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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

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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.

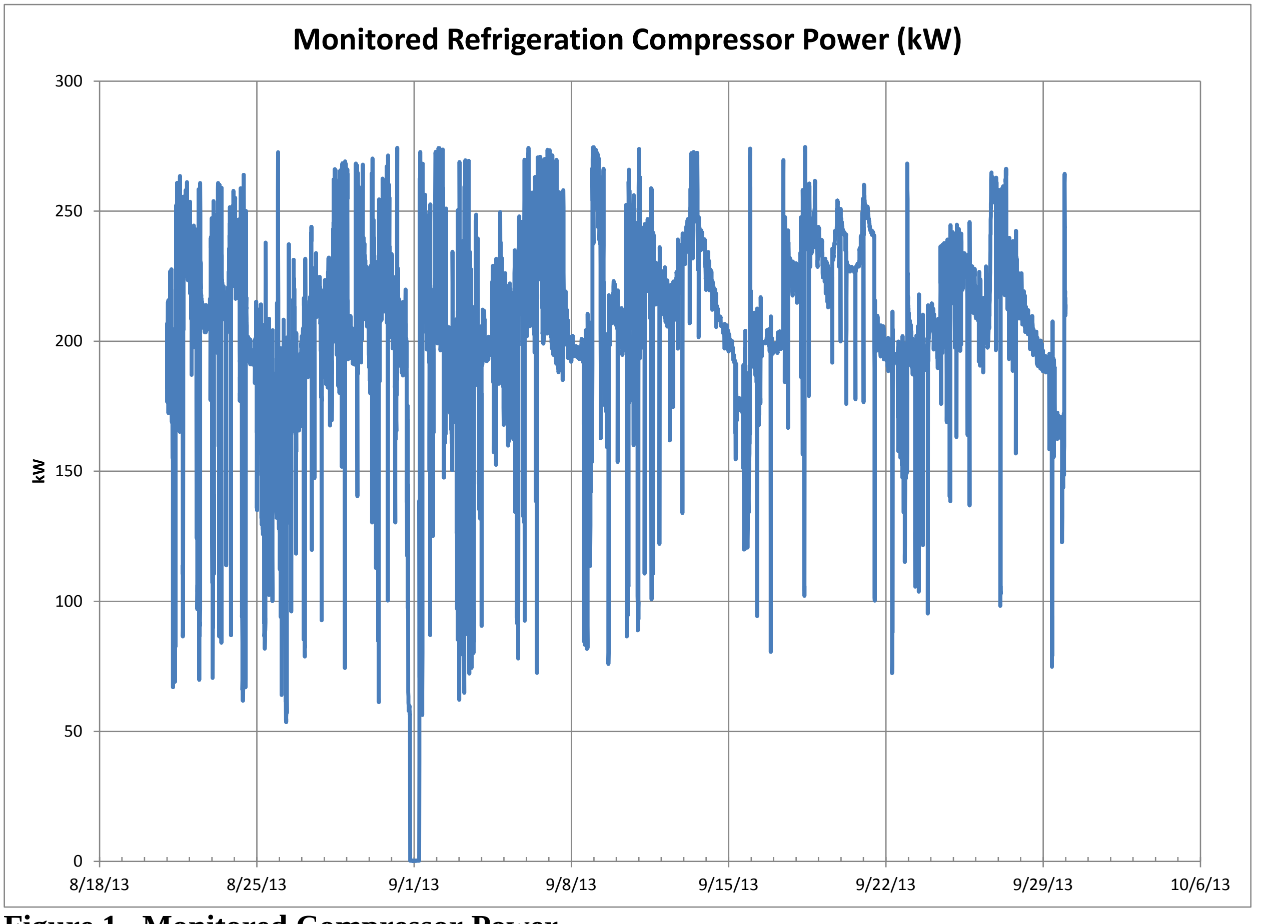

Figure 1. Monitored Compressor Power

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.)

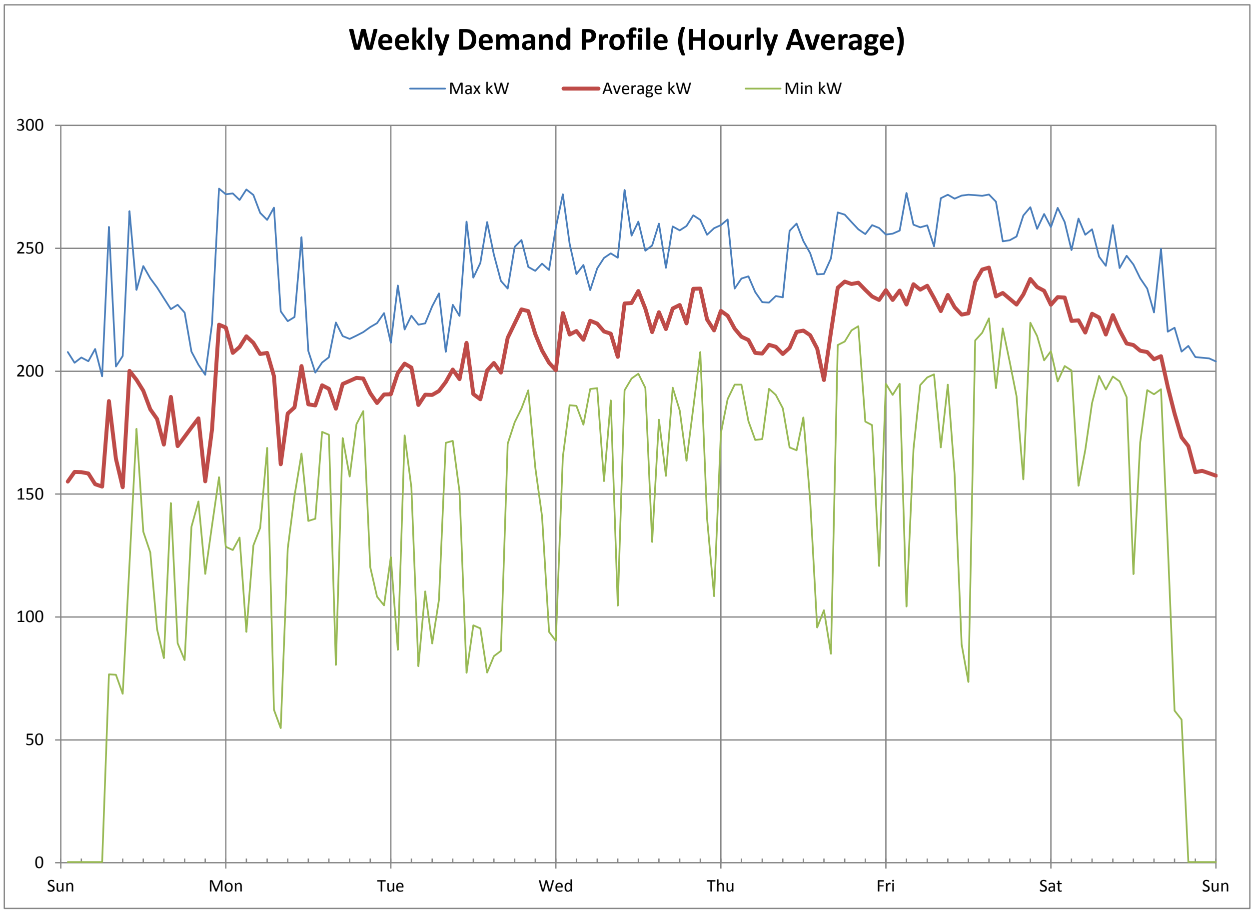

Figure 2. Weekly Compressor Electric Demand Profile

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**

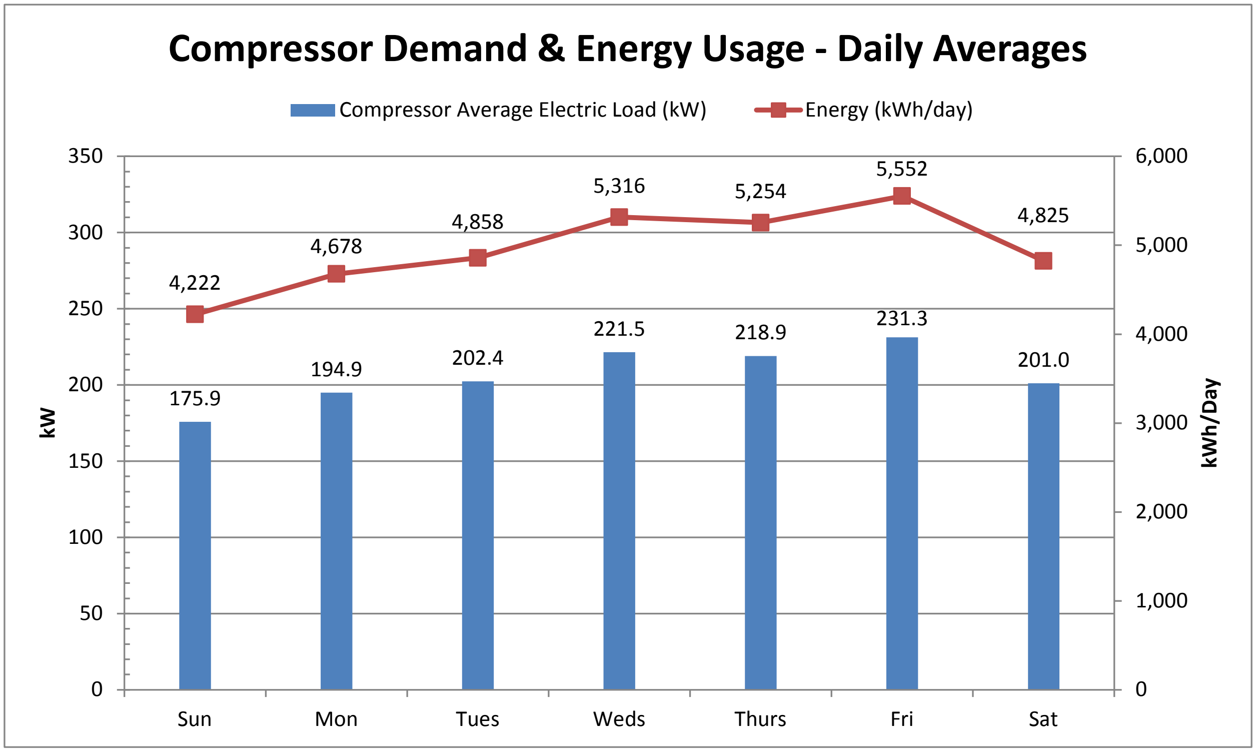

Figure 3. Average Compressor Load and Energy Usage by Day-Type

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 Figure 4 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			kW Range		Monitored Data				M&V-Projected Baseline			
Compressor Power (kW in 10% steps)	No. of Hours at Indicated Compressor kW				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

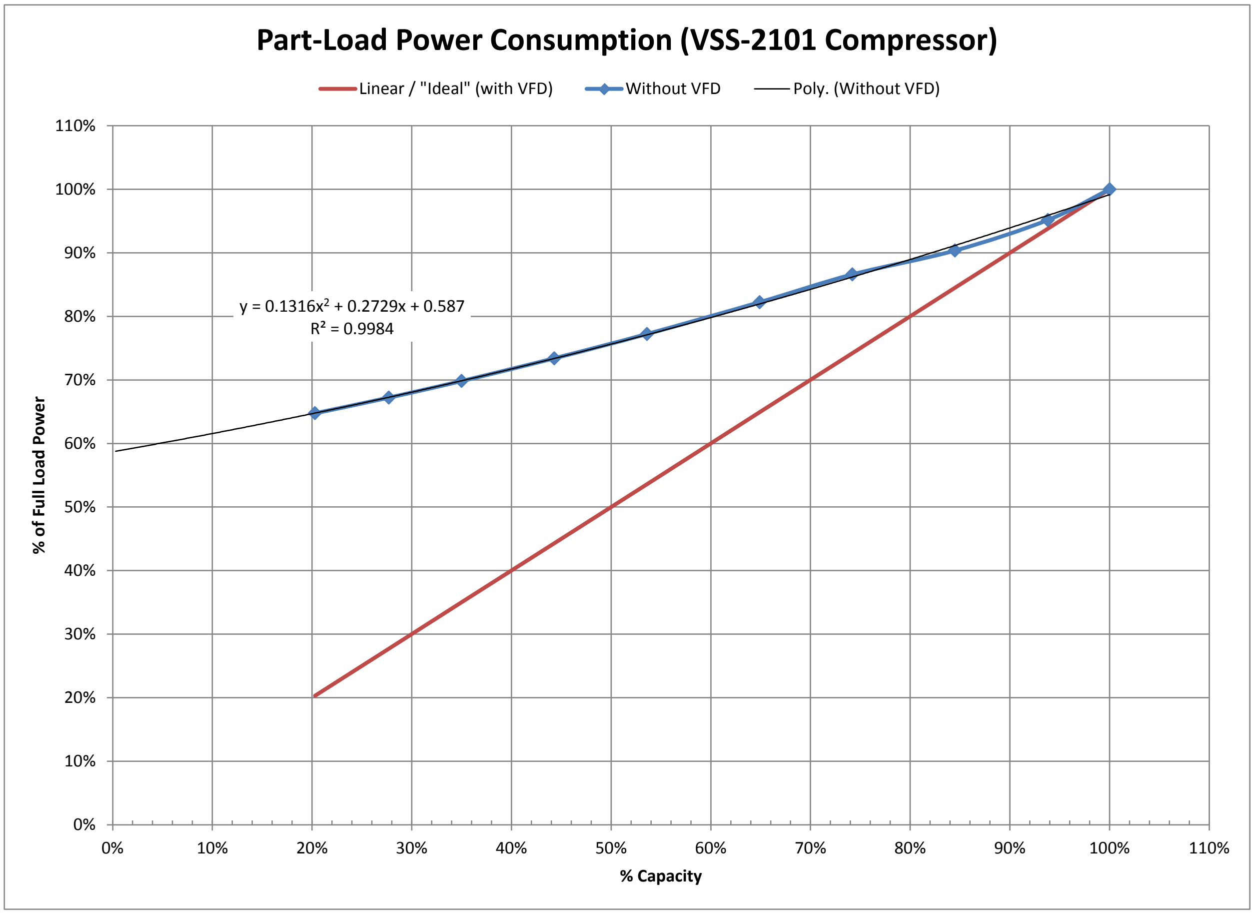

Figure 4. Compressor Part-Load Performance

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.

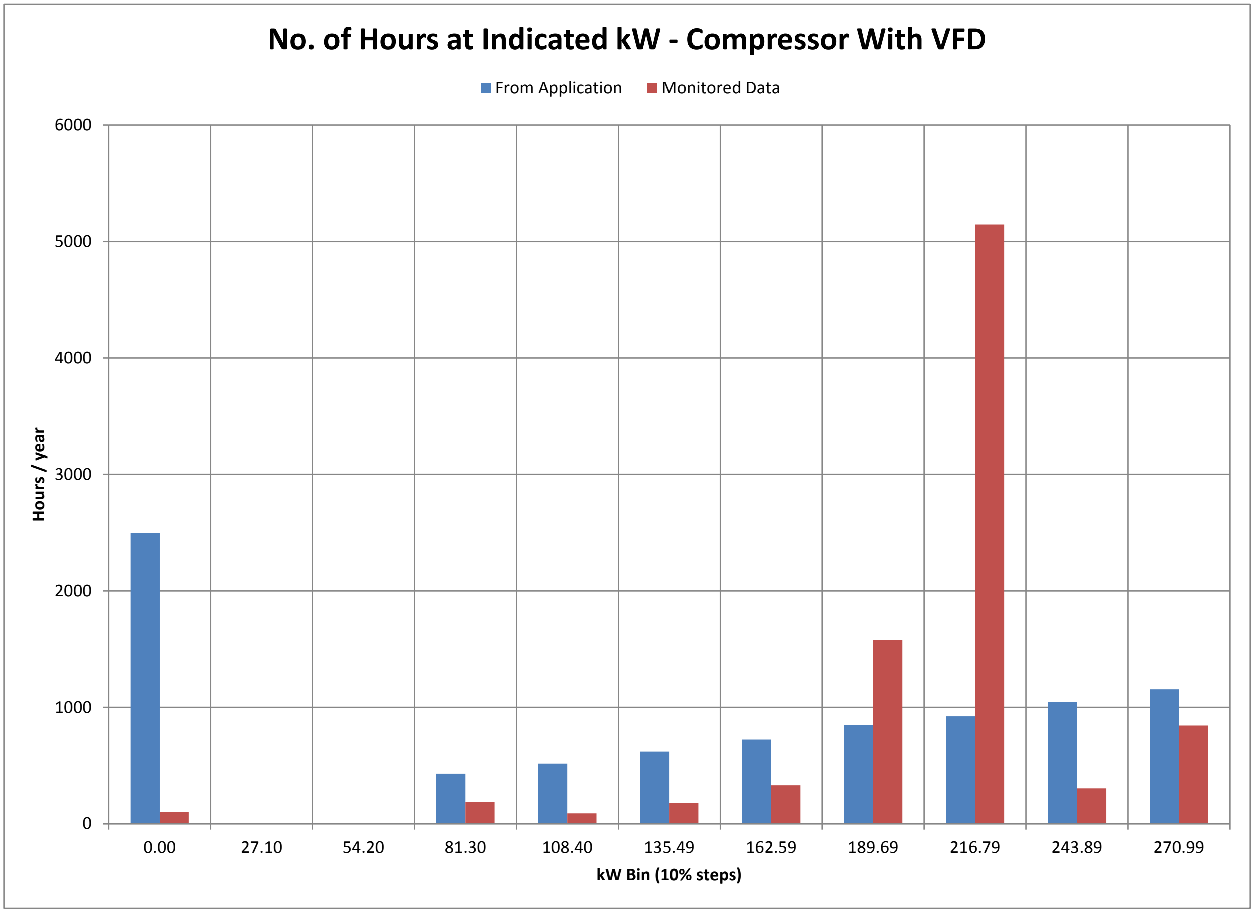

Figure 5. Post-Retrofit Hours of Operation (Original Projection vs. M&V Data)

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.

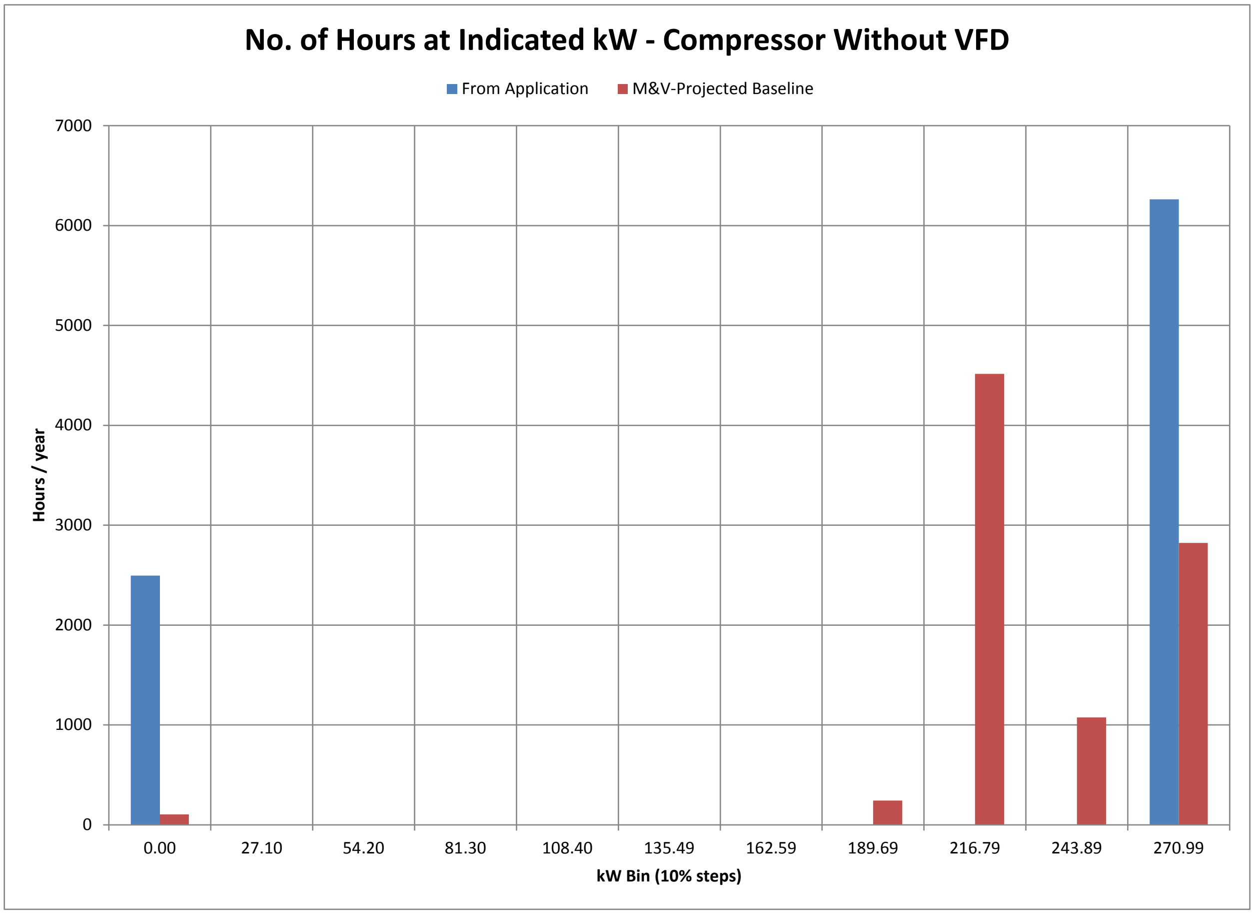

Figure 6. Pre-Retrofit Hours of Operation (Original Projection vs. M&V Data)

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:

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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

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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 Figure 1. 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.

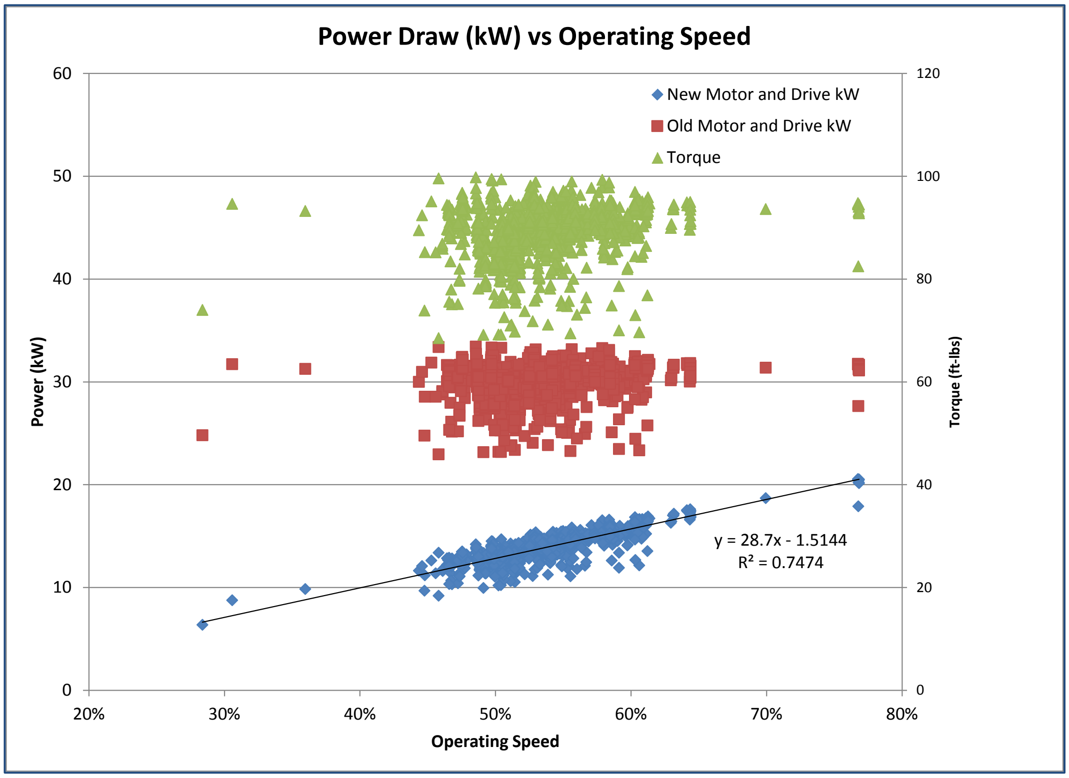

Figure 1: Motor and Drive kW vs Operating Speed

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.

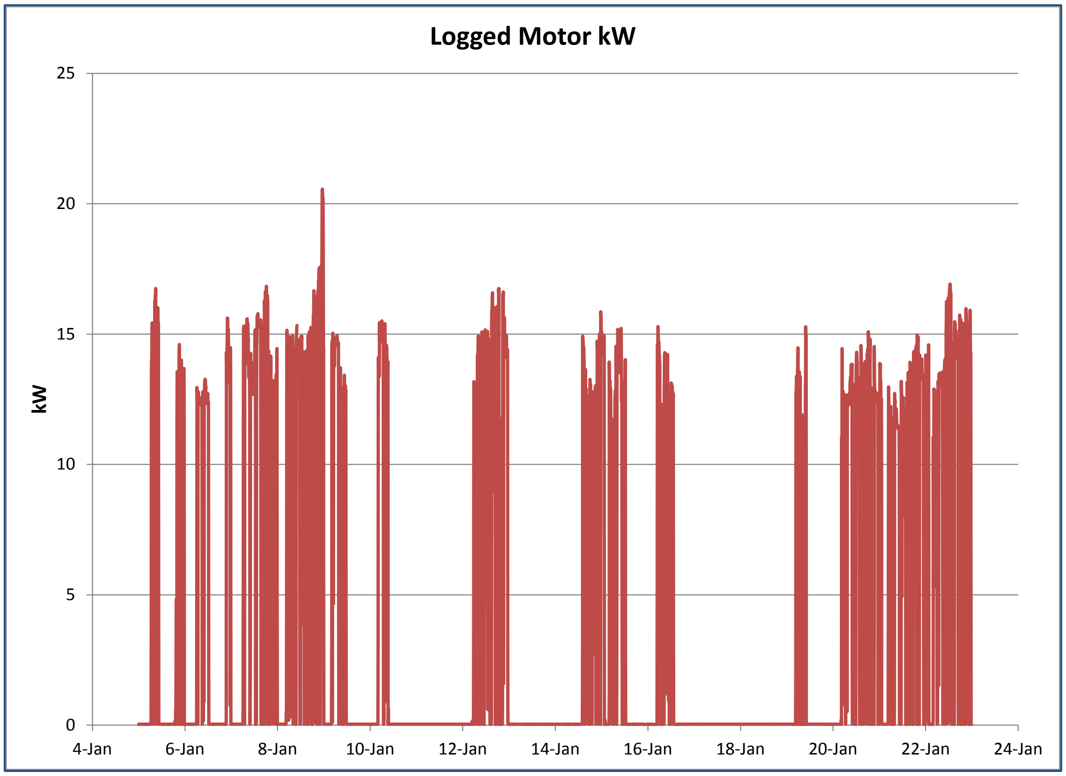

Figure 2: Logged Motor and VFD kW

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.

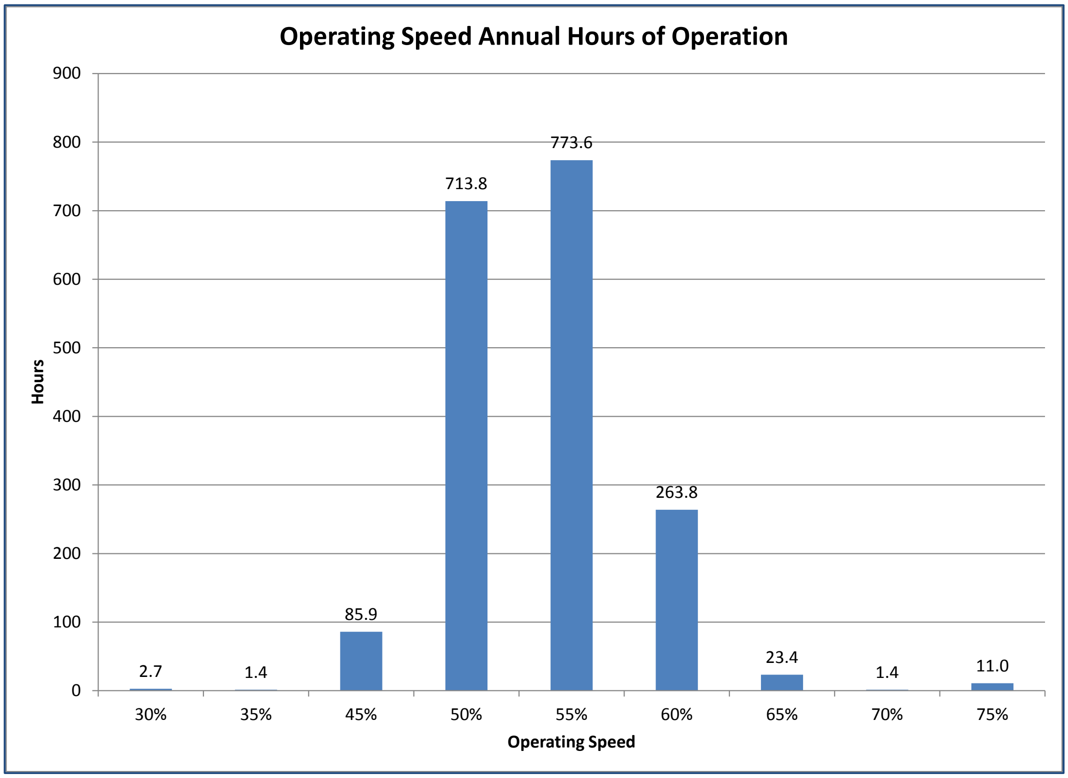

Figure 3: Operating Speeds

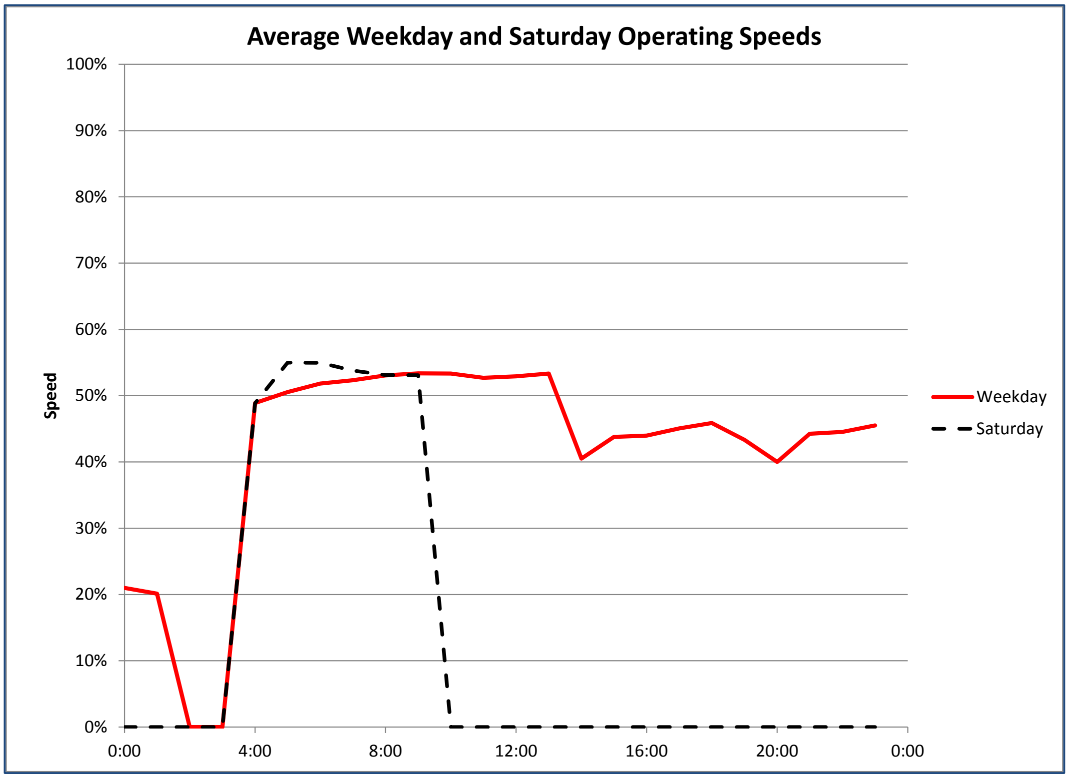

Figure 4: Load Shapes

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].

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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.

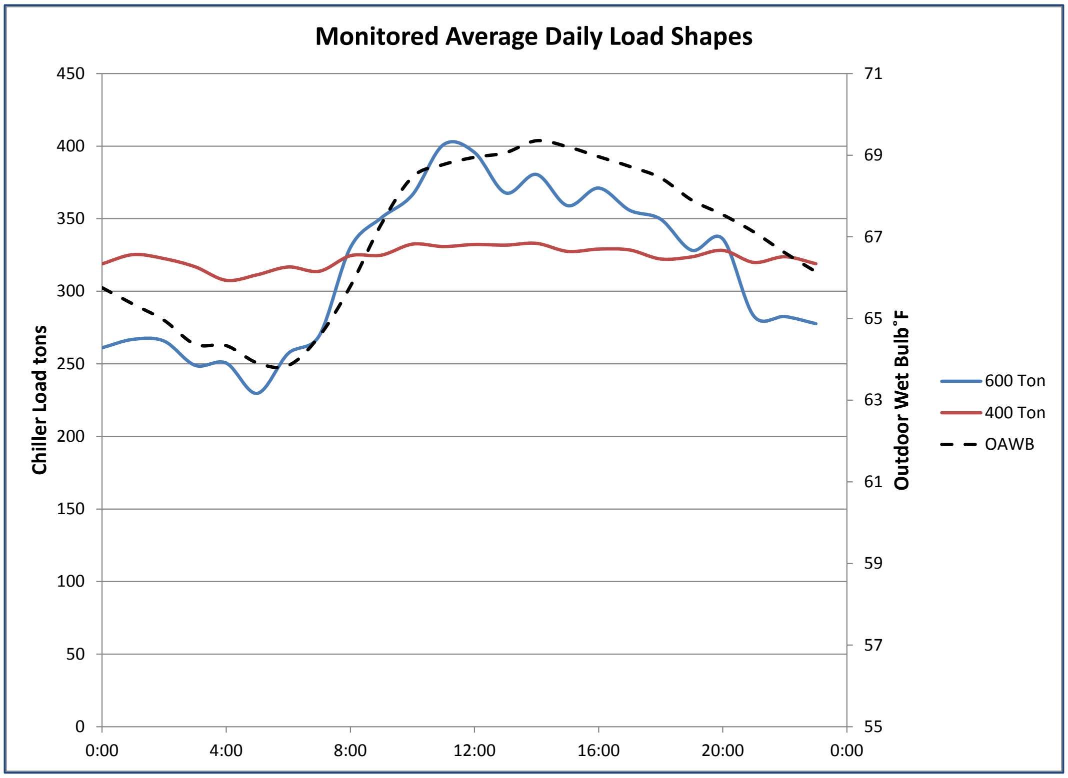

Figure 1: Monitored Chiller Load Shapes

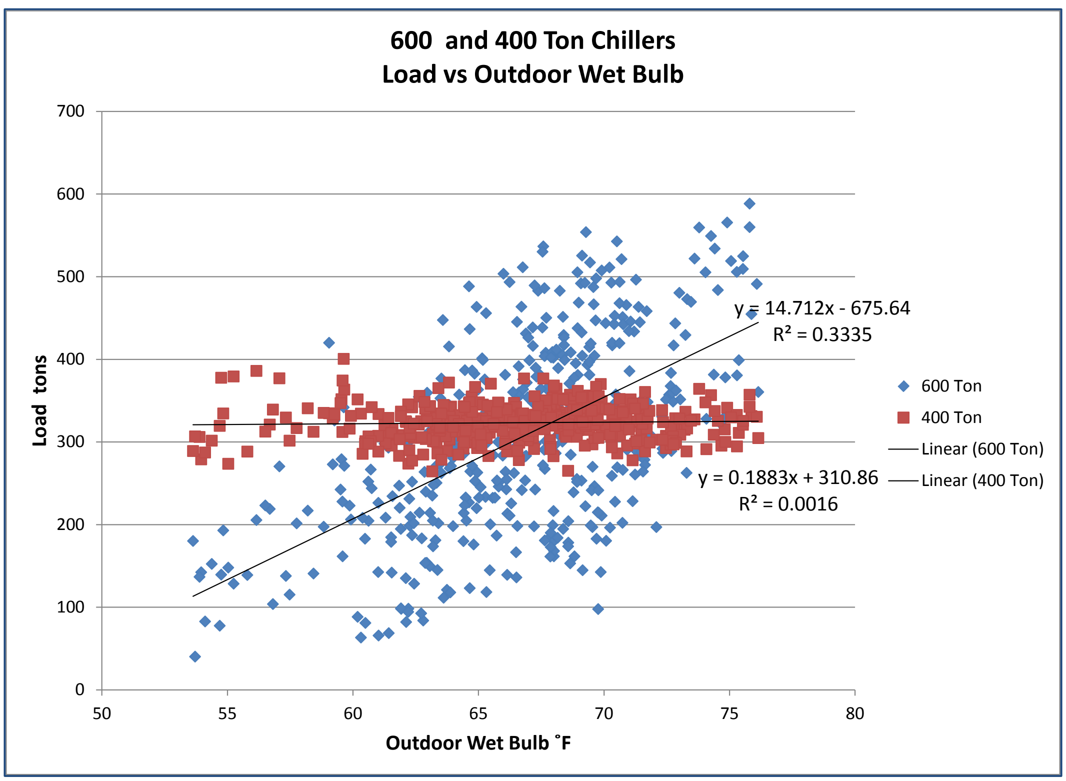

Figure 2: 400 and 600 Ton Chiller Loads vs Outdoor Wet Bulb.

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.

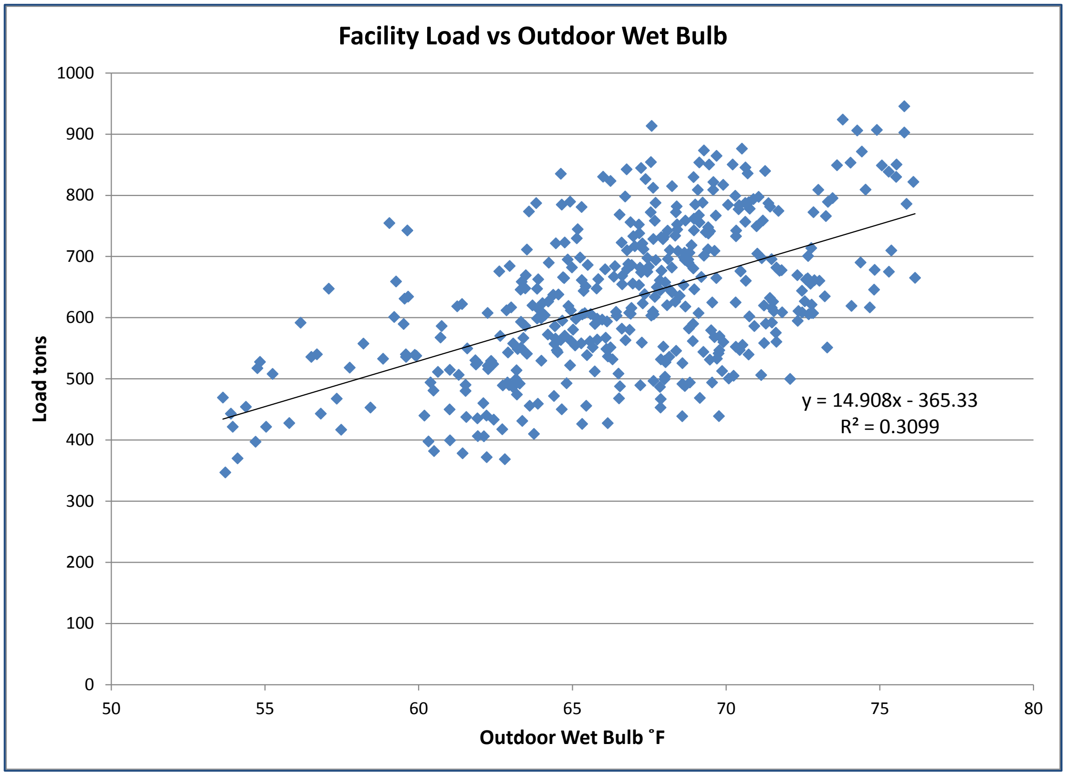

Figure 3: Total Monitored Load

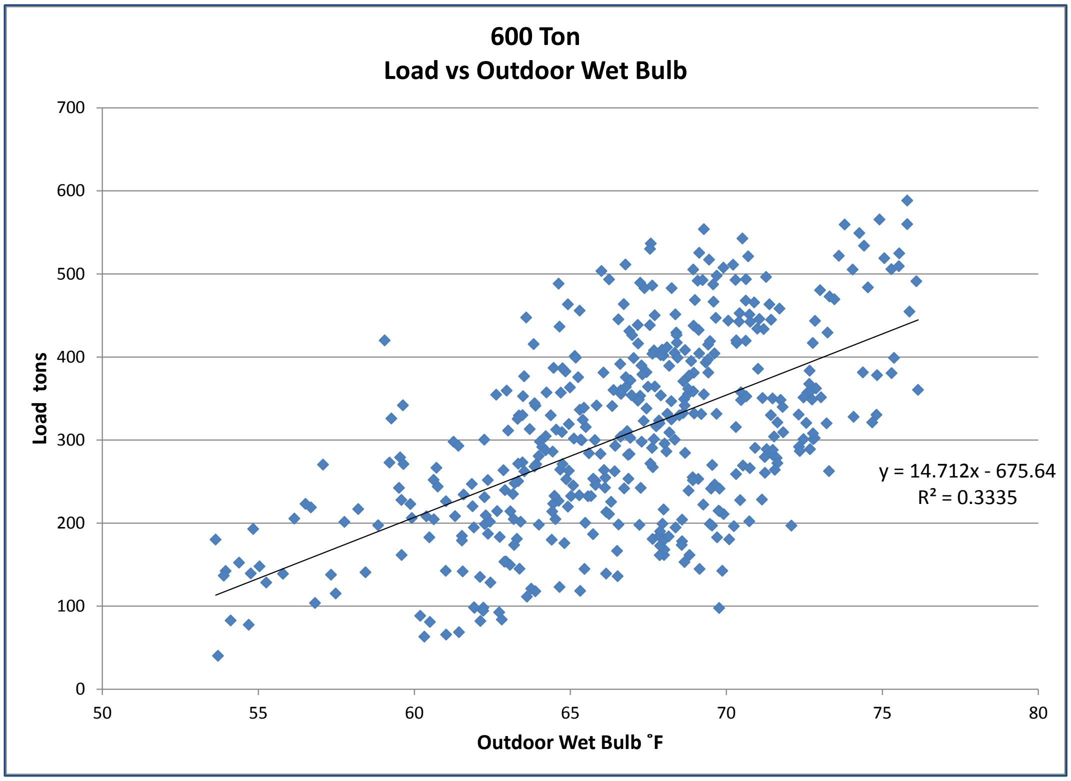

Figure 4: 600 Ton Chiller Observed Load vs Outdoor Wet Bulb

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

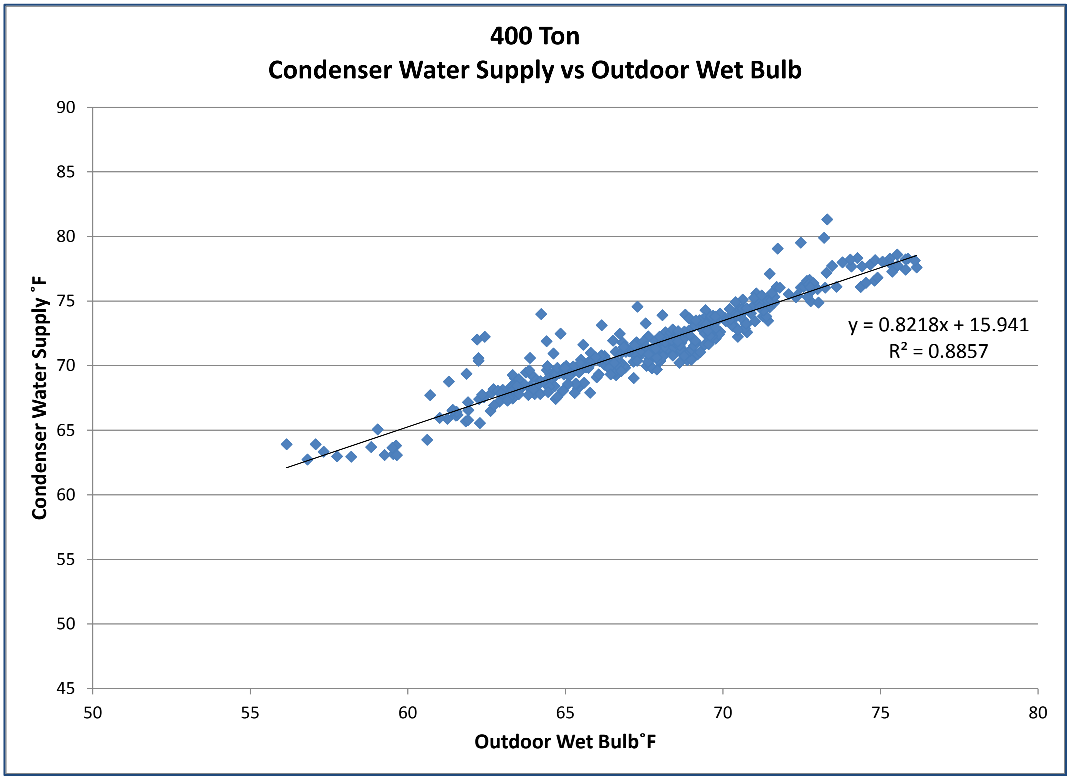

Figure 5: 400 Ton Observed Condenser Water Supply vs Outdoor Wet Bulb ˚F

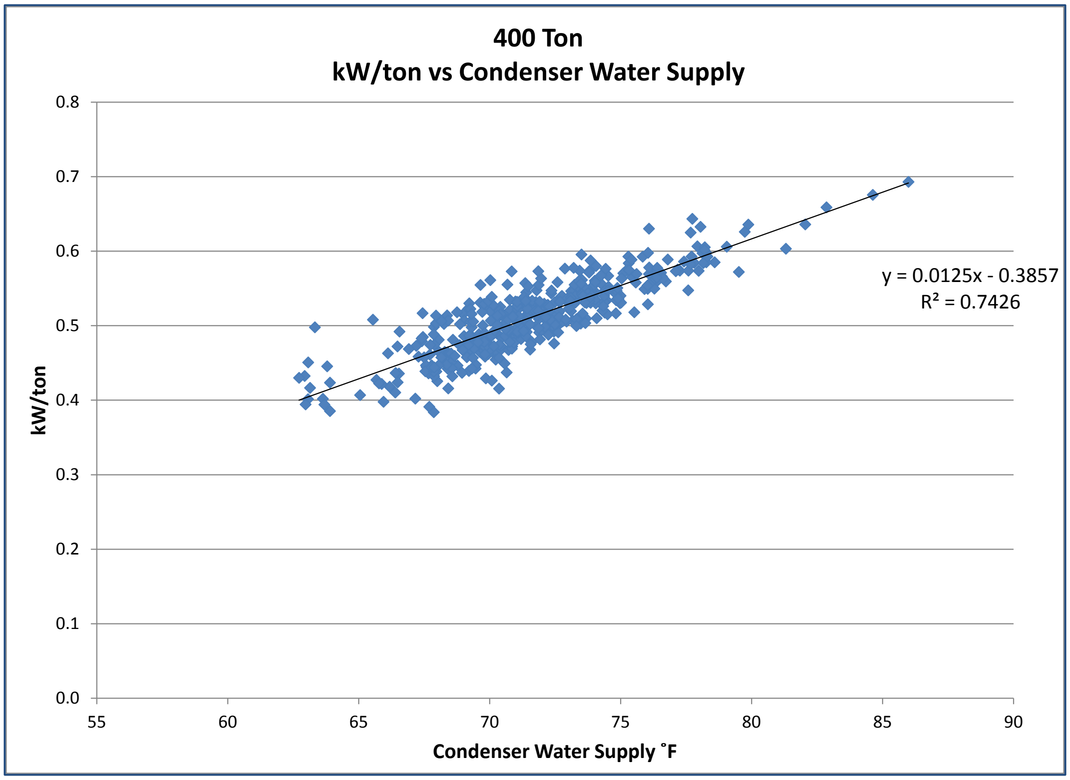

Figure 6: Observed 400 Ton Chiller kW/ton vs Condenser Water Supply ˚F

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 7. The adjusted chiller curve appears to be a close match for the actual measured data.

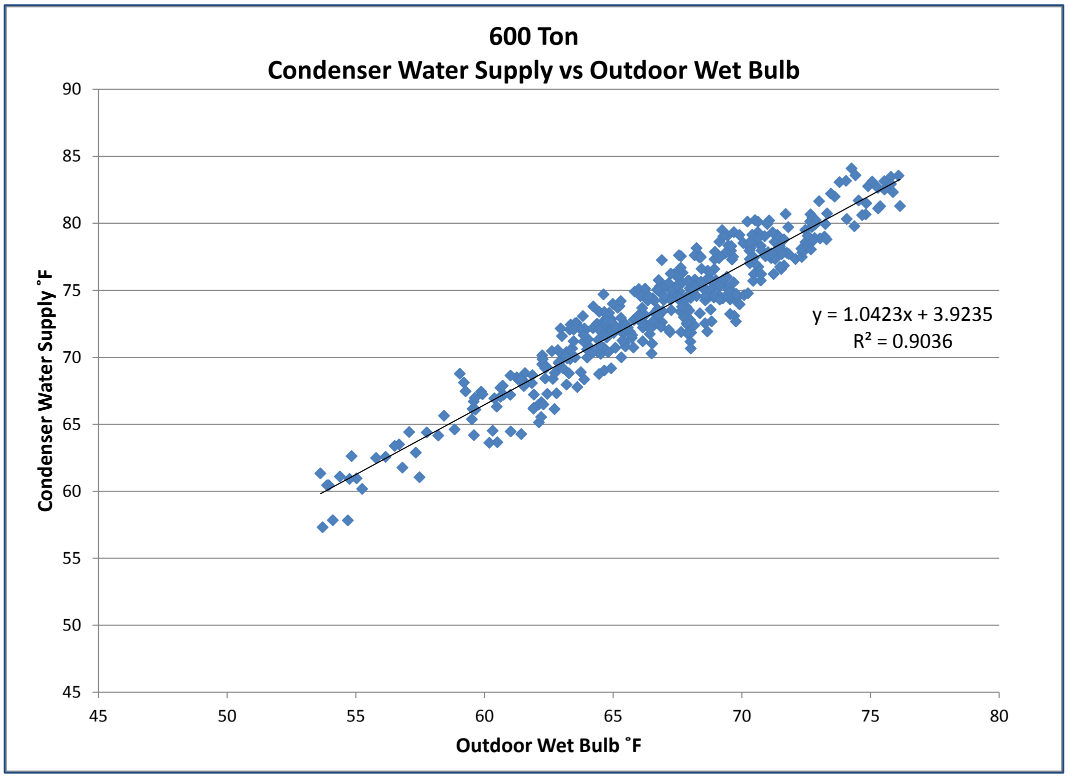

Figure 7: 600 Ton Observed Condenser Water Supply vs Outdoor Wet Bulb ˚F

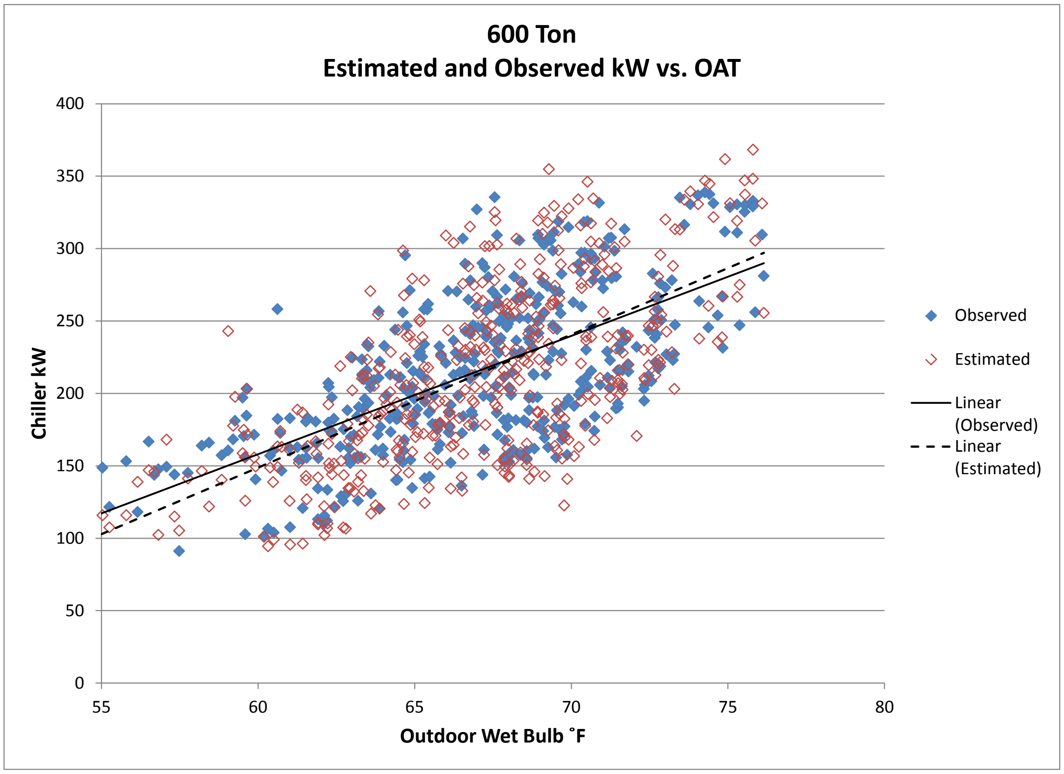

Figure 8: Estimated (DOE2 Chiller Curve Generated) and Observed Chiller kW vs OAT

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%

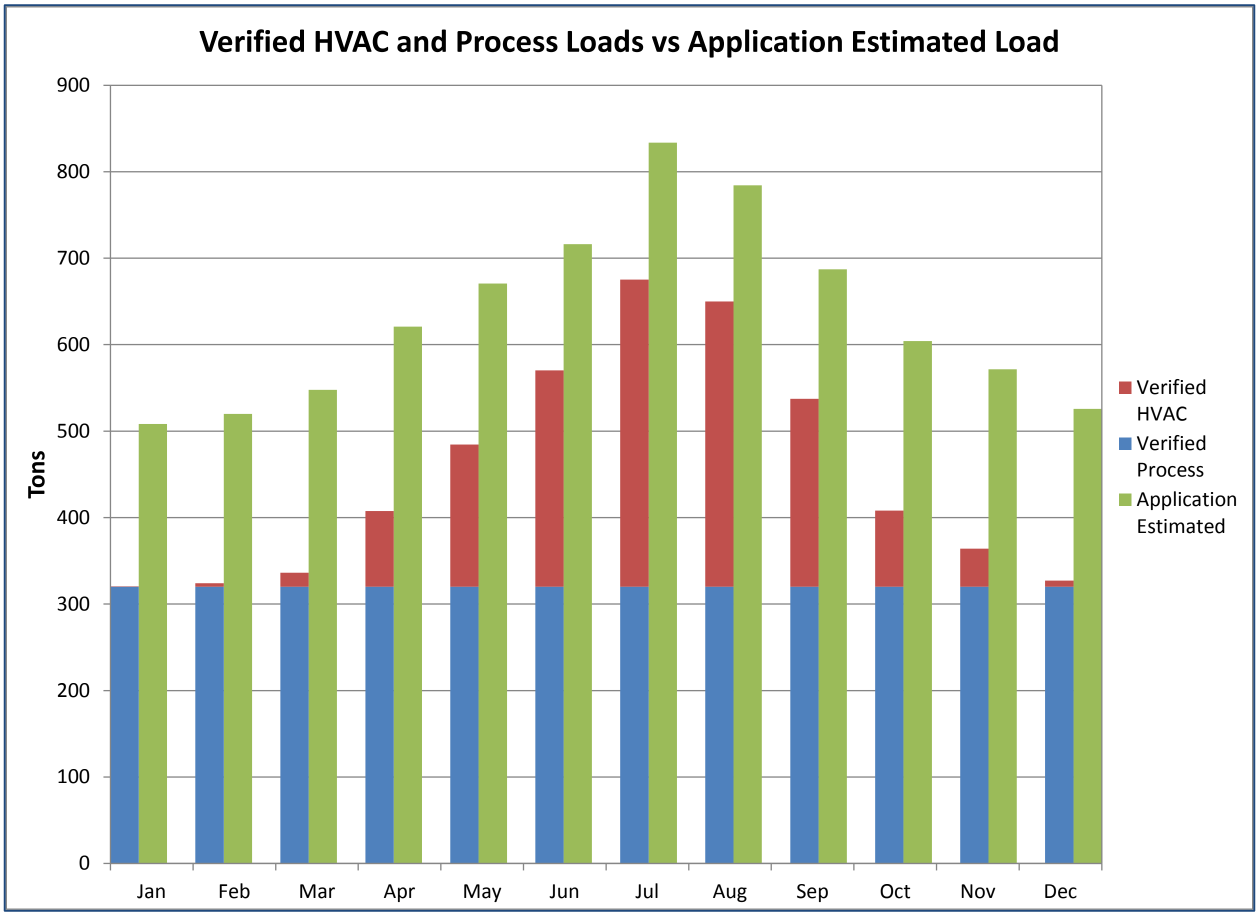

Figure 9: Average Verified vs Application Loads

[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

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80301

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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.

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

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

Where

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

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

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

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

NLogged = population of logged control points

NControlPoints = population of all control points

- Created separate schedules for weekdays and weekends using LF(t).
- Tabulated average operating hours by 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%

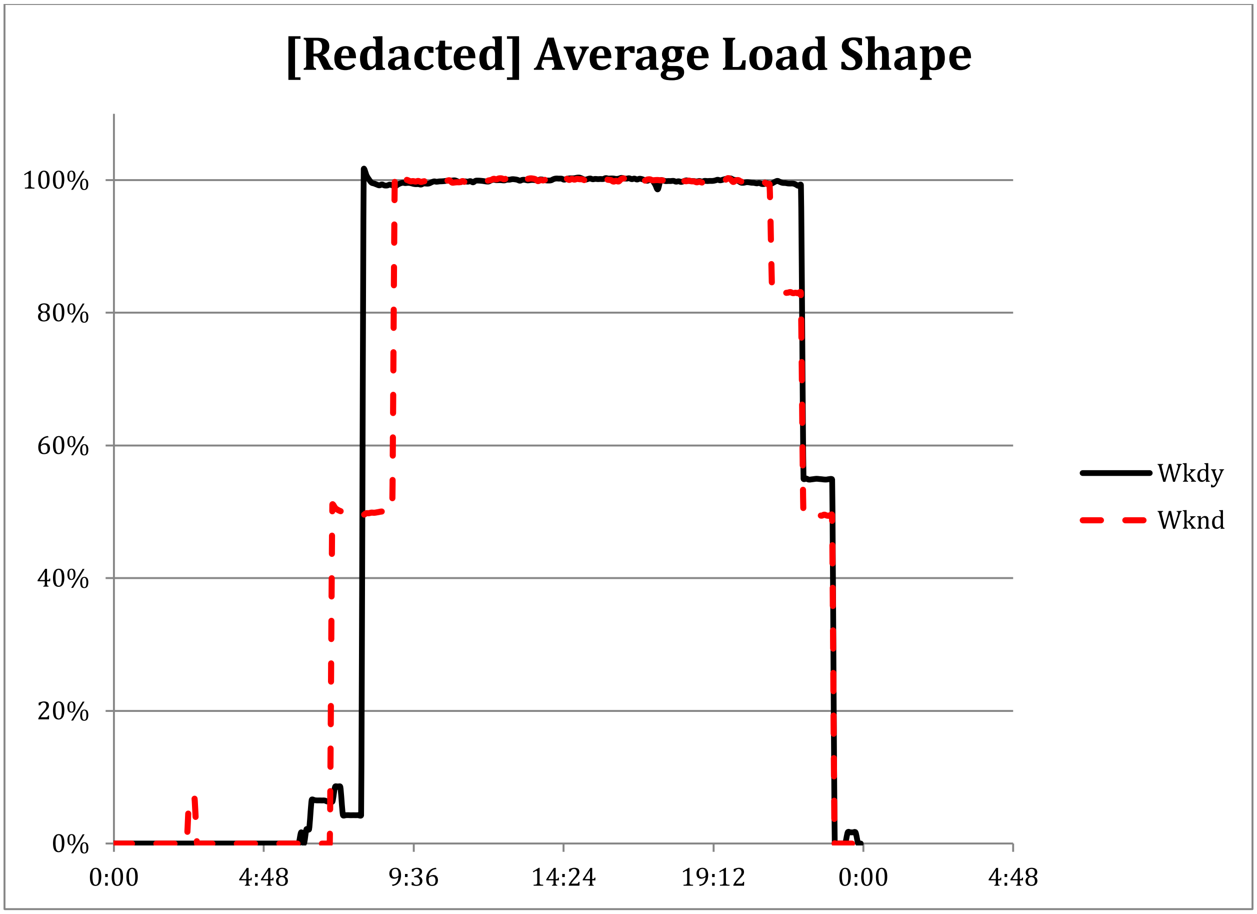
The savings presented in the application were 3 kW NCP demand savings and 13,104 kWh energy savings. These savings did not take into account interactive effects with the HVAC system. It appears that the demand savings of 3 kW in the application was rounded up from 2.5kW. The application does not calculate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

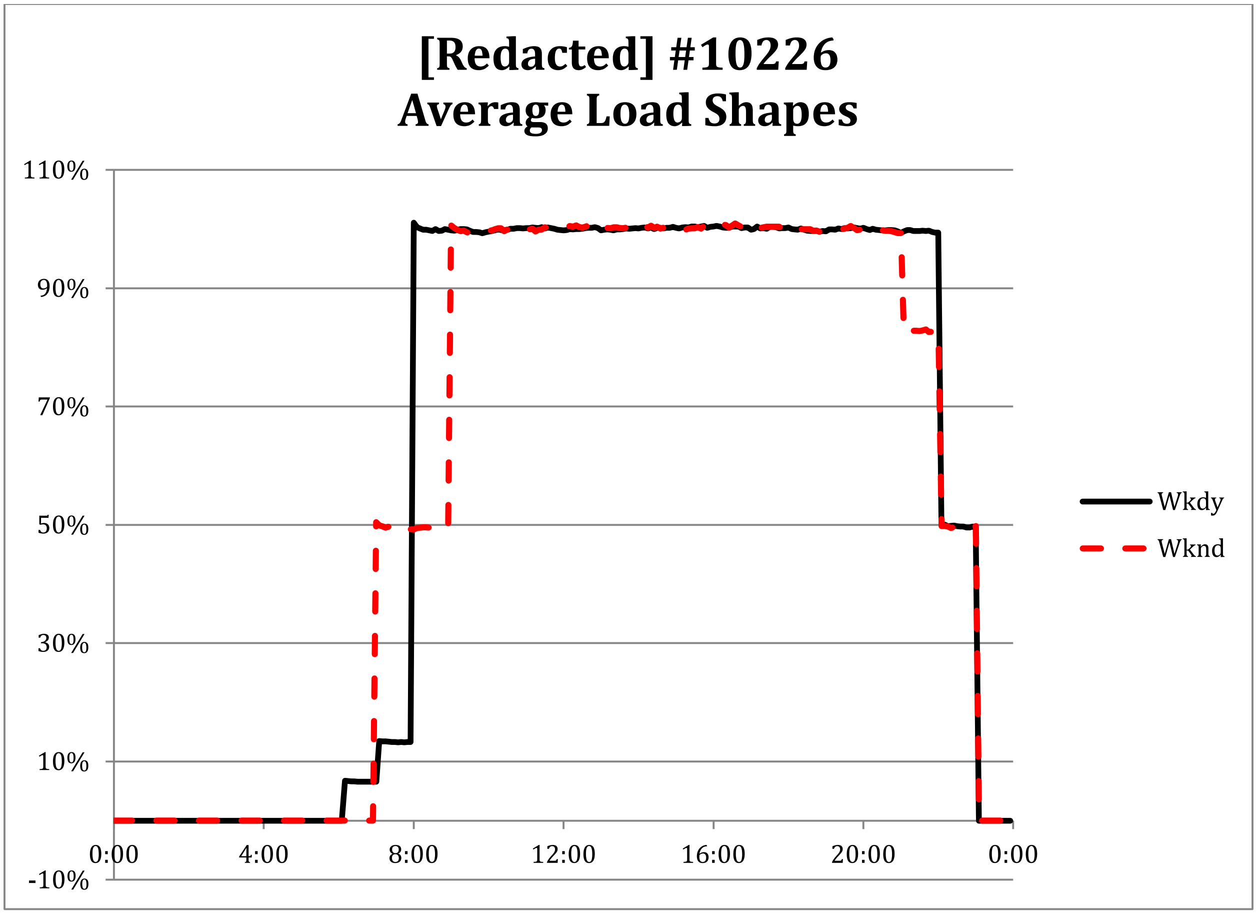
The following figure shows the average daily load shape. When extrapolated to the year, the annual operating hours are 5,297.2 which are two percent greater than the hours stated in the application, which contributes to a realization rate greater than 100 percent.

