Where

LF(t) = Load factor at time = t

$kWVendingMachine_i$ = connected load of control point i

$WattsVendingMachine_i$ = logged watts at vending machine i from time series data

NLogged = population of logged vending machines

NVendingMachines = population of all vending machines

- Created separate schedules for weekdays and weekends using LF(t).
- Tabulate 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 vending machine kW against the actual schedule of post operation for each daytype.
- Calculated pre annual operating hours using the adjusted load shape by daytype and extrapolated to the full year. Methodology for creating an adjusted pre-retrofit load shape is discussed below.
- Calculated energy savings and compared to project application:

$$kWh_{savings} = \left(N_{VendingMachines} * kW_{VendingMachine} * Hours\right)_{PRE} - \left(N_{VendingMachines} * kW_{VendingMachine} * Hours\right)_{Post}$$

$$NCP\ kW_{savings} = \left(N_{VendingMachines} * kW_{VendingMachine}\right)_{PRE} - \left(N_{VendingMachines} * kW_{VendingMachine}\right)_{Post}$$

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

where:

$N_{VendingMachines}$ = number of vending machines with Vending Miser controls installed.

$kW_{VendingMachine}$ = Average connected load per vending machine

HOURS = equivalent full load hours per vending machine

NCP $kW_{savings}$ = non-coincident peak savings

CP $kW_{savings}$ = coincident peak savings

CF = coincidence factor

- The savings with HVAC interactions were 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 time series data for gaps
2. Compared readings to nameplate values; identified out of range data
3. Looked for physically impossible combinations

Recording and Data Exchange Format

1. WattsUp Logger binary files
2. Excel spreadsheet

Results

Figure 1 and Figure 2 show data that was collected in order to calculate savings for the application.

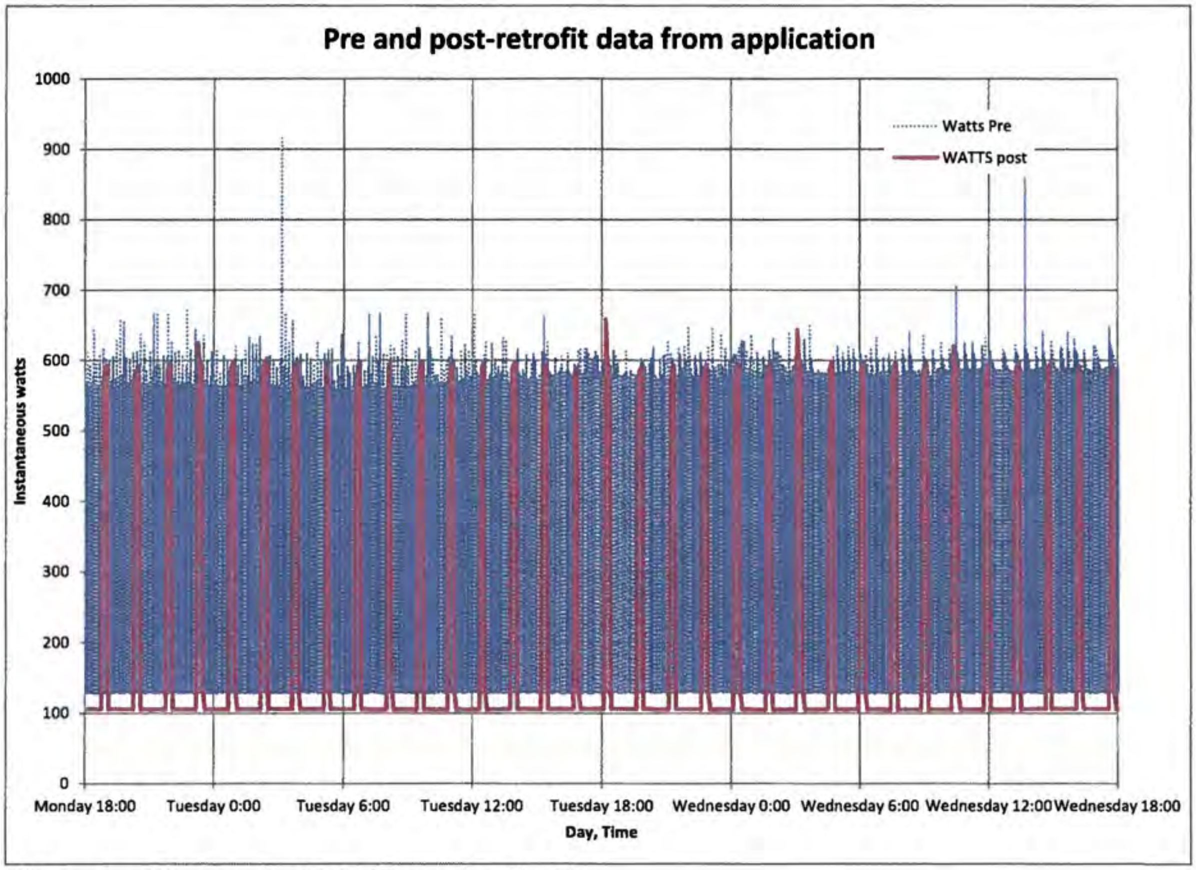

Figure 1 – Time-series Data From Application

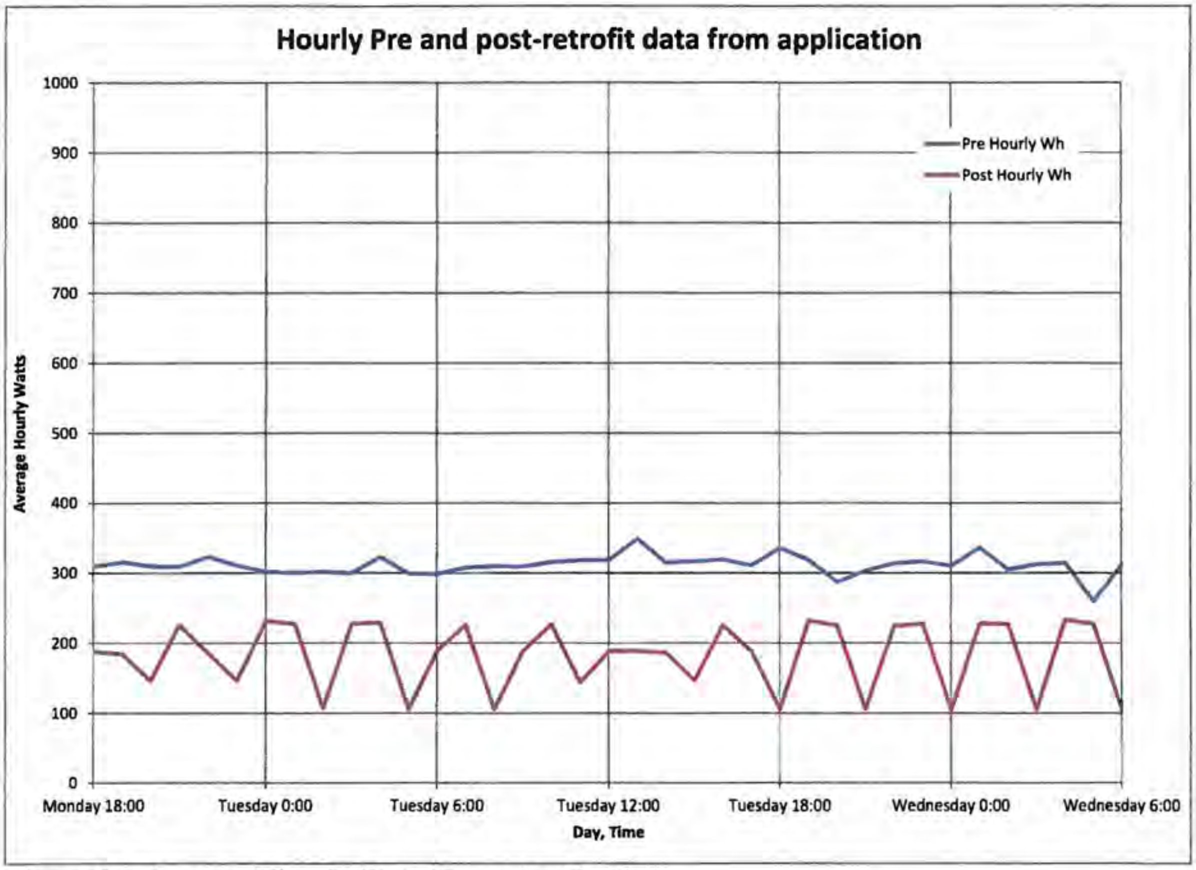

Figure 2 – Average Hourly Data From Application

Error! Reference source not found. and **Error! Reference source not found.** show the results of the Vending Miser controls retrofit at the University of Cincinnati.

Table 1

		Realized Savings		Realization Rate	
	Duke Savings	**Vending Machines Only**	**Vending Machines and HVAC**	**Vending Machines Only**	**Vending Machines and HVAC**
Energy (kWh)	93,447	156,075.3	165,127.7	167%	177%
Demand (kW)	10.70	32.02	34.68	299%	324%

Table 2

	Vending	HVAC	Total
Pre kW	47.07		
Post kW	23.60		
Demand Savings	32.02	2.66	**34.68**

Coincident Peak Demand Savings (kW):	26.56	2.20	**28.76**

- Equivalent full load hours (EFLH) were found to be 4,892 for all modified vending machines.

Figure 3 shows the average daily loadshape for the Central Utility Plant. The Pre load-shapes for each machine logged were assumed to be the peak kW for each machine logged because the machines would run 24/7 regardless of usage. Actual logged data of a machine before the addition of the VendMiser controls can be seen in Figure 2. The "Pre" data average is fairly consistant, which is why the "Pre" logged data for each building was assumed to be constant. This approach was used for all machines logged across the campus.

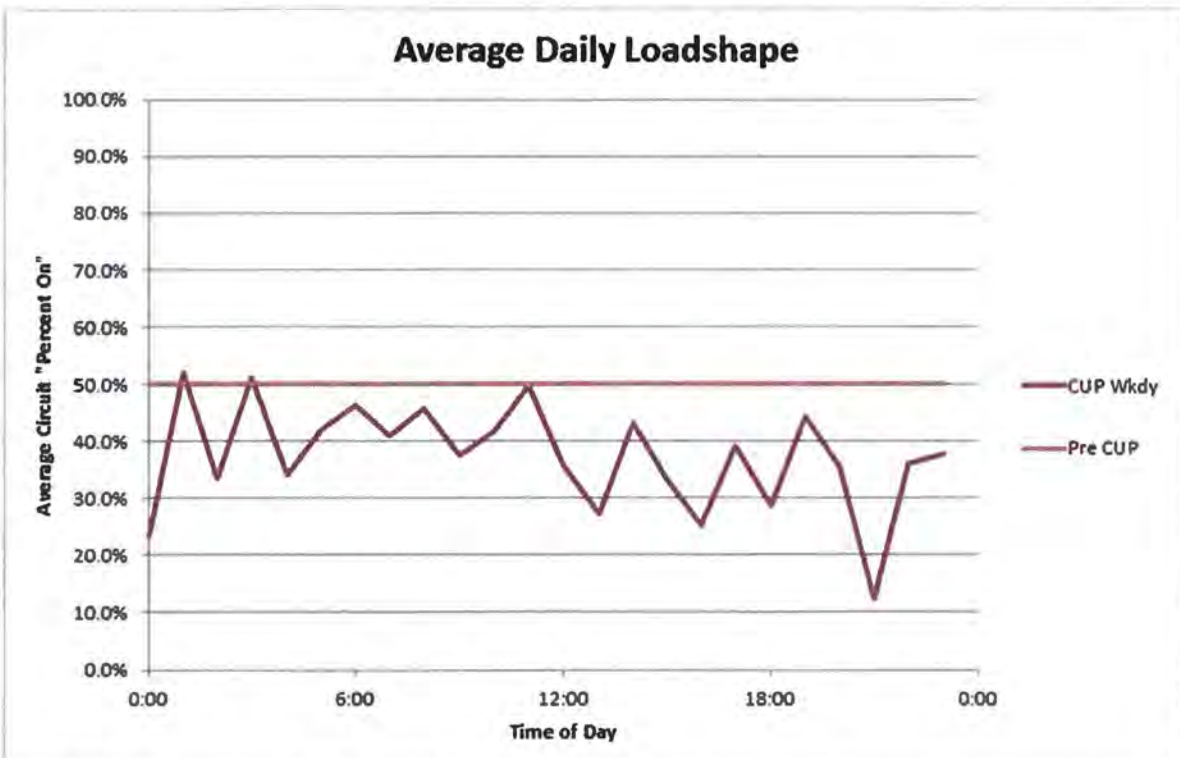

Figure 3 – Average Daily Loadshape for Central Utility Plant

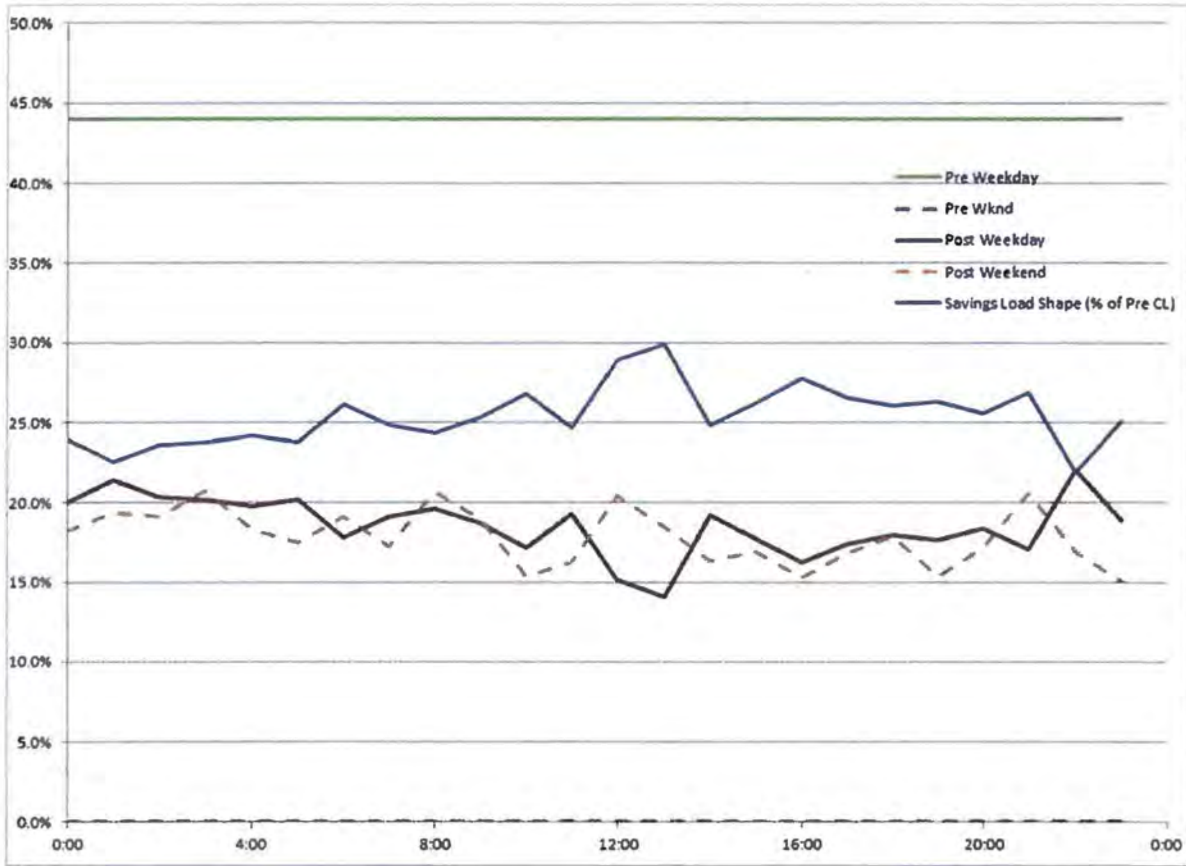

Figure 4

Figure 4 is a combined average daily load-shape of each machine in Figure 3. The maximum savings were noted to occur around noon.

[Redacted]
Chiller Replacement
M&V Report

Prepared for
Duke Energy Ohio

May 2014

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

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

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

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Introduction

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

The measures include:

ECM-1

- Replace existing 953 Ton Trane CVHB095 AHA chiller (0.665 kW/Ton) with a new 1000 Ton Trane CVHF0910 Chiller (0.319 kW/Ton). The new chiller has a factory mounted VFD.

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

Goals and Objectives

The projected savings goals identified in the application are:

ECM	Application Proposed Annual savings (kWh)	Application Proposed Peak Savings (kW)	Duke Projected savings (kWh)	Duke Projected Coincident Peak savings (kW)	Duke Projected Non-Coincident Peak savings (kW)
1	731,560	270	**580,966**	**193.4**	**224.5**

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

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Customer Contact O&M Site Ops Sprvsr	[Redacted]	[Redacted]	[Redacted]

Site Locations/ECM's

Address

[Redacted]

Data Products and Project Output

- Average pre/post load shapes by day-type 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 Sequence

- ECM's dictated that monitoring should be implemented during the summer months (peak cooling season).
- Post data only was collected.
- The monitoring period included both normal workday and weekend periods.

