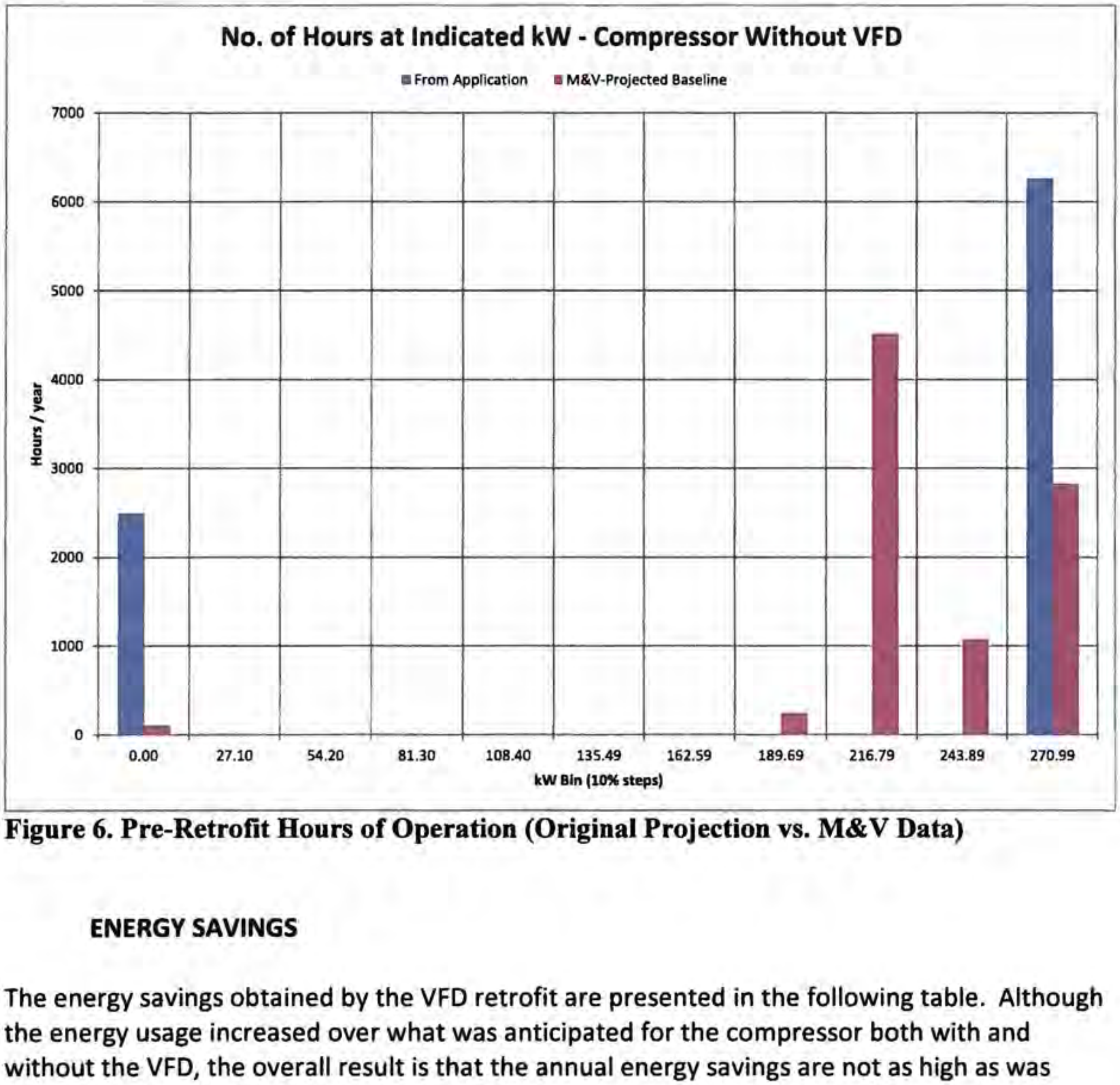


Figure 6. Pre-Retrofit Hours of Operation (Original Projection vs. M&V Data)

ENERGY SAVINGS

The energy savings obtained by the VFD retrofit are presented in the following table. Although the energy usage increased over what was anticipated for the compressor both with and without the VFD, the overall result is that the annual energy savings are not as high as was initially predicted.

The Duke-adjusted projected energy annual savings are shown at the bottom of the table. The final energy savings for the VFD-driven compressor are 265,983 kWh/year. Compared to the Duke-projected savings of 428,765 kWh/year, the energy Realization Rate is 62.0%.

Table 3. M&V Energy Usage and Savings Summary

	M&V-Projected Baseline		Monitored Data	
Compressor Power (kW in 10% steps)	No. of Hours at Indicated Compressor kW	Energy (kWh)	No. of Hours at Indicated Compressor kW	Energy (kWh)
0.00	103.4	0.0	102.5	34
27.10	0.0	0.0	0.9	34
54.20	0.0	0.0	2.6	141
81.30	0.0	0.0	187.7	15,255
108.40	0.0	0.0	88.6	9,608
135.49	0.0	0.0	177.3	24,017
162.59	0.0	0.0	330.2	53,693
189.69	242.5	45,654	1,575.6	298,871
216.79	4,515.6	1,047,083	5,146.5	1,115,706
243.89	1,075.0	262,629	303.3	73,971
270.99	2,823.5	720,238	844.7	218,291
Totals:	8,760	**2,075,604**	8,760	**1,809,621**
	Savings			**265,983**
	Savings %			12.8%
	Duke Projected Savings			**437,515**
	Energy Savings Realization Rate			**61%**

The following table presents the demand savings and realization rate for the [Redacted] Custom Incentive Program project. For Ohio in 2013, 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; however, since the demand of the compressor is process-dependent and not weather-dependent, the maximum demand seen in the 4-5 PM hour in the collected data is taken to be representative of the coincident demand.

Table 4. Peak Demand Savings and Realization Rate

Facility: [Redacted]		
	Summer Coincident Peak Demand (kW)	**Summer Non-Coincident Peak Demand (kW)**
Pre-Retrofit Demand	271	271
Post-Retrofit Demand	264.6	273.9
Savings	6.4	-2.9
Duke Projected Savings	-6.9	50.3
Realization Rate	-92%	-6%

[Redacted]
Cutter 4 VFD Retrofit Project
M&V Report

Prepared for
Duke Energy Ohio

April 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:

Katie Gustafson
NORESCO, Inc.

Stuart Waterbury
NORESCO, Inc.

2540 Frontier Avenue, Suite 100
Boulder CO
80301

(303) 444-4149

NORESCO
United Technologies

Introduction

This document discusses the M&V activities for the motor and VFD retrofit at [Redacted] in Mason, Ohio. The implemented measure is described below:

ECM-1 –VFD Motor Replacement

- [Redcted] replaced an eddy current motor and drive with a higher efficiency, 40-hp variable frequency AC drive and motor.

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 Coincident Peak savings (kW)	Duke Projected Non-coincident Peak savings (kW)
19670	0	15,879	5.8	4

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

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

Project Contacts

NORESCO Contact	Katie Gustafson	kgustafson@noresco.com	o: 303-459-7409
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

- Peak demand (kW) savings
- Summer utility coincident peak demand (kW) savings
- Annual energy (kWh) savings
- kWh & kW Realization Rates

M&V Option

IPMVP Option

M&V Implementation Schedule

- Data was collected during normal operating hours from December 29 through January 23, 2015.
- Verified the post-retrofit sequence of operations and/or operating schedule for the motor and VFD.
- Deployed post-retrofit loggers to record kW and VFD speed at five minute intervals.
- Evaluated the energy and demand savings for the retrofit measure.

Data Accuracy

Measurement	Sensor	Accuracy
Voltage	DC Voltage	±2.7%
kW	ElitePro	±1%

Field Data Points

Survey data

- Nameplate data for new drive and motor.
- Determined the sequence of operations and operating hours for the motor.
- Determined typical operating speeds of motor.

Data Logging

Data loggers were installed to log the following data points at 5 minute intervals. Data was collected from December 29, 2014 through January 23, 2015, although the period prior to January 5 included a plant shutdown and so was not included in the analysis.

- Motor kW
- VFD Speed

Data Analysis

Eddy current drives are slip-controlled systems where the slip energy is dissipated as heat. At lower speeds, these drives are less efficient than variable frequency drives. The motor develops the torque required by the load and operates at full speed. The output shaft transmits the same torque to the load, but turns at a slower speed. Since power is proportional to torque multiplied by speed, the input power is proportional to the product of the motor speed and operating torque while the output power is the product of output speed and operating torque. The difference between the motor speed and the output speed is called the slip speed. The power proportional to the product of slip speed and operating torque is dissipated as heat in the clutch.

Using the following algorithms, we determined the pre and post operating characteristics of the retrofitted and new motor drive systems.

$$hp_{Delivered} = \frac{\eta_{VFD@RPM} * \eta_{Motor@RPM} * kW_{logged}}{.746}$$

$$\%Speed_{VFD} = 10 * V_{Control}$$

$$\tau = \frac{hp_{Delivered} * 5252}{RPM_{New}}$$

$$Motor\ Output\ hp_{Baseline} = \frac{\tau * RPM_{Rated}}{5252}$$

$$kW_{Baseline} = \frac{Motor\ Output\ hp_{Baseline} * 0.746}{\eta_{Motor}}$$

Where:
η_{VFD} = VFD efficiency
η_{Motor} = Motor efficiency, this varied with speed based on manufactures specifications.
0.746 =kW/HP
τ = delivered torque
5252 = (33,000 ft lbf/min)/(2π rad/revolution)
RPM = revolutions per minute

The operating characteristics of the pre and post systems are shown in **Error! Reference source not found.**. A clear correlation between the operating speed and input power (kW) for the new system can be seen. Torque is also shown in this plot to show that for this application, torque is relatively flat as shaft speed varies. Since the input power for the eddy-current drive is the product of torque and motor shaft speed, which will be constant, the input power for the old motor and drive is proportional to torque.

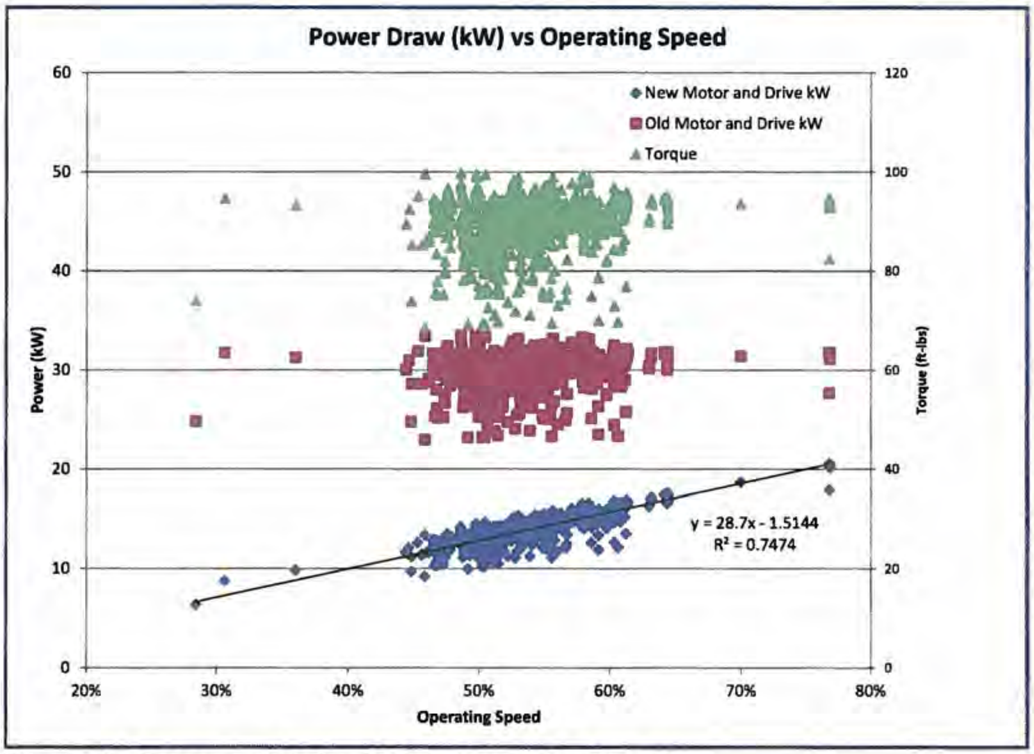


Figure 1: Motor and Drive kW vs Operating Speed

The facility operates with similar schedules Monday through Thursday, has shortened schedules on Friday and Saturdays, and is closed on Sundays. Though the facility is operating, the rebated motor and VFD only operated 22% of the time during the analyzed logging period. This is shown in Figure 2 below.