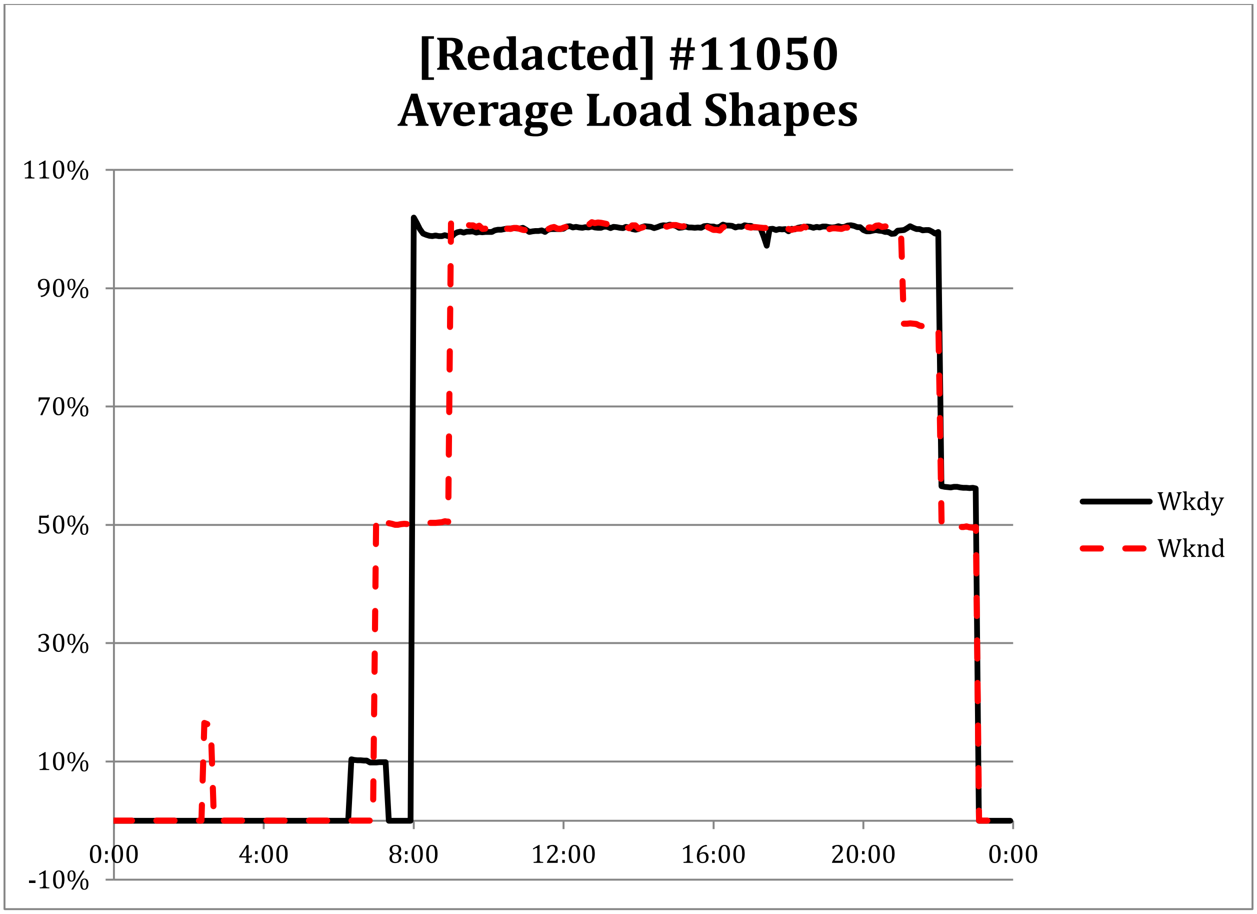


To calculate the total savings for the three [Redacted] stores we analyzed the savings at each location separately and used the sum of savings from the three locations as the realized savings. The reason that we ran three separate analyses is because the logging equipment was installed and removed on 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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Average Load Shapes
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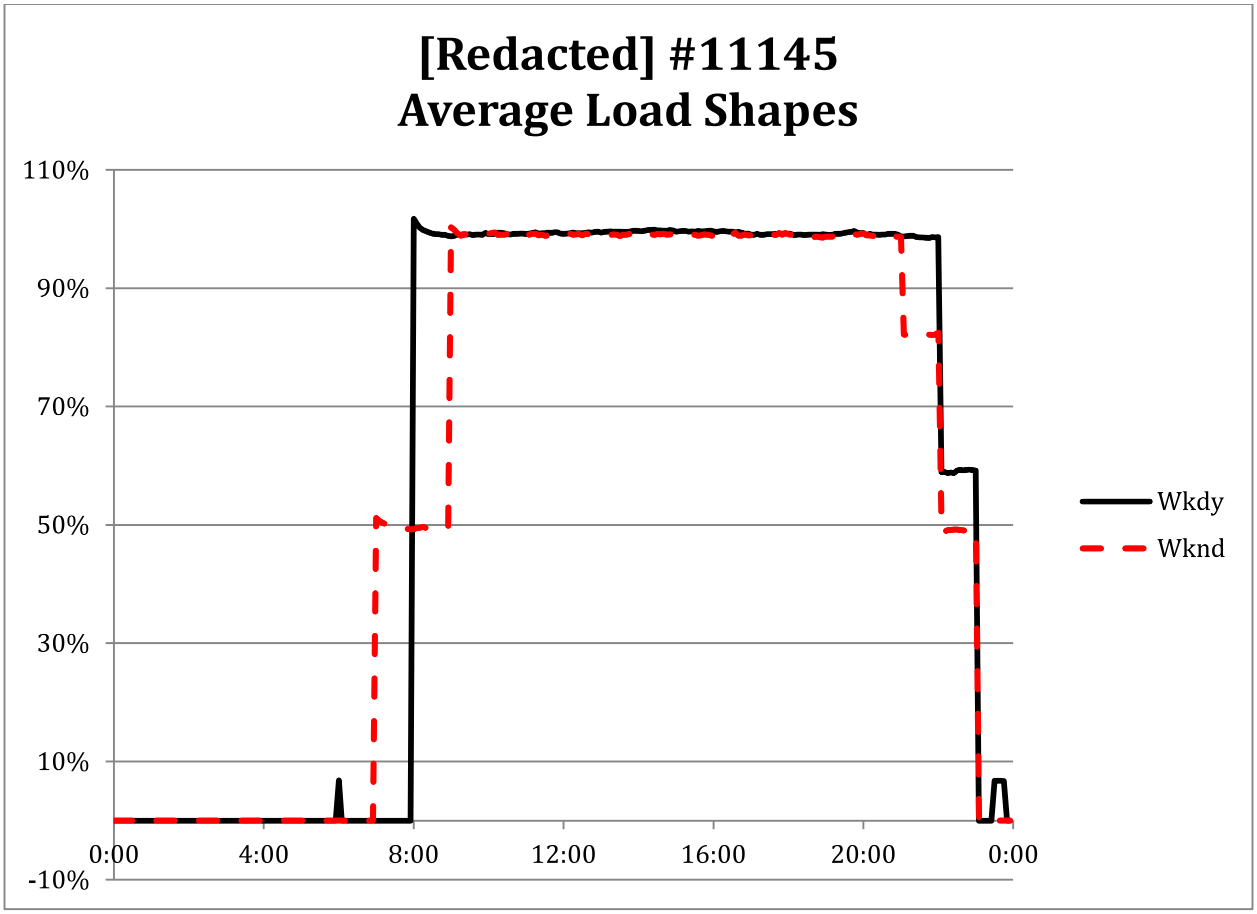
Wkdy
Wknd



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

[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].

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

[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).

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.

  - 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>.

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

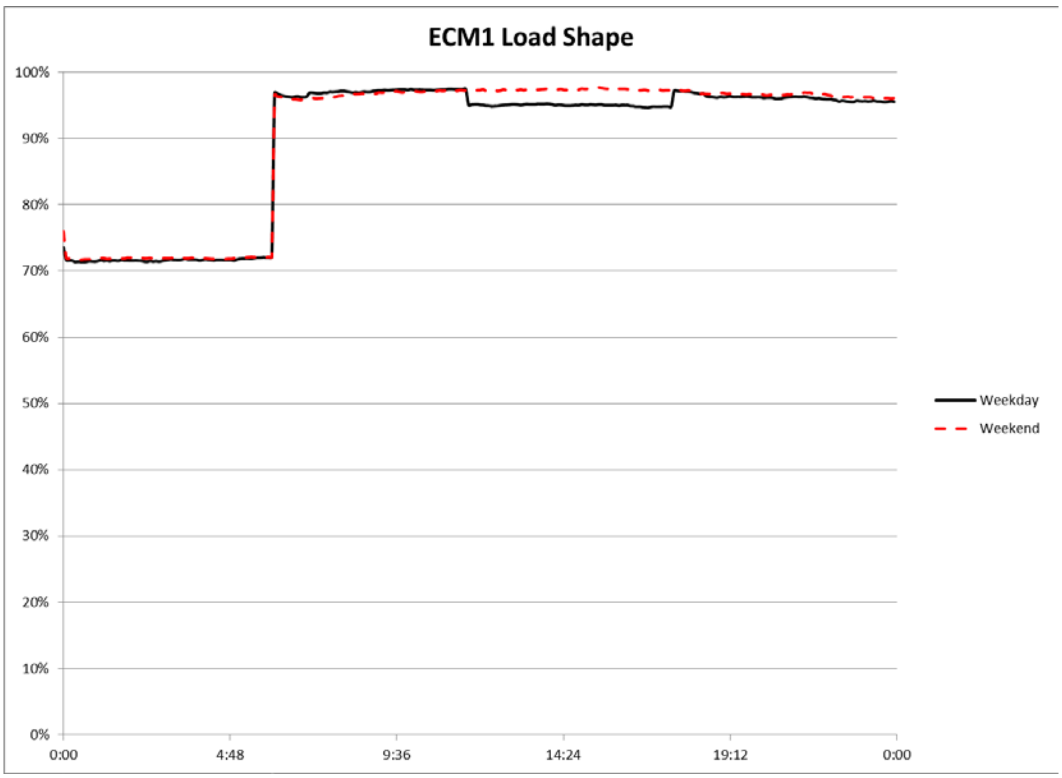
The following results account for the savings associated with the lighting retrofits for the 17 stores associated with the [Redacted] application.

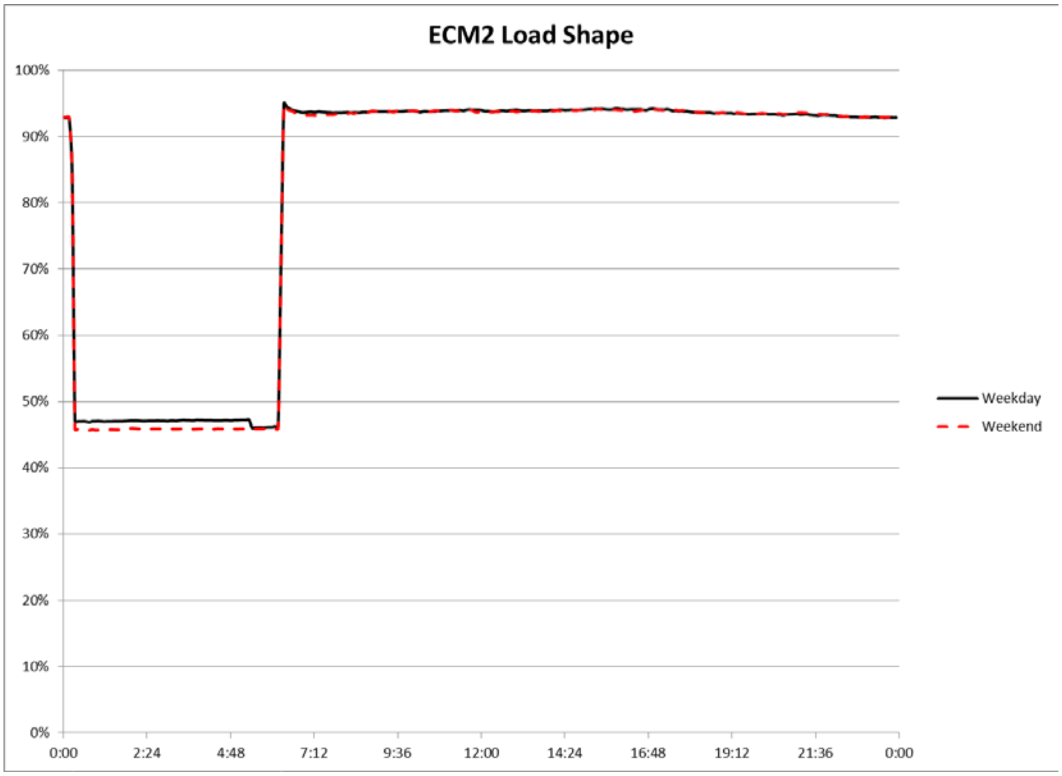
Table 1. Annual Energy Savings

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

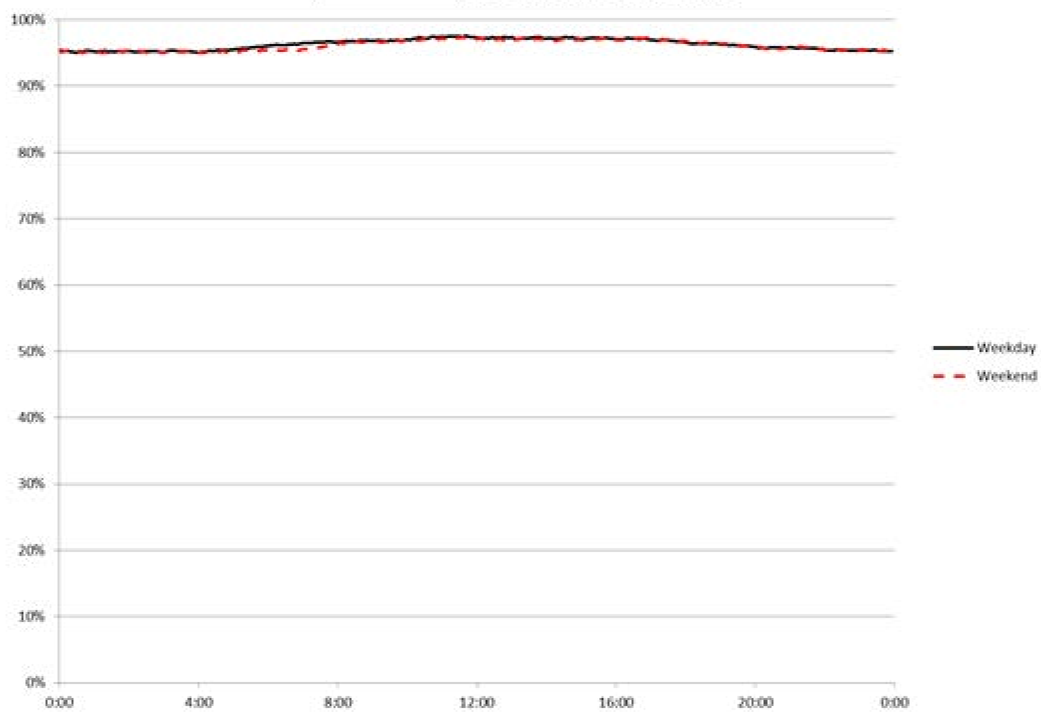
Energy (kWh)	130,021	70,434	99,312	54%	76%
Peak Demand (kW)	11.6	9.0	12.7	78%	109%
Coincident Demand (kW)	10.5	8.8	12.4	84%	118%

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.





[redacted] 353 & ECM3 Load Shape



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**

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.

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%

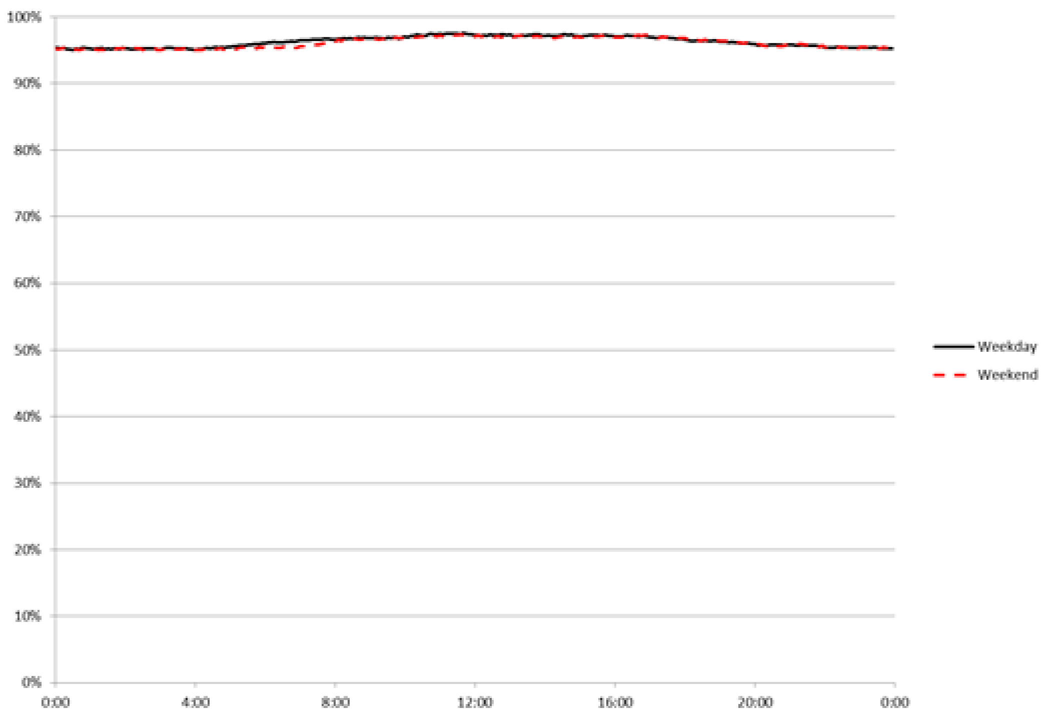
Notes:

- 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.

- 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.

- 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**

Store [Redacted]

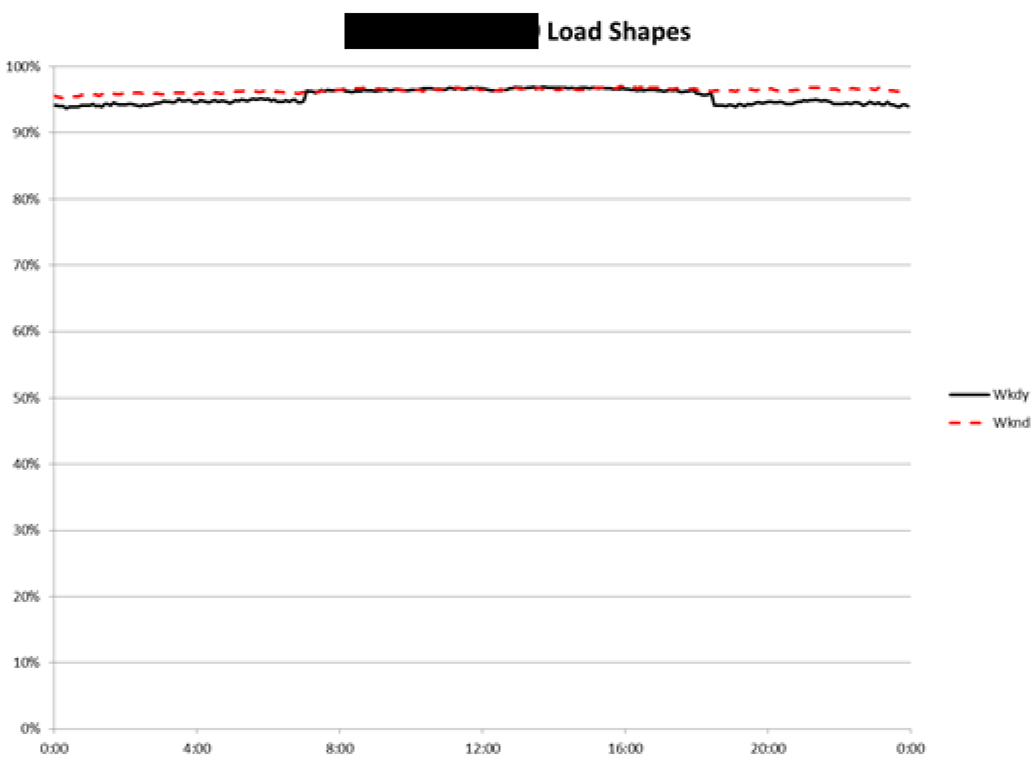
	Duke Reported Savings	Realized Savings		Realization Rate	
		Lighting Only	Lighting and HVAC	Lighting Only	Lighting and HVAC
kWh	2,551	2,281	3,217	89%	126%
kW	0	0.3	0.4	N/A	N/A

Notes:

- Application indicates:

- o 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**



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%

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]

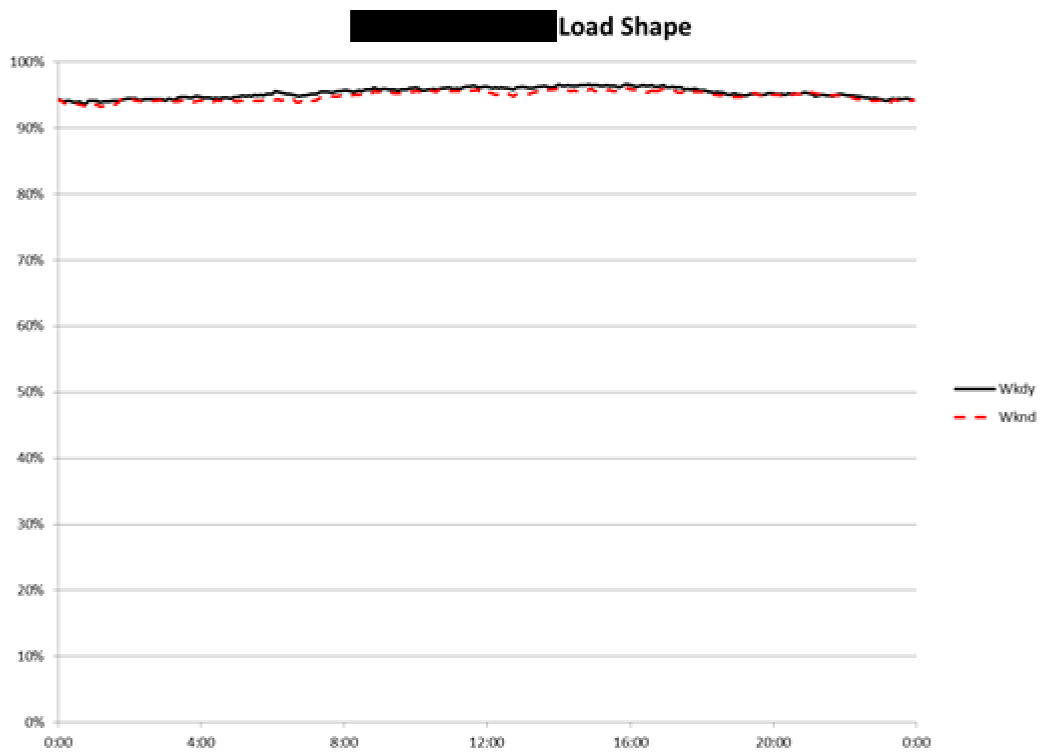
	Duke Reported Savings	Realized Savings		Realization Rate	
		Lighting Only	Lighting and HVAC	Lighting Only	Lighting and HVAC
kWh	4,176	5,603	7,901	134%	189%
kW	1	0.6	1	65%	92%

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.

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

	Lighting	HVAC	Total
Pre kW	2.00		
Post kW	1.35		
Demand Savings	0.65	0.27	**0.92**
Coincident Pk Demand Svgs	0.65	0.27	**0.91**



Store [Redacted]

	Duke Reported Savings	Realized Savings		Realization Rate	
		Lighting Only	Lighting and HVAC	Lighting Only	Lighting and HVAC
kWh	4,660	5,674	8,000	122%	172%
kW	1	0.7	0.9	66%	93%

Notes:

- Application indicates:
  - 14, 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 all 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.Only holiday is Christmas Eve from 6PM to 12PM assumed standard case operation during this time.

	Lighting	HVAC	Total
Pre kW	2.02		
Post kW	1.37		
Demand Savings	0.66	0.27	**0.93**
Coincident Pk Demand Svgs	0.65	0.27	**0.92**

Store [Redacted]

- The site visit tech was unable determine other equipment that shared the circuit with the retrofitted lighting. For this reason we did not use analyze data from this site.

Store [Redacted]

	Duke Reported Savings	Realized Savings		Realization Rate	
		Lighting Only	Lighting and HVAC	Lighting Only	Lighting and HVAC

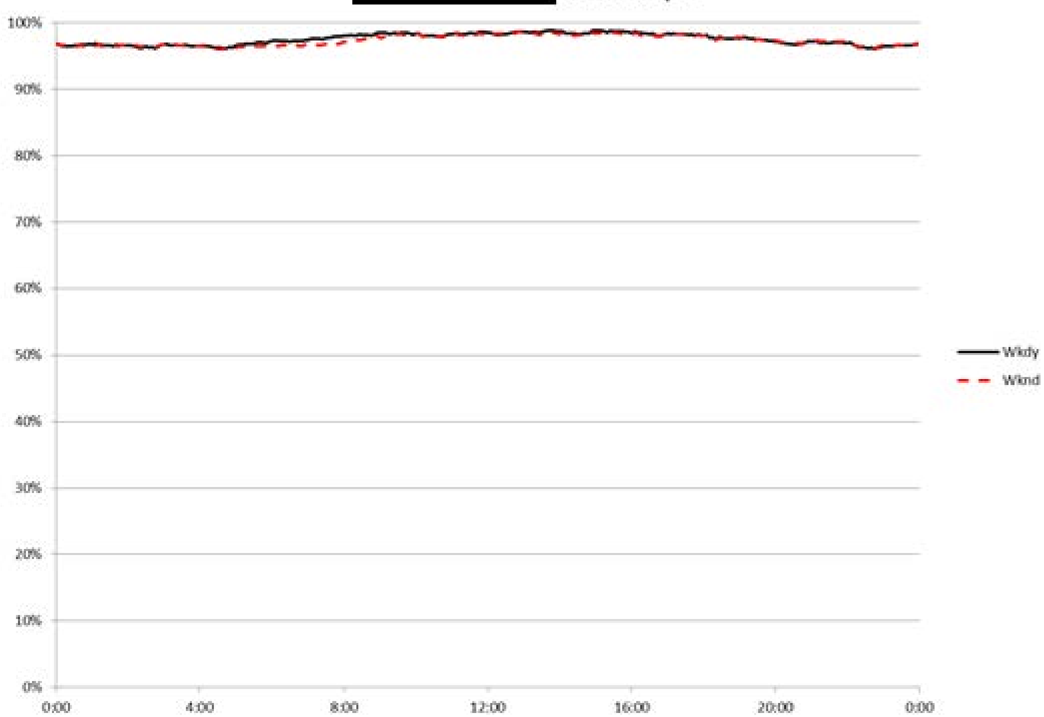
kWh	4,468	3,774	5,322	84%	119%
kW	1	0.4	0.6	44%	62%

Notes:

- Application indicates:
  - 15, 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 13 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 84W/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	1.52		
Post kW	1.08		
Demand Savings	0.44	0.18	**0.62**
Coincident Pk Demand Svgs	0.44	0.18	**0.62**

[redacted] **Load Shape**



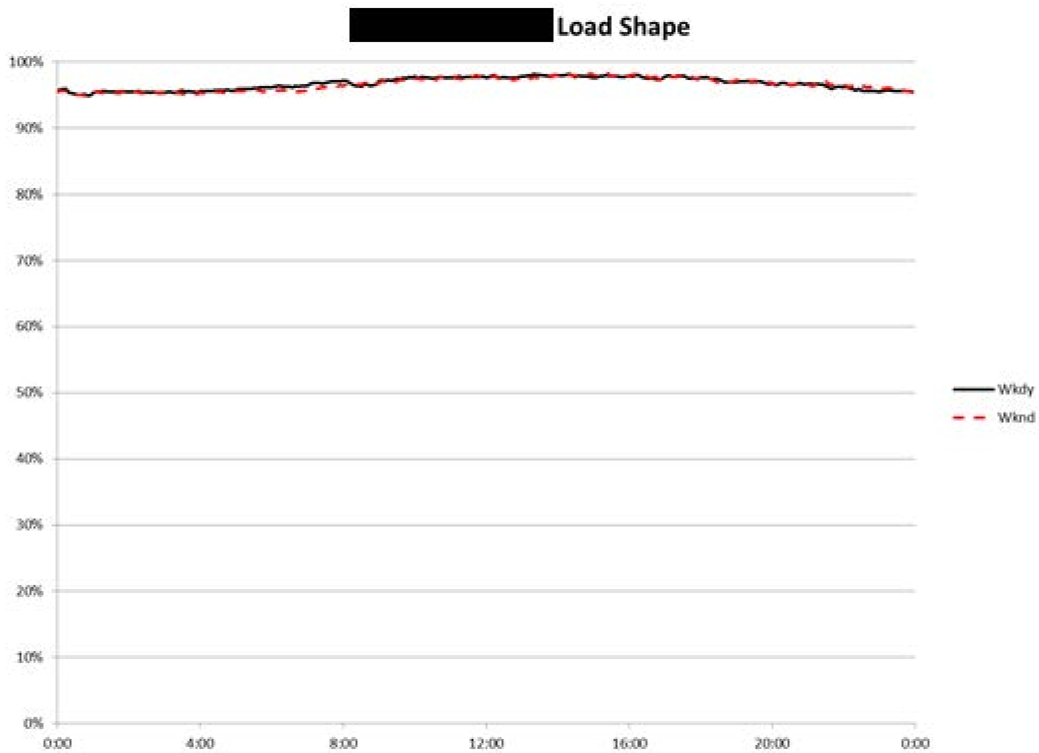
Store [Redacted]

	Duke Reported Savings	Realized Savings		Realization Rate	
		Lighting Only	Lighting and HVAC	Lighting Only	Lighting and HVAC
kWh	4,468	4,320	6,091	97%	136%
kW	1	0.5	0.7	50%	71%

Notes:

- Application indicates:
  - 15, 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 all 15 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 84W/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	1.74		
Post kW	1.24		
Demand Savings	0.50	0.21	**0.71**
Coincident Pk Demand Svgs	0.50	0.21	**0.71**



Remaining Store Analysis

ECM1

Table 2. Annual kWh Savings per Fixture for ECM1

	Days/ Year	Daily EFLH	Annual EFLH	Post		Pre		Savings
				Daily kWh/ fixture	Annual kWh/ fixture	Daily kWh/ fixture	Annual kWh/ fixture	Annual kWh Savings/ fixture
Sun	52	21.76	1131.78	1.83	95.07	2.57	133.55	38.48
Mon	52	21.81	1134.03	1.83	95.26	2.57	133.82	38.56
Tue	52	21.12	1098.13	1.77	92.24	2.49	129.58	37.34
Wed	52	21.73	1129.97	1.83	94.92	2.56	133.34	38.42
Thurs	52	21.66	1126.09	1.82	94.59	2.56	132.88	38.29
Fri	52	21.56	1121.06	1.81	94.17	2.54	132.29	38.12
Sat	52	21.72	1129.39	1.82	94.87	2.56	133.27	38.40
Holiday	1	21.76	21.76	1.83	1.83	2.57	2.57	0.74
Total	365		7892.2		662.9		931.3	**268.3**

Table 3. Annual kW Savings per Fixture for ECM1

	Lighting	HVAC	Total
Pre kW/fixture	0.12		
Post kW/fixture	0.08		

Demand Savings/fix	0.03	0.01	**0.05**
Coincident Pk Demand Svgs (kW)/fix	0.03	0.01	**0.05**

Table 4. Annual kWh and kWh savings for unmetered stores that implemented ECM1

Store	app fixtures	adjusted fixtures	ltg only svgs kWh	ltg and HVAC kWh	ltg only savings kW	ltg and HVAC svgs kW	coincident ltg only kW	coincident ltg and HVAC svgs kW
[Redacted]	13	12.17	3266.88	4606.30	0.41	0.57	0.39	0.56
[Redacted]	12	11.24	3015.58	4251.97	0.38	0.53	0.36	0.51
[Redacted]	13	12.17	3266.88	4606.30	0.41	0.57	0.39	0.56
[Redacted]	14	13.11	3518.17	4960.63	0.44	0.62	0.42	0.60

ECM2

Table 5. Annual kWh Savings per Fixture for ECM2

				Post		Pre		Savings
	Days/ Year	Daily EFLH	Annual EFLH	Daily kWh/ fixture	Annual kWh/ fixture	Daily kWh/ fixture	Annual kWh/ fixture	Annual kWh Savings/ fixture
Sun	52	20.04	1042.25	2.00	104.22	2.97	154.25	50.03
Mon	52	19.98	1039.21	2.00	103.92	2.96	153.80	49.88
Tue	52	20.11	1045.47	2.01	104.55	2.98	154.73	50.18
Wed	52	20.38	1059.95	2.04	105.99	3.02	156.87	50.88
Thurs	52	20.10	1045.27	2.01	104.53	2.97	154.70	50.17
Fri	52	20.09	1044.43	2.01	104.44	2.97	154.58	50.13
Sat	52	20.04	1041.96	2.00	104.20	2.97	154.21	50.01
Holiday	1	20.04	20.04	2.00	2.00	2.97	2.97	0.96
Total	**365**		**7338.6**		**733.9**		**1086.1**	**352.3**

Table 6. Annual kW Savings per Fixture for ECM

	Lighting	HVAC	Total
Pre kW/fixture	0.14		
Post kW/fixture	0.10		
Demand Savings/fix	0.05	0.02	**0.07**
Coincident Pk Demand Svgs (kW)/fix	0.05	0.02	**0.07**

Table 7. Annual kWh and kWh savings for unmetered stores that implemented ECM2

Store	app fixtures	adjusted fixtures	ltg only svgs kWh	ltg and HVAC kWh	ltg only savings kW	ltg and HVAC svgs kW	coinciden t ltg only kW	coinciden t ltg and HVAC svgs kW

[Redacted]	11.00	10.30	3628.75	5116.54	0.48	0.68	0.48	0.67
[Redacted]	12.00	11.24	3958.64	5581.68	0.53	0.74	0.52	0.73
[Redacted]	12.00	11.24	3958.64	5581.68	0.53	0.74	0.52	0.73
[Redacted]	14.00	13.11	4618.41	6511.96	0.62	0.87	0.61	0.85

[Redacted]
Replace Wrapper Sealers with Heat Seal 625-ES 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 the [Redacted].

Submitted by:

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NORESCO
United Technologies

Introduction

This plan addresses M&V activities for a combination of two Ohio custom program applications for the [Redacted]. The measure includes:

ECM-1 – Replace Wrapper Sealers with Heat Seal 625-ES

- Replace 137 existing wrapper-sealers with new, energy-efficient heat sealers in 30 stores in the Cincinnati, Ohio, area.

During periods when the sealer is not actively being used, the heat sealer does not energize the seal plate. The film cut-off rod in the sealer remains energized at 100 W, although this usage may cycle on and off. Only when the sealer is activated, approximately 1900 W is drawn for a few seconds.

The original wrapper-sealers that the new heat sealers replaced reportedly drew 400 W continuously.

Areas where heat sealers are used vary by store and can include the meat, deli and bakery and other departments.

The energy usage of a heat sealer may depend on the ambient temperature of the space in which it is located.

Note: The new sealers have already been implemented. Only post-replacement measurements were taken, with the exception of one old sealer that was still operating and available to monitor.

Goals and Objectives

The projected savings goals identified in the application are:

Duke Applicn. #	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)
Duke-1001	31,536	3.6	31,538	3.6	3.6
13-1447139	--	--	328,522	37.5	37.5
Total	--	--	360,060	41.1	41.1

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

- Verify installed sealer information
- Verify store operating hours and sealer operating hours (if controlled)
- Obtain information about the building HVAC system
- Verify annual gross electric energy (kWh) savings
- Verify summer coincident peak demand (kW) savings
- Determine energy, demand and coincident demand Realization Rates.

Project Contacts

Duke Energy M&V Coordinator	Frankie Diersing	513-287-4096	Frankie.diersing@duke-energy.com
Customer Contact	[Redacted]	[Redacted]	[Redacted]
AEC Contact	Doug Dougherty	303-459-7416	ddougherty@archenergy.com

Site Locations/ECM's

To provide a statistical sample of the new heat sealers, 19 sealers in seven stores were monitored.

Store No.	Address	Application ID	No. of Heat Sealers
[Redacted]	[Redacted]	[Redacted]	2
[Redacted]	[Redacted]	[Redacted]	3
[Redacted]	[Redacted]	[Redacted]	4
[Redacted]	[Redacted]	[Redacted]	3
[Redacted]	[Redacted]	[Redacted]	4
[Redacted]	[Redacted]	[Redacted]	1
[Redacted]	[Redacted]	[Redacted]	2

In addition, one original wrapper-sealer was monitored.

Store No.	Address	Application ID	No. of Heat Sealers
[Redacted]	[Redacted]	[Redacted]	1

Data Products and Project Output

- Post-replacement survey of heat sealers.
- Average post-replacement heat sealer load shapes.
- Energy usage by day type (weekday/weekend).
- Annual peak demand savings.
- Summer utility coincident peak demand savings.

M&V Option

IPMVP Option A

M&V Implementation Schedule

- Post-replacement data was collected for a thorough evaluation.
- Survey data was collected during normal operating hours.

Field Data Points

Post – installation only.

Contacted Customer via Phone

- Indicated to the customer that there are three parts to the M&V process (details below):
  - Customer Interview
  - Field Survey
  - Logger Deployment
- Customer Interview was conducted via phone with further contact on-site.
- Agreed on a date and time to visit the store and install loggers.

Field Survey - For each site:

- Prior to installing loggers, a pre-install visit to three stores was conducted to verify the following:
  - To confirm that the heat sealers are on individual circuits. The logging approach requires that each heat sealer be monitored separately. This would have been best accomplished if the heat sealers are on separate breakers, however, this was found not to be the case for most sealers.
  - Heat sealers that were not on separate breakers had to be monitored at the plug level. Determined the receptacle and plug type used for the heat sealers. Photographed and recorded the receptacle and plug types.

Installation and survey:

- Verified whether the old sealer-wrappers are no longer on site or are out of service. This was usually true with just one exception.
- Identified all the new heat sealers installed. Although invoices were provided in the application documents for all sealers listed in the application, which indicates that they were purchased, the quantities found at the samples stores varied from the quantities listed in the application, due most likely to redistribution between stores. A number of new sealers were present at the stores but had not been placed in operation yet. All old sealers had been retired in stores where the new sealers had not yet been placed in operation.
- Recorded the location of each heat sealer (i.e., Meat Dept., Deli, Bakery, etc.)
- Recorded the approximate temperature in the area, i.e., normal room temperature, overheated, refrigerated, etc.

Field Data Logging

A total of four ElitePro data loggers, each paired with a 20-amp current transducer, were available for this effort. Since a sample size of 17 sealers was to be monitored (see Results section for more discussion), the four loggers were moved from store to store for three weeks at a time over a period of four and a half months in order to capture the necessary data.

<u>Elite Pro loggers</u>

- Installed one energy measurement logger for each heat sealer to measure average voltage, current, power, and power factor readings.
- Used the portable power meter to spot measure the load connected to the circuit by measuring the voltage, current draw, power, and power factor of the circuit. Recorded the readings. Due to the difficulty of capturing the peak power with the portable power

meter because of the short duration of the heat sealer load, only the idling power was recorded.

- Recorded the data logger voltage, current, power, and power factor readings in addition to the measurements from the portable power meter.
- Set up loggers for 5 minute average readings and allowed loggers to operate for a minimum period of three weeks.

Data Accuracy

Measurement	Sensor	Accuracy
Energy (W-hr)	Dent ElitePro	+/-1 W
Current	ACCU CT 20A	+/-1% from 1-120% of rating

Data Analysis

- Created a calculation template for estimating post-replacement demand and energy consumption that incorporates the methodology described below.
- The monitored data recorded the actual post-replacement heat sealer power draw in five-minute intervals.
- Monitored power was processed to calculate the energy consumption (Watt-hours) per interval and per day.
- Tabulated average operating energy by day type (weekdays and weekends) to determine the average power level for a typical week.
- Determined the percent-on time for each sealer. The sealers fall into to two broad groups, those that operate continuously and those that are turned off at night.
- Extrapolated annual operating energy from the average weekly power level.
- Plotted the load shapes of sealer energy usage vs. day type.
- Estimated the pre-replacement sealers' annual energy usage based on the average percent-on time for sealers that are on-at-night and those that are turned off-at-night. Reviewed data and existing heat sealer reports to determine if 400 W, as specified in the application documents, should be used as the average power requirement of the pre-replacement sealers. Determined that a revised value was more realistic and calculated pre-replacement energy usage and pre-replacement energy savings based on the revised value (see Results section).
- Calculated energy and demand savings:

$$kWh_{savings} = (N_{Sealers} * kWh_{Sealer}\ per\ year)_{PRE} - (N_{Sealers} * kWh_{Sealer}\ per\ year)_{Post}$$

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

$$CP\ kW_{savings} = NCP\ kW_{savings}\ during\ Coincident\ Peak\ Hour$$

Where:

$N_{Sealers}$	= number of sealers installed or replaced
kWh_{Sealer} per year	= total average energy used by one sealer in a year
kW_{Sealer}	= average maximum 15-minute load per sealer while energized
Hours	= equivalent full load hours per sealer
NCP $kW_{savings}$	= non-coincident peak savings
CP $kW_{savings}$	= coincident peak savings

- Compared the savings calculated above to Duke Energy's projected savings and calculated energy and demand savings realization rates.

Verification and Quality Control

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

Recording and Data Exchange Format

1. Logger data files
2. Excel spreadsheets

Results

The ECM of this project replaced older-model wrapper-sealers with new models. According to the application documents, the old models drew 400 W of power continuously, but new models draw only 100 W when not sealing and 2000 to 2200 W in short bursts only when sealing. Since the high-energy bursts occur infrequently, the energy saving were estimated to be about 300 W nearly continuously, or about 2,628 kWh per year per sealer replaced.

Duke received two applications for [Redacted] in Ohio, the first having a small pilot study of twelve sealers at five stores (a.k.a. Phase 1), and the second having a larger quantity of 125 sealers at 25 stores (a.k.a. Phase 2). These two applications were combined for the purposes of this M&V effort, for a total of 137 sealers in the population. Total energy savings would be 360,036 kWh per year with demand savings of 41.1 kW.

In order to characterize the savings of 137 new sealers, we determined that a sample of at least two sealers from Phase 1 plus at least 15 sealers from Phase 2, for a minimum total of 17 sealers, should be monitored. The stores identified in the applications listed two to seven sealers at each store. We randomly selected one store in Phase 1 with three sealers, plus three stores in Phase 2 with a total of 15 sealers, to meet this required sample size.

Monitoring Challenges

A pre-installation visit was made to the three Phase 2 stores to determine the feasibility of monitoring individual sealers. The issues identified in these visits included:

- Sealers are often not on dedicated circuits.
- There is often insufficient space inside breaker panels to install loggers.
- Not all of the expected quantities of sealers were present at the stores, and some new sealers were not in service yet.

The first two items above meant that we would need to monitor individual sealers at the plug level. Complicating the ability to do this were these additional factors:

- Due to their approximate 2 kW intermittent load, the sealers are supplied with NEMA 5-20 plugs and must be provided with a 20-amp circuit.
- Some new sealers were in potentially damp environments (such as produce storage).

After investigating existing plug-in-type data loggers, we found that none would accommodate the NEMA 5-20 plug. We therefore constructed an enclosure to contain a Dent ElitePro data logger. The enclosure consists of a NEMA 4 box to protect the logger from moisture, and includes a NEMA 5-20 receptacle on one end and a short cord with a NEMA 5-20 plug on the other end. All the voltage and current monitoring connections are made to pass-through wiring within the box. In the field, the existing sealer is simply unplugged from its receptacle in the store and plugged into the logger enclosure, then the logger enclosure is plugged into the receptacle. To save time in the field, the logger can be pre-launched before arriving at the store.

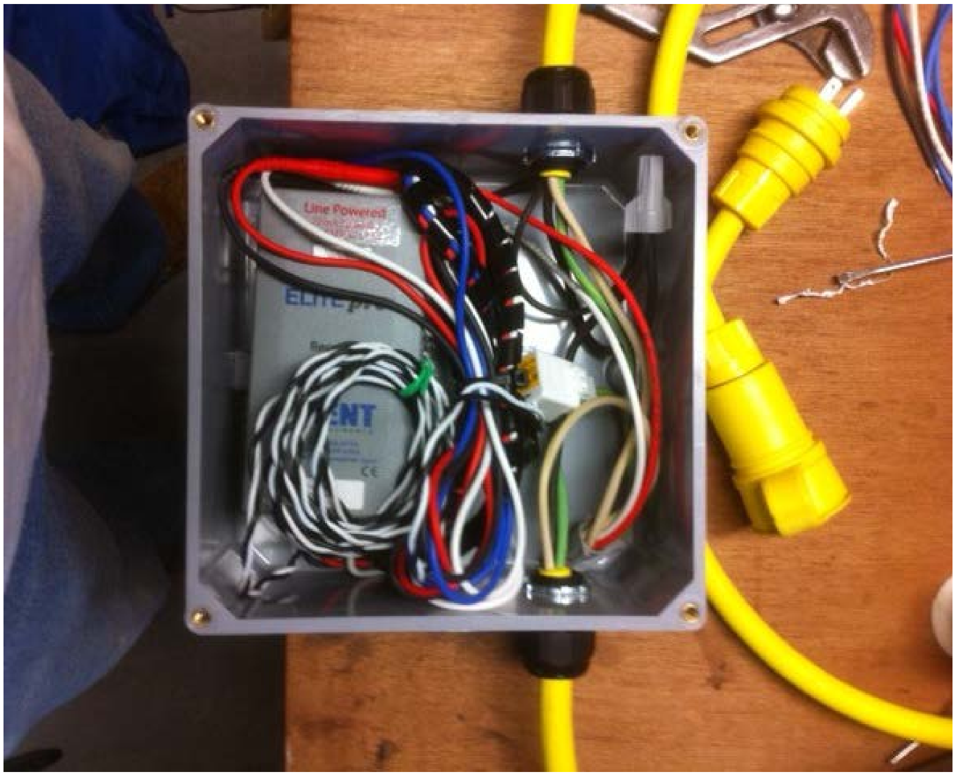


Figure 1: Photo of logger enclosure

Monitoring all the sealers at once would have meant constructing 18 logger enclosures and would have tied up a lot of data loggers. Therefore, the decision was made to construct four enclosures and rotate them through a new store every three weeks. The total time for data collection was four and a half months.

As previously mentioned, the pre-installation store visits revealed that not all of the expected quantities of sealers were present at the stores, and some new sealers were not in service yet. This finding meant that we would have to install data loggers at additional stores in order to reach our target quantity of 18 sealers to monitor.

The logged data initially consisted of average volts, average amps, and average kilowatts over five-minute intervals. After monitoring the first store, we realized that recording average amps was not sufficient to determine the actual power required during the sealing operation. Although the act of sealing a package lasts only a few seconds, product literature describes the sealers drawing 2000 to 2200 W at that time. Also, the product literature describes the sealers drawing about 100 W (about 0.83 amps) when the equipment is not actively sealing. However, the measured average amps over the five-minute intervals seemed to be too low (typically 0.36 – 0.40 amps) to confirm that value. Subsequently, we started adding the maximum and minimum amps observed in each five-minute interval to the logged data.

Data Sample – [Redacted]-Seafood

Data is presented in Figures Figure 2 through Figure 7 for a typical sealer. Figure 2 below shows the average logged power drawn by the sealer over five-minute intervals. Note that this sealer is always on, and has a baseline load of about 43 W.

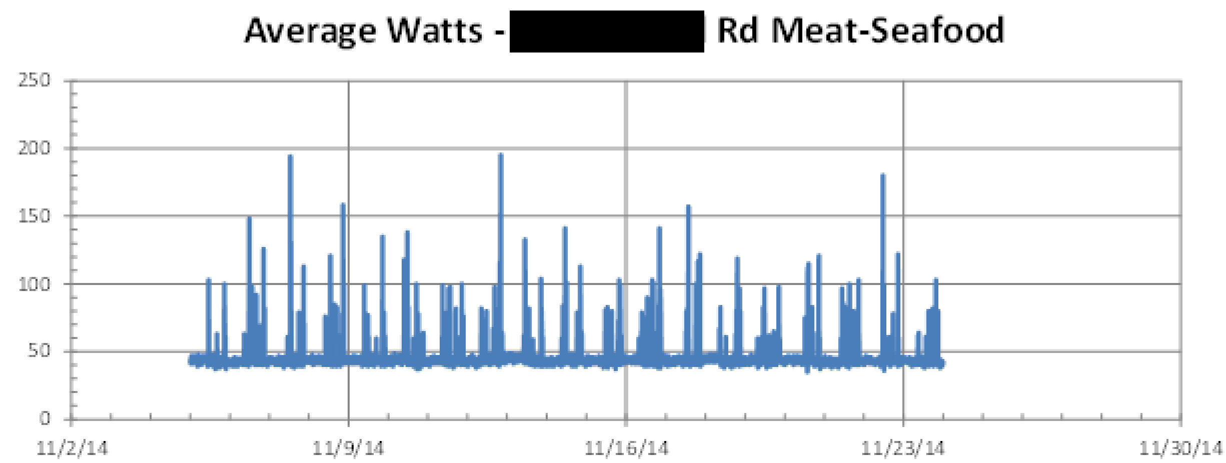


Figure 2: Average Watts Recorded over 5-minute Intervals

Figure 3 consolidates the five-minute power data into 15-minute averages, which are more appropriate for demand reporting. Note that the 15-minute peak values are always significantly lower than the five-minute values as far as the peaks are concerned (although the 43 W baseline value remains the same). The maximum demand in any five-minute period for this sealer was 195 W; however, the maximum demand in any 15-minute period for this sealer was 125 W.

For Ohio in 2014, the coincident peak demand hour is on July 17, for the hour between 4-5 PM. Monitoring was not in progress on that date for this project; therefore, for each sealer, the available monitored data was used to determine the peak power expended during the 4-5 PM time period on any weekday. For this sealer, the coincident peak power thus determined was 63.3 W.

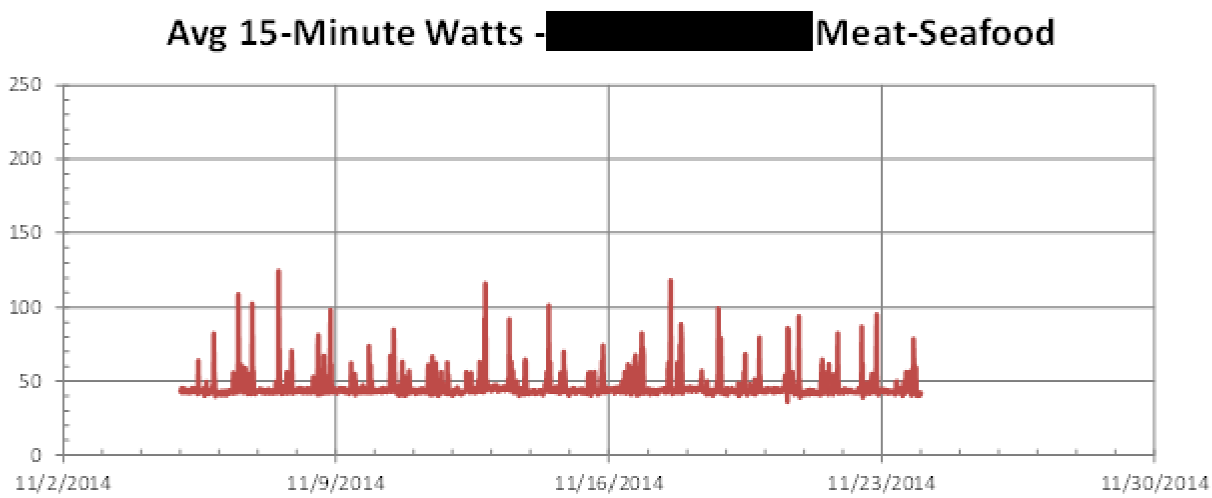


Figure 3: Average Watts over 15-minute Intervals

Average current and maximum current are shown in Figure 4 and Figure 5 below. Although the average current is never more than 1.71 amps in any five-minute interval, the maximum amps is typically 16 to 18 amps, averaging 16.9 amps for this particular sealer, indicating that the sealer was used at least once during the interval when this high current occurs. Based on the corresponding logged voltage and power factor (1.0), the corresponding power is about 1980 W.

When the sealer is on but not used ("idling"), the maximum current is about 0.85 amps; however, the average current is only 0.37 amps. The minimum amps, which was also recorded, is always zero in every five-minute interval. These values indicate that the equipment cycles, drawing zero amps about 56% of the time and 0.85 amps 44% of the time, for an average of 0.37 amps.

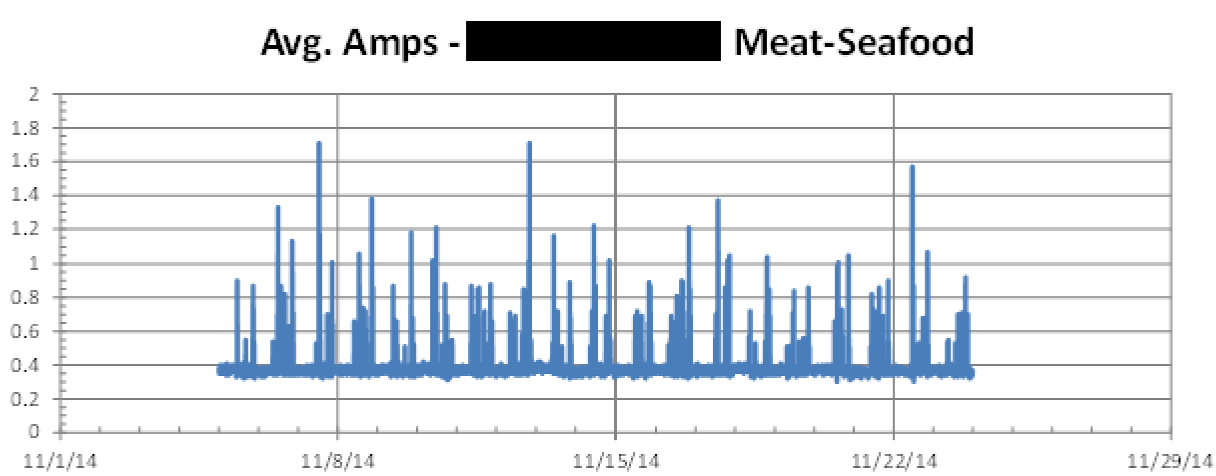


Figure 4: Average Current

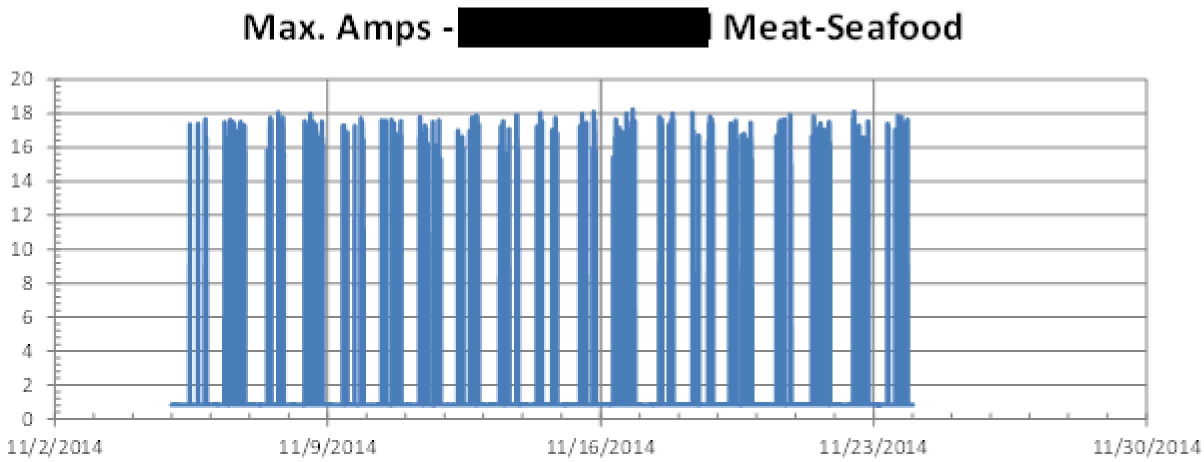


Figure 5: Maximum Current

Note that the number of times the sealer is used during any logging interval is reflected in discreet step changes in average amps for that interval. In the graph in Figure 4 above, if the sealer is not used during an interval, the average amps are at the baseline level of about 0.37 amps (the corresponding average power is about 43 W). When the sealer is used once within the interval – drawing about 17 amps for about 3 seconds – the average amps shows a step up to 0.54 amps (62 W). If the sealer is used twice, the average amps steps up to 0.70 amps (80 W). If used three times, 0.87 amps (99 W); if used four times, 1.02 amps (117 W); etc.

From the average logged power data for each day, the daily total energy consumption may be calculated. The results are shown in Figure 6 below. The overall average energy consumption is about 1.09 kWh/day for this sealer; the energy usage does not vary much by day of the week (see Figure 7).

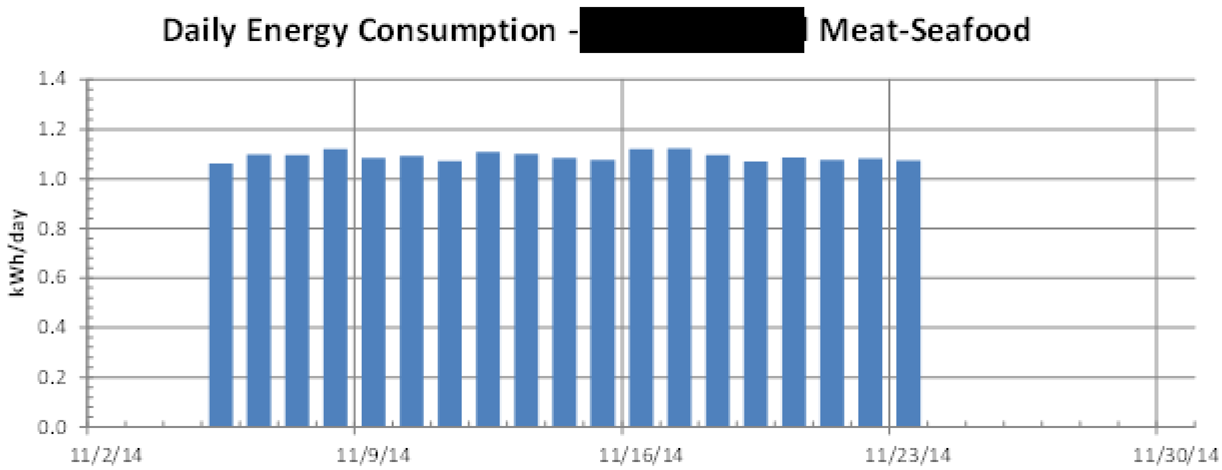


Figure 6: Daily Energy Usage History

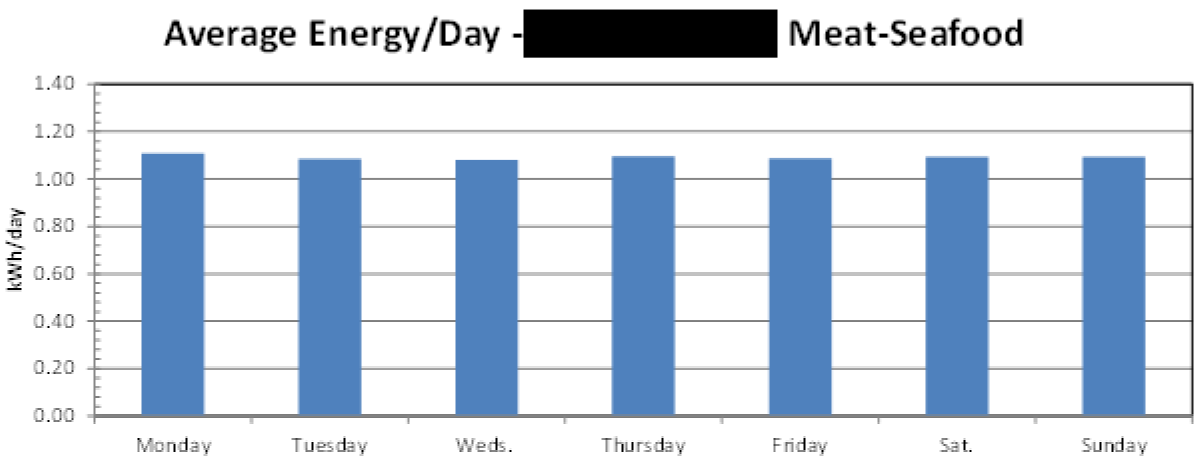


Figure 7: Average Energy Usage by Day of the Week

Data Sample – [Redacted] Ave Cheese

As noted earlier for the data presented above for the [Redacted] sealer, that sealer was always on. About a quarter of the sealers monitored in this M&V investigation were turned off at night. Figure 8 through Figure 13 show the data for such a sealer. Figure 8 below shows the average logged power drawn by the sealer over five-minute intervals. This sealer has a baseline load of about 42 W, but draws zero watts when off at night. The maximum demand in any five-minute period for this sealer was 157 W; however, the maximum demand in any 15-minute period for this sealer was only 102 W.

For this sealer, the coincident peak power was determined to be 76.7 W.

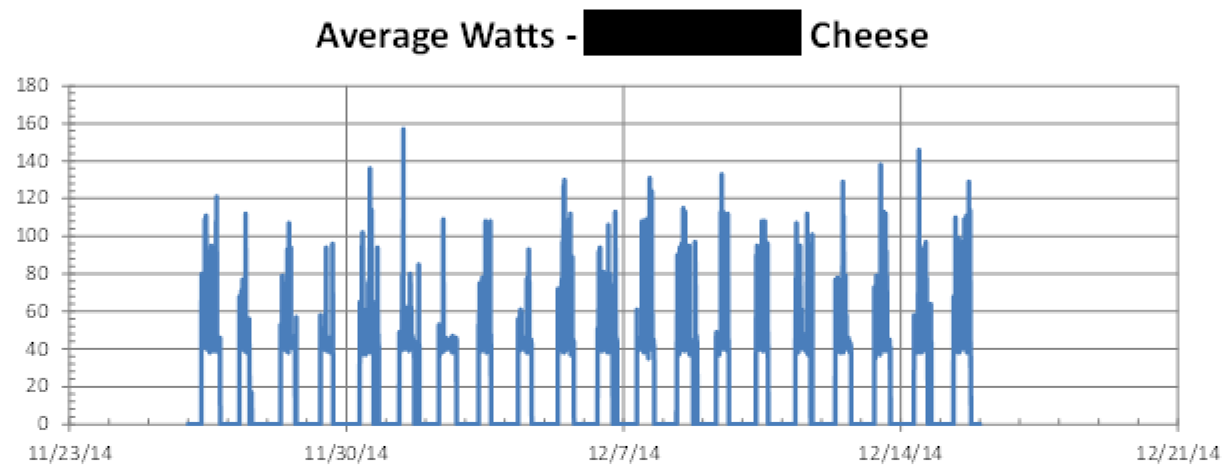


Figure 8: Average Watts Recorded over 5-minute Intervals – Sealer Off at Night

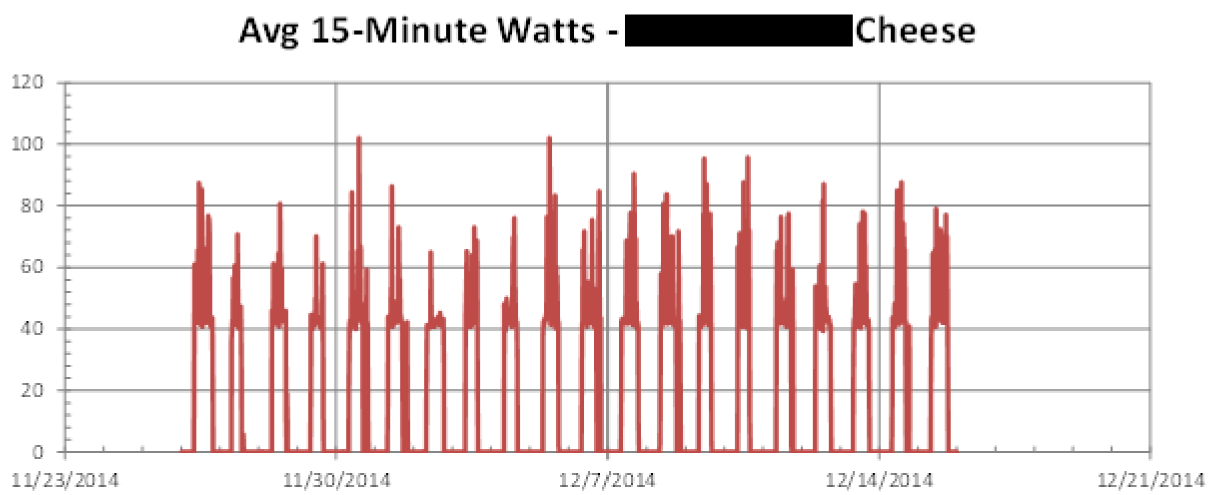


Figure 9: Average Watts over 15-minute Intervals – Sealer Off at Night

Average current and maximum current are shown in Figure 10 and Figure 11 below. Similar to the always-on sealer, the average current is never more than 1.4 amps in any five-minute interval, but the maximum amps is typically 15 to 17 amps, averaging 15.6 amps for this particular sealer when it is used. The corresponding power is about 1840 W. Note that the off periods are clearly observed each night when the current drops to zero.

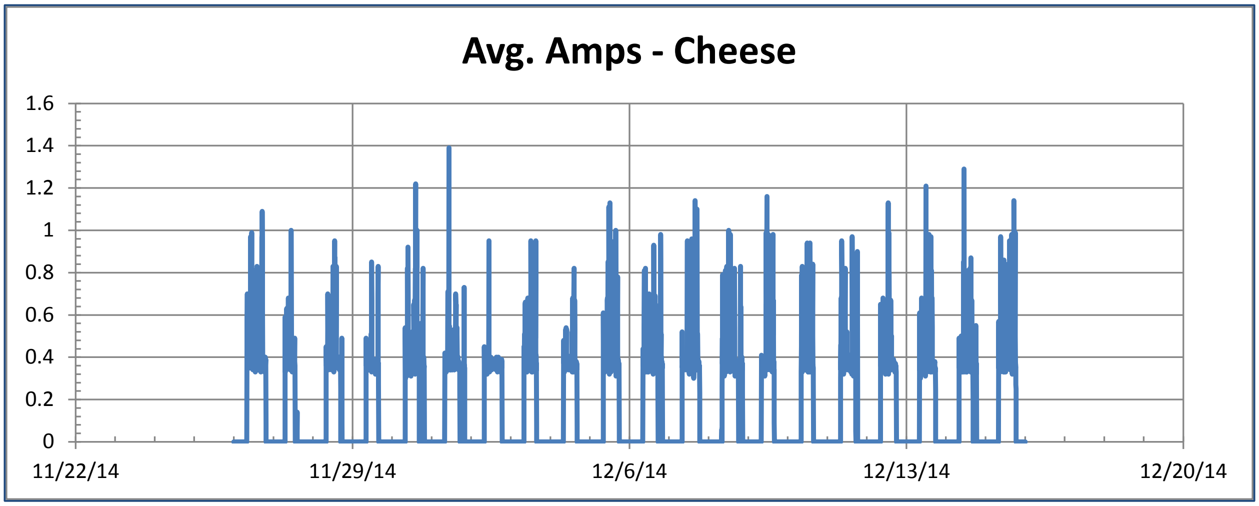


Figure 10: Average Current – Sealer Off at Night

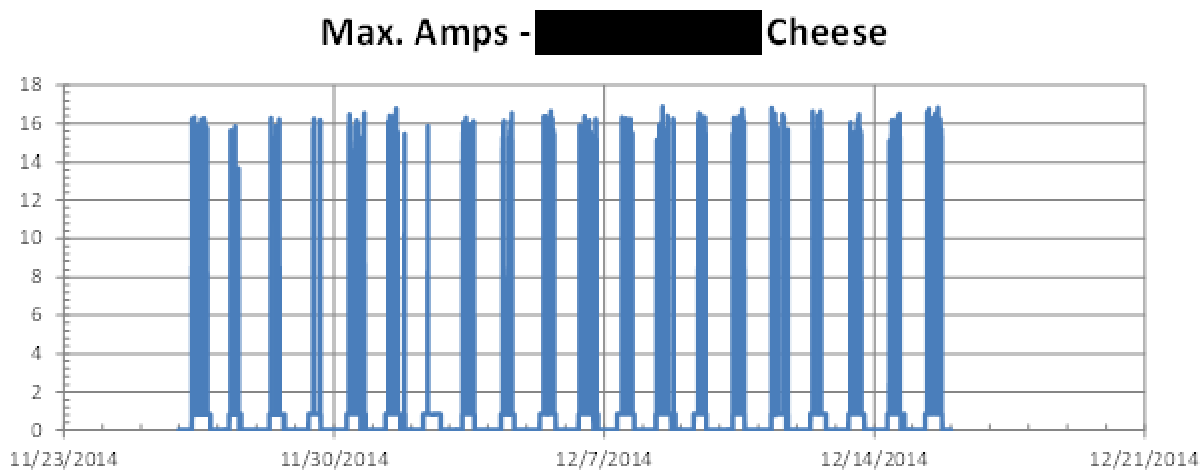


Figure 11: Maximum Current – Sealer Off at Night

The daily total energy consumption is shown in Figure 12 below. The overall average energy consumption is about 0.46 kWh/day for this sealer; about 58% less than the always-on sealer.