Field Survey Points

Survey data (for all equipment logged)

- Obtained chiller sequence of operations for both the pre and post installation cases. Confirmed this sequence for the primary chiller, cooling tower(s), and distribution pump(s) (primary and secondary).
- 1000 ton chiller make/model/serial number
- 1000 ton chiller VFD make/model
- 1000 ton chiller flow rate
- Cooling Towers 1&2 make/model/serial number
- Cooling Towers 1&2 VFD make/model
- CHW pump capacity (hp)
- CW pump capacity (hp)

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

- 1000 ton chiller volts, amps, kW and power factor, and VFD speed
- CHW pump volts, amps, kW, and power factor
- CW pump volts, amps, kW, and power factor
- OA Temperature and RH

Data Accuracy

Measurement	Sensor	Accuracy	Notes
Current	DENT Split-Core CT	±1%	> 10% of rating
kW	Dent ElitePro	±1%	

Field Data Logging

- ECM-1 – Installed data loggers to log the following data points in 5 minute intervals.

  1. 1000 ton chiller kW
  2. CHW pump kW
  3. CW pump kW.

  Note: All points must be logged at the same time.

For the chiller, configure the Elite Pro logger to record the following information:

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

- The EMS was capable of trending the following points. Data was collected for three weeks.

  1. Chilled Water Supply Temperature
  2. Chilled Water Return Temperature
  3. Condenser Water Supply Temperature
  4. Condenser Water Return Temperature
  5. CHW flow rate
  6. CW flow rate
  7. CHW pump VFD Speed
  8. CW pump VFD Speed
  9. Cooling Tower 1 VFD Speed
  10. Cooling Tower 2 VFD Speed
  11. OA temperature

Logger Table

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

ECM	Elite-Pro	Elite-Pro CT's	Weather Station
Chiller	1	(3) 1000 A	
CHW Pump	1	(3) 100A	
CW Pump	1	(3) 100A	

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 4-5 pm local time.

- **ECM-1**

  1. Calculate Post chiller tons by using the following equation developed from factory efficiency ratings:

  $Tons = 384.57 \ln(kW) - 1418.1$

  where

  Tons = Chiller load
  kW = Measured chiller input power

  2. Used IPLV information to estimate previous chiller operating conditions. Chiller load from equation above remains the same.
  3. Determined kWh for both Pre and Post operating conditions.
  4. Converted time series data on logged equipment into pre/post average load shapes by day-type. Compared pre/post peak kW for evidence of peak demand limiting. Calculated peak demand savings.
  5. Regressed data into a temperature dependent load model. Form of the regression equation is:

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

  where

kWh/day = daily energy consumption
T_{avg} = Daily average dry-bulb temperature

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

Verification and Quality Control

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

Recording and Data Exchange Format

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

Results

The chiller power data collected with the ElitePro data logger is shown in the following chart. Data were collected for over five weeks.

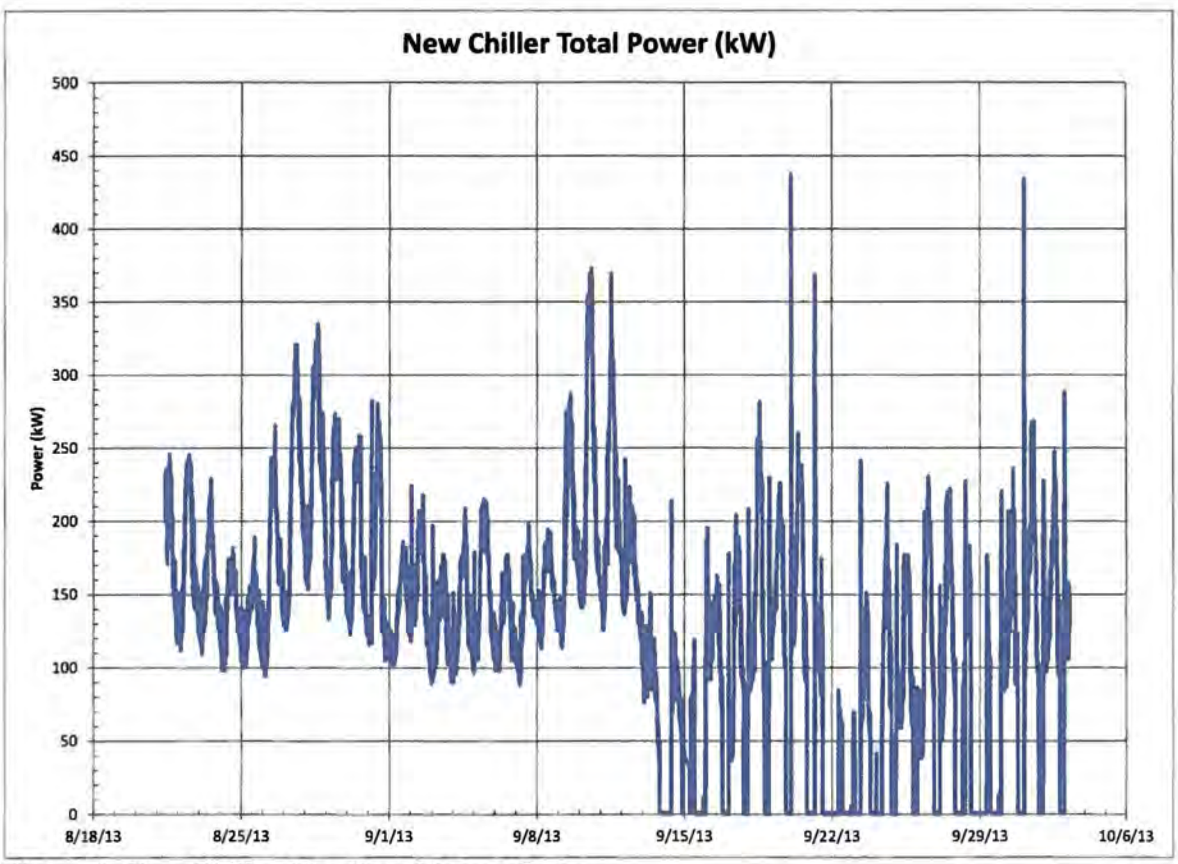

Figure 1. New Chiller Monitored Power Data

Note the change in the operating schedule on September 14th. On this date the chiller began to cycle off at night. This may be a programmed response to low outside air temperatures (further discussed after Figure 4).

This date also corresponds to the beginning of the chiller system data received from the facility's EMS, including outside air temperatures (OAT) that we received. Unfortunately, there is no EMS data before this date.

An expanded view of the OAT and corresponding chiller power is shown in the following chart. The overall average power draw of the chiller is 131.0 kW <u>when running</u> during this time.

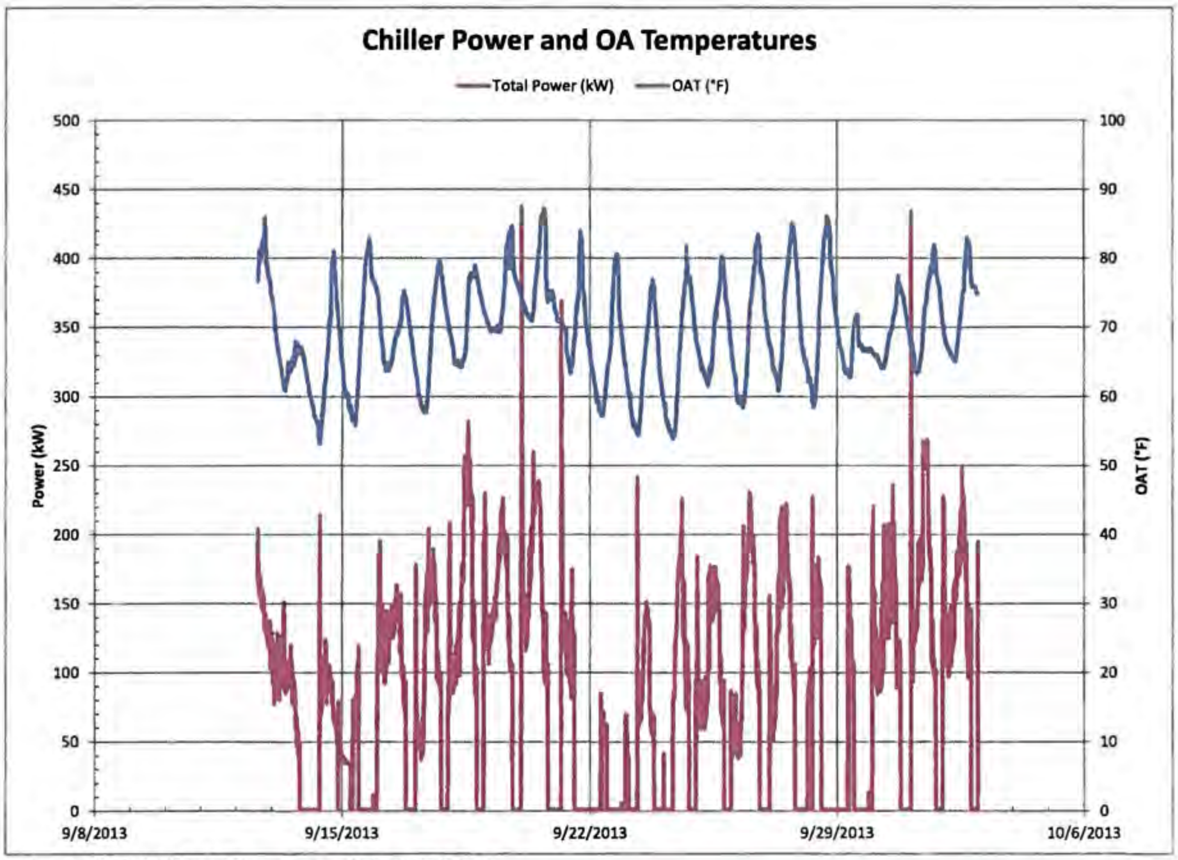

Figure 2. Chiller Power and OAT Data

In the following chart, average daily chiller power profiles for weekdays and weekends are plotted. The average OAT profiles are shown as well.

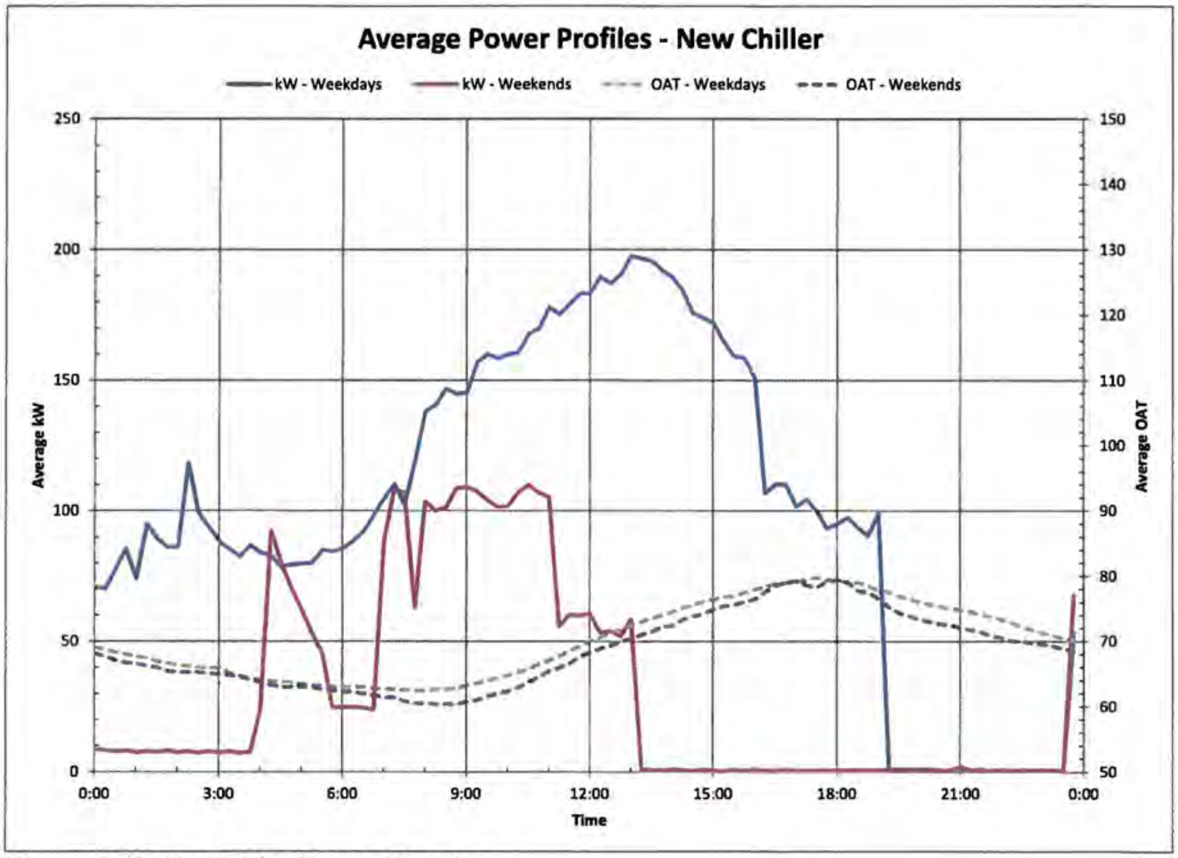

Figure 3. Daily Chiller Power Profiles

In an attempt to correlate chiller input power with outside air temperature, plotting power against OAT for each monitored data point leads to the following chart.

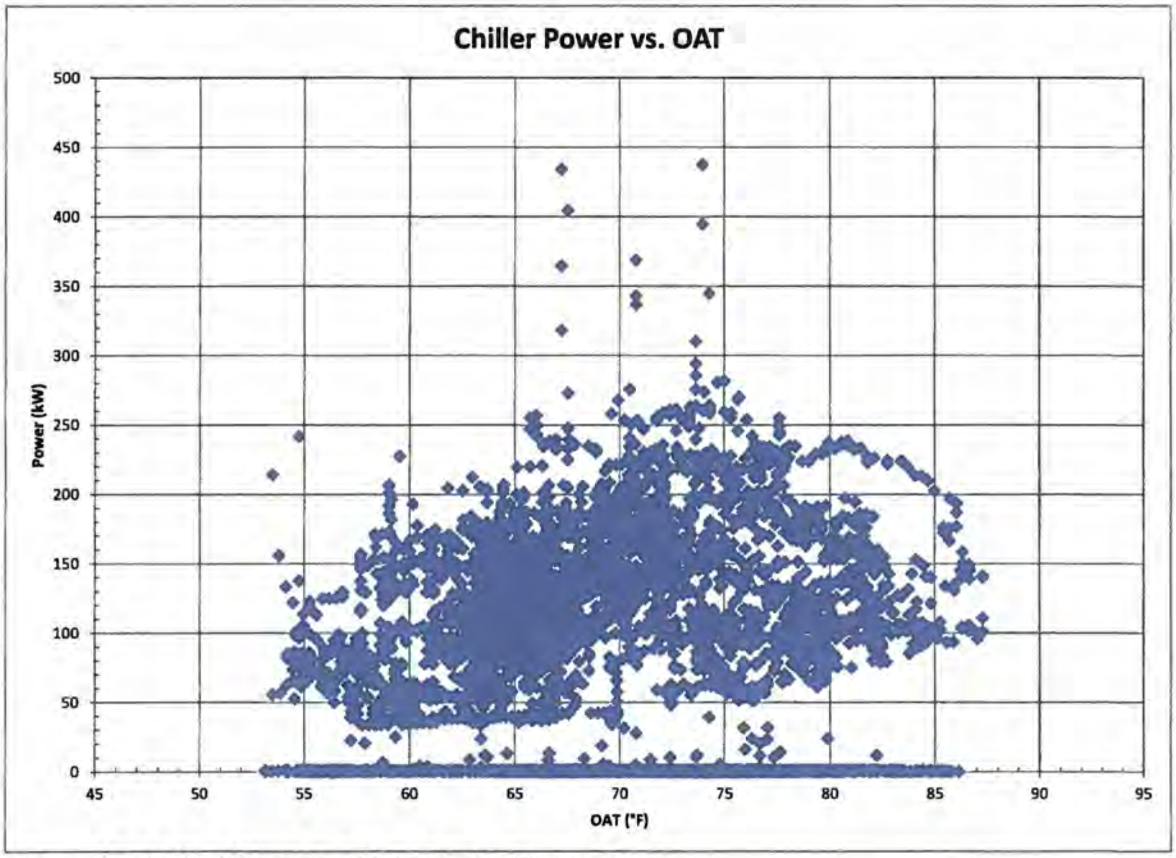

Figure 4. Chiller Power vs. Outside Air Temperature

Information obtained during the site visit indicated that the chiller is activated when the OAT rises above 60°F, and deactivated when the OAT falls below 60°F. However, the above chart shows that the chiller was operating at OA temperatures as low as 53°F during the monitoring period. Furthermore, note in the two charts above that there are many data points when the power is zero at OA temperatures as high as 86°F, these corresponding to the times in the chart above when the chiller is off overnight. (This fact will be addressed again later.)