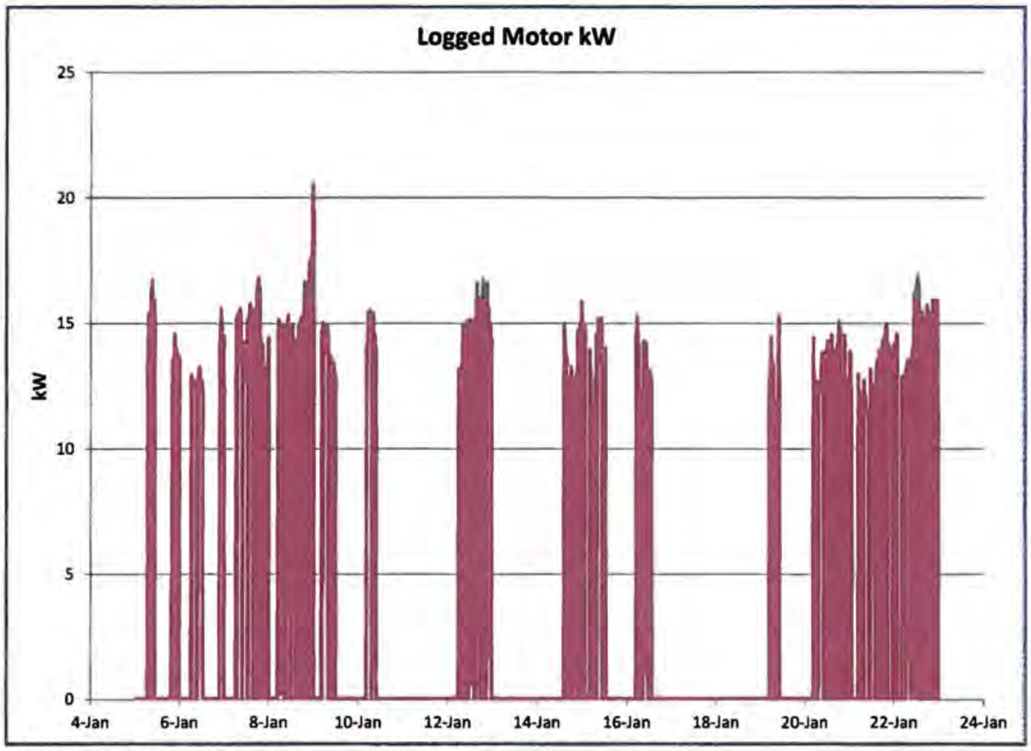


Figure 2: Logged Motor and VFD kW

We extrapolated the logged data to determine the annual hours operated at various speeds. Figure 3 below shows the profile of the annual hours operated at various post-retrofit speeds. Figure 4 shows the average operating speeds of the system when the system is operating. Using the relationship between the new systems power vs speed we determined the annual kWh consumption. We took the average of the calculated power consumption of the eddy current system to determine the energy and demand of the replaced motor and drive. To determine the coincident peak savings we took the average savings of the logged data for weekdays between 4 and 5pm.

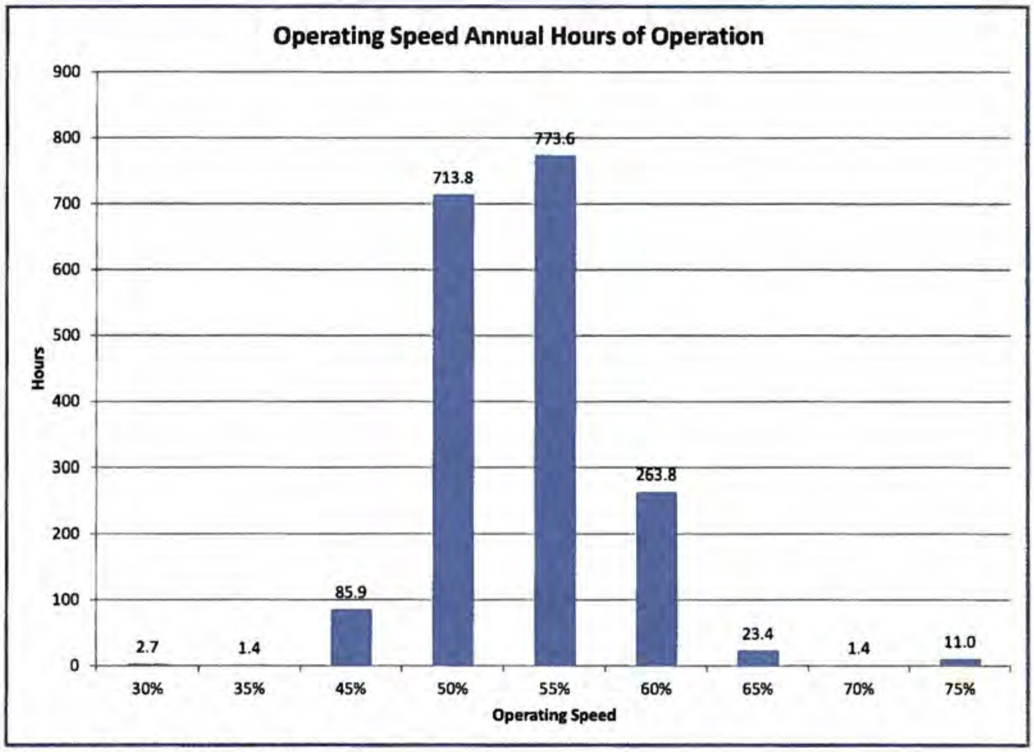


Figure 3: Operating Speeds

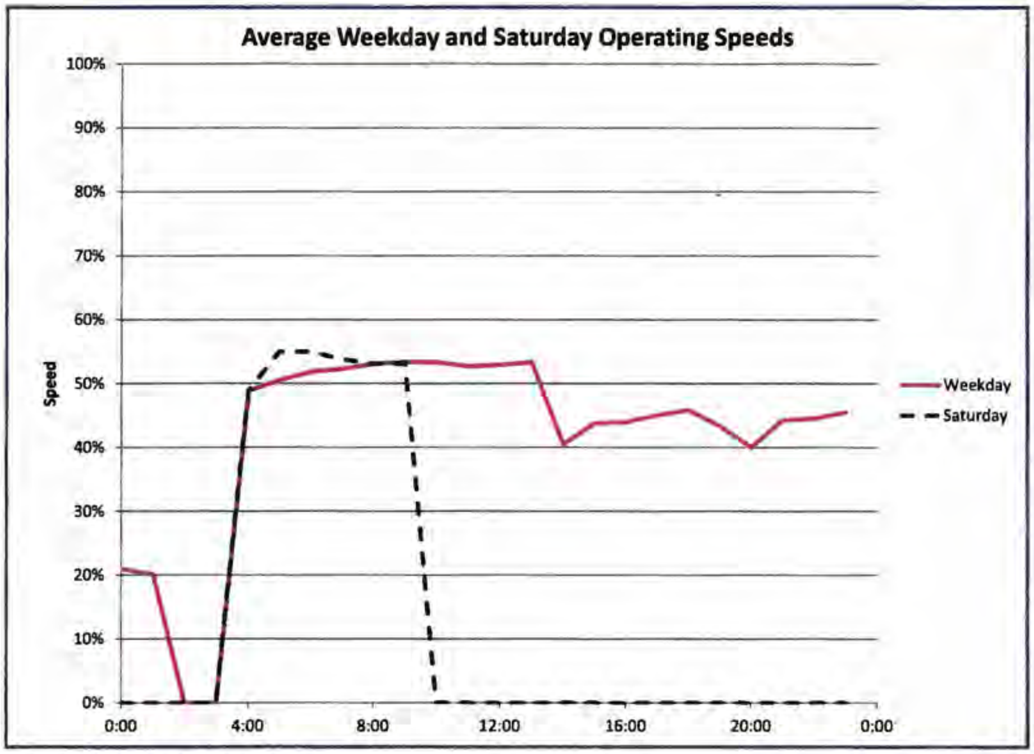


Figure 4: Load Shapes

Verification and Quality Control

1. Visually inspected logger data for consistent operation. Sorted and removed invalid data.
2. Verified pre-retrofit and post retrofit equipment specifications were consistent with the application.

Recording and Data Exchange Format

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

Results Summary

The Motor and VFD retrofit resulted in greater than anticipated energy and NCP demand savings. This is a result of the following two factors. First, the application included for review, calculated savings for a new motor and drive replacing a motor without a drive where the speed was not modulated, which ignores the efficiency of the replaced eddy current drive. Second, the application calculation assumed that the load of the pre and post case would always be 100%. As shown in Figure 3 and Figure 4 the typical operating speed is well below

100%. The CP savings were evaluated by determining the average demand savings during the CP hour over the evaluation period. Since the system only ran about 22% of the time, the CP demand savings are substantially less than the NCP demand savings, but still very close to the Duke estimates.

	Annual Consumption (kWh)	NCP Demand (kW)	CP Demand (kW)
Pre	55,820	29.7	11.3
Post	26,001	7.1	5.4
Savings	29,818	22.6	6.0

	Energy Savings (kWh)	NCP Demand Savings (kW)	CP Demand Savings (kW)
Duke Estimated	15,879	4	5.8
Verified	29,818	22.6	6.0
Realization Rate	188%	571%	104%

[Redacted]
Chiller Replacement
M&V Report

Prepared for
Duke Energy Ohio

April 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:

Katie Gustafson
NORESCO, Inc.

Stuart Waterbury
NORESCO, Inc.

2540 Frontier Avenue, Suite 100
Boulder CO
80301
(303) 444-4149

NORESCO
United Technologies

Introduction

This report discusses the M&V findings for the [Redacted] custom program application. The implemented measure is described below.

ECM-1 – Chiller Replacement

A constant speed 290 ton chiller was removed and a 400 centrifugal chiller with factory mounted variable speed drive (VSD) was installed through the Smart $aver Custom Incentive Program. Two existing chillers, a 300 ton centrifugal chiller with VSD and a constant speed 600 ton centrifugal chiller, remained in place. The control sequencing of the chillers was also modified to incorporate the new chiller. The 290 ton chiller was installed in 1941 and was originally a steam turbine chiller. In 1963 this chiller was retrofitted to operate off of a 6 speed motor.

The new 400 ton chiller was installed with the objective of using the 600 and 300 ton chillers more efficiently by optimizing the sequencing of the 300, 400, and 600 ton chillers. There was not an increase in production load.

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 Coincident Peak savings (kW)	Duke Projected Non-coincident Peak savings (kW)
404,309	78	**346,708**	**17.9**	**17.9**

The objective 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
- kWh & kW Realization Rates

Project Contacts

NORESCO Contact	Katie Gustafson	kgustafson@noresco.com	303-459-7430
Duke Energy M&V Coordinator	Frankie Diersing	Frankie.Diersing@duke-energy.com	513-287-4096

Customer Contact	[Redacted]	[Redacted]	[Redacted]

Site Locations/ECM's

Address
[Redacted]

Data Products and Project Output

- Average pre/post load shapes vs outdoor air wet bulb temperature (OAWB)
- Model predicting pre/post kWh as a function OAWB
- Summer peak demand savings
- Coincident peak demand savings
- Annual Energy Savings

M&V Option

IPMVP Option A

M&V Implementation Schedule

- Data was collected during normal operating hours (avoiding holidays or atypical operating hours). The data was collected from July 27 through August 17, 2014.
- The production and HVAC schedules were obtained and verified for the chiller plant.
- Trending was setup to record temperature and flow on controlled equipment.
- Power for the 300 ton, 400 ton, and 600 ton chillers were logged at five minute intervals.
- The energy and demand savings of the retrofit measure were evaluated.

Field Survey Points

Survey data (for all equipment logged)

- Confirmed chiller plant sequence of operations for both the pre and post installation cases.
- Verified the 300, 400, & 600 ton chiller make/model/serial numbers.
- Verified the 300 and 400 ton chillers VFD make/model.
- Verified the 300, 400, & 600 ton chiller flow rates. Confirmed flow rate of logged chillers .

Took one-time measurements for all logged equipment in order to validate the Elite Pro data.

- 300, 400, & 600 ton chiller volts, amps, kW, power factor, and VFD speed

Data Accuracy

Measurement	Sensor	Accuracy	Notes
Current	Magnelab CT	±1%	Recorded load must be < 130% and >10% of CT rating
kW	Dent ElitePro	±1%	
Temperatures and Flowrates	BAS trends	Unknown	
Outdoor Conditions	Onset Weather Station	Temp: ±0.4F RH: ±2.5%	

Field Data Logging

Chillers

Data loggers were installed to log the following data points in 5 minute intervals. Data was collected from July 27 through August 17, 2014

- 300 ton chiller kW
- 400 ton chiller kW
- 600 ton chiller kW

The following points were trended through the BAS during the logging period.

- Chilled Water Supply (CHWS) Temperature
- Chilled Water Return (CHWR) Temperature
- Condenser Water Supply (CWS)Temperature
- Condenser Water Return (CWR)Temperature
- CHW flow rate for the 400 ton chiller
- CW flow rate for then 400 ton chiller

Outdoor Air

A weather station was installed to record outside air temperature and relative humidity at five-minute intervals.

Logger Table

The following table summarizes the logging equipment that was installed to accurately measure the ECM.

Table 1: Logger Table

Logging	Elite-Pro	Magnelab CT's	Hobo U-12	Weather Station
300 ton Chiller	1	(3) 500A	1	-
400 ton Chiller	1	(3) 500A	1	-
600 ton Chiller	1	(3) 1000A	1	-
Weather Conditions	-	-	-	1

Data Analysis

[Redacted] is a manufacturing facility that requires process cooling as well as HVAC cooling when weather conditions require. Before the retrofit, during the winter months, which range from mid-October to early June, the 600T chiller would meet the process and HVAC loads of the facility. During the summer months, from June through mid-October, the 600 ton chiller would meet the process load and the 300 ton chiller would trim the remainder of the load. When the 600 and 300 ton chillers could not meet the total process and cooling load in the summer the 290 chiller would be brought online.