The energy usage varies slightly by day of the week in this case (see Figure 13).

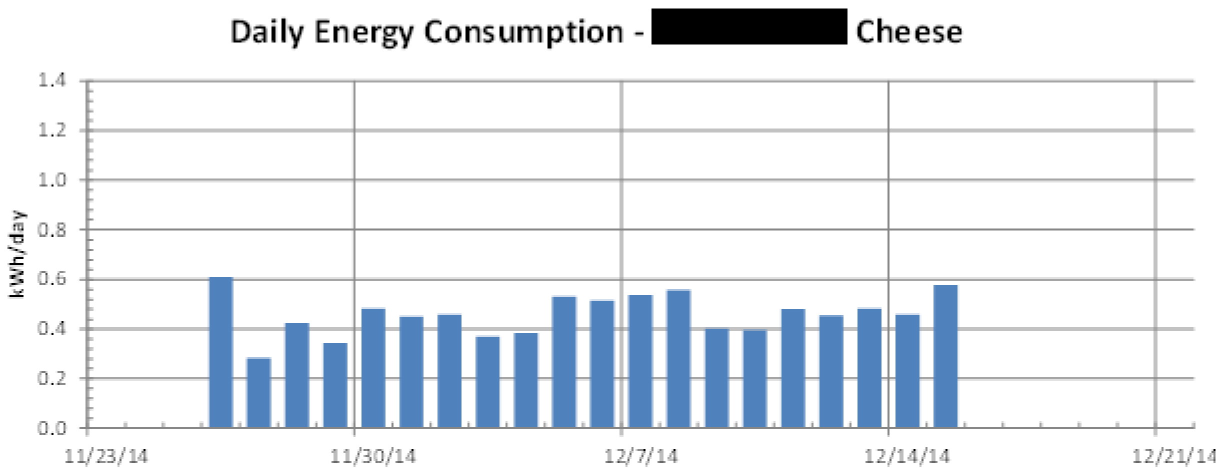


Figure 12: Daily Energy Usage History – Sealer Off at Night

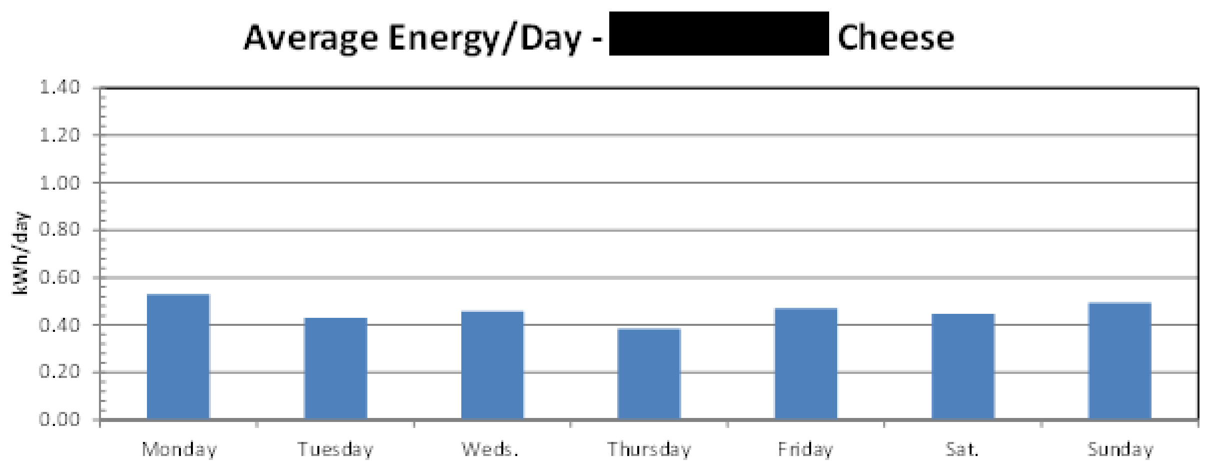


Figure 13: Average Energy Usage by Day of the Week – Sealer Off at Night

Data for the remaining new sealers is presented at the end of the report

Table 1 on the next page presents the results for all the monitored sealers. Relevant findings include:

- For Sealers that are always on, the average overall power was 44.7 W and the energy consumption was 1.07 kWh/day, giving an annual energy consumption of 392 kWh/year. The average peak power was 124 W and the average coincident peak 64 W.

- Sealers that are turned off at night had average power of 21.4 W, and consumed energy at the rate of 0.513 kWh/day, giving an annual energy consumption of 187 kWh/year. The average peak power was 82 W and the average coincident peak 61 W.

Table 1: Summary of New Sealers

Store Location	Dept.	Max Watts (avg. over any 5 min.)	Max Watts (avg. over any 15 min.)	Max Coincident W (Weekdays, 4-5 PM)	Overall Average Watts	Max Energy/Day (kWh/day)	Average Daily Energy (kWh/day)	Annual Energy (kWh/yr)	Always ON?	What % of Time ON?
[Redacted]	[Redacted]	134	70.3	51.7	39.3	1.000	0.943	344.2	Yes	96.3%
[Redacted]	[Redacted]	171	109.3	80.0	45.1	1.127	1.083	395.4	Yes	100.0%
[Redacted]	[Redacted]	149	96.0	69.3	46.2	1.163	1.108	404.5	Yes	100.0%
[Redacted]	[Redacted]	99	63.0	51.7	15.5	0.733	0.373	136.2	No	33.3%
[Redacted]	[Redacted]	195	124.7	63.3	45.5	1.123	1.092	398.5	Yes	100.0%
[Redacted]	[Redacted]	274	170.7	81.0	44.8	1.106	1.076	392.7	Yes	100.0%
[Redacted]	[Redacted]	157	102.0	76.7	19.1	0.610	0.459	167.6	No	38.8%
[Redacted]	[Redacted]	214	103.7	43.7	38.1	1.063	0.914	333.6	Yes	89.5%
[Redacted]	[Redacted]	263	180.7	49.0	43.0	1.060	1.031	376.3	Yes	100.0%
[Redacted]	[Redacted]	161	126.3	79.0	47.3	1.192	1.135	414.2	Yes	100.0%
[Redacted]	[Redacted]	115	84.3	74.0	20.9	0.901	0.502	183.1	No	48.1%
[Redacted]	[Redacted]	85	56.0	44.3	18.9	0.680	0.454	165.8	No	45.8%
[Redacted]	[Redacted]	269	143.7	53.0	41.5	1.099	0.996	363.4	Yes	97.2%
[Redacted]	[Redacted]	268	125.0	71.3	46.4	1.169	1.113	406.2	Yes	100.0%
[Redacted]	[Redacted]	263	157.3	49.7	51.0	1.298	1.223	446.6	Yes	100.0%
[Redacted]	[Redacted]	156	88.3	63.0	44.2	1.102	1.061	387.1	Yes	100.0%
[Redacted]	[Redacted]	270	130.7	65.3	48.2	1.191	1.157	422.3	Yes	100.0%
[Redacted]	[Redacted]	205	106.7	58.0	32.4	1.110	0.778	284.0	No	64.1%
[Redacted]	[Redacted]	194	115.3	74.7	45.4	1.171	1.089	397.4	Yes	100.0%
	Count									
Sample Totals	19				732.8		17.587	6,419		
Max of Any One Sealer		274.0	180.7	81.0	51.0	1.298	1.2	446.6		
Min of Any One Sealer		85.0	56.0	43.7	15.5	0.610	0.4	136.2		
Averages	Count	% of Sample								
Off at Night	5	26.3%	82.4	60.9	21.4	0.807	0.513	187.4	No	46.0%
Always ON	14	73.7%	124.4	63.9	44.7	1.133	1.073	391.6	Yes	98.8%
Total	19	100.0%	113.4	63.1	38.6		0.926	337.8		
No. Sealers in Apps	137		kW	kW	kW		kWh/day	kWh/yr		
Population Totals			15.53	8.64	5.28		126.8	46,285		

In addition to the new sealers monitored above, the data collection effort captured data for one old sealer, still in use at the [Redacted]. The data is presented in Figure 14 through Figure 19 below, with a summary in Table 2. The old sealer is thermostatically controlled to maintain a constant temperature. This sealer happened to be one that is turned off at night, and the relevant findings include:

- The average overall power over a 24 hour day was 104.7 W, considering that the sealer was turned off about 12 hours each day.
- The energy consumption was 2.51 kWh/day, for an annual energy consumption of 917 kWh/year.
- The average peak power was 481 W.
- The average coincident peak was 295 W.
- The old sealer has a morning warm-up time during which the power is as high as 648 W.
- The average power draw of the old sealer during operating hours, including warmup, was about 206 W.

The average current is more variable than for the new sealers, and we could not determine the number of sealing events per interval as before. However, when a sealing event does occur, the maximum current is about 6.0 amps.

If the sealer had been allowed to be on continuously:

- The average overall power would be 127 W, considering that the sealer would be idling for about 12 hours each night.
- The energy consumption would be 3.05 kWh/day,
- The annual energy consumption would be 1113 kWh/year.
- The peak power values would be the same as above.

Table 2: Summary of Old Sealer – Monitored Data

Store Location, Dept	Max Watts (avg. over any 5 min.)	Max Watts (avg. over any 15 min.)	Max Coincident W (Weekdays 4-5 PM)	Overall Avg Watts	Max Energy / Day (kWh/ day)	Average Daily Energy (kWh/ day)	Annual Energy (kWh/ yr)	Always ON?	What % of Time ON?
[Redacted]	648	481.3	295.3	104.7	3.518	2.513	917	No	51.3%
if Sealer operated 24/7		481.3	295.3	127.0	4.268	3.049	1,113	Yes	100.0%

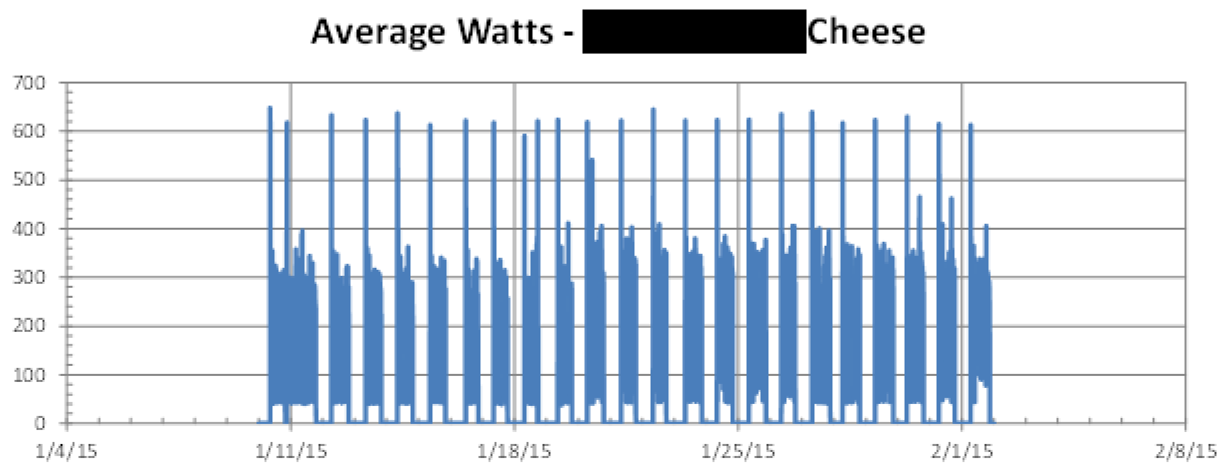


Figure 14: Average Watts Recorded over 5-minute Intervals – Old Sealer

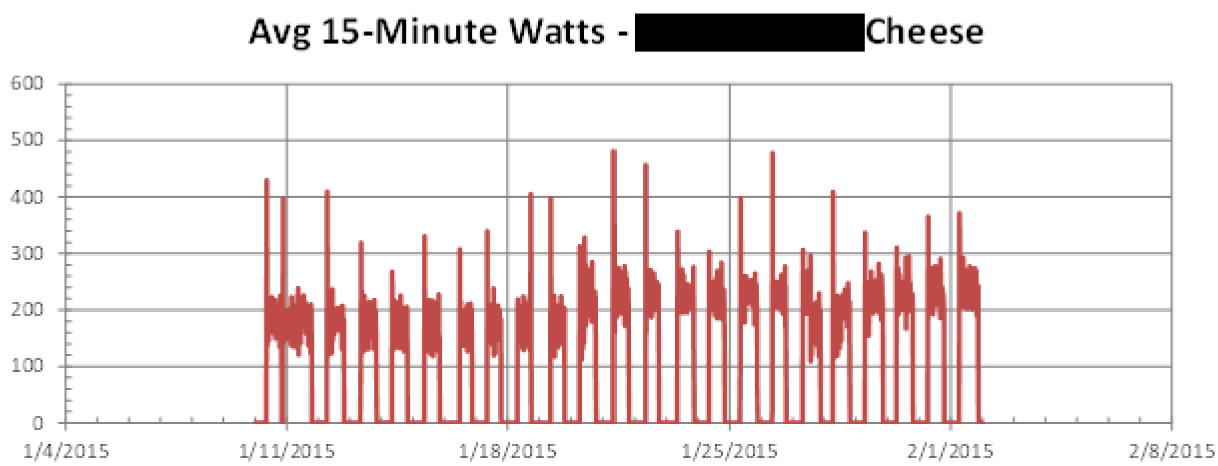


Figure 15: Average Watts over 15-minute Intervals – Old Sealer

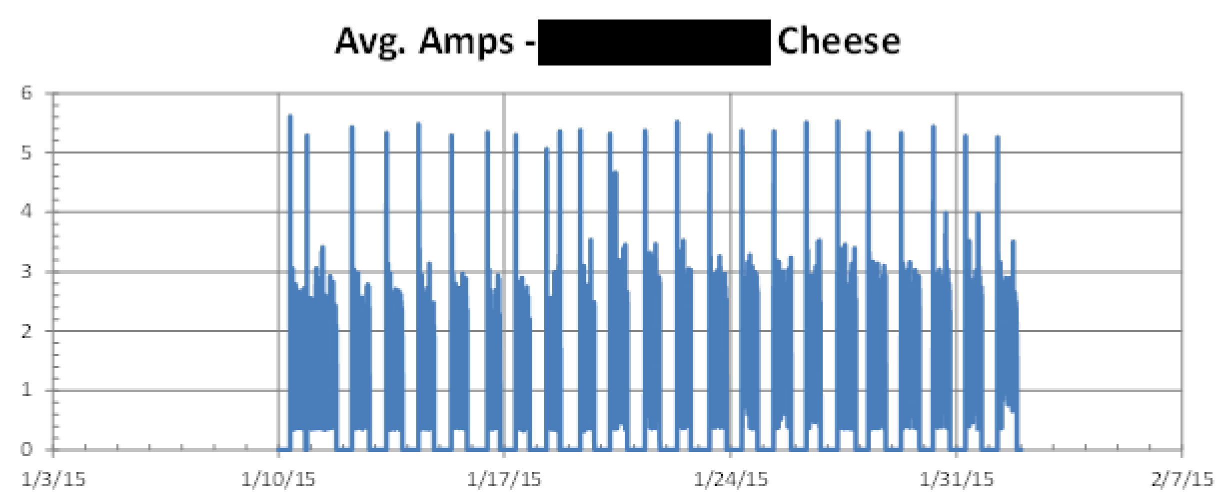


Figure 16: Average Current – Old Sealer

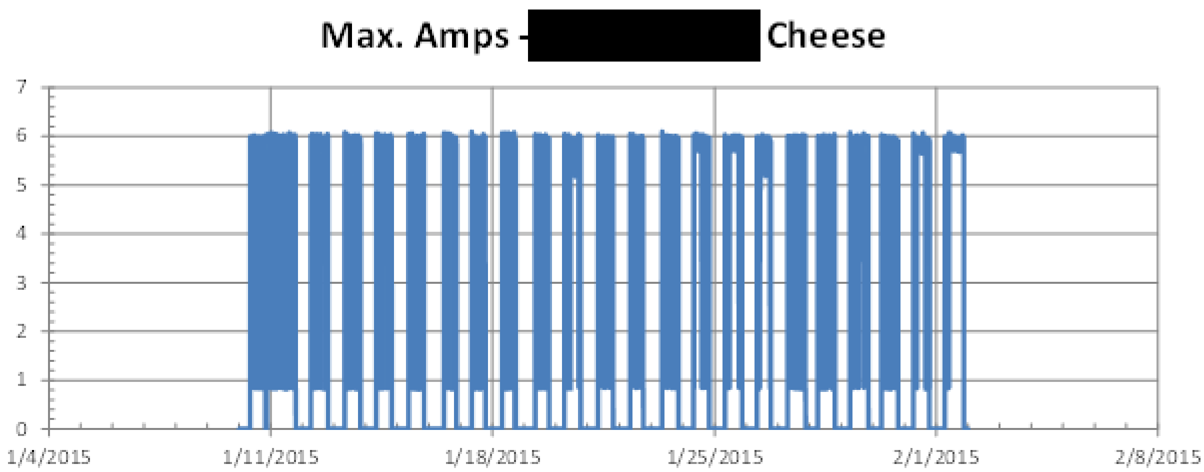


Figure 17: Maximum Current – Old Sealer

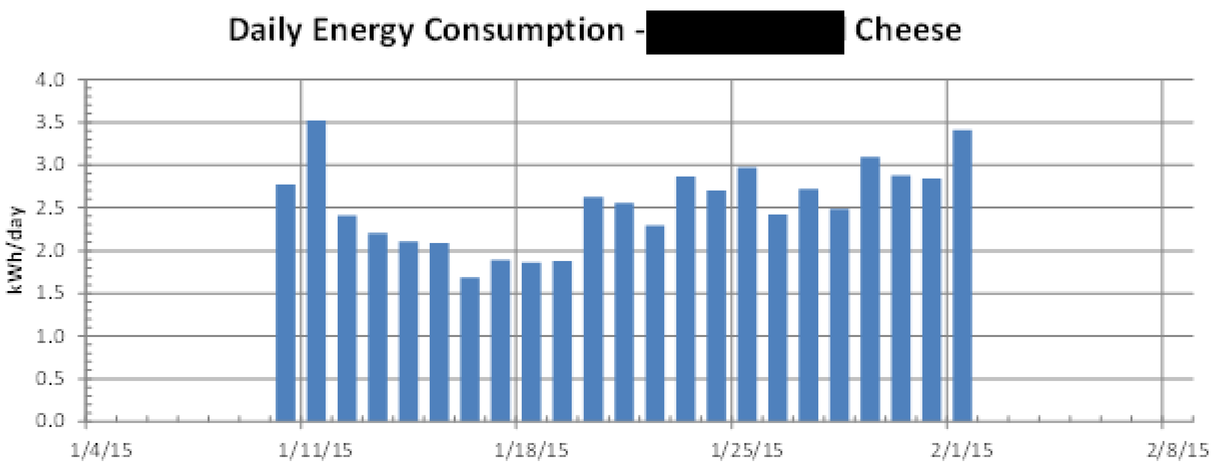


Figure 18: Daily Energy Usage History – Old Sealer

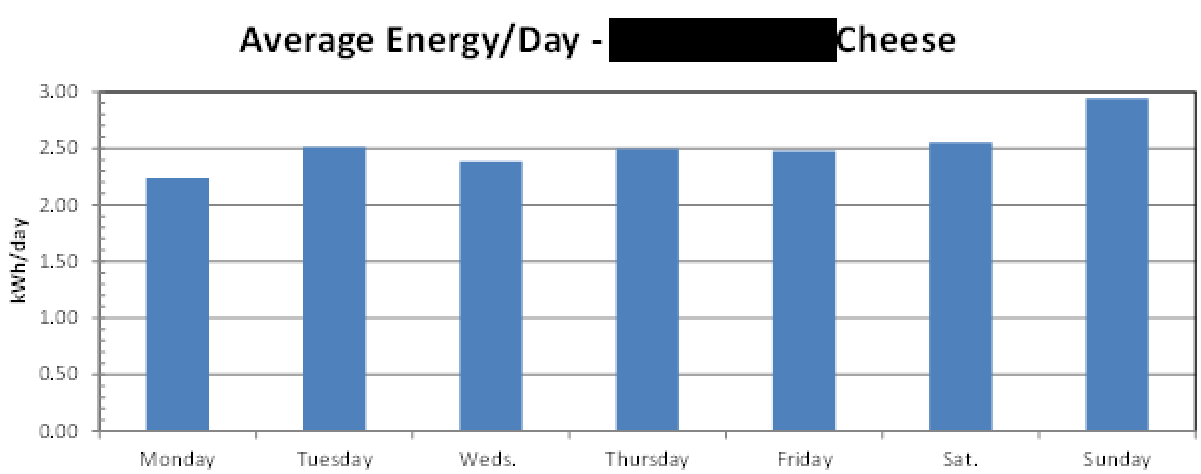


Figure 19: Average Energy Usage by Day of the Week – Old Sealer

M&V Savings Calculation

The results for the old sealer at the [Redacted] store do not support the application assumption of a 400 W average power draw over 24 hours. Using the results for a single sealer for the baseline is not appropriate, and so additional research was performed to determine if 400 W is the correct baseline wattage, or if not, what baseline wattage should be used to estimate the savings. Two reports were found, both located on the Heat Seal, LLC website that support a lower average power draw.[1,2] Reference 1 is a report performed by Southern California Edison comparing conventional to on-demand heat sealers, and Reference 2 is a report developed by Heat Seal LLC that compared a conventional Model 625A to an Energy Smart 625-ES (on-demand).

The average demand in Reference 2 for the conventional Model 625A ranged from 218 W at an ambient temperature of 75°F, to 312 W, at an ambient temperature of 65°F.

To be able to use the results from Reference 1, we normalized the average demand (including warmup, idle, and use) by developing a ratio between the maximum demand to the average demand. The results from these different sources are shown in Table 3. The data shown in the table for the SCE tests were derived from long term energy consumption.

Because of the variations in units, and the variation in demand as a function of ambient temperature, an average was used for the Model 625A tests, which resulted in an average operating demand of 265 watts when the sealer is turned on, i.e., ignoring periods when the sealer is turned off at night. This value is in line with the measured results for M&V, SCE, and the Heat Seal tests.

Table 3: Conventional heat sealer demand comparison

Model/Location	Max watts	Average watts	Average / Max watts
[Redacted]	718	206	0.287
[Redacted]	1020	260	0.255
[Redacted]	1020	330	0.324
HeatSeal Model 625 Tests (75F)	725	218	0.301
HeatSeal Model 625 Tests (65F)	725	312	0.430
Value for Baseline	725	265	0.366

In the calculations that follow in Table 4, we present the energy savings estimate using the baseline value of 265 W for the old sealer power as discussed above. Slight adjustments to the energy usage for old sealers have been made to account for the percentages of the sample of sealers that were found to operate continuously versus off at night (we assume that if a sealer

[1] https://www.heatsealco.com/uploads/documents/1699/ET10SCE1450%20Sealing%20Packaging%20Machine%20Report_final2.pdf

[2] https://www.heatsealco.com/uploads/documents/1700/HS%20ES%20Energy%20Usage%20Analysis.pdf

is turned off at night in our monitored data, that employee behavior is not new and they turned off the old sealer in the same manner before it was replaced). Also, the overall percent-on times found for the sample are also applied (even always-on sealers had brief off times).

In addition, demand savings also change from what would be estimated by using a constant load of 400 W for the baseline sealer. With a connected load of 725 W, the maximum 15-minute load is estimated at 486 W and the coincident peak demand is estimated at 298 W.

The net results for the application's population of 137 sealers are:

	Savings	Realization Rate
• Annual Energy savings:	223,750 kWh/year	63.3%
• Peak (Non-coincident) Demand Savings:	51.0 kW	126.5%
• Coincident Peak Demand Savings:	32.2 kW	79.8%

Table 4. Savings Projection Summary

Store & Dept.	% ON	Max Watts (Connected Load)	Max Watts (avg. over any 15 min.)	Average Coincident W (Weekdays, 4-5 PM)	Average Operating W	Overall Average Watts	Average Daily Energy (kWh/day)	Annual Energy (kWh/yr)
Old Sealers								
Off at Night	46.0%	725	486	298	265	122.0	2.929	1,069
Always ON	98.8%	725	486	298	265	261.8	6.283	2,293
New Sealers								
Off at Night	46.0%		82.4	60.9		21.4	0.5	187.4
Always ON	98.8%		124.4	63.9		44.7	1.1	391.6
Savings per sealer								
Off at Night			403.2	237.0		100.6	2.415	882
Always ON			361.1	234.1		217.1	5.210	1,902
Population Savings	Population Quantity	Population %	(kW)	(kW)		(kW)		
Off at Night	36	26.3%	14.5	8.5		3.6	87.1	31,784
Always ON	101	73.7%	36.5	23.6		21.9	525.9	191,967
Total Savings			**51.0**	**32.2**		25.5	613.0	**223,750**
Duke Projections			41.1	41.1				360,060
Realization Rates			**NCP: 124%**	**CP: 78%**				**Energy: 62%**

Data for the remaining new sealers follows in Figure 20 through Figure 38.

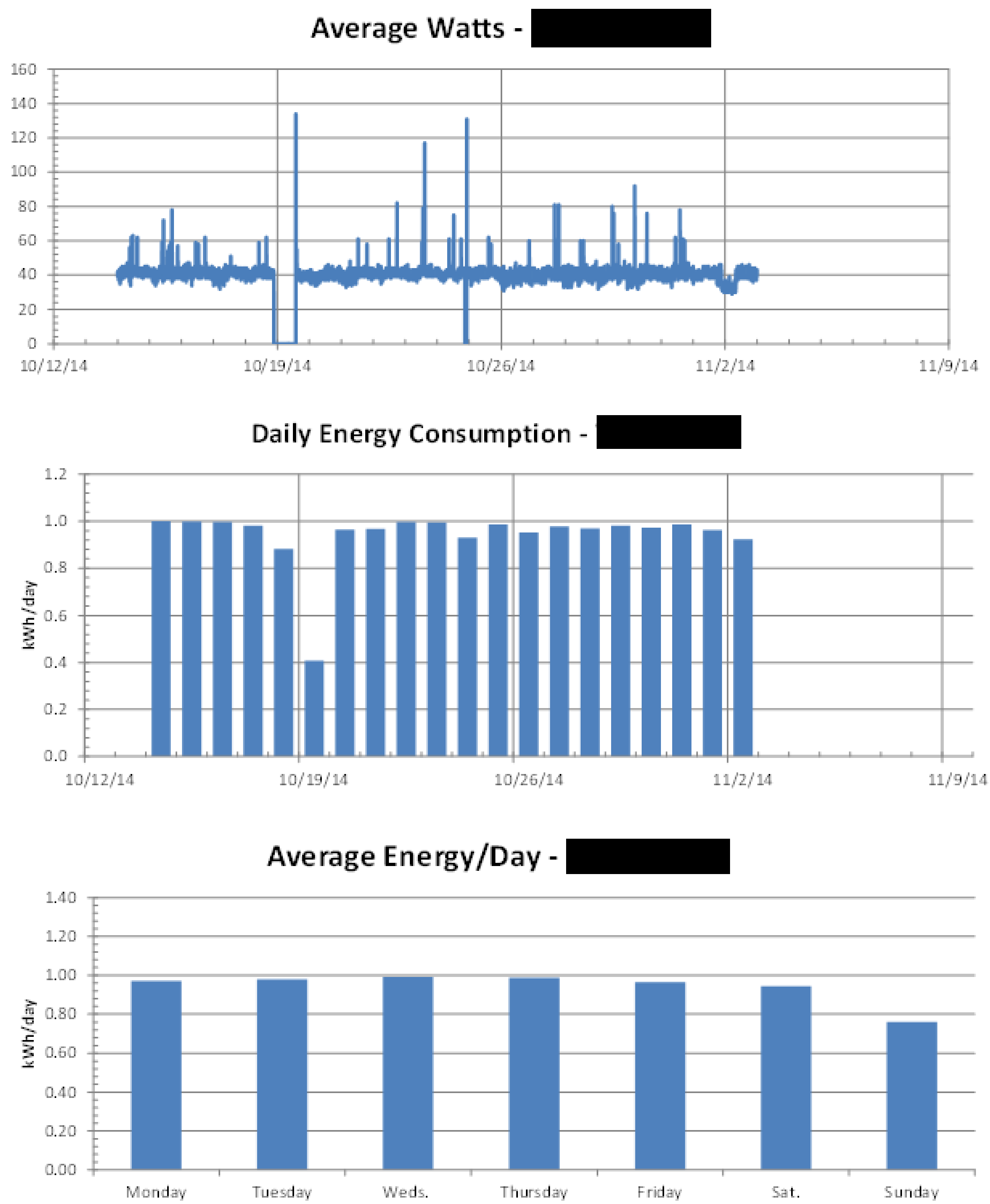


Figure 20: Data for [Redacted]

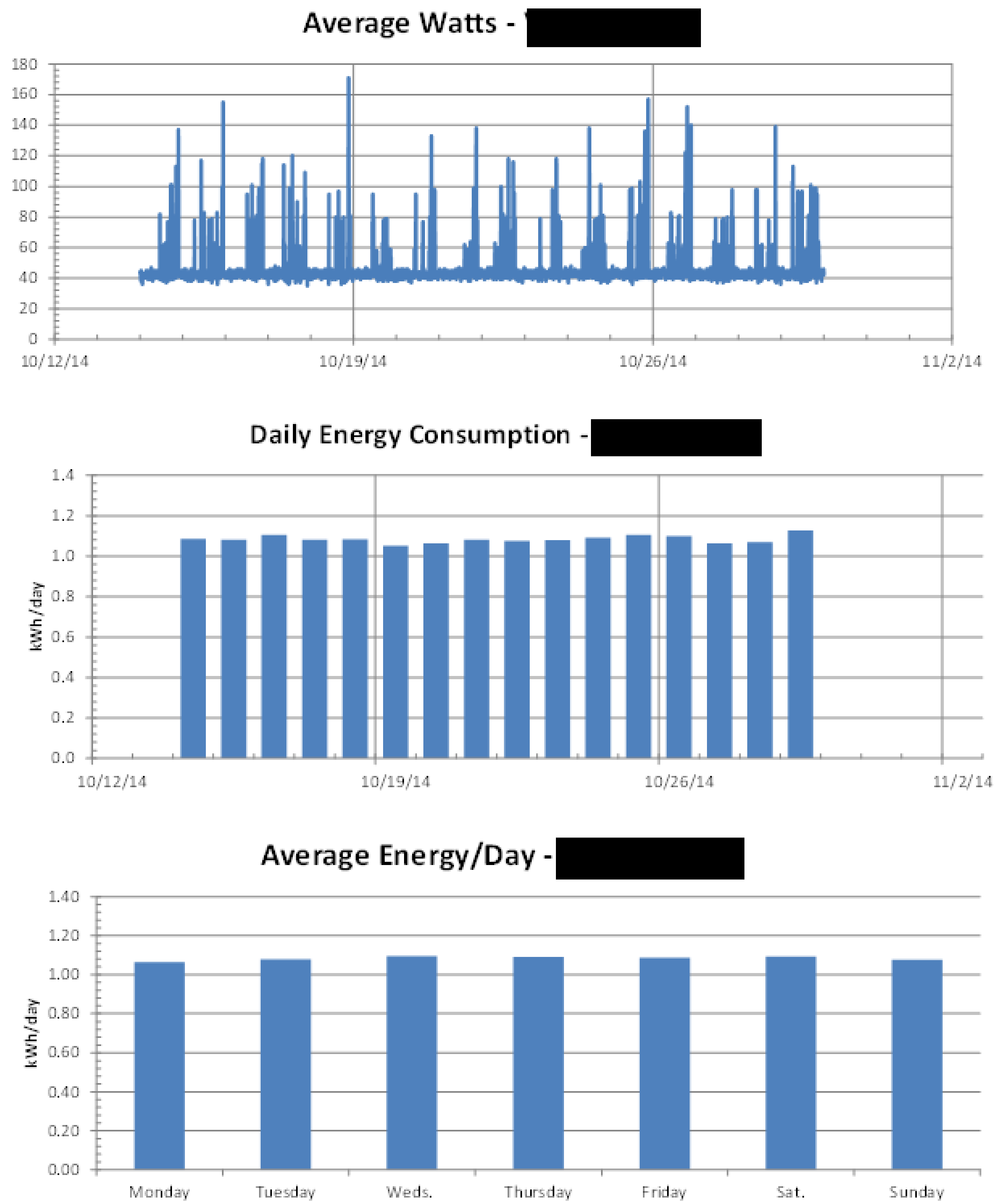


Figure 21: Data for [Redacted].

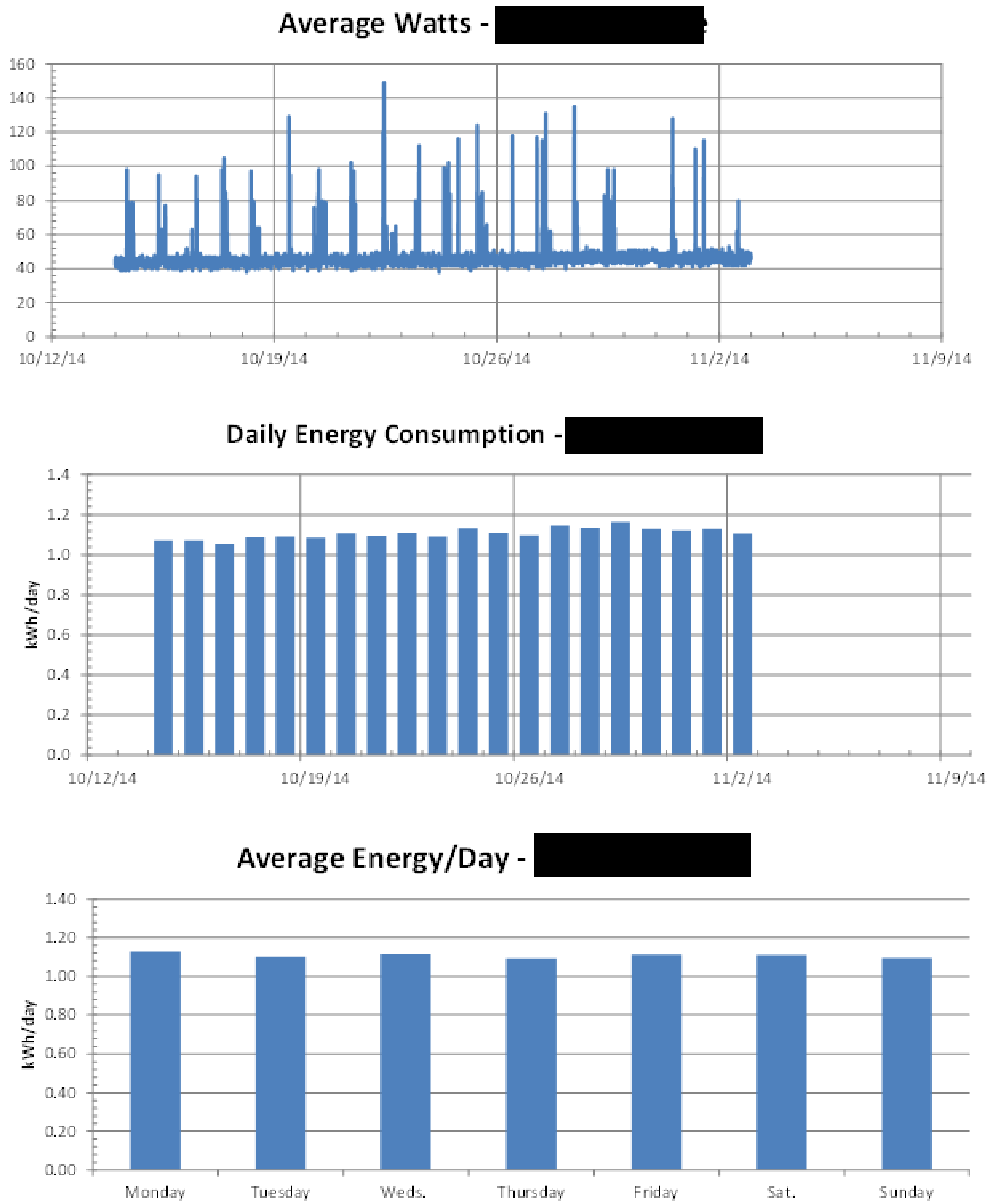
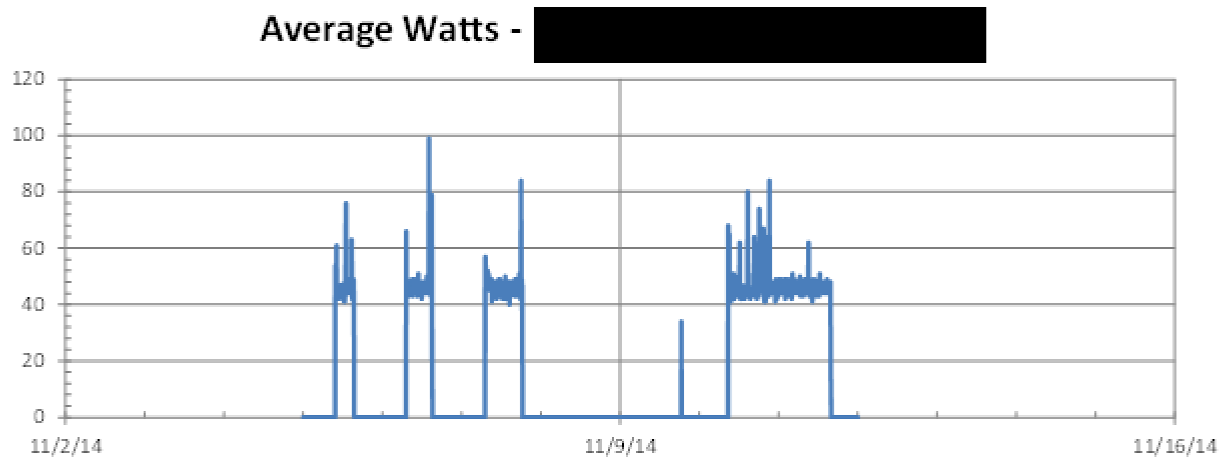
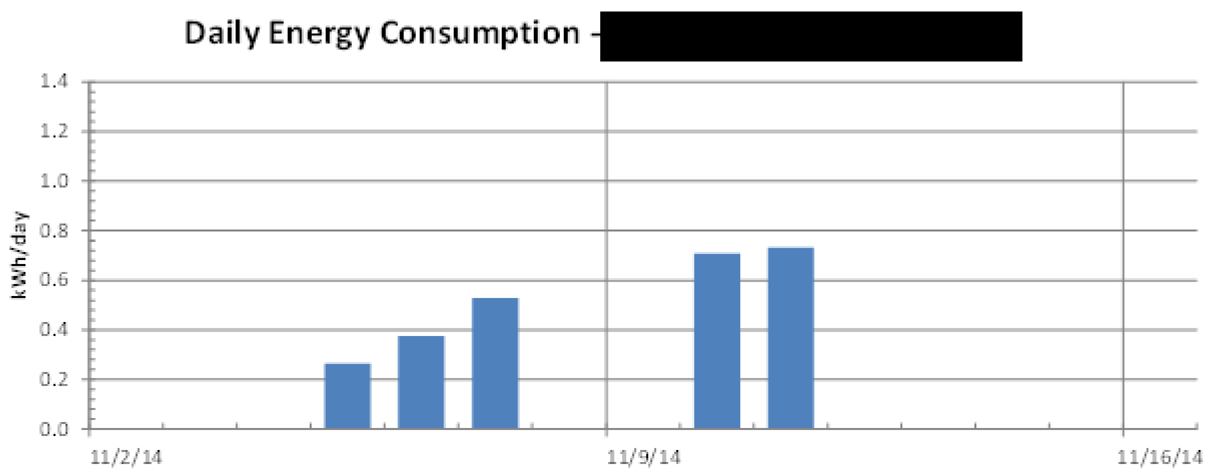


Figure 22: Data for [Redacted].



(Note: Data was collected for seven days only.)



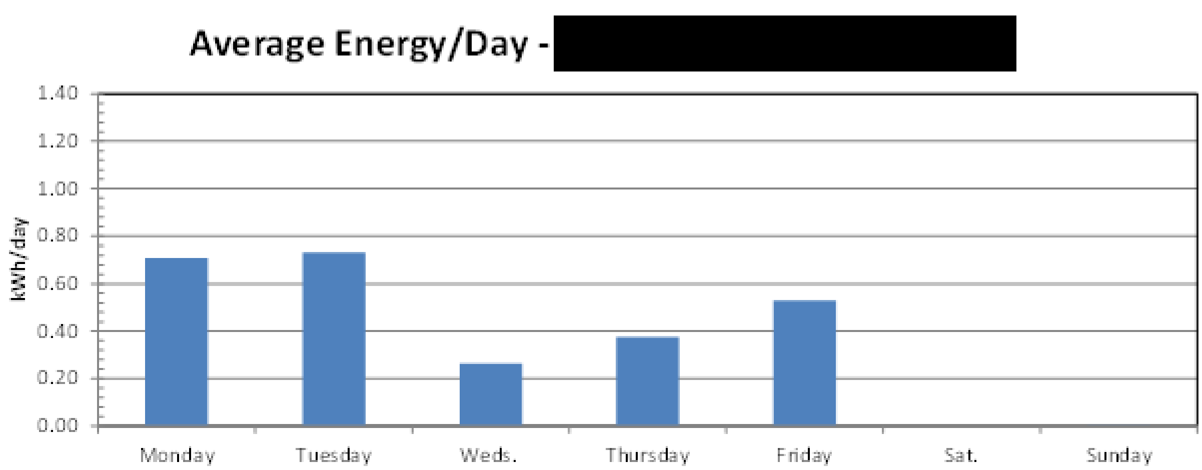


Figure 23: Data for [Redacted]

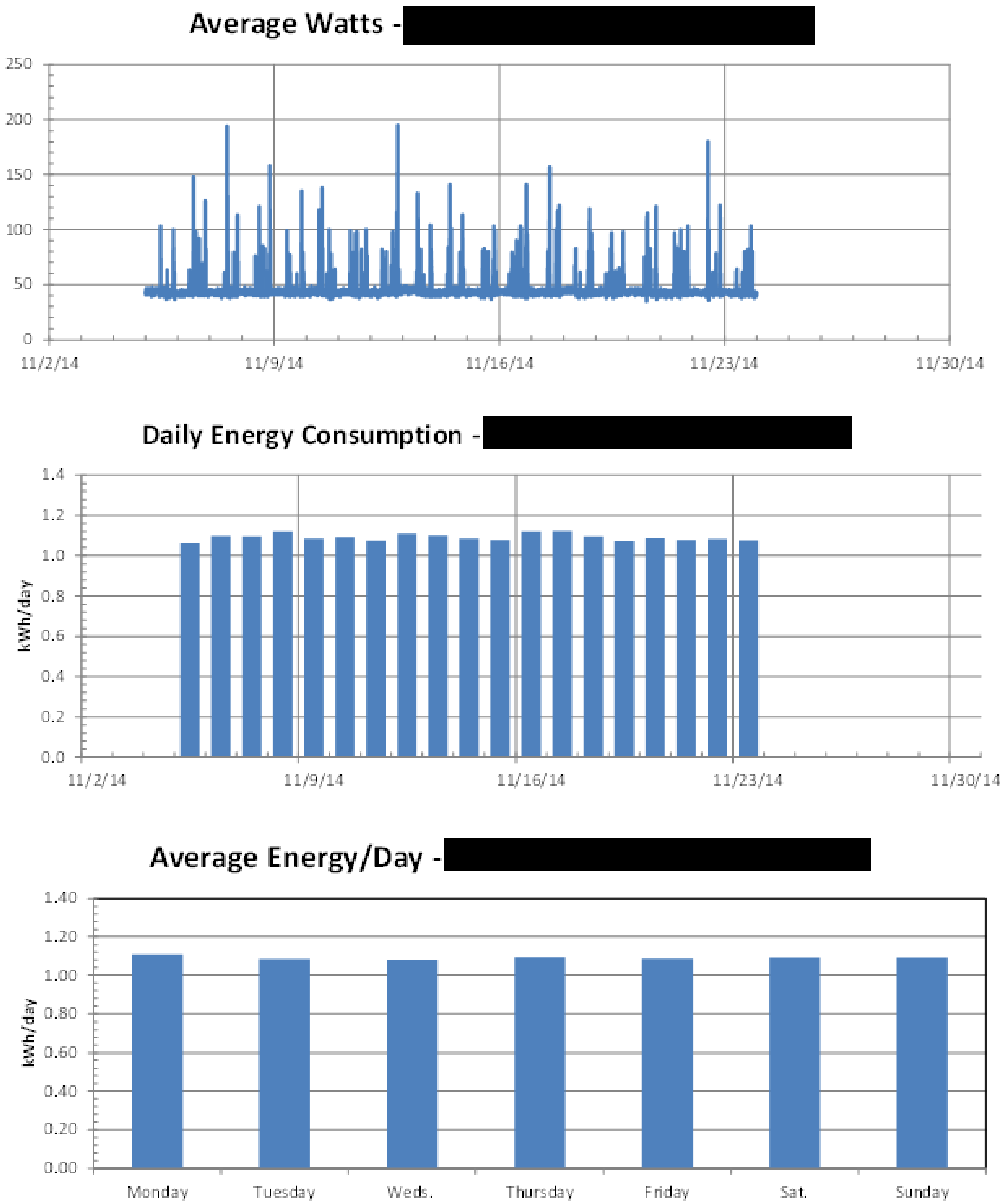
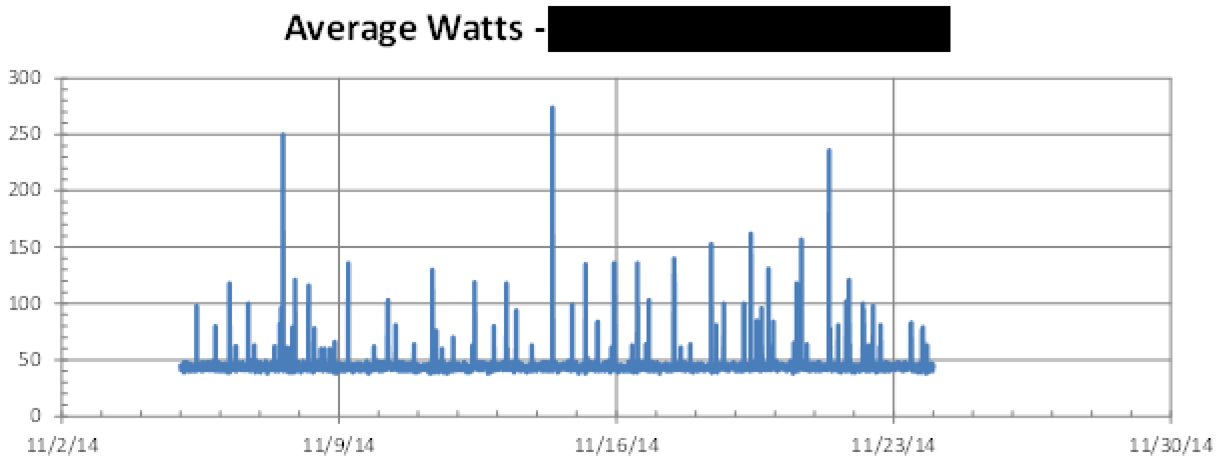
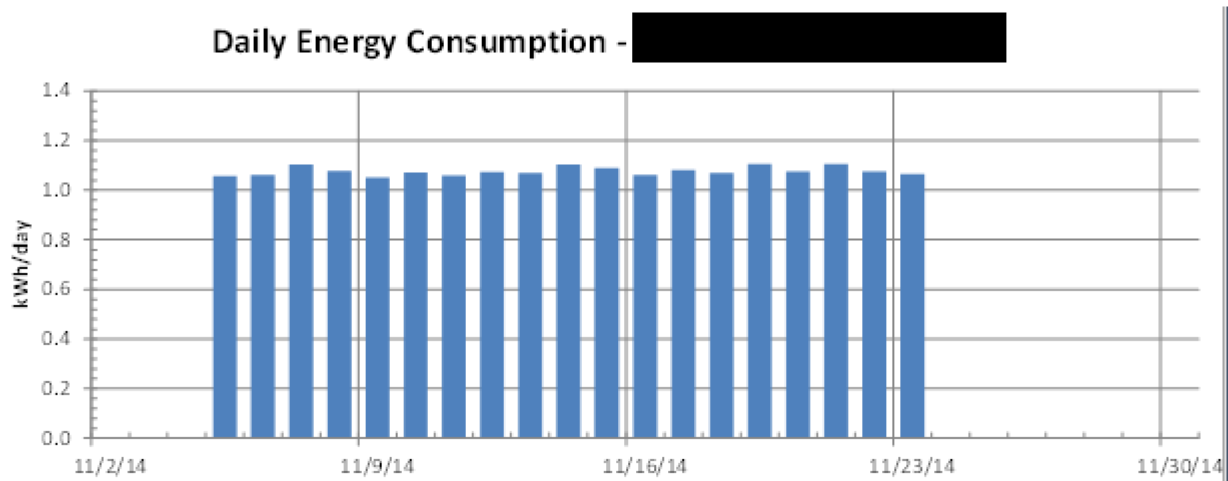


Figure 24: Data for [Redacted].





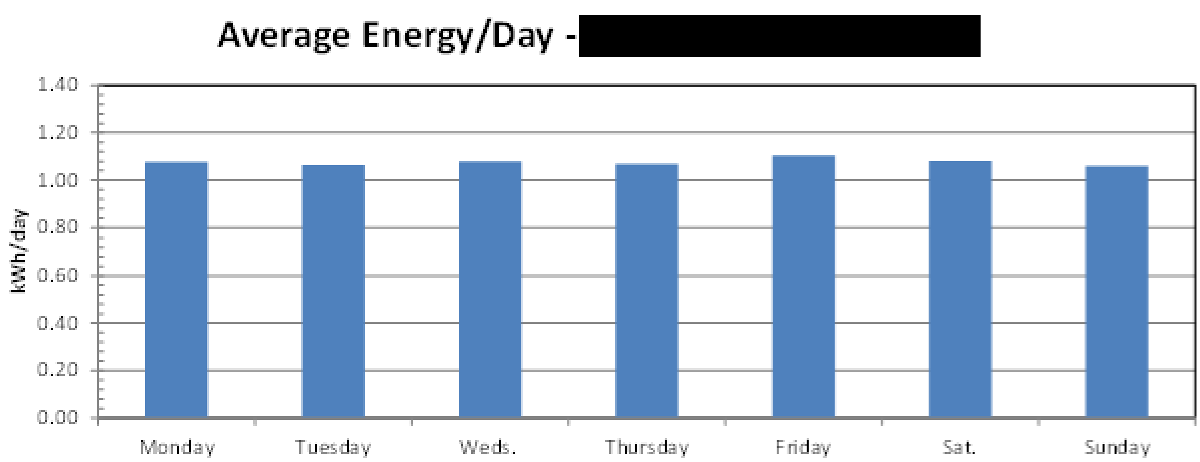
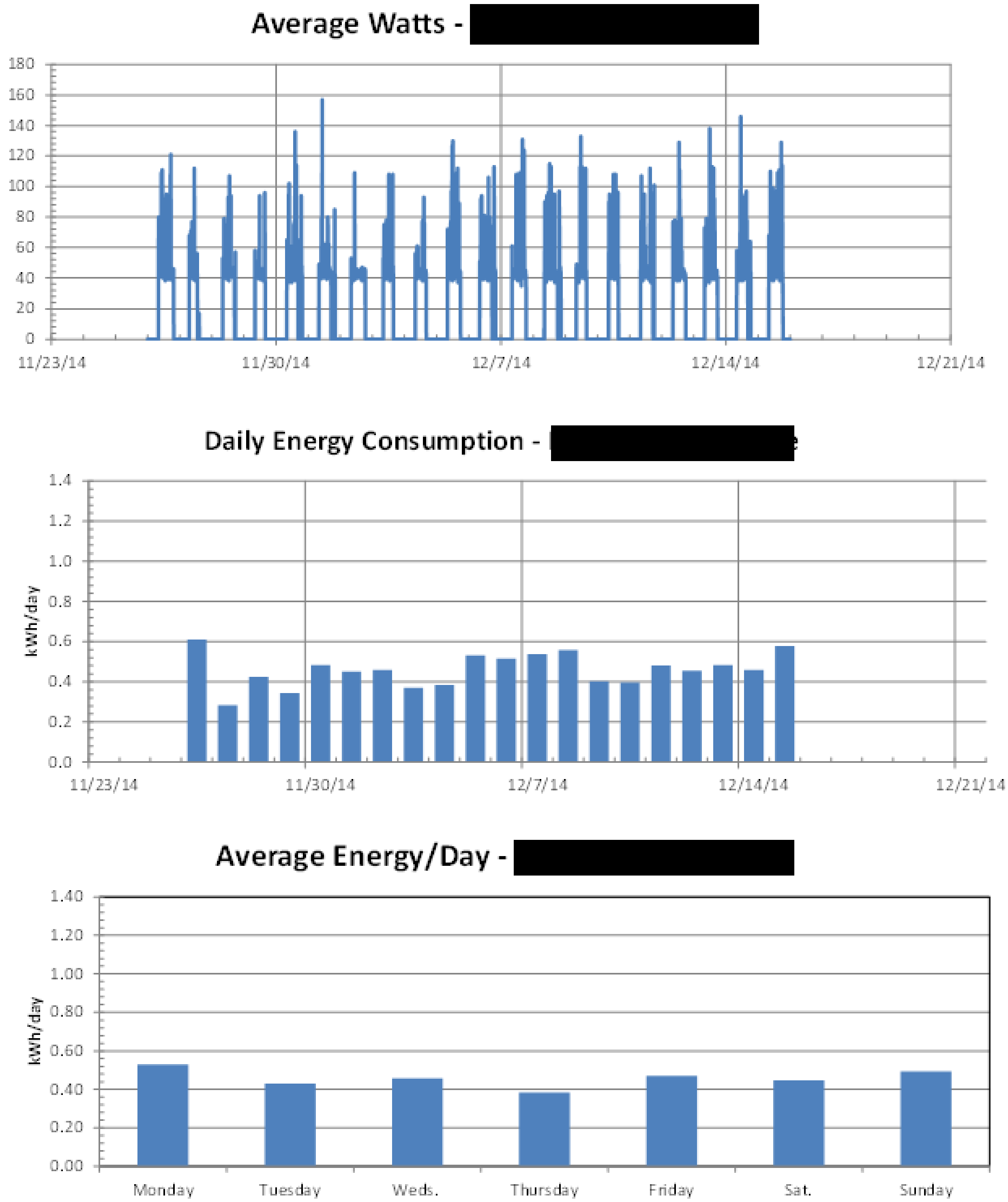


Figure 25: Data for [Redacted].



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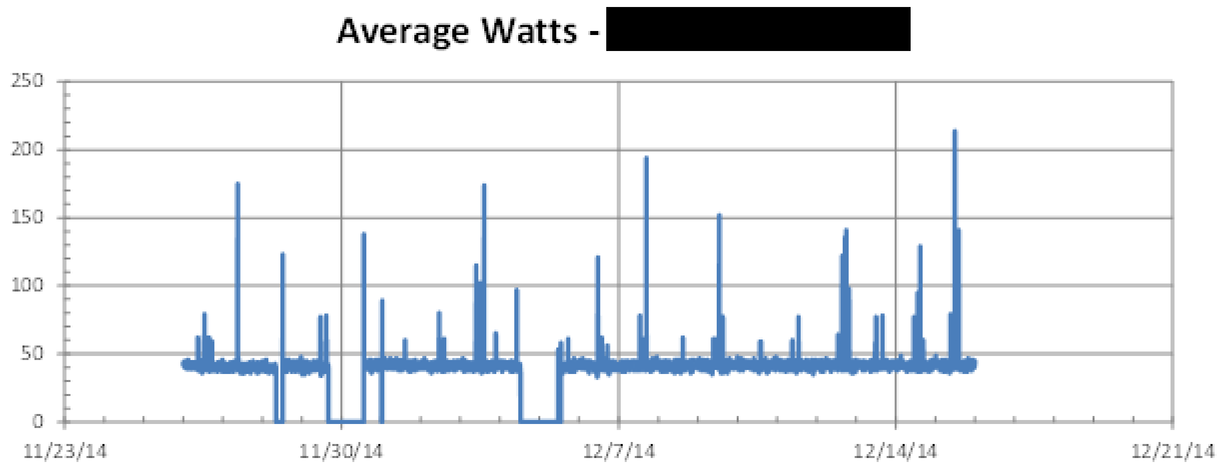
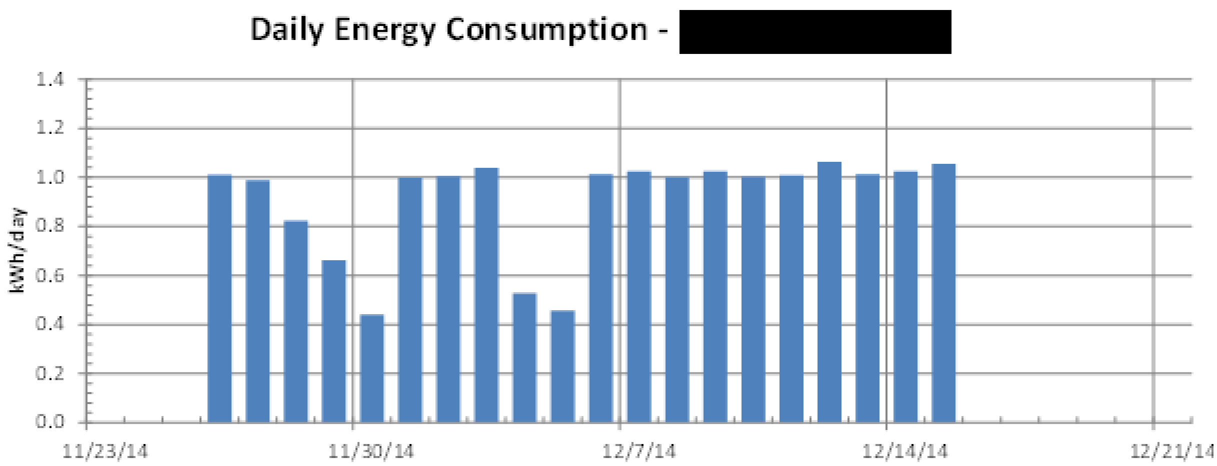




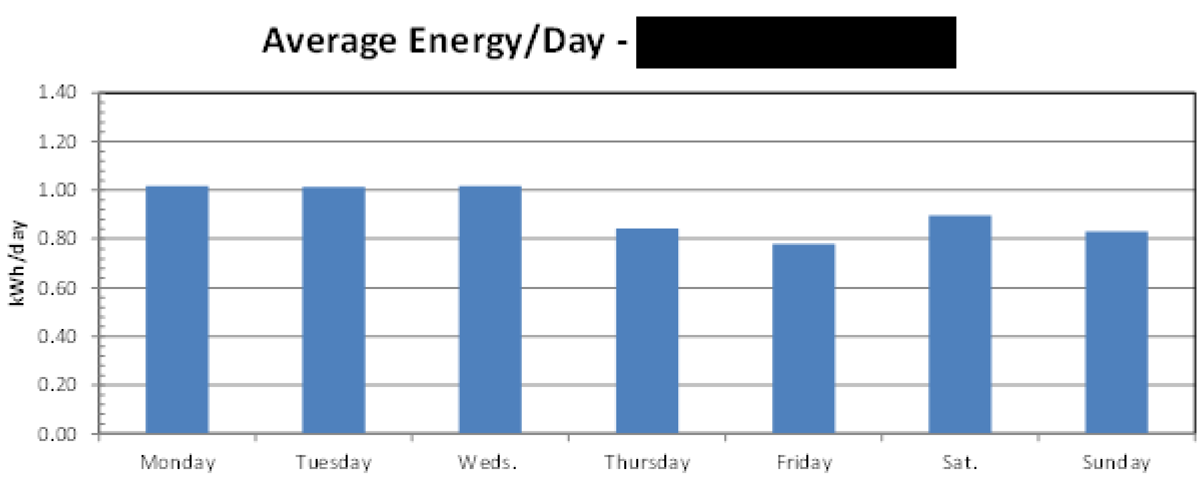


Figure 27: Data for [Redacted]

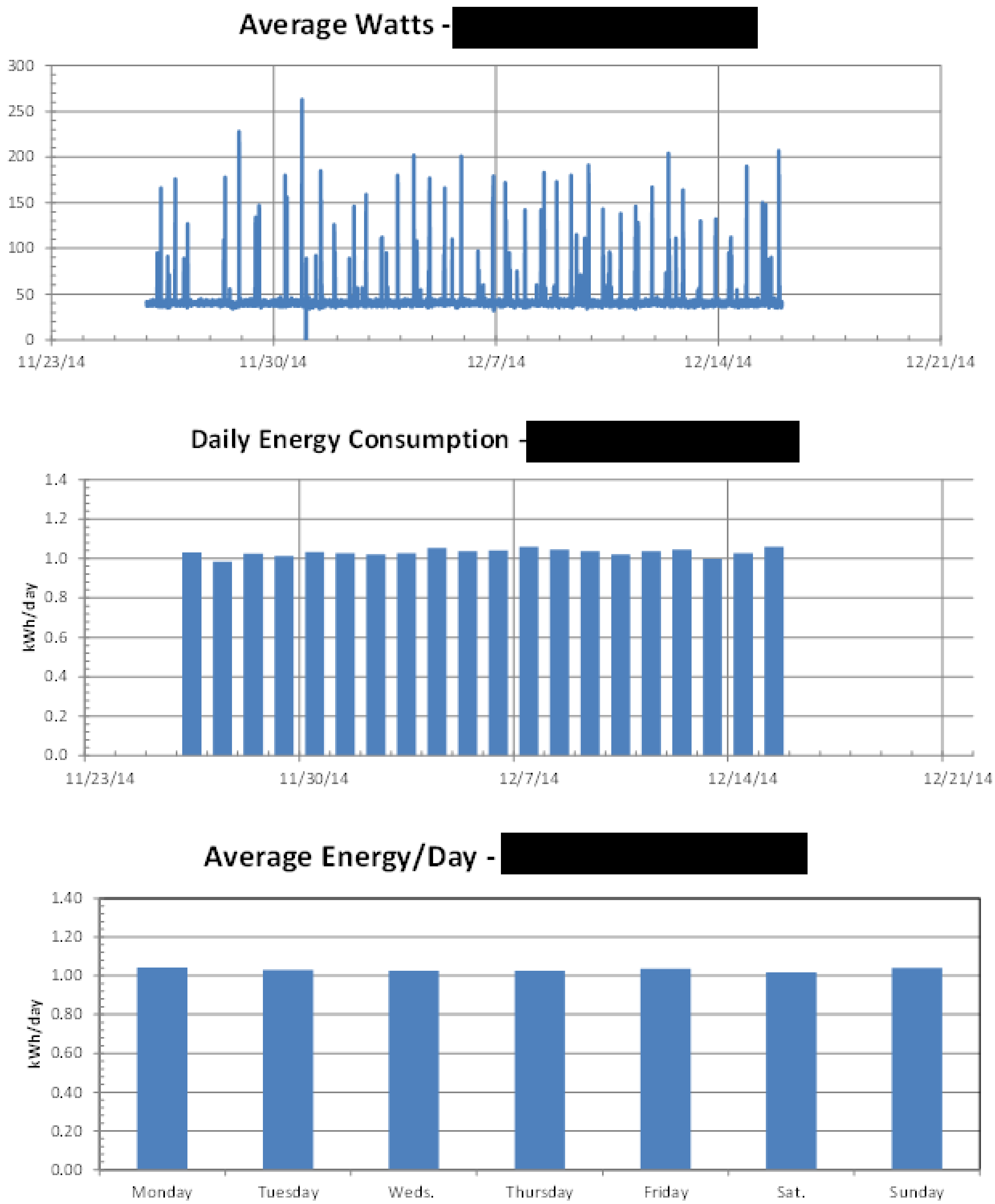


Figure 28: Data for [Redacted].