Even after eliminating the zero-power points, there is not a good correlation of 5-minute power data with OAT. However, on a daily average basis, a more reasonable correlation can be obtained. This is displayed in the next chart, which plots total daily chiller energy as a function of average daily temperature, separated by weekdays and weekend days.

For weekdays, the curve-fit formula estimates that chiller energy is greater than zero when the average daily OAT is greater than about 56°F. This correlates well with the minimum OAT of 53°F observed in the monitored data. For weekends this lower bound is about 64°F.

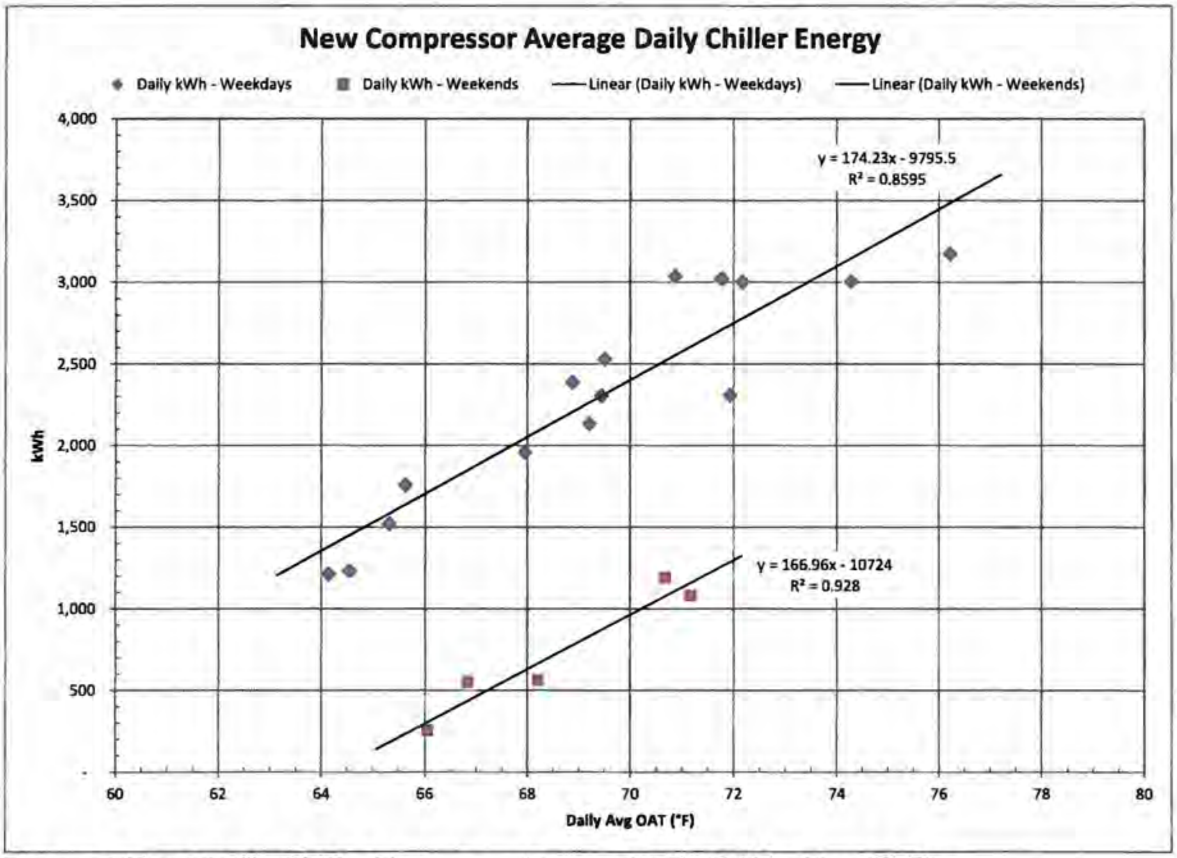

Figure 5. Total Daily Chiller Energy vs. Average Daily OAT – New Chiller

To estimate what the original chiller energy would have been under the same operating circumstances as the new chiller experienced during the monitoring period, and to estimate the annual energy savings achieved by replacing the chiller, chiller efficiency data provided with the application was used. The following data for the old chiller was provided:

Table 1. Old Chiller Efficiency Data

% Load*	Entering Condenser Water Temp (°F)*	Efficiency (kW/Ton)
1.00	85	0.792
0.75	75	0.676
0.50	65	0.624
0.25	65	0.805

* These are standard rating points for listing a chiller's efficiency and power requirements.

From the above, a power vs. load profile was developed in the application; this profile is presented in the following table, along with data for the new chiller that was also provided in the application.

Table 2. Comparing Old & New Chillers – Power Profiles

Old Chiller		New Chiller	
Load (tons)	Est. Power (kW)*	Load (tons)	Est. Power (kW)
500	345	250	79.9
596	419.7**	500	136.1
715	531	750	289.7
834	678	1000	537.7
953	837		

* The application developed these power values for the old chiller assuming a 10% decrease in chiller efficiency from the factory values, due to the chiller's age and condition.

** This value is the average of two values that were given in the application documents.

The above data is plotted in the following chart.

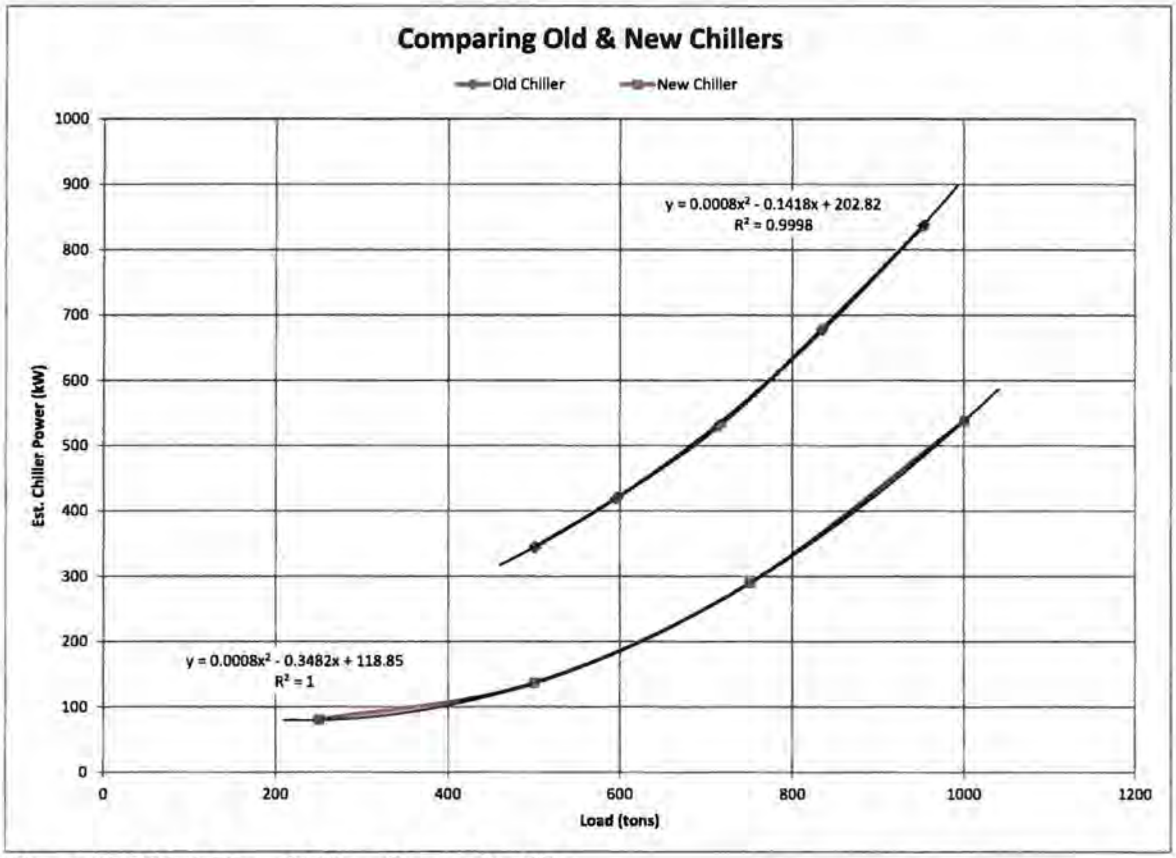

Figure 6. Old & New Chillers Power Profiles

By using the above correlations, the new chiller's measured power input can be converted to cooling load in tons. Then, the load can be converted back to an estimated power input for the old chiller.

NOTE: Implicit in this process of using factory efficiency data is the assumption that higher loads and power requirements correspond with higher Entering Condenser Water Temperatures (ECWT). Since attempting to correlate monitored power readings with ECWT from the facility's EMS is inconclusive, using the factory data is the more reasonable approach for this analysis.

The conversion described above was done on a per-time-interval basis. The results for the estimated old chiller power input show as much scatter on a per-interval basis as the original new chiller data did, and these results are not presented here. However, the daily average results again show a reasonable correlation, and are shown in the chart below.

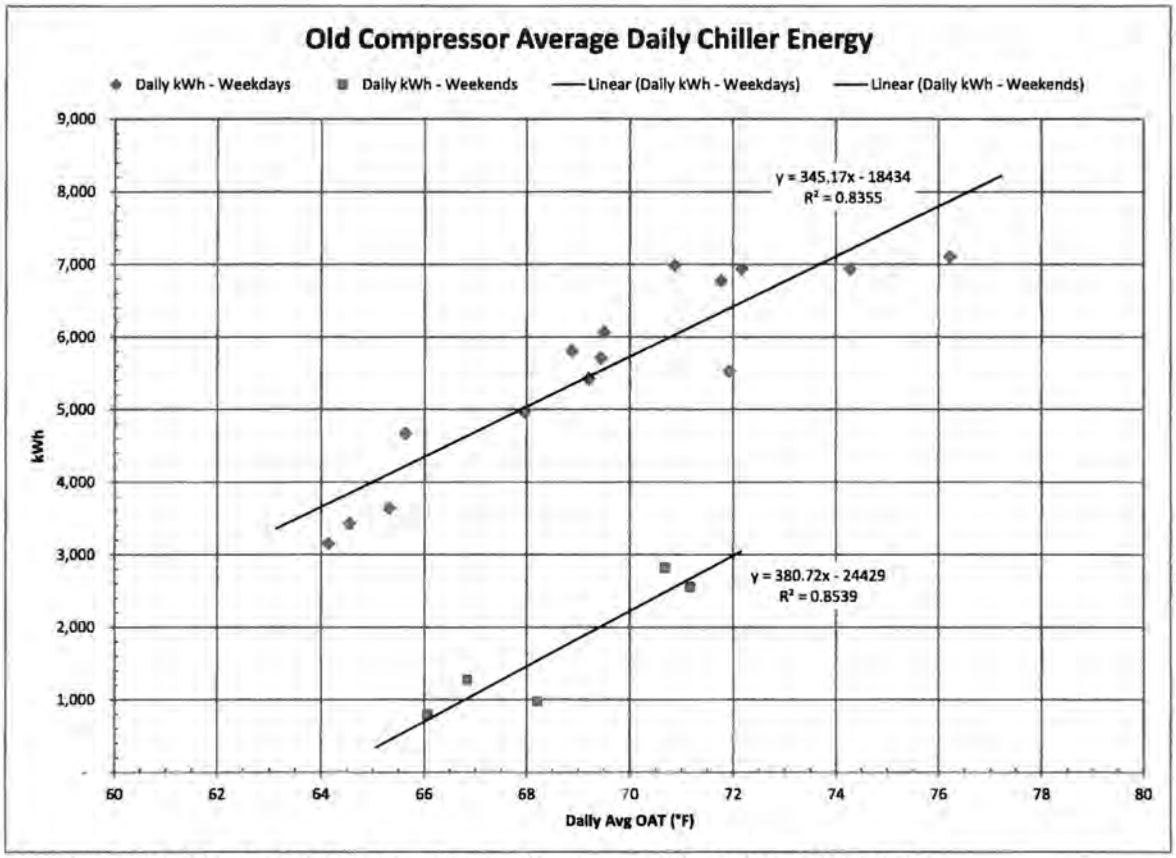

Figure 7. Total Daily Chiller Energy vs. Average Daily OAT – Old Chiller

To estimate annual energy usage for both the old and new chillers, the daily average OAT for each day of the year was determined from TMY3 weather data for Cincinnati. Then, applying the curve-fit formulas for both the old and the new chiller's daily average energy usage gives the calculated daily energy values shown in the next chart. (The old chiller is assumed to operate only down to the same cut-off temperatures as the new chiller's curve-fit allows; i.e., 56°F on weekdays and 64°F on weekends.)

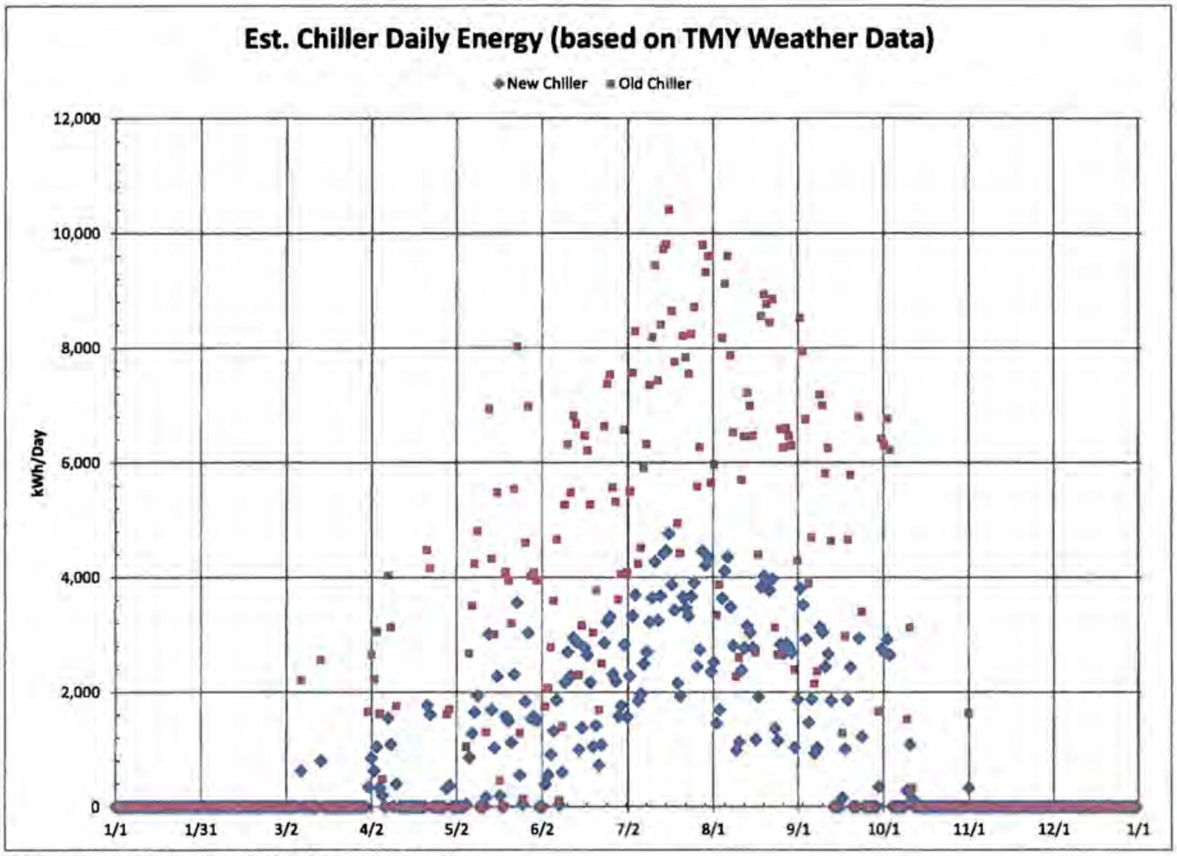

Figure 8. Estimated Chiller Daily Energy

Totaling all the daily values for both the old and new chillers give the annual energy usage presented in the following table.