The application indicated that the post retrofit sequencing of the 300, 400, and 600 ton chillers would be as follows: During the winter months, the 400 ton chiller would operate to meet the process and HVAC loads. During the winter period when the 400 ton chiller could not meet the total facility load the 300 ton would be brought online. During the summer months, the 600 ton chiller would operate to meet the process load and the 400ton chiller would provide the HVAC cooling. During the periods in the summer when the 600 and 400 ton chiller could not meet the load the 300 ton chiller would come online.

During the logging period, the 400 and 600 ton chillers operated and the 300 ton chiller did not. In contrast to how the application indicated the 400 and 600 ton chillers would be scheduled we observed that the 400 ton chiller was providing a consistent amount of cooling regardless of the outdoor conditions, and the 600 ton chiller was providing cooling that corresponded to the outdoor conditions. This indicates that the 400 ton chiller was providing the bulk of the process load and that the 600 ton chiller was trimming the load based on the outdoor weather conditions. This is shown in Figure 1 and Figure 2.

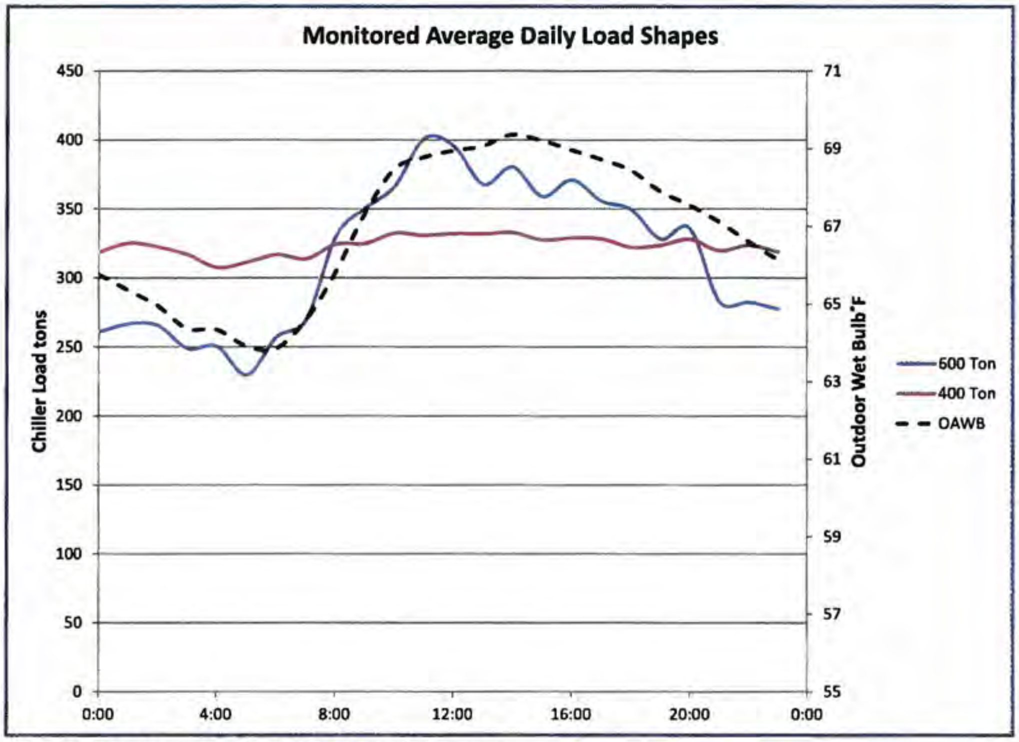


Figure 1: Monitored Chiller Load Shapes

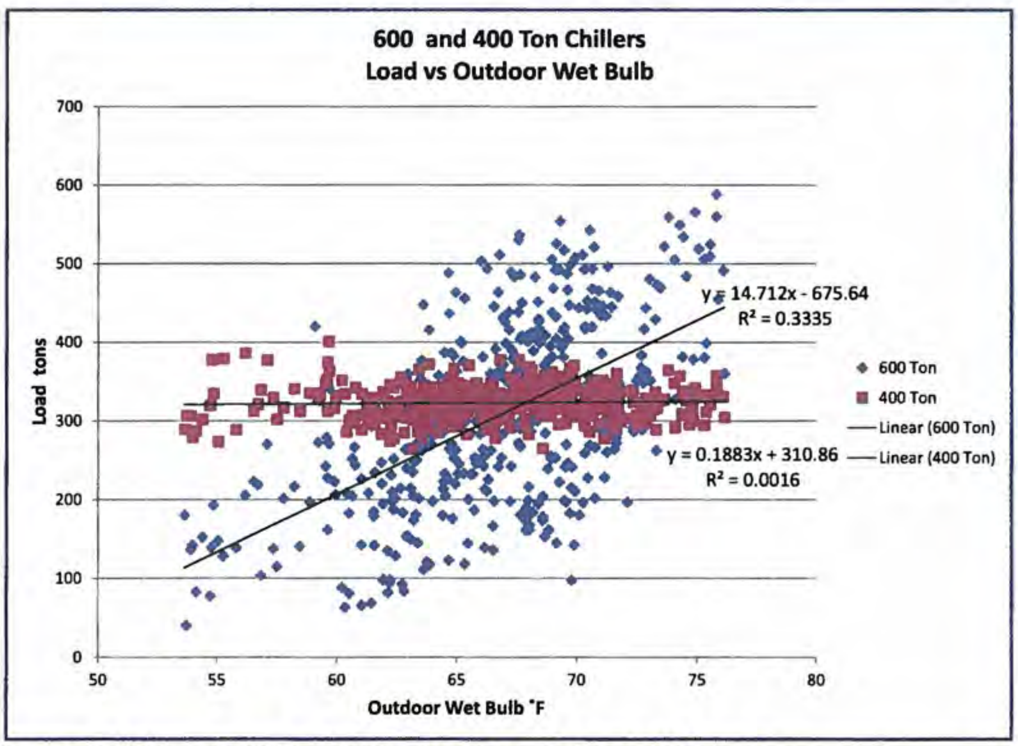


Figure 2: 400 and 600 Ton Chiller Loads vs Outdoor Wet Bulb.

From the logged data we determined the cooling load in tons for the 400 and 600 ton chillers using the following equation:

$$tons_{Cooling} = 500 * GPM * \Delta T / 12{,}000$$

Where:

Tons	=	Chiller load.
GPM	=	Chilled water flow rate. This value was trended by the BMS for the 400 ton chiller. The BMS does not log this flow rate for the 600 ton chiller because it is constant flow. We assumed this to be 1440 as specified by the manufacturer.
ΔT	=	Chilled water supply/return temperature differential.
500	=	Constant relating the heating capacity of flowing water and DT to BTU/hr.
12,000	=	Conversion from Btu/hour to tons.

An annual estimate of the total cooling load of the facility was calculated using TMY3 data from Cincinnati, OH and the regression based on logged data shown in Figure 3. From the daily load shape of the 400 ton chiller shown in Figure 1, it was assumed the facility process load is 320 tons. This is also evident in Figure 3. The total chiller plant load was fixed at 320 tons below 46˚F wet bulb. It was assumed that the pre and post load cases were the same. The design wet bulb for Cincinnati is 74.5˚F. Based on the facility load shown in Figure 3 the 400 and 600 ton chillers are able to meet the total facility load. For the post retrofit case during the summer months we determined the load of the 600 ton chiller using the regression of the 600 ton chiller load during the monitored months as shown in Figure 4.

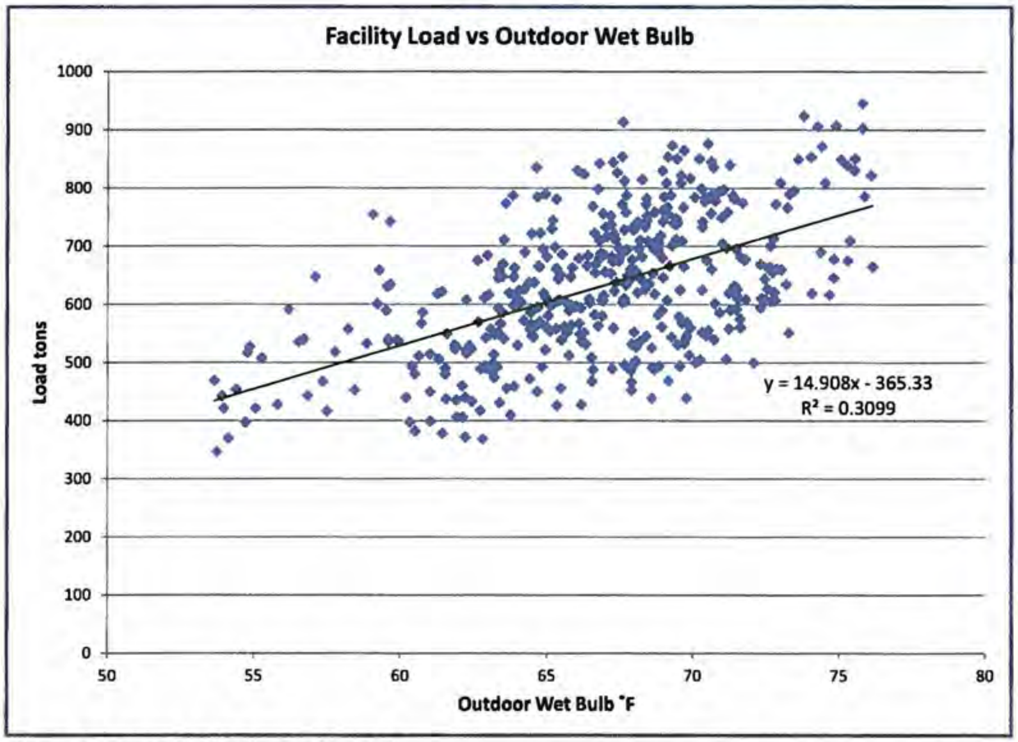


Figure 3: Total Monitored Load

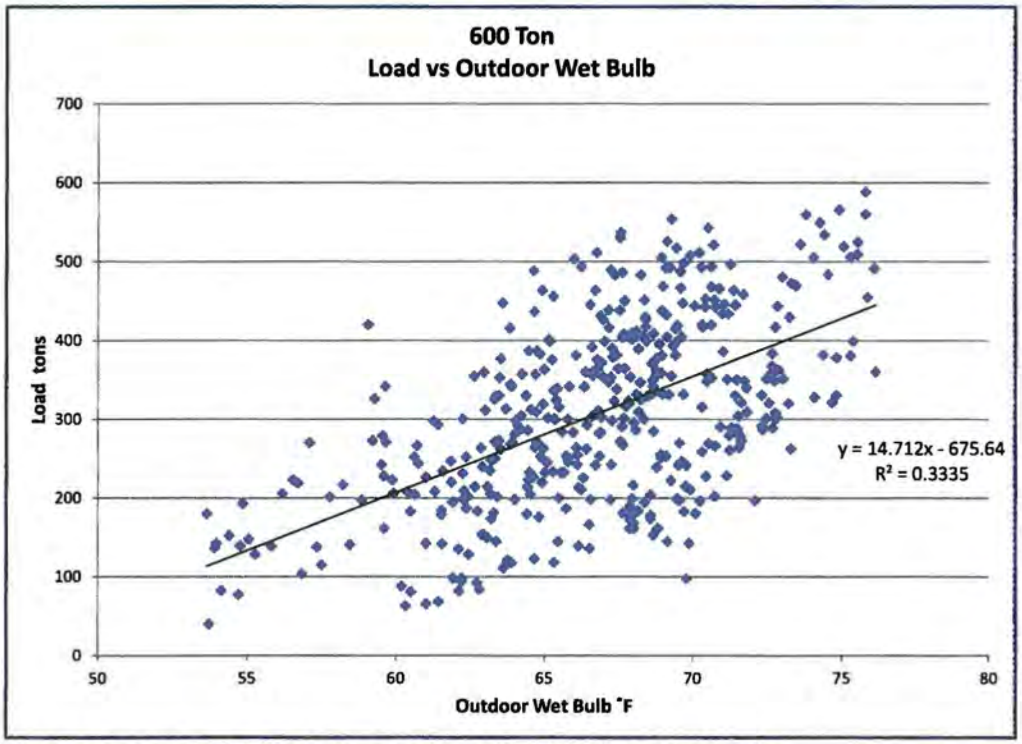


Figure 4: 600 Ton Chiller Observed Load vs Outdoor Wet Bulb

We used the regressions shown in Figure 5 and Figure 6 based on the monitored data and TMY3 data to determine the annual operating characteristics and energy consumption of the 400 ton chiller.