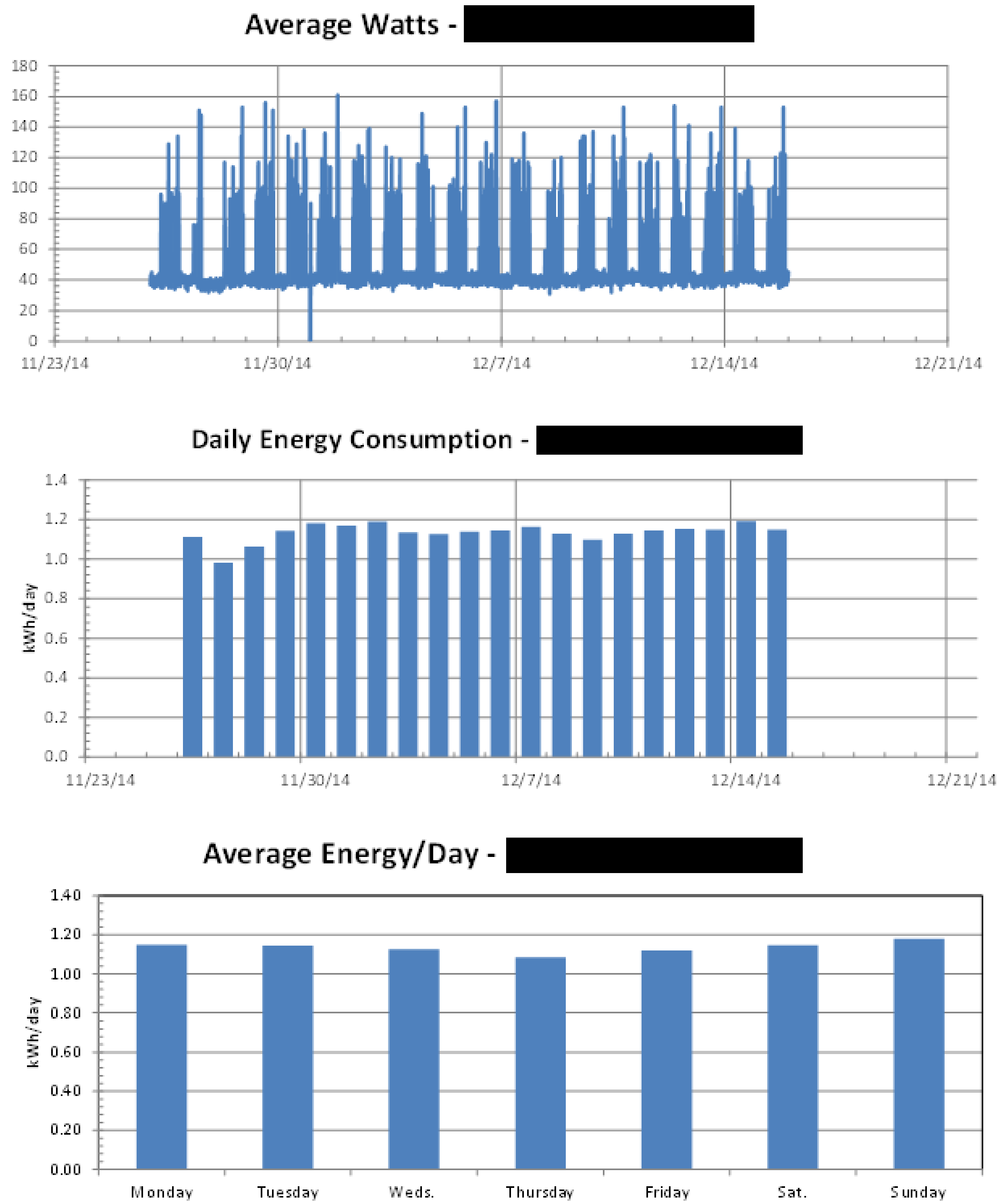
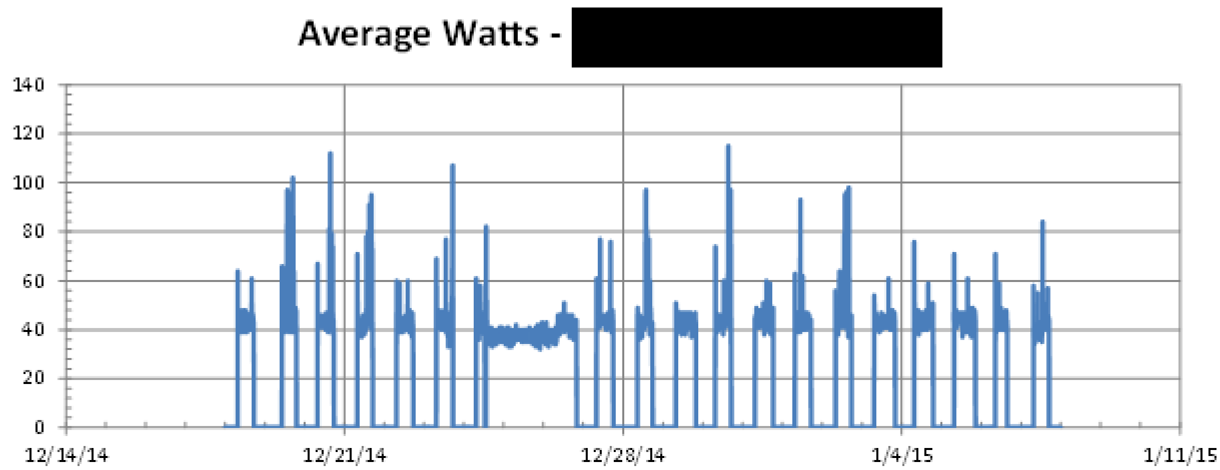
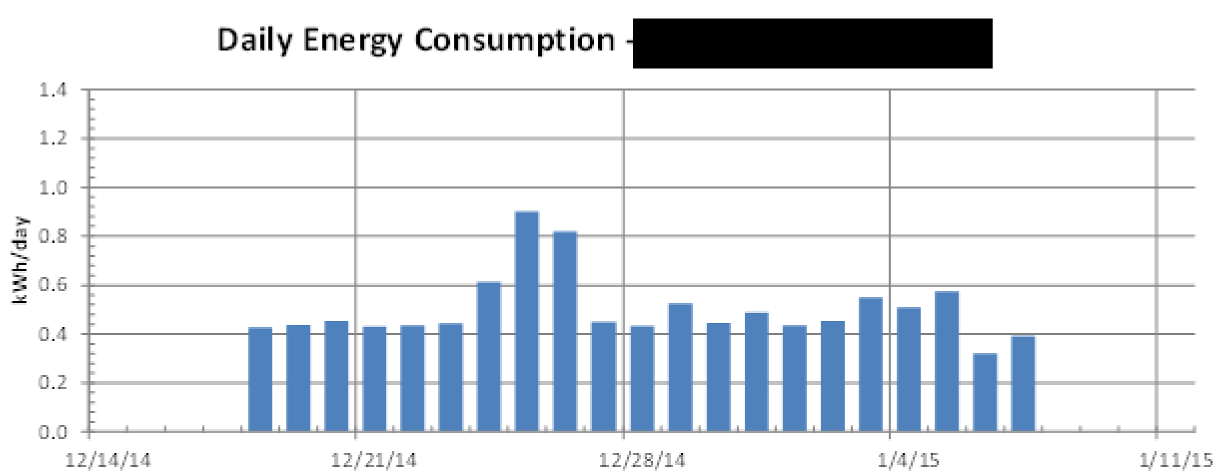


Figure 29: Data for [Redacted].





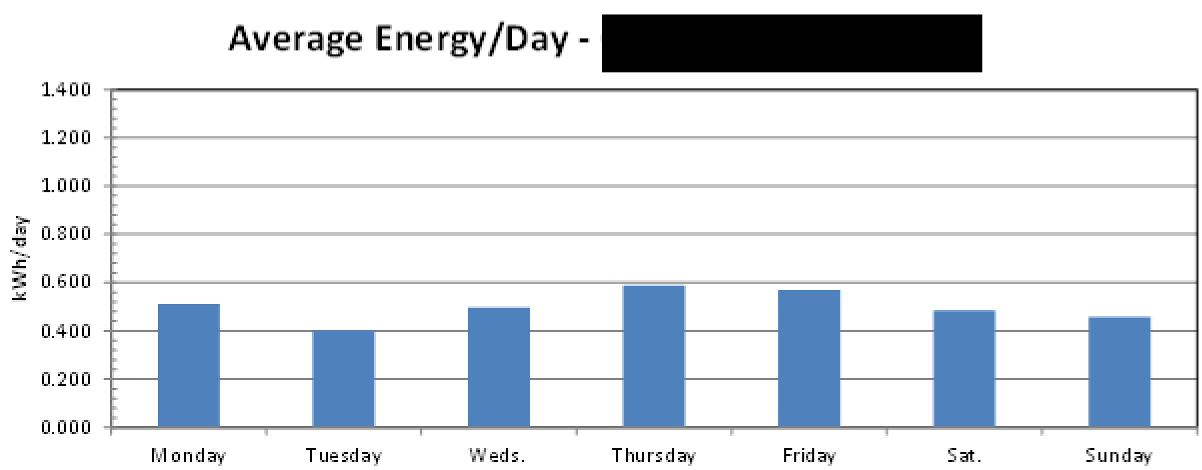
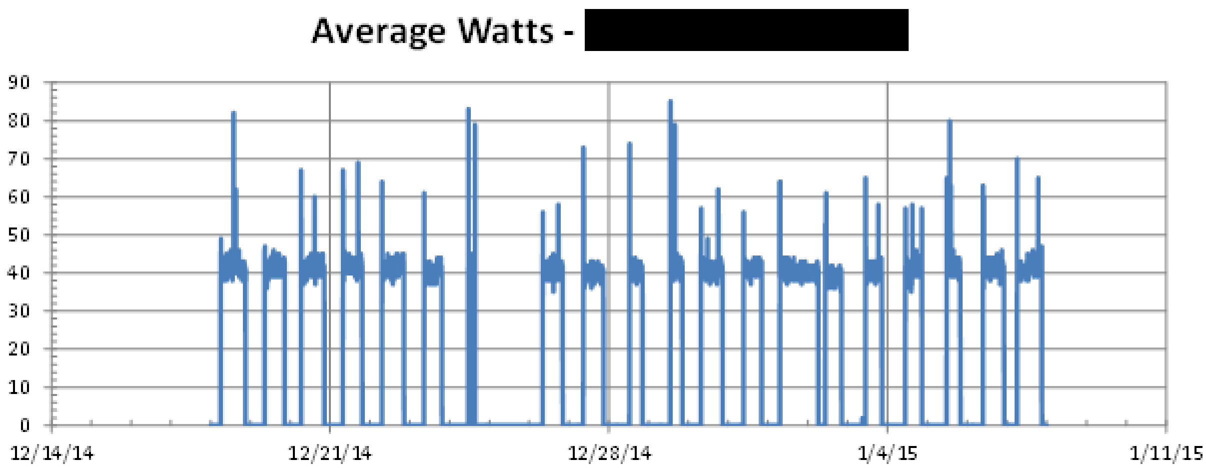
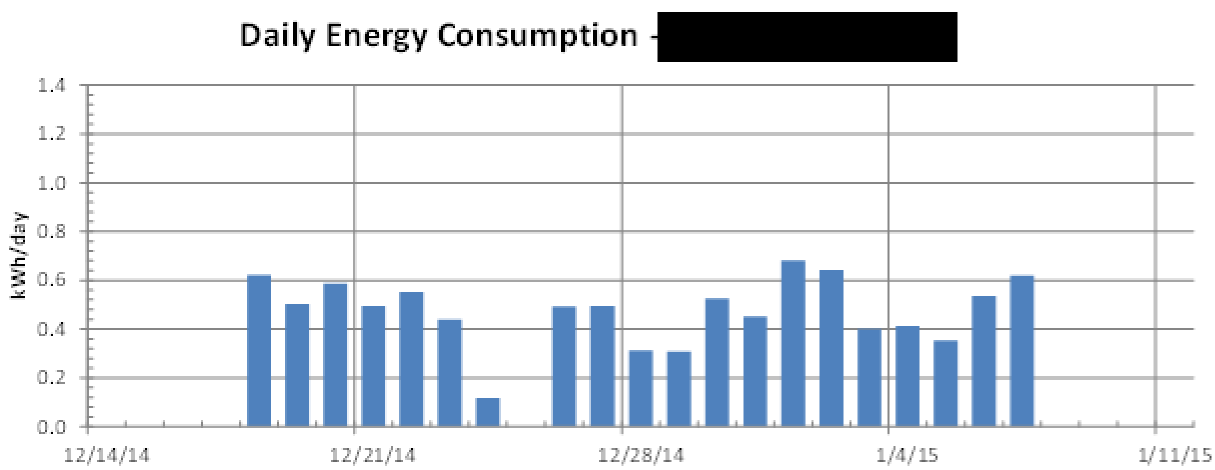


Figure 30: Data for [Redacted].





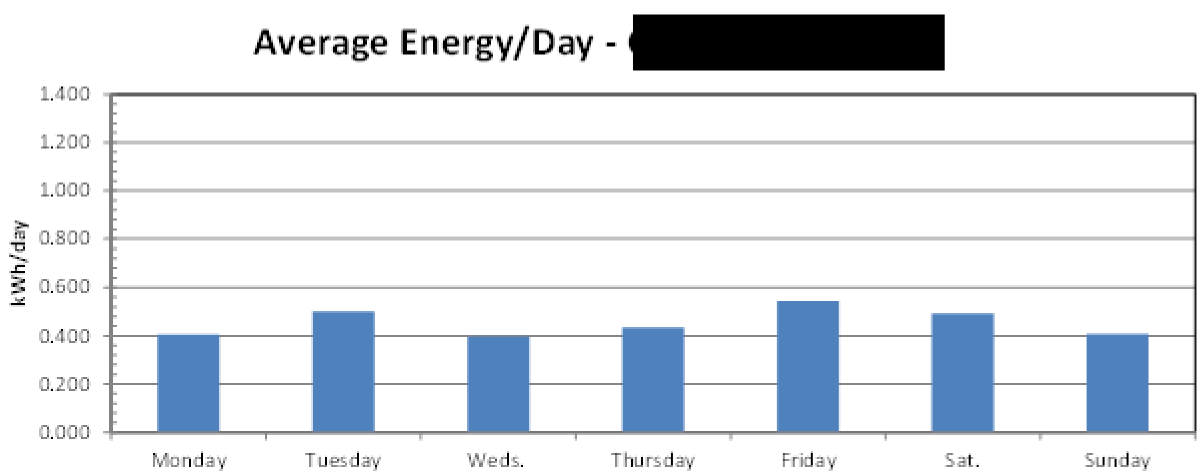


Figure 31: Data for [Redacted]

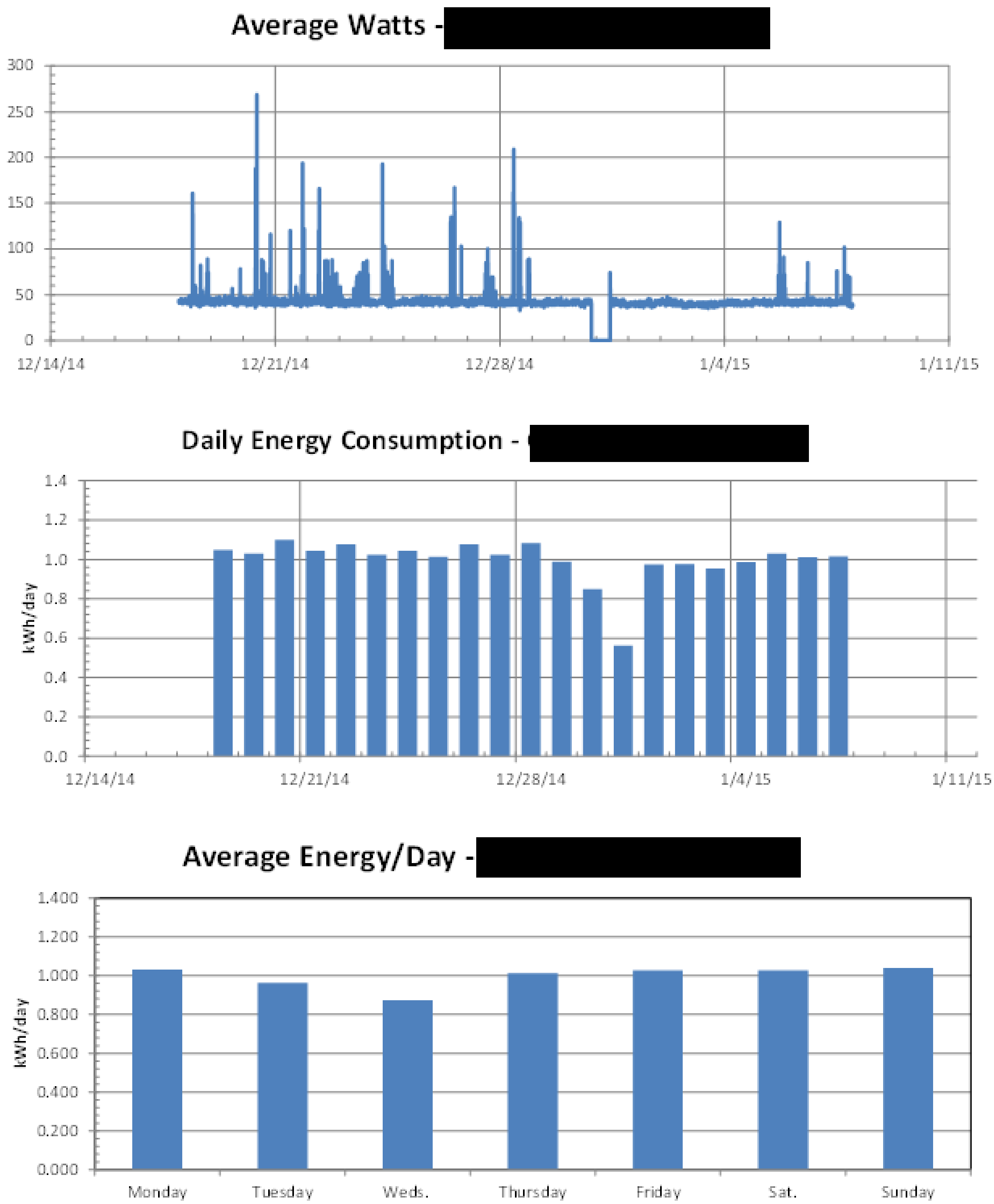
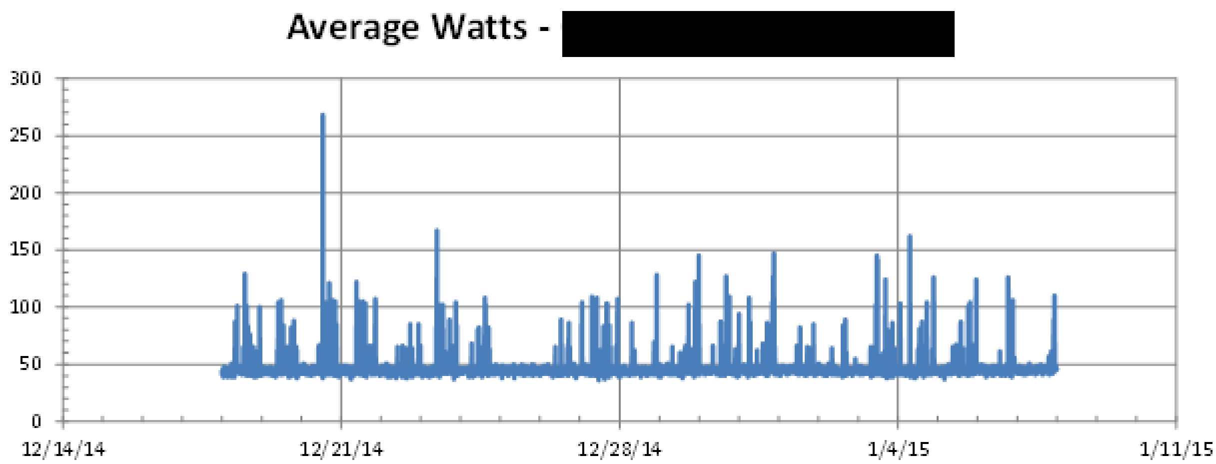
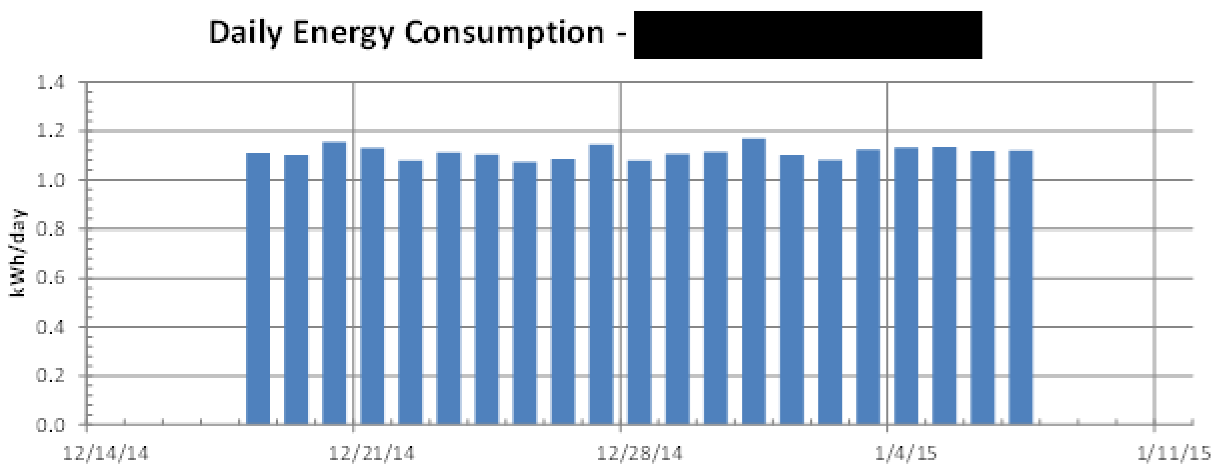
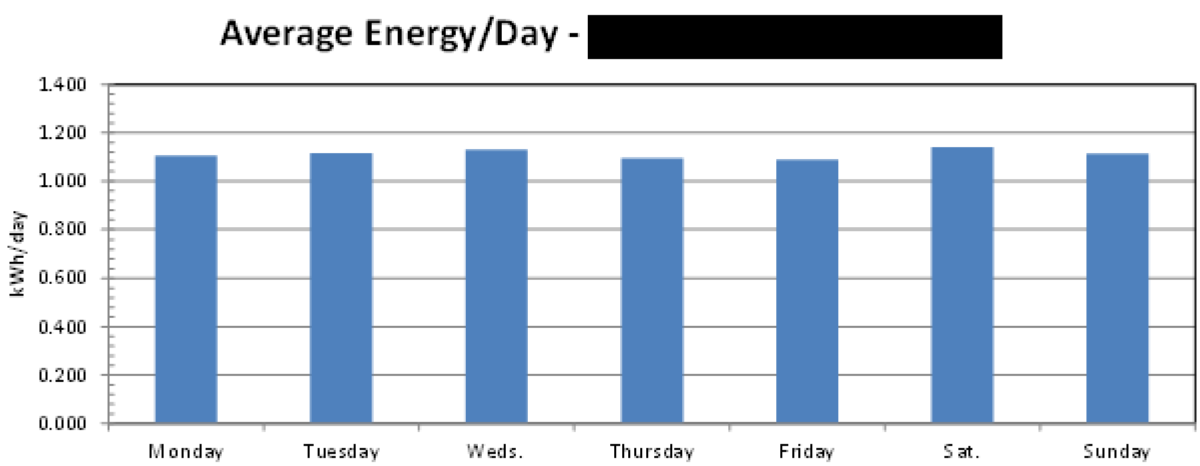


Figure 32: Data for [Redacted].







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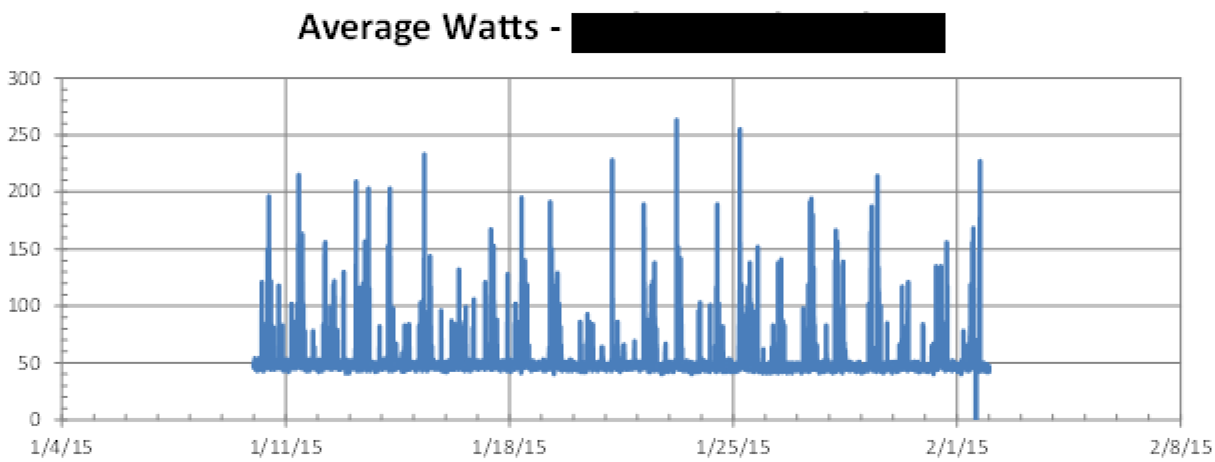

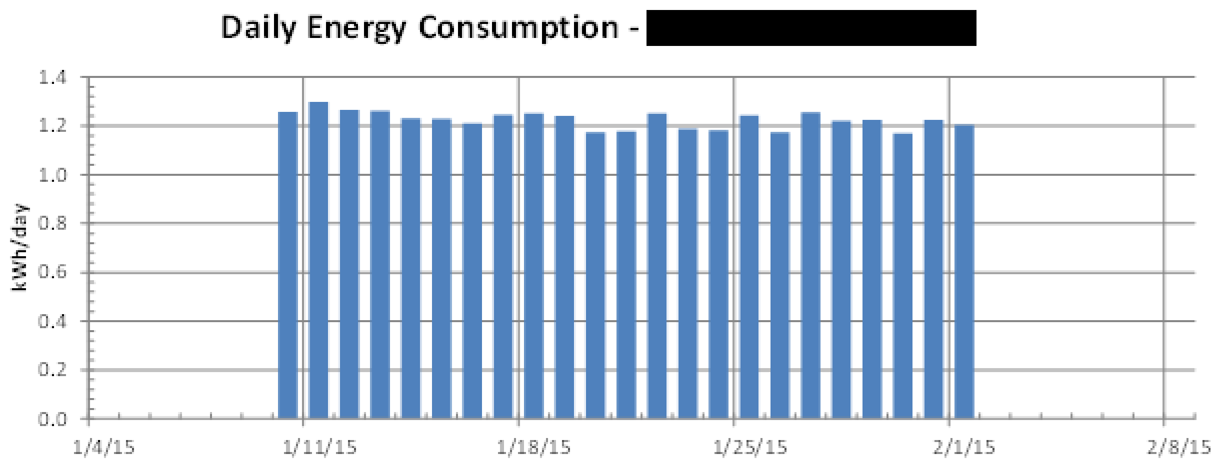

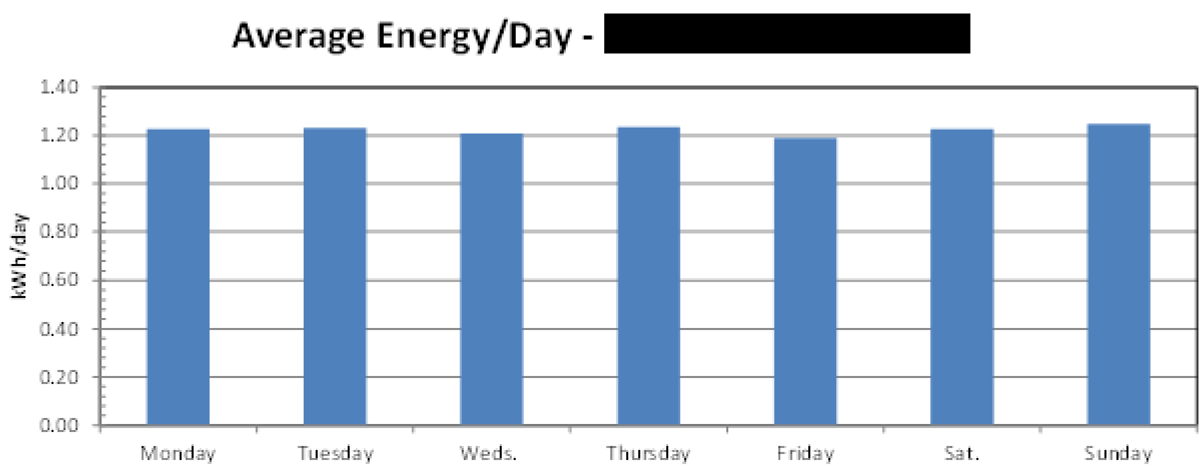

Figure 34: Data for [Redacted].

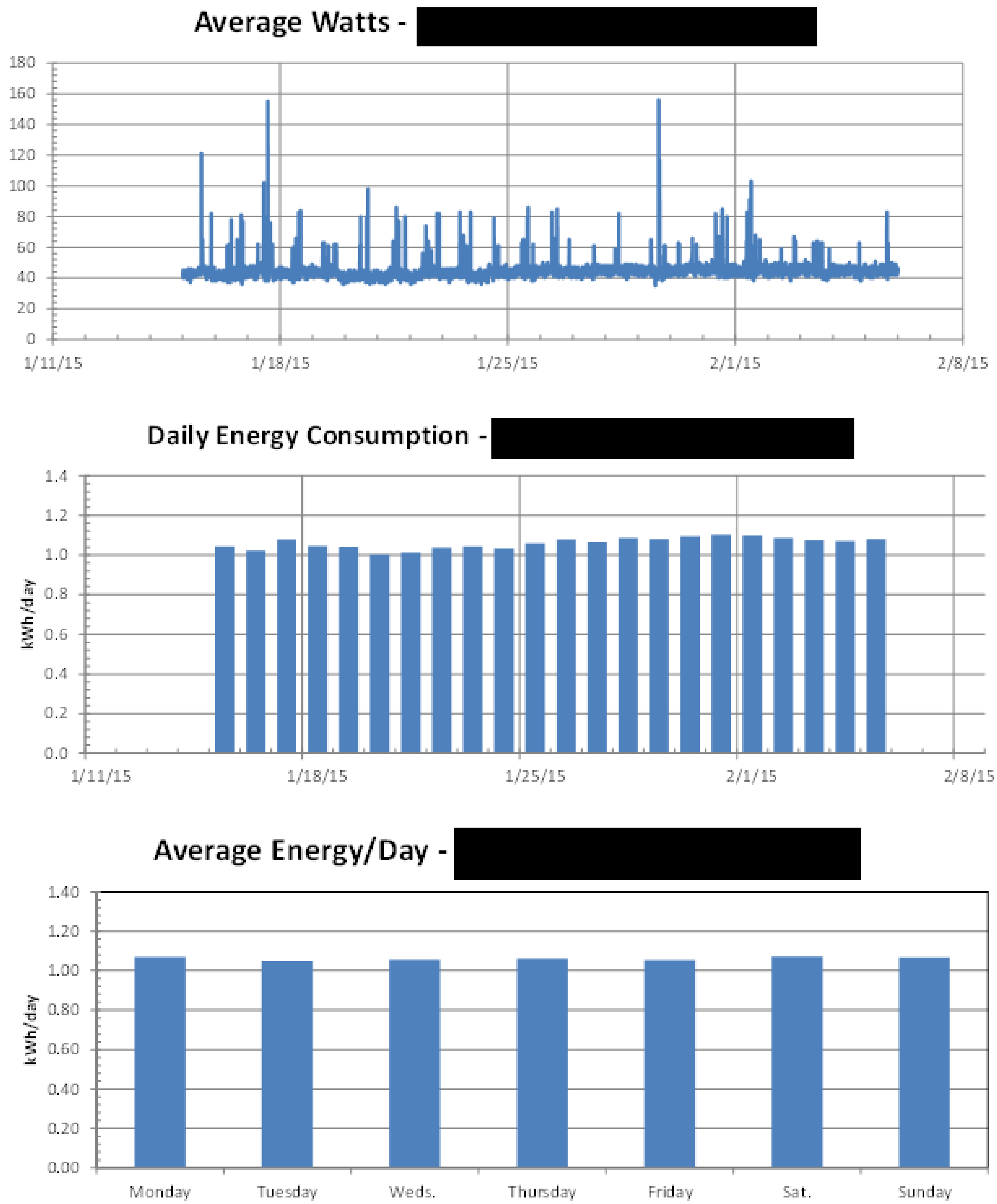

Figure 35: Data for [Redacted]

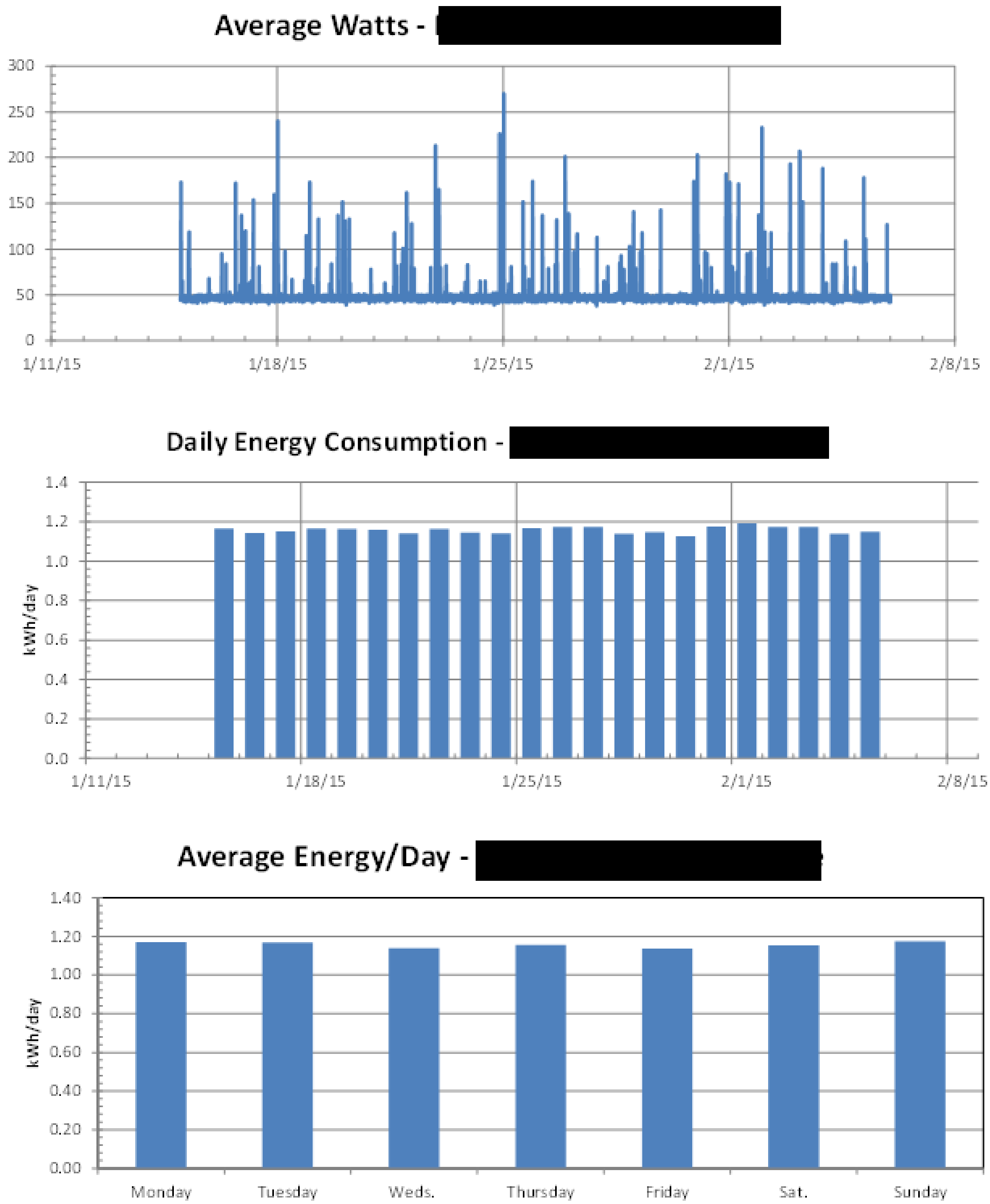

Figure 36: Data for [Redacted].

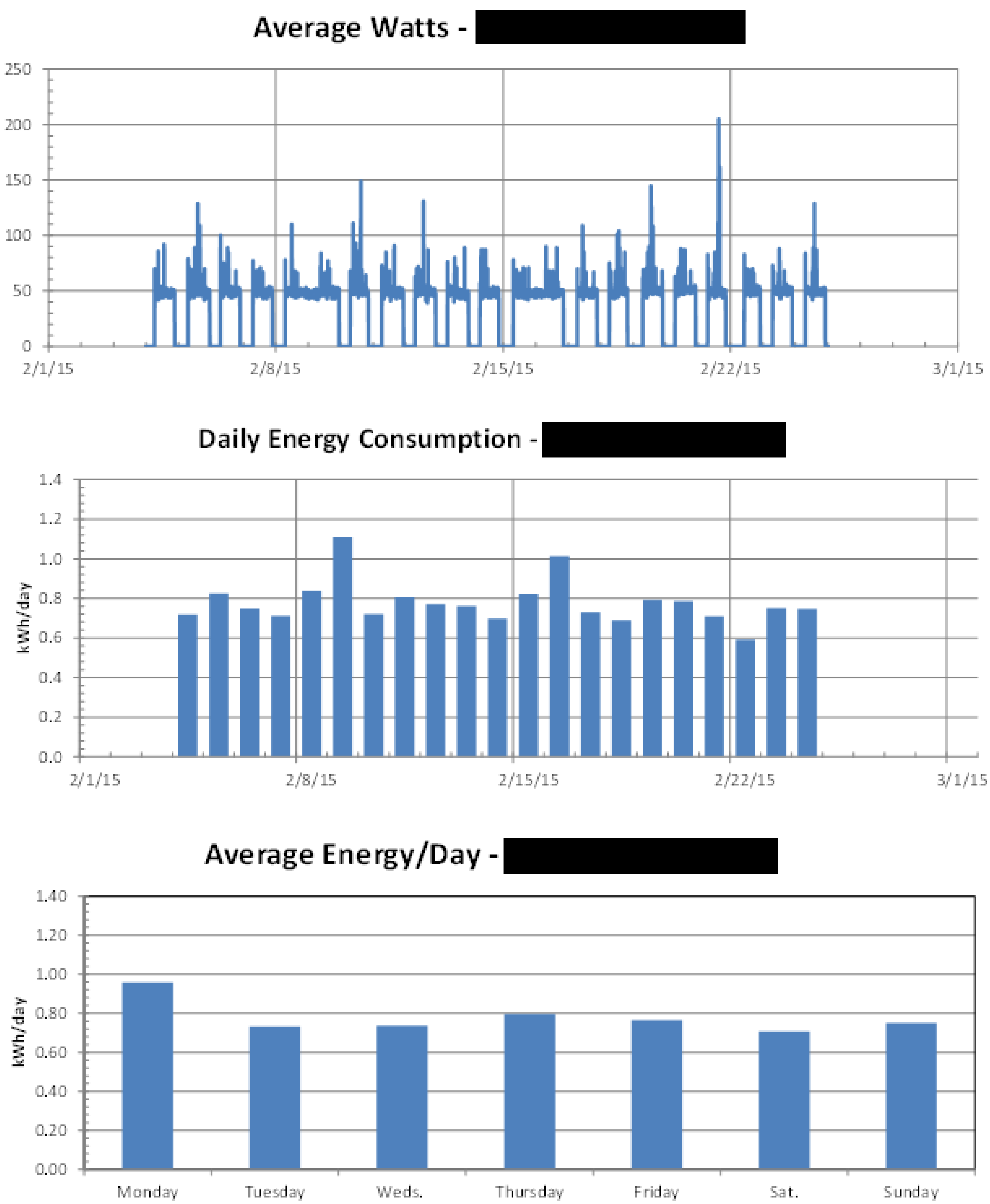

Figure 37: Data for [Redacted].

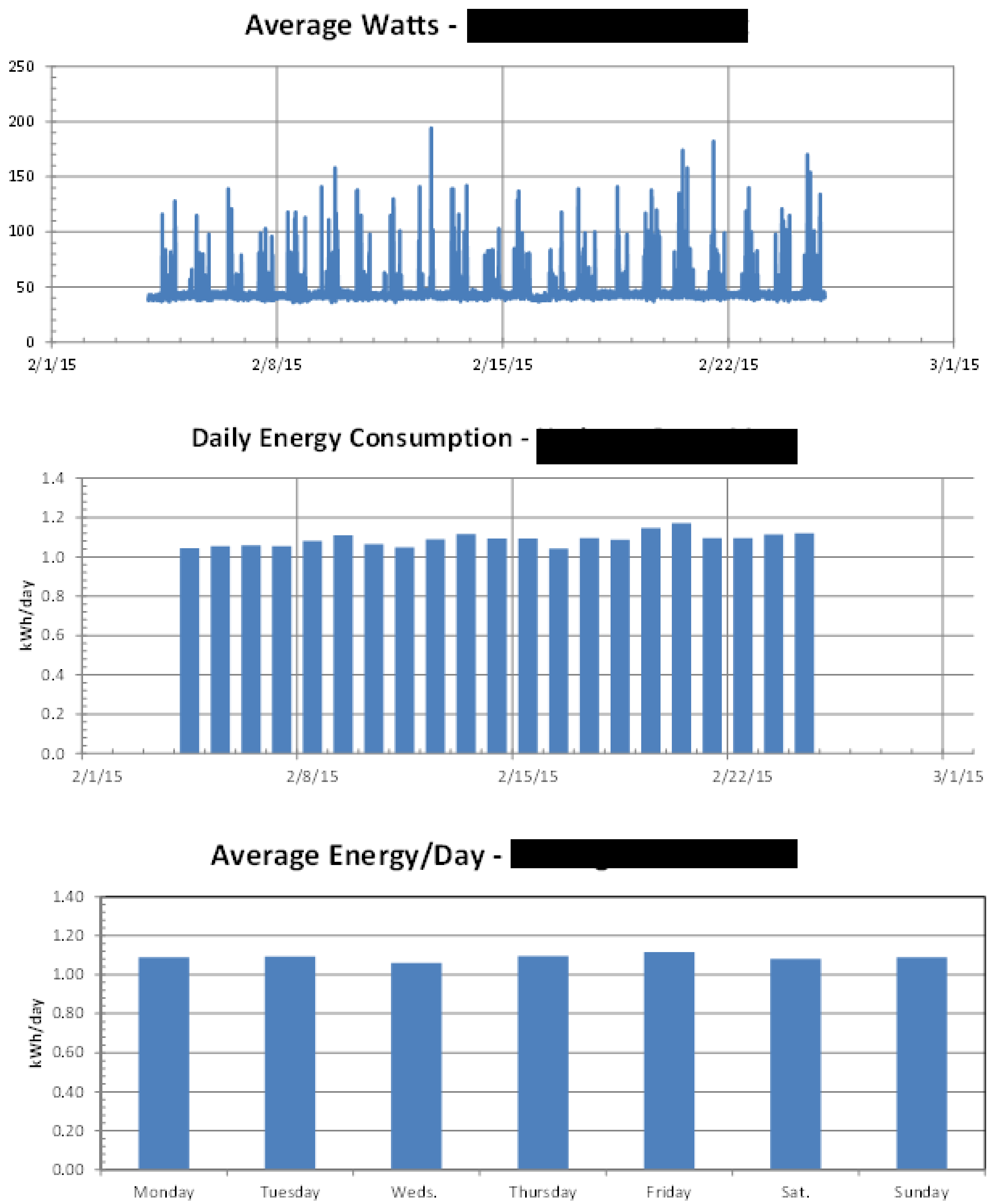

Figure 38: Data for [Redacted].

[Redacted]
Lighting Replacement
M&V Report

Prepared for
Duke Energy Ohio

May 2014

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

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

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

Submitted by:

Katie Gustafson
Architectural Energy Corporation

Stuart Waterbury
Architectural Energy Corporation

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Boulder CO
80301

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ARCHITECTURAL ENERGY CORPORATION

TABLE OF CONTENTS

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.

Proposed Custom Program Lighting					
ECM	**QTY**	**New**	**New Fixture Wattage**	**Application Hours of Operation**	**Expected Controls**
1	71	15W Twin Tube CFL	15	8760	Switch
2	1	4' 1L 25W T8	24	2002	Switch
3	127	4' 1L 25W T8	24	8760	Switch
4	72	28W Triple Tube CFL	28	3094	Switch
5	41	28W Triple Tube CFL	28	5096	Switch
6	30	28W Triple Tube CFL	28	5460	Switch
7	165	28W Triple Tube CFL	28	8760	Switch
8	18	4' 2L 25W T8	43	2000	Switch
9	79	4' 2L 25W T8	43	3094	Switch
10	45	4' 2L 25W T8	43	5096	Switch
11	155	4' 2L 25W T8	43	8760	Switch
12	16	4' 2L 50W T5HO	109	4368	Switch
13	31	4' 2L 50W T5HO	109	8760	Switch
14	1	4' 2L 25W T8	43	2000	Switch
15	25	4' 2L 25W T8	43	8760	Switch
16	4	4' 4L 25W T8	85	2000	Switch
17	4	4' 4L 25W T8	85	5096	Switch
18	8	4' 2L 50W T5HO	109	4368	Switch
19	156	4' 4L 50W T5HO	220	8760	Switch
20	2	2' 2L 15W T8	39	5460	Switch
21	7	4' 2L 25W T8	58	5460	Switch
22	147	4' 2L 25W T8	58	8760	Switch
23	24	4' 3L 50W T5HO	177	8760	Switch

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)
108,219	14	138,545	17.1

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

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

Project Contacts

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

Site Locations/ECM's

Address	ECM's Implemented
[Redacted]	1-23

Data Products and Project Output

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

M&V Option

IPMVP Option A

Field Data Points

Post-Installation

Survey data

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

Field Data Logging

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

ECM	Dent Light Loggers
4	1
5	1
6	1
8	2
10	2
13	1
15	2
20	1
21	1
22	2
Total	**14**

Data Analysis

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

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

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

Where

LF(t) = Lighting Load factor at time = t
$kWControlPoint_i$ = connected load of control point i
$Status_i$ = on/off status of control point i from time series data
N_{Logged} = population of logged control points
$N_{ControlPoints}$ = population of all control points

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

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

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

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

where:

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

- The savings with HVAC interactions are calculated from:

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

where:

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

Verification and Quality Control

1. Visually inspected lighting logger data for consistent operation. Sorted by day type and removed invalid data.

2. Verified the post retrofit lighting fixture specifications and quantities were consistent with the application.
3. Verified that pre-retrofit lighting fixtures were removed from the project. Inspected storeroom for replacement lamps or fixtures.

Recording and Data Exchange Format

1. Post-installation Lighting Survey Form and Notes.
2. DENT 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)	138,545	105,170	113,142	76%	82%
Peak Demand (kW)	17.1	13.4	16.9	78%	99%
CP Demand (kW)	16.3	12.6	16.0	77%	98%

The savings presented in the application for all accepted measures were 14kW NCP demand savings and 108,219 kWh energy savings. These savings do not take into account interactive effects with the HVAC system. It appears that the demand savings from the application was rounded up from 13.4 kW. 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 decreased operating hours discussed below, both contribute to the difference in energy savings, and consequently, a decreased energy realization rate.

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

Table 2. Summary of Energy and Demand Savings Calculations

<table>
<tr><th rowspan="4">Base kW</th><th rowspan="4">EE kW</th><th rowspan="4">HOURS</th><th rowspan="4">CF</th><th colspan="3" rowspan="3">Lighting Only</th><th></th><th>With HVAC interactions</th><th></th></tr>
<tr><th>WHFe=</th><td>0.0758</td><td></td></tr>
<tr><th>WHFd=</th><td>0.268</td><td></td></tr>
<tr><th>kWh savings</th><th>NCP kW</th><th>CP kW</th><th>kWh savings</th><th>NCP kW</th><th>CP kW</th></tr>
<tr><td>94.3</td><td>80.9</td><td>7875.8</td><td>0.94</td><td>105,170</td><td>13.4</td><td>12.6</td><td>113,142</td><td>16.9</td><td>16.0</td></tr>
</table>

- Used AEC-developed HVAC interaction factor for Big Box Store with gas heat, DX cooling and an economizer in OH.
- The pre and post wattages were nearly all based on cut sheets which were included with the application. For the one ECM where the cut sheet could not be located, Appendix B was used, as shown in Table 3.

The Duke application had six different space with unique annual hours of operation. These hours of operation ranged from 2,000 to 8,760 hours per year. We logged thirteen different spaces that covered five of the six various space types from the Duke application. We did not log the sixth space type because there was only one measure in the application that used these operating hours, and this measure made up less than one percent of the Duke estimated savings. For this measure, we used the realized hours of operation of the space type with the closet hours of operation estimate.

With our logged data, we determined the verified annual operating hours for each of the thirteen logged spaces. We then used the logged data to represent the pre and post wattages of the ECMs that were not logged based on space type.

We then used our standard lighting analysis template and determined the average weekday and weekend load shapes for all of the fixtures at [Redacted]. The average load shapes are weighted based on the post kW, meaning measures with greater post kW have more influence on the average load shape than measures with lesser post kW. Using the average load shapes, we determined the average annual operating hours and determined the realized annual energy savings.

The following figure shows the average daily load shape. When extrapolated to the year, the M&V annual operating hours are 7,875.8 which are one percent less than weighted hours from the application, which contributes to a realization rate less than 100 percent.

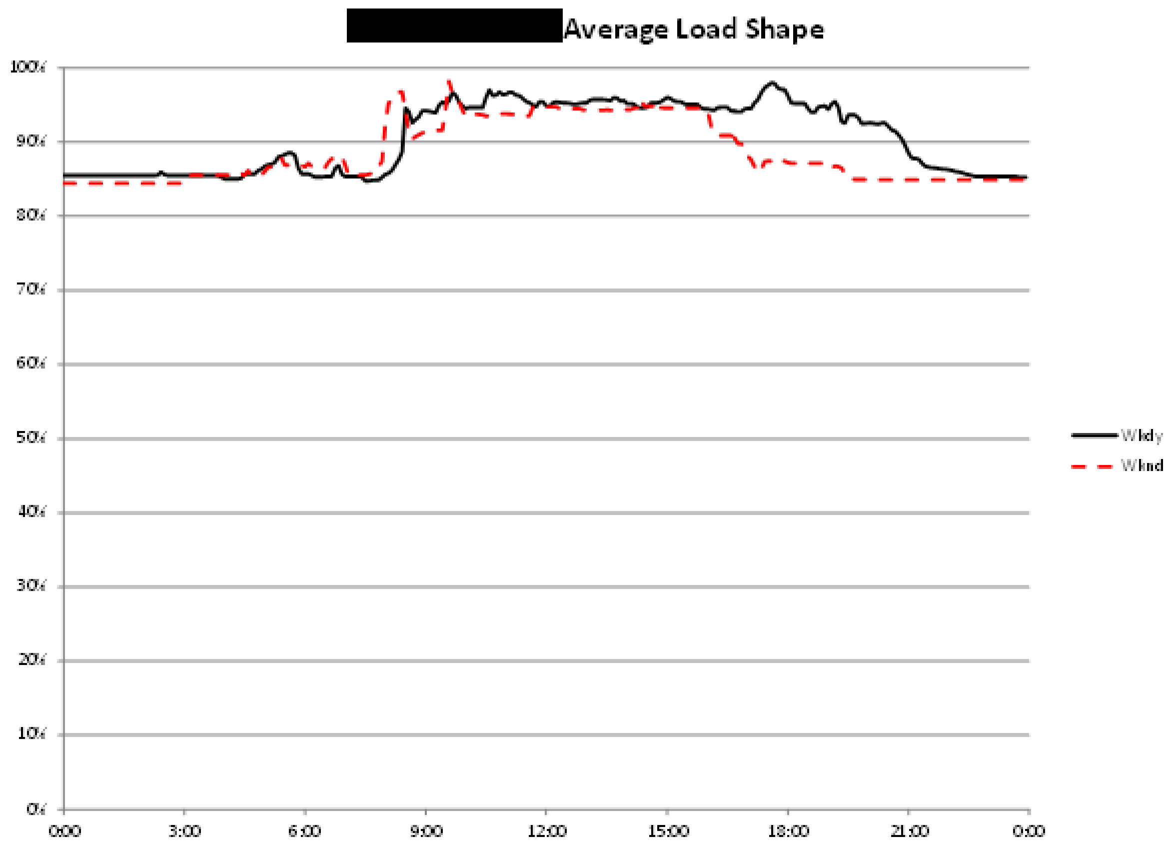
[redacted] Average Load Shape
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
0:00
3:00
6:00
9:00
12:00
15:00
18:00
21:00
0:00
Wkdy
Wknd

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	71	CF18 DDE 15W/841	15	Cut Sheet	1.1	71	CF18DD/E/841/ECO	18	Cut Sheet	1.3
2	1	FO32/25W/800/XV/ECO	24	Cut Sheet	0.0	1	FO32/28W/800/XV/ECO	28	Cut Sheet	0.0
3	127	FO32/25W/800/XV/ECO	24	Cut Sheet	3.0	127	FO32/28W/800/XV/ECO	28	Cut Sheet	3.6
4	72	CF32DT/E/IN/28W/841/SS/ECO	28	Cut Sheet	2.0	72	CF32DT/E/IN/841/ECO	32	Cut Sheet	2.3
5	41	CF32DT/E/IN/28W/841/SS/ECO	28	Cut Sheet	1.1	41	CF32DT/E/IN/841/ECO	32	Cut Sheet	1.3
6	30	CF32DT/E/IN/28W/841/SS/ECO	28	Cut Sheet	0.8	30	CF32DT/E/IN/841/ECO	32	Cut Sheet	1.0
7	165	CF32DT/E/IN/28W/841/SS/ECO	28	Cut Sheet	4.6	165	CF32DT/E/IN/841/ECO	32	Cut Sheet	5.3
8	18	FO32/25W/800/XV/ECO	43	Cut Sheet	0.8	18	FO32/28W/800/XV/ECO	48	Cut Sheet	0.9
9	79	FO32/25W/800/XV/ECO	43	Cut Sheet	3.4	79	FO32/28W/800/XV/ECO	48	Cut Sheet	3.8
10	45	FO32/25W/800/XV/ECO	43	Cut Sheet	1.9	45	FO32/28W/800/XV/ECO	48	Cut Sheet	2.2
11	155	FO32/25W/800/XV/ECO	43	Cut Sheet	6.7	155	FO32/28W/800/XV/ECO	48	Cut Sheet	7.4
12	16	FP54/50W/841/HO/SS/ECO	109	Cut Sheet	1.7	16	FP54/841/HO/SS/ECO	120	Cut Sheet	1.9
13	31	FP54/50W/841/HO/SS/ECO	109	Cut Sheet	3.4	31	FP54/841/HO/SS/ECO	120	Cut Sheet	3.7
14	1	FO32/25W/800/XV/ECO	43	Cut Sheet	0.0	1	FO32/28W/800/XV/ECO	72	Cut Sheet	0.1
15	25	FO32/25W/800/XV/ECO	43	Cut Sheet	1.1	25	FO32/28W/800/XV/ECO	72	Cut Sheet	1.8
16	4	FO32/25W/800/XV/ECO	85	Cut Sheet	0.3	4	FO32/28W/800/XV/ECO	97	Cut Sheet	0.4
17	4	FO32/25W/800/XV/ECO	85	Cut Sheet	0.3	4	FO32/28W/800/XV/ECO	97	Cut Sheet	0.4
18	8	FP54/50W/841/HO/SS/ECO	109	Cut Sheet	0.9	8	FP54/841/HO/SS/ECO	120	Cut Sheet	1.0
19	156	FP54/50W/841/HO/SS/ECO	220	Cut Sheet	34.3	156	FP54/841/HO/SS/ECO	234	Cut Sheet	36.5
20	2	FO17/15W/800XP/SS/ECO3	39	Cut Sheet	0.1	2	31W T8 U-bend	90.1	SPC Apdx B	0.2
21	7	FO32/25W/800/XV/ECO	58	Cut Sheet	0.4	7	FO32/28W/800/XV/ECO	97	Cut Sheet	0.7
22	147	FO32/25W/800/XV/ECO	58	Cut Sheet	8.5	147	FO32/28W/800/XV/ECO	96.6	Cut Sheet	14.2
23	24	FP54/50W/841/HO/SS/ECO	177	Cut Sheet	4.2	24	FP54/841/HO/SS/ECO	186.3	Cut Sheet	4.5
Total					80.9					94.3

Notes:

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

[Redacted]
New Air Compressor VFD
M&V Report

Prepared for
Duke Energy Ohio

February 2015, Version 1.0

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

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

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

Submitted by:

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United Technologies

Introduction

This plan addresses M&V activities for the [Redacted] custom program application. The application covers a new air compressor upgrade in Fairfield, Ohio. The measure includes the following:

ECM-1: Air Compressor VFD Retrofit

- Replace an existing 100 HP compressor having load/no-load controls with a new 100 HP air compressor with a variable speed drive.
- In the pre-retrofit case, both the existing 100 HP compressor and a 50-HP compressor were operated. The 50-HP compressor also had load/no-load controls.
- In the post-retrofit case, only the new 100 HP VFD compressor is operated (it has a higher capacity than the existing compressor). The 50-HP compressor is either not operated or is a backup.

The project was completed in July, 2012.

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)
235,144	65.3	98,972	11.3	11.3

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	ddougherty@noresco.com	o: 303-459-7416 c: 303-819-8888
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 Location

Address
[Redacted]

Data Products and Project Output

- Average pre-retrofit and post-retrofit 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

- Interviewed site personnel to obtain information on pre- and post-retrofit system operations.
    - Obtained the pre-retrofit operating schedule for the compressed air system.
    - Verified whether the 50-HP compressor is either removed from the site, is not operated or is a backup. *It is a backup and was off at the time of the site visit. The site contact did not anticipate that it would be operated during the monitoring period.*

   - Obtained and verified the post-retrofit sequence of operations and/or operating schedule for the new compressed air system.
   - NOTE any differences between pre- and post-retrofit operations resulting from changes in production or operating schedules.
- Deployed a data logger to record electrical parameters on the retrofit compressor. Due to a logger failure, and customer refusal of a re-deployment of the logger, no time-series data was collected. Therefore, an alternative calculation was used which used pre-retrofit load data that was collected during the application process.
- Collected spot-watt data during normal operating hours.
- Evaluated the energy savings of the compressor replacement.

Field Data Points

<u>Post – installation only</u>

Data was to be collected for the 100 HP VFD compressor, and for the pre-existing 50-HP compressor, if it is in service. *The 50-HP compressor was not in service and no measurements were taken.*

Survey data

- Compressor make/model/serial number
- Photographs of compressors and nameplates.

One-time spot measurements

- Compressor volts, amps, kW and power factor

Field Data Logging

<u>Post – installation only</u>

ECM-1

- Spot measured 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. *Data was not available.*
- Installed one ElitePro power/energy data logger on the 100-hp compressor compressor that was to be monitored. *Due to the logger failure and the customer refusal to allow re-deployment of the logger, no post-retrofit trend data was collected.*

Data Analysis

Due to logger failure and customer refusal to allow additional data collection, no logged data was collected. A desk review of the application and supporting documentation was conducted, along with an independent calculation of energy savings.

1. Established a pre-retrofit load shape (characterized by CFM readings over time) using daily charts of flow data provided with the application documents. The charts covered one week of recorded data. Estimated the average CFM for each 15-minute interval of data.

2. Binned the established pre-retrofit CFM load shape into 20-CFM bins, and determined the average flow and the amount of time per week the CA system was operated in each bin.

3. Using the bin data and information obtained from the manufacturer about the capacity and power requirements of the existing compressors, applied an efficiency curve for load/no-load controls to establish pre-retrofit power levels and energy consumption.

4. Using the bin data and information supplied in the application documents about the capacity and power requirements of the VFD compressor, applied an efficiency curve for the VFD controlled air compressor to establish post-retrofit power levels and energy consumption.

5. Determined the maximum average 15-minute air flow, determined the maximum power demand for both the pre-and post-retrofit compressor systems, and for both overall demand and coincident peak demand.

6. Determined the overall energy (kWh), coincident peak demand (kW) and non-coincident peak demand (kW) savings as the differences between the pre-and post-retrofit values of these quantities.

7. Compared the savings found above to Duke Energy’s anticipated savings to determine the realization rate for each savings value.

Recording and Data Exchange Format

1. Excel spreadsheets

Results

This project involved retrofitting an existing 100 HP compressor having load/no-load controls with a new variable speed drive. In the pre-retrofit case, both the existing 100 HP compressor and a 50-HP compressor were operated. The 50-HP compressor also had load/no-load controls. In the post-retrofit case, only the new 100 HP VFD compressor is operated. The new compressor has a higher airflow capacity than the old compressor had, and is capable of handling the entire air load by itself. The 50-HP compressor is either not operated or is a backup.

As was stated earlier, post-retrofit logger compressor data was not available for this site. An alternative, independent calculation was performed using pre-retrofit time-series air load data provided with the application.

An “Air Study” that was provided with the application documents included some basic information for the two compressors, and charts of compressed air demand (CFM) trend data for seven days. The available compressor information from the air study is presented in the following table, along with additional information as noted.

Table 1: Baseline Compressor Equipment Specifications

Number of Compressors	2		Units	Source
Configuration:	Lead/Lag (i.e. Base/Trim)			
	Base Compressor	**Trim Compressor**		
Make	ATLAS COPCO	ATLAS COPCO	-	1
Model	GA75 Elek	GA37 Elek	-	1
Full Load Operating Pressure:	125	125	psi	3
System Pressure	115	115	psi	3
Max CFM	420	210	CFM	1
Compressor Motor Nominal HP (reference only)	110	55	hp	1
Compressor Motor Efficiency (reference only)	94.5%	93.6%	%	3
Total Package Full Load kW	82.0	41.1	kW	2
Total Package Input Power at Zero Flow	62.6	14.1	kW	2
Compressor Control Type	Load/No-load, 1 gal/CFM	Load/No-load, 1 gal/CFM	-	4

Sources

1. Stated in the Application documents.
2. Derived from Application documents.
3. Compressed Air and Gas Institute (CAGI) Compressor Data Sheets (obtained from mfr's website). This data is for equipment that is the closest match for the application's information, although it is probably for newer equipment than existed at the project site.
4. The results match the (application's) baseline energy usage best when using this load/no-load storage selection.

From the air study, a composite air demand chart for the week is presented in the following figure. Separate charts for each day were also included. The charts provide only the total air load; there is no breakdown of the load history by compressor. According to the air study, the smaller compressor only ran for 52 hours during the week, and only nine of those hours were loaded hours. We assume that these load times occurred when the demand exceeded the rated capacity of the larger compressor.

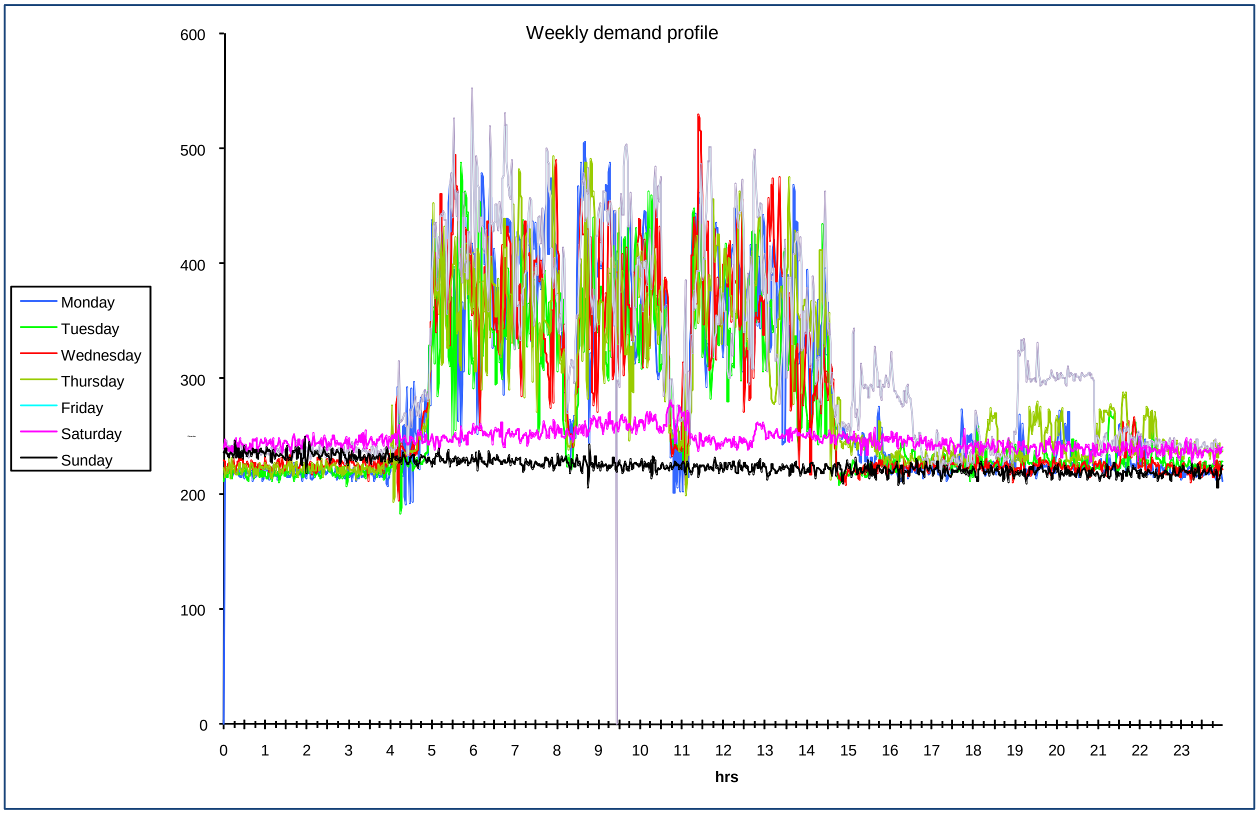


Figure 1: One-Week Composite Air Demand History – Pre-Retrofit

In order to estimate the post-retrofit energy consumption, a weekly air load (delivered air in CFM) profile was created from the daily pre-retrofit data. The weekly profile is found by determining hour many hours during the week the compressor delivers a particular amount of air.

To determine the load profile, each of the application's daily charts was overlaid with a second chart on which an estimated average load was plotted at 15-minute intervals. These daily charts and overlays are presented at the end of this report. The solid lines are the original data plots, and the dashes are the estimated average power in each 15-minute interval.

Using the 15-minute overlays, the number of occurrences at each power level were tallied and converted to hours of operation. These hours were further binned into 20-CFM ranges, resulting in the weekly distribution presented in the following chart.