Table 3. Summary of Estimated Annual Energy Usage

	Weekdays	Weekends	Total kWh
Old Chiller	692,396	103,336	795,732
New Chiller	289,148	44,955	334,103
Savings			**461,629**
Duke Estimated Savings			580,966
Energy Realization Rate			**79%**

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; therefore, the available monitored data was used to generate a correlation of the peak power expended during the 4-5 PM time period on each weekday with the peak temperature on the same day. The monitored data was supplemented with NOAA weather data for the days prior to the availability of trended weather data from the facility. This correlation is presented in the following chart:

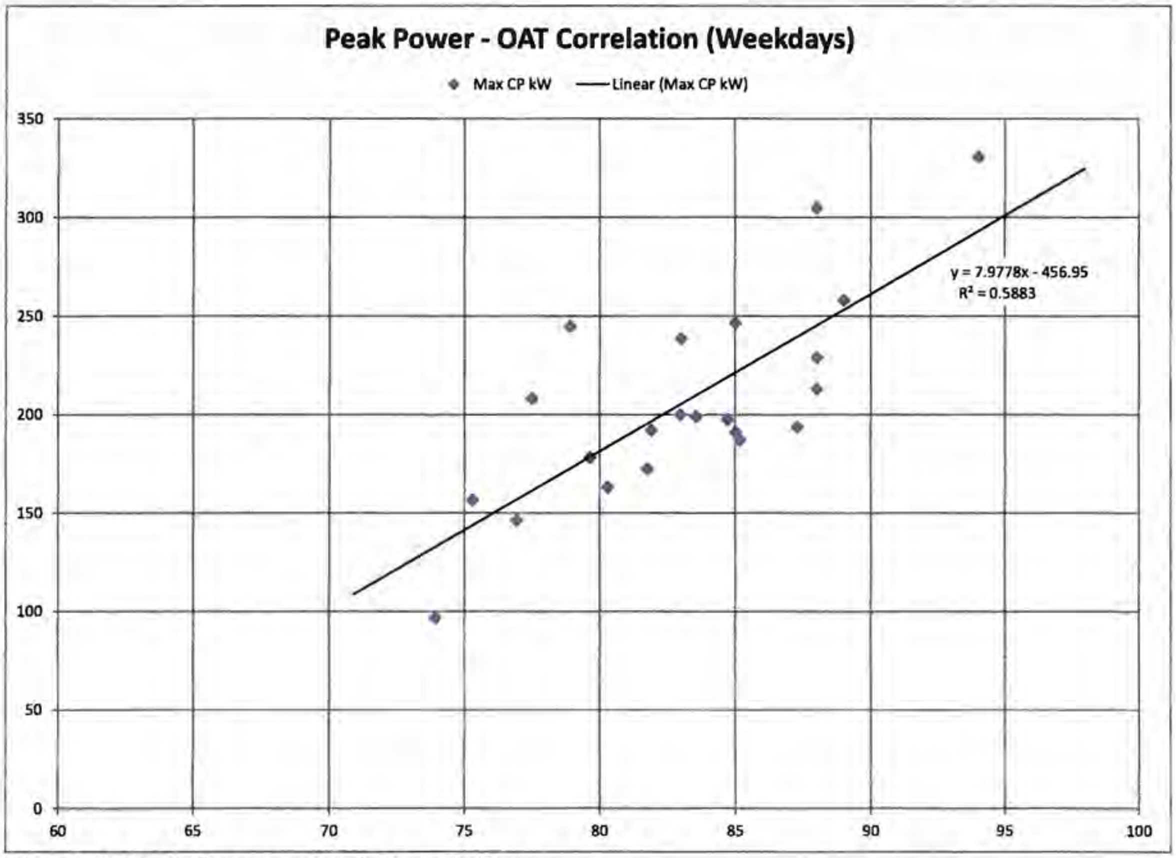

Figure 9. Peak Power - OAT Correlation

Next, TMY3 weather data was reviewed to determine the maximum outside air temperature during the month of July (the peak temperature in the TMY data will not necessarily align with the July 17 date determined by Duke). This maximum OAT turns out to be 97°F. Finally, the curve-fit equation presented in Figure 9 above was used to predict the coincident peak power demand for the project, which is 316.7 kW.

The following table presents the demand savings and realization rate for the [Redacted] Custom Incentive Program project.

Table 4. Summary of Estimated Peak Electrical Demand

	Max Coincident Peak Power	Overall Max Power
New Chiller Power (kW)	316.7	437.4
Load (tons)	796.2	920.4
Equiv. Old Chiller Power (kW)	627.7	790.8
Savings	311.0	**353.4**
Duke Projected Savings	193.4	224.5
Demand Realization Rate	**161%**	**157%**

Regarding the energy realization rate, which is lower than expected, this result is at least partially explained by decreased operating hours compared to what was originally estimated in the application. The application estimated the chiller would operate 3,612 hours per year. This turns out to be all of the hours for which the OAT is greater than about 60°F in Cincinnati. However, the change in operating schedule that is evident in Figure 1 reduces those operating hours. For the data recorded since the schedule change, the chiller is on only about 63% of the time. While turning the chiller off does save more energy, comparing the old and new chillers on equal operating schedules is the fairest way to estimate annual energy savings going forward.

The low energy realization rate is balanced by the demand realization rate, which is higher than expected.

[Redacted]
Custom EMS Retrofit
M&V Report

Prepared for
Duke Energy Ohio

March 2015, Version 1.0

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

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

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

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NORESCO
United Technologies

Introduction

This plan addresses M&V activities for the [Redacted] custom program application. The application covers the retrofit of individual rooftop controls, VAV controls and the central controller and Building Automation System (BAS) at the [Redacted] in Cincinnati, Ohio. The installation was started in December 2012 and was completed in April 2013, so the M&V activities were for post-retrofit only. The measure includes:

ECM-1 – HVAC RTU Controls Retrofit

A controls retrofit was implemented to enable individual rooftop unit (RTU) control, allowing for the modification of the equipment operation schedule around actual hours of building operation and optimal start times, with the goal of reducing weekend and night-time occupied operating hours. Previously, the RTUs ran 100% of the time. The control retrofit was to allow for coordination of HVAC operations/modes, global setpoints and change-over schedules. [Redacted] was also implementing night and weekend space temperature set-backs.

The application savings estimates for this measure were based on 30 RTUs and a supply fan runtime reduction of 50 percent. One of the RTUs serves a zone that has extended operating hours and was exempted from the schedule reduction.

Goals and Objectives

Post-retrofit data trends of the controlled equipment's energy use were compared with pre-retrofit controls behavior (as determined by site operator interviews) to determine the energy and power reduction achieved by the control system upgrade.

The projected savings goals identified in the application are:

	APPLICATION		DUKE PROJECTIONS	
Facility	**Proposed Annual kWh savings**	**Proposed Summer Peak kW savings**	**Proposed Annual kWh savings**	**Proposed Summer Peak kW savings**
[Redacted]	705,103	0	694,307	0

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

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

Project Contacts

AEC Contact	Doug Dougherty	ddougherty@archenergy.com Office: 303-459-7409
Duke Energy M&V Admin.	Frankie Diersing	513-287-4096
Customer Contact	[Redacted]	[Redacted]

Site Locations/ECM's

Site	Address	Sq. Footage	ECMs Implemented
[Redacted]	[Redacted]	212,000	1

Data Products and Project Output

- Average pre- and post-retrofit load shapes by day-type for controlled equipment
- Energy consumption pre- and post-retrofit for controlled equipment
- Utility bill (kWh and kW) information from 2011 to present
- Annual Energy Savings
- Peak demand savings
- Coincident peak demand savings.

M&V Option

IPMVP Option D

M&V Implementation Schedule

Data collection was for post-retrofit only.

- Conducted an interview with the building contact.
- Obtained utility bill (kWh and kW) information from 2011 to present.
- Identified all HVAC equipment currently on the new control system (subject to the rebate application).
- Verified that equipment on the new control system is operational.
- Obtained pre-retrofit and post-retrofit sequences of operation for all controlled equipment.

- Deployed data loggers to monitor operation of AHU supply fans and outdoor air conditions.
- Deployed loggers for three weeks.
- Evaluated the energy impacts of the building control system retrofit using eQUEST model.

Data Accuracy

Measurement	Sensor	Accuracy	Notes
Current – RTU Fans	Magnelab CT	±1%	Recorded load must be >10% of CT rating
Current - Lighting	Onset CTV	±4.5%	
Temperature	Onset Temp/RH	±0.36°F	

Field Data Points

Survey data

- Pre-retrofit and post-retrofit sequences of operation for all controlled equipment.
- Utility bill (kWh and kW) information from 2011 to present.

Spot-Measurements

- Eleven of the 30 RTUs were spot-measured for volts, amps, watts and power factor. The sample included RTUs 1, 3, 5, 9, 10, 12, 17, 25, 26, 28 and 30.

Time series data on controlled equipment

Deployed data loggers as noted to monitor the points defined below.

General points:

- Outdoor air temperature and relative humidity

Eleven RTUs were intended to be monitored; however, only four data loggers returned useful data. For each of the sampled RTUs, the following points were logged:

- Unit kW. Configured the Elite Pro logger to record the following information:
  - Average Voltage
  - Average Current

- Average Power factor
- Average KVA
- Average KVAR
- Average Power

- Set up loggers for 5-minute readings and allowed operation for three weeks.
- Collected data during normal operating hours.

Logger Table

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

Function	Hobo Weather Station	ElitePro Loggers	Current Transducers (for ElitePro)
RTUs (11 out of 30)		11	33 (50A)
OAT/RH	1		
Total	1	11	33

Data Analysis

Used the data collected in the operator interview to verify equipment specifications, schedules, setpoints and sequence of operation data for the pre-retrofit (baseline) eQUEST energy model. Confirmed that pre-retrofit HVAC is properly represented in the baseline model.

Confirmed that the as-received eQUEST baseline energy model was calibrated to utility data for the period before the modifications were installed.

Compared logged data on schedules and setpoints to the post-retrofit eQUEST model and updated the model with as-built and as-controlled conditions. Confirmed that the post-retrofit building HVAC is properly represented in the post-retrofit model.

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. If they are not consistent, record discrepancies.

Recording and Data Exchange Format

1. Hobo logger binary files
2. ElitePro logger binary files
3. Excel spreadsheets
4. eQUEST model files

Results

The goal of this ECM was to reduce weekend and night-time occupied operating hours. A controls retrofit was implemented to enable this operating time reduction. Previously, the RTU fans ran 100% of the time, although the RTU compressors would cycle off normally nights and weekends when loads are reduced.

The intended new operating schedule was as follows:

Weekdays:	Occupied schedule	= 6 a.m. to 6 p.m., M-Fri.
	Unoccupied schedule	= 6 p.m. to 6 a.m., M - Fri.
Weekends:	Occupied schedule	= 6 a.m. to 12 noon, Saturday;
	Unoccupied schedule	= 12 noon to 6 a.m., Saturday
	Unoccupied Schedule	= 12 a.m. to 12 a.m., Sunday (no occupancy).

Proposed schedules also include unoccupied temperature set points of 65°F for heating and 75°F for cooling.

RTU13 was also removed from analysis for temperature setbacks due to the fact that this space operates two shifts, six days per week.

Due to high internal loads, the proposed unoccupied cooling is done by economizer up to 65°F outside air dry-bulb temperature.

An "eQUEST" building simulation model was previously prepared as part of the application process. The above improvements were incorporated into parametric runs, which could be compared to the baseline energy performance of the building. The differences in total electric energy usage and demand between the two models are the savings that are expected to be achieved.

Note: the previously-prepared baseline eQUEST model had already been calibrated to utility data. For the 12-month period ending with the December 2012 billing, when the controls retrofit began, the total electrical usage was 6,118,127 kWh. The baseline model predicted total annual electrical usage of 5,840,165 kWh. This compares well – within 95% - to the actual utility billing value. A chart of the ratio of the electricity usage by month, as calculated by the model, to the monthly utility billing for 2012 is shown in the figure below.

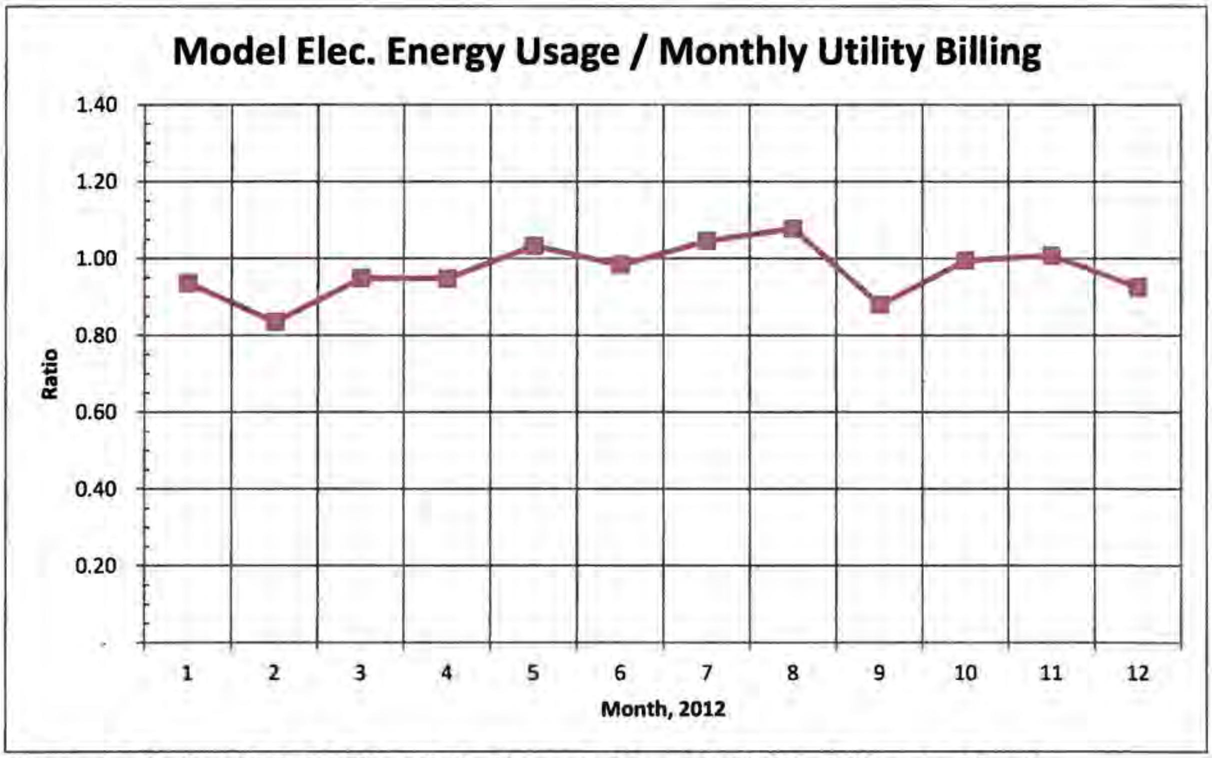

Figure 1: Ratio of Model Electricity Usage to Monthly Utility Billing by Month.

M&V Findings

RTU fans

As part of the M&V effort, data loggers were installed on a sample of the RTUs to record electrical energy usage and demand for three weeks. Four of the loggers provided useful data. The results are shown in Figures 1 through 4 below.

Although the intent of the ECM was to shut off the RTU fans during unoccupied hours, the data shows that this goal was not achieved. The fans still run continuously. This situation was confirmed by field personnel, who report that only two RTUs (12 and 15) are not operating continuously.

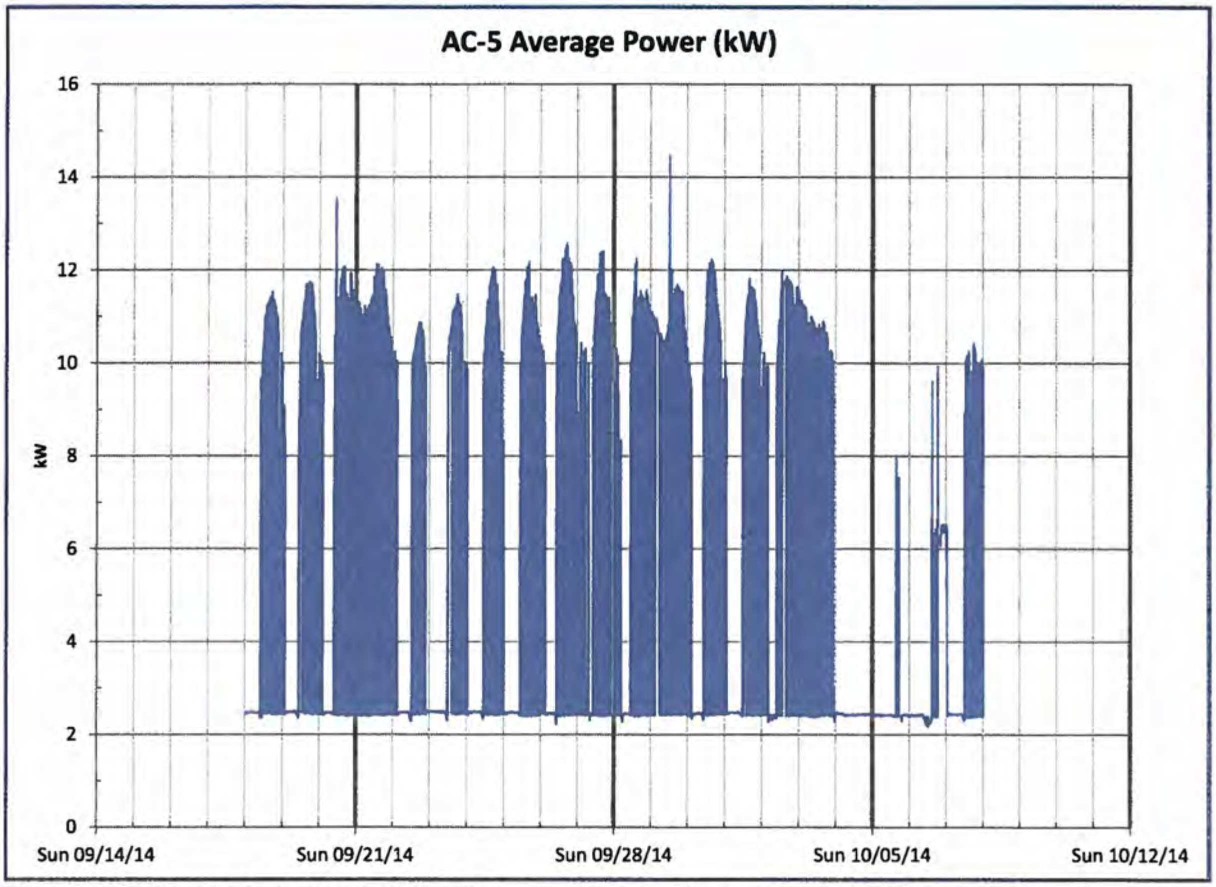

Figure 2 – Power Data for AC-5; minimum observed power = 2.4 kW.