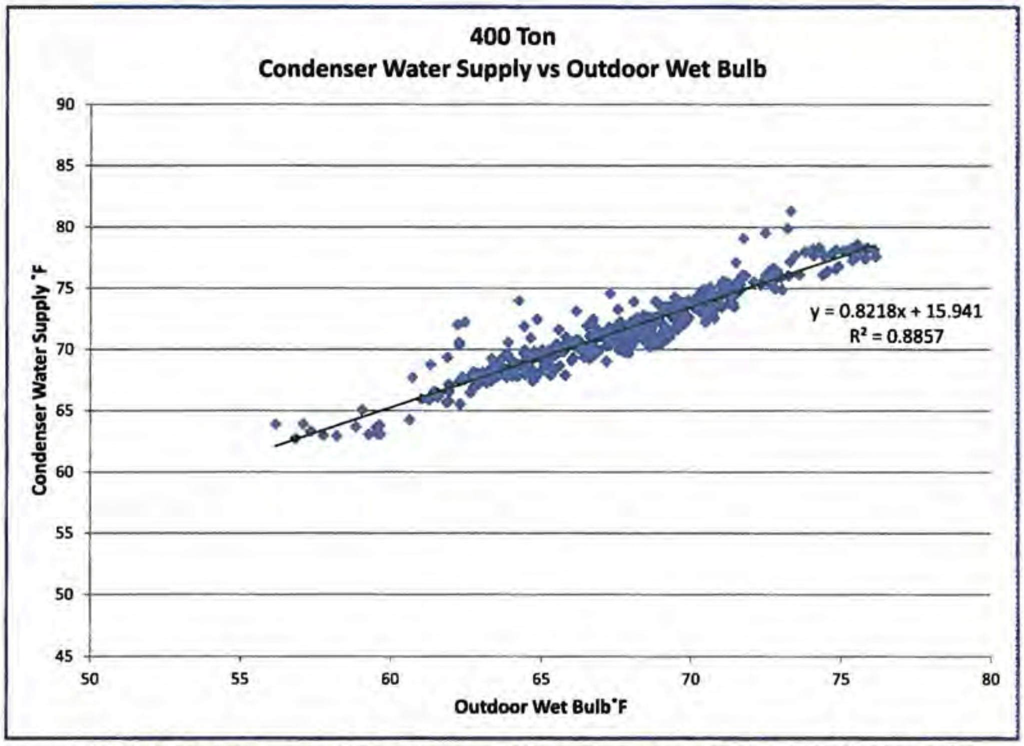


Figure 5: 400 Ton Observed Condenser Water Supply vs Outdoor Wet Bulb °F

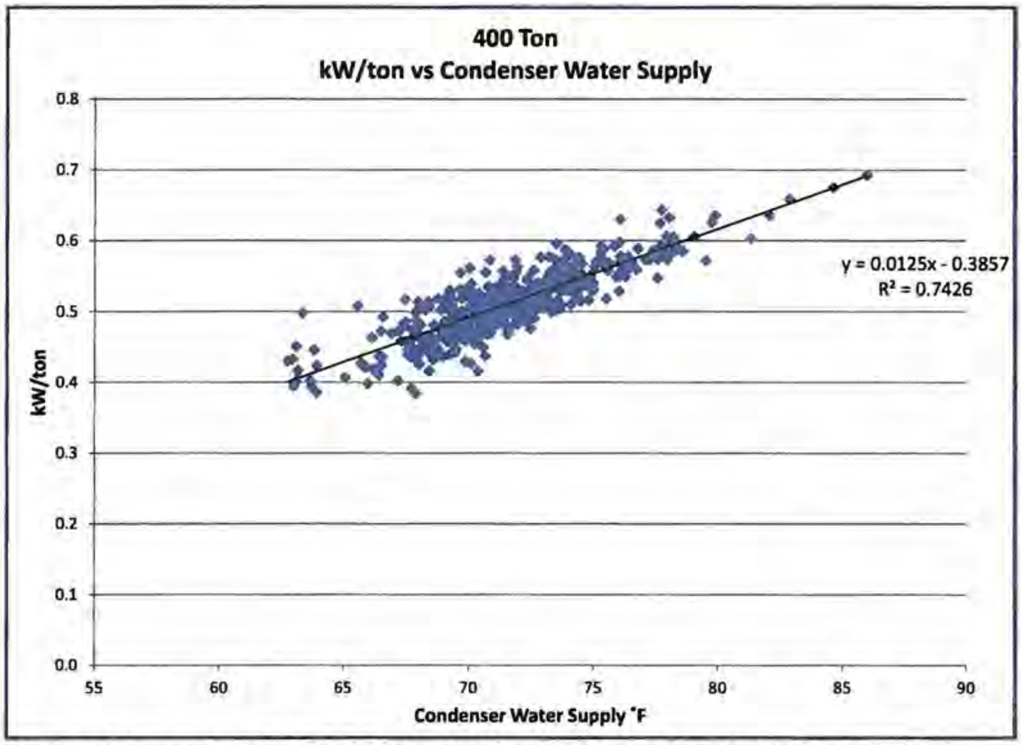


Figure 6: Observed 400 Ton Chiller kW/ton vs Condenser Water Supply °F

The annual pre and post retrofit kW/ton estimates for the 600 ton chiller were calculated for every hour of the year using the chiller curves generated by DOE 2 building energy modeling software, for a non-VSD centrifugal chiller. The DOE 2 curves use the CHWS, CWS, and chiller part load ratio (PLR) to predict the energy input ratio (EIR). Using the EIR and the chiller's ARI kW/ton the estimated kW/ton of the chiller at various conditions throughout the year can be predicted. The chilled water supply temperature (CHWS) remained relatively constant at 42.25°F during the monitoring period. We used the regression shown in Figure 7 to determine the condenser water supply temperature (CWS). We then determined the PLR based on the predicted load on the 600 ton chiller and the maximum available tons.

The ARI kW/ton for the installed chiller was specified as 0.635 kW/ton to generate the chiller curves, but was later adjusted to 0.690 kW/ton in order to match the actual measured data. On average the difference between the observed and predicted kW/ton was 0.01. Note that ARI chiller test conditions are confined to specific temperatures at a particular chiller loading profile, and that actual chiller efficiency performance will not reflect the ARI efficiency numbers except at those specific conditions. A comparison of the measured data and DOE-2 curve-generated data for chiller kW can be seen in Figure 8. The adjusted chiller curve appears to be a close match for the actual measured data.

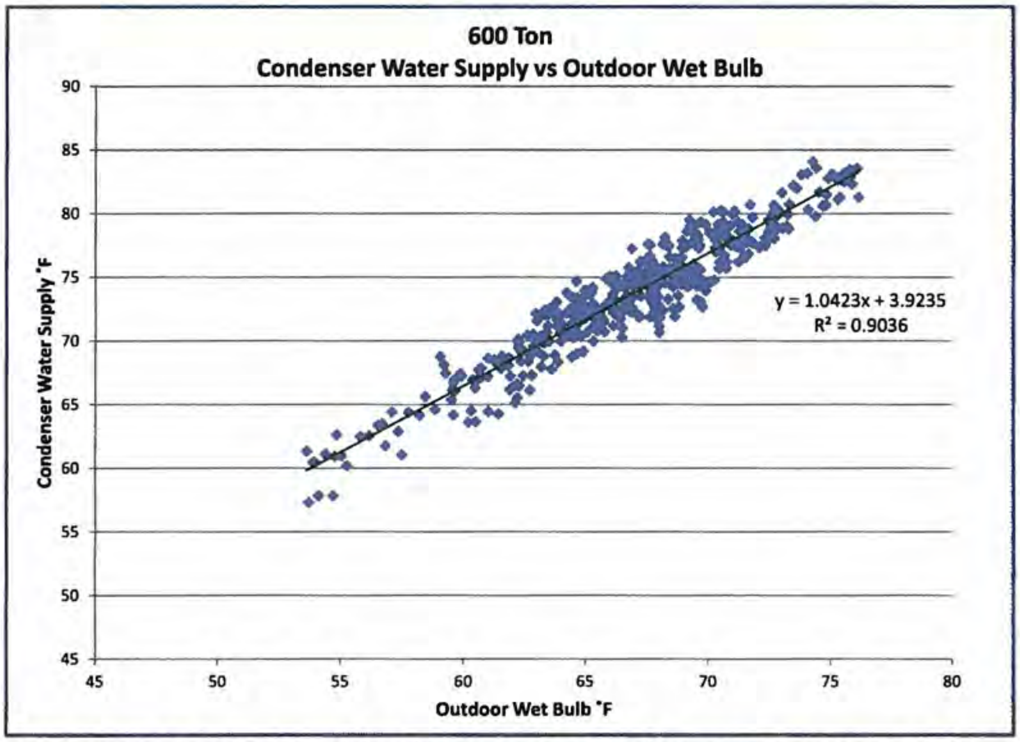


Figure 7: 600 Ton Observed Condenser Water Supply vs Outdoor Wet Bulb °F

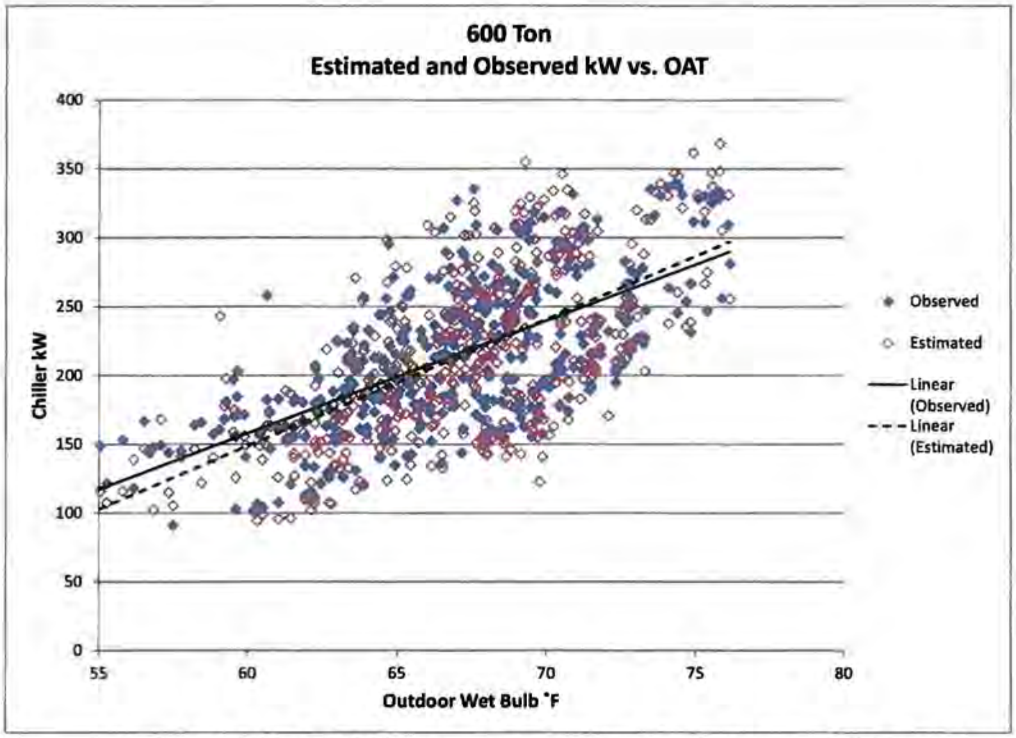


Figure 8: Estimated (DOE2 Chiller Curve Generated) and Observed Chiller kW vs OAT

The annual pre and post retrofit kW/ton estimates for the 300 ton and 290 ton chillers were calculated for every hour of the year using the same methodology used for the 600 ton chiller. We used the CHWS and CWS from the 400 ton chiller data to generate the chiller curves for the these chillers. We also used these values to determine the maximum available tons for the 300 and 290 ton chillers. The calculated PLR was based on the predicted loads on each chiller and the maximum available tons. Because the 300 ton chiller did not operate during the logging period we used the ARI specified 0.635 kW/ton as specified by manufactures data. Because the 290 ton that was replaced was manufactured in 1941 this did not qualify as an early replacement and we used 0.634 kW/ton per ASHRAE 90.1 for the baseline case.

Verification and Quality Control

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

Recording and Data Exchange Format

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

Results Summary

The chiller retrofit resulted in less than anticipated energy and coincident peak demand savings and significantly more non-coincident peak demand savings. This is a result of two factors. One, the application savings analysis assumed that the operation of the chiller plant was solely weather dependent and didn't include any non-weather-dependent process loads. Two, the post sequencing of the chillers was observed to be not as specified in the application documents. Figure 9 shows the monthly loads estimated in the application documentation vs the breakdown of the verified HVAC and process loads. The application indicated that during the summer months the 600 ton would meet the process load and the 400 ton chiller would trim the remaining load. During the observation period, the load met by the 400 ton chiller remained constant and the load on the 600 ton chiller varied with the weather conditions. This staging resulted in less than expected energy and coincident peak savings. If the sequencing of these chillers were updated to reflect the sequencing that was outlined in the application documentation Coincident peak savings could be realized.

The coincident peak savings were determined by taking the difference between the pre and post demand from 4 to 5pm on the weekday with the greatest dry bulb temperature. The Non-coincident peak savings are greater than coincident peak savings because the greatest pre and post demand occurred during the time with the greatest wet bulb temperature.