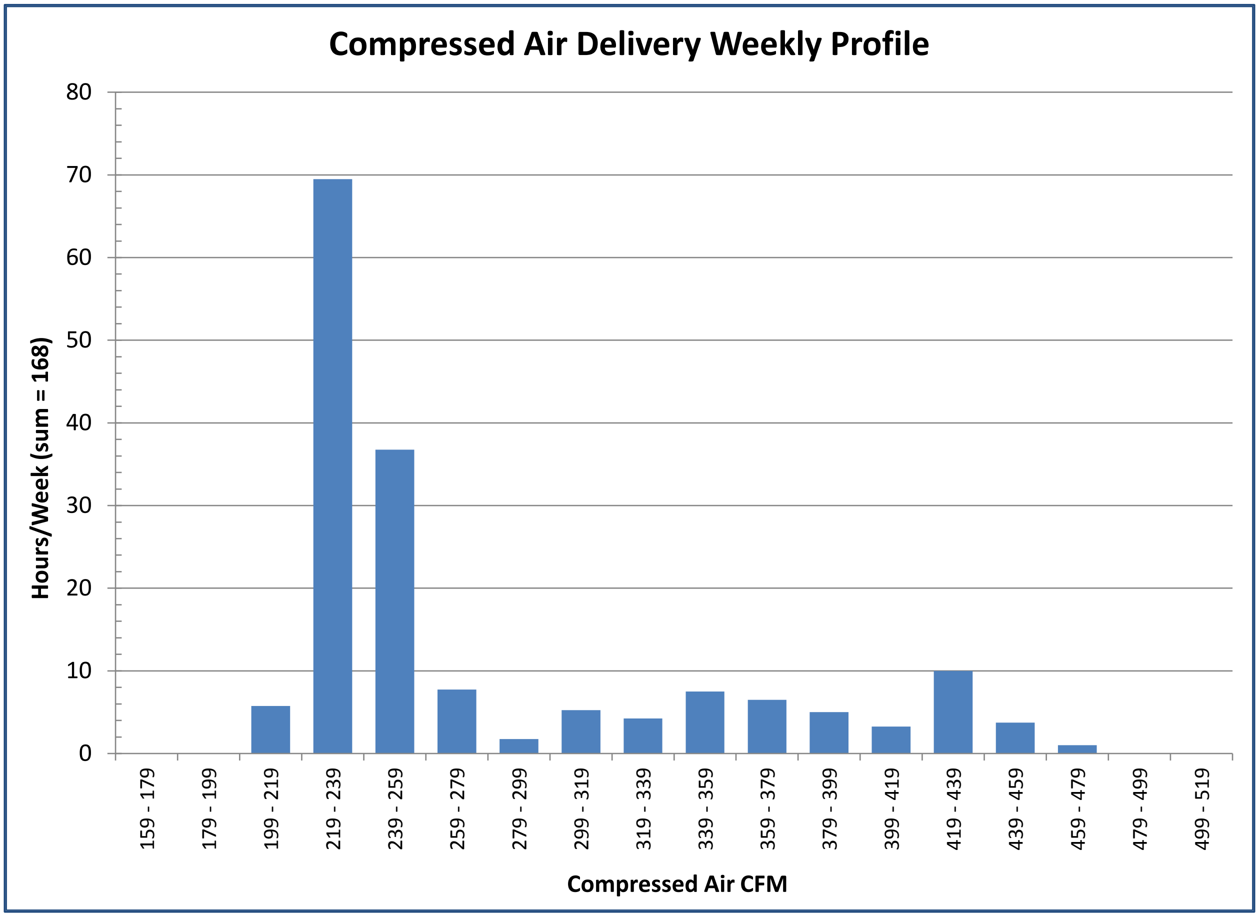


Figure 2: Compressed Air Delivery Weekly Profile – 20-CFM Bins

For each bin, the average compressed air flow was also determined. This information is presented in the following table.

Table 2: Compressed Air Load Profile

Hours / Week	Hours / Year	CA CFM	% of Total Baseline Compressor Capacity
5.75	300	215.0	34.1%
69.5	3,585	225.8	35.8%
36.75	1,955	245.4	38.9%
7.75	404	265.5	42.1%
1.75	91	286.4	45.5%
5.25	274	303.3	48.1%
4.25	222	325.3	51.6%
7.50	391	346.3	55.0%
6.50	339	365.0	57.9%
5.00	261	384.8	61.1%
3.25	169	401.5	63.7%
10.00	521	426.9	67.8%
3.75	196	445.3	70.7%
1.00	52	462.5	73.4%
168.0	8,760		

The compressor electric power (in kW) depends on the CFM delivered and also the compressor's control method. Curves and tables of part-load efficiency, or the percent of full-load power as a function of full-load air delivery, are available from a number of sources (e.g., National Renewable Energy Laboratory (NREL), The Uniform Methods Project, Chapter 22: Compressed Air Evaluation Protocol, or "Best Practices for Compressed Air Systems," www.compressedairchallenge.org). In this case, the existing compressor had load/no-load controls and the new compressor has a variable frequency drive. For the pre-retrofit case, applying a load/no-load efficiency curve to the load profile developed above results in the power levels and energy consumption, per compressor, shown in the table on the next page. The trim compressor is assumed to operate when the air load exceeds the base compressor's capacity.

Table 3: Baseline Compressor Performance

		Base Compressor					Trim Compressor					Total	
Hours per Week	Compressed Air Load (CFM)	Air Load (CFM)	Percent of full Capacity	Percent of Full Load Power (kW)	Power Demand (kW)	Weekly Energy (kWh)	Air Load (CFM)	Percent of full Capacity	Percent of full load (kW)	Power Demand (kW)	Weekly Energy (kWh)	Power Demand (kW)	Weekly Energy (kWh)
5.75	215	215	51%	87.6%	72.1	416						72.1	416
69.5	226	226	54%	88.9%	73.1	5,096						73.1	5,096
36.75	245	245	58%	91.2%	75.0	2,763						75.0	2,763
7.75	265	265	63%	93.0%	76.4	594						76.4	594
1.75	286	286	68%	94.5%	77.6	136						77.6	136
5.25	303	303	72%	95.6%	78.5	413						78.5	413
4.25	325	325	77%	97.0%	79.6	339						79.6	339
7.50	346	346	82%	98.5%	80.8	608						80.8	608
6.50	365	365	87%	99.4%	81.5	531						81.5	531
5.00	385	385	92%	100.0%	82.0	411						82.0	411
3.25	402	402	96%	100.0%	82.0	267						82.0	267
10.00	427	420	100%	100.0%	82.0	822	7	3%	32.9%	14.4	145	96.4	967
3.75	445	420	100%	100.0%	82.0	308	25	12%	50.5%	21.4	81	103.4	389
1.00	463	420	100%	100.0%	82.0	82	43	20%	64.2%	26.9	27	108.9	109
Weekly Compressor Energy Usage						12,787					252		13,039
Total Annual Energy Usage (kWh/year)													678,020

A similar calculation was performed for the post-retrofit VFD compressor. The table below summarizes the features of this compressor.

Table 4: Efficient Compressor Equipment Specifications

	Base Compressor	Trim Compressor	
Make	ATLAS COPCO	None	Units
Model	GA 75 VFD		
Full Load Operating Pressure:	102		psi
System Pressure	189		psi
Max CFM	519		CFM
Compressor Motor Nominal HP (reference only)	100		hp
Compressor Motor Efficiency (reference only)	95.0%		%
Total Package Full Load kW	91.6		kW
Total Package Input Power at Zero Flow	0.0		kW
Compressor Control Type	Variable Speed		

Source: CAGI Compressor Data Sheet included with application.

The new compressor specifications result in the performance summarized in the following table.

Table 5: Retrofit Equipment Performance

		100-HP Compressor Only				
Hours per Week	Compressed Air Load (CFM)	Air Load (CFM)	Percent of full Capacity	Percent of full load kW	Power Demand (kW)	Weekly Energy (kWh)
5.75	215	215	41%	47.1%	44.2	255
69.5	226	226	44%	48.8%	45.7	3,186
36.75	245	245	47%	51.8%	48.4	1,785
7.75	265	265	51%	55.0%	51.3	399
1.75	286	286	55%	58.7%	54.6	96
5.25	303	303	58%	61.6%	57.2	301
4.25	325	325	63%	64.9%	60.1	256
7.50	346	346	67%	67.7%	62.7	471
6.50	365	365	70%	70.3%	65.0	423
5.00	385	385	74%	73.7%	68.0	341
3.25	402	402	77%	76.6%	70.7	230
10.00	427	427	82%	82.2%	75.7	759
3.75	445	445	86%	85.8%	78.9	297
1.00	463	463	89%	89.1%	81.8	82
Weekly Compressor Energy Usage						8,881
Total Annual Energy Usage (kWh/year)						**461,794**
Baseline Total Annual Energy Usage (kWh/year)						678,020
Total Annual Energy Savings (kWh/year)						**216,227**

From Table 3 and Table 5, the pre- and post-retrofit power profiles can be plotted. The chart below shows the total electric demand (kW) for each case as a function of the air demand (CFM). The VFD on the 100-hp compressor has clearly reduced the total power requirement at all air flows.

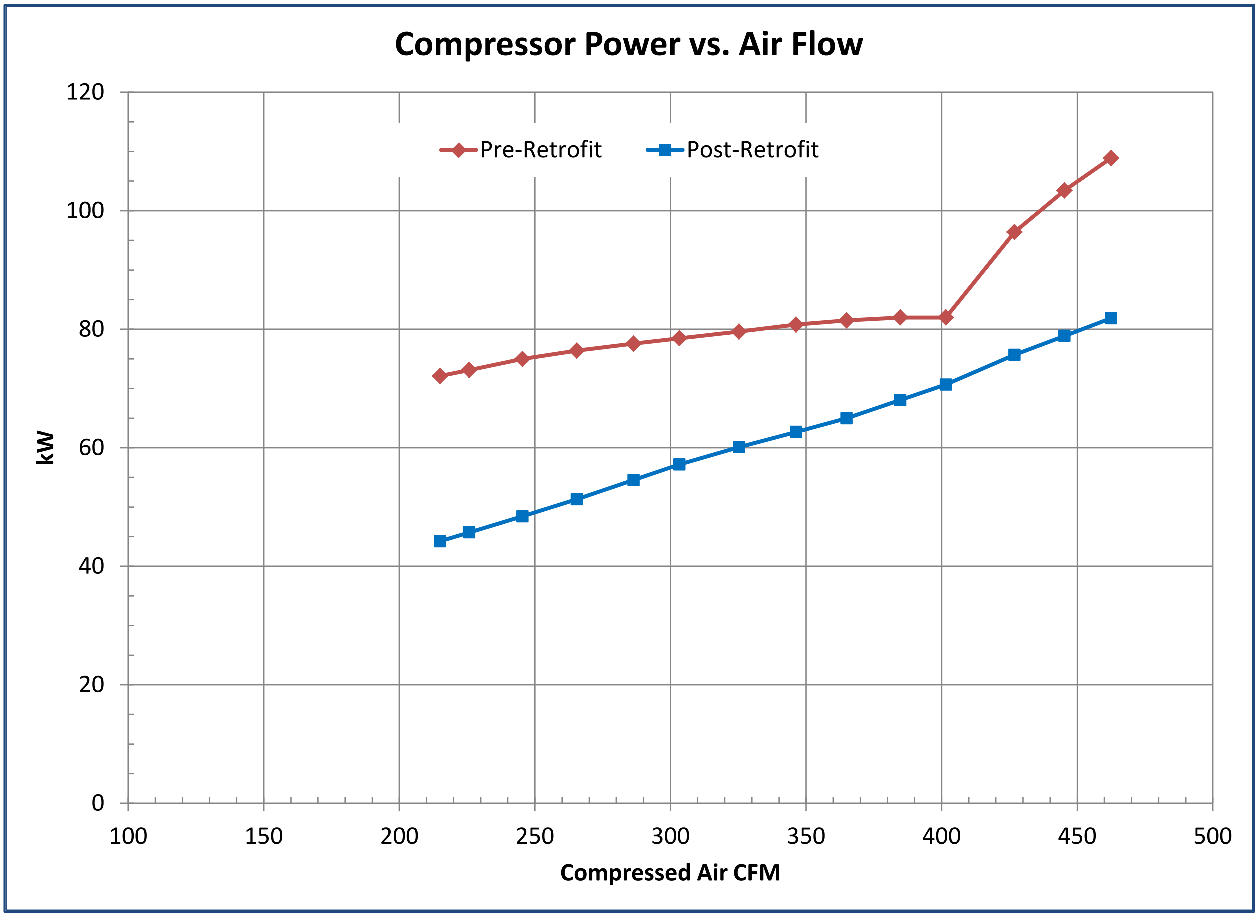


Figure 3: Compressor Power vs. Air Flow, Pre- and Post-Retrofit

Note from the Baseline Compressor Equipment Specifications table (Table 1), the maximum powers of the pre-retrofit compressors are:

100 Hp compressor:	82.0 kW
50 Hp compressor:	41.1 kW

The total maximum power of the two pre-retrofit compressors is 123.1 kW. However, since the total compressor air capacity is greater than the maximum actual air load, the two pre-retrofit compressors may not ever have run at peak power simultaneously. By examining the air demand daily profiles in the application, the following peak powers can be estimated. (Note: 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 provided data, the coincident peak demand was estimated as the maximum demand observed in the 4-5 PM hour on any weekday of the data.)

Table 6: Pre-Retrofit Peak Demand

	Max Overall Demand (Non-Coincident Peak)	Coincident Peak	Units
A. Maximum 15-min average CFM (as estimated from Application's Air Study)	470	300	CFM
B. Maximum capacity air load of large compressor	420	n/a	CFM
C. Subtract B from A to determine air Load on small compressor at peak total air load	50	n/a	CFM
D. Small compressor power at specified air load	28.3	n/a	kW
E. Large compressor power at peak total load	82.0	78.3	kW
F. Total Peak Power Demand	110.3	78.3	kW

For the post-retrofit compressor:

Table 7: Post-Retrofit Peak Demand

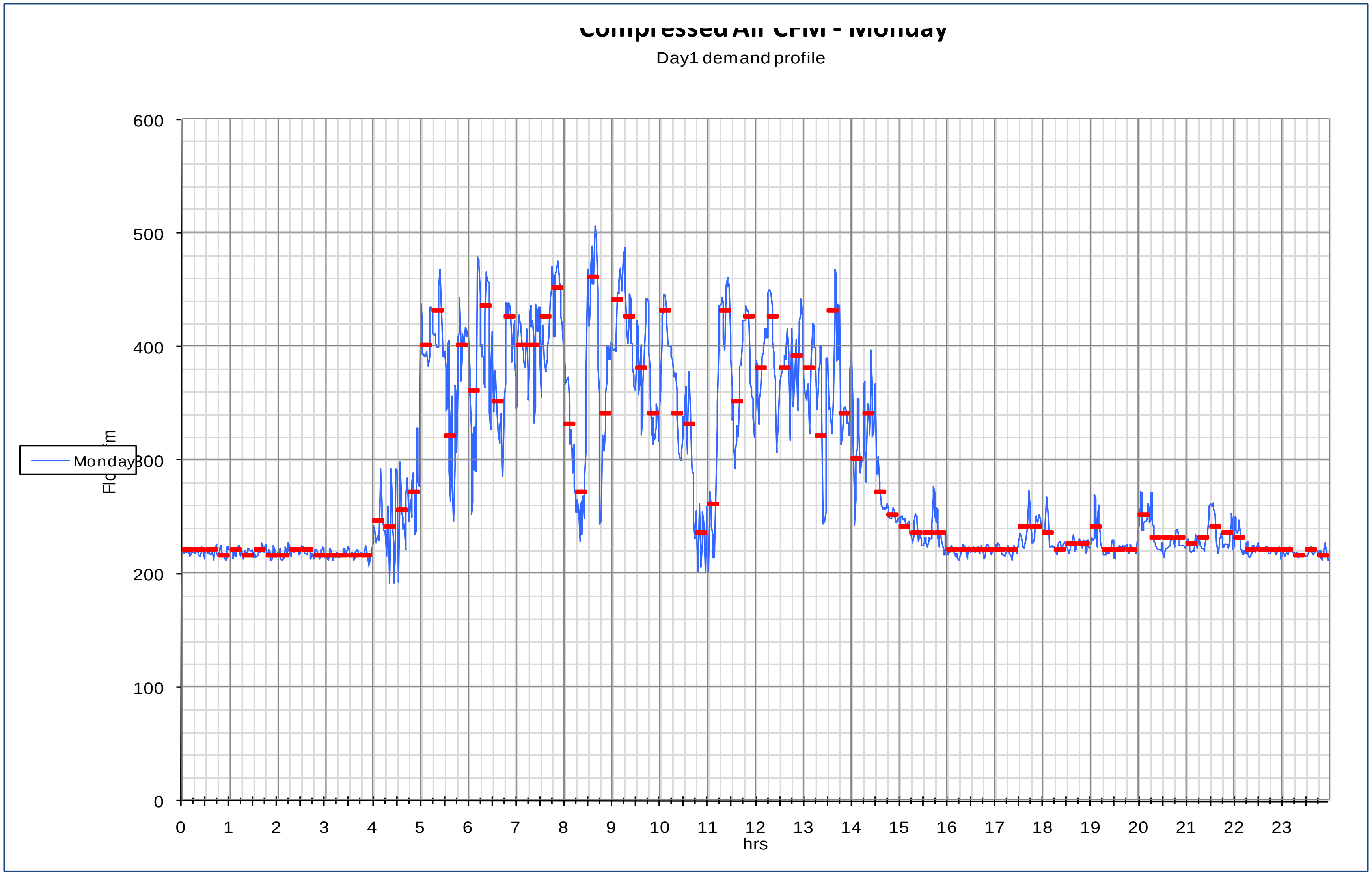
	Max Overall Demand (Non-Coincident Peak)	Coincident Peak	Units
Max 15-min average CFM (as estimated from Application's Air Study)	470	300	CFM
Total Peak Power Demand	83.1	56.7	kW

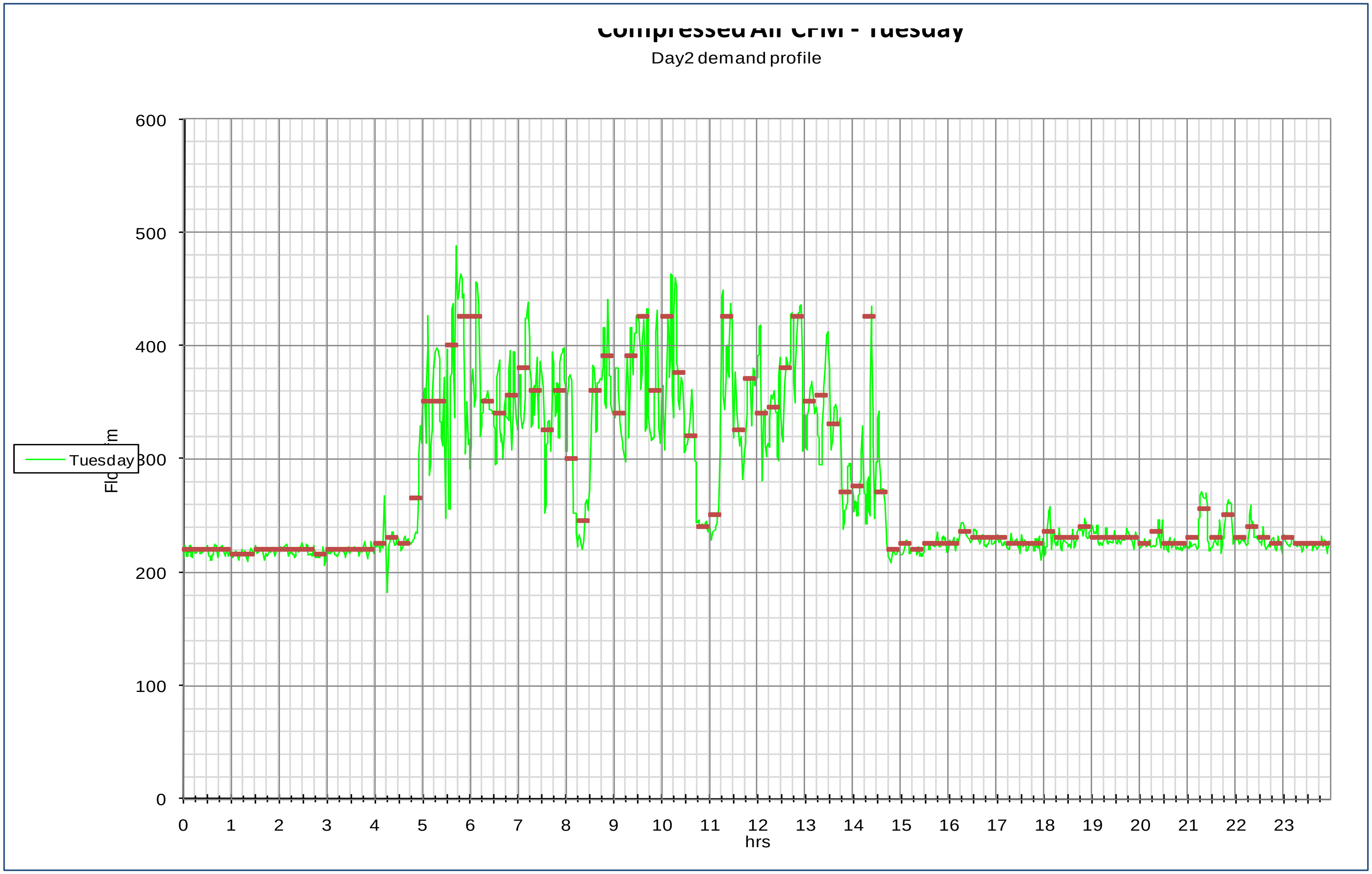
A summary of the energy and demand savings, as well as the savings realization rates compared to Duke's anticipated savings, is presented below.

Table 8: Energy and Demand Savings Summary

	Annual Energy (kWh)	Annual Non-Coincident Peak Demand (kW)	Annual Coincident Peak Demand (kW)
Pre-Retrofit Baseline	678,020	110.3	78.3
Post-Retrofit M&V Results	461,794	83.1	56.7
M&V Savings	216,227	27.2	21.6
Duke Projected Savings	98,972	11.3	11.3
Realization Rates	218.5%	240%	192%

Application's Daily Load History Charts with 15-Minute Average Overlays




Compressed Air CFM - Tuesday
Day2 demand profile
Flow cfm
Tuesday
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500
400
300
200
100
0
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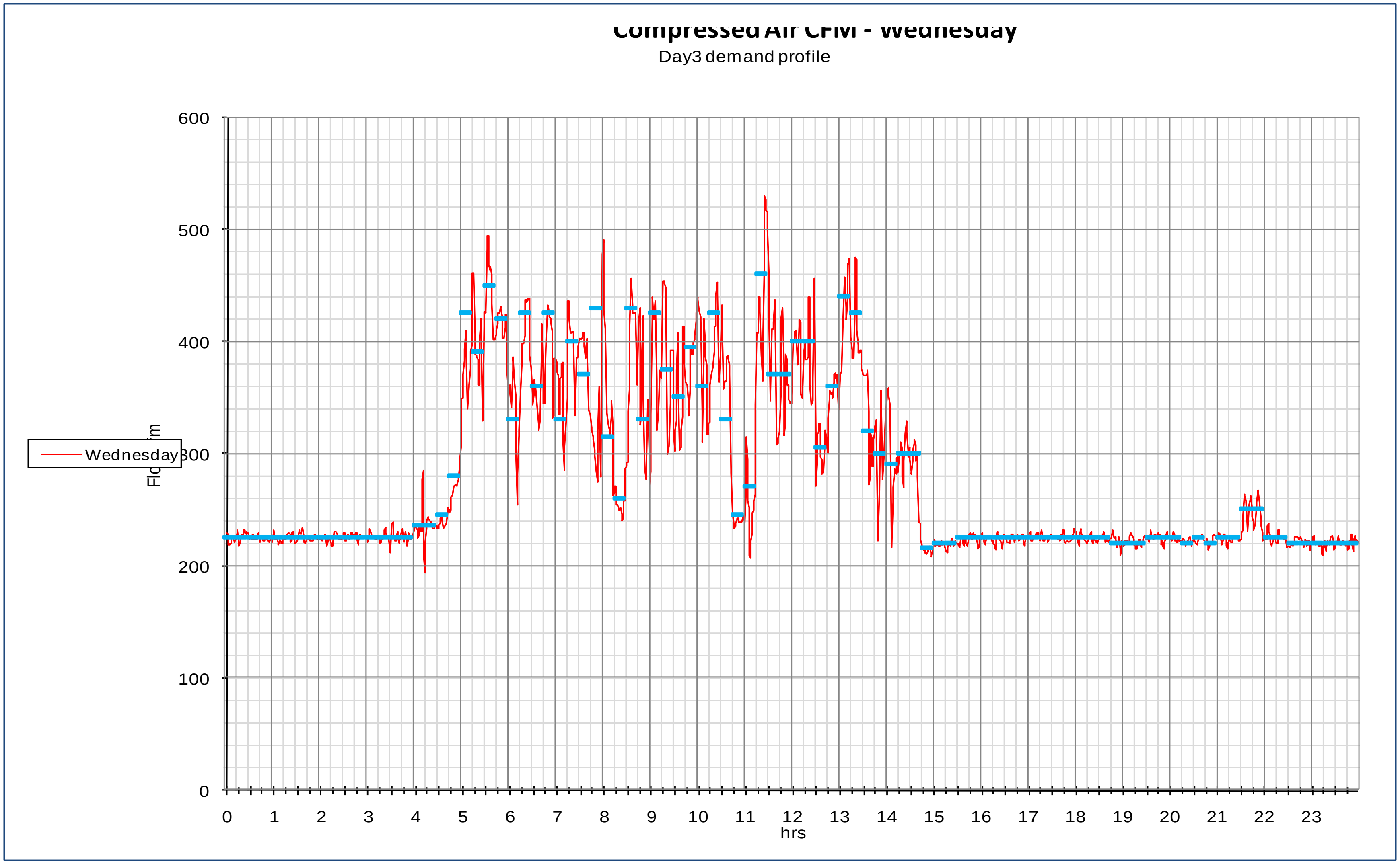
hrs


Compressed Air CFM - Wednesday
Day3 demand profile
Wednesday
Flow cfm
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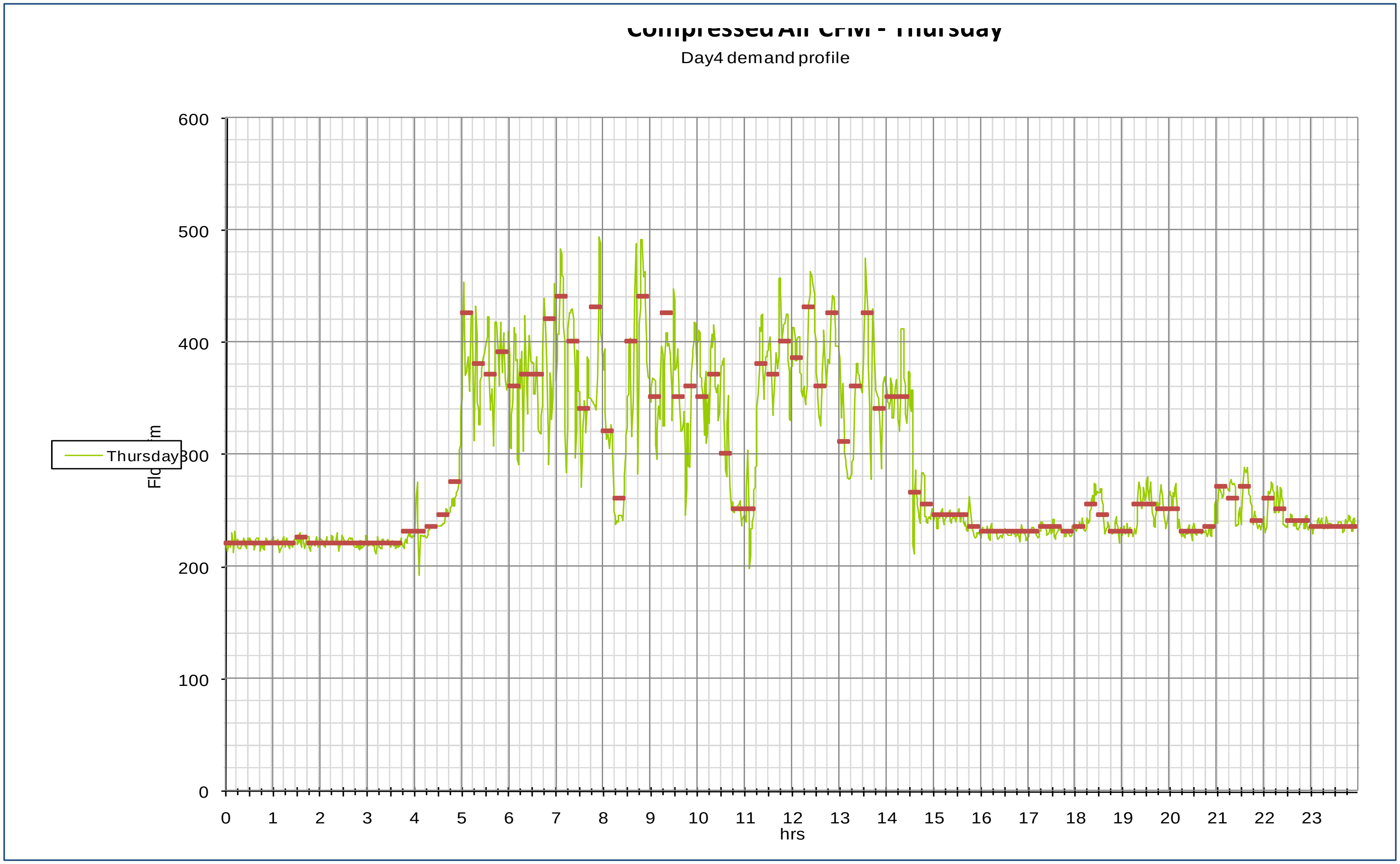
500
400
300
200
100
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23
hrs


Compressed Air CFM - Thursday
Day4 demand profile
Thursday
Flow cfm
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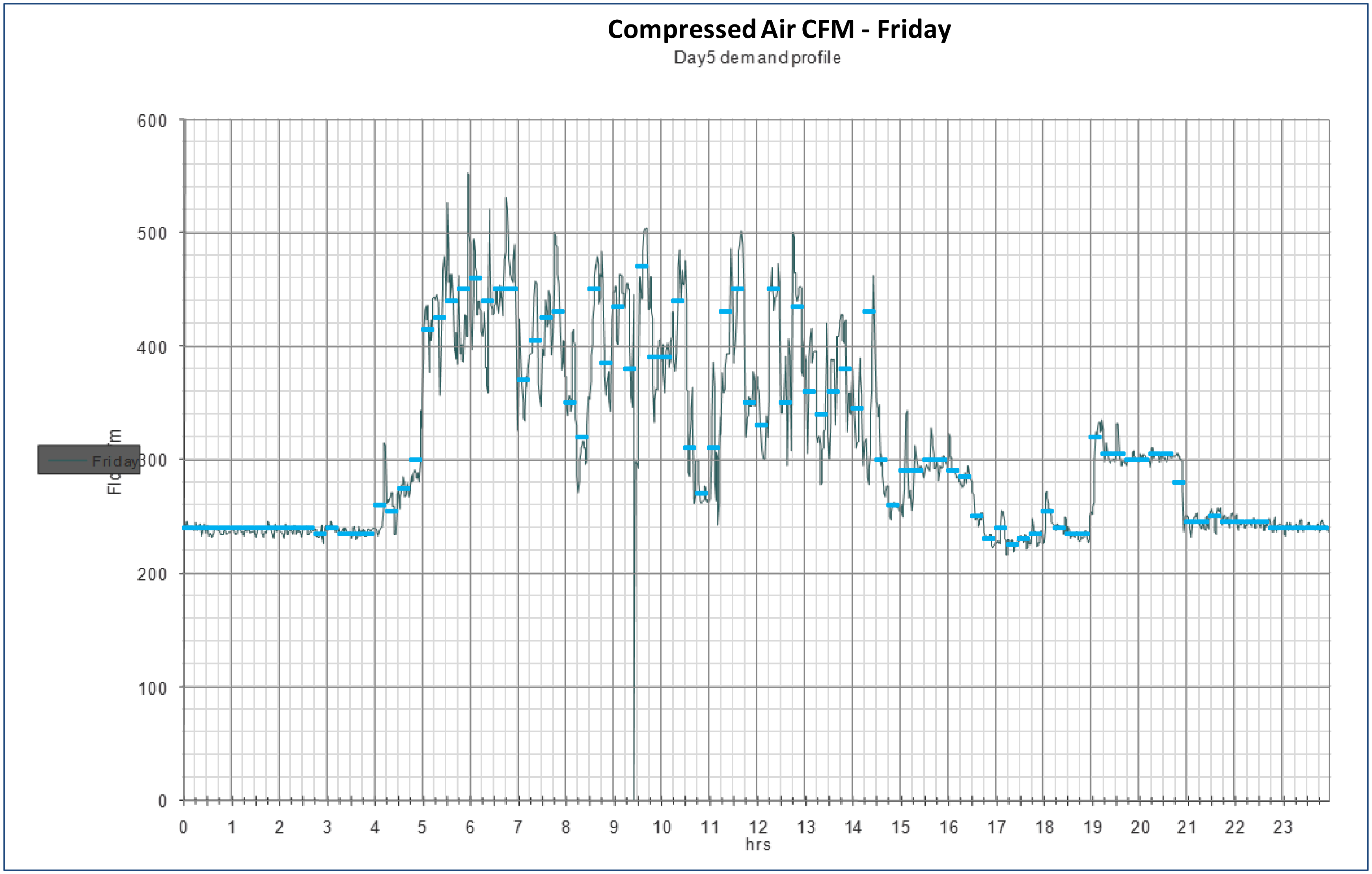
500
400
300
200
100
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23
hrs


Compressed Air CFM - Friday
Day5 demand profile
600
500
400
300
200
100
0
Friday
0
1
2
3
4
5
6
7
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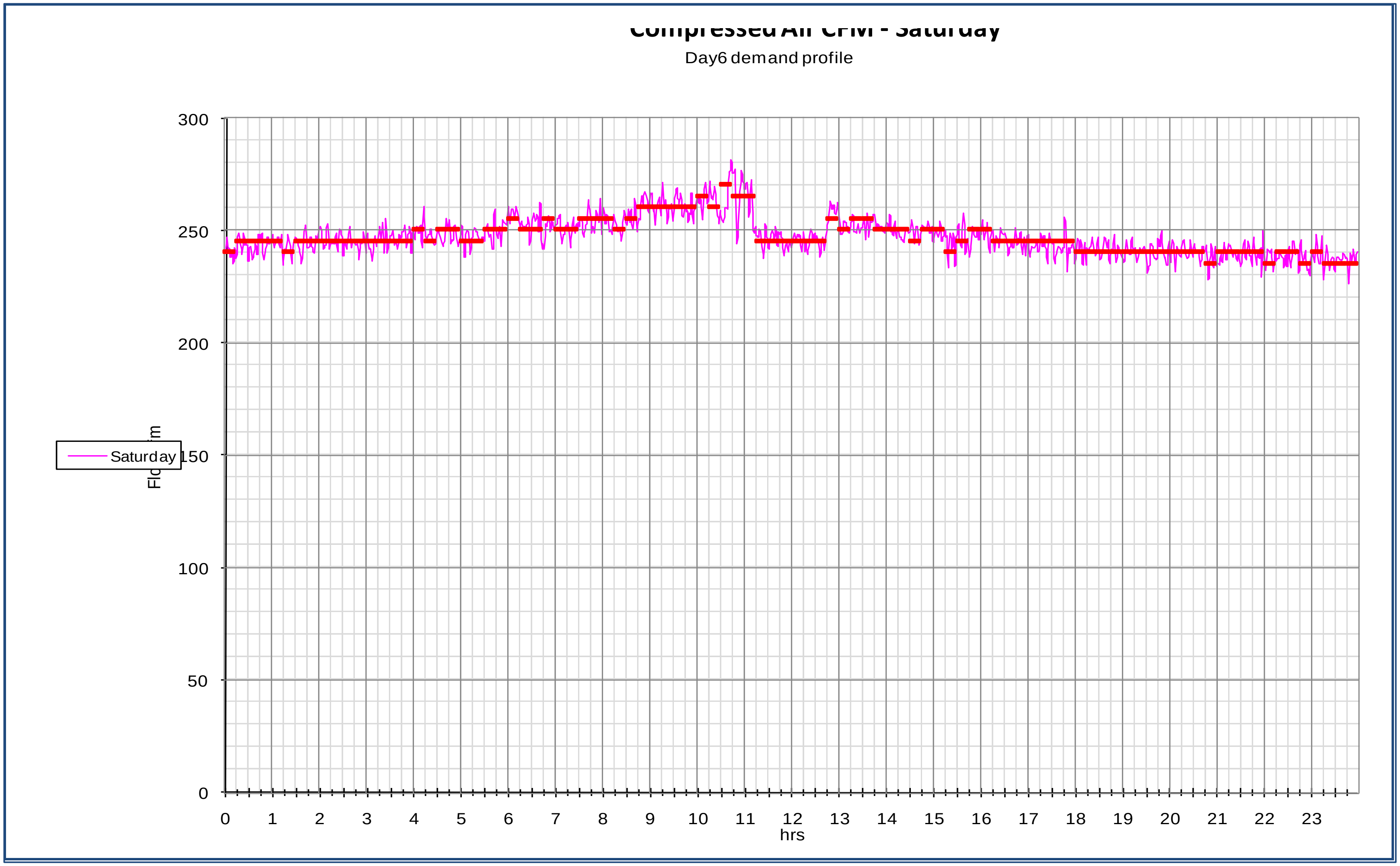
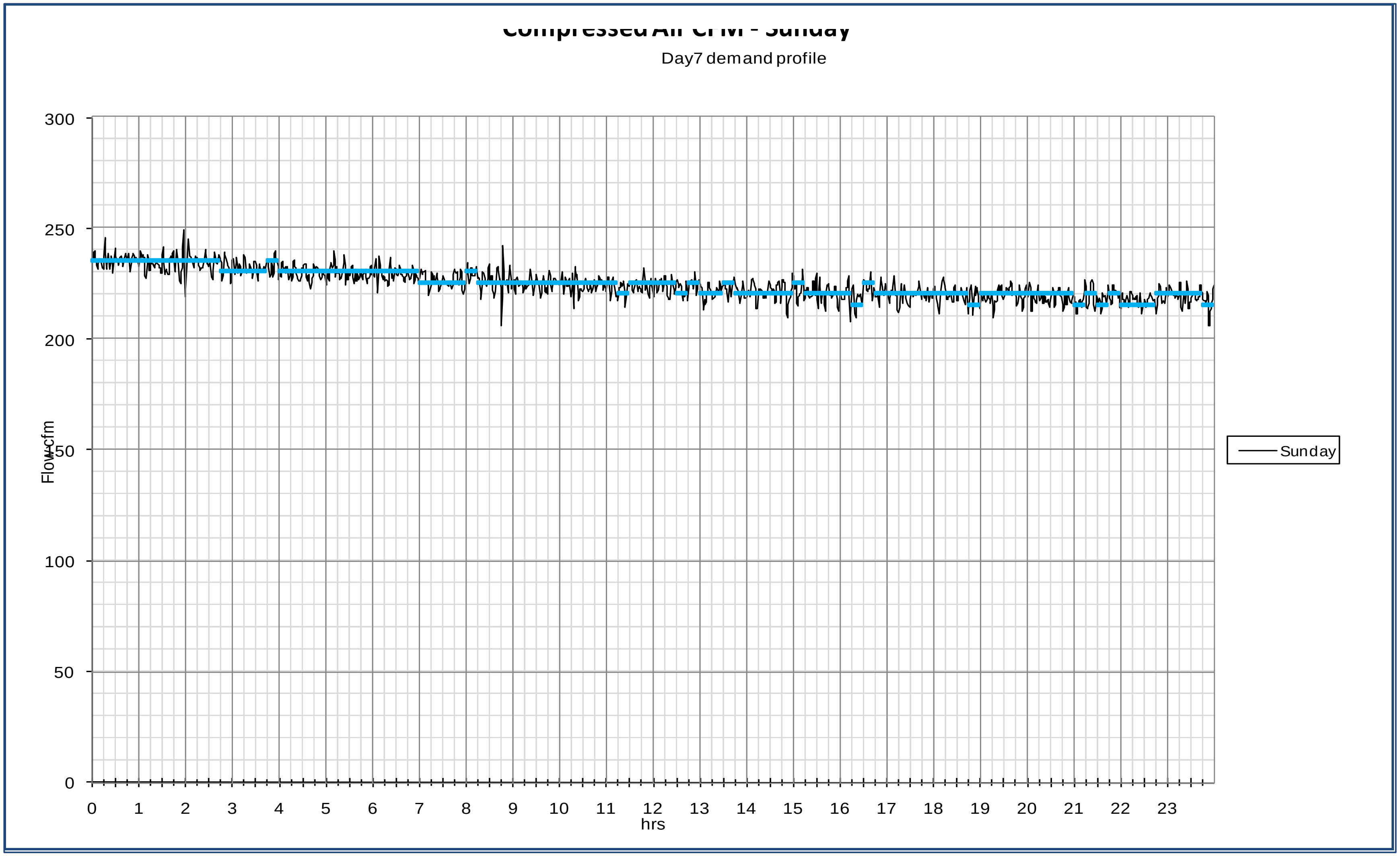
22
23
hrs


Compressed Air CFM - Saturday
Day6 demand profile
Saturday
Flow cfm
300
250
200
150
100
50
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23
hrs


Compressed Air CFM - Sunday
Day7 demand profile
Flow cfm
300
250
200
150
100
50
0
0
1
2
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4
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8
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10
11
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16
17
18
19
20
21
22
23
hrs
Sunday

[Redacted]
Chiller VFD Addition
M&V Report

Prepared for
Duke Energy Ohio

April 2015, Version 2.0

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

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

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

Submitted by:

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NORESCO, Inc.

Jerry Moechnig
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NORESCO
United Technologies

Introduction

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

ECM-1 – Chiller VFD

- Install a VFD on an existing 700 ton chiller.

Note: ECM's have already been implemented. Only post measurements were taken.

Goals and Objectives

The projected savings goals identified in the application are:

Application Proposed Annual savings (kWh)	Application Proposed Peak Savings (kW)	Duke Projected savings (kWh)	Duke Projected Coincident Peak savings (kW)	Duke Projected Non-coincident Peak savings (kW)
523,500	0	**532,027**	**38.8**	**79.0**

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

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

Project Contacts

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

Site Locations/ECM's

Address
[Redacted]

Data Products and Project Output

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

M&V Option

IPMVP Option A

M&V Implementation Schedule

- Data logging was performed during summer months (peak cooling season).
- Post data only was collected.
- Monitoring period included both normal workday and weekend periods

Field Survey Points

The following survey data was collecte3d (for all equipment logged)

- Obtained chiller sequence of operations for both the pre and post installation cases.
- Confirmed the cooling tower sequence of operations.
- 700 ton chiller make/model/serial number
- 700 ton chiller VFD make/model
- 700 ton chiller flow rate

Data Accuracy

Measurement	Sensor	Accuracy	Notes
Temperature	Hobo thermistor	±0.5°	

Current	Magnelab CT	±1%	> 10% of rating
Power	Elite Pro CT/Voltage Leads	±1% with CTs	

Field Data Logging

- **ECM-1 – BAS trends were set up to log the following data points in 5 minute intervals. Data was collected for 3 weeks.**

  - 700 ton chiller kW
  - Chilled Water Supply Temperature
  - Chilled Water Return Temperature
  - Condenser Water Supply Temperature
  - Condenser Water Return Temperature

  Note: All points were logged at the same time and interval.

Data Analysis

1. Converted time series data on logged equipment into post average load shapes by day-type.
2. Generated pre-retrofit model from performance curves and post retrofit consumption field data.
3. Developed pre/post regression model of total daily kWh as a function of average outdoor drybulb temperature,
4. Estimated peak demand savings by subtracting pre/post time series data during peak ambient temperatures. Calculated coincident peak savings by subtracting pre/post peak kW values at equivalent hot days at 5 pm local time.

- **ECM-1**

  1. Calculated Post chiller tons by using the following equation:

  $$tons = 500 \times GPM \times \Delta T$$

  where

  Tons = Chiller load
  GPM = Chilled water flow rate
  ΔT = Chilled water supply/return temperature differential

2. Calculated kW/Ton for each interval. Develop kW/Ton vs. Part Load Ratio Curve for the new chiller.
3. Used DOE2 chiller curves to estimate Pre chiller kw/ton from observed operating conditions. Chiller load from equation above remains the same.
4. Determined kWh for both Pre and Post operating conditions.
5. Converted time series data on logged equipment into pre/post average load shapes by daytype. Compared pre/post peak kW for evidence of peak demand limiting. Calculated peak demand savings
6. Regressed data into a temperature dependent load model. Form of the regression equation is:

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

where

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

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

Verification and Quality Control

1. Visually inspected time series data for gaps

Recording and Data Exchange Format

1. BAS output files
2. Excel spreadsheets

Results

The following results show the benefits of the VFD retrofit at [Redacted].

Figure 1 depicts the chiller kW/ton as a function of part load ratio. DOE2 chiller curves were used to predict the savings for this application. These curves were generated using the logged condenser water and chilled water supply temperatures. As can be seen in Figure 1, the DOE2 curves line up very closely with the curves that were supplied with the application documentation.

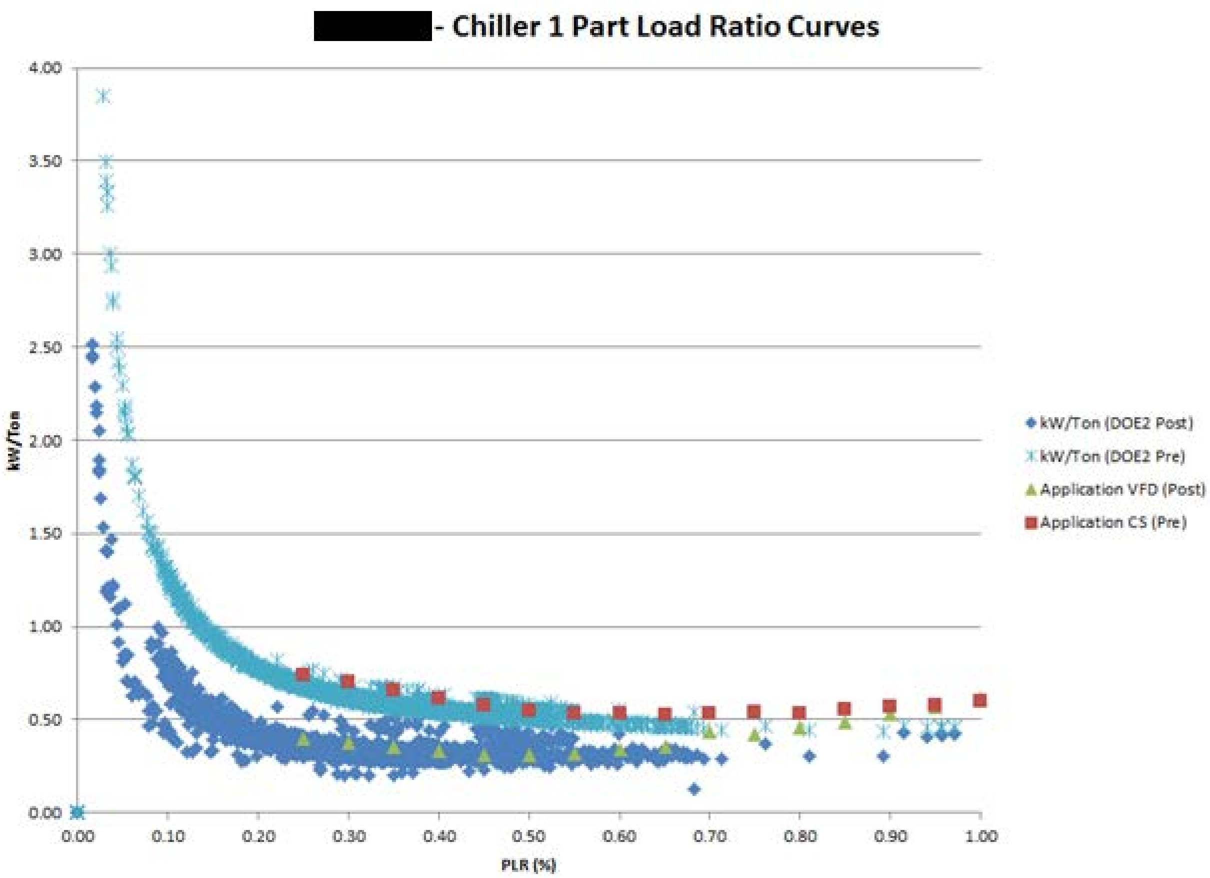


Figure 1. Chiller 1 efficiency curves

Figure 2 and Figure 3 show chiller kW as a function of outside air temperature. Figure 3 shows the measured chiller demand, and Figure 2 shows the chiller demand based on the pre-retrofit chiller efficiency curve shown in Figure 1, and the measured post-retrofit chiller load.

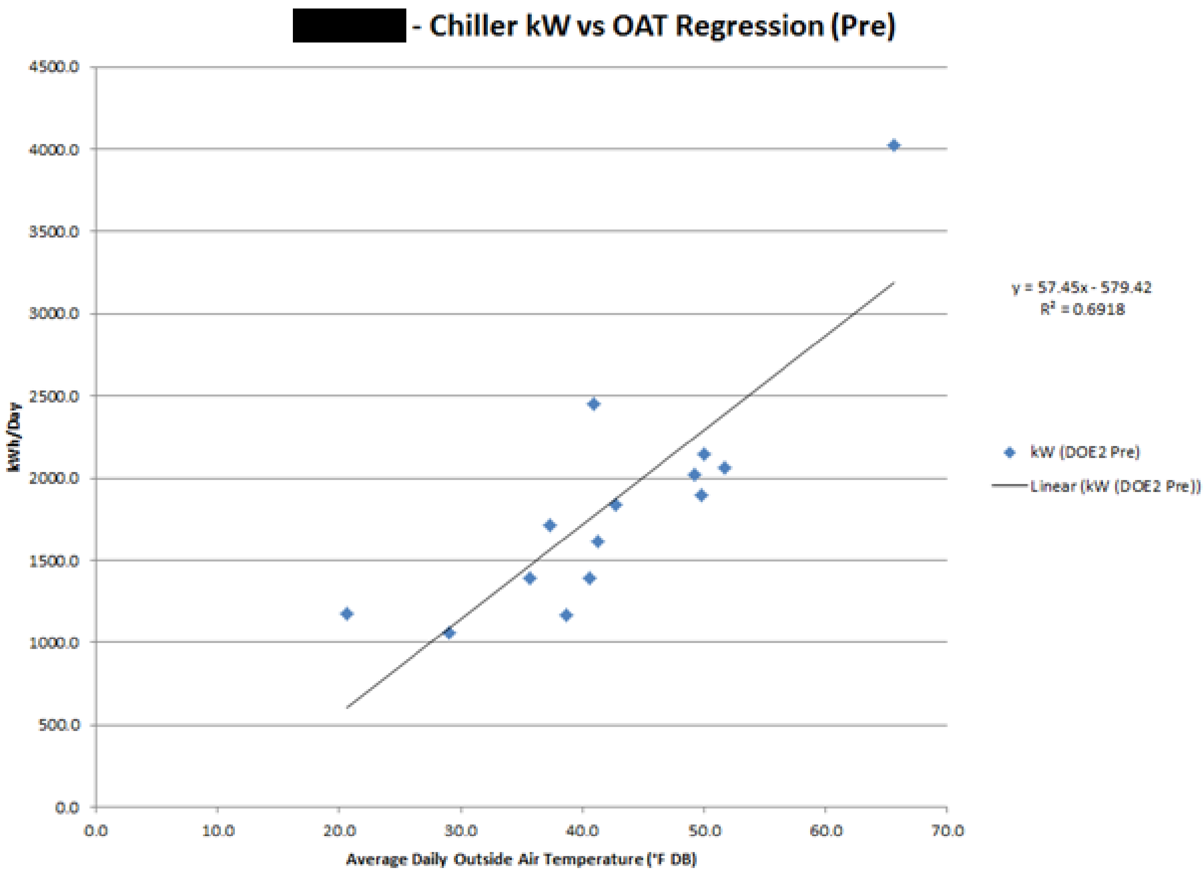


Figure 2. Pre-retrofit estimated chiller demand versus outside temperature

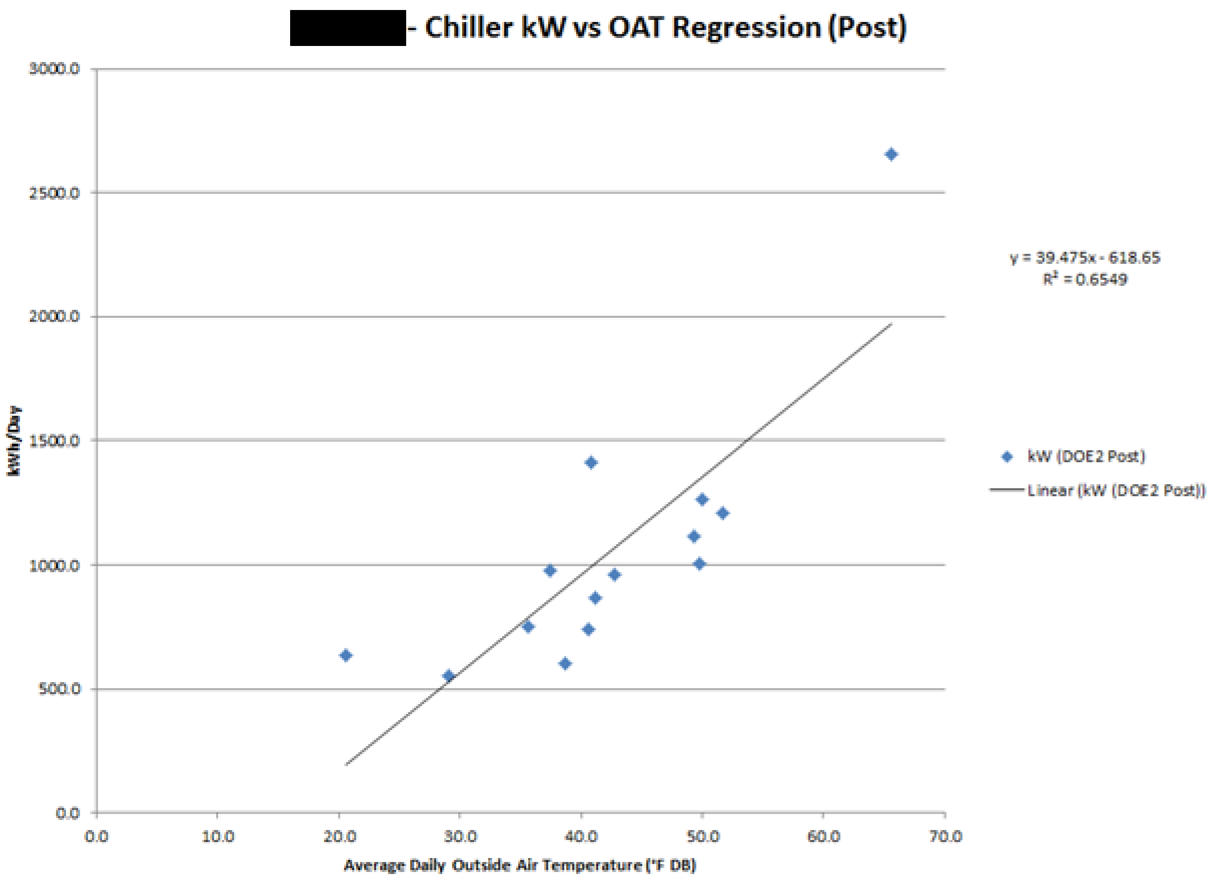


Figure 3. Post-retrofit measured chiller demand versus outside temperature

Figure 4 depicts demand for the pre and post-retrofit chiller equipment extrapolated over the course of one year. kWh/day were extrapolated for the year by substituting TMY3 outside air temperatures (dry bulb) into the linear regression equations for both pre and post ECM install. The chiller was assumed to follow the linear regressions noted shown in Figure 2 and Figure 3.

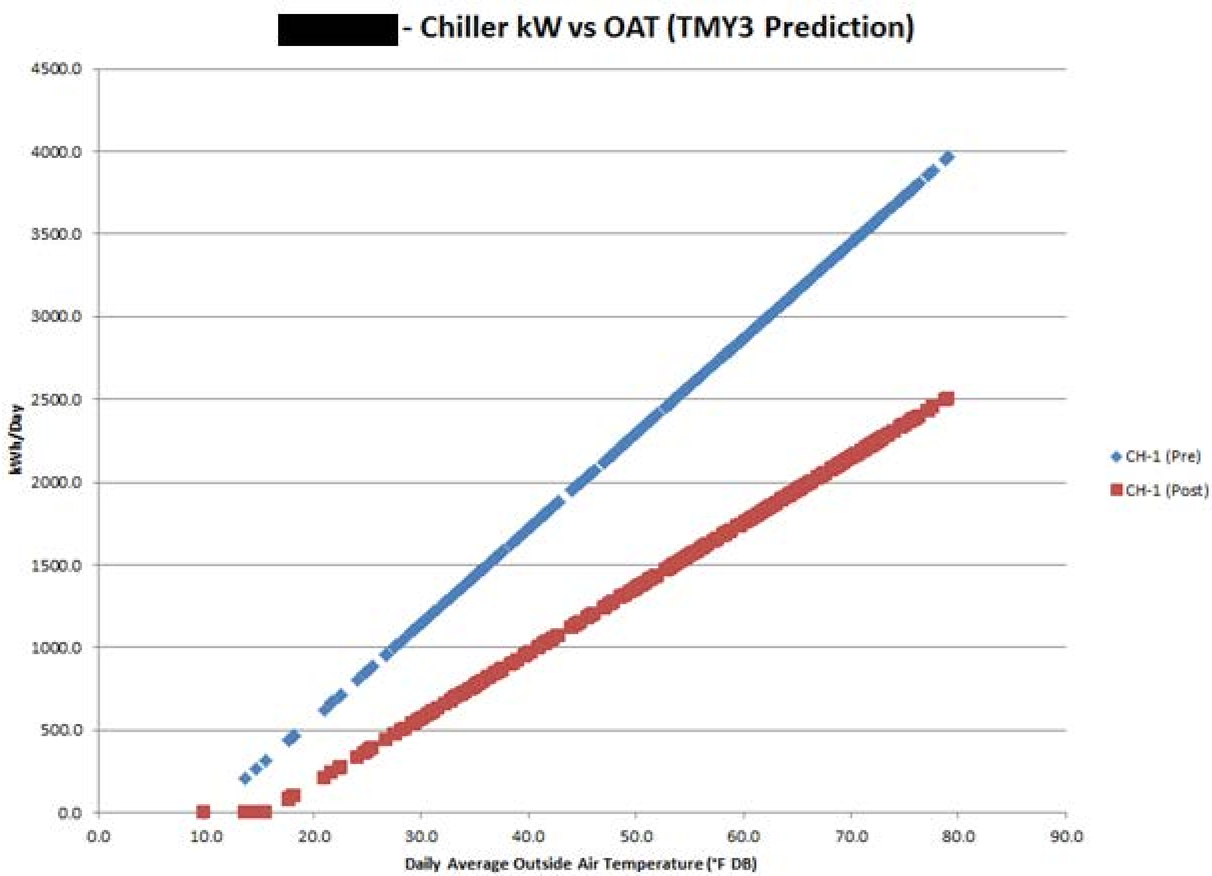

[redacted] - Chiller kW vs OAT (TMY3 Prediction)
kWh/Day
4500.0
4000.0
3500.0
3000.0
2500.0
2000.0
1500.0
1000.0
500.0
0.0
0.0
10.0
20.0
30.0
40.0
50.0
60.0
70.0
80.0
90.0
Daily Average Outside Air Temperature (°F DB)
CH-1 (Pre)
CH-1 (Post)

Figure 4

A summary of the estimated total annual savings is shown in Table 1, Table 2, and Table 3.

Table 1

Energy Reduction Results		
	Pre (kWh)	Post (kWh)
	916,622.8	549,683.2
Total Savings (kWh)	366,939.6	
Duke Estimated Savings (kWh)	532,027	
Duke Realization Rate	69%	

Table 2

Coincident Peak Demand Reduction Results		
	Pre (kWh)	Post (kWh)
	230.4	149.3
Total Savings (kWh)	81.1	
Duke Estimated Savings (kW)	38.8	
Duke Realization Rate	209%	

Table 3

Non-coincident Peak Demand Reduction Results		
	Pre (kWh)	Post (kWh)
	237.4	154.4
Total Savings (kWh)	83.0	
Duke Estimated Savings (kW)	79	
Duke Realization Rate	105%	

[Redacted]

- Lighting Retrofit -

Report

PREPARED FOR:
Duke Energy
Ohio

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

PREPARED IN:
August 2012

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

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

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

Introduction

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

ECM-1 – Incandescent fixtures replaced with LED fixtures

- This project retrofitted 14 existing 75W incandescent fixtures with 14 new 20.3W LED fixtures. This will result in an overall power reduction of 766W.

Goals and Objectives

Post-retrofit surveys of the lighting usage were 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 Annual kWh savings	Duke Summer Peak kW savings
[Redacted]	4,135	1	3,766	0.8
Total	**4,135**	**1**	**3,766**	**0.8**

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

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

Project Contacts

Duke Energy M&V Coordinator	Frankie Diersing	513-287-4096
Duke Energy BRM	Terry Holt	
Customer Contact	[Redacted]	[Redacted]
Architectural Energy Corporation Contact	Katie Gustafson	p: 303-459-7430 kgustafson@archenergy.com

Site Locations/ECM's

Site	Address	Sq. Footage	ECM's Implemented

[Redacted]	[Redacted]	4,900	# 1

Data Products and Project Output

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

M&V Option

IPMVP Option A

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 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

- Current loggers were deployed on the two circuits that powered the retrofitted fixtures. These circuits however, also powered several other fixtures that were not a part of this retrofit. The field technician was unable to take spot measurements at the fixtures in question. For this reason the metered data was only used to determine the annual equivalent full load hours.

Logger Table

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

ECM	Hobo U-12	20A CT	DENT TOU Lighting Loggers (If circuits are not dedicated)
1	2	2	2
Total	**2**	**2**	**2**

Data Analysis

ECM-1

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

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

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

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

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

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

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

Verification and Quality Control

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

Recording and Data Exchange Format

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

Field Staff

☐ Verifiable Results
☐ AEC
■ **Other**

Contracting type

■**T&M**
☐ Per logger

Results Summary

The below tables summarize the estimated savings for the lighting retrofit at [Redacted].

	Lighting	HVAC	Total
Pre kW	1.02		
Post kW	0.27		
Demand Savings	0.74	0.20	**0.94**
Coincident Pk Demand Svgs (kW):	0.74	0.20	**0.94**

		Realized Savings		**Realization Rate**	
	Duke Savings	**Lighting Only**	**Lighting and HVAC**	**Lighting Only**	**Lighting and HVAC**

Energy (kWh)	3,766	3,284	3,534	87%	94%
NCP Demand (kW)	0.8	0.74	0.94	93%	118%
CP Demand (kW)	0.8	0.74	0.94	93%	118%

Analysis of the metered data reveals that the lighting system runs for an average of 4,244 equivalent full load hours annually. This compares to the 5,400 annual operating hours listed in the application.

As discussed in the Field Data Logging section above the field technician was unable to take spot measurements at the retrofitted fixtures. To determine the annual savings we analyzed the metered data to determine the annual equivalent full load hours. These hours were used to determine the annual consumption of the pre and post retrofit fixtures.

This site has five holidays per year where the store lighting is off.

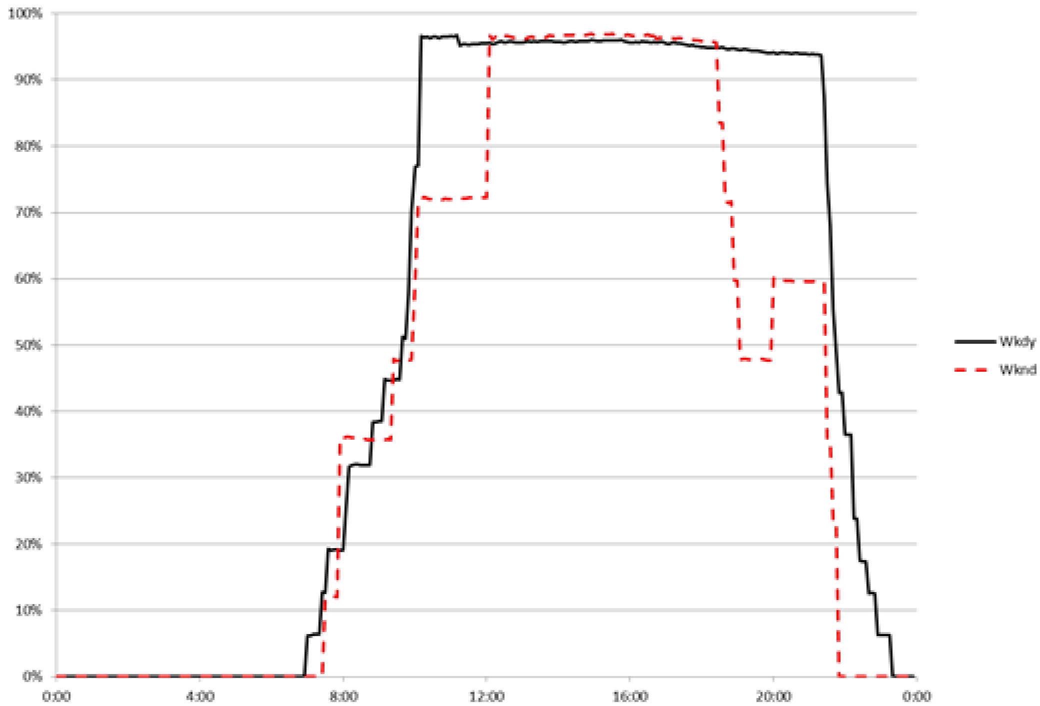
The overall lighting wattage in the pre-retrofit case was 1.05kW (14 fixtures x 75W) This pre-retrofit wattage was taken from the application. In the post-retrofit case, that figure decreased to 0.28kW (14 fixtures x 20.3W)As the site visit tech was not able to isolate the retrofitted fixtures to take spot measurement the new wattage was taken from the product cut sheet that was provided along with the application.

Combining the annual equivalent full-load hours with the pre- and post-retrofit lighting wattage allowed us to calculate the annual energy and demand savings.

To determine the associated HVAC savings and penalties we assumed that this location has furnace heat, DX cooling, and an operational economizer.

The three week load shape of the monitored lighting circuits can be seen below.

[redacted] Load Shapes



[Redacted] Chiller Retrofit M&V Report

Prepared for
Duke Energy Ohio

January 2015, Version 2.0

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.

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

Submitted by:

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NORESCO, Inc.

Stuart Waterbury
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Introduction

This report addresses M&V activities for the [Redacted] custom program application. The application covered a chiller retrofit at one location in Cincinnati, Ohio. The measure included:

ECM-1 – Chiller Retrofit

A new 638,000 square foot [Redacted] facility was scheduled for completion in the fall of 2013. This program involved the installation of a more energy-efficient chilled water plant, which consists of four 800-ton water cooled VSD centrifugal chillers and one 360-ton heat recovery chiller. One of the 800-ton chillers is provided for redundancy.