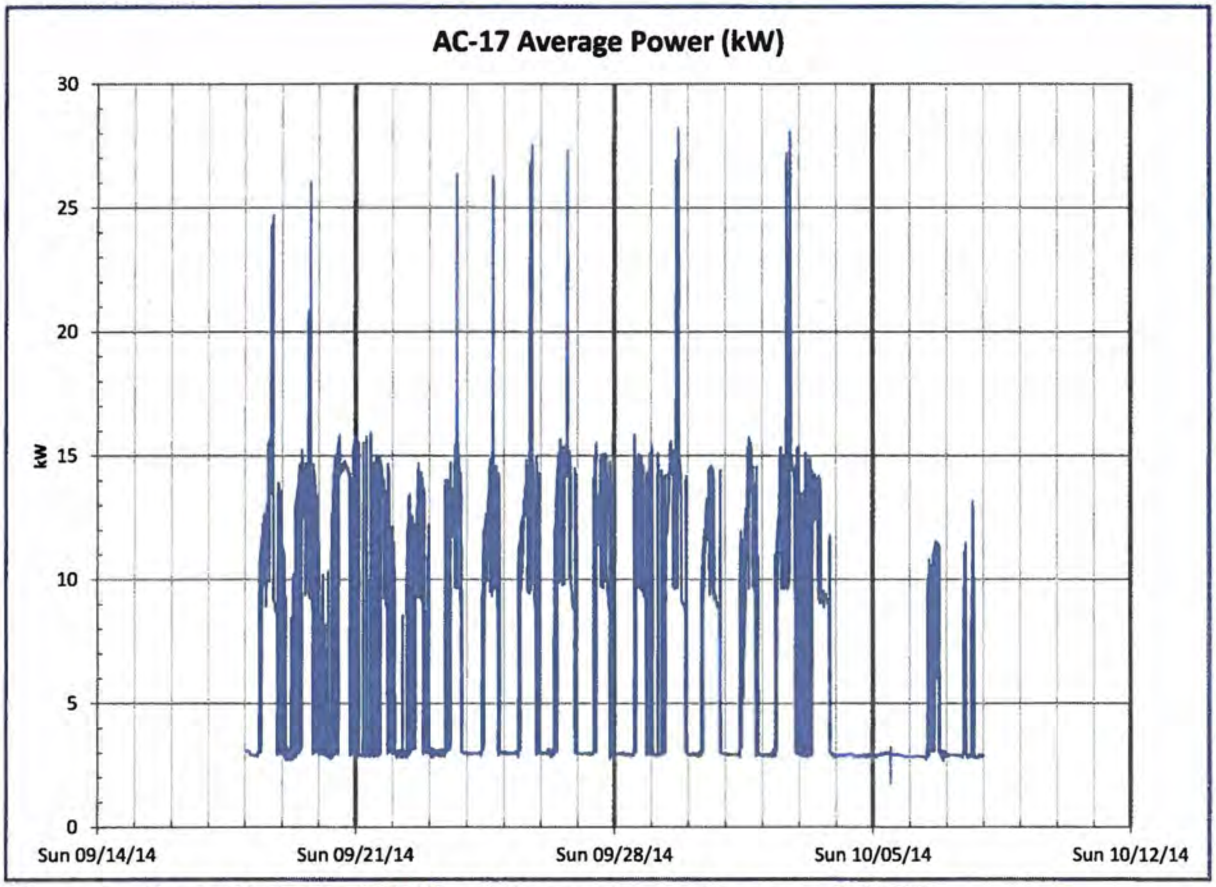

Figure 3 – Power Data for AC-17; minimum observed power = 2.8 kW.

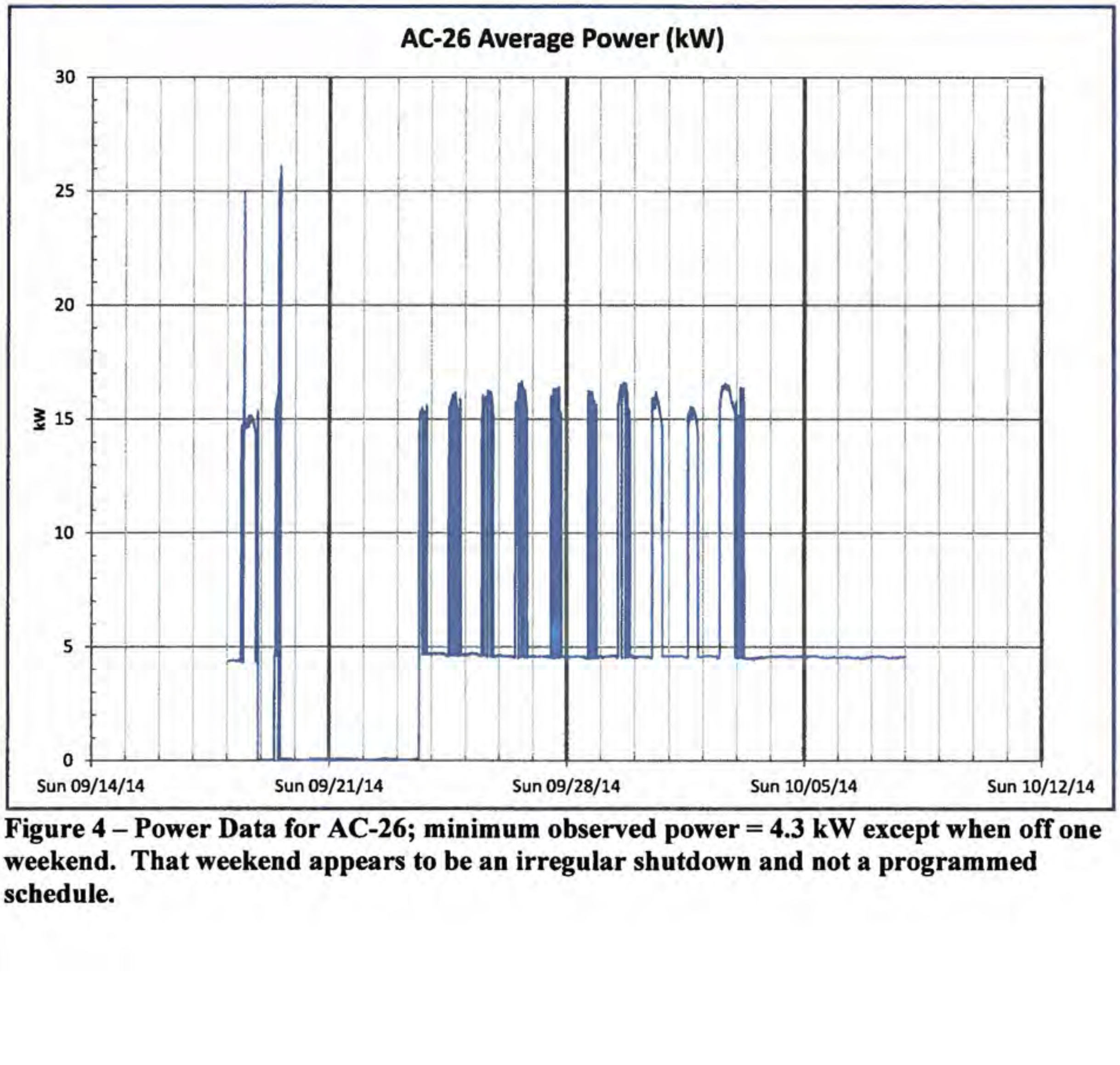

Figure 4 – Power Data for AC-26; minimum observed power = 4.3 kW except when off one weekend. That weekend appears to be an irregular shutdown and not a programmed schedule.

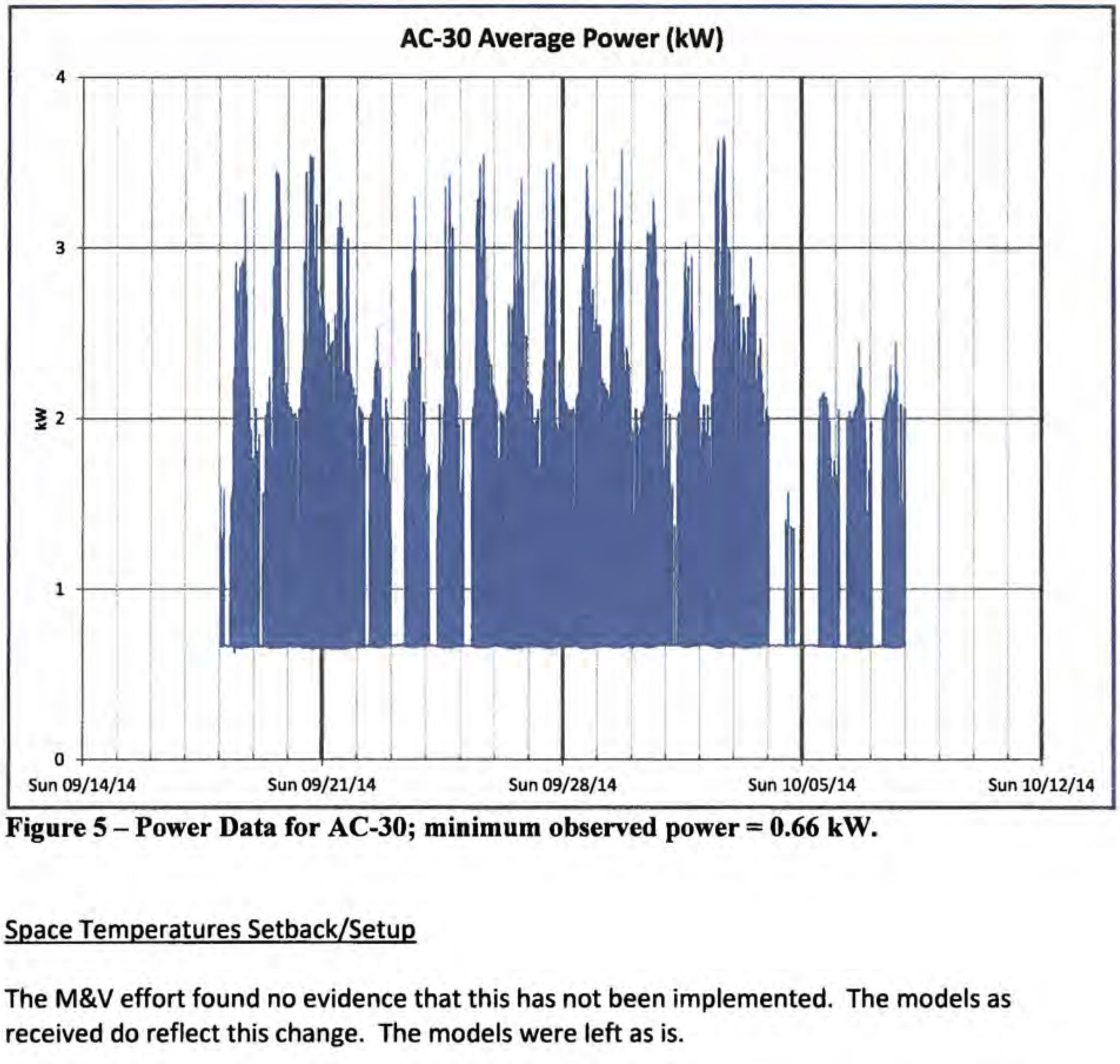

Figure 5 – Power Data for AC-30; minimum observed power = 0.66 kW.

Space Temperatures Setback/Setup

The M&V effort found no evidence that this has not been implemented. The models as received do reflect this change. The models were left as is.

Economizer Unoccupied Cooling

The models as received do reflect this change. The outside air dampers are allowed to close at night (down to 1% of maximum OA flow), but are allowed to open if a cooling load is present and the outside air temperature is cool enough to satisfy it. The M&V effort found no evidence that this has not been implemented, so the models were left as is.

Results

Since the monitored data shows, and field personnel confirmed, that the RTU fans do not go off at night, the unoccupied scheduling was removed from the post-retrofit model. This part of the ECM turns out to be responsible for the majority of the anticipated savings. The revised savings below are adjusted to allow for RTU 12 and RTU 15 having unoccupied scheduling implemented. These two units represent about 7-1/2% of the capacity of the 29 RTUs affected by the schedule change.

The ECM eQUEST model result, showing predicted total annual electrical usage of 5,767,607 kWh, compares well – within 97% - to the actual total utility billing value of 5,898,456 kWh for the 12-month billing period June 2013 – May 2014.

Table 1 - Annual Energy and Demand Savings - [Redacted].

Facility: [Redacted]			
	Annual Energy (kWh)	Non-Coincident Peak Demand (kW)	Coincident Summer Peak Demand (kW)
Application			
Pre-Retrofit	5,840,165	0	0
Post-Retrofit	5,135,062	0	0
Savings	705,103	0	0
M&V			
Pre-Retrofit	5,840,165	1,152	1,076
Post-Retrofit	5,767,607	1,168	1,089
Savings	72,558	-16	-14
Duke Projections	694,307	0	0
Realization Rates	10%	N/A	N/A

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[Redacted]

- Lighting Retrofit -

M&V Report

PREPARED FOR:
Duke Energy
Ohio

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

PREPARED IN:
December 2012
V1.2

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

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

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

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Introduction

This report addresses M&V activities for the [Redacted] custom program application. The application covers a lighting retrofit at one location in Batavia, Ohio. This M&V Report is for hybrid pre- post-retrofit monitoring, since the lighting has not been completely replaced, and will be replaced as the existing lighting fails. The measures include:

ECM-1 – High bay fixture retrofit with motion sensors

- This project involves the removal of 48 existing 1000W metal halide fixtures (actual input wattage 1086W), to be replaced by 48 new 830W metal halide fixtures (actual input wattage 910W). This will result in an overall power reduction of 8,448W.

Goals and Objectives

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

The projected savings goals identified in the application are:

Facility	Proposed Annual kWh savings	Proposed Summer Peak kW savings	Duke Estimated Annual kWh savings	Duke Estimated Summer Peak kW savings
[Redacted]	35,363	8	35,021	8.45
Total	**35,363**	**8**	35,021	8.45

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

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

Project Contacts

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

Site Locations/ECM's

Site	Address	Sq. Footage	ECM's Implemented

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[Redacted]	[Redacted]	228,800	# 1

DATA PRODUCTS AND PROJECT OUTPUT

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

M&V OPTION

IPMVP Option A

M&V IMPLEMENTATION SCHEDULE

- Conducted the lighting survey after the customer performed at least 50 percent of the lighting retrofit.
    - Deployed loggers to determine lighting schedule.
    - Spot measured the lighting load connected to the circuit by measuring the kW load and current draw of the circuit.
- Since the customer is currently performing the lighting retrofit, pre- and post-retrofit operating hours were determined from the total post-retrofit hours of operation. Pre-retrofit fixture information was taken from the application and from pre-retrofit fixtures still in place. The field survey verified that the pre-retrofit fixture specifications and quantities removed from the project matched the application.
- Collected data during normal operating hours (avoid holidays or atypical operating hours).

DATA ACCURACY

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

FIELD DATA POINTS

Post-Installation

Survey data

- Determined fixture count and wattage

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

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

- Lighting circuit power when lights are on

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

- Typical lighting load shape
    - Deploy current measurement CT loggers to measure current at the panelboard.
    - NOTE: If monitoring current at the panelboard, the quantity of pre and post retrofit fixtures on each monitored circuit MUST be recorded.
    - Sampling was not required since all fixtures were able to be monitored at the circuit panel.
    - Set up loggers for 5 minute instantaneous readings and allow loggers to operate for a minimum period of three weeks.
- Spot measure the lighting load connected to the circuit by measuring the kW load and current draw of the circuit during both the pre-retrofit and post-retrofit survey. The lighting load circuit in nearly all cases had both pre and post-retrofit fixtures installed since the retrofit had not yet been completed. Since access to the fixtures was impractical, manufacturer's product sheets for the new and existing fixtures were used for lighting connected load.
- NOTE: When performing spot measurements on monitored circuits, since these circuits were a mix of pre and post-retrofit fixtures, the quantity of pre- and post-retrofit fixtures on each circuit was recorded.