	Annual Consumption (kWh)	NCP Demand (kW)	CP Demand (kW)
Pre	2,186,672	639.6	550.6
Post	1,966,734	601.8	565.7
Savings	219,938	37.8	-15.2

	Energy Savings (kWh)	NCP Demand Savings (kW)	CP Demand Savings (kW)
Duke Estimated	346,708	17.9	17.9
Verified	219,938	37.8	-15.2
Realization Rate	63%	211%	-85%

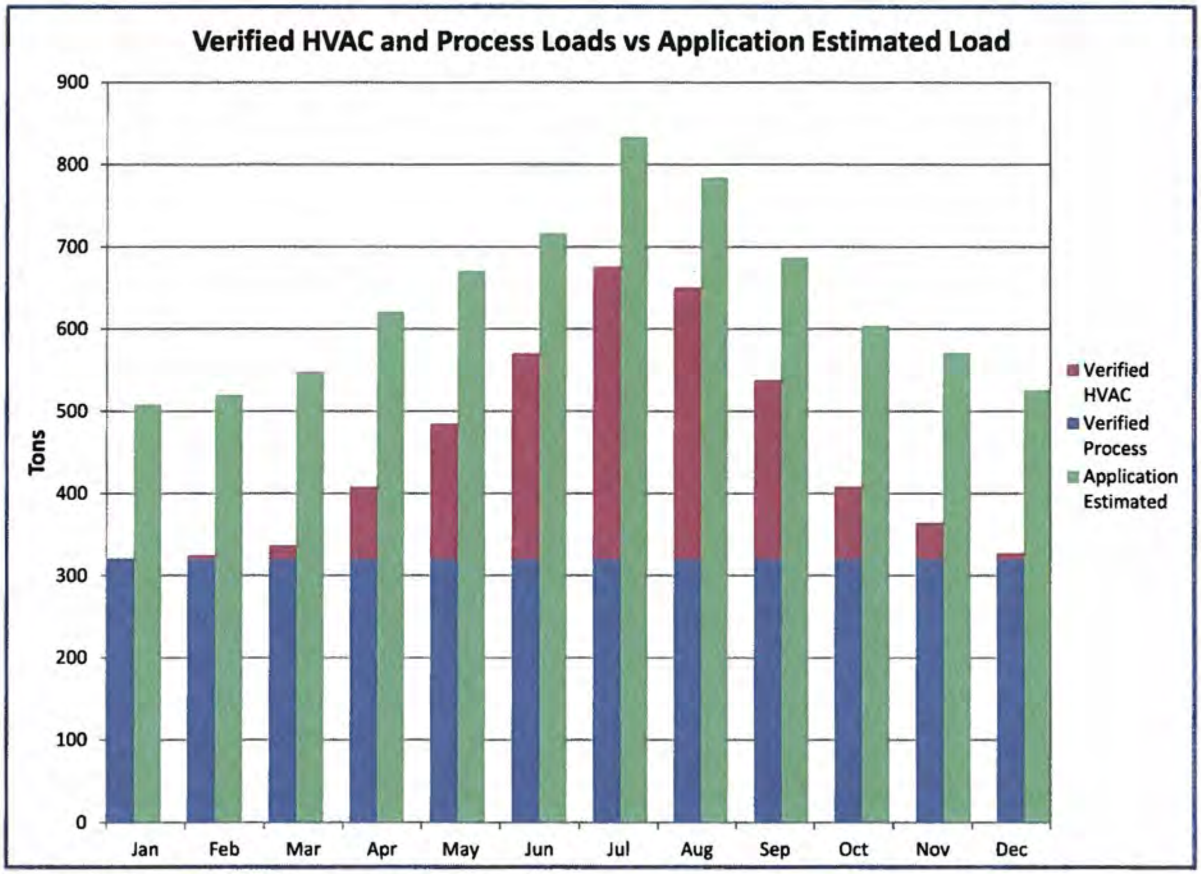


Figure 9: Average Verified vs Application Loads

[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 program participant.

Submitted by:

Katie Gustafson
Architectural Energy Corporation

Stuart Waterbury
Architectural Energy Corporation

2540 Frontier Avenue, Suite 100
Boulder CO
80301

(303) 444-4149

ARCHITECTURAL ENERGY CORPORATION

TABLE OF CONTENTS

Introduction

This document addresses M&V activities for the new lighting fixtures at three [Redacted]. This M&V report is for post-retrofit monitoring only. The lighting retrofit includes:

ECM-1- Retrofit (270) 24 W MH fixtures with 21 W LED fixtures in the sales area.
ECM-2- Retrofit (360) 24 W MH fixtures with 21 W LED fixtures in the sales area.
ECM-3- Retrofit (210) 24 W MH fixtures with 21 W LED fixtures in the sales area.

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 identified in the application are:

Application Proposed Annual savings (kWh)	Application Proposed Peak Savings (kW)	Duke Projected Savings (kWh)	Duke Projected Peak Savings (kW)
13,104	3	12,611	2.5

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	
Customer Contact	[Redacted]	[Redacted]	[Redacted]
AEC Contact	Katie Gustafson	303-459-7430	kgustafson@archenergy.com

Site Locations/ECM's

Site	Address	ECM
[Redacted]	[Redacted]	#1
[Redacted]	[Redacted]	#2
[Redacted]	[Redacted]	#3

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

Field Data Points

Post-Installation

Survey data

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

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

- Lighting circuit power when lights were on

Field Data Logging

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

ECM	Hobo (U12)	CTV-A 20A
1	1	4
2	2	8
3	1	4
Total	**4**	**16**

Data Accuracy

Measurement	Sensor	Accuracy	Notes
Current	CTV-A 20A	±4.5%	> 10% of rating

Data Analysis

- 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 determine the actual schedule of post operation.

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

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

Where

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

- Created separate schedules for weekdays and weekends using LF(t).
- Tabulated average operating hours by day type (e.g. weekday and weekend).
- 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 compare to project application:

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

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

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

where:

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

- The savings with HVAC interactions are calculated from:

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

where:

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

Verification and Quality Control

1. Visually inspected lighting logger data for consistent operation. Sorted by day type and removed invalid data.
2. Verified 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. Inspected storeroom for replacement lamps or fixtures.
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 [Redacted] lighting retrofit.

Table 1. Energy Savings and Realization Rates

	Duke Savings	Realized Savings		Realization Rate	
		Lighting Only	Lighting and HVAC	Lighting Only	Lighting and HVAC
Energy (kWh)	12,611	13,349	14,365	106%	114%
NCP Peak Demand (kW)	2.5	2.5	3.2	100%	130%
CP Demand (kW)	2.5	2.5	3.2	100%	130%

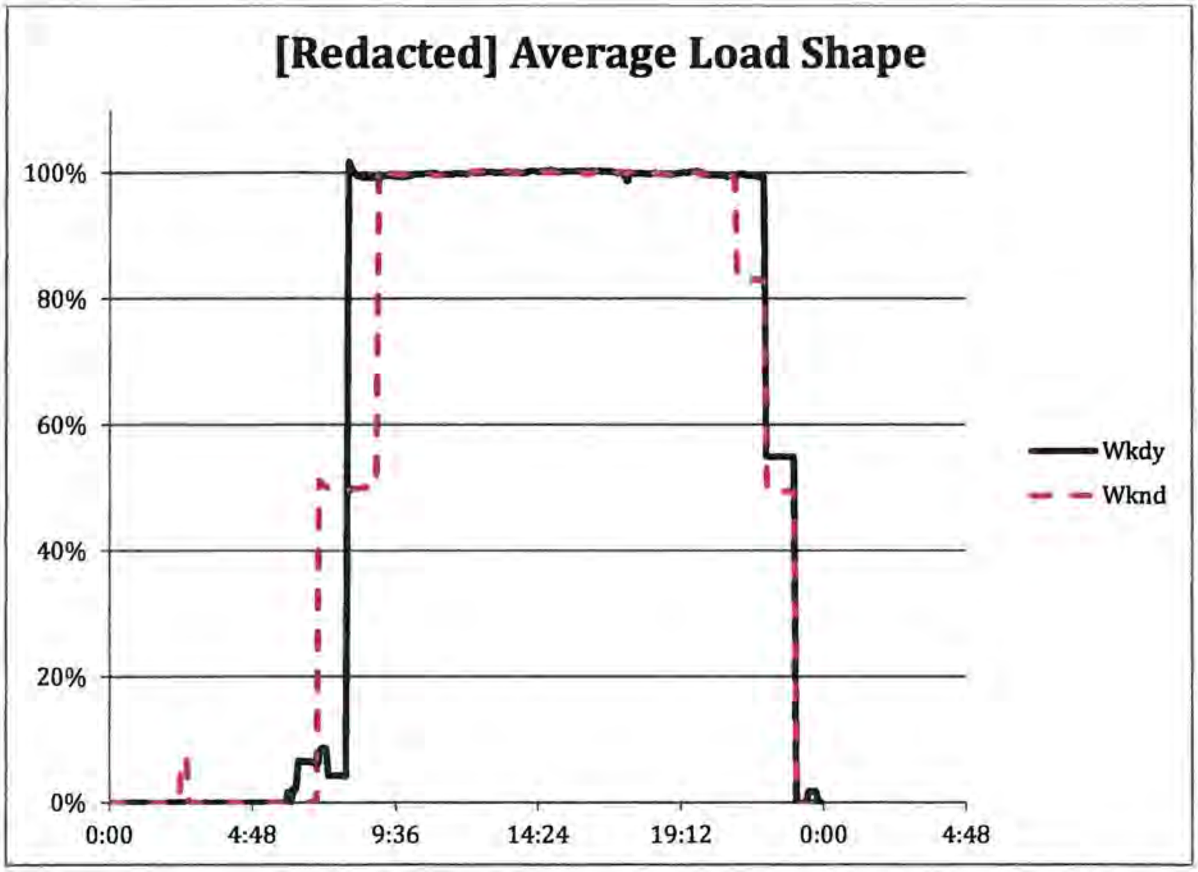
The savings presented in the application were 3 kW NCP demand savings and 13,104 kWh energy savings. These savings did not take into account interactive effects with the HVAC system. It appears that the demand savings of 3 kW in the application was rounded up from 2.5kW. The application does not calculate 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.

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

Table 2. Summary of Energy and Demand Savings Calculations

Base kW	EE kW	EFLH	CF	Lighting Only			With HVAC interactions WHFe= 0.076 WHFd= 0.268122		
				kWh savings	NCP kW	CP kW	kWh savings	NCP kW	CP kW
20.2	17.6	5297.2	1.00	13,349	2.5	2.5	14,365	3.2	3.2

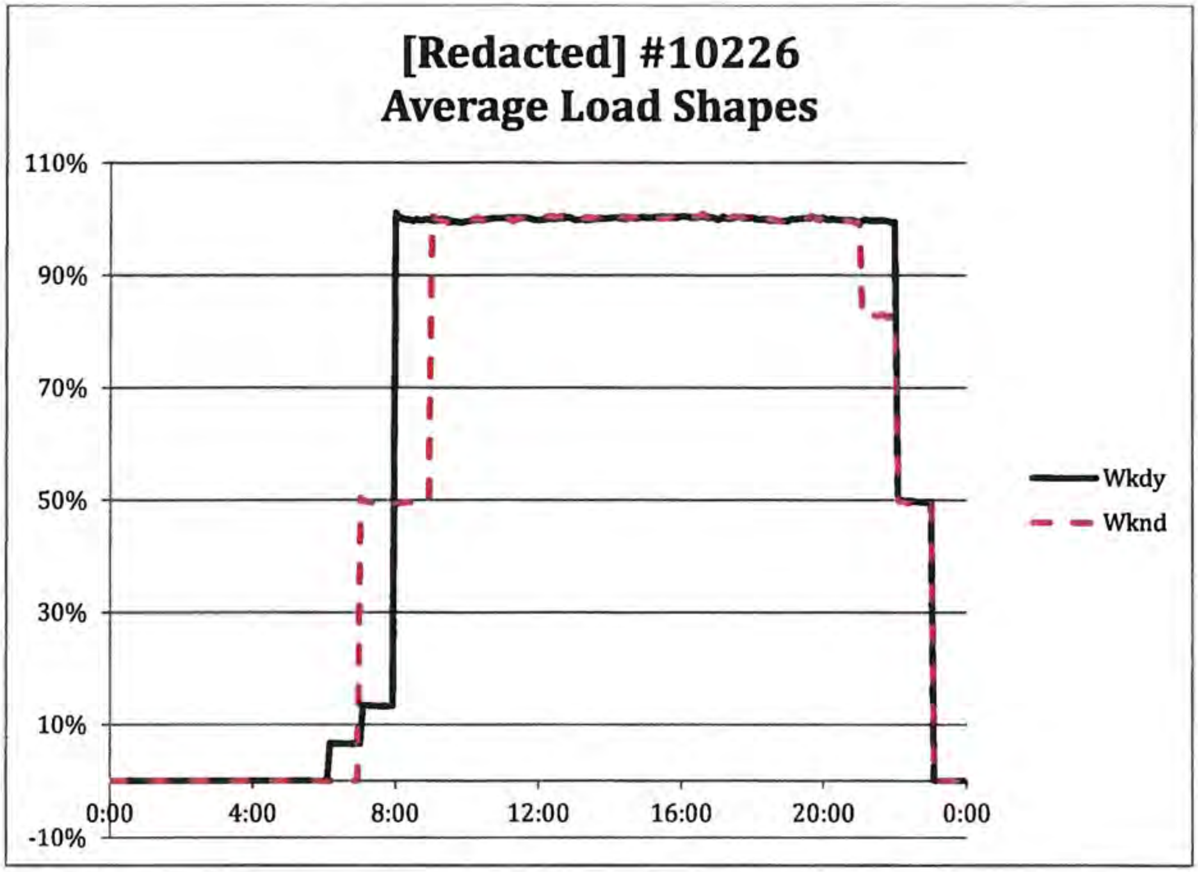
The following figure shows the average daily load shape. When extrapolated to the year, the annual operating hours are 5,297.2 which are two percent greater than the hours stated in the application, which contributes to a realization rate greater than 100 percent.