The baseline chillers to be considered would meet the minimum ASHRAE 90.1 standards, which include a COP of 5.11 (0.688 kW/ton) with an NPLV of 5.37 (0.6547 kW/ton). The installed chillers are equipped with VSDs, and have a kW/ton of 0.627 at the stated ARI design conditions.

This project was completed in October 2013, so this plan was for post-retrofit M&V only.

Goals and Objectives

The projected savings goals identified in the application were:

Facility	Proposed Annual kWh savings	Proposed kW Savings	Duke Projected Annual kWh savings	Duke Projected NCP kW savings	Duke Projected CP kW savings
[Redacted]	445,790	100	788,563	**153**	**-53**
Total	**445,790**	**100**	**730,151**	**142**	**-48.9**

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

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

Project Contacts

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

Customer Contact	[Redacted]	[Redacted]

Site Locations/ECMs

Address
[Redacted]

Data Products and Project Output

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

M&V Option

IPMVP Option A

M&V Implementation Schedule

- The survey was conducted after the customer had completed the new construction.
    - Data was collected during normal operating hours (avoiding holidays or atypical operating hours). The data was collected from September 10 to October 1, 2014.
    - The HVAC schedules were obtained and verified for the chiller plant.
    - Trending was setup to record temperature, flow and power measurements on controlled equipment.
- The energy and demand savings of the retrofit measure were evaluated.

Field Survey Points

Pre – installation

N/A. New construction

Post – installation

Nameplate data was collected for the chiller plant and individual chillers.
Information on schedules, setpoints and other sequence of operations data was also collected.

Spot measurements

- V/A/kW/PF on each of the 4 main chillers
- V/A/kW/PF on the cooling tower fans

Time series data on controlled equipment

- Power on each of the 4 main chillers
- Chilled water supply temperature, chilled water return temperature, chilled water flow on each of the 4 main chillers
- Condenser water flow, condenser water supply temperature, condenser water return temperature and fan power on the cooling tower

Loggers and trend logs were setup for 5-minute instantaneous readings and deployed for 3 weeks from September 10 to October 1, 2014.

Field Data Logging

- **ECM-1**

  Data was collected on the cooling tower and each of the 4 main chillers. On the cooling tower, condenser water flow, condenser water supply temperature, condenser water return temperature and fan power was collected. For each of the 5 chillers, chilled water supply temperature, chilled water return temperature and chilled water flow was collected.

Data Analysis

The baseline case for this project was a non-VSD chilled water plant that meets ASRHAE 90.1 code, with a COP of 5.11 (0.688 kW/ton) with an NPLV of 5.37 (0.6547 kW/ton). Since this was new construction, no pre-retrofit measurements were possible. The chiller load in both the base- and as-built cases was assumed to be identical. Chillers were staged such that 2 or 3 chillers were running at all times, as seen in Figure 1.

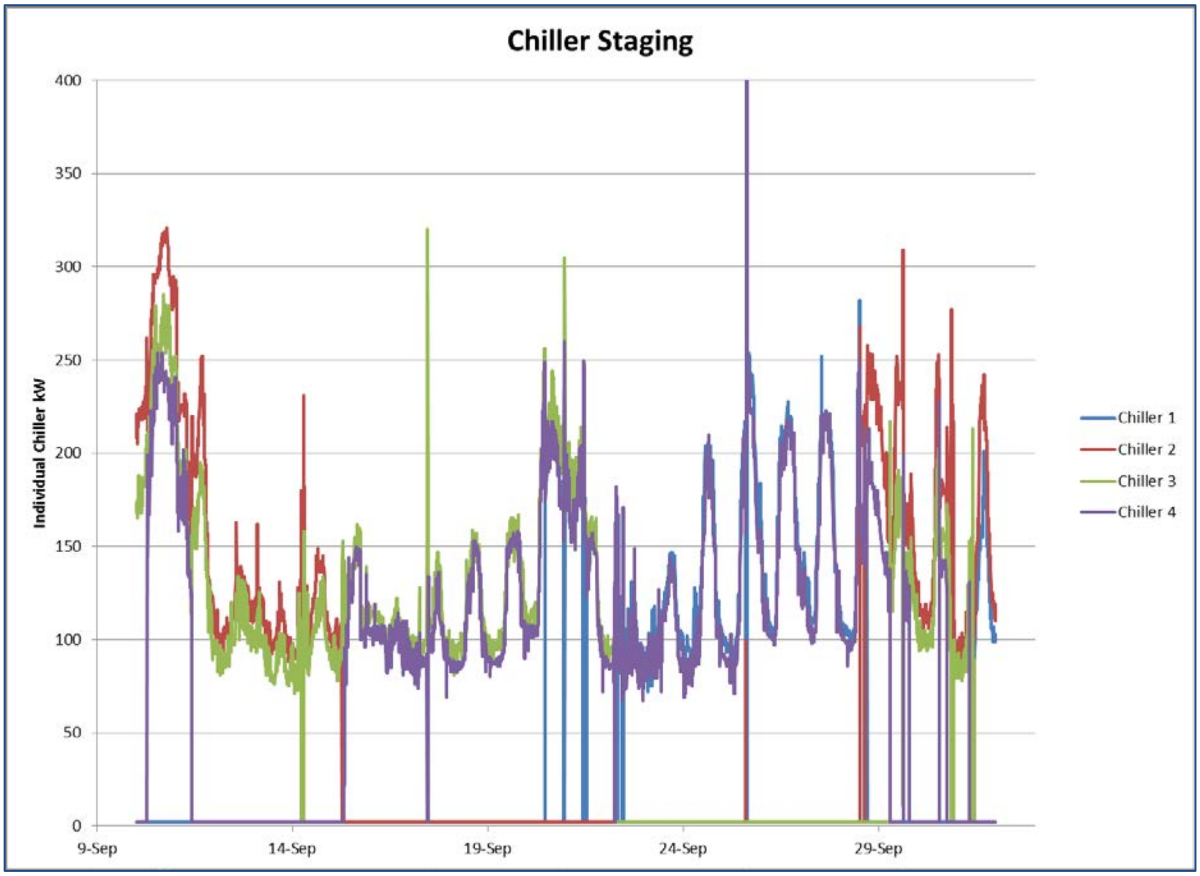

Figure 1: Individual chiller staging.

Load was characterized by temperature differential across each individual chiller, multiplied by the water flowrate in gallons per minute. Only chillers that were actively ON were considered, and the total chiller plant flow was assumed to be equal among the active chillers. The cooling load equation is seen below:

Cooling load [tons] = 500 X Flow [GPM] X Temperature Differential [F] / 12,000

Where: 500 is a constant related to the heat capacity of water

12,000 is a conversion factor between BTU/hr and tons

Temperature Differential is chiller entering water temperature minus chiller leaving water temperature

It was possible to calculate the actual kW/ton for the installed chillers by comparing the kW logger data to the calculated tons of cooling obtained from the flow and temperature differential:

kW/ton = Measured Chiller kW / Calculated Chiller Cooling Load [tons]

An annual estimate of cooling load was calculated using TMY3 data from Cincinnati, OH and the following regressions based on monitored data:

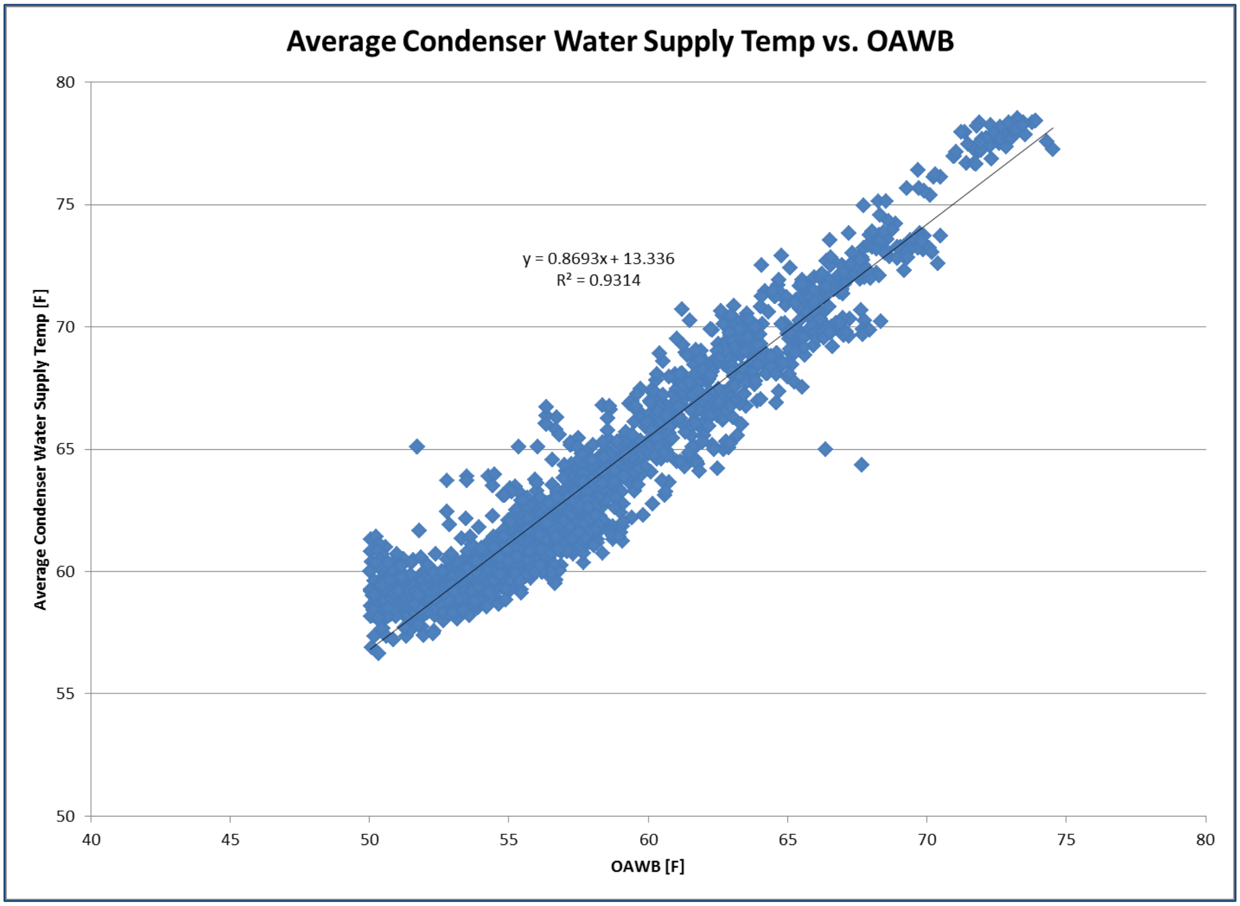

Figure 2: Average condenser water supply temperature vs. OA wetbulb temperature. The graph is assumed to be horizontal below about 52F OAWB.

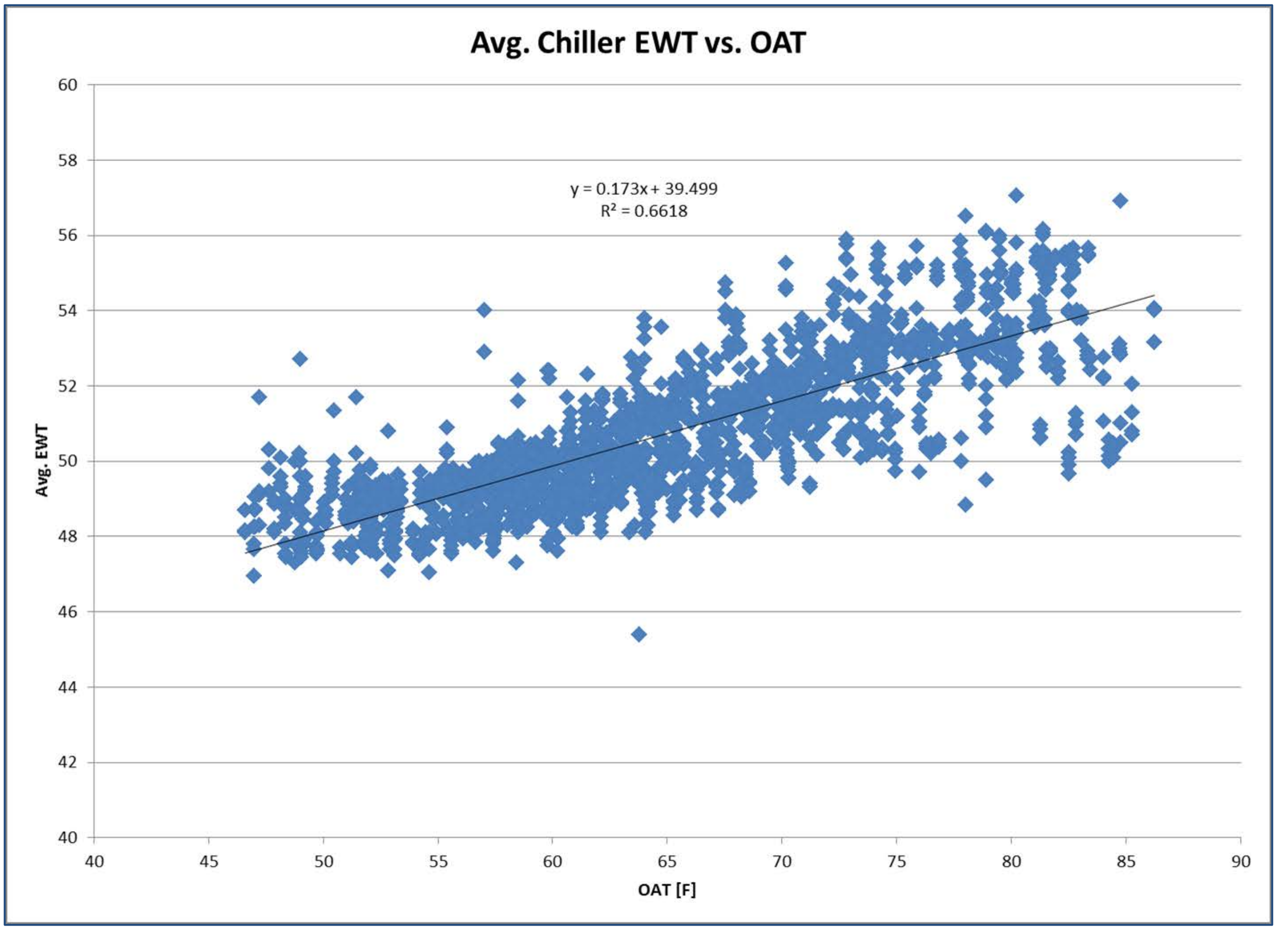

Figure 3: Average chiller entering water temperature vs. OAT. Chiller EWT was assumed to be fixed at 49F below about 52F OAT.

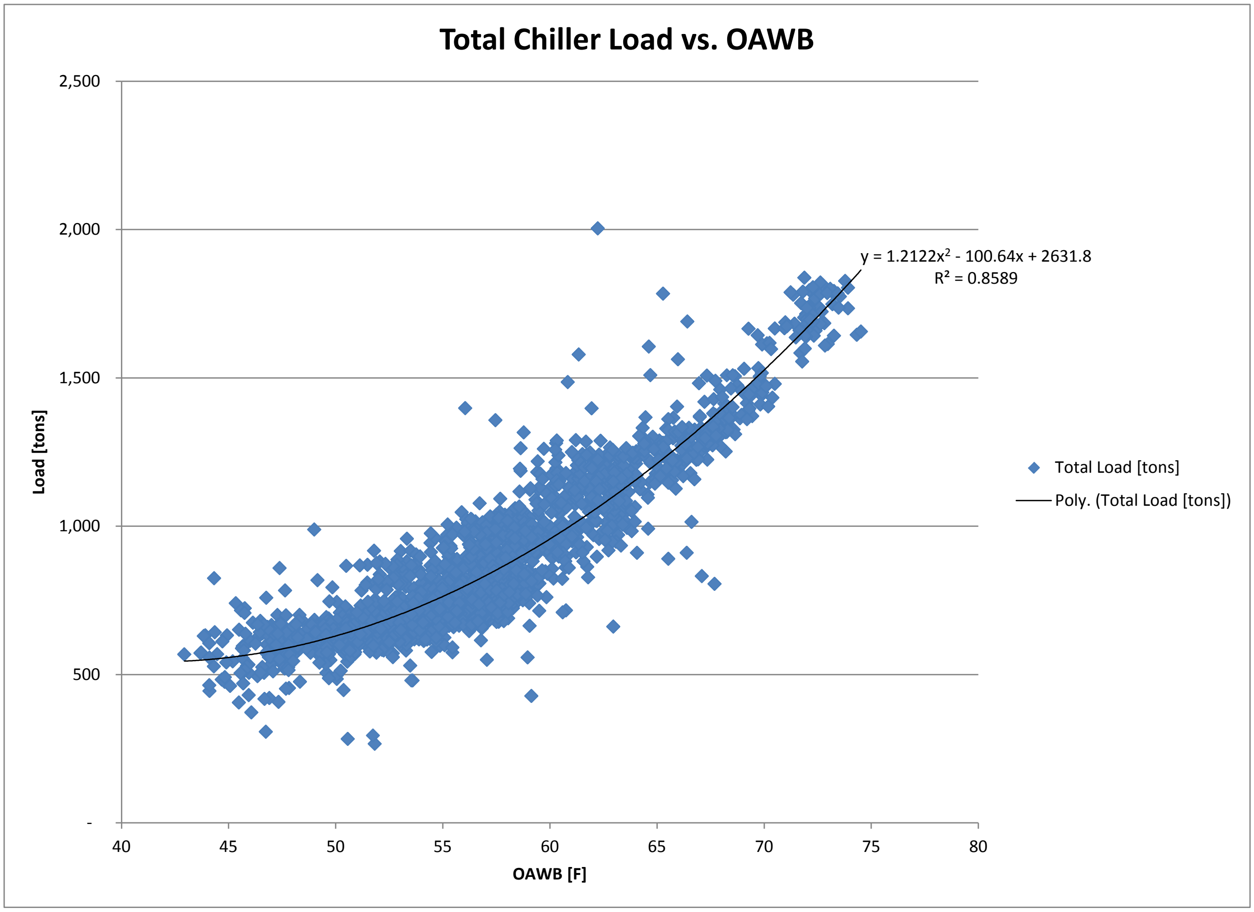

Figure 4: Total chiller load vs. OA wetbulb temperature. Total chiller load was assumed to be fixed at 600 tons below about 52F OAT.

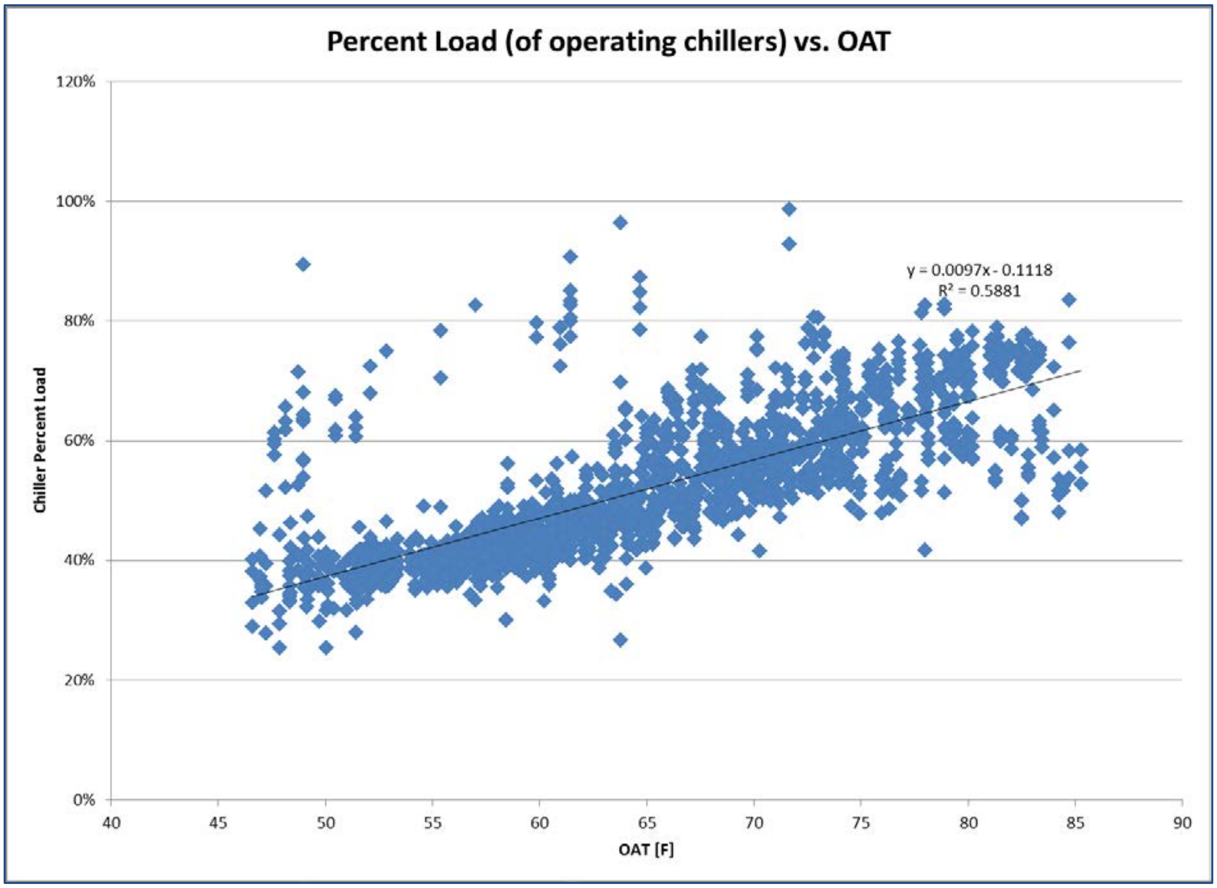

Figure 5: Percent load (of operating chillers only) vs. OAT. Chiller percent load was assumed to be fixed at 35% below about 52F.

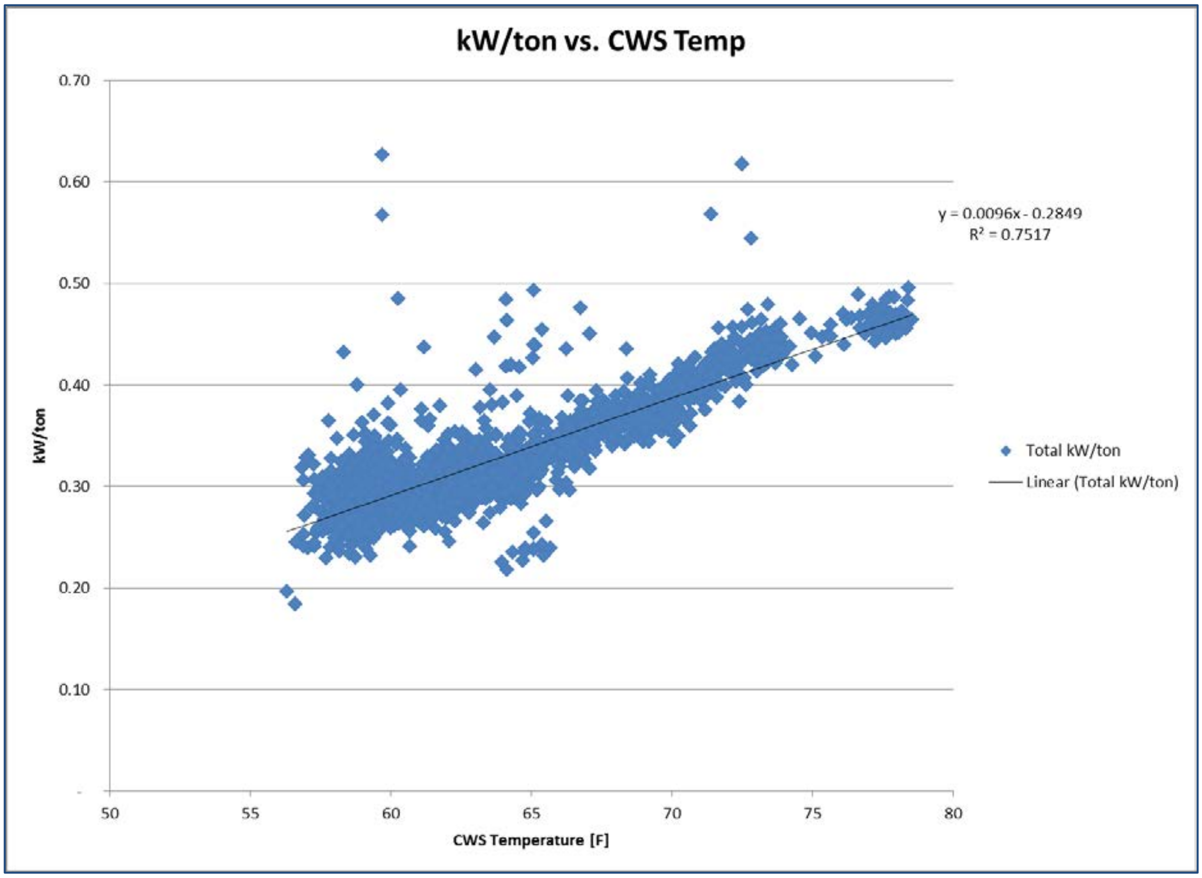

Figure 6: Observed chiller kW/ton vs. condenser water supply temperature.

Baseline chiller performance was calculated using chiller curves generated by DOE-2 building energy modeling software, based on a non-VSD centrifugal chiller (DOE-2 chiller type: CentH2O) that meets minimum ASHRAE standards (with a COP of 5.11 (0.688 kW/ton) with an NPLV of 5.37 (0.6547 kW/ton)). Baseline chiller kW/ton was calculated at every hour of the year, using entering condenser water temperature, entering chilled water temperature and chiller percent load as inputs.

Installed chiller performance was calculated in exactly the same way, using York water-cooled centrifugal VSD chiller curves, also generated from DOE-2 (DOE-2 Chiller type: CentH2OVSD) . The ARI kW/ton for the installed chiller was originally specified as 0.627 kW/ton to generate the chiller curves, but was later adjusted to 0.850 kW/ton in order to match the actual measured data. Note that ARI chiller test conditions are confined to specific temperatures at a particular chiller loading profile, and that actual chiller efficiency performance (seen in Figure 6 above) 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 7. The adjusted chiller curve appears to be a very close match for the actual measured data. Figure 8 also shows the good agreement between the model and measured data.

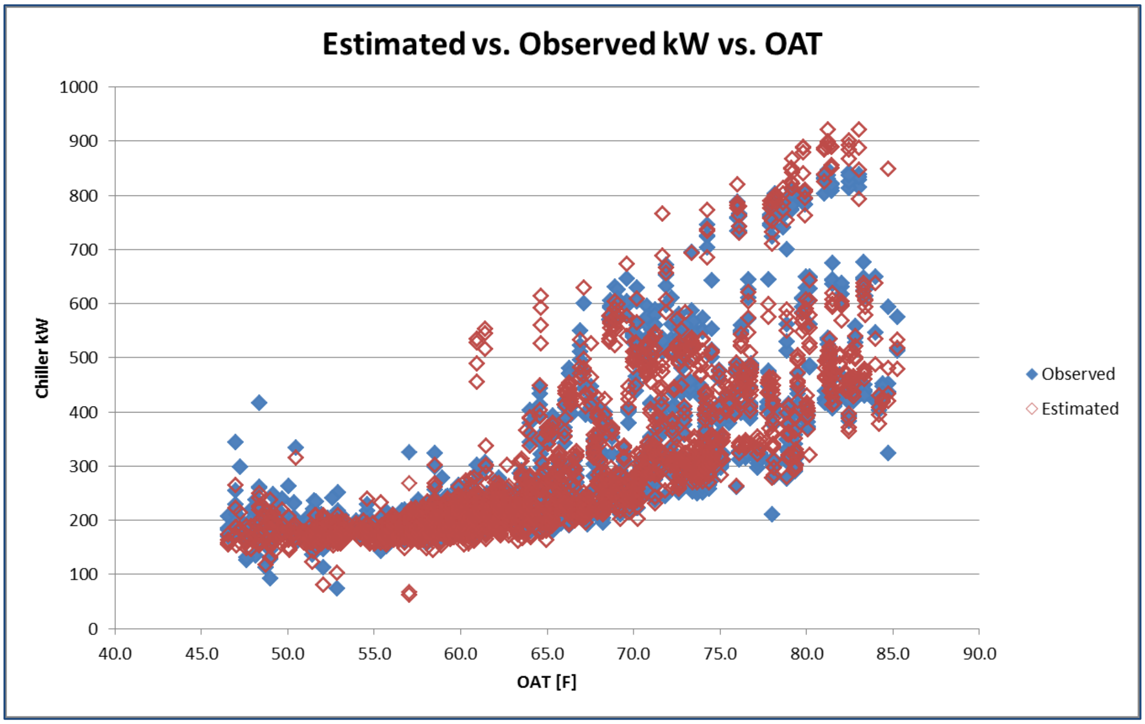

Figure 7: Estimated (DOE-2 chiller curve-generated) vs. Observed (via monitored data) chiller kW vs. OAT.

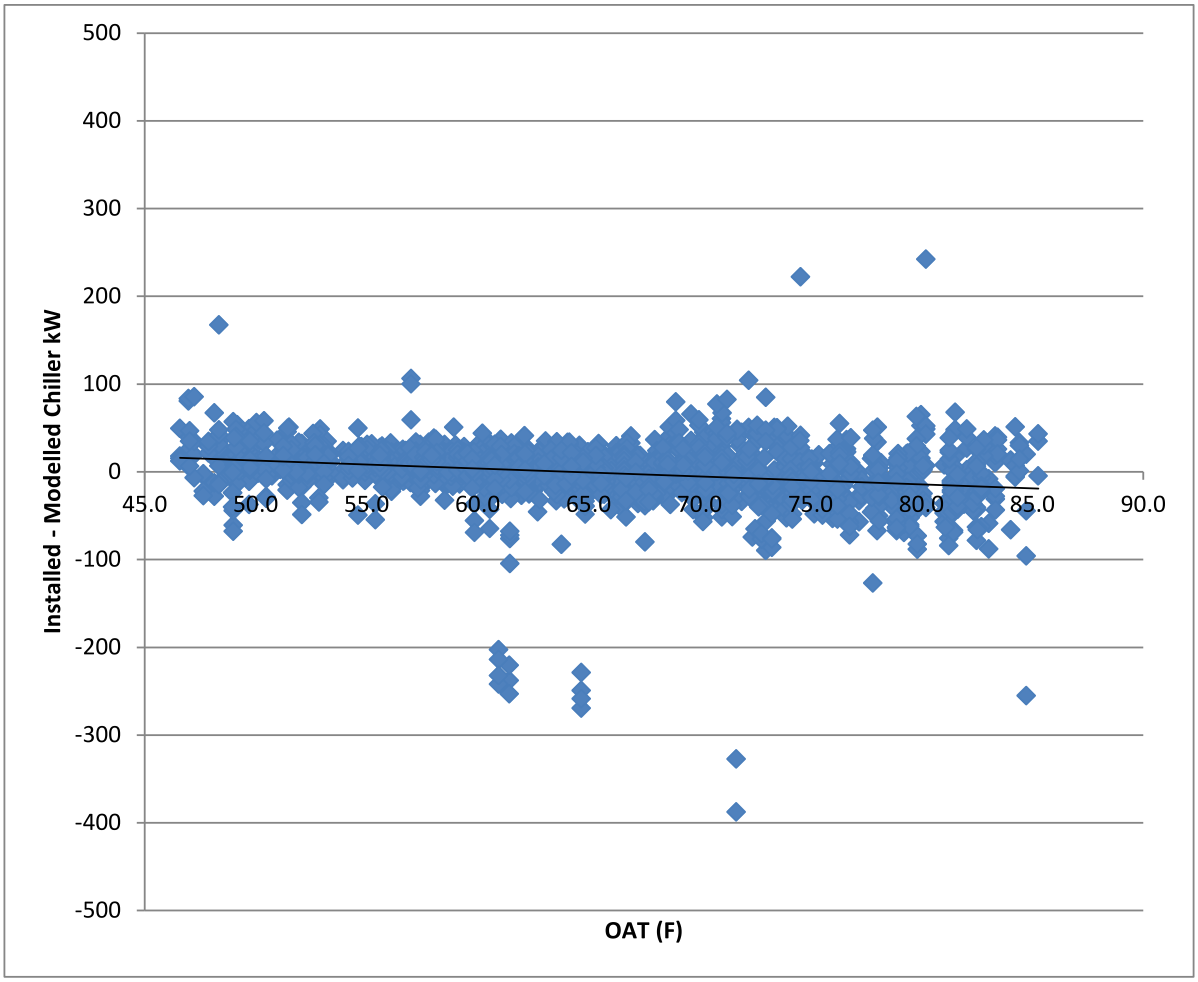

Figure 8. Difference between model vs observed chiller demand.

Using the DOE-2 generated chiller curves for both the baseline non-VSD chiller and the (adjusted) York VSD chiller and the inputs of chiller entering water temperature, condenser entering water temperature and chiller percent load (all regressed from monitored data), it was possible to calculate baseline and installed chiller kW for all hours of the year, given TMY3 data for OAT and OAWB. Energy savings was calculated for each hour of the year using the following equation:

$$Energy\ Savings\ [kWh] = \sum_{0}^{8760}(Baseline\ Chiller\ kW - Installed\ Chiller\ kW) \times 1\ hour$$

Non coincident peak demand savings was the maximum hourly value of (Baseline Chiller kW – Installed Chiller kW).

Coincident peak demand savings was the value of (Baseline Chiller kW – Installed Chiller kW) at 4-5pm on July 17th.

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 were physically impossible.
2. Verified that post-retrofit equipment specifications and quantities are consistent with the application.

Recording and Data Exchange Format

1. Building Automation System data files
2. Excel spreadsheets

Results Summary

This measure resulted in an energy savings much greater than originally predicted. The very high efficiency of the installed chiller at part load (low chiller % load) results in a great improvement over the baseline ASHRAE minimum chiller, and is likely the cause of the better-than-expected energy savings. The energy and demand savings results can be seen in Tables 1 and 2 below.

Table 1: Baseline and As Built energy and demand results.

	Annual Consumption (kWh)	NCP Demand (kW)	CP Demand (kW)
Baseline	4,902,357	1,659.4	876.7
As Built	2,814,090	1,532.0	735.2
Savings	2,088,267	127.4	141.5

Table 2: Energy and Demand Savings Summary.

	Energy Savings [kWh]	**NCP Demand Savings [kW]**	**CP Demand Savings [kW]**
Duke Estimate	730,151	142.0	-48.9
Verified	2,088,267	127.4	141.5
Realization Rate	286%	90%	-289%

Note that the CP Demand Savings realization rate is negative because the Duke estimated demand savings were negative. The M&V CP demand savings were actually positive rather than negative.

[Redacted]
Green Building Design Retrofit M&V Report

Prepared for
Duke Energy Ohio

January 2015, Version 4.0

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 participant.

Submitted by:

Rob Slowinski
NORESCO

Jerry Moechnig
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Introduction

This document addresses M&V activities for the [Redacted] custom program application. The application covered green building design retrofits—encompassing many different measures—at six schools in Cincinnati, Ohio. The measures included:

ECM-1 –Green Building Design

This project included major retrofits at several different [Redacted]. Many of the retrofits involved replacement of HVAC equipment, installation of VFDs and new control strategies. By far the largest savings (over 80% of total savings) occur at [Redacted], but other projects were conducted at [Redacted]. Specific retrofits are broken down by location below:

[Redacted]

- The existing constant-flow chilled water system was converted to a primary/secondary variable flow system with VFDs.
- VFDs were also added to a chiller.
- Existing constant-volume AHUs were converted to VAV units by adding VFDs to fan motors.
- Old electric reheat boxes were replaced with parallel fan-powered VAV boxes and tied into new room occupancy sensors.
- Dynamic air cleaners were installed to reduce the required outside air quantities.
- Existing gymnasium RTUs were replaced with new VFD RTUs.
- A condensate reclamation system was installed to collect water for cooling tower makeup.
- Several existing RTUs were removed.
- Existing single-pane clear glass skylights were replaced with double-pane low-e tinted skylights.
- A solar thermal heating system was installed on the roof to heat the swimming pool.
- CO2 sensors were installed in the gymnasium, cafeteria and auditorium.
- Existing DDC controls were connected to a campus-wide DDC system.

[Redacted]

- The existing constant flow chilled water plant was converted to a primary/secondary variable flow plant, by adding VFDs to existing pumps. New chiller optimization control strategies were also implemented.
- VFDs were added to cooling tower fans, and new control strategies were implemented.
- Old, 80% efficiency cast-iron boilers were replaced with new 93% efficient condensing boilers. This constant volume system was also converted to variable volume by adding VFDs to existing building hot water pumps.
- Existing constant-volume AHUs were converted to VAV by adding VFDs to fan motors.
- Existing unit ventilators were replaced with new units.
- Existing VAV boxes were tied into new room occupancy sensors.
- Dynamic air cleaners were installed to reduce outside air requirements.

- The existing kitchen makeup air unit was replaced with a new unit.
- Existing FCU and inefficient rooftop condensing units serving media center offices were replaced by high-efficiency mini split systems.
- CO2 sensors were installed in the gymnasium, cafeteria and auditorium AHUs.
- All new DDC controls were installed and tied into the campus-wide DDC system.

[Redacted]

- Old, 80% efficiency cast-iron boilers were replaced with new 93% efficient condensing boilers. This constant volume system was also converted to variable volume by adding VFDs to existing building hot water pumps.
- Two existing RTUs were replaced with new, high efficiency units with hot-gas reheat.
- 6 existing DX cooling unit ventilators and condensing units were replaced with new unit ventilators and tied into the building chilled/hot water system.
- CO2 sensors were installed in the gymnasium, cafeteria and auditorium AHUs.
- All new DDC controls were installed and tied into the campus-wide DDC system.
- Dynamic air cleaners were installed to reduce outside air requirements
- Existing electric reheat coils were replaced with VAV boxes with hot water reheat coils.
- Existing single zone constant volume RTUs were converted to VAV units.
- Gym units had dampers and controls installed to enable stage operation during unoccupied periods.

[Redacted]

- A water-to-water heat pump was installed and connected to the chilled water system.
- A thermal ice storage system was installed to reduce demand.
- Existing DDC controls were connected to the campus-wide DDC system.

[Redacted]

- A water-to-water heat pump was installed and connected to the chilled water system.
- A thermal ice storage system was installed to reduce demand.
- Existing DDC controls were connected to the campus-wide DDC system.
- The existing uninsulated 750-gallon hot water storage tank was insulated.
- 4 existing inoperable energy recovery wheels were repaired with new VFD wheel motors.

[Redacted]

- One existing 100-ton chiller and one existing 30-ton chiller were replaced with a new 120-ton high efficiency chiller. The system was also converted from constant-flow to variable-flow.
- A thermal ice storage system was installed to reduce demand.
- Old, 80% efficiency cast-iron boilers were replaced with new 93% efficient condensing boilers. This constant volume system was also converted to variable volume by adding VFDs to existing building hot water pumps.
- Old unit ventilators were replaced with new units and control strategies.
- Existing electric reheat coils were replaced with new VAV boxes with hot water reheat.

- Existing CV AHUs were converted to VAV by installing VFDs on fan motors.
- Gravity backdraft dampers were installed on building relief louvers.
- All new DDC controls were installed and tied into the campus-wide DDC system.

Goals and Objectives

The projected savings goals identified in the application are:

Facility	Proposed Annual kWh savings	Proposed kW Savings	Duke Projected Annual kWh savings	Duke Coincident Peak kW savings	Duke non Coincident Peak kW savings
[Redacted]	2,254,745	4,654	(listed by entire project)	(listed by entire project)	(listed by entire project)
[Redacted]	184,412	440	-	-	-
[Redacted]	204,804	425	-	-	-
[Redacted]	27,521	41	-	-	-
[Redacted]	31,404	52	-	-	-
[Redacted]	99,023	242	-	-	-
Total	2,801,909	5,854	3,448,380	216.8	633.1

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

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

Project Contacts

Duke Energy M&V Admin.	Frankie Diersing	p: 513-287-4096
NORESCO Engineer	Rob Slowinski	p: 303-459-7409
Customer Contact	[Redacted]	[Redacted]

Site Locations/ECMs

Address
[Redacted]

Data Products and Project Output

- Pre- and post-retrofit utility bills, by facility
- Historical and TMY3 Degree Days for Cincinnati, OH
- Annual gross energy savings (kWh)
- Facility peak demand (kW) savings
- Summer utility coincident peak demand (kW) savings
- kWh & kW Realization Rates

M&V Option

IPMVP Option C – Whole Facility

Field Survey Points

Post - Installation

- Two schools were evaluated—[Redacted]. These schools comprised nearly 90% of the total projected energy savings.
- A field survey was conducted to confirm equipment quantities and specifications at both of the schools being evaluated. This included all pumping, HVAC, solar thermal and other equipment. Aside from some reductions in the chilled water plant ECMs at the high school, all of the measures were fully implemented as reported.
- No major significant changes to total occupancy, schedules, or finished square footage were encountered between the completion of the projects and the field survey.
- Schedules and use patterns were confirmed to be identical, pre- and post-retrofit.
- [Redacted] occupancy was confirmed to be 1,800 students, both pre- and post-retrofit. The middle school enrollment was approximately 860 students both pre- and post-retrofit.
- The actual start date of the projects was 6/2011, with the actual completion date of 8/2012 (except for some final control programming).
- Both pre- and post-retrofit utility data was collected for a thorough evaluation.
- Pre-retrofit utility data was collected for all accounts back to January 2012, with post retrofit data collected up to June 2014. For select accounts, pre-retrofit data was gathered back to 2008.

Utility and Weather Data Collection

[Redacted] utility data was comprised of 4 separate meters, from which continuous data was gathered from January 2010 to August 2014. In order to further (visually) confirm the baseline state, data for the largest of the four utility accounts was collected from as early as January 2008.

[Redacted] data was also comprised of data from 4 different meters, and was collected from January 2010 to July 2014.

In order to properly normalize utility energy consumption based upon changing weather conditions, both heating and cooling degree days (with a base temperature of 65F) were obtained for Cincinnati, OH from DegreeDays.net over the same time period (January 2010 to July 2014). In addition, in order to estimate energy and demand savings over a typical year, the theoretical heating and cooling degree days were calculated from the Cincinnati, OH TMY3 weather dataset.

Data Analysis

Option C involves the use of utility meters to assess the energy performance of a whole building. Since whole-building meters are used, savings reported under Option C include the impact of any other changes made in facility energy use.

Common independent variables affecting energy consumption include weather and occupancy. Weather has many dimensions, but for whole building analysis weather is most often just daily outdoor air temperature (or associated heating and cooling degree days). Occupancy may be defined in several ways, such as room occupancy factor, core occupancy hours or number of occupied days. For the purposes of this analysis, no significant changes in occupancy (measured either by number of occupants or operating hours) were observed. In addition, there were no major changes to the facilities to report. For this analysis, the only normalization required was that of changes in weather.

This analysis utilized 12 months of pre-retrofit utility data for electricity consumption and electric demand to determine and characterize a pre-retrofit baseline of energy consumption and demand. That data was compared to 12 months of post-retrofit energy usage data to determine the post-retrofit conditions.

Monthly utility data was refined on a usage-per-day level, by dividing total monthly consumption by the number of days in each billing period. Monthly usage per day was normalized through the use of regression analysis and TMY3 degree days to account for outdoor air temperature differences and schedule variation, compared on pre- and post-retrofit basis and then compiled for the entire year to determine annual energy savings.

In general, savings calculations follow the equation:

Savings = (Baseline Energy – Reporting Period Energy) ± Routine Adjustments ± Non-Routine Adjustments

Demand savings were calculated using a similar regression of the maximum annual demand for both pre- and post-retrofit conditions.

Statistical analysis was conducted on the large high school account to ensure that the created regressions are statistically significant (f-statistic test) and that the pre- and post-retrofit regressions are statistically different from one another. These tests verified that the energy savings are in fact real in a rigorous statistical sense.

Verification and Quality Control

1. With a couple of minor exceptions, pre-retrofit and post retrofit equipment specifications and quantities were verified to be consistent with the application.
2. No changes in schedules, occupancies or other facilities retrofits were reported.

Recording and Data Exchange Format

1. Utility data files
2. Excel spreadsheets

Results Summary

[Redacted] experienced by far the greatest energy savings of any of the school retrofit projects. Figure 1 shows the raw energy consumption data from January 2010 to August 2014 for Account 1, the largest of all the accounts. Note the drastic reduction in consumption that occurs in the summer of 2011, and the relative consistency of the data both before and after the change. According to discussions with school operations staff, a significant change that occurred during that period was to quit running all the HVAC continuously, and to start scheduling the equipment on and off according to an occupancy schedule.

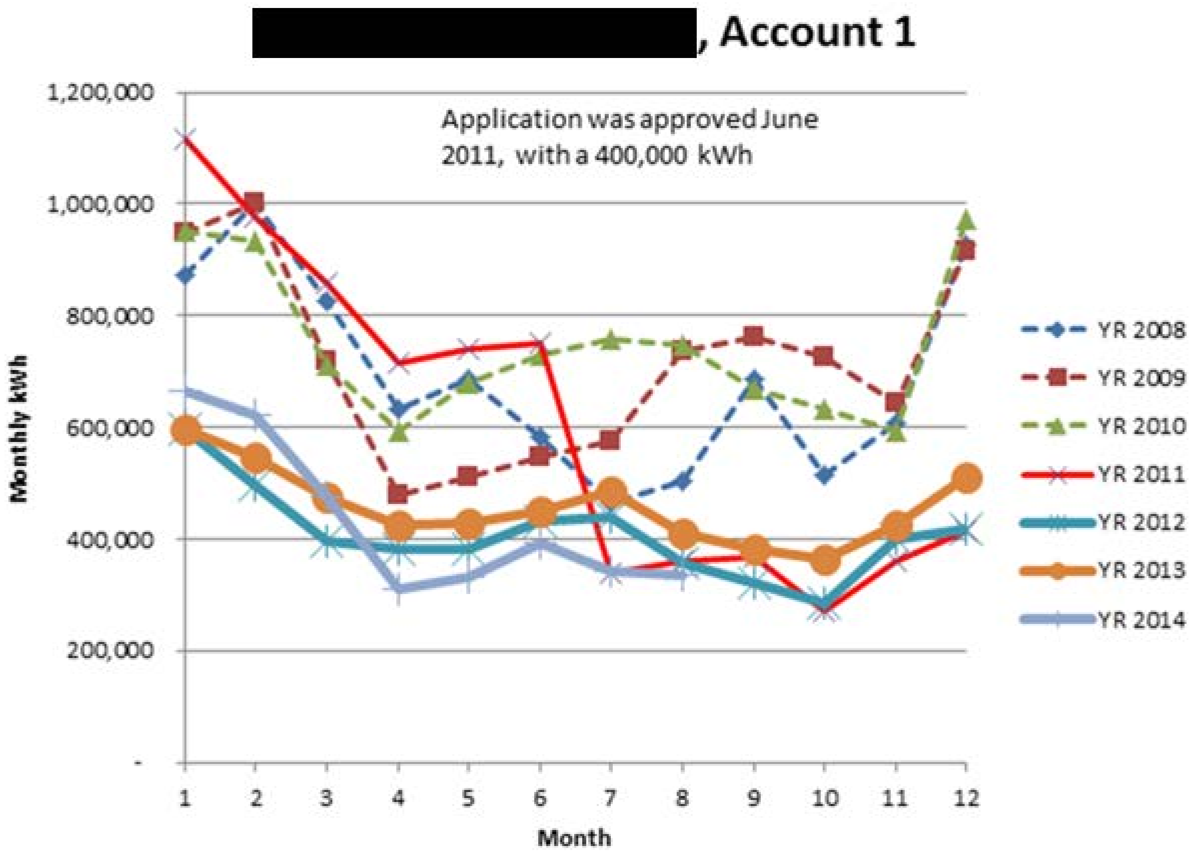

Figure 1: [Redacted] energy usage (Account 1) from 2008 to 2014.

Excluding the months between June 2011 and August 2012, data for both schools (4 accounts each) was compiled, normalized on a daily basis, and then matched with both heating and cooling degree days for the time period.

Table 1 shows the raw utility and degree-day data for [Redacted].

Table 1: [Redacted] Pre- and Post-Retrofit utility and degree-day data.

	COMBINED PRE DATA				
Date	kWh	kW	CDD65	HDD65	Days in Period
1/1/2010	1,623,629	3491.92	0.0	1180.0	31
2/1/2010	1,577,074	3479.21	0.0	1045.8	28
3/1/2010	1,217,141	3594.52	2.7	605.1	31
4/1/2010	945,177	3372.01	63.5	236.9	30
5/1/2010	1,034,994	3167.93	146.5	100.2	31
6/1/2010	1,011,105	2847.73	307.9	5.0	30
7/1/2010	1,059,152	2687.37	396.6	3.2	31
8/1/2010	1,056,147	2596.61	405.6	3.6	31
9/1/2010	992,136	2810.75	220.5	66.9	30
10/1/2010	946,205	3034.60	56.8	288.9	31
11/1/2010	930,964	3334.87	7.0	599.0	30
12/1/2010	1,511,621	3828.10	0.0	1181.5	31
1/1/2011	1,679,988	3625.09	0.0	1191.5	31
2/1/2011	1,474,221	3360.26	0.3	809.4	28
3/1/2011	1,272,159	3230.89	11.0	647.0	31
4/1/2011	1,044,971	3248.99	38.1	281.9	30
5/1/2011	1,055,021	3042.07	130.4	178.5	31
6/1/2011	1,030,218	2957.39	251.7	10.0	30

	COMBINED POST DATA				
Date	kWh	kW	CDD65	HDD65	Days in Period
09/20/12	496,258	1554.24	243.0	43.7	30
10/19/12	483,194	1693.19	24.3	266.7	29
11/19/12	713,425	2104.46	14.7	581.1	31
12/20/12	755,208	2390.31	0.8	645.3	31
01/23/13	1,066,599	2416.7	0.0	1090.8	34
02/21/13	985,156	2593.4	0.1	929.0	29
03/22/13	854,762	2310.37	0.0	834.6	29
04/23/13	702,111	1990.77	36.2	498.4	32
05/22/13	656,520	1727.97	85.8	164.3	29
06/21/13	636,990	1597.03	195.8	39.0	30
07/23/13	657,225	1476.77	338.1	0.7	32
08/21/13	575,751	1463.23	210.2	22.1	29
09/20/13	591,298	1616.38	264.7	28.5	30
10/21/13	599,887	1546.49	68.0	183.7	31
11/20/13	722,203	2002.62	0.0	569.0	30
12/20/13	873,795	2101.6	0.0	918.8	30
01/23/14	1,031,840	2708.4	0.1	1225.3	34
02/21/14	1,026,742	2701.28	0.1	1145.1	29
03/24/14	806,675	2327.23	2.0	885.5	31
04/23/14	549,156	2022.37	29.6	418.0	30
05/22/14	559,458	1671.77	89.0	160.3	29
6/23/14	594,661	1613.63	258.2	20.4	32

A multi-variable linear regression was carried out for energy consumption (kWh) with independent variables cooling degree days (CDD65), heating degree days (HDD65) and days in period. The same regression was also calculated for electric demand (kW).

Perhaps because [Redacted] , these kWh and kW regressions all produced very high R^2 values (all four equations R^2 above 84%). The R^2 values for the (electric and natural gas) Junior High are not as strong, but still should be considered credible.

Although the data were regressed using HDD and CDD, it is difficult to show the models when plotted as a function of degree days. Therefore, the charts in Figures 2 through 5 provide a more visible comparison between the regression models and the observed pre- and post-retrofit data as compared to monthly average outdoor air temperatures.

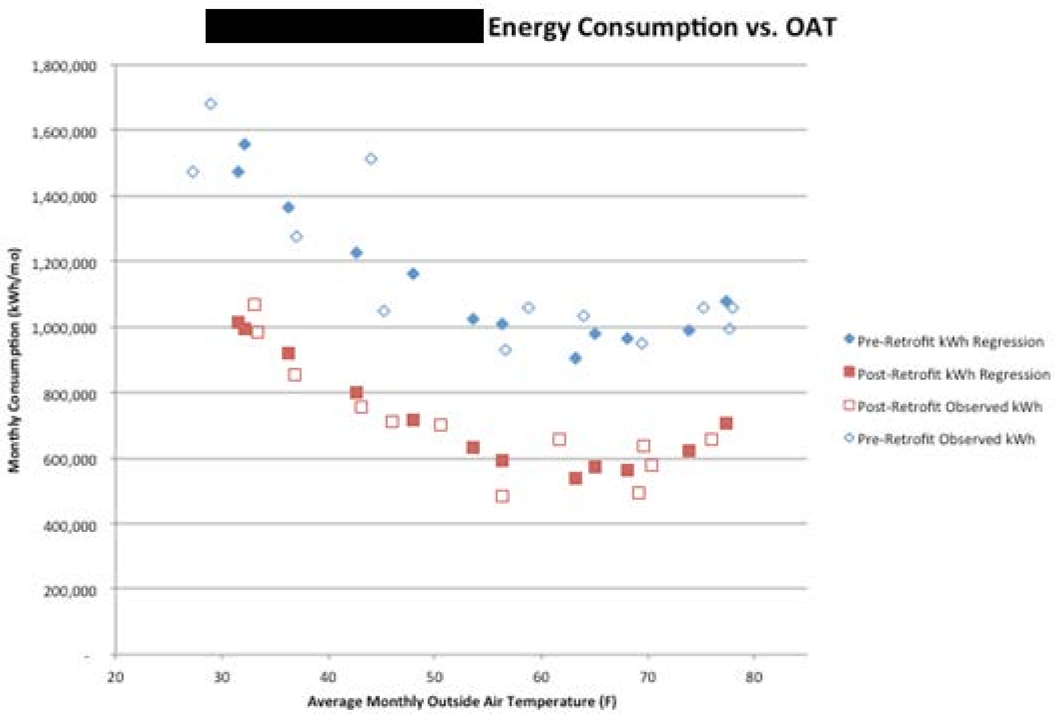

Figure 2. [Redacted] monthly consumption versus monthly average temperature.

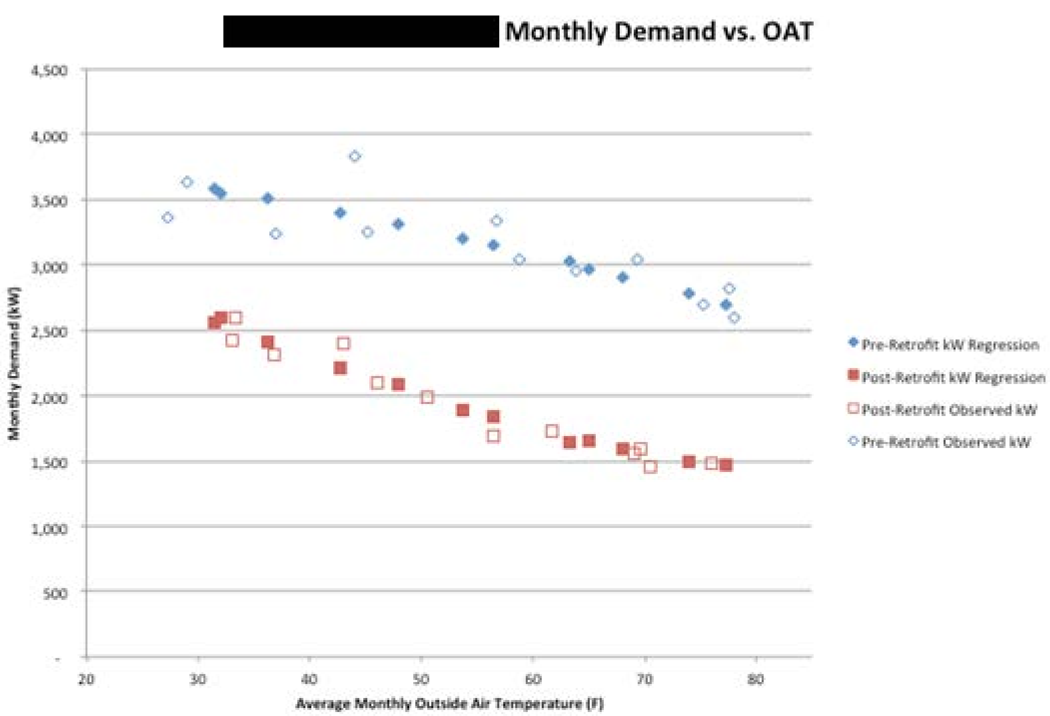

Figure 3. [Redacted] monthly demand versus monthly average temperature.

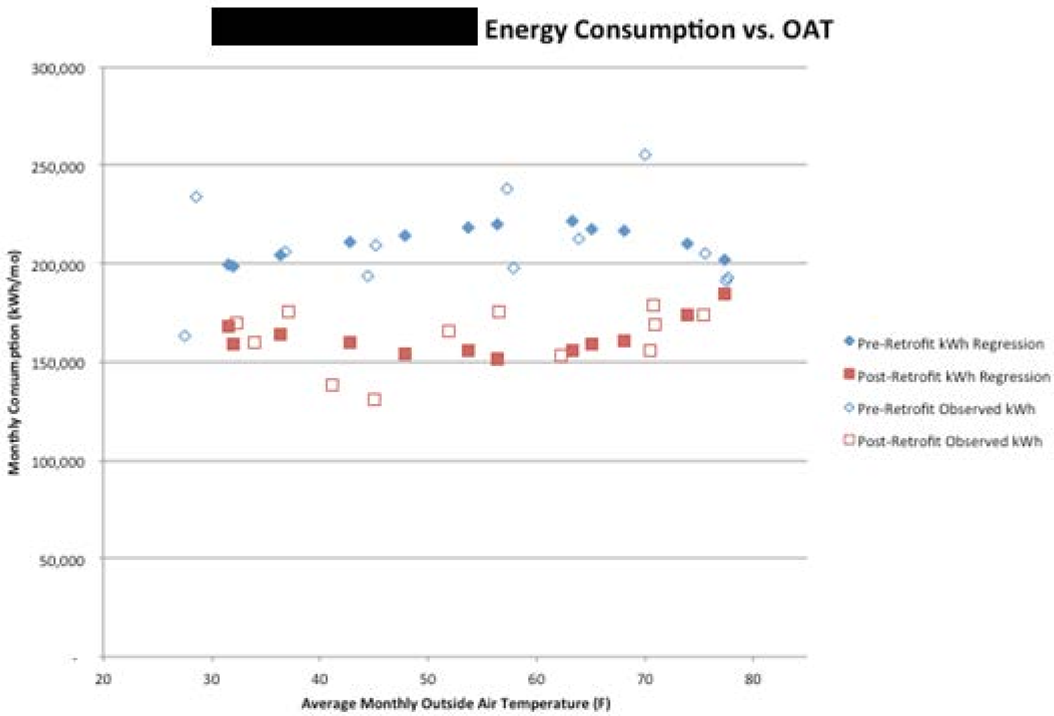

Figure 4. [Redacted] monthly consumption versus monthly average temperature.

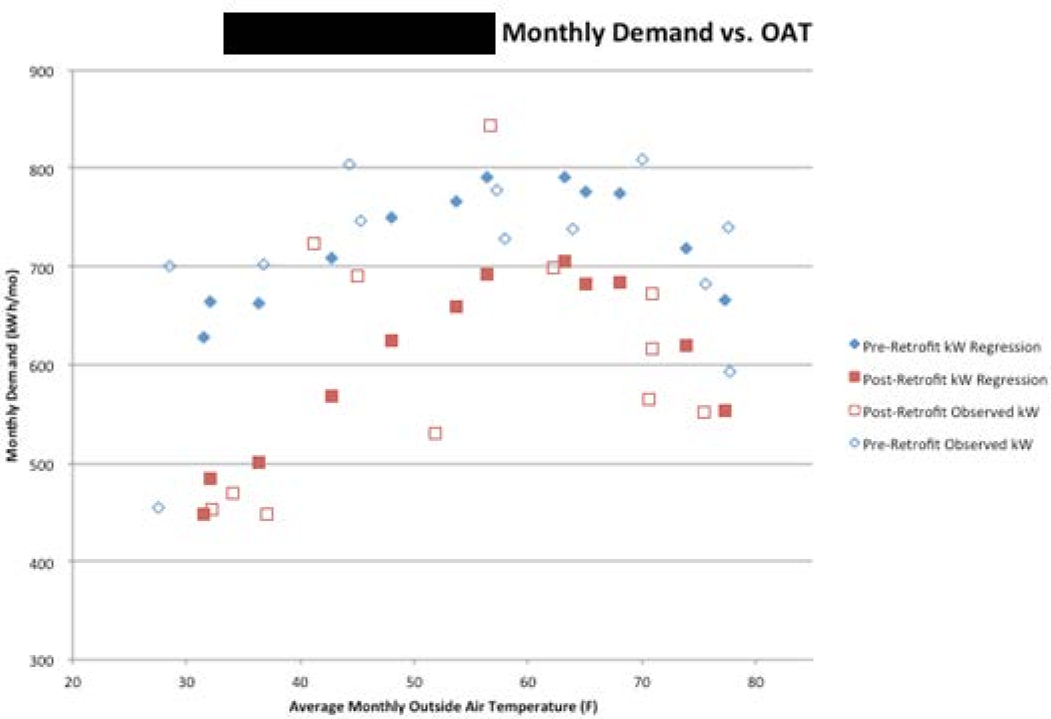

Figure 5. [Redacted] monthly demand versus monthly average temperature.

Figures 6 and 7 show the estimated monthly energy consumption for [Redacted] and [Redacted], based on the regression equations.

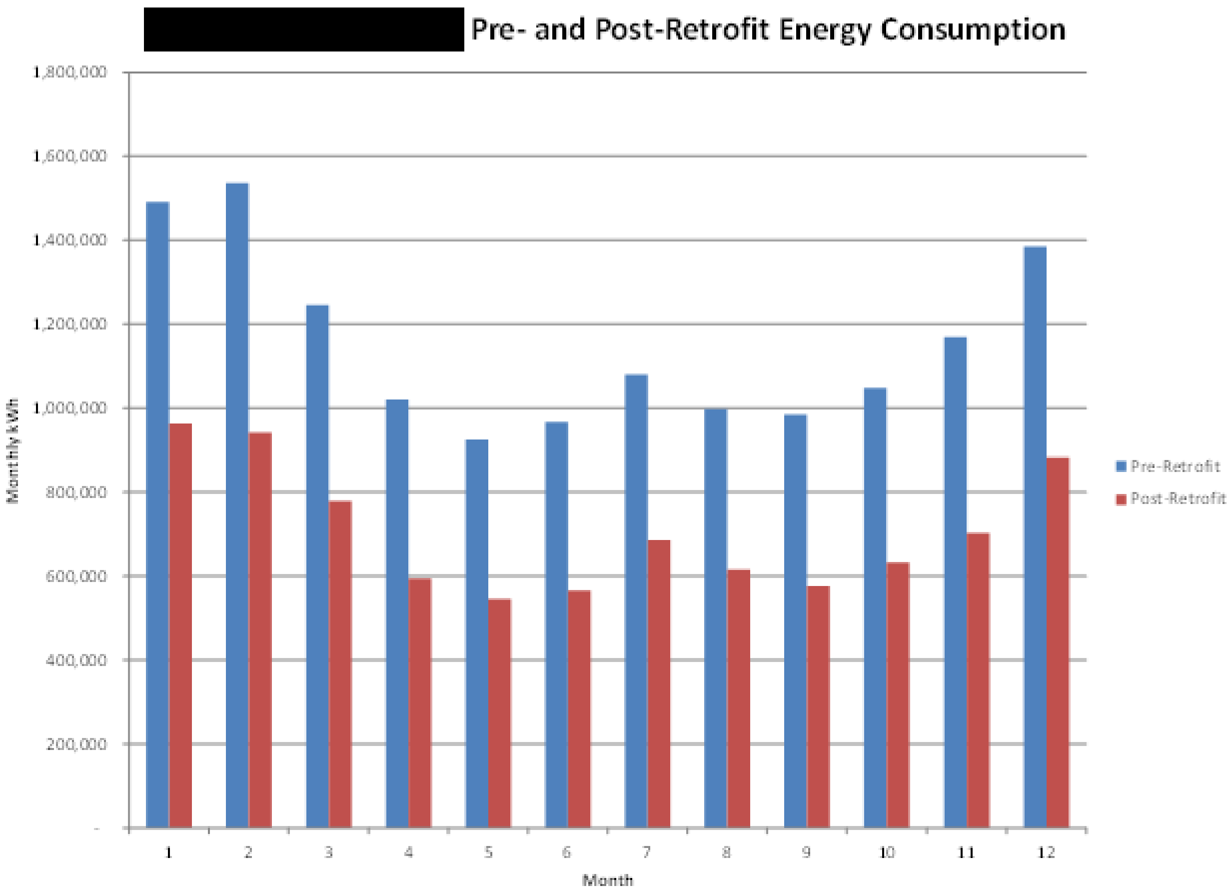

Figure 6: Estimated Pre- and Post-Retrofit energy consumption for [Redacted].

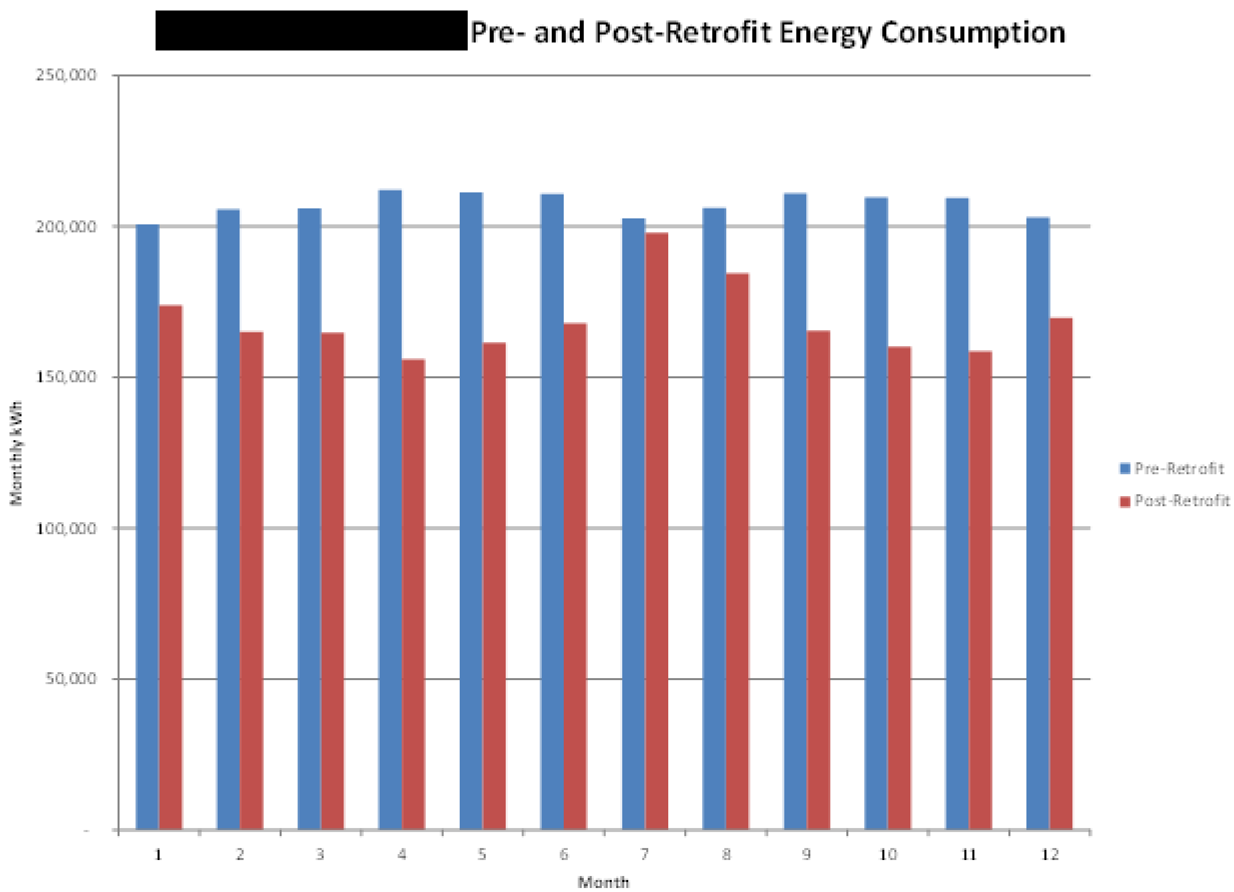

Figure 7: Estimated Pre- and Post-Retrofit energy consumption for [Redacted].