Logger Table

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

ECM	Hobo U-12	20A CT
1	3	9
Total	**3**	**9**

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DATA ANALYSIS

- **ECM-1**

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

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

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

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

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

$$\frac{kWh}{year_{Savings}} = \frac{kWh}{year_{Pre}} - \frac{kWh}{year_{Post}}$$

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

VERIFICATION AND QUALITY CONTROL

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

RECORDING AND DATA EXCHANGE FORMAT

1. Pre-installation Lighting Survey Form and Notes.
2. Post-installation Lighting Survey Form and Notes.

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3. Hobo/Elite Pro logger binary files
4. Excel spreadsheets

FIELD STAFF

☐ Verifiable Results
☐ AEC
■ **Other**

Contracting type

■ **T&M**
☐ Per logger

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RESULTS SUMMARY

The following results account for benefits of the lighting replacement at [Redacted].

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

TABLE 1. ESTIMATED ANNUAL ENERGY SAVINGS

[Redacted] Results	
Lighting Savings (kWh/year)	30230
HVAC Savings (kWh/year)	0
Total Actual Savings (kWh/year)	30230
Claimed Savings (kWh/year)	35021
Realization Rate (kWh/Year)	**86%**
Actual Savings (Coincident Peak kW)	8.4
Actual Savings (Non-Coincident Peak kW)	8.4
Claimed Savings (Coincident Peak kW)	8.45
Realization Rate (Coincident Peak kW)	**99%**
Realization Rate (Non-Coincident Peak kW)	**99%**

The lighting was initially estimated to run 4186 hours/year with motion control on all of the fixtures. Actual run hours were determined to be 3578 hours/year. The decreased kWh/year realization rate could possibly be explained by the decrease in actual run hours (both pre and post) from the original estimation.

Graphs of actual logger data are shown in Figures 1-2.

FIGURE 1.

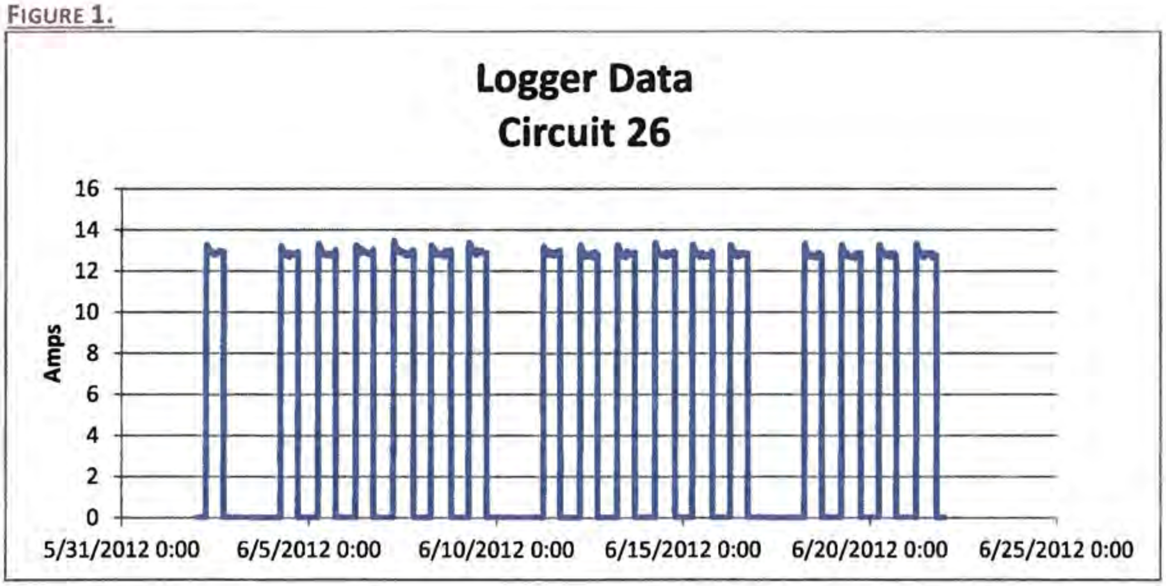

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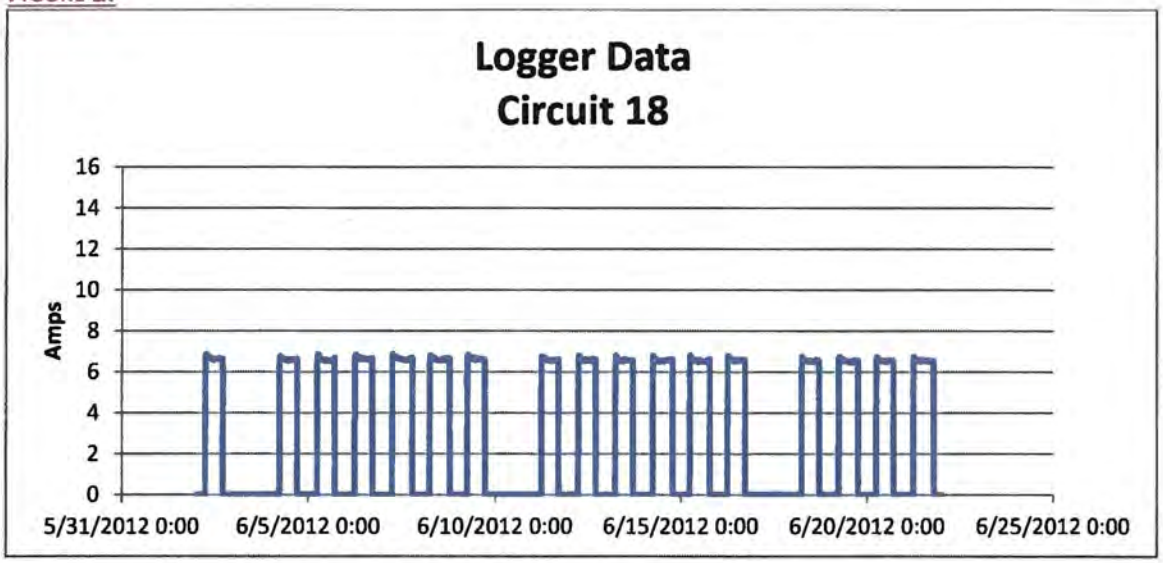
FIGURE 2.



[Redacted]
Air Compressor Replacement
M&V Report

Prepared for
Duke Energy Ohio

December 2013

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:

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ARCHITECTURAL ENERGY CORPORATION

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Introduction

This plan addresses M&V activities and results for [redacted] custom program application. The application covers an air compressor replacement in Florence, Kentucky. The measure includes the following:

ECM-1: Replace Air Compressor

- Replace a 25 HP compressor with modulation controls with a new 25 HP compressor with load/no-load controls.
- Both the old and the new air compressors have an integral refrigerated air dryer.
- The baseline for the pre-retrofit compressor's energy consumption and electric demand consists of a week's worth of metered compressed air flow (CFM) pressure and power (kW) data, from which the annual energy consumption was estimated. This data was provided with the application documents.

Goals and Objectives

The projected savings goals identified in the application are:

Application Estimated Annual Savings (kWh)	Application Estimated Peak Savings (kW)	Duke Projected Annual Savings (kWh)	Duke Projected Coincident Peak Savings (kW)	Duke Projected Non-Coincident Peak Savings (kW)
33,250	4.4	36,433	4.21	4.14

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

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

Project Contacts

AEC Contact	Doug Dougherty	(w) 303-459-7416 (c) 303-819-8888	ddougherty@archenergy.com
E$ Energy Consultant	Cory Gordon		

Customer Contact	[Redacted]	[Redacted]	
Duke Energy M&V Coordinator	Frankie Diersing	Frankie.Diersing@duke-energy.com	o: 513-287-4096 c: 513-673-0573

Site Locations/ECM's

Address
[Redacted]

Data Products and Project Output

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

M&V Option

IPMVP Option 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 compressed air system.
  - Obtained the pre-retrofit operating pressure.
- 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 compressed air system.
  - Noted any differences between pre- and post-retrofit operations resulting from changes in production or operating schedules.
  - Obtained the post-retrofit operating pressure.
  - Noted any difference between the pre- and post-retrofit operating pressure.

- o Obtained the facility's holiday schedule.
- o Determined whether the facility has periodic or annual shut-downs for maintenance or other reasons.

- Deployed a datalogger to record electrical parameters on the new compressor. This data was used to determine post-retrofit load shapes and energy consumption.
    - o 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%	

Field Data Points

Post – installation

Survey data (for all compressors)

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

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

- Compressor volts, amps, kW and power factor
- Pressure at the same time as measurements noted above.

Time series data on ECM compressor

- Compressor volts, amps, kW and power factor.

Field Data Logging

Post – installation

ECM-1

- Spot measured ECM compressor voltage, amps, power factor and power using a 3-phase power meter.
- Installed one ElitePro power/energy datalogger on the new compressor
- Set up the logger to monitor voltage, amps, power factor and compressor power (kW) on each leg, and to totalize same (on Channel 5).
- Set up logger for 5 minute readings. Deployed for 3 weeks.

Logger Table

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

ECM	ElitePro Energy Logger	100A CT*
Air Compressor with Load/No-Load Controls	1	3

Data Analysis

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

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

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

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

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

2. The above equations were applied to weekday separately to account for slight day-to-day differences and differing numbers of each weekday captured in the monitored data.

3. Determined the maximum power (kW), and the maximum coincident power (kW), in the measured data.

4. CFM data could not be trended, so it was necessary to infer the post-retrofit air flow rate history based upon the time series power measurements, combined with the system pressure, equipment specifications, and generic information on compressor power versus air flow rate for the particular control method in use. This load shape was used in the pre- retrofit calculation to characterize the energy usage of the pre-retrofit compressor and the energy savings from the compressor retrofit.

5. Using power and flow data provided with the application for the pre-retrofit compressor, a power versus air flow rate relationship was derived for the pre-retrofit case. A review of the provided data revealed inconsistencies that had to be resolved before the power - flow relationship could be determined.

6. Using the established post-retrofit CFM load shape and the pre-retrofit power - flow relationship developed in the two previous steps, estimated the annual energy consumption (kWh) of the pre-retrofit compressor.

$$\frac{kWh}{year}_{pre-adjusted} = \sum_i \left[CFM_{i,post} \times \frac{kW}{CFM}_{pre} \times dt \right]$$

7. Determined the annual baseline (pre-retrofit) maximum power (kW) and the maximum coincident power (kW).

8. If necessary, normalize the pre-retrofit energy consumption value for changes in production or year-to-year operation by using the following equation: *(Not required.)*

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

9. If necessary, adjust the pre-retrofit energy consumption value for the change in system pressure by using the following equation: *(Not required.)*

$$\frac{kWh}{year_{pre-adjusted}} = \frac{kWh}{year_{pre}} \times \left[1+0.01 \left(\frac{P_f-P_o}{2}\right)\right]$$

Where: P_o = Initial System Pressure

P_f = Final System Pressure

Note: The Compressed air handbook from the National Resource Canada states: 1% change in kW per 2 psi change in system pressure.

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

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

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

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

12. Estimated the *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:

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

13. 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 compressor power data collected with the ElitePro data logger is shown in the following chart. Data was collected for almost three weeks. The new control method is performing well, allowing the power drawn by the compressor to go from its peak load of about 23.4 kW down to as low as 7 kW (when running but not off). Note that the compressor is turned off for the weekends, and is sometimes off overnight during the workweek but runs at low loads during other overnight periods.

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 next. (Since the data was short one Monday of three full weeks of data, an extra "average" Monday was added to the data to develop this profile and the tables that follow. This technique avoids under-weighting the missing day.)

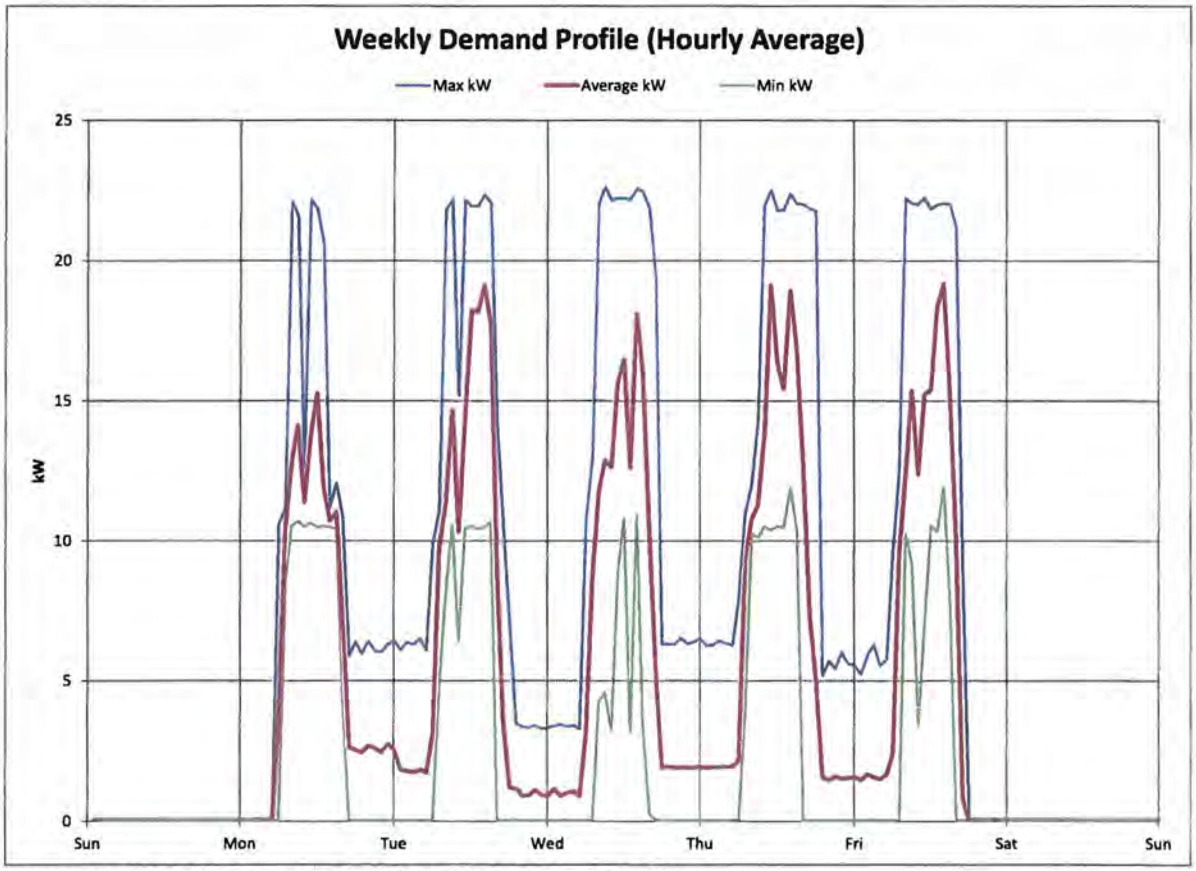

Figure 2: Weekly Compressor Electric Demand Profile

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 40,370 kWh per year.

Table 1: Average Compressor Load by Day-Type

Day of the Week	Compressor Average Electric Load (kW)	Energy (kWh/day)
Sun	0.05	1
Mon	5.97	143
Tues	6.89	165
Weds	6.73	162
Thurs	7.41	178
Fri	6.44	155
Sat	0.05	1
Average week	4.79	**805**

Operating Hours/Year		8,424
Weeks/year		50.143
Annual Total		**40,370**

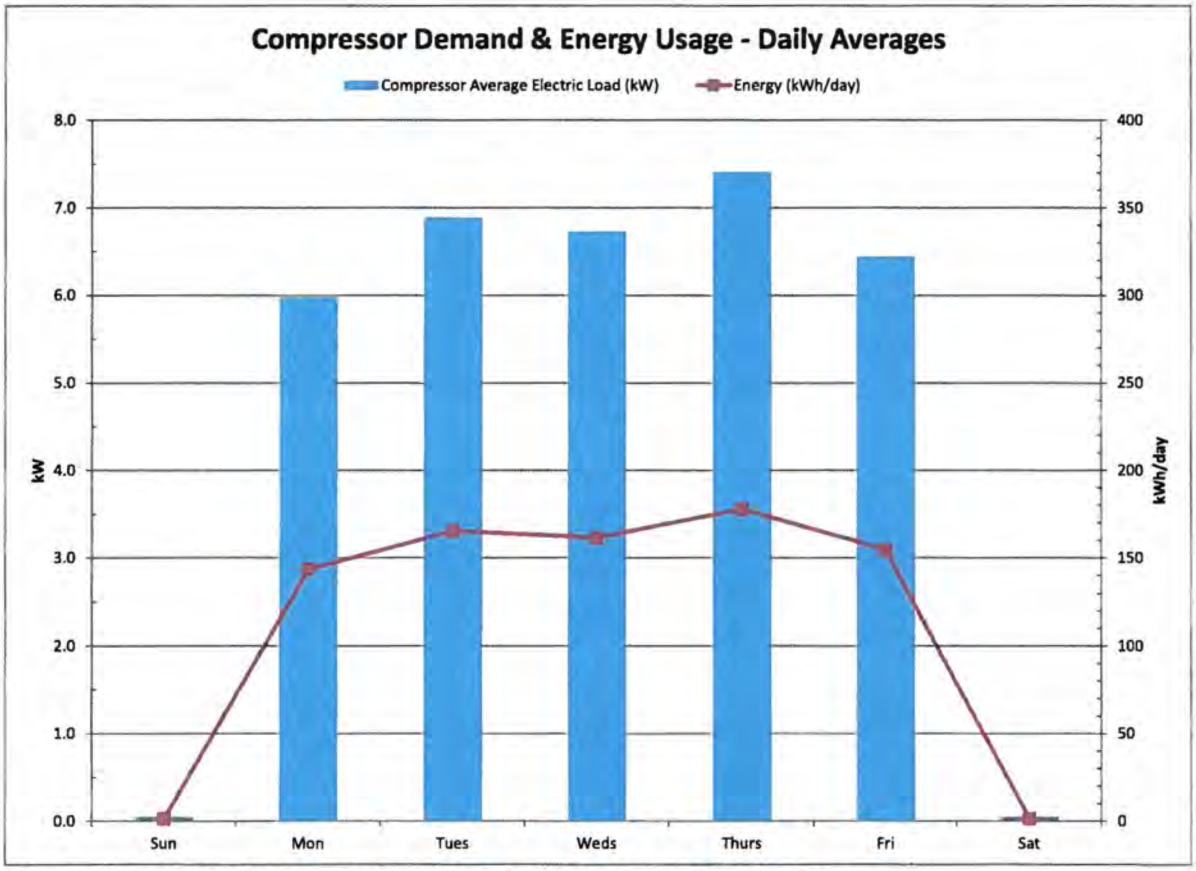

Figure 3: Average Compressor Load and Energy Usage by Day-Type

BASELINE

The application documents included a spreadsheet of one week's worth of compressed air flow (CFM) and power data. This data is plotted in the following chart.