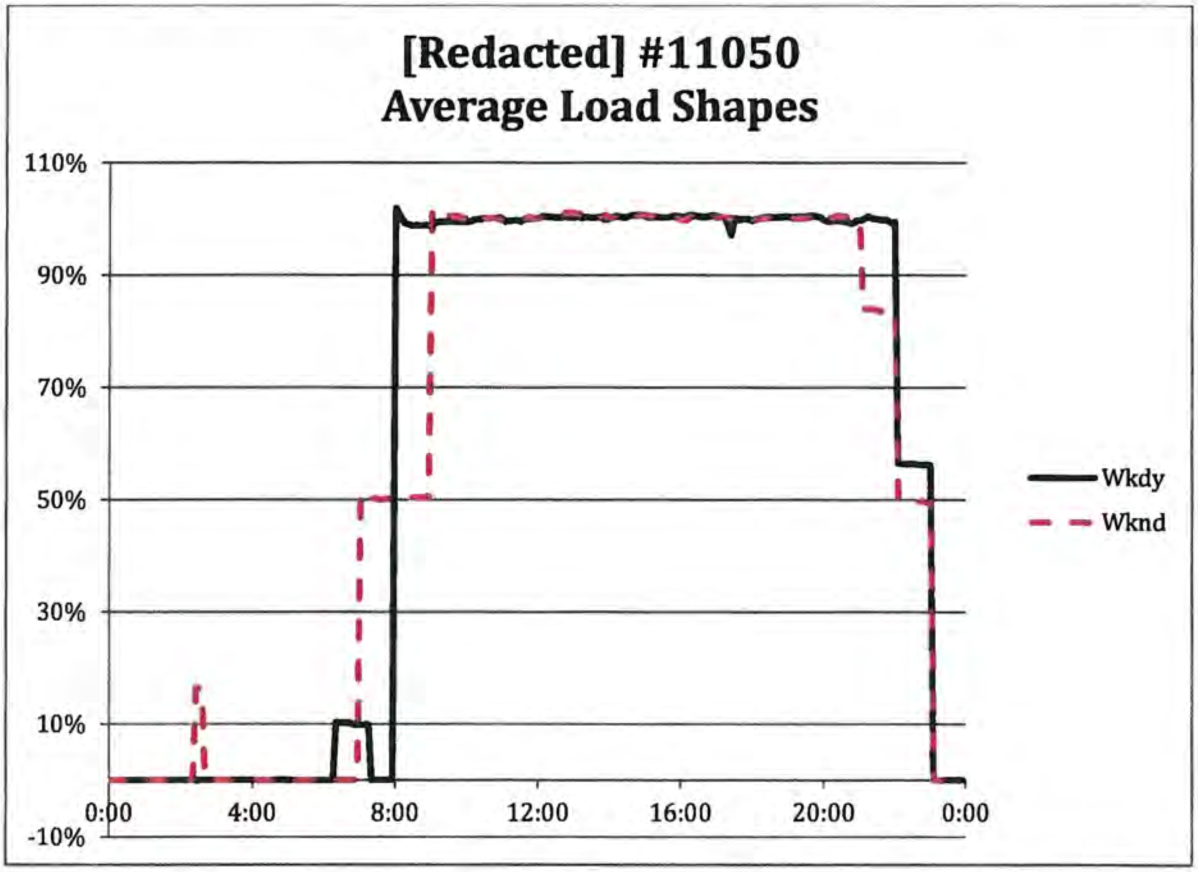


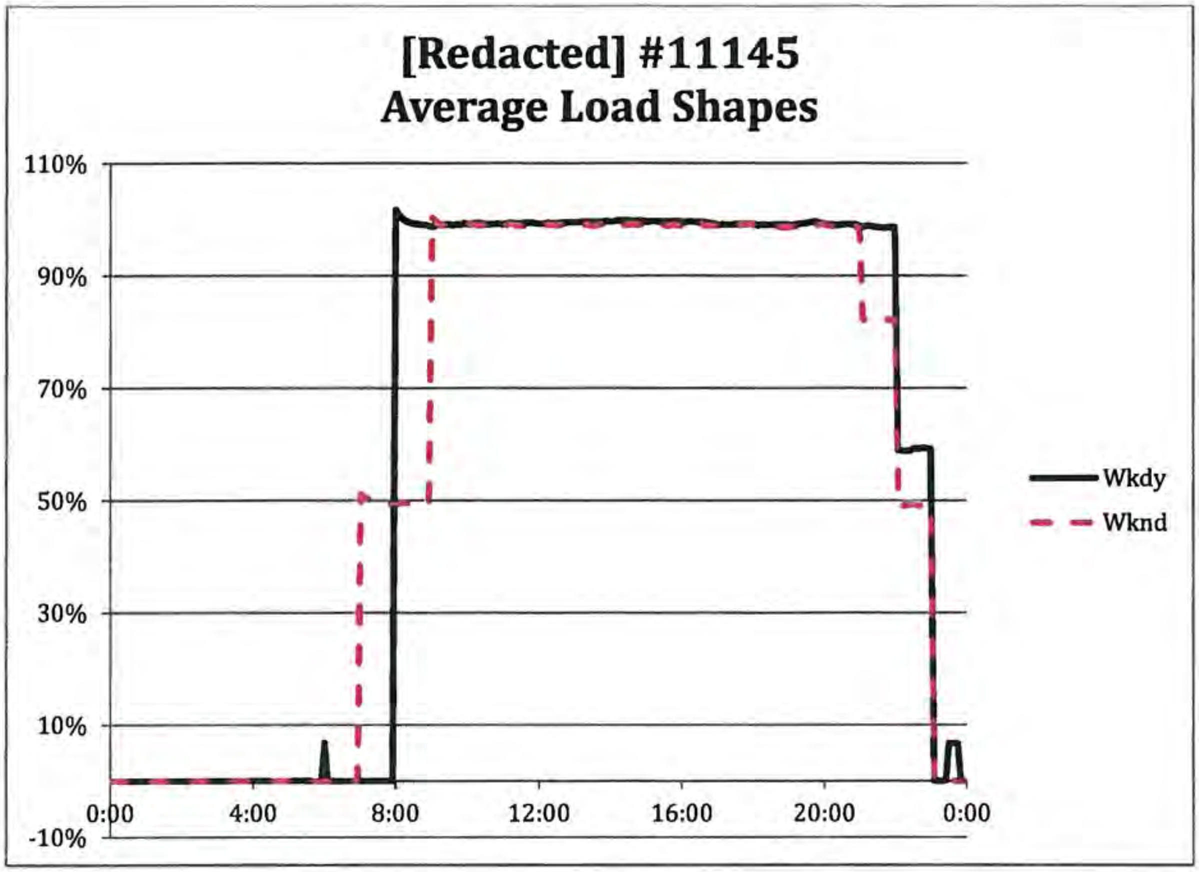
To calculate the total savings for the three [Redacted] stores we analyzed the savings at each location separately and used the sum of savings from the three locations as the realized savings. The reason that we ran three separate analyses is because the logging equipment was installed and removed on different days at each location. By running three separate analyses we were able to maximize the amount of data used in our calculations. To develop the total load shape for all three locations we took a weighted average of the individual stores load shapes. Using the weighted average we were able to develop the average loadshape for each store and calculate the annual hours of use. As previously mentioned the hours were calculated to be 5,297.2 which is two percent greater than the hours stated in the application.

- Used 24W/fixture for the retrofitted fixtures and 21W/ fixture for the new fixtures as supported by product cut sheets. These were also the wattages presented in the application.
- Used AEC-developed HVAC interaction factor for Big Box Store with gas heat, DX cooling and an economizer in OH.

The following figures show the load shapes for each individual store.


[Redacted] #10226
Average Load Shapes
110%
90%
70%
50%
30%
10%
-10%
0:00
4:00
8:00
12:00
16:00
20:00
0:00
Wkdy
Wknd


[Redacted] #11050
Average Load Shapes
110%
90%
70%
50%
30%
10%
-10%
0:00
4:00
8:00
12:00
16:00
20:00
0:00
Wkdy
Wknd



The demand savings details are summarized in the table on the following page.

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	270	21 W LED	21	Cut sheet	5.7	270	24 W MH	24	Cut sheet	6.5
2	360	21 W LED	21	Cut sheet	7.6	360	24 W MH	24	Cut sheet	8.6
3	210	21 W LED	21	Cut sheet	4.4	210	24 W MH	24	Cut sheet	5.0
Total					17.6					20.2

ARCHITECTURAL ENERGY
CORPORATION

[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:
November 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].

ARCHITECTURAL ENERGY
CORPORATION

Introduction

This plan addresses M&V activities for the [Redacted] custom program application. The application covers a lighting retrofit at 17 locations near Cincinnati, Ohio. This M&V report is for post-retrofit monitoring only. All measures include retrofit of older, higher wattage fixtures with an equivalent number of more efficient fixtures. More specifically, the measures include:

ECM-1 – Conversion of 118W refrigerated case lighting fixtures to 84W fixtures

- 4-foot T8 fluorescent bulbs were converted to more efficient LED fixtures.

ECM-2 – Conversion of 148W refrigerated case lighting fixtures to 100W fixtures

- 4-foot T8 fluorescent bulbs were converted to more efficient LED fixtures.

ECM-3 – Conversion of 177W refrigerated case lighting fixtures to 100W fixtures

- 4-foot T8 fluorescent bulbs were converted to more efficient LED fixtures.

Goals and Objectives

A post-retrofit survey of the lighting usage was conducted to determine the power reduction from the lighting upgrade. Eleven of the 17 locations were sampled however the final results are based off of nine sites. This is because one of the metered sites data was corrupted and at the other site the technician was not able to meter exclusively the case lighting.

The Duke adjusted savings projections total 130,021 kWh and 11.6 kW from the application proposed savings of 69,662 kWh and 12 kW.

The objective of this M&V project was 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	Katie Gustafson	p: 303-459-7430 kgustafson@archenergy.com

Site Locations/ECM's

Site	Address	Annual Operating Hours	ECM's Implemented
[Redacted]	[Redacted]	7,300	1

ARCHITECTURAL ENERGY CORPORATION

[Redacted]	[Redacted]	**6,935**	**2**
[Redacted]	[Redacted]	**7,300**	**2**
[Redacted]	[Redacted]	**8,760**	**1**
[Redacted]	[Redacted]	**7,176**	**1**
[Redacted]	[Redacted]	7,300	2
[Redacted]	[Redacted]	**6,396**	**2**
[Redacted]	[Redacted]	**6,935**	**1**
[Redacted]	[Redacted]	**6,935**	**2**
[Redacted]	[Redacted]	6,396	2
[Redacted]	[Redacted]	**5,772**	**1**
[Redacted]	[Redacted]	7,300	2
[Redacted]	[Redacted]	6,570	1
[Redacted]	[Redacted]	7,300	2
[Redacted]	[Redacted]	**6,935**	**1**
[Redacted]	[Redacted]	**8,760**	**1**
[Redacted]	[Redacted]	**6,570**	**3**

*Locations that were sampled are in **BOLD**

** The meter data for location 305 was not used as it was corrupted.

***The meter data for location 432 was not used because the site visit tech was unable to identify the additional components that shared the circuit with the light fixtures.

Data Products and Project Output

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

M&V Option

IPMVP Option A

M&V Implementation Schedule

- Conducted the post-retrofit survey after the customer performed the lighting retrofit.
    - Deployed post-retrofit loggers.
    - Spot measurements were taken of the lighting load connected to the circuit by measuring the kW load and current draw of the circuit.
- Since the customer had already performed the lighting retrofit, pre- fixture information was taken from the application. The field surveys verified the pre-retrofit fixture specifications and quantities retrofitted.
- Collected logger data during normal operating hours (avoid holidays or atypical operating hours).

ARCHITECTURAL ENERGY
CORPORATION

Data Accuracy

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

Field Data Points

Post-Installation

Only the following stores were surveyed and sampled:

- [Redacted] (The metered data for this store was corrupted and therefore not analyzed)
- [Redacted]
- [Redacted]
- [Redacted]
- [Redacted]
- [Redacted]
- [Redacted]
- [Redacted]
- [Redacted] (The site visit tech was unable to determine the wattage of other equipment that shared the circuit with the retrofitted fixtures. For this reason we did not analyze this meter data).
- [Redacted]
- [Redacted]

Survey data

- Determined fixture count and wattage at each sampled location
- Verified that all new fixture specifications and quantities were consistent with the application
- Determined how lighting is controlled and recorded controller settings
- Verified that all pre-existing fixtures were removed
- Determined what holidays the building observes over the year
- Determined if the lighting zones are disabled during the holidays

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
    - Sampling was not required because all of the retrofitted lights were able to be monitored at the circuit panel.