Tables 2 and 3 summarize the energy and demand savings resulting from the energy retrofits at [Redacted].

Table 2: [Redacted] Estimated kWh and kW Savings.

	Pre-Retrofit kWh Regression	Post-Retrofit kWh Regression	kWh Savings	Pre-Retrofit kW Regression	Post-Retrofit kW Regression	kW Savings
January	1,470,577	1,012,478	458,098	3,587	2559	1,028
February	1,554,742	994,680	560,062	3,542	2594	948
March	1,223,006	801,596	421,410	3,396	2210	1,186
April	1,009,608	592,157	417,451	3,149	1841	1,308
May	904,309	536,222	368,087	3,021	1645	1,375
June	963,741	562,965	400,776	2,903	1587	1,316
July	1,077,623	705,568	372,055	2,692	1474	1,217
August	988,395	622,208	366,187	2,779	1489	1,290
September	980,364	574,961	405,403	2,962	1652	1,310
October	1,024,328	634,347	389,982	3,201	1893	1,308
November	1,158,917	717,337	441,580	3,307	2089	1,217
December	1,363,363	921,069	442,294	3,506	2410	1,097
Total	**13,718,973**	**8,675,588**	**5,043,385**		**NCP kW Savings**	**1,375**
					CP kW Savings	**1,316**

Table 3: [Redacted] Estimated kWh and kW Savings.

	Pre-Retrofit kWh Regression	Post-Retrofit kWh Regression	kWh Savings	Pre-Retrofit kW Regression	Post-Retrofit kW Regression	kW Savings
January	198,958	167,696	31,262	627	448	179
February	197,996	159,177	38,819	663	485	178
March	210,378	159,697	50,681	708	568	139
April	220,009	151,375	68,633	791	691	99
May	221,739	155,929	65,810	791	705	87
June	216,712	160,477	56,235	774	683	91
July	201,846	184,797	17,049	666	554	112
August	209,992	174,034	35,958	718	620	99
September	217,131	158,696	58,435	776	682	94
October	218,454	155,405	63,050	766	659	107
November	214,218	154,054	60,164	749	625	124
December	203,949	164,142	39,808	662	500	162
Total	**2,531,382**	**1,945,479**	**585,903**		**NCP kW Savings**	**179**
					CP kW Savings	**91**

Table 4 shows the estimated energy and demand savings of the entire [Redacted] project, based on data extrapolated from the [Redacted] utility data. Statistical analysis was conducted on the large [Redacted] account to ensure that the created regressions are statistically significant (f-statistic test) and that the pre- and post-retrofit regressions are statistically different from one another. These tests verified that the energy savings are in fact real in a rigorous statistical sense.

Table 4: Predicted vs. Verified Savings and Realization Rates.

	Savings			Savings			Savings		
	Predicted kWh	Verified kWh	Realization Rate	Predicted NCP kW	Verified NCP kW	Realization Rate	Predicted CP kW	Verified CP kW	Realization Rate
[redacted]	2,774,971	5,043,385	182%		1,375			1,316	
[redacted]	226,960	585,903	258%		179			91	
HS & JHS	3,001,931	5,629,288	188%		1,554			1,407	
Entire Project	3,448,380	6,466,479	188%	633	1,784	282%	217	1,616	745%

This project predicted a massive energy and demand savings due to the green building retrofits, and this analysis indicates that the verified savings is even greater than expected. The engineering team conducting this analysis requested more information from the project team, including both anecdotal evidence and further baseline utility data. The facilities manager at the [Redacted] indicated that the large and sudden savings occurring in June/July of 2011 was likely the result of switching to a more sophisticated control strategy (night setbacks, turning equipment off, etc) when there was previously no such program. Additional pre-retrofit utility data (back to January 2008) also confirms that the energy savings due to the retrofit project is, in fact, real.

[Redacted]
New Construction – Green Building Design M&V Report

Prepared for
Duke Energy Ohio

March 2015, Version 1.0

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

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

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

Submitted by:

Doug Dougherty
NORESCO, Inc.

Stuart Waterbury
NORESCO, Inc.

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NORESCO
United Technologies

Introduction

This report addresses measurement and verification (M&V) activities for the [Redacted] custom program application. The application covers certain features of the green building design at the [redacted] in Cleves, Ohio. The school was completed in March, 2014.

ECM-1 – New Construction – Green Building Design

Several of the energy conservation measures that were to be implemented at the school were eligible for Smart Saver incentives. These measures were:

- High-efficiency lighting (including vacancy/occupancy sensors in all rooms)
- Daylighting controls (including skylights and roof monitors)
- Triple-pane low-E argon-filled glazing
- Sun shades (exterior light shelves)
- Reduced site lighting power
- High efficiency transformers.

Goals and Objectives

Pre-and post-retrofit energy models of the building were previously created by the applicant's Architect. The energy savings projections are based on 2010 weather data against a baseline of ASHRAE 90.1-2007, HVAC system 8, modeled per the requirements of LEED 2009. These models were obtained from Duke Energy, and were used to determine the energy and power reduction achieved by the control system upgrade. Modifications to the models that were necessary as a result of the M&V investigation were incorporated and are described in the Results section of this report.

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 (Non-coincident) kW savings	Proposed Coincident Peak kW savings
[Redacted]	1,321,613	431	806,200	310.0	78.9

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

- Annual gross electric energy (kWh) savings
- Building peak demand (kW) savings
- Coincident peak demand (kW) savings

- Energy, demand and coincident demand Realization Rates

Project Contacts

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

Site Locations/ECM's

Site	Address	Sq. Footage
[Redacted]	[Redacted]	283,014

Data Products and Project Output

- Energy consumption pre- and post-retrofit for the entire facility
- Annual energy savings
- Peak demand savings
- Coincident peak demand savings.

M&V Option

IPMVP Option D: Calibrated Simulation

M&V Implementation Schedule

Since this project is new construction, this survey and data collection was for the as-built building only.

- Obtained copies of the building lighting plans.
- Obtained copies of the HVAC/Mechanical systems design schedules.
- Obtained copies of the existing computer energy models (baseline and proposed).
- Compared the pre- and post-upgrade models to determine what changes were made in the post-upgrade model to improve the building's energy performance.
- Ran the existing energy models to verify the reported energy and demand savings are obtained.

- Conducted an interview with the building contact. Determined if all the energy measures were accomplished in the new construction. Documented the measure installations with photographs (including product labels/nameplates where appropriate).
- Identified the high-efficiency lighting types in use and where they are located.
- Identified the area where skylights and daylighting controls are located.
- Obtained the facility's operating schedules, including any differences for normal (occupied) periods, reduced-occupancy periods, and closed periods. Obtained the school's academic calendar.
- Deployed data loggers to monitor operation of a sample of the lighting for both daylight-controlled areas and uncontrolled areas, as detailed in the "Field Data Points" section below.
- Deployed data loggers as needed for a minimum of three weeks.
- Revised the building energy models as required based on the findings of the M&V investigation.
- Ran the revised energy models to obtain updated energy and demand savings values.
- Compared the updated savings values to the original reported values and calculate the energy and demand savings realization rates.

Field Data Points

Survey data

- Interviewed the building contact to obtain the following information.
  - Building layout
  - Space usages
  - Normal occupancy schedules and academic year calendar
  - Number of holidays observed per year
  - Operating schedules for lighting
  - Operating schedules for mechanical equipment
  - Typical space heating and cooling temperature setpoints
  - Night/weekend heating setback / cooling set-up of space temperatures.
- "High-performance" HVAC systems include energy recovery wheels in 5 of 11 Air handling units (AHUs), ground-source water loop for 10 heat pumps supplying hot and chilled water to AHUs, CO2 controls for outside air for all AHUs.

- Photographed all building exterior exposures.

Spot-Measurements

All circuits have daylighting controls with the exceptions of the Health Clinic, cafeterias and theater, which are controlled manually.

For a random sample of the Lighting circuits:

- Measured circuit Volts, Amps, Watts and Power Factor

Fifteen circuits were sampled, limited to major usage areas such as classrooms, main corridors, administrative offices, auditoriums, cafeterias, gymnasium, etc. Minor areas such as restrooms, storage rooms, mechanical/electrical rooms, etc., were disregarded.

Time series data on controlled equipment

- Deployed data loggers to monitor the circuits sampled above.

Data Accuracy

Measurement	Sensor	Accuracy	Notes
Current	Onset CTV	±4.5%	> 10% of rating

Field Data Logging

- Set up loggers for 5-minute readings and allowed operation for a minimum of three weeks.
- Collected data during normal operating hours (avoiding atypical operating situations such as maintenance shutdowns or school vacations).

Logger Table

The following table summarizes the logging equipment needed to accurately measure the above noted lighting.

Function	Hobo U-12 Data Loggers	CTV-A's
Lighting Circuits (sampled qty = 15)	4	15 (20-amp)
Total	**4**	**15**

Data Analysis

- Ran the existing baseline and proposed building energy models to verify the reported energy and demand savings are obtained.
- Determined from the field survey data and customer contact interview if all of the model changes for the proposed building model had been implemented.
- Revised the proposed building model with any changes required. This becomes the "M&V" model.
- Ran the M&V model to determine the M&V annual energy consumption.
- Compared the revised M&V model output with the baseline output to determine the annual energy savings.
- The energy and demand savings realization rates were calculated by the following formula:

  Realization Rate for kWh = $kWh_{M\&V} / kWh_{Projected}$
  Realization Rate for kW = $kW_{M\&V} / kW_{Projected}$

Verification and Quality Control

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

Recording and Data Exchange Format

1. Applicable field notes
2. Data logger files
3. Excel spreadsheets
4. eQUEST energy model data files.

Results

The following ECM features were verified as described below.

High-Efficiency Lighting (including vacancy/occupancy sensors in all rooms)

All lights are controlled by occupancy motion sensors except in the Health Clinic, cafeterias, gymnasiums, theater, music room, and corridors. No change was required for the ECM model.

Thirty spaces were spot-surveyed to verify the installed lighting fixtures and room dimensions. The details are presented in the table at the end of this report. The overall Lighting Power Density (LPD) in the baseline building was modeled as 1.20 watts per square foot (W/ft2), and the new building was modeled as 0.82 W/ft2. However, the on-site survey shows that the overall LPD for the surveyed spaces (see Table 2 at the end of the report) is 1.188 W/ft2, which is very close to the baseline value. Therefore the LPD was changed to 1.188 in the ECM model.

Daylighting Controls (including skylights and roof monitors)

All lights are on daylighting photocells except the theater, certain classrooms, corridors, administrative offices , the Health Clinic, cafeterias, and the vocal room. No change was required for the ECM model.

Triple-Pane Low-E Argon-Filled Glazing

The project narrative calls for triple-paned low-E argon-filled glazing. The submittals show the glass units as one-inch units with two quarter-inch glass lites and a half-inch airspace, or double-pane, not triple-pane. However, the window performance parameters (glass conductance and shading coefficient) already in the ECM model were close to the submitted values and therefore were not changed.

Sunshades (exterior light shelves)

To reduce solar gains in the spaces, many windows have exterior overhangs to block direct sunlight from entering the spaces through the lower portions of the windows. These overhangs also reflect sunlight upward through the upper portions of the windows for indirect daylighting.

The overhangs are included in the ECM model, but they were also included in the baseline model. Overhangs are not required for the ASHRAE 90.1 baseline. The overhangs were removed from the baseline model.

Windows around the circular administration area had vertical side fins in the ECM model. Photographs of the building don’t show any side fins for this area. Like the overhangs, the baseline model also included these side fins. The vertical fins were deleted from both models.

Reduced Site Lighting Power

The site lighting is installed as designed. Site lighting was not specifically monitored. No change was made to the ECM model.

High-Efficiency Transformers

The high-efficiency transformers are installed as designed. The transformers were not specifically monitored. No change was made to the ECM model.

Results

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

Table 1: Energy and Demand Summary

Facility: [Redacted]			
	Annual Energy (kWh)	Non-Coincident Peak Demand (kW)	Coincident Summer Peak Demand (kW)
Application			
Pre-Retrofit	3,967,267	1,905	n/a
Post-Retrofit	2,645,654	1,474	n/a
Savings	1,321,613	431	n/a
M&V			
Pre-Retrofit	3,977,756	1,916.6	353.2
Post-Retrofit	2,735,750	1413.8	230.6
Savings	1,242,006	502.9	122.6
Duke Projections	806,200	310.0	78.9
Realization Rates	154%	162%	155%

For Ohio in 2014, the coincident peak demand hour is on July 17, for the hour between 4-5 PM. In the simulation, July 17 happened to fall on a Sunday, so the values for the hottest weekday in the weather data, Thursday July 14, were used instead.

The coincident peak demands are so much lower than the non-coincident peak demands because school gets out at 3 PM, and the demands drop off rapidly after that time. The non-coincident peak demand occurs on June 10 in the baseline model. The demand history for both the coincident peak day and the non- coincident peak day are shown in Figure 1and Figure 2 below.

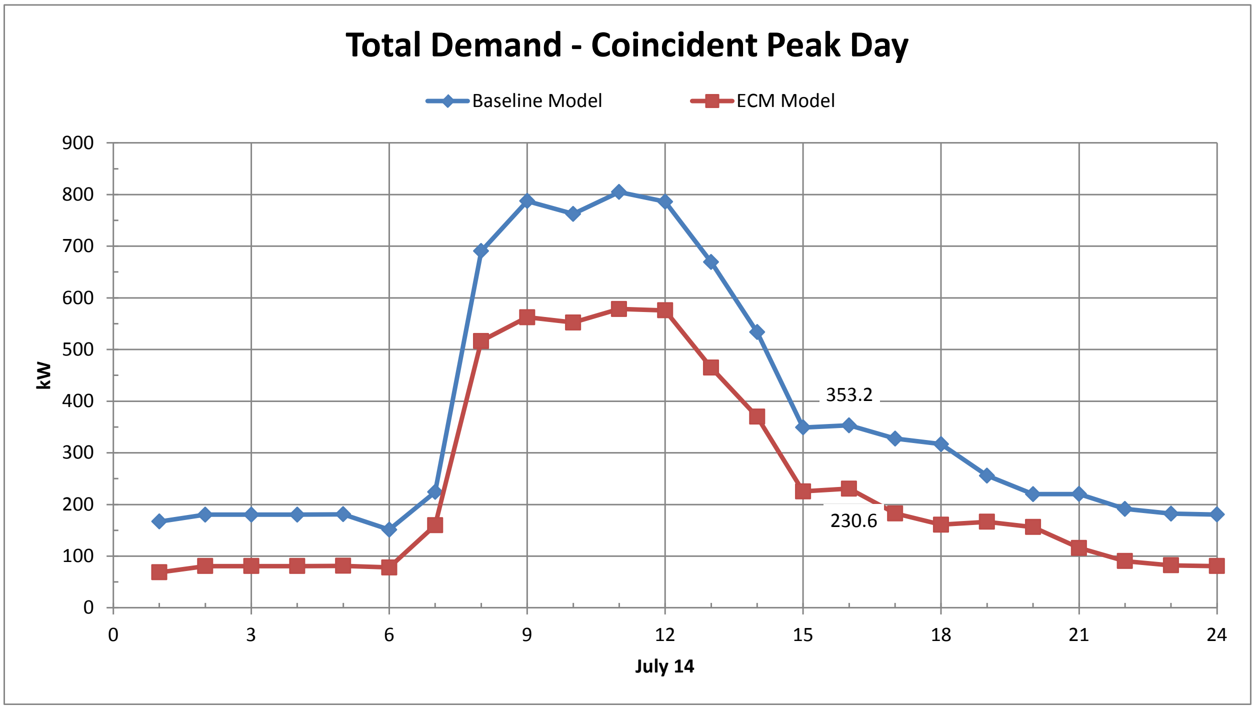

Figure 1: Total Demand on Coincident Peak Day

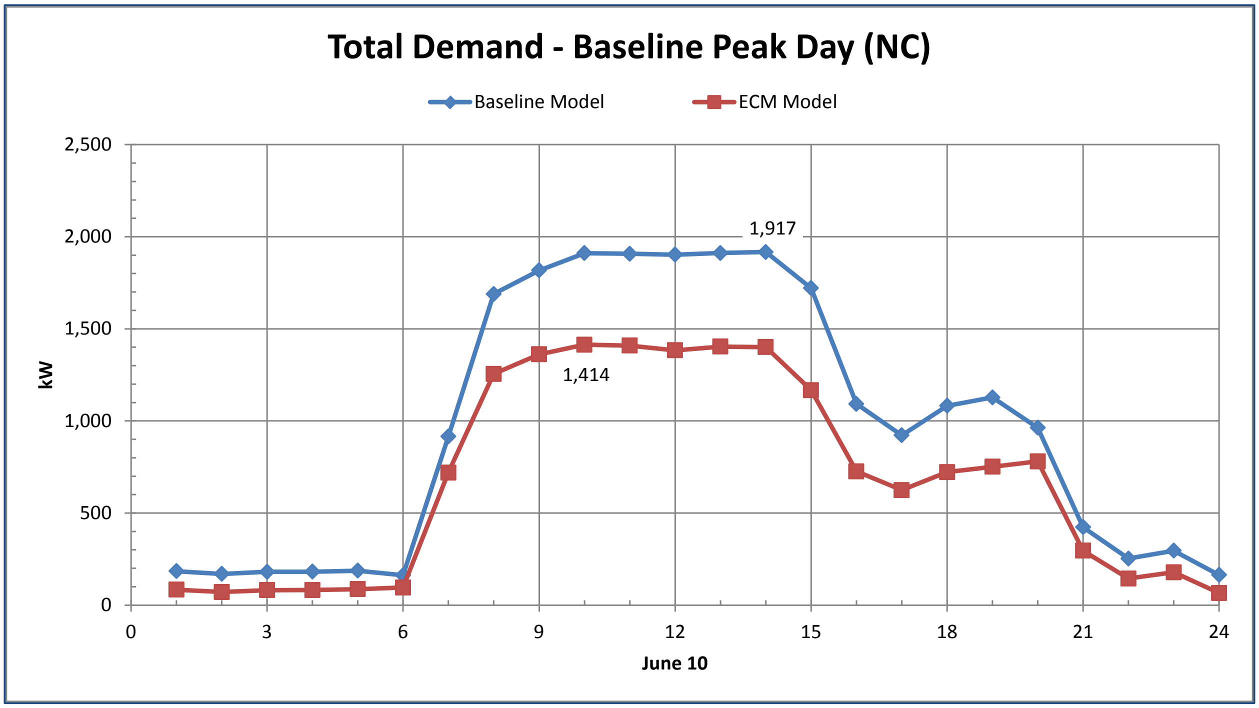

Figure 2: Total Demand on Non-Coincident Peak Day

Lighting Survey

Table 2: Lighting Survey

Space #	Space ID	Fixt. Type	Fixt. W	No. of Fixts.	OS?	Subt. Watts	Total Watts	Room L	Width	Area	**LPD**
1	[Redacted]	A32 and A3D	92	12	Y		1104	27	30.67	828	1.333
2	[Redacted]	A32 and A3D	92	16	Y		1472	36	32.67	1176	1.252
3	[Redacted]	A32 and A3D	92	16	Y		1472	36.67	32.67	1198	1.229
4	[Redacted]	A32 and A3D	92	16	Y		1472	36.25	32.67	1184	1.243
5	[Redacted]	A32 and A3D	92	16	Y		1472	35.5	32.67	1160	1.269
6	[Redacted]	A32 and A3D	92	16	Y		1472	36.25	32.67	1184	1.243
7	[Redacted]	A32	92	16	Y		1472	31.67	35.67	1130	1.303
8	[Redacted]	A32	92	8	Y		736	18.67	31.67	591	1.245
9	[Redacted]	A3,A32 and A3D	92	22	Y	2024					
	[Redacted]	A22	70	2	Y	<u>140</u>					
	[Redacted]					*Rm Total:*	2164	59.33	30.67	1820	1.189
10	[Redacted]	L4	62	25	N	1550					
	[Redacted]	J2	300	2	N	<u>600</u>					
	[Redacted]					*Rm Total:*	2150	228	8	1824	1.179
11	[Redacted]	L8	118	18	N	2124					
	[Redacted]	J2	300	2	N	<u>600</u>					
	[Redacted]					*Rm Total:*	2724	228	11.25	2565	1.062
12	[Redacted]	B1	71	2	Y		142	12	12	144	0.986
13	[Redacted]	B3	70	4	Y		280	12	13	156	1.795
14	[Redacted]	B1	71	13	N	923					
	[Redacted]	C3L	34	8	N	<u>272</u>					
	[Redacted]					*Rm Total:*	1195	30	31	930	1.285
15	[Redacted]	D1	114	1	N	114					
		C4L	18	7	N	<u>126</u>					

Space #	Space ID	Fixt. Type	Fixt. W	No. of Fixts.	OS?	Subt. Watts	Total Watts	Room L	Width	Area	**LPD**
						Rm Total:	240	17.67	16	283	0.848
16	[Redacted]	A32 and A3D	92	12	Y		1104	28	40.5	1134	0.974
17	[Redacted]	A32 and A3D	92	12	Y		1104	28	43	1204	0.917
18	[Redacted]	A3,A32 and A3D	92	24	Y		2208	64.67	28	1811	1.219
19	[Redacted]	A32 and A3D	92	12	Y		1104	30	28	840	1.314
20	[Redacted]	G1	360	9	N	3240					
	[Redacted]	G2	240	15	N	3600					
	[Redacted]					*Rm Total:*	6840	93.25	65	6061	1.129
21	[Redacted]	D12	360	12	N	4320					
	[Redacted]	D8	230	12	N	2760					
	[Redacted]	C3L	34	5	N	170					
	[Redacted]					*Rm Total:*	7250	106.67	46.25	4933	1.470
22	[Redacted]	A3D	92	18	N		1656	30.25	25.5	771	2.148
23	[Redacted]	B4	90	28	N	2520					
	[Redacted]	F4	35	13	N	455					
	[Redacted]					*Rm Total:*	2975	50.67	47	2381	1.249
24	[Redacted]	A4	114	3	Y	342					
	[Redacted]	A3D	92	9	Y	828					
	[Redacted]	A4D	114	3	Y	342					
	[Redacted]	C242	90	2	Y	180					
	[Redacted]						1692	28.25	42	1186	1.427
25	[Redacted]	A4	114	4	Y	456					
	[Redacted]	A3D	92	15	Y	1380					
	[Redacted]					*Rm Total:*	1836	39.25	44	1727	1.063
26	[Redacted]	G1	360	36	N		12,960	100	117	11,700	1.108

Space #	Space ID	Fixt. Type	Fixt. W	No. of Fixts.	OS?	Subt. Watts	Total Watts	Room L	Width	Area	**LPD**
27	[Redacted]	G1	360	18	N	6480					
	[Redacted]	G2	240	9	N	2160					
	[Redacted]					*Rm Total:*	8640	100	78	7800	1.108
28	[Redacted]	A32 and A3D	92	9	Y		828	29.5	28	826	1.002
29	[Redacted]	A32 and A3D	92	12	Y		1104	29.33	32.5	953	1.158
30	[Redacted]	A32 and A3D	92	9	Y		828	30	28	840	0.986
Surveyed Total Watts and Square Footage							71,696			60,340	
Overall Average Lighting Power Density (LPD, W/sqft)											**1.188**
										Max.	2.148
										Min.	0.848

[Redacted]
HVAC Upgrades to [Redacted]
M&V Report

Prepared for
Duke Energy Ohio

March 2015, Version 1.1

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

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

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

Submitted by:

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Introduction

This report addresses measurement and verification (M&V) activities for the [Redacted] custom program application. The application covers upgrading the existing Heating, Ventilating and Air-Conditioning (HVAC) system. The measure includes:

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

- The CARE building consists of seven floors of open labs and procedure rooms. The building was constructed as a two-position HVAC system with substantial excess air provided to laboratory spaces. The HVAC system originally provided 12 air changes per hour (ACH) in the open labs and 24 ACH in the procedure rooms, reflecting standards that were in place when the building was first constructed. The air supplied to the building is 100% outside air.

- Recent industry practice and [redacted] policy now recommend ventilation rates in the range of 4 to 12 ACH. The renovation that is the subject of this project was to reduce the ventilation rates to 8 ACH when the labs are occupied and 4 ACH when they are unoccupied.

- In tandem with the supply air change rate reduction, fume hoods have been modified with sash sensors. Originally, under occupied conditions, a constant volume of air was exhausted by the fume hoods and a similar constant amount of make-up air was supplied to the rooms. Through the addition of horizontal sash sensors, the exhaust air can be modulated to reduce exhaust air in a variable volume manner while still maintaining negative pressures in the fume hoods. Supply air rates will then also be able to modulate to meet the greater of the hood demands, the minimum ACH rates, or maintain space temperatures.

- The building also has biosafety cabinets (BSC), which are HEPA-filtered enclosures used to contain biological hazards but not necessarily vapors. When directly ducted to the exhaust system, they require a constant exhaust air flow. The project reduced the number of ducted biosafety cabinets in the building, and all but one BSC were disconnected from their direct exhaust connection. Exhaust from rooms with unducted BSCs was reduced to meet the [redacted] new requirements of 8 ACH for occupied and 4 ACH for unoccupied rooms.

- The air flow reductions were achieved by retrofitting supply and exhaust air valves with full variable volume controls. Normal occupancy is determined by a time of day schedule programmed into the existing building automation system. If during unoccupied times the space occupancy sensors show people in the spaces, the systems will revert to occupied settings for a set period of time.

- Electric energy savings are achieved by reducing supply and exhaust fan energy. The supply air handlers were already equipped with variable volume supply fans, but the constant volume fume hoods limited the ability of the supply air systems to take advantage of the variable volume capability.

- The laboratory exhaust fan systems run continuously. An N+1 configuration of fans in each exhaust unit operates to maintain a set exhaust static pressure in a common suction plenum. These fans run at constant speed. If the exhaust pressure increases in magnitude, then bypass dampers open to bring in outside air (extra fan capacity is present). If the bypass dampers are 100% open and pressures are still above setpoint, then the lag exhaust fan is shut off. With the reductions in ACH, and with the fume hoods now capable of variable volume exhaust, savings are expected to be achieved by staging off more fans than could be allowed to be off in the pre-retrofit situation. Demand and consumption savings are based on fewer fans running.

- Since the amount of incoming outside air has been reduced, additional electric energy savings are achieved at the central chiller plant by reducing the cooling energy expended to cool the incoming outside air to 55°F. The supply air temperature is maintained at 55°F whenever the outside air temperature is above 30°F. (Heating and reheating energy, provided by central plant steam, are also saved by this retrofit, but are not subject to verification under this investigation.)

The installation was completed in March of 2014, so the data collection effort was for post-retrofit M&V activities only.

Goals and Objectives

Pre- and post-retrofit energy calculations for the building HVAC systems were previously created by the applicant's engineering firm. These calculations were included in the application, and will be updated to determine the energy and power reduction achieved by the retrofit. Certain modifications to the calculations made necessary as a result of the M&V investigation have been incorporated.

The projected savings goals identified for this project are:

	APPLICATION		DUKE PROJECTIONS		
Facility	**Proposed Annual kWh savings**	**Proposed Summer Peak kW savings**	**Proposed Annual kWh savings**	**Proposed Maximum Demand (Non-coincident) kW savings**	**Proposed Summer Peak (Coincident) Demand kW savings**
[Redacted]	1,957,873	416	1,957,873	415.4	349.1

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

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

Project Contacts

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Customer Contact	[Redacted]	[Redacted]	[Redacted]

Site Locations/ECM's

Site	Address	Sq. Footage	ECMs Implemented
[Redacted]	[Redacted]	236,600	1

Data Products and Project Output

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

M&V Option

IPMVP Option A

M&V Implementation Schedule

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

- Obtained a copy of the final air test and balance (TAB) report.
- Conducted an interview with the building contact.
- Collected nameplate data for the HVAC equipment.

- Spot-measured the fan motor parameters as detailed in the "Field Survey Points" section below.
- Established trend logs in the Customer's Energy Management System (EMS) and deployed data loggers to monitor the operation of HVAC equipment and outdoor air conditions, as detailed in the "Field Data Points" section below.
- Trended data and deployed loggers as needed for a minimum of three weeks.
- Revised the application's air systems energy usage calculations as required based on the findings of the M&V investigation.
- Calculated updated energy and demand savings values.
- Compared the updated savings values to Duke's projected values and calculated the energy and demand savings realization rates.

Field Data Points

Customer Interview

Interviewed the building contact.

- Determined the normal occupancy schedules
- Determined the number of holidays observed per year
- Obtained a copy of the final air test and balance (TAB) report.
- Confirmed the configurations of the AHUs:

System:	AHU-S101	AHU-S102	AHU-S103	AHU-S104	Totals
Total # Fans available	2	2	2	2	8
HP each	125	125	100	100	
#Running when Occ'd	2	2	2	2	8
#Running when Unocc'd	2	2	2	2	8

- Confirmed the configurations of the exhaust systems (post-retrofit):

System:	FEF-101	GEF-102	FEF-103	GEF-104	Totals
Total # Fans available	4	4	3	3	14
HP each	60	50	60	60	
#Running when Occ'd	2	1	1	2	6
#Running when Unocc'd	2	1	1	2	6

- Obtained pre-retrofit and post-retrofit sequences of operation for the HVAC equipment:
    - Air Handling units (4)

- General Exhaust units (2)
- Fume Hood Exhaust units (2).

- Has any sequence changed between the pre- and post-retrofit? *No.*
- Confirmed the supply air temperature setpoints. *55°F.*
- Verified that the heat recovery systems are operational. *Yes.*
- Determined how occupancy sensors affect the operation of the HVAC systems. *VFDs respond to collective air valve positions as planned.*

Survey data

- Collected nameplate data for the above HVAC equipment, including CFMs and motor horsepowers.
- Photographed all units and nameplates for HVAC equipment listed above.

Spot-Measurements

For all AHUs, general exhaust and fume exhaust systems:

- Measured supply fan volts, amps, watts and power factor.
- For AHUs, recorded the VFD speed (%) or frequency (Hz) coinciding to the above measurements. (Exhaust system fans are constant speed but have bypass dampers.)

Time series data on controlled equipment

General points:

The site EMS trended OA temperature and RH.

AHUs and Exhaust Systems:

Trended the following AHU points as available in the EMS:

- Supply fan VFD speed
- Supply fan air flow (CFM)
- Supply air temperature setpoint
- Actual supply air temperature
- Supply air static pressure setpoint
- Actual supply air static pressure

Note: Although all of the above variables' trend data were requested for all four AHUs, data was received only for S102 and S104, plus the supply air CFM for S103.

Field Data Logging

- Set up loggers (or trend logs) for 5 minute readings and allowed operation for a minimum of three weeks.
- Collected data during normal operating hours (avoiding atypical operating situations such as maintenance shutdowns).

Logger Table

The following table summarizes the logging equipment needed to accurately measure the above noted ECM's. For the AHUs, General Exhaust units and Fume Hood Exhaust units, a combination of DENT Elite Pro data loggers and Onset Energy Logger Pro's was configured to monitor the units as follows. With Elite Pro's, voltage, average amps, power factor and average power (kW) were logged. With Energy Logger Pro's, average amps only were logged.

Below, "SF" is a supply air fan unit, "FEF" is a fume hood exhaust fan unit, and "GEF" is a general exhaust fan unit. Individual fans within the units are designated A, B, C, etc.

Function	Fan Motor HP	ElitePro Energy Logger	Magnelab CTs	Hobo Energy Logger Pro	TRMS Modules*
[Redacted]	125	2	(6) 150A		
[Redacted]	125	2	(6) 150A		
[Redacted]	50		(2) 100A	1	1
[Redacted]	60		(4) 100A	1	2
[Redacted]	100	2	(6) 100A		
[Redacted]	100	2	(6) 150A		
[Redacted]	60	2	(6) 100A		
[Redacted]	60		(3) 100A	1	2
Total		**10**	**39** (18) 150A (21) 100A	**3**	**5**

*TRMS modules are required to interface CTs to the Energy Logger Pro.

Data Accuracy

Measurement	Sensor	Accuracy	Notes
Current	Magnelab CT	±1%	Recorded load must be < 130% and >10% of CT rating
--	TRMS Module	±0.3%	
Power	ElitePro	±1%	

Data Analysis

NOTE: The analysis intent is to review and update the application bin analysis spreadsheets with data gathered through trend data logging. The approach is presented below.

1. Monitored post-retrofit AHU fan power data was found to correlate with time of day (i.e., occupancy) but not to correlate with outside air temperature (OAT).
2. For each supply and exhaust fan unit, determined the average fan power by time of day and for weekdays vs. weekends.
3. Calculated the annual post-retrofit fan energy consumed from the average fan power for 8,760 hours per year.
4. Determined the post-retrofit maximum demand and the coincident peak demand observed during the monitoring period.
5. From observations of the numbers of fans operating in each fan unit, and comparing these numbers to the expected pre- and post-retrofit operation provided in the application, adjusted the quantities of pre-retrofit fans operating as necessary.
6. From the adjusted numbers of fans operating, and the actual average fan power determined from the M&V data, calculated the annual pre-retrofit fan energy consumed for 8,760 hours per year.
7. Determined the corresponding pre-retrofit maximum demand and coincident peak demand.
8. From site trend data, determined the average supply air flow in CFM for each eight-hour day period (1st 8 hours, 2nd 8 hours, and 3rd 8 hours).
9. Recreated the AHU bin analysis spreadsheets presented in the Application (part 2), substituting the average 8-hour supply air flows values for the application's estimated values. These analyses give the post-retrofit chiller plant input energy (kWh) and peak demands for each supply air unit.
10. Using trended supply airflow CFMs and ratios of the application's estimated pre-to-post-retrofit air flows, re-estimated actual pre-retrofit air flows.

11. Using re-estimated pre-retrofit air flows in the AHU bin analysis spreadsheets, calculated the pre-retrofit chiller plant input energy (kWh) and peak demands for each supply air unit.
12. Summed the AHU fans, exhaust fans and chiller energies to determine the total annual pre- and post-retrofit energy consumption.
13. Summed the AHU fans, exhaust fans and chiller demands to determine the total annual pre- and post-retrofit demands.
14. Compare the revised post-retrofit model outputs with the pre-retrofit outputs to determine the annual energy savings.

Verification and Quality Control

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

Recording and Data Exchange Format

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

Results

Utility Data

Historical utility data for the past three years (July 2011 – June 2014) was provided with the application documents. Although there has been a discernable downward trend during that time period, the retrofit was not scheduled to be completed until February 2014. Thus, no savings can be attributed to the retrofit until March 2014. The figure below shows that Monthly Electricity Consumption (kWh) during February through June of 2014 trended well below the previous years. (Note: Other electric savings or increases in other systems or building functions - not due to the retrofit - would be included in this trend.)

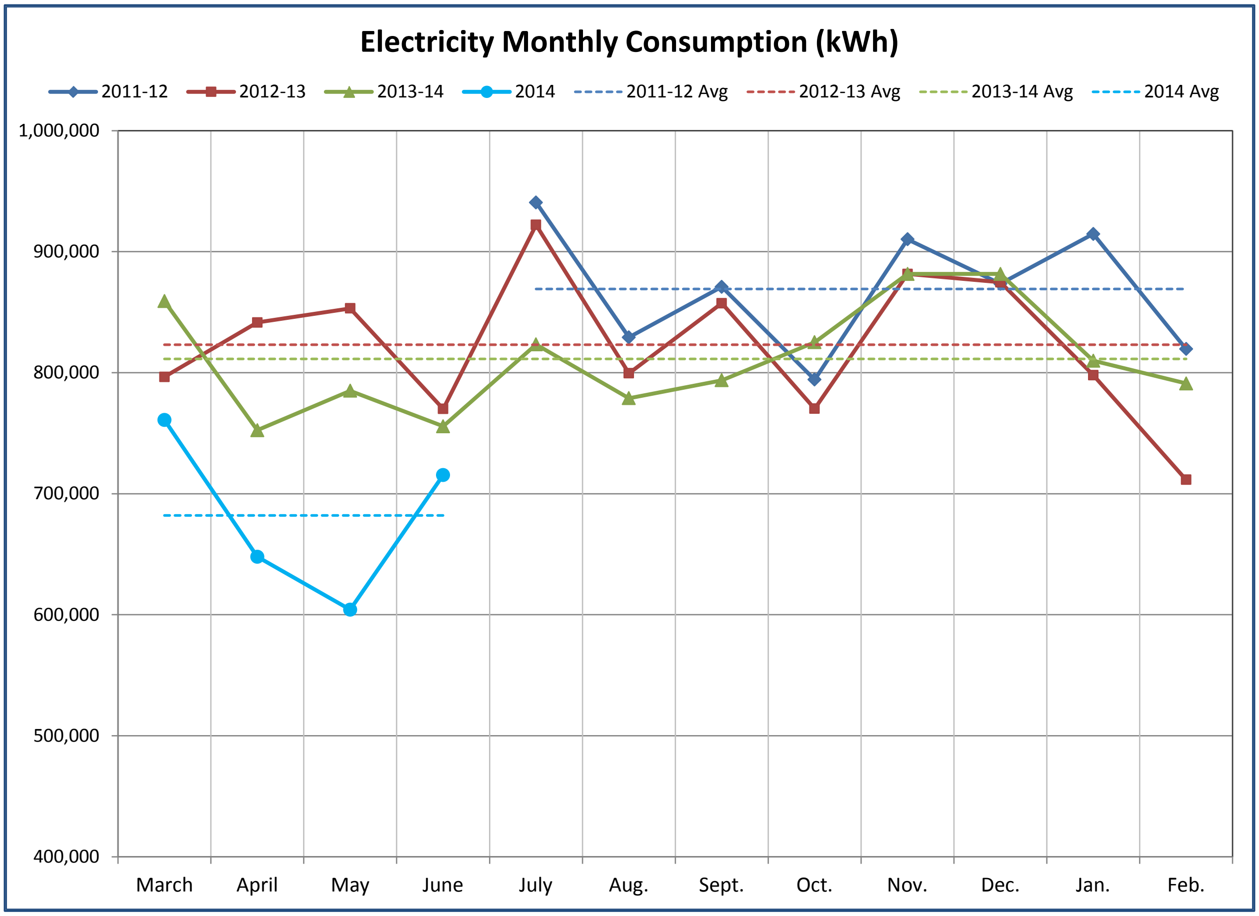

Figure 1: Monthly Electrical Energy Consumption.

Supply Air Units

Air Flow Rates

Air flow rate data was trended for S102, S103 and S104 for about two weeks. (S101's air flow was trended as well, but the value was constant at a very high value and could not be used.) Figure 2 shows that the three fans that were monitored clearly have high flows during the day, lower flows on the weekends and minimum flows at night.

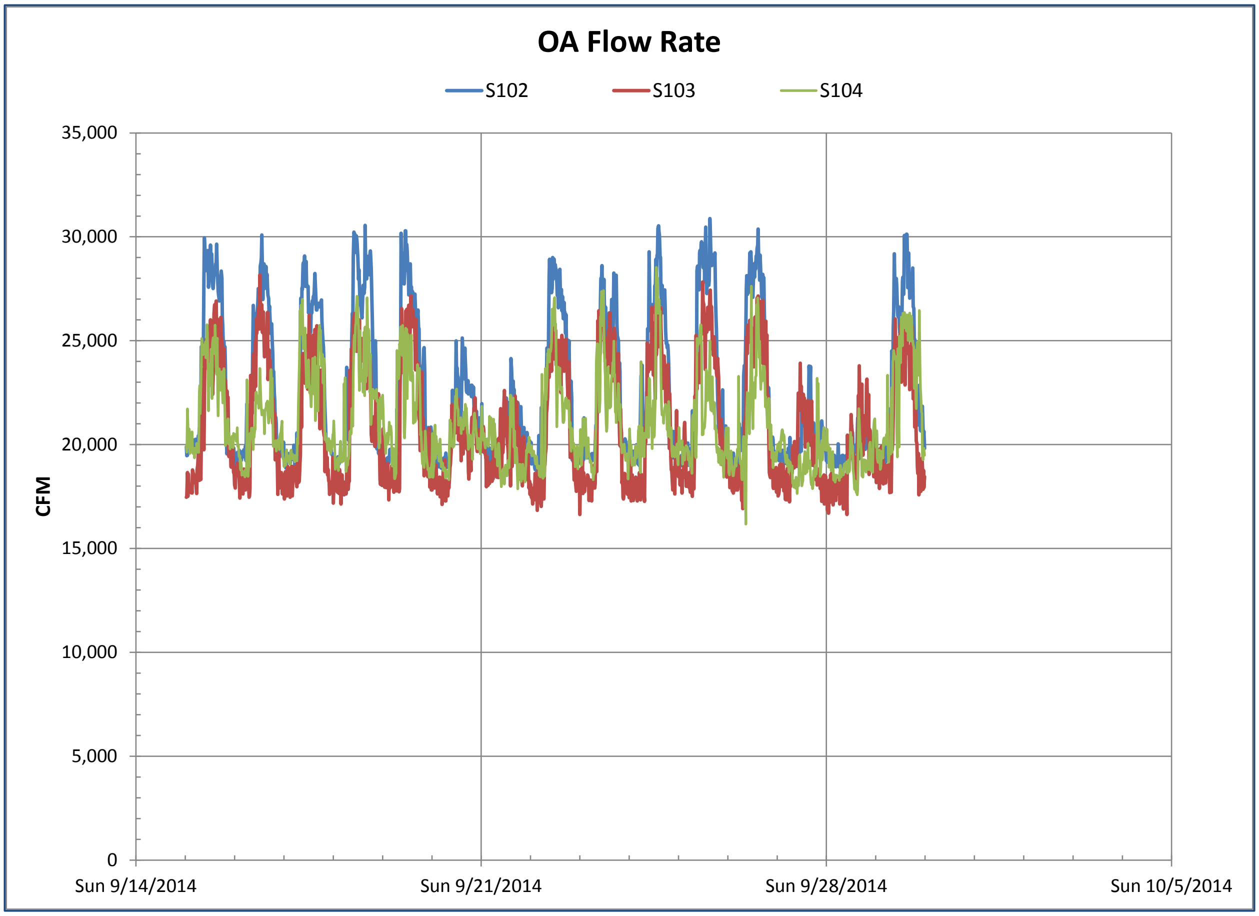

Figure 2: Outside Air Flow Rates.

VFD Speeds

VFD speeds were also trended for S102 and S104 for the same two weeks. Figure 3 shows that the two fans' VFDs do vary in a pattern similar to the air flows. However, there does not seem to be enough variation in the VFD speeds to produce the amount of variation seen in the air flows –the air flows drop to around 60% of their peak monitored values at night, while the VFD speeds drop only to 87% for S102 and 77% for S104. At this time the discrepancy is unexplained, and we will use the air flow data as the basis for further calculations.

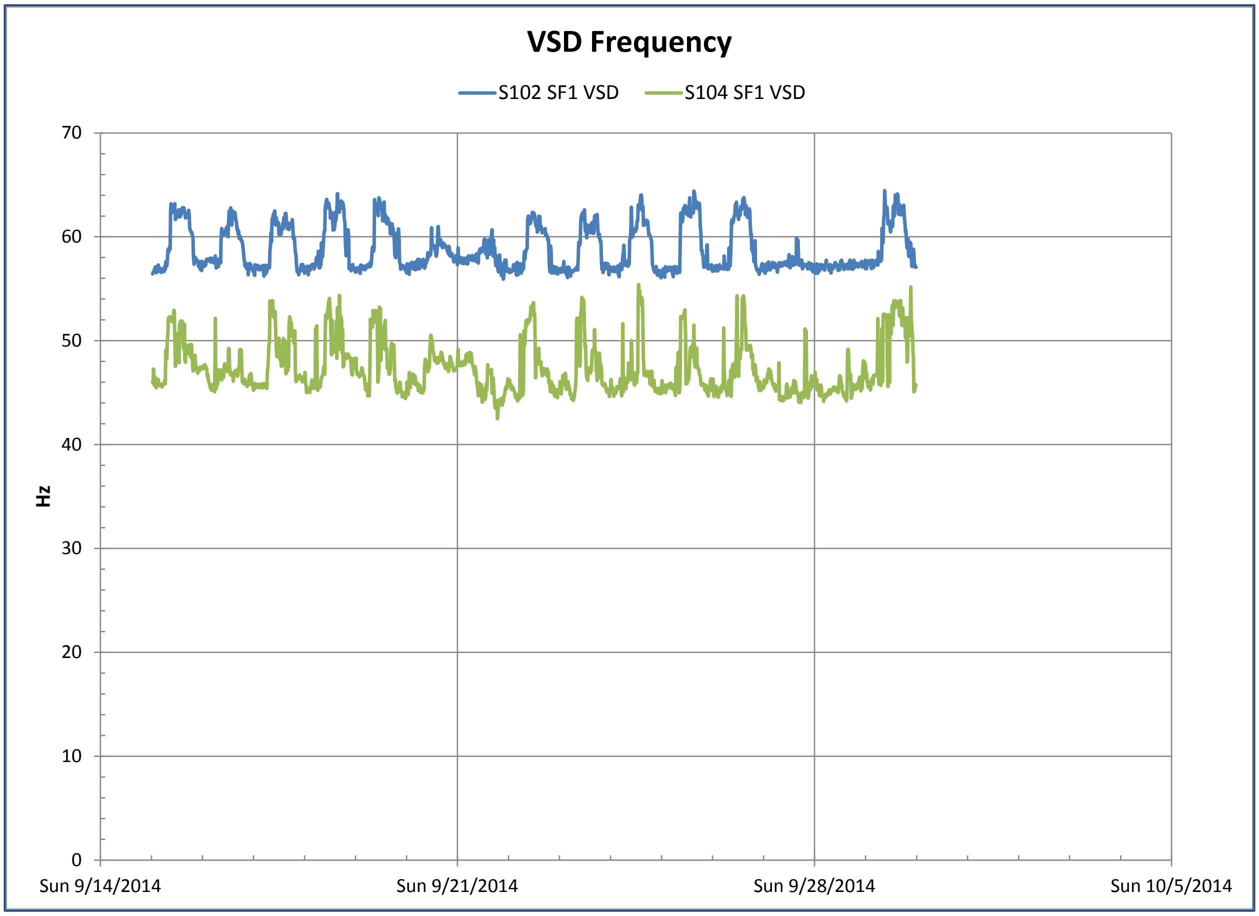

Figure 3: Variable Speed Drive Frequencies.

Discharge Air Temperatures and OA Temperature

The outside air temperature (OAT) was trended, and the discharge air temperatures (DAT) of two of the supply air units, S102 and S104, were trended for part of the same time period. These trends are displayed in Figure 4 below.

The trend data shows that the DAT for S104 is held very steady at 55°F. The DAT for S102 is never higher than 55°F, but it begins to drop below 55 F as the OAT drops below 70. This is not an economizer cycle, as with an economizer the DAT would be equal to the OAT (100% OA system). Therefore the chiller must still be working to provide DAT's less than the OAT.

This DAT behavior appears to be the result of a leaky CHW control valve and not a deliberate control sequence. S104 did not show the same change, and we have no DAT data for S101 or S103 that would support a programmed sequence.

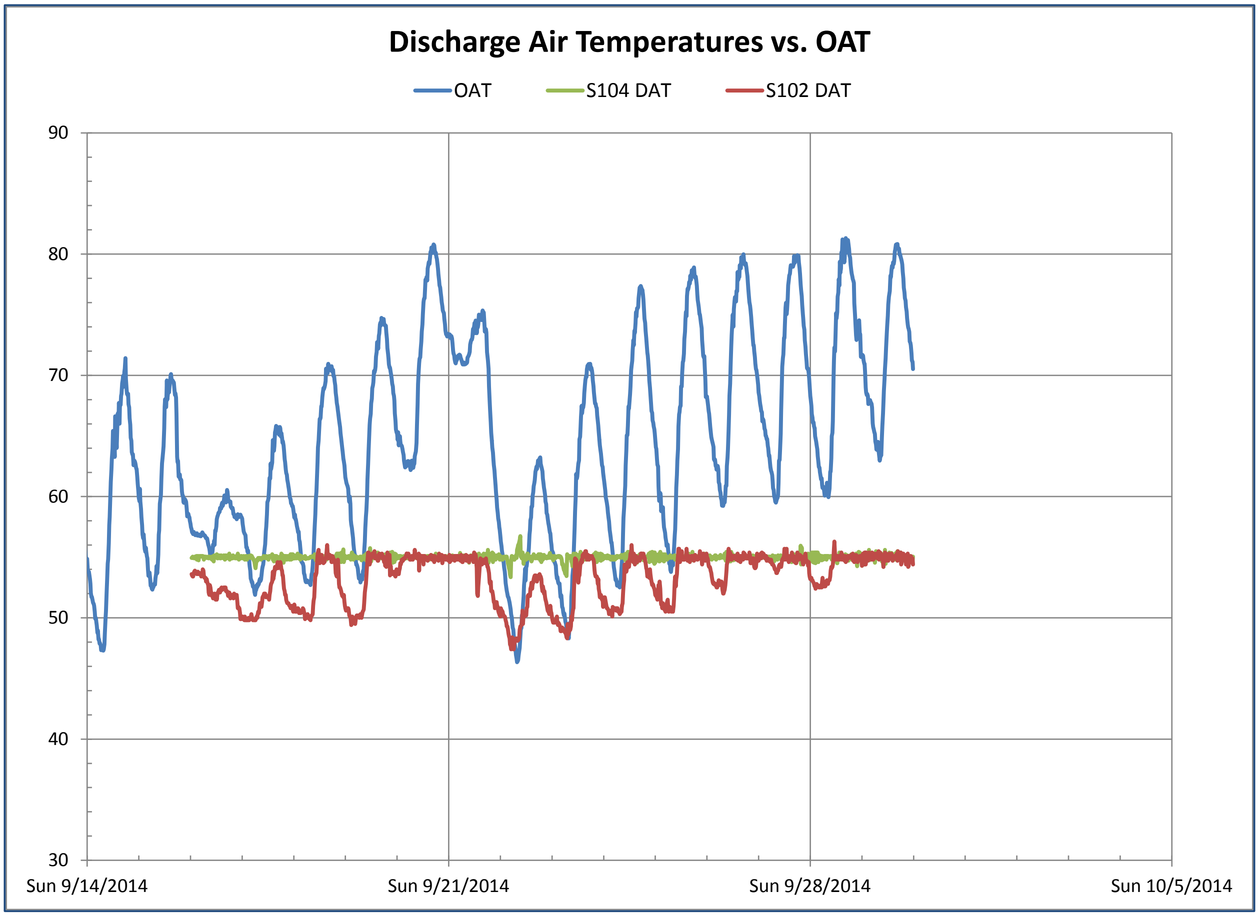

Figure 4: Discharge Air Temperatures.

<u>Static Pressure</u>

About two weeks of valid static pressure trend data was provided for supply air units S102 and S104 only. The data shows that the pressures were very steady for these units, at 1.40 and 1.50 in-WC respectively.

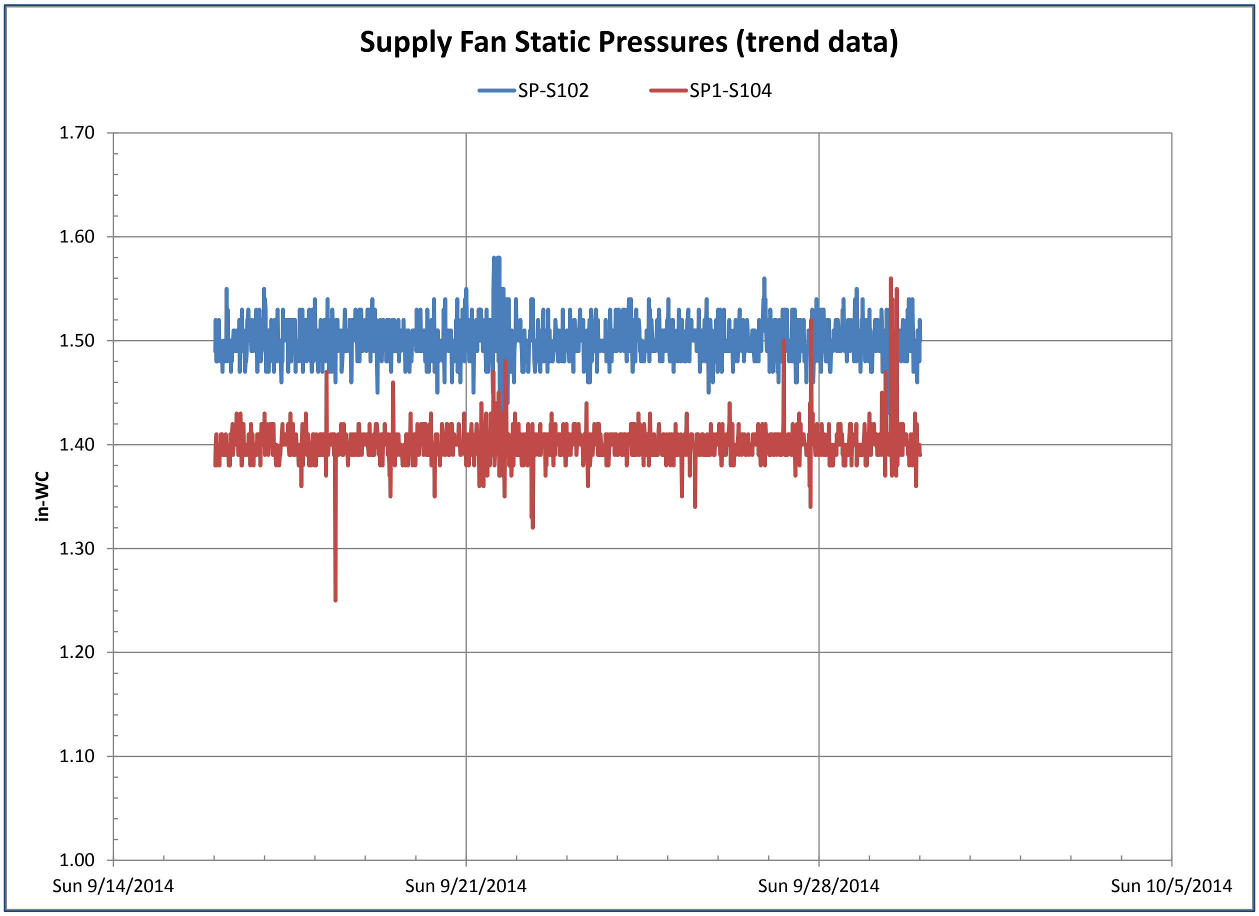

Figure 5: Static Pressures.

Fan Powers

The majority of the electric energy savings to be achieved by the project are expected to result from reducing the supply and exhaust fan energy. Thus, for each of the supply air units (S101, S102, S103 and S104) and each of the exhaust units (Fume exhaust units and General exhaust units FEF101, GEF102, FEF103 and GEF104), fan power was monitored with data loggers. Supply air units were monitored for six to nine weeks, and exhaust units were monitored for three to seven weeks. (The varying time periods occurred because all the loggers were not able to be installed at the first site visit.)

Supply Fans

Below, charts are presented that show the fan power history for each unit and the average weekly power profile derived from the data. In addition, air flow histories for each unit, as provided from site trend data, and their weekly profiles are also shown, when available.

All the charts for the supply units are presented after the following discussion of those units.

Unit S101 / Supply Fans SF101 A & B

These two fans' powers are almost exactly the same at all times. Both fans are controlled by VFDs. The data is presented in Figure 6 and Figure 7. A clear daily variation is evident, and weekends use less energy than weekdays. The average total weekday daytime maximum ("occupied") power is about 30 kW and the overnight minimum ("unoccupied") is about 18 kW.

Air flow trend data for S101 was provided for part of the monitoring period, but the value was fixed and high by a factor of 25 compared to the expected value. Therefore, this data is considered invalid.

Unit S102 / Supply Fans SF102 A & B

SF102B's logged power, while exhibiting the same pattern as SF102A's, was only 20-33% of A's value and is considered invalid. The two fans are identical in configuration and service, and should have about the same readings, similar to the other supply units. Therefore, the total fan power for this unit is computed as twice that of SF102A. Otherwise, the behavior is similar to S101 except that the weekends exhibit even less variation. The data is presented in Figure 8 and Figure 9. The average total weekday daytime maximum power is about 35 kW and the overnight low is 29 kW.

About two weeks of air flow data was available. The data and resulting profiles are presented in Figure 10 and Figure 11. The flow varies from about 19,000 to 30,000 CFM.

Unit S103 / Supply Fans SF103 A & B

Like S101, these two fans' powers are almost exactly the same at all times. The data is presented in Figure 12 and Figure 13. The average total weekday daytime maximum power is about 15 kW and the overnight low is 9.5 kW.

About two weeks of air flow data was available. The data and resulting profiles are presented in Figure 14 and Figure 15. The flow varies from about 18,000 to 27,000 CFM.

Note: since the supply air volumes to this building are driven by air change requirements, there is not a meaningful correlation of supply air volume or fan power to outside air temperature. The high amounts of supply air are more than sufficient to remove building envelope loads. This lack of correlation is illustrated for S103 only in Figure 16. Although a trend line can be computed, almost any total power exhibited by the unit can occur at any OAT.

Unit S104 / Supply Fans SF104 A & B

Again, these two fans' powers are almost exactly the same at all times. The data is presented in Figure 17 and Figure 18. The average weekday daytime maximum power is about 17 kW and the overnight low is 12 kW.

About two weeks of air flow data was available. The data and resulting profiles are presented in Figure 19 and Figure 20. The flow varies from about 18,000 to 27,000 CFM.

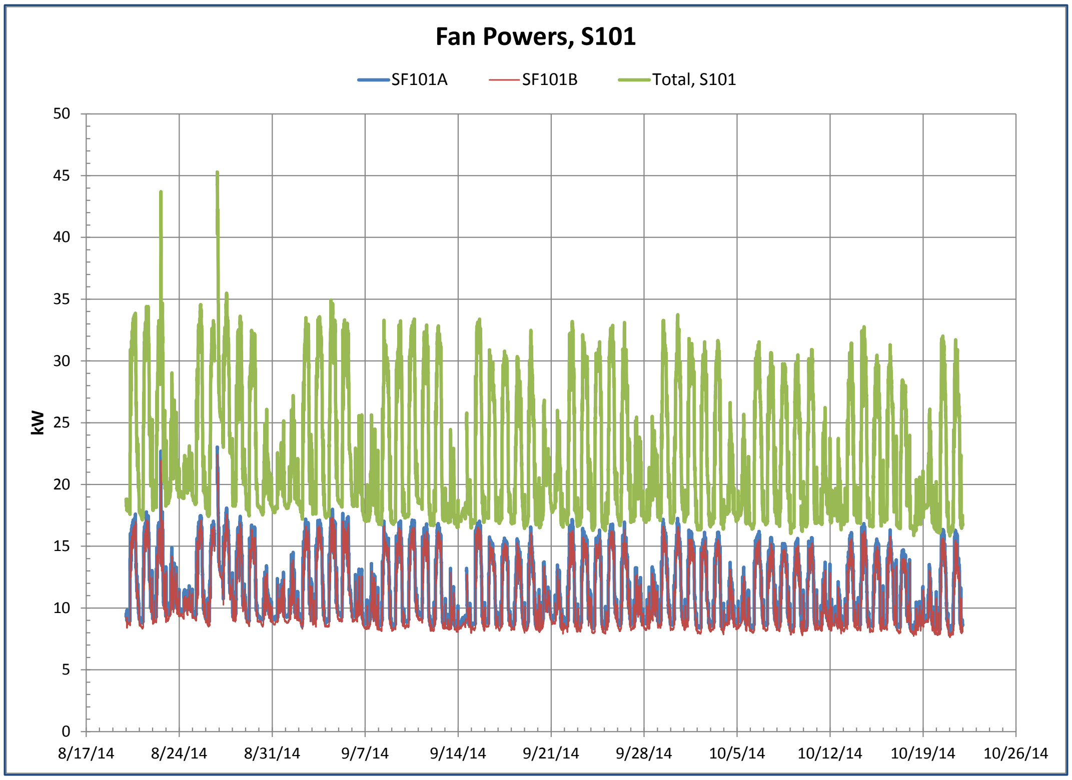

Figure 6: Fan Power, S101.

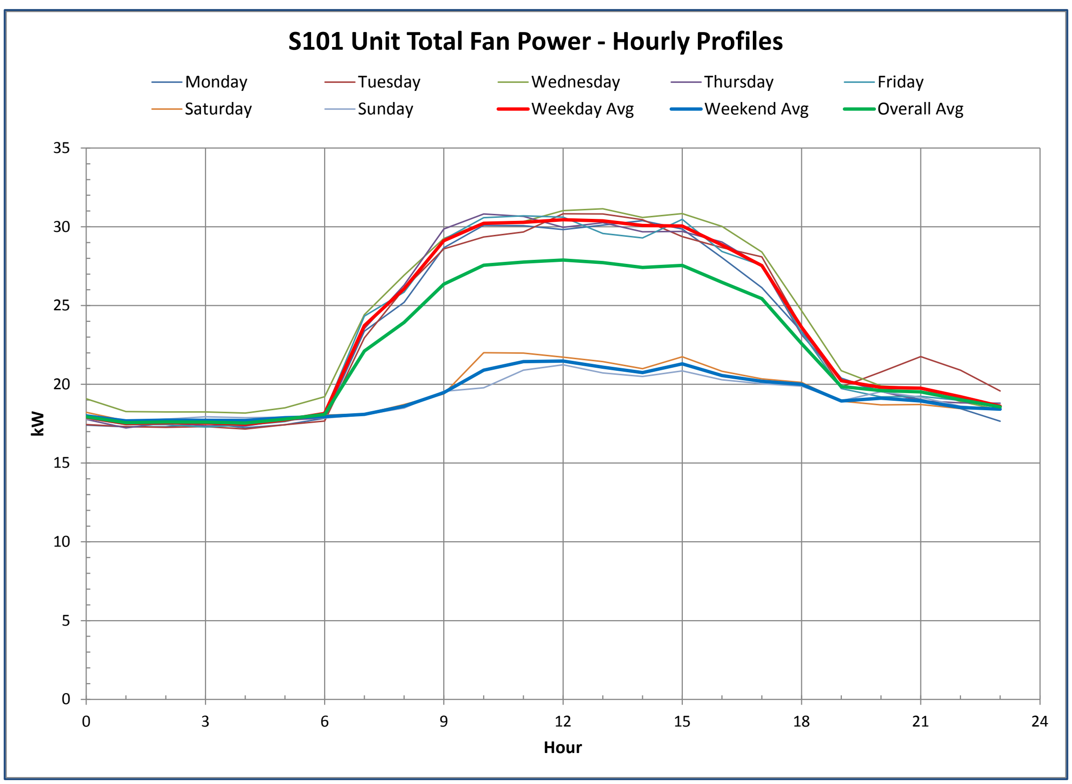

Figure 7: Fan Power Hourly Profiles, S101.

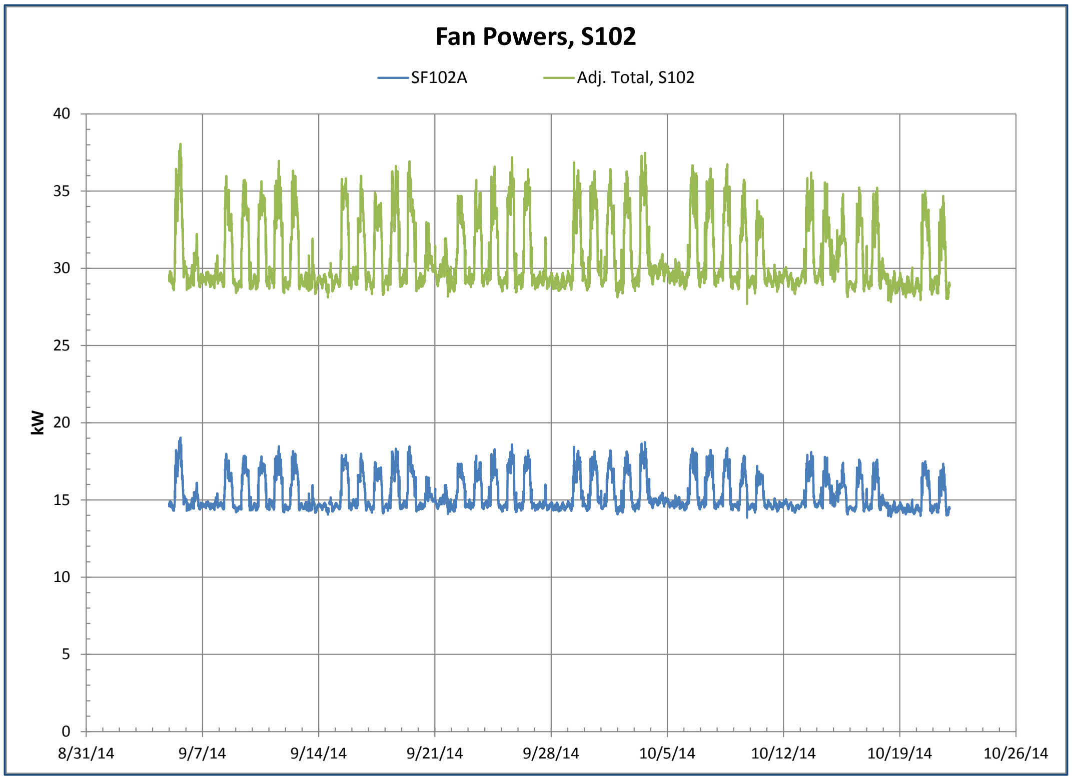

Figure 8: Fan Power, S102.