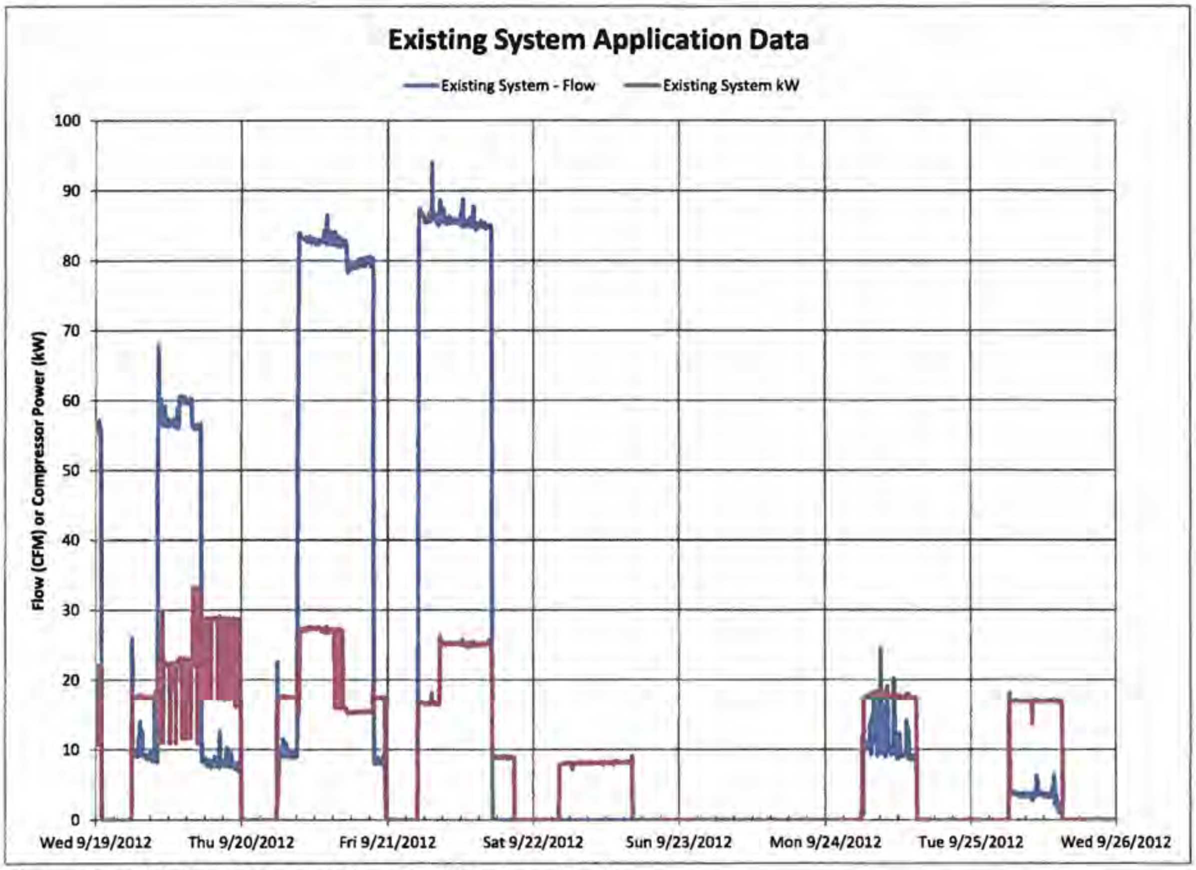

Figure 4: Old Compressor Flow and Demand Data

The power data consisted of values for "Load," "Idle" and "System" (i.e., "total") power in five-minute time steps. In the provided data, total kW was calculated as the sum of Load kW plus Idle kW. It is not clear whether the flow, Load kW and Idle kW values are all measured, or whether either flow or power is measured and the other variable is calculated from the measured one.

This leads to some confusion as seen in the following chart of power values vs. flow. Note that the same flow does not consistently draw about the same power. Note that some total power values reach as high as 33 kW, which exceeds the capacity of the 25-hp compressor.

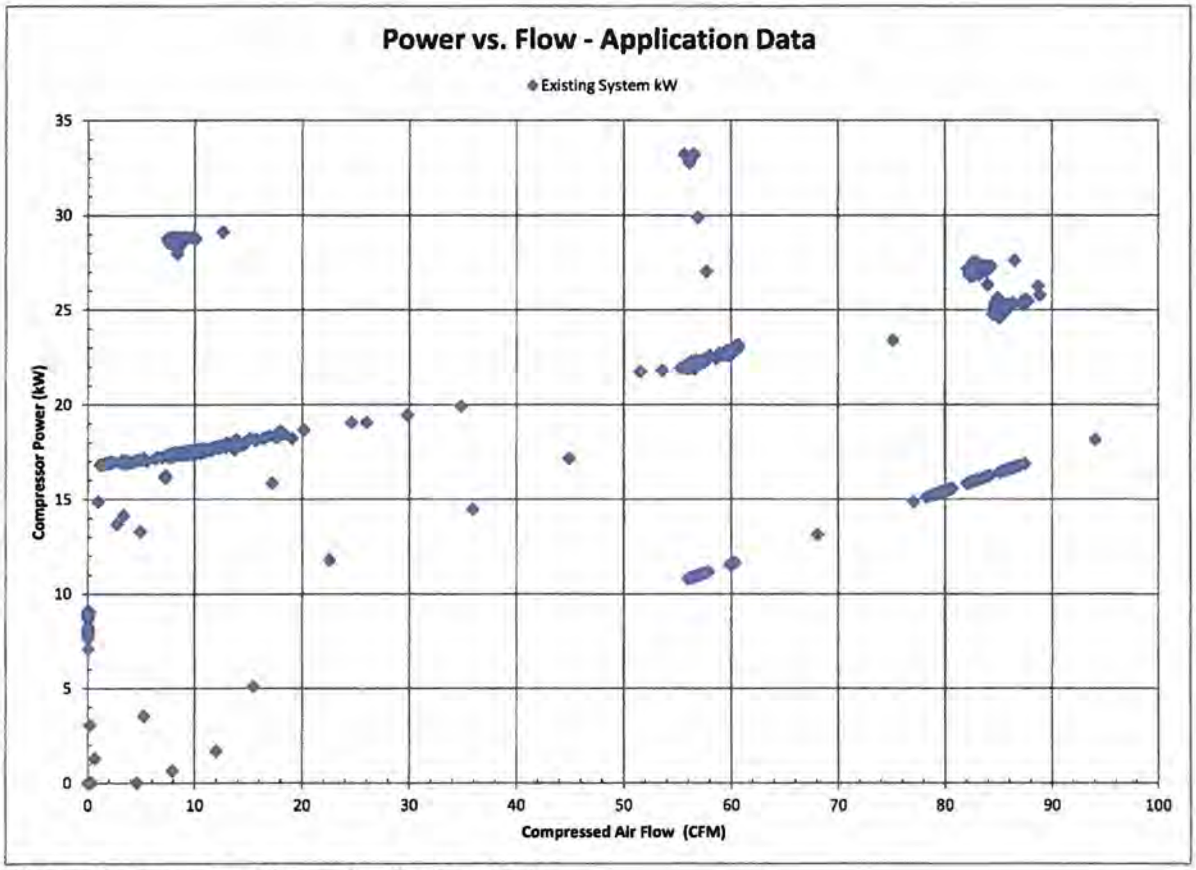

Figure 5: Power vs. Flow - Application Data

The application provided power values for the proposed new compressor as well, and proceeded to use the above data and the new compressor data to provide average power values for the both compressor in a number of power bins, shown here:

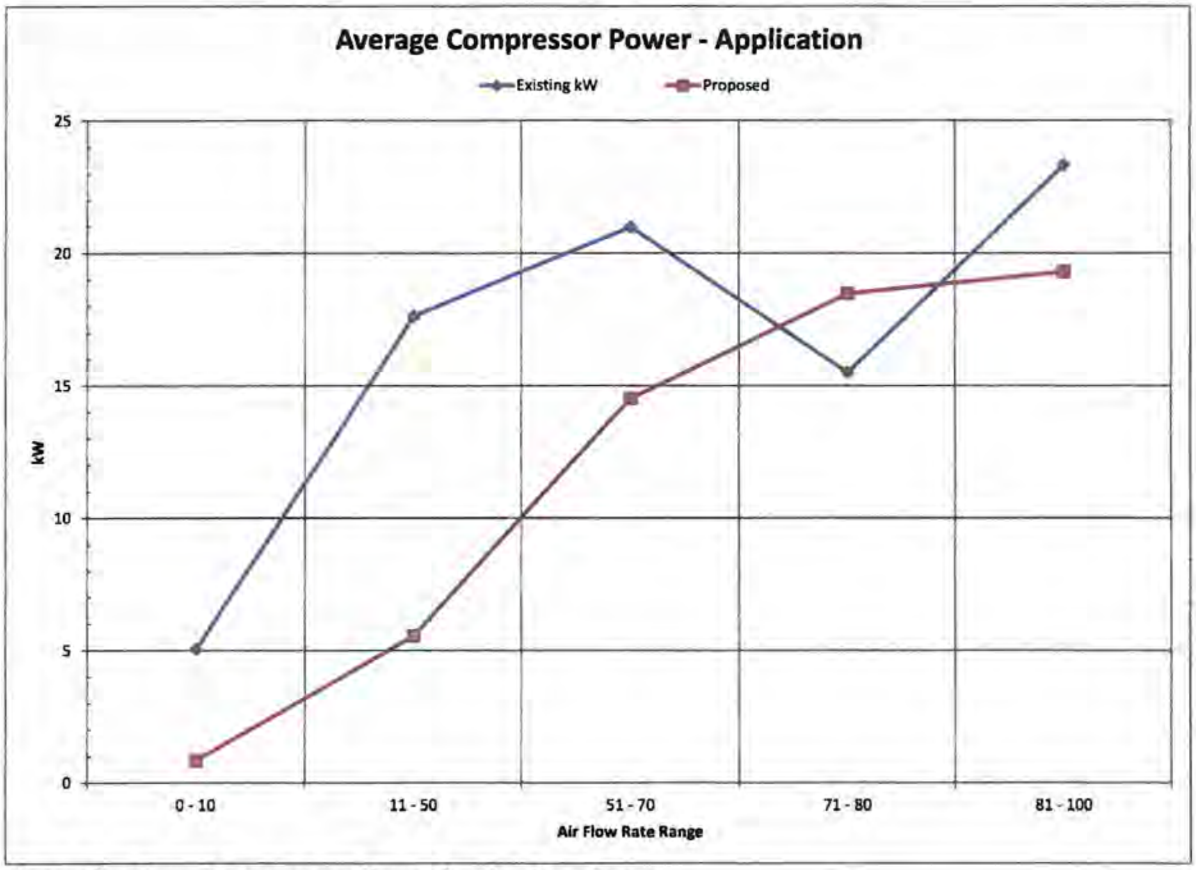

Figure 6: Binned Power vs. Flow - Application Data

Note the inconsistent "dip" in power for the old compressor in the 71-80 CFM bin. This does not appear to be realistic behavior, and is the result of capturing mostly idling power in the data at those flows.

The wide scatter in Figure 5, and the dip in Figure 6, are found to be a result of inconsistent data that is apparent in Figure 4, where it is evident that differing power values were recorded for similar flows. As mentioned earlier, in the provided data, total kW was calculated as the sum of the Load kW plus the Idle kW, and as a result, some total power values are as high as 33 kW, exceeding the maximum input power of the 25-hp compressor. Our conclusion is that some of the system, or total, power data is artificially high and should be removed from the analysis. Correcting the data and plotting only the Load kW and flow vs. time results in Figure 7, which is believed to be a more realistic picture of the compressor's behavior.

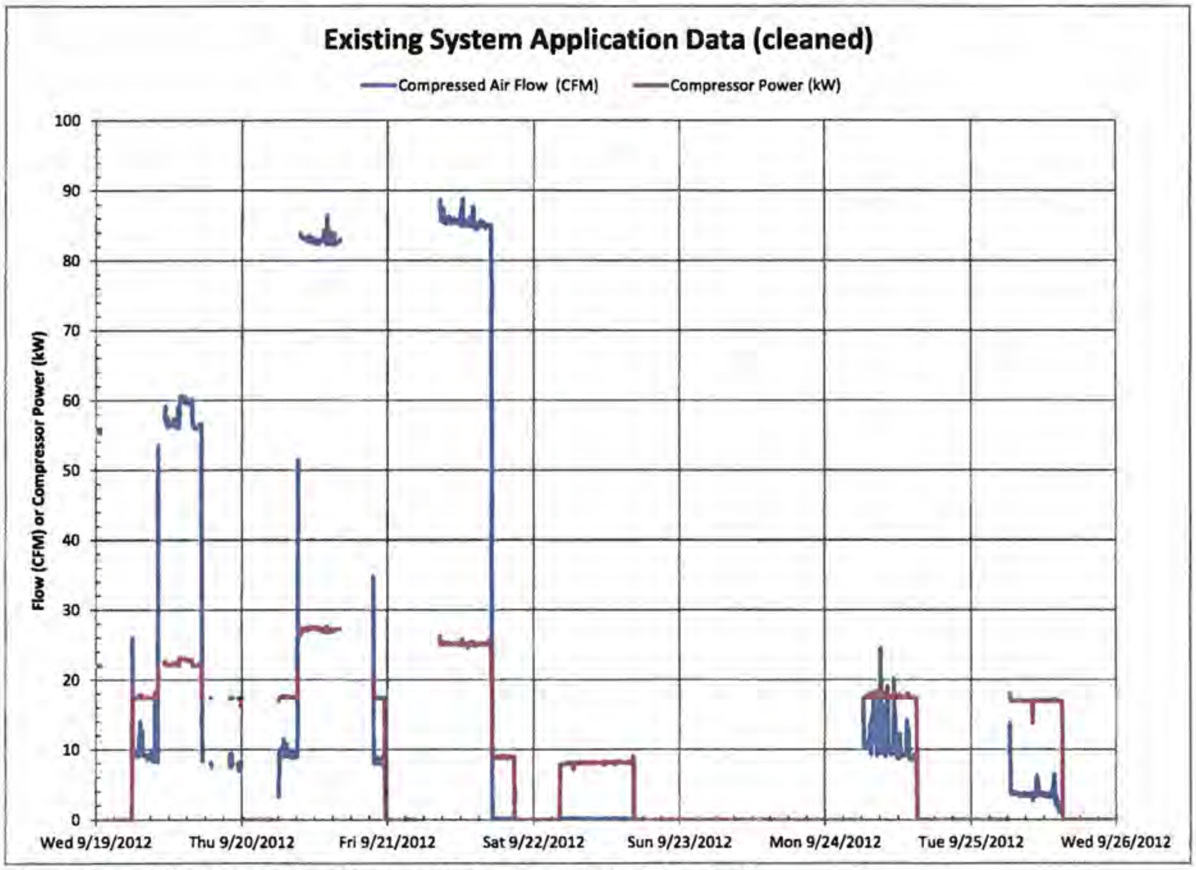

Figure 7: Old Compressor Flow and Demand Data (cleaned)

Using the above remaining data to develop a power relationship results in the following "cleaned" version of Figure 5, as well as a more appropriate curve-fit to replace Figure 6. Additional time-history flow and power data provided with the application (files "Air Demand Analysis 1.pdf" and "Air Demand Analysis 1 (con't).pdf" confirm this approach.