ARCHITECTURAL ENERGY
CORPORATION

- The loggers were set up for 5 minute instantaneous readings and were allowed to operate for a minimum period of three weeks.

- Spot measurements of the lighting load connected to the circuit were taken by measuring the kW load and current draw of the circuit during the post-retrofit survey. Each circuit only had one connected fixture type.

LOGGER TABLE

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

ECM	Hobo U-12	20A CT
1,2, &3	1	20
Total for 11 Stores	**1**	**20**

DATA ANALYSIS

The application included eight stores that implemented ECM1, eight stores that implemented ECM2, and one store that implemented ECM3. The sampled stores that had useable metered data included four stores that implemented ECM1, four stores that implemented ECM2, and the one store that implemented ECM3.

In order to estimate the total savings associated with this [Redacted] application we calculated the energy savings for the nine stores that were metered and then estimated the savings for the remaining stores based of the metered data analysis.

Meter Data Analysis

The following approach was used to calculate the savings for each of the nine [Redacted] stores that were metered and had useable data.

1. Converted time series data on logged equipment into post-retrofit average load shapes by the following day types: weekday, weekend, and holiday.
2. The Pre annual kWh was calculated using the following equations:

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

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

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

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

5.
$$\frac{kWh}{year}_{Savings} = \frac{kWh}{year}_{Pre} - \frac{kWh}{year}_{Post}$$

6. The peak demand savings were determined by subtracting the measured post retrofit connected load from the estimated pre retrofit connected load.
7. The coincident demand savings were determined by subtracting the post retrofit connected load from the estimated pre-retrofit connected load at the grid peak.

Unmetered Savings Estimates

The following section discusses the approach that was used to estimate the savings for the remaining 8 [Redacted] stores that were not metered, or had unusable meter data.

Using the energy and demand savings that were calculated for each of the metered stores we used the following approach to calculate the average annual savings per fixture for ECM1 and ECM2. In essence, savings were estimated on a per-fixture basis, and then scaled to total fixtures within each store.

1. Determined the average EFLH per day for each day of the week and holidays where applicable.
2. Determined the average pre and post kWh per day per fixture for each day of the week and holiday days.
3. Determined the annual pre and post kWh consumption per fixture.
4. Calculated the average annual kWh savings per fixture.
5. Calculated the average peak and coincident demand savings per fixture from the coincident and peak demand savings.
6. Applied an energy and demand cooling interaction factor for refrigerated case lighting. The energy and demand interaction factor that we used was 0.41 kWh and 0.41 kW cooling savings per kWh and kW of lighting savings. This value was pulled from the 2010 Ohio TRM[1].
7. Determined total installation rate of 94% based on the fixtures that were verified installed at the 9 sampled sites vs. the quantity of proposed fixtures per store as listed in the application.
8. The following equations were used to estimate the annual energy and demand savings for each of the 8 remaining stores.

$$\frac{Store\ kWh\ Savings}{year} = Fixtures_{app} * Installation\ Rate * \frac{kWh_{avg}}{year * fixture}$$

$$\frac{Store\ kW\ Savings}{year} = Fixtures_{app} * Installation\ Rate * \frac{kW_{avg}}{year * fixture}$$

[1] *State of Ohio Energy Efficiency Technical Reference Manual.* N.p.: Vermont Energy Investment Corporation, 2010. Web. <http://amppartners.org/pdf/TRM_Appendix_E_2011.pdf>.

ARCHITECTURAL ENERGY
CORPORATION

The total verified savings are the sum of estimated savings for each of the eight stores that were not metered and the savings calculated for each of the nine stores with metered data.

Verification and Quality Control

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

Recording and Data Exchange Format

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

Field Staff

☐ Verifiable Results
☐ AEC
■ **Other**

Contracting type

■**T&M**
☐ Per logger

Results Summary

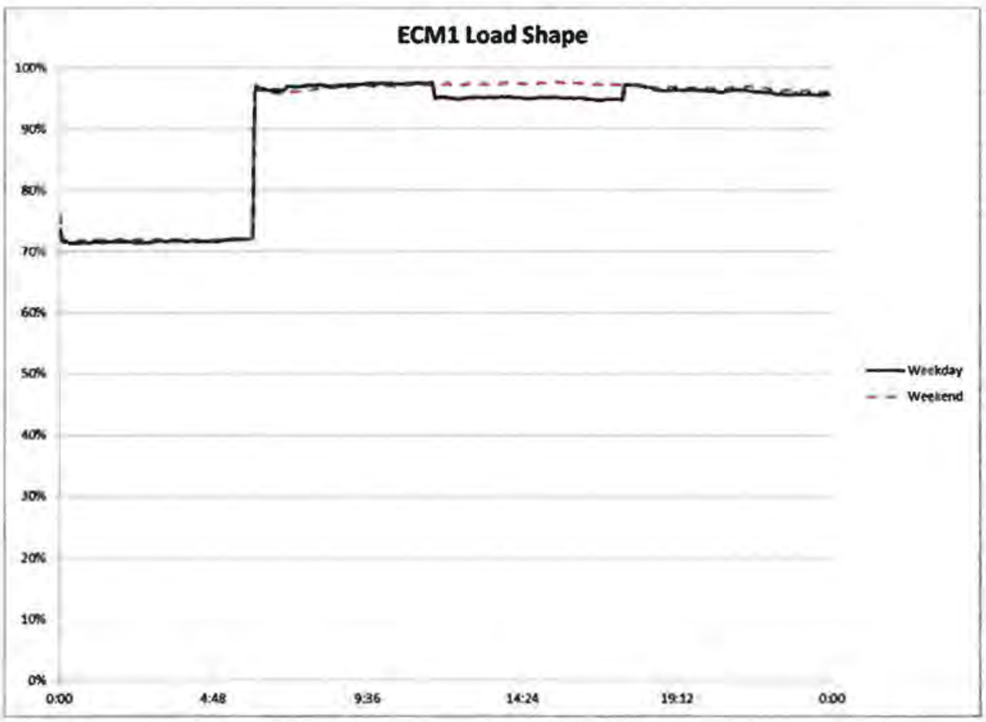
The following results account for the savings associated with the lighting retrofits for the 17 stores associated with the [Redacted] application.

Table 1. Annual Energy Savings

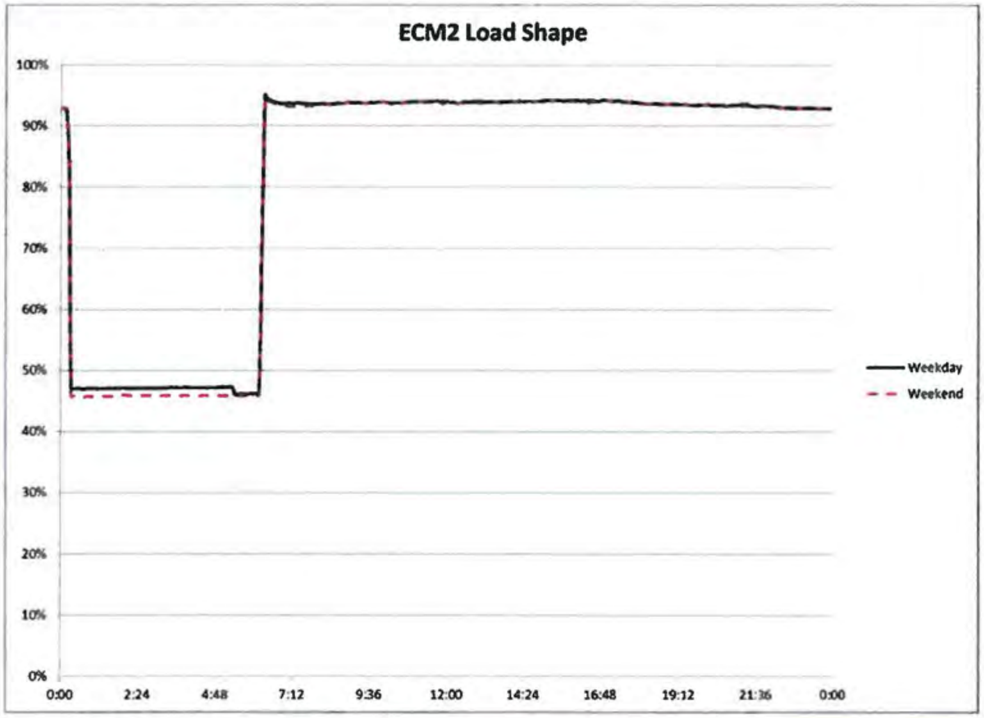
Duke Savings	Realized Savings		Realization Rate	
	Lighting Only	Lighting and Refrigeration	Lighting Only	Lighting and Refrigeration

Energy (kWh)	130,021	70,434	99,312	54%	76%
Peak Demand (kW)	11.6	9.0	12.7	78%	109%
Coincident Demand (kW)	10.5	8.8	12.4	84%	118%

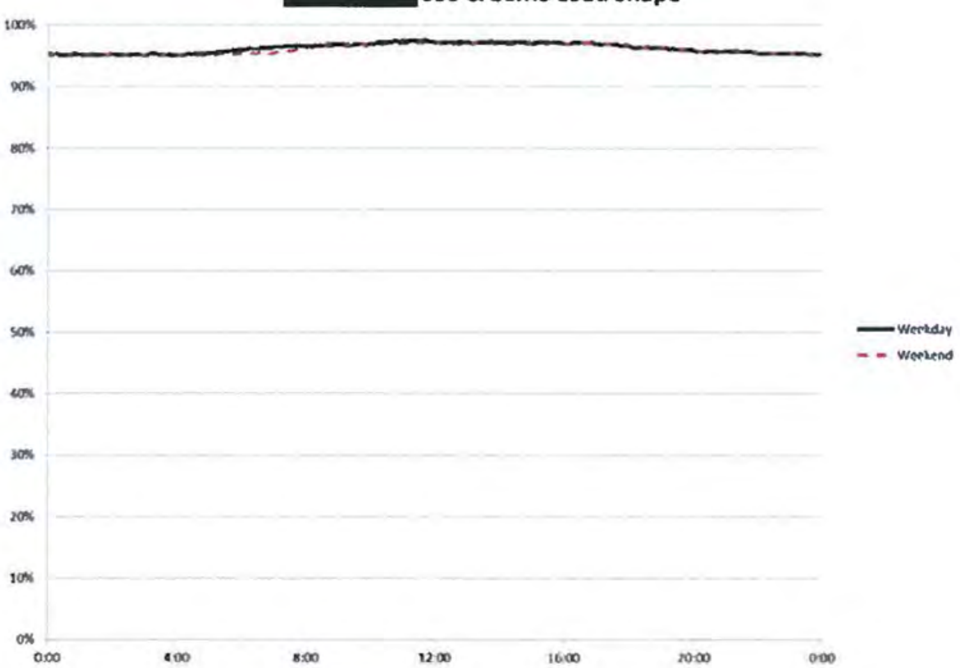
The above table shows the realization rates for lighting only savings and lighting and refrigeration savings. The likely cause of the kWh realization rate being greater than 100% is that the proposed savings were calculated using the store operating hours. We found that in most cases these retrofitted refrigerated case fixtures were not turned off at night. This can be seen in the loadshape graphs below, which are the averages for all monitored stores.



ARCHITECTURAL ENERGY
CORPORATION



[redacted] 353 & ECM3 Load Shape



ARCHITECTURAL ENERGY CORPORATION

METERED STORE ANALYSIS

Store [Redacted]

- The data for this site was corrupted. We did not analyze savings for this site.