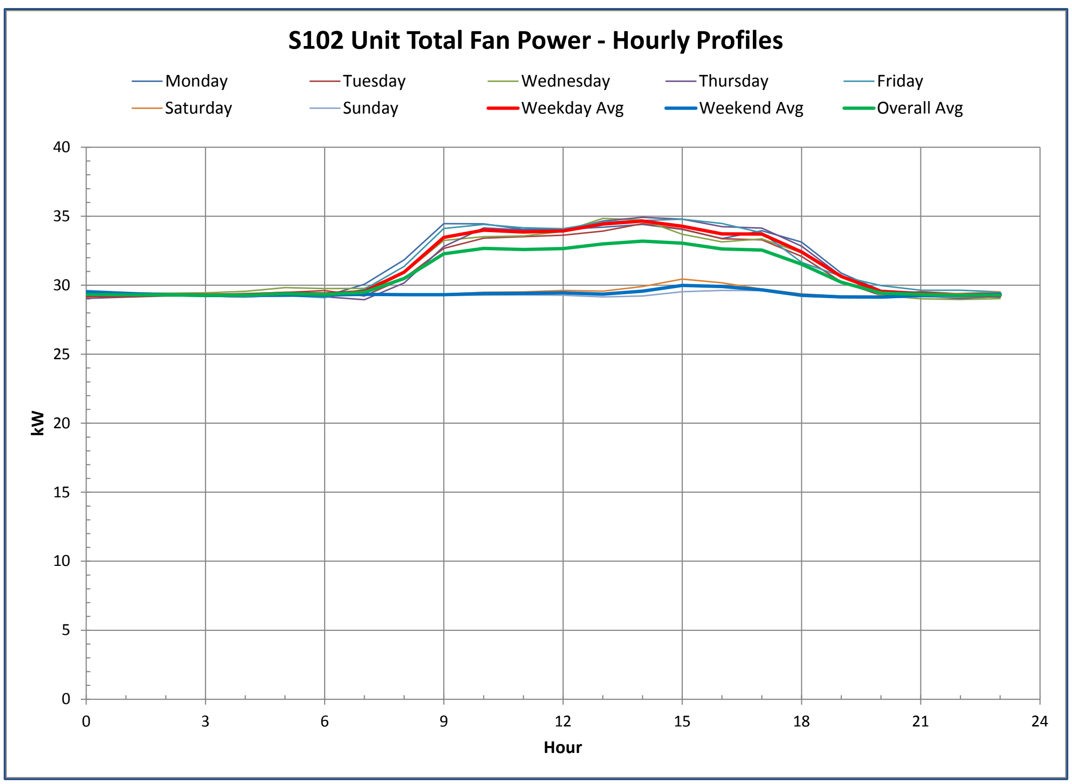

Figure 9: Fan Power Hourly Profiles, S102.

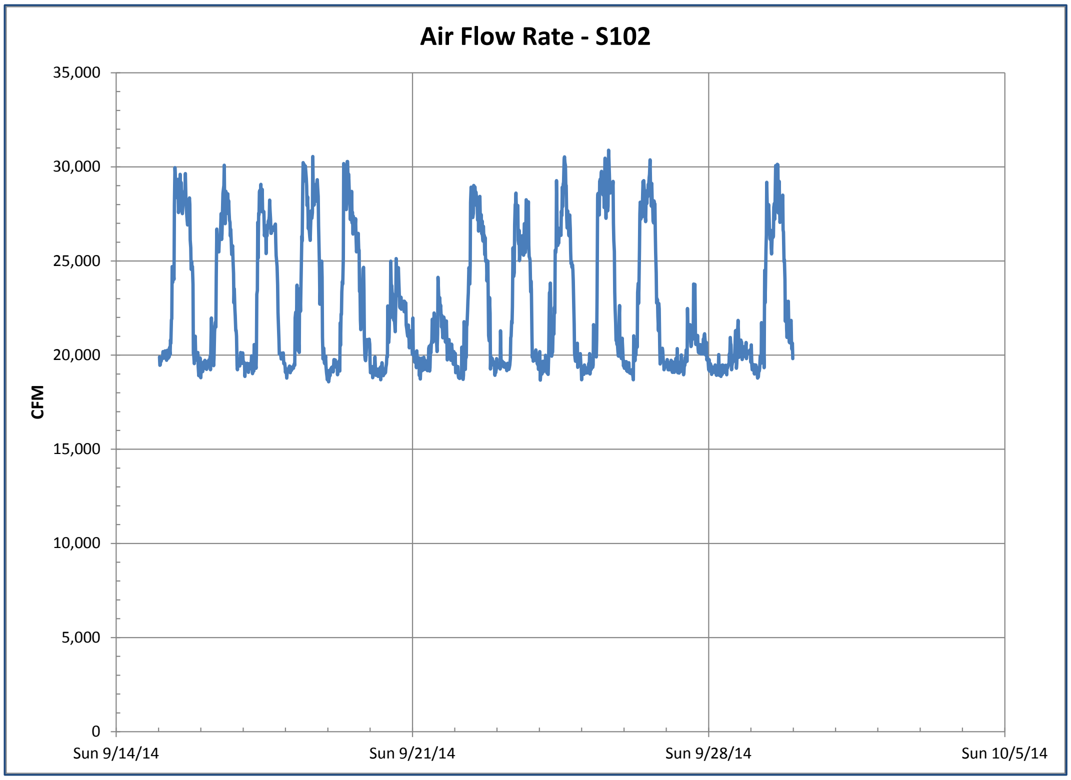

Figure 10: Air Flow Rate, S102.

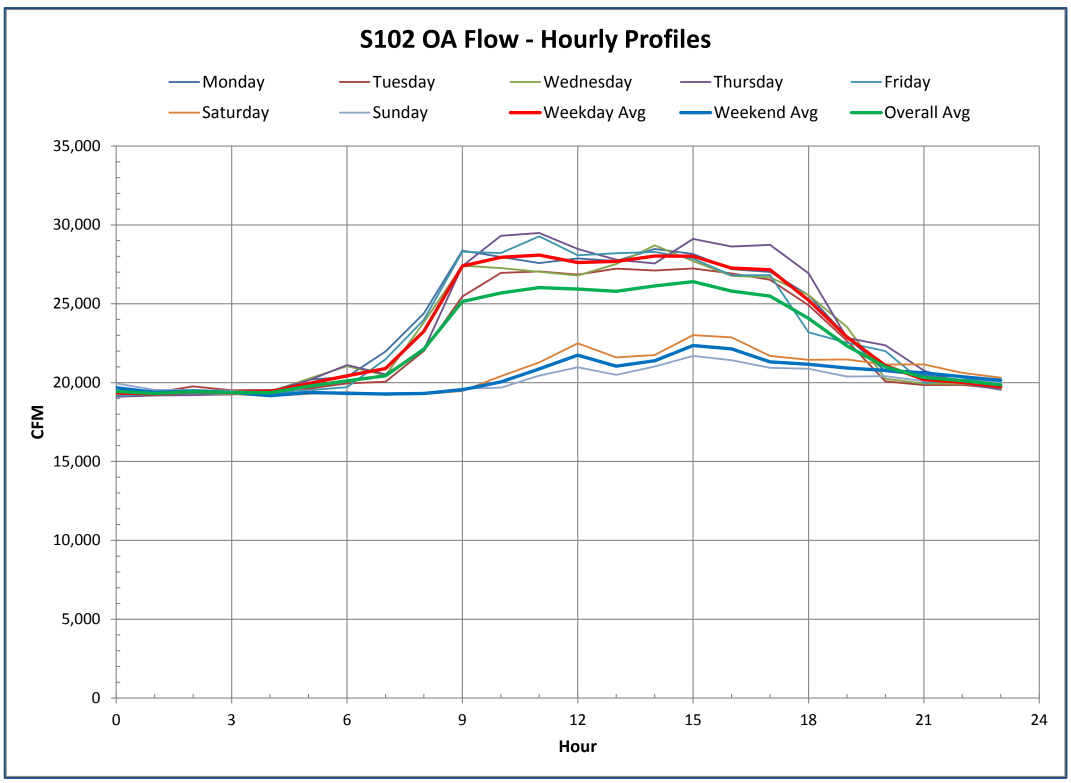

Figure 11: Air Flow Hourly Profiles, S102.

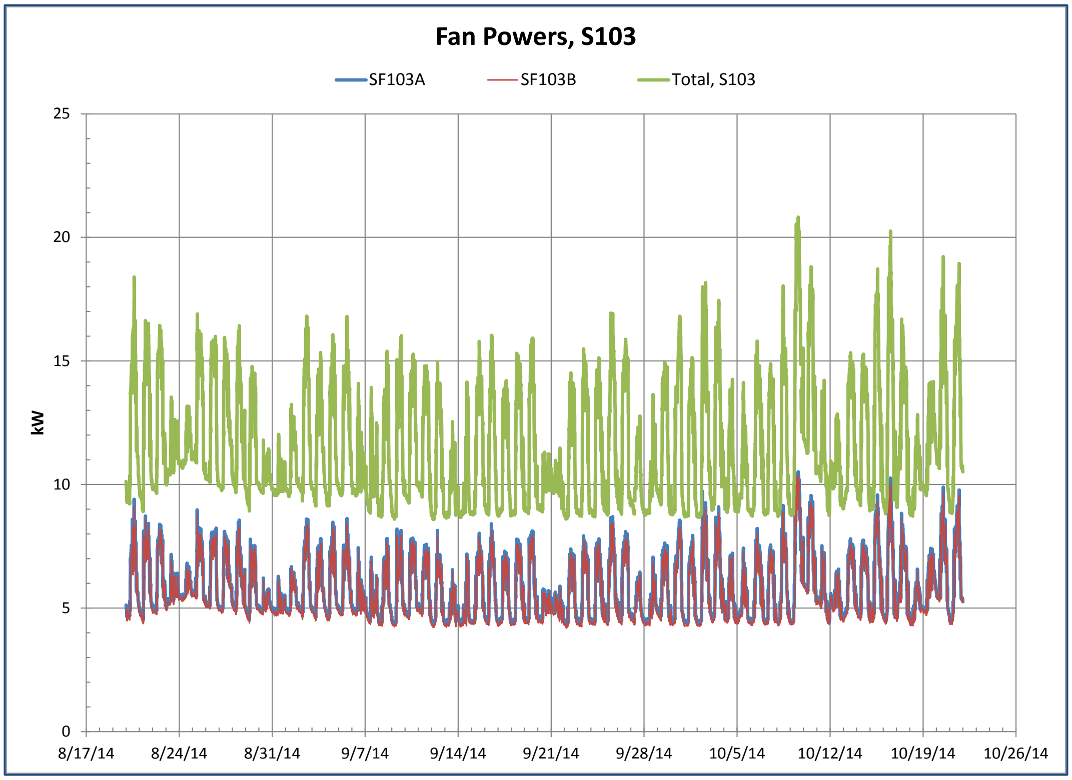

Figure 12: Fan Power, S103.

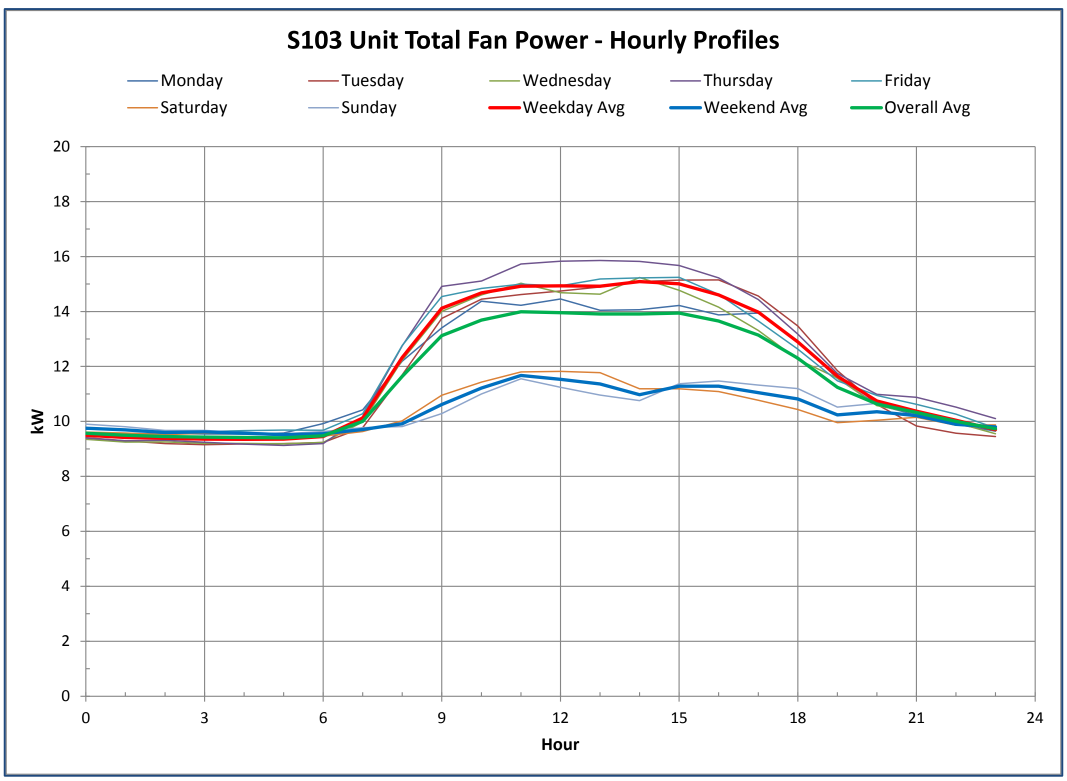

Figure 13: Fan Power Hourly Profiles, S103.

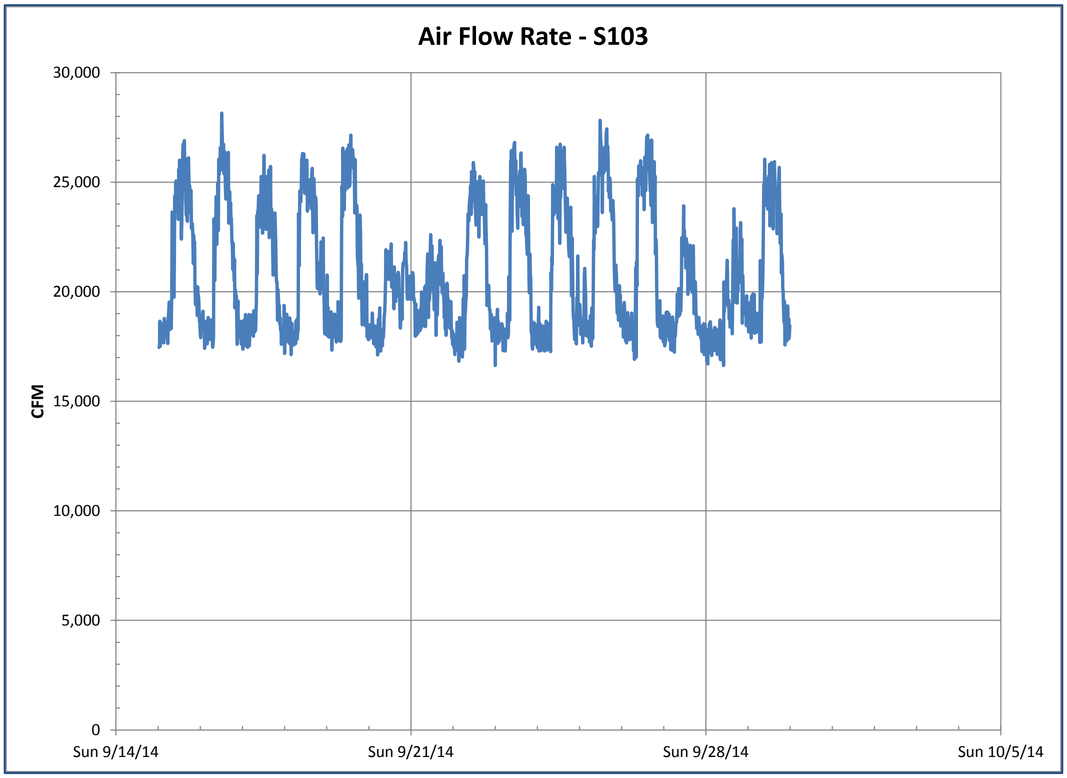

Figure 14: Air Flow Rate, S103.

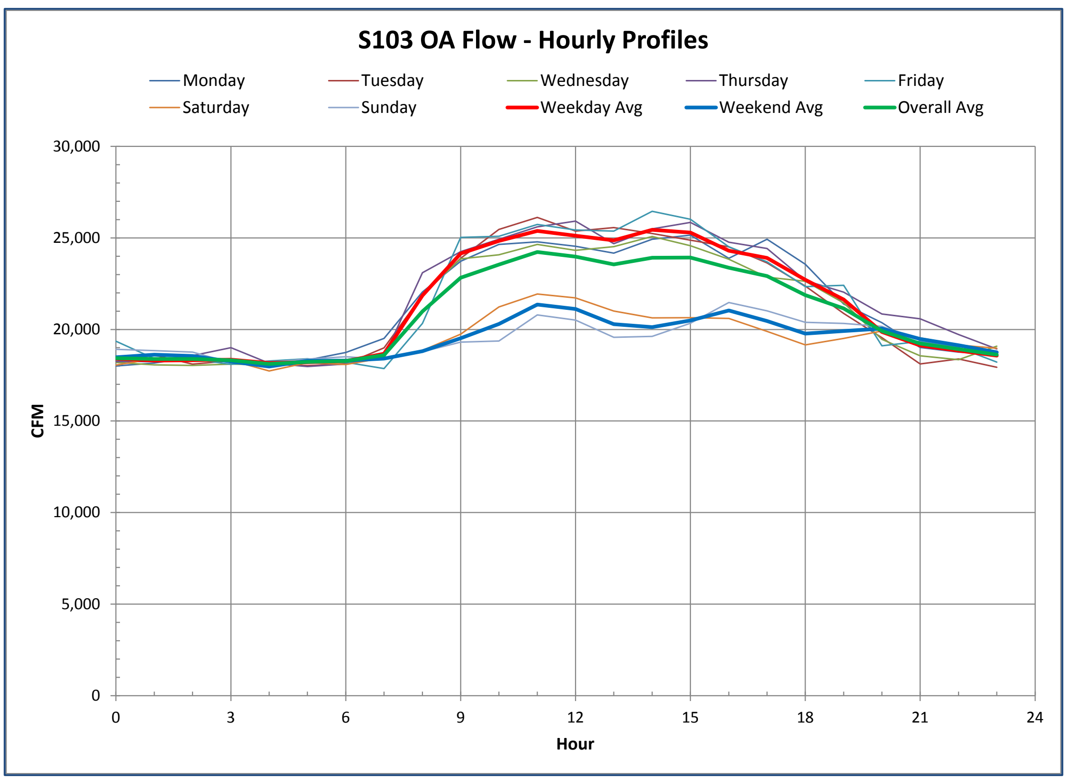

Figure 15: Air Flow Hourly Profiles, S103.

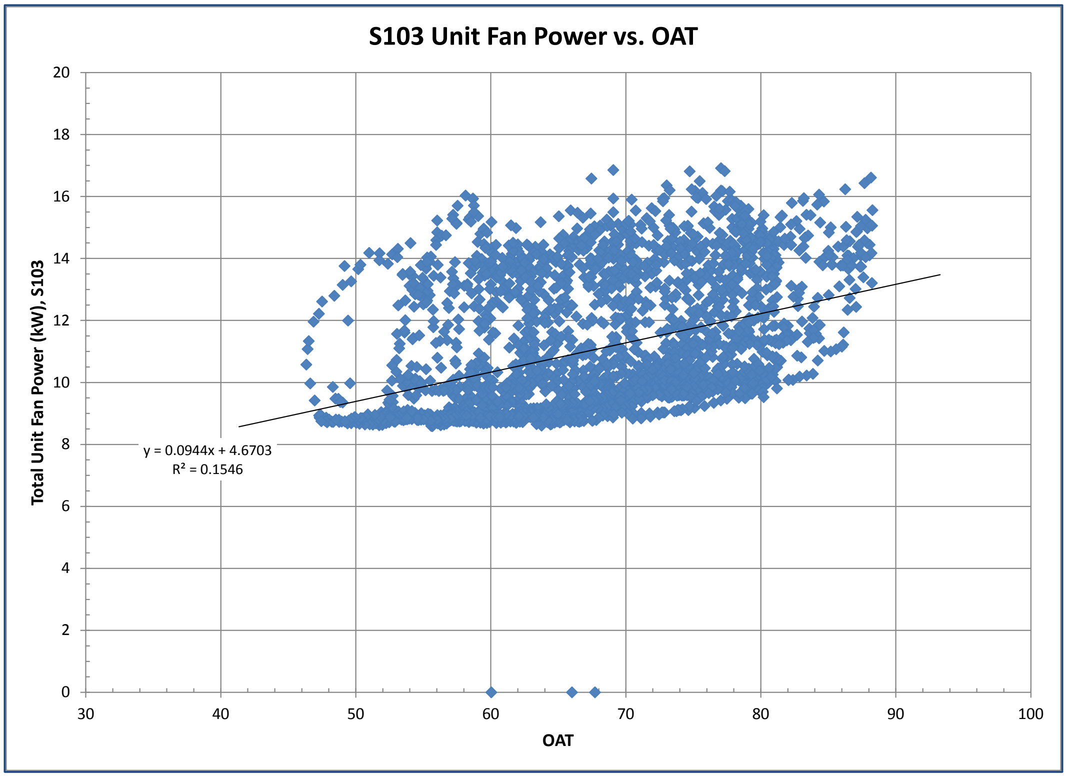

Figure 16: Unit Fan power vs. OA Temperature (example, S103).

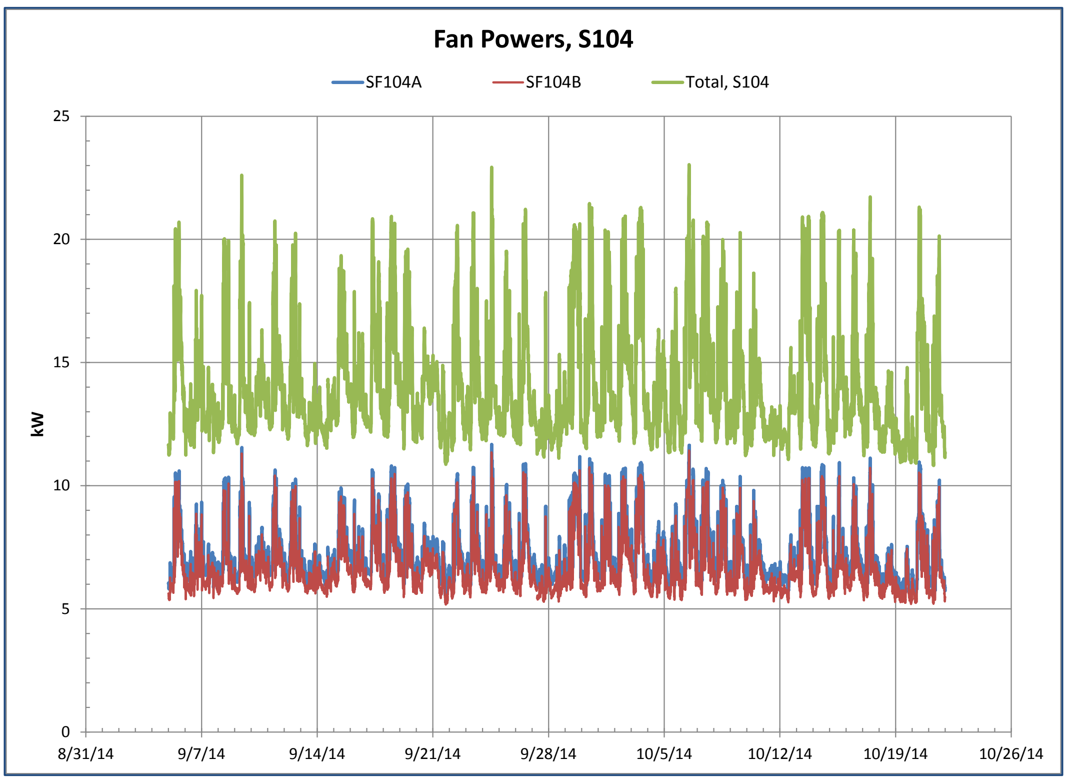

Figure 17: Fan Power, S104.

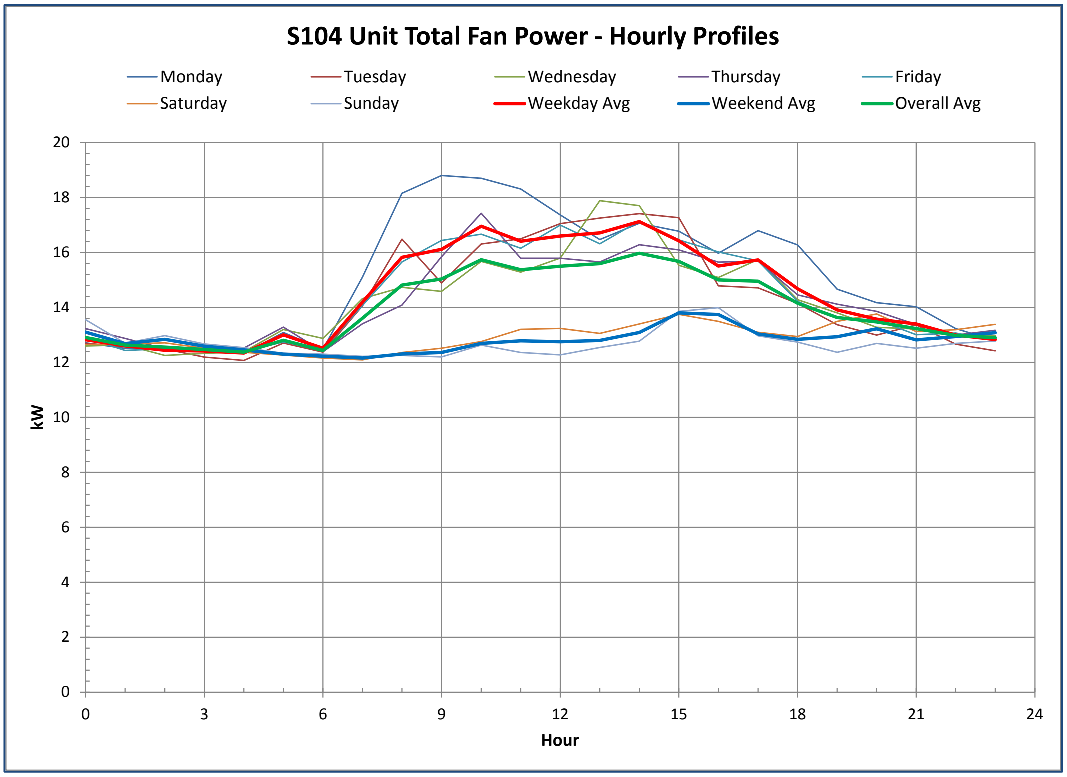

Figure 18: Fan Power Hourly Profiles, S104.

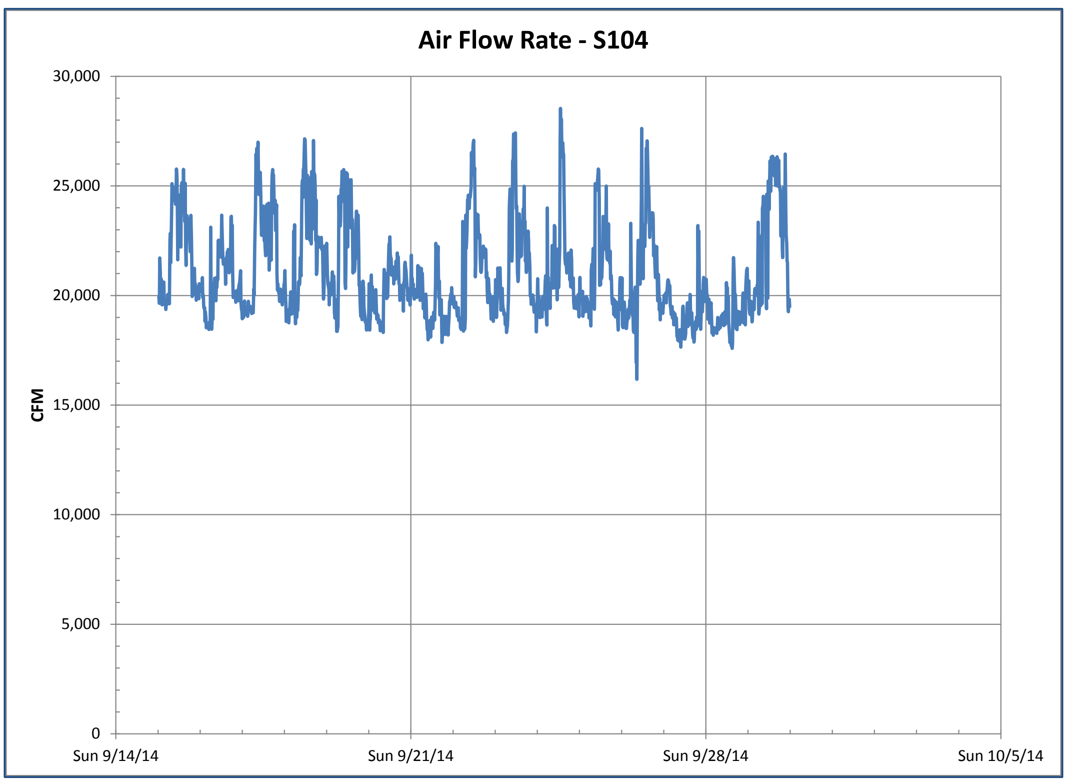

Figure 19: Air Flow Rate, S104.

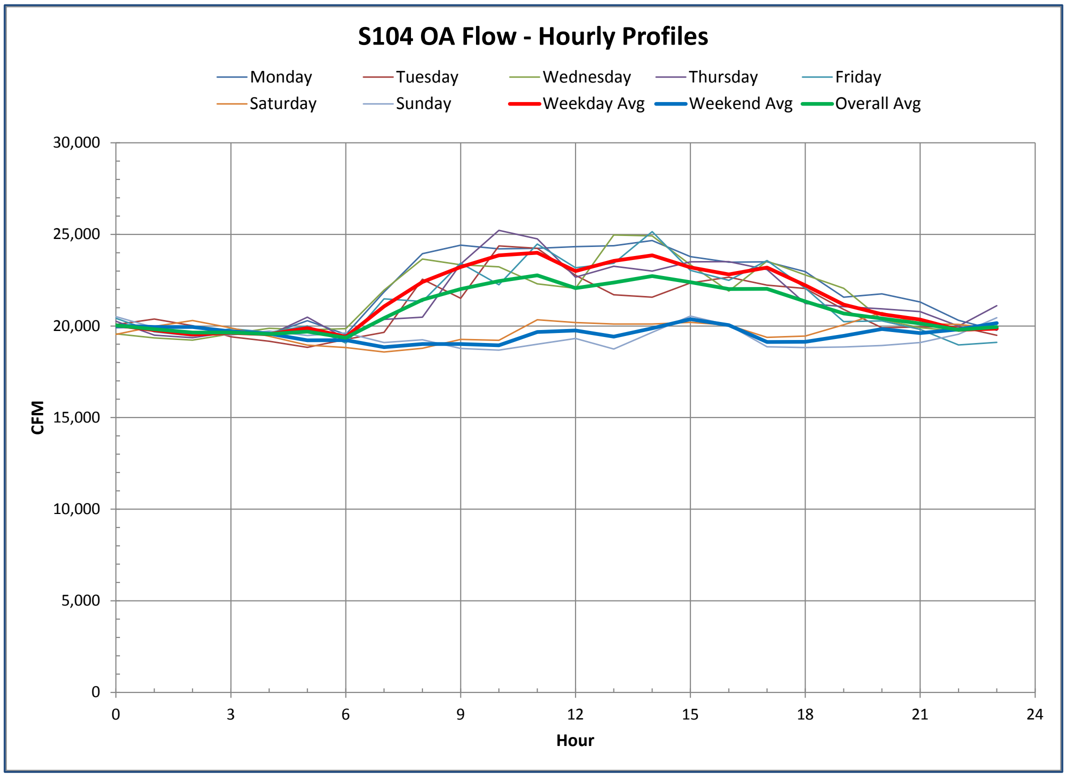

Figure 20: Air Flow Hourly Profiles, S104.

<u>Exhaust Fans</u>

Each exhaust unit (Fume Exhaust Fan units and General Exhaust Fan units FEF101, GEF102, FEF103 and GEF104) has multiple internal fixed-speed fans that stage on and off to maintain exhaust pressure in a common suction plenum. If the exhaust pressure increases in magnitude, then bypass dampers open to bring in outside air (extra fan capacity is present). If the bypass dampers are 100% open and pressures are still above setpoint, then the lag exhaust fan is shut off. No modifications were performed on these units, but energy savings were anticipated to be achieved in two ways:

1) For most of these units (all except GEF104), since the supply air flow to the building has been reduced, the exhaust air flow would be reduced commensurately, and fewer internal fans would need to operate to provide the required exhaust in both occupied and unoccupied conditions.

2) Since the supply and exhaust air valves were retrofitted with full variable volume controls, the systems are expected to be more responsive to unoccupied conditions. Occupied conditions were expected to be reduced during the first 8-hours of the day from 50% to 10% “occupied,” and during the third 8-hours of the day from 50% to 25% “occupied.” In this context, “occupied” does not indicate actual building occupancy (the actual occupancy pattern has not changed), but rather the fraction of the time each exhaust unit would have to operate at its high flow rate to accommodate the exhaust requirements of the building during those 8-hour periods.

<u>FEF101</u>

According to site trend data and photos, FEF 101 Fans A, B, C and D exist. We did not know Fan D existed before the site visit. We monitored all four Fans A, B, C and D. The data is presented in Figure 21 and Figure 22.

Per Part 2 of the application, post-retrofit operation was supposed to be two fans running when occupied, and one when unoccupied. According to the data, two fans are always operating. Pre- retrofit operation was supposed to be three fans running when occupied, and two when unoccupied. The pre-retrofit operation is accepted as accurate, while the post-retrofit situation is operating with higher energy than expected (two fans continuously instead of one fan when unoccupied). In addition, the data shows that each fan is operating at slightly lower power than the application estimated (36.7 kW instead of 40.3 kW, on average). These findings will reduce the energy savings predicted for FEF101.

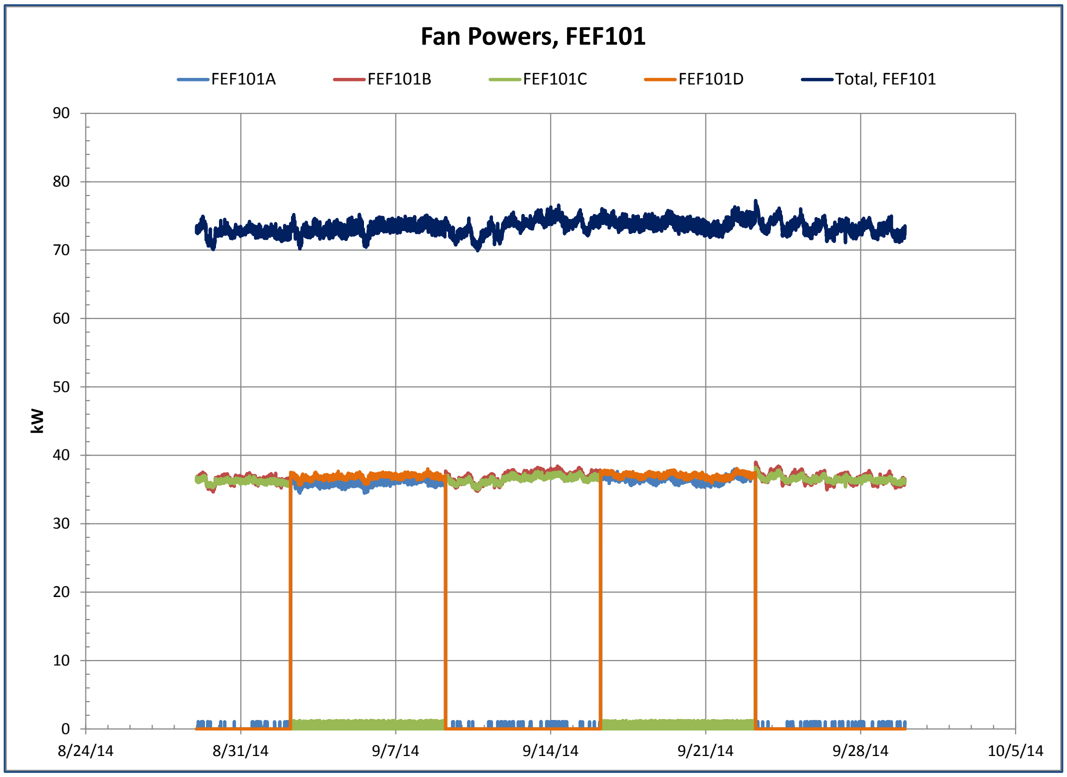

Figure 21: Fan Power, FEF101.

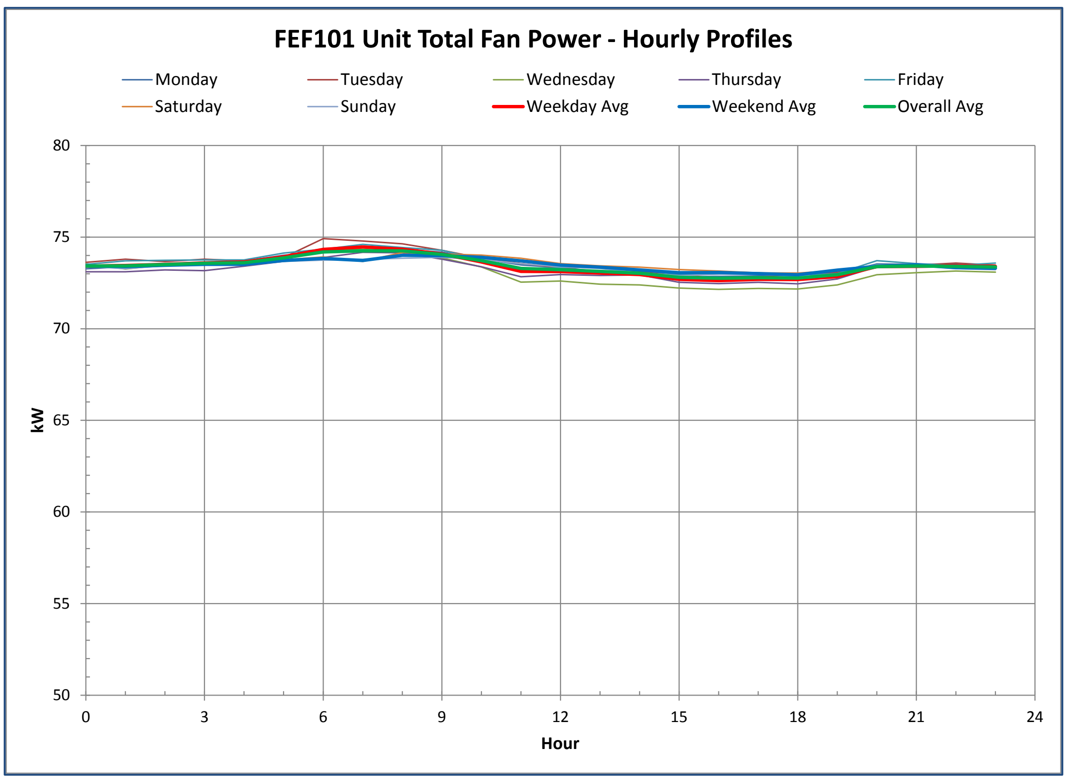

Figure 22: Fan Power Hourly Profiles, FEF101.

<u>FEF103</u>

According to site trend data and photos, FEF 101 Fans A, B and C exist. We monitored all three Fans A, B and C. The data is presented in Figure 23 and Figure 24.

Per Part 2 of the application, post-retrofit operation was supposed to be two fans running when occupied, and one when unoccupied. According to the data, only one fan ever operates. Pre-retrofit operation was supposed to be three fans running when occupied, and two when unoccupied.

The pre-retrofit operation is accepted as accurate, while the post-retrofit situation is operating with lower energy than expected (one fan continuously instead of two fans when occupied). In addition, the data shows that each fan is operating at slightly lower power than the application estimated (37.8 kW instead of 38.0 kW, on average). Net result is that the energy savings are increased for FEF103.

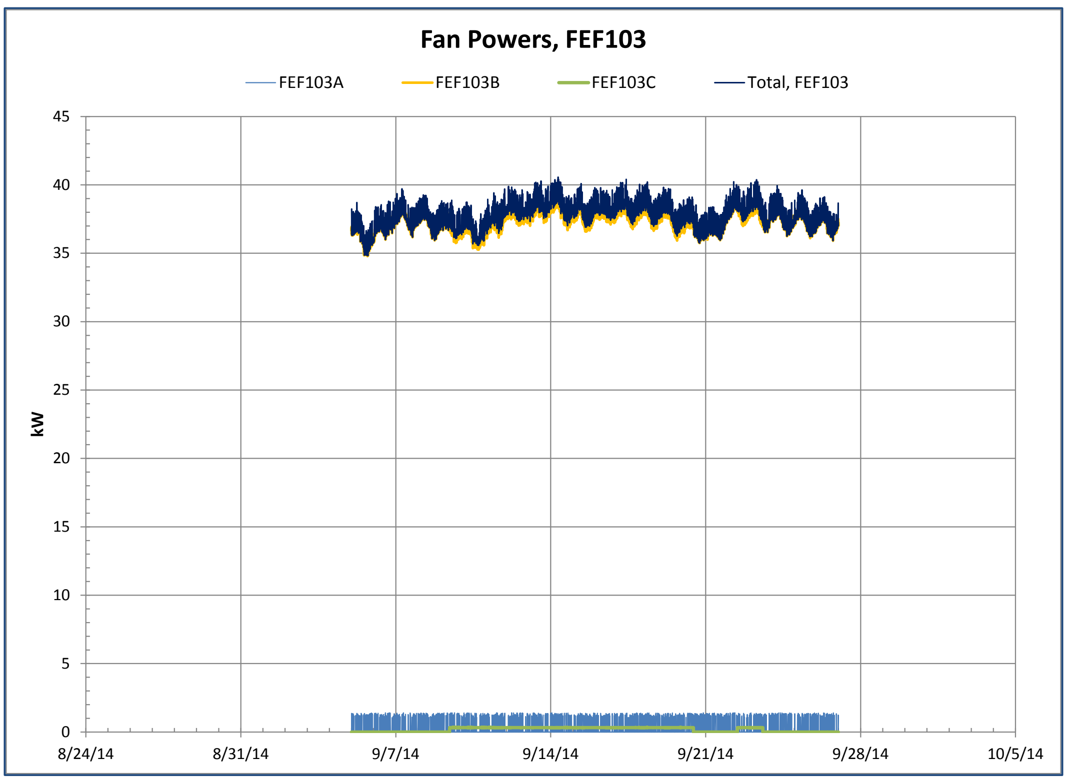

Figure 23: Fan Power, FEF103.

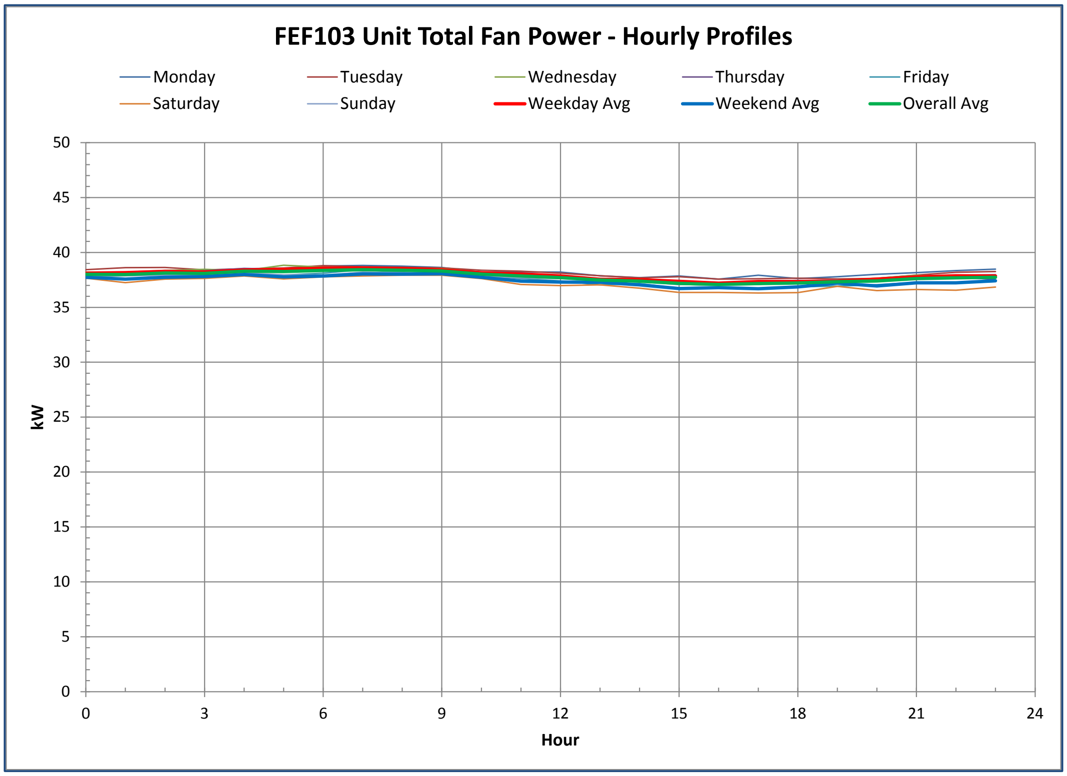

Figure 24: Fan Power Hourly Profiles, FEF103.

<u>GEF 102</u>

In the Application document (Part 2), general exhaust unit GEF 102 was described as having three fans. In the pre-retrofit case, two fans were listed as operating during both occupied and unoccupied hours. In the post-retrofit case, only one fan was to operate during unoccupied hours.

According to site trend data and photos, GEF 102 Fans A, B, C and D exist. We did not know Fan D existed before the site visit. We monitored Fans A and B. The data is presented in Figure 25 and Figure 26. The monitored data shows that Fan A was off for the entire period and Fan B ran continuously.

According to the site trend data, Fan C was also “on” during this period; however, observations on site were that the fan was not running.

The post-retrofit analysis is based on one GEF 102 fan running continuously.

One fan running continuously is less than the expected operation of the post-retrofit situation (two fans were supposed to operate during “occupied” times). Without information to the contrary, the pre-retrofit analysis is based on the application’s stated situation, which is two fans running continuously. In addition, the data shows that each fan is operating at slightly lower power than the application estimated (30.8 kW instead of 33.5 kW, on average). Net result is that the energy savings are increased for GEF102.

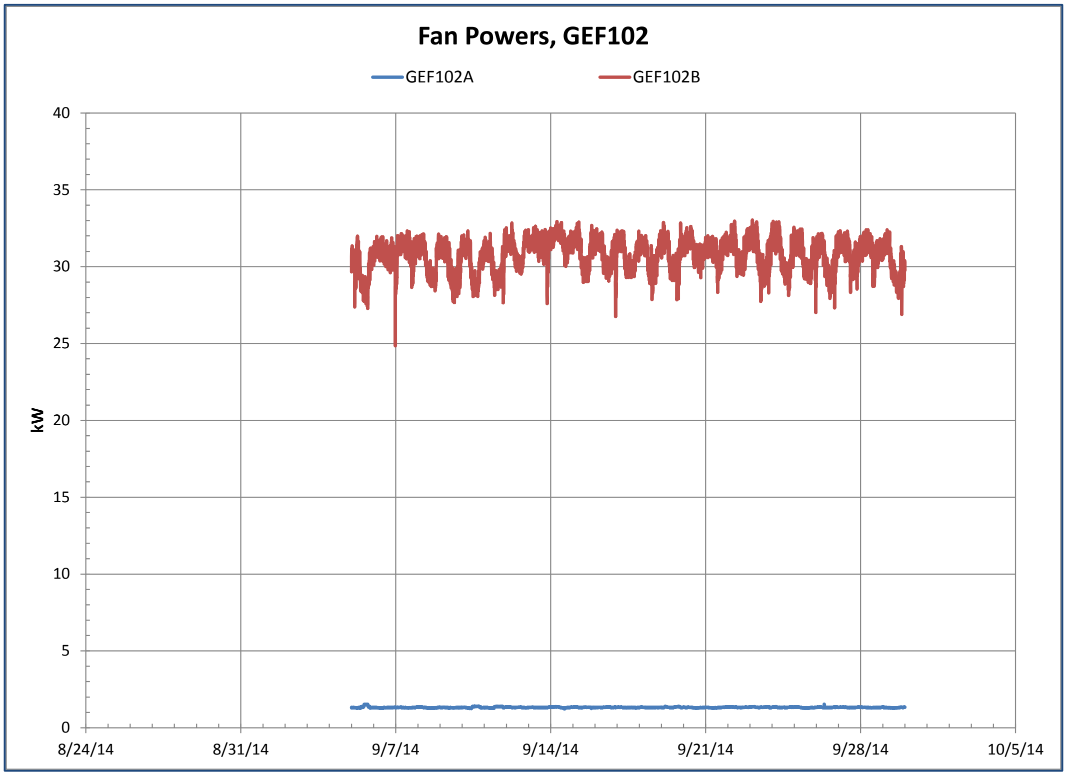

Figure 25: Fan Power, GEF102.

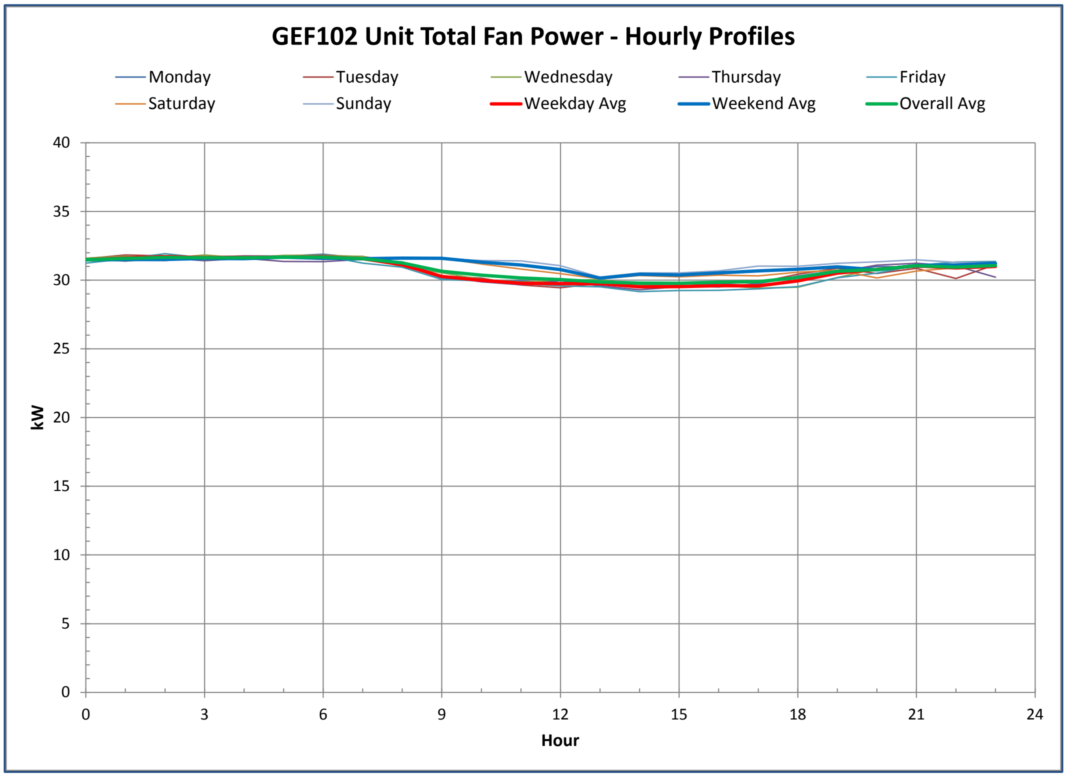

Figure 26: Fan Power Hourly Profiles, GEF102.

<u>GEF104</u>

In the Application document (Part 2), general exhaust unit GEF 104 was described as having two fans. Two fans were listed as operating during occupied hours and one fan during unoccupied hours, in both pre- and post-retrofit cases. Thus the energy savings for this unit were all expected to result from reduced "occupied" percentages during the first and third 8-hours periods of the day.

According to site trend data and photos, GEF 104 Fans A, B and C exist. We monitored Fans A and B. The data is presented in Figure 27 and Figure 28. The monitored data shows that Fans A and B started off running together. Fan A ran for the entire trend period. Fan B went off on 9/5; however, the site trend data on/off flag indicates that Fan C came on in its place. Therefore, the post-retrofit analysis is based on two GEF 104 fans running continuously. (Note: Fan B's data was sporadic due to data logger issues and is not presented below. The total fan power is estimated as twice that of Fan A.)

Since two fans running continuously exceeds the expected operation of even the pre-retrofit situation, the pre-retrofit analyses is also based on this condition (we do not expect that more energy is being used post-retrofit than pre-retrofit). Since the pre-retrofit and post-retrofit situations are the same, there are no energy or demand savings for GEF 104.

Although the data shows that each fan is operating at a higher power than the application estimated (54.6 kW instead of 41.0 kW, on average), this is immaterial if the pre- and post-retrofit operations are the same.

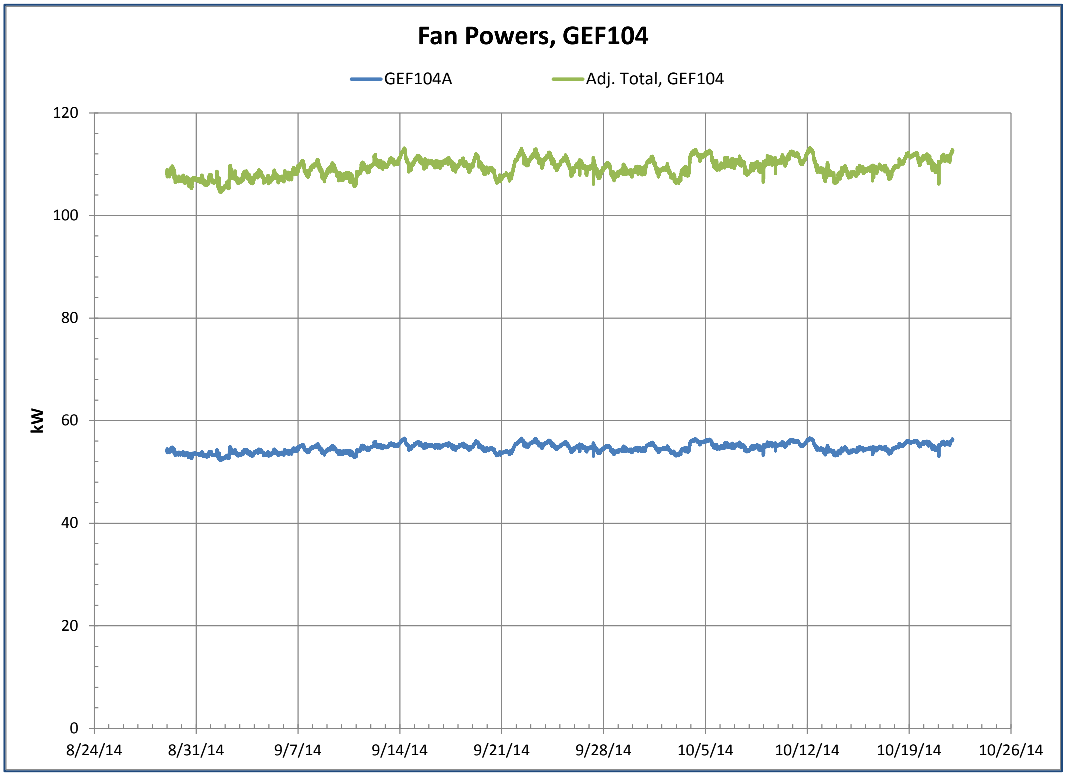

Figure 27: Fan Power, GEF104.

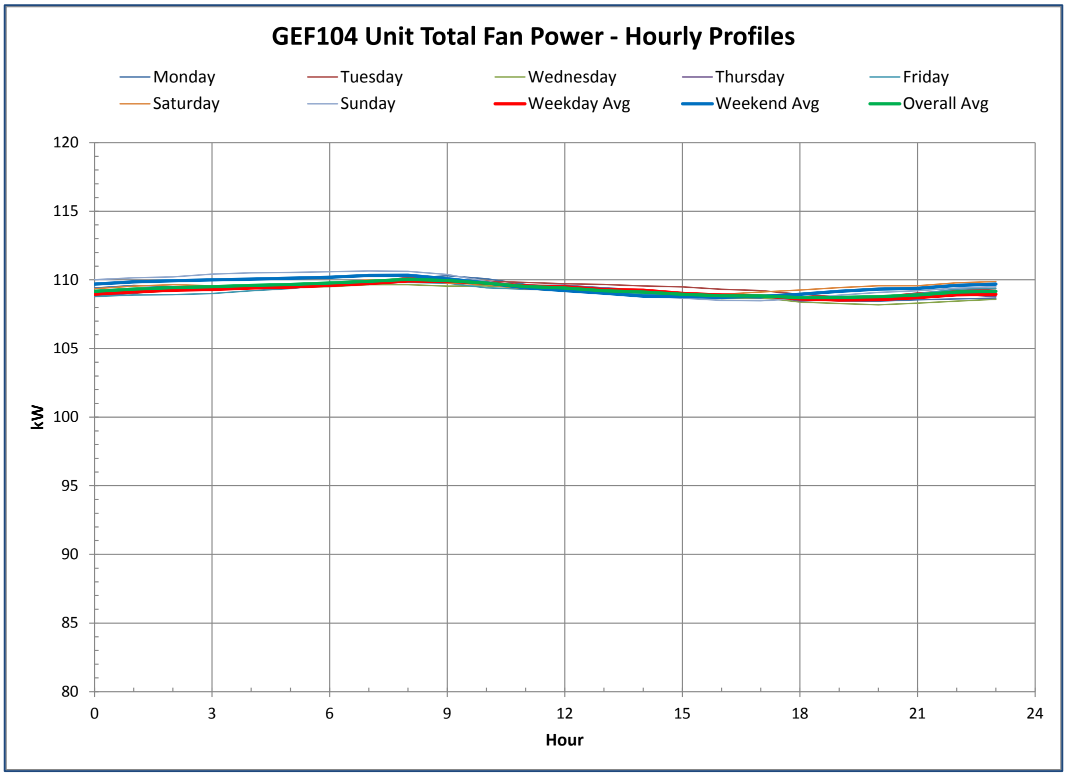

Figure 28: Fan Power Hourly Profiles, GEF104.

M&V Results

The goal of this M&V effort was to measure the post-retrofit energy performance of the various supply and exhaust systems, estimate the pre-retrofit performance, and determine the likely energy and demand savings that result from the retrofit. Finally, the estimated savings are compared to the savings that were projected by Duke before the retrofit was performed, and "realization rates" are calculated for both energy and demand savings.

This effort is concerned only with the electric savings. Although heating savings were also anticipated, the potential savings of steam for heating purposes is not part of this investigation.

The electric savings have three contributions: supply air fan motors, exhaust fan motors, and a chiller contribution resulting from cooling the 100% outside air for distribution into the building.

Supply Air Fans

Beginning with the supply air fans, Table 1 shows a summary of the pre- and post-retrofit supply fan powers and annual energy consumption provided in the application documents for "Occupied" and "Unoccupied" conditions. Table 2 shows the actual average powers and projected annual energy consumption based on measured data taken during the M&V monitoring, which was presented above. Also shown are the maximum and coincident peak demands recorded in the measured data.

Comparing the annual energy usage values in the two tables, the post-retrofit energy consumption developed from the measured data is much higher than the application's value, and is even higher than the application's pre-retrofit value! The application's estimates for post-retrofit fan powers – perhaps derived using fan laws – were significantly lower than the actual measured values.

If we compare the M&V post-retrofit energy consumption to the application's pre-retrofit energy usage, the savings are negative. However, since the measured post-retrofit powers are much higher than the application's corresponding values, and the retrofit was performed, it is likely that the actual pre-retrofit powers were higher than the application stated as well. We will therefore need to estimate what the actual pre-retrofit fan powers that correspond to the measured post-retrofit values should be.

The application's fan powers correspond to their estimated pre- and post-retrofit air flows. The calculated pre-retrofit CFMs were based on the original as-built HVAC drawings. Most spaces were designed to be supplied with 12 (in open labs) to 24 (in procedure rooms) air changes per hour (ACH). For the post-retrofit CFMs, the air flows for the labs were reduced to 8 ACH when occupied and 4 ACH when not occupied. The calculations resulted in the CFMs presented in Table 3 in the column, "Application's Air Flows (CFM)."

Also presented in this table are the maximum and minimum hourly average air flows derived from the site-provided trend data. Note that the M&V total post-retrofit air flow is only about 80% of the application's estimate (109,614 CFM vs. 137,170 CFM). It is important to know that the application's value is the expected peak flow at 100% occupancy, but the M&V value is a measured value that accounts for the possibility that every space in the building may not operate at full occupancy.

From the application's pre- and post-retrofit air flows, ratios of the pre-to-post-retrofit air flows can be calculated for each fan system. Assuming that the retrofit was successful in reducing the overall amount of air flow by these ratios, the ratios can be applied to the actual post-retrofit air flows to develop corresponding pre-retrofit air flows. Then, using fan law relationships, an estimate of the actual pre-retrofit average power can be calculated as the M&V annual average power times the ratio of the estimated pre-retrofit CFM to the post-retrofit CFM raised to an exponent (see table footnote for formula). An exponent of 1.0 is appropriate for a system with constant static pressure.

Using the same technique, the pre-retrofit peak demands can also be estimated. Finally, the energy and demand savings are presented on the right side of Table 3. Comparing these savings to the application's savings in Table 1, the M&V energy savings for the supply air fan units are about 18% higher, the peak demand savings are about 14% higher, and the coincident peak demand savings are about 5% lower. (The application did not differentiate between maximum and coincident peak savings.)

Table 1: Application's Supply Air Systems Results - Fan Performance.

	Application's Estimates					
	Pre-Retrofit		Post-Retrofit		Annual Energy (kWh/year)*	
System	Occupied Fan Power (kW)	Unoccupied Fan Power (kW)	Occupied Fan Power (kW)	Unoccupied Fan Power (kW)	Pre-Retrofit	Post-Retrofit
S101	28.23	10.6	11	5	161,740	67,706
S102	34	12	17.6	6.6	191,548	100,893
S103	22	6.6	3.8	3.4	118,278	31,408
S104	31.1	8.4	5.8	3.9	163,281	41,850
TOTALS	115.3	37.6	38.2		**634,847**	**241,857**
	Predicted Savings		**77**			**392,990**

* Pre-retrofit and post-retrofit fan energies were calculated assuming 10% Occupied for the first 8 hr of the day, 100% Occupied for the second 8 hr, and 25% Occupied for the last 8 hr.

Table 2: M&V Supply Air Systems Results - Post-Retrofit Fan Performance.

	M&V Post-Retrofit Avg Power (kW)								
	Occupied		Unoccupied						
System	Weekdays	Weekends	Weekdays	Weekends	Overall Average Power (kW)	Maximum Peak Power (kW)	Coincident Peak Power (kW)	Op. Hours / year	Annual Energy (kWh/yr)
S101	30.5	21.5	17.5	17.7	22.2	45.3	34.2	8760	194,723
S102	34.6	30.0	29.2	29.1	30.8	38.1	28.2	8760	269,680
S103	15.1	11.7	9.4	9.5	11.5	20.8	20.1	8760	100,529
S104	17.1	13.8	12.3	12.2	14.0	23.0	20.7	8760	122,563
TOTALS	97.3	76.9	68.4	68.5	78.5	127.2	103.1		**687,495**

Table 3: M&V Supply Air Systems Results - M&V Adjusted Pre-Retrofit Fan Performance and Savings.

	Application's Air Flows (CFM)						Actual Post-Ret CFM (site trend data)		Estimated Pre-Ret CFMs[3]		Est. Pre-ret Power [4]	Est. Pre-ret Energy		Est Pre-ret Peak Demand		Demand Savings	
	Pre-Retrofit		Post-Retrofit		Ratio of Pre/Post CFMs												
System	Occupied Air Flow (CFM)	Unoccupied Air Flow (CFM)	Occupied Air Flow (CFM)	Unoccupied Air Flow (CFM)	Occupied	Unoccupied	Max. Air Flow[1] (CFM)	Min. Air Flow[1] (CFM)	Max. Air Flow (CFM)	Min. Air Flow (CFM)	Annual Avg (kW)	Annual Energy (kWh/yr)	Annual Energy Savings (kWh/yr)	Maximum Peak (non-coinc) (kW)	Coincident Peak Power (kW)	Peak (non-coinc) (kW)	Coincident Peak (kW)
S101[2]	60,200	36,850	37,850	20,736	1.590	1.777	32,090	21,857	51,038	38,843	35.4	309,705	114,982	72.0	54.4	26.7	20.2
S102	73,900	44,840	47,685	25,400	1.550	1.765	28,086	19,168	43,526	33,838	47.7	417,938	148,258	59.0	43.6	20.9	15.5
S103	44,165	24,195	22,495	14,410	1.963	1.679	25,439	17,971	49,944	30,174	22.5	197,372	96,842	40.9	39.4	20.1	19.3
S104	54,305	29,335	29,140	16,234	1.864	1.807	24,000	18,840	44,725	34,043	26.1	228,406	105,844	42.9	38.5	19.9	17.8
TOTALS	**232,570**		**137,170**				**109,614**		**189,234**		**131.7**	**1,153,421**	**465,926**	**214.8**	**175.9**	**87.6**	**72.8**

Notes:
[1] Maximum and minimum values from weekly hourly average profiles.

[2] Although trend data for S101's air flow was provided for part of the monitoring period, the value was fixed and high by a factor of 25 compared to the expected value. Therefore, the air flows shown for S101 are the application's estimated air flows multiplied by the overall ratio of the total air flow for the three units for which valid data was provided to the expected total air flow. These ratios are 85% for occupied hour values and 105% for unoccupied hours.

[3] Calculated as the Actual Post-Ret CFM times the corresponding ratio of Application's Pre/Post CFMs.

[4] Calculated as the M&V annual average power times the ratio of the estimated pre-retrofit CFM to the post-retrofit CFM raised to an exponent [kWpre = kWpost * (CFMpre / CFMpost) ^EXP]. An exponent of 1.0 is appropriate for a system with constant static pressure.