Store [Redacted]

	Duke Reported Savings	Realized Savings		Realization Rate	
		Lighting Only	Lighting and HVAC	Lighting Only	Lighting and HVAC
kWh	3,537	3,148	4,439	89%	126%
kW	1	0.5	0.7	51%	71%

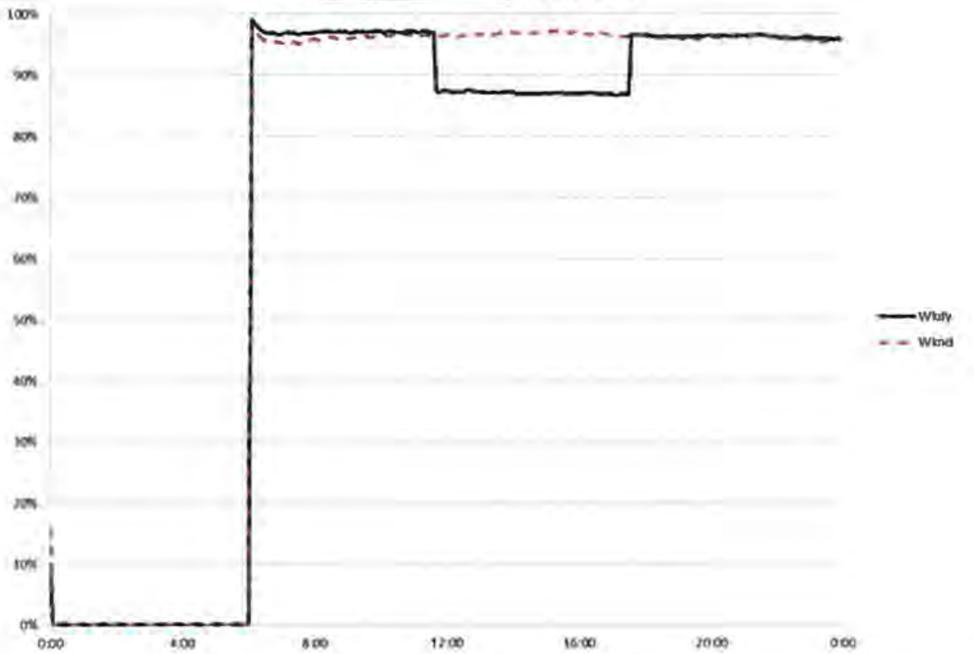
Notes:

- Application indicates:
  - 15, 4ft sections with , F44 T8 fixtures that were replaced with LED fixtures
- This retrofit falls under our definition of ECM 1.
- Site visit pictures and notes verify the fixture type and indicate that all 15 LED fixtures were installed.
- Pre retrofit: used 118 W/ 4ft section as supported by Appendix B: Table of Standard Fixture Wattages, 2008 and supporting documentation.
- Post retrofit: used 84 W/ 4ft section from the application and supporting product documentation. .
- Only holiday is Christmas Eve from 6PM to 12PM. Assumed standard case operation during this time

	Lighting	HVAC	Total
Pre kW	1.76		
Post kW	1.25		
Demand Savings	0.51	0.21	**0.71**
Coincident Pk Demand Svgs	0.45	0.18	**0.63**

ARCHITECTURAL ENERGY
CORPORATION

[redacted] Load Shape



<u>The average load shape shown above shows a dip mid-day because there was an instance during the metered data period where the metered amps dropped to zero for several hours during normal operation hours. We included this event in our analysis because it does not appear that the meters malfunctioned.</u>

Store [Redacted]

	Duke Reported Savings	Realized Savings		Realization Rate	
		Lighting Only	Lighting and HVAC	Lighting Only	Lighting and HVAC
kWh	7,082	8,853	12,483	125%	176%
kW	1	1.0	1.4	102%	144%

Notes:

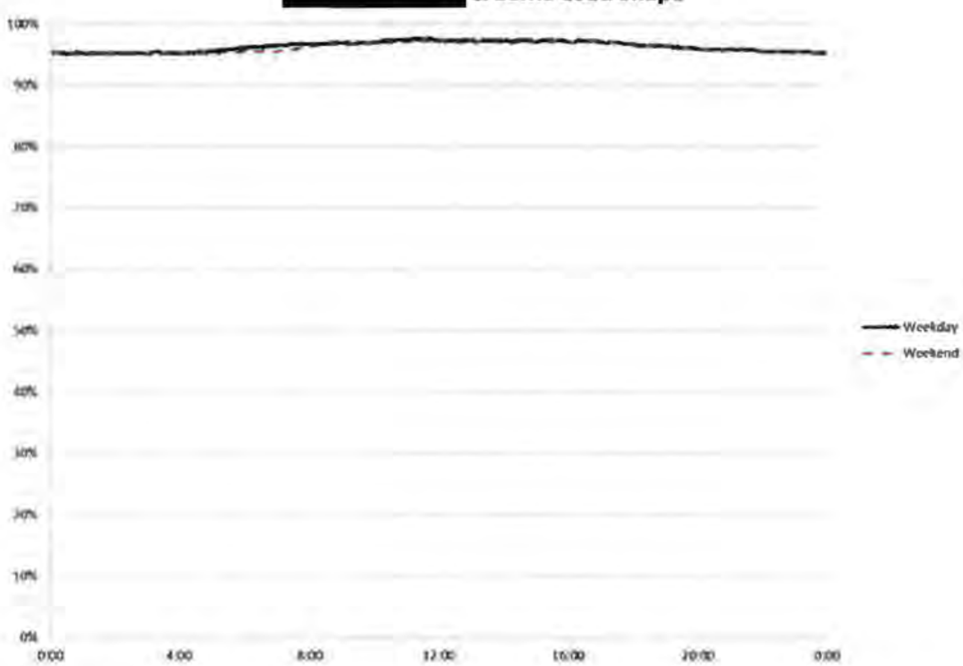
- Application indicates:
  - 14, 4ft sections with F46 T8 fixtures were replaced with LED fixtures
- This retrofit falls under our definition of ECM3.
- Pre retrofit: used 175 W/ 4ft section as supported by Appendix B.
- Post retrofit: used 100W/ 4ft section from the application and supporting product documentation.
- Site visit pictures and notes verify the fixture type and indicate that all 15 LED fixtures were installed.

ARCHITECTURAL ENERGY
CORPORATION

- Only holiday is Christmas Eve from 6PM to 12PM. Assumed standard case operation during this time.

	Lighting	HVAC	Total
Pre kW	2.39		
Post kW	1.37		
Demand Savings	1.02	0.42	**1.44**
Coincident Pk Demand Svgs	1.02	0.42	**1.44**

[redacted] & ECM3 Load Shape



Store [Redacted]

	Duke Reported Savings	Realized Savings		Realization Rate	
		Lighting Only	Lighting and HVAC	Lighting Only	Lighting and HVAC
kWh	4,298	4,246	5,987	99%	139%
kW	1	0.663	0.935	66%	94%

Notes:

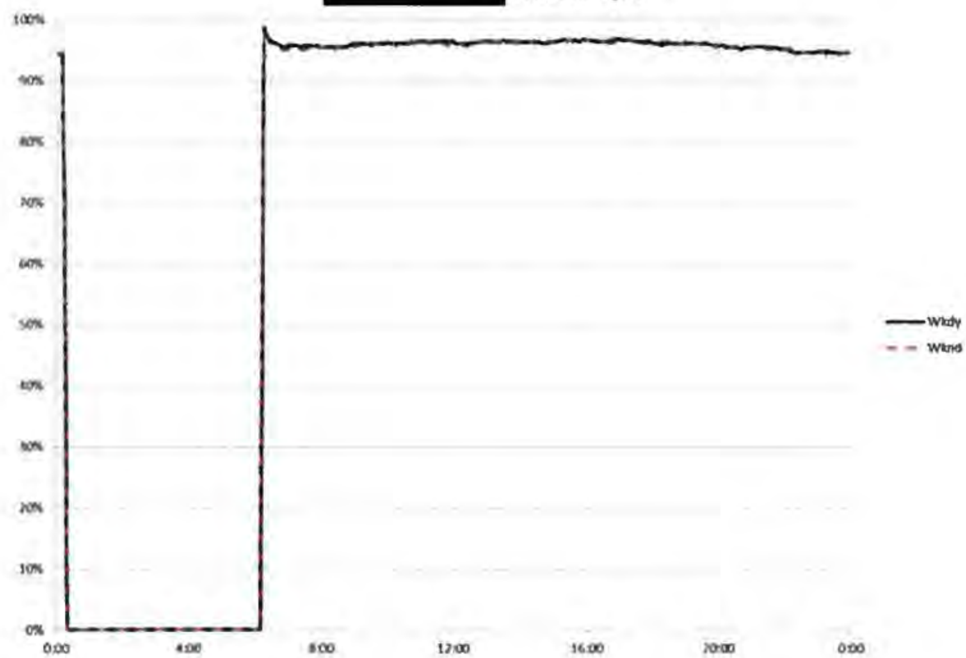
- Application indicates:
  - 14, 4ft sections with F45 T8 fixtures were replaced with LED fixtures
- This retrofit falls under AEC's definition for ECM2.
- Site visit pictures and notes verify the fixture type and indicate that all 14 LED fixtures were installed.

ARCHITECTURAL ENERGY
CORPORATION

- Pre retrofit: used 148 W/ 4ft section as supported by Appendix B and supporting documentation.
- Post retrofit: 100 W/fixture from the application and supporting product documentation.
- Only holiday is Christmas Eve from 6PM to 12PM. Assumed standard case operation during this time.

	Lighting	HVAC	Total
Pre kW	2.05		
Post kW	1.38		
Demand Savings	0.66	0.27	**0.94**
Coincident Pk Demand Svgs	0.65	0.27	**0.91**

[redacted] Load Shapes



Store [Redacted]

	Duke Reported Savings	Realized Savings		Realization Rate	
		Lighting Only	Lighting and HVAC	Lighting Only	Lighting and HVAC
kWh	2,551	2,281	3,217	89%	126%
kW	0	0.3	0.4	N/A	N/A

Notes:

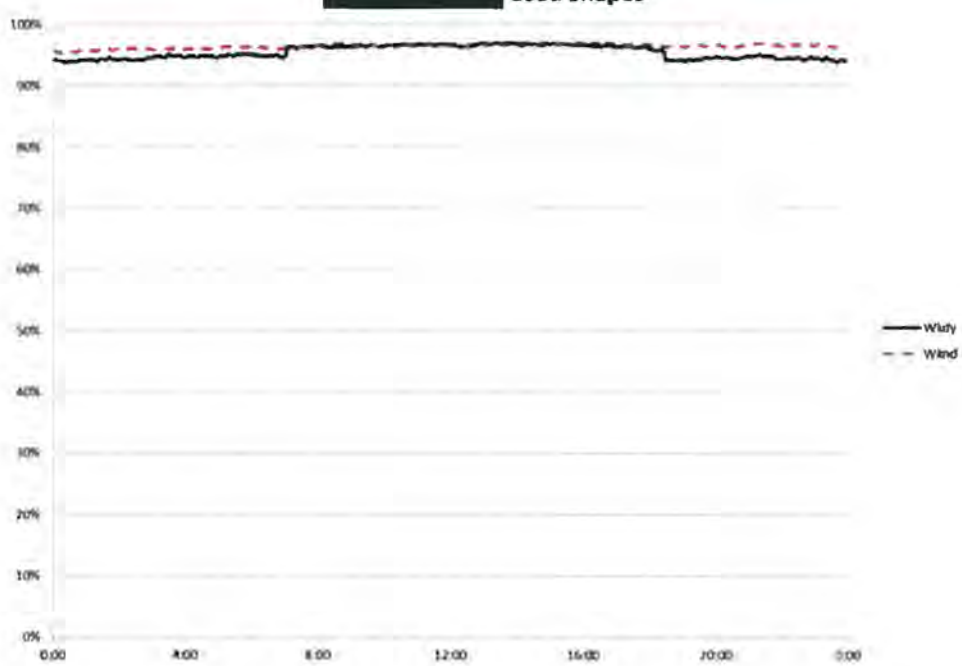
- Application indicates:

- 13, 4ft sections with F44 T8 fixtures were replaced with LED fixtures.

- This retrofit falls under AEC's definition of ECM1.
- Site visit tech verified that only eight fixtures had been installed.
- Site visit pictures and notes verify the fixture type.
- Pre retrofit: used 118 W/ 4ft section as supported by Appendix B and supporting documentation.
- Post retrofit: used 84 W/ 4ft section from the application and supporting product documentation
- Only holiday is Christmas Eve from 6PM to 12PM. Assumed standard case operation during this time.

	Lighting	HVAC	Total
Pre kW	0.91		
Post kW	0.65		
Demand Savings	0.26	0.11	**0.37**
Coincident Pk Demand Svgs	0.26	0.11	**0.37**

[redacted] Load Shapes



Store [Redacted]	Duke Reported Savings	Realized Savings		Realization Rate	
		Lighting Only	Lighting and HVAC	Lighting Only	Lighting and HVAC
kWh	3662	3,303	4,657	90%	127%

ARCHITECTURAL ENERGY CORPORATION

kW	1	0.52	0.73	52%	73%

Notes:
- Application indicates:
  - 11, 4ft sections with F45 T8 fixtures were replaced with LED fixtures.
- This retrofit falls under AEC's definition of ECM2
- Site visit notes verify the fixture type and indicate that all 11 LED fixtures were installed.
- Pre retrofit: used 148 W/ 4ft section as supported by Appendix B and supporting documentation.
- Post retrofit: used 100W/4ft section from the application and supporting product documentation.
- There was no picture of this case from the site visit.
- Only holiday is Christmas Eve from 6PM to 12PM. Assumed standard case operation during this time.

	Lighting	HVAC	Total
Pre kW	1.60		
Post kW	1.08		
Demand Savings	0.52	0.21	**0.73**
Coincident Pk Demand Svgs	0.50	0.20	**0.70**

Store [Redacted]

	Duke Reported Savings	Realized Savings		Realization Rate	
		Lighting Only	Lighting and HVAC	Lighting Only	Lighting and HVAC
kWh	4,176	5,603	7,901	134%	189%
kW	1	0.6	1	65%	92%

Notes:
- Application indicates:
  - 15, 4ft sections with F45 T8 fixtures were replaced with LED fixtures.
- This retrofit falls under AEC's definition of ECM2
- Site visit pictures and notes verify the fixture type and indicate that only 14 LED fixtures were installed.
- Pre retrofit: used 148 W/ 4ft section as supported by Appendix B and supporting documentation.
- Post retrofit: used 100W/4ft section from the application and supporting product documentation.