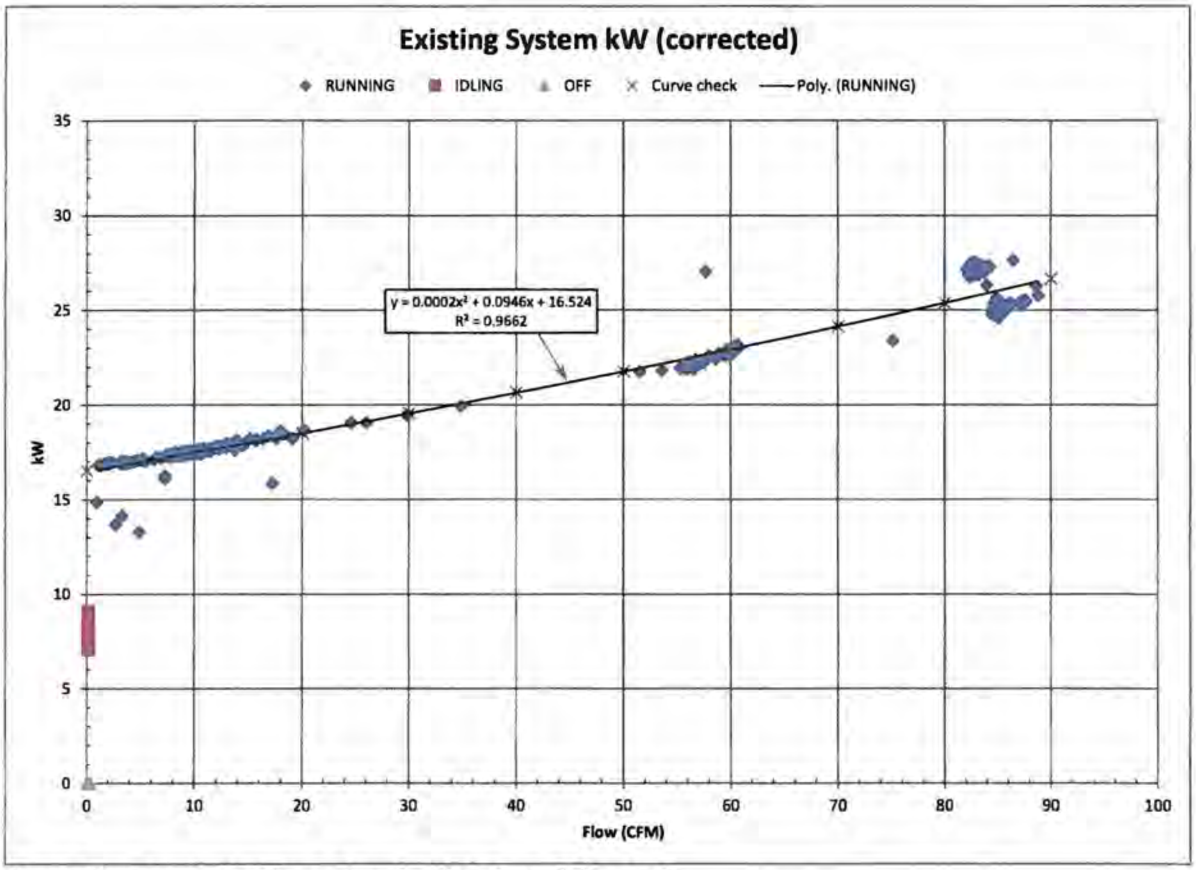

Figure 8: Power vs. Flow - Application Data (cleaned)

ENERGY SAVINGS

Comparing the application's flow and power readings (Figure 7) and the power readings measured during the M&V monitoring period (Figure 1 or Figure 2), it is evident that the compressor usage profile is different between the two data sets. To compare the old and new compressors on an equal footing – with the same flow requirements – a flow profile was developed for the monitored data. The first step is to bin the monitored power values as follows:

Table 2: New Compressor Binned Power Data

Minimum kW	Maximum kW	Range	Data Points Counted	Minutes	Hours (data)	Hours / Week	Hours / Year	Average kW
0	0.06	0 - 0.06	3,494	17,470	291.2	97.1	4,866.6	0.05
0.06	11.27	0.06 - 11.27	1,513	7,565	126.1	42.0	2,107.4	7.00
11.27	11.7	11.27 - 11.7	288	1,440	24.0	8.0	401.1	11.42
11.7	15	11.7 - 15	126	630	10.5	3.5	175.5	12.94
15	17	15 - 17	60	300	5.0	1.7	83.6	16.07
17	19	17 - 19	16	80	1.3	0.4	22.3	17.92
19	20.8	19 - 20.8	8	40	0.7	0.2	11.1	19.92
20.8	22	20.8 - 22	292	1,460	24.3	8.1	406.7	21.57
22	23	22 - 23	249	1,245	20.8	6.9	346.8	22.22
23	97	23 - 97	2	10	0.2	0.1	2.8	23.26
		Totals:	6,048		504	168	8,424	
				#days:	21.00			

Above, annual operation of 8424 hours per year reflects information obtained during the site visit that the facility observes 10 holidays per year, and does not have any other planned closures during the year.

Next, generic profiles of load vs. flow for some types of air compressor controls are available from the DOE Compressed Air Challenge program. The relationship shown here is applicable to this case.

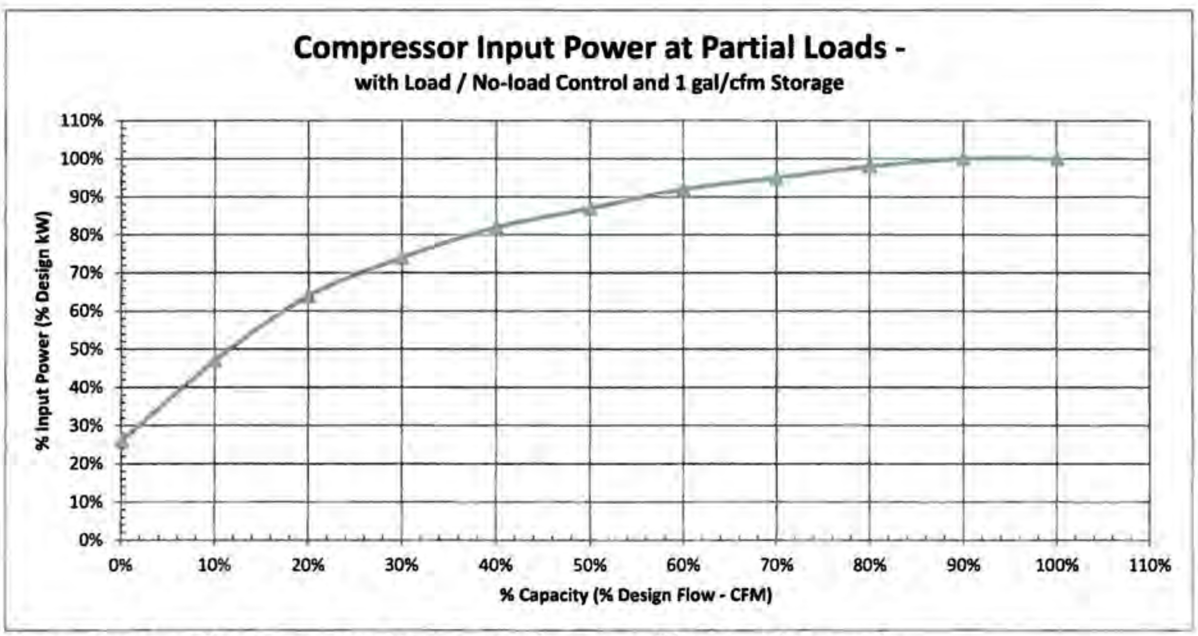

Figure 9: Generic Compressor Power vs. Flow - Load/No-Load Controls

Applying the above relationship to the monitored power values result in the following flow-power curve for the new compressor. For reference, the old compressor's curve and the curves proposed in the application documents are also shown.

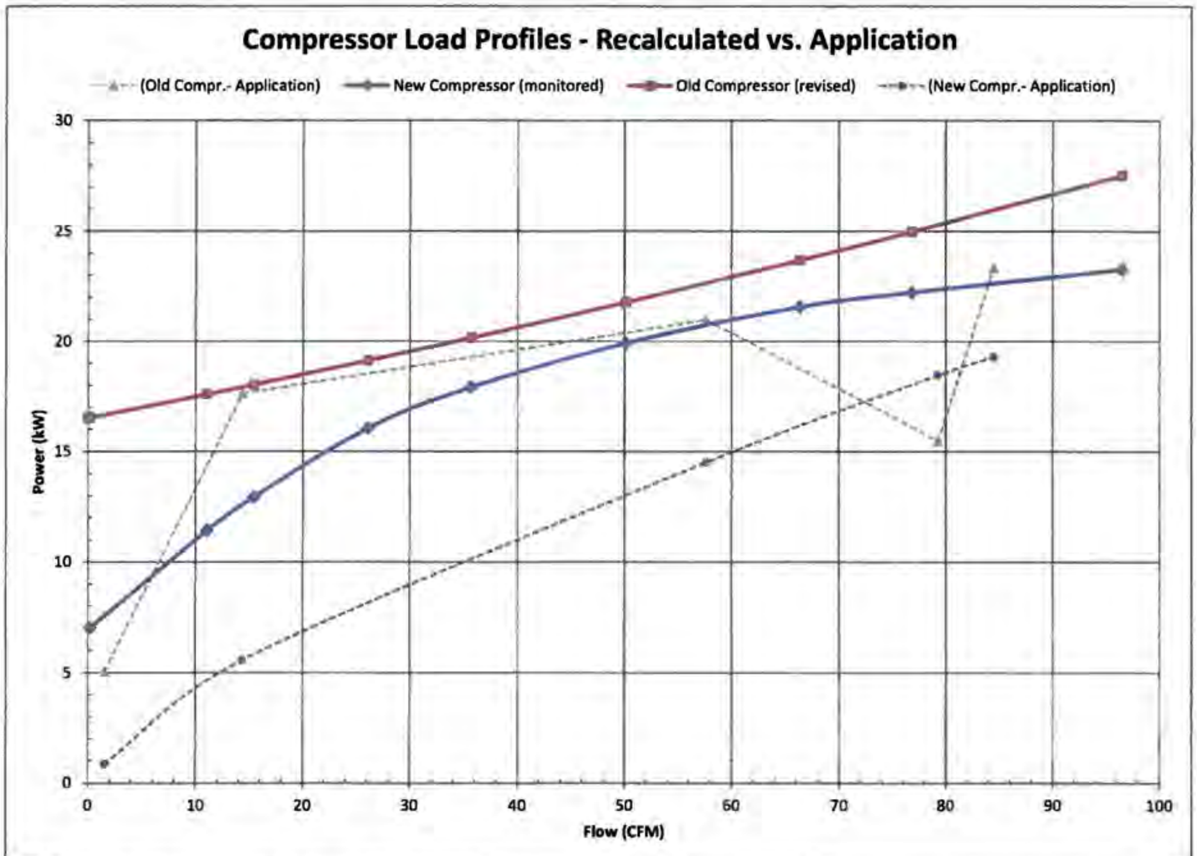

Figure 10: Power vs. Flow Profiles - Old and New Compressors

(Note: Figure 10 shows non-zero power values at zero flow, but these are the powers when the compressor is on and idling. When the compressor is off, which is a good portion of the time, the power is zero.)

Applying the above relationship to the M&V monitored power values results in the flows shown in the following table. Then, applying the power-flow curve-fit determined above for the existing (old) compressor results in power values for the old compressor for the same CFM profile that was determined from the monitored data. Finally, the old and new weekly and annual energy usage may be found by multiplying the power values by the number of hours per week the compressor operates in that bin.

In the following table, comparing the old and new annual energy usage shows the energy savings for this project. Compared to the Duke-projected savings of 34,945 kWh/year, the energy Realization Rate is 72.6%. The major reason for the shortfall is the difference in the monitored new and recalculated old compressor power-flow relationships, as applied to the observed operating schedule. While the recalculated old compressor relationship is higher than the original relationship, the monitored new compressor relationship is also higher, with the net result that there are fewer savings available overall in the low- to mid-flow ranges.

Table 3: Energy Savings and Realization Rate

Range (kW)	Average kW - New Compressor	Flow (CFM)	Power - Old Compressor	Hours / Week	Energy (kWh/ week)	
					Old Compressor	New Compressor
0 - 0.06	0.05	0	0	97.1	0	5.0
0.06 - 11.271	7.00	0.16	16.54	42.0	695.1	294.4
11.271 - 11.7	11.42	11.0	17.59	8.0	140.7	91.3
11.7 - 15	12.94	15.4	18.03	3.5	63.1	45.3
15 - 17	16.07	26.1	19.13	1.7	31.9	26.8
17 - 19	17.92	35.7	20.15	0.4	9.0	8.0
19 - 20.8	19.92	50.1	21.76	0.2	4.8	4.4
20.8 - 22	21.57	66.3	23.68	8.1	192.1	174.9
22 - 23	22.22	76.8	24.97	6.9	172.7	153.7
23 - 97	23.26	96.5	27.51	0.1	1.5	1.3
		Total:		168.0	1,310.9	805.1
		kWh / year			65,731	40,370
		Savings				25,361
		Duke Projected Savings				36,433
		Energy Savings Realization Rate				69.6%

DEMAND SAVINGS

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: Demand Savings and Realization Rate

Facility: [Redacted]		
	Summer Coincident Peak Demand (kW)	Summer Non-Coincident Peak Demand (kW)
Post-Retrofit Demand	21.85	23.39
CA Flow (CFM)	73.1	96.9
Pre-Retrofit Demand	24.50	27.57
Savings	2.65	4.19
Duke Projected Savings	4.21	4.14
Realization Rate	63.0%	101.2%

[Redacted]
Custom EMS Project
M&V Report

Prepared for
Duke Energy Ohio

November 2013

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:

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ARCHITECTURAL ENERGY CORPORATION

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Introduction

This report addresses M&V activities for the [REDACTED] custom program application. The application covers the installation of a new digital control system at the [REDACTED] facility in Cincinnati, Ohio. The installation had already been completed, so these M&V activities were conducted post-retrofit only.

In general, the intent of the project was to provide new energy efficient sequences of operation and energy saving strategies for:

- Central Building Basement AHU
- Trane Packaged AHU 1, 2, 3
- Hot Water Boilers (2)
- Variable Volume Boxes (43) and VAV Boxes w/ HW Reheat (67)

Specifically, the energy savings measure included:

ECM-1 – New Direct Digital Control System Installation

- Replacement of existing pneumatic building controls with a digital control system.
- Provide and install New EMS (DD controls, wiring and conduit as required, computer, software, control valves and motors, communication infrastructure, low-voltage power trunks, etc.).
- Implement a functional night setback system.
- Reset supply air temp based on actual building load.
- Convert all pneumatic VAV boxes to DDC for improved control, tenant scheduling, night setback/setup, and CFM volume reduction based on occupancy.
- Retrofit obsolete VAV box piston dampers to blade type for improved control.
- Install new outside air dampers, and
- Repair defective relief dampers for an operational fresh air economizer and much improved building pressurization scheme.

Goals and Objectives

Pre-and post-retrofit energy models of the building's energy use were created to determine the energy and power reduction achieved by the control system upgrade.

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 Coincident Peak kW savings	Proposed Non-Coincident Peak kW savings
[Redacted]	353,169	717	244,110	25.9	18.6

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

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

Project Contacts

Contact information for the individuals involved with this M&V effort is listed below.

AEC Contact	Doug Dougherty	ddougherty@archenergy.com Office: 303-459-7416 Cell: 303-819-8888.
Duke Energy M&V Admin.	Frankie Diersing	513-287-4096
Duke Energy BRM	Cory Gordon	
Customer Contact	[Redacted]	[Redacted]

Site Locations/ECM's

Site	Address	Sq. Footage	ECM's Implemented
[Redacted]	[Redacted]	80,600	1

Data Products and Project Output

- Annual Energy Savings
- Peak demand savings
- Coincident peak demand savings

M&V Option

IPMVP Option D

M&V Implementation Schedule

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

- Conducted an interview with the building contact.
- Obtain copies of building floor plans. *(Not available)*
- Collected billing data (monthly kWh and demand) for July 2012 – May 2013.
- Identified HVAC equipment currently on the new digital control system and collected nameplate data.
- Verified that equipment moved to the new control system is operating properly.
- Obtained pre-retrofit and post-retrofit sequences of operation for all controlled equipment.
- Established trend logs to monitor operation of supply fans, compressors, economizers, HW pumps, CO2 levels, outdoor air temperature and relative humidity, and a sampling of VAV terminals (discharge temperature and room temperature).
    - *Notes: Heating Water pumps were not monitored as they run continuously. Spot power measurements were obtained.*
    - *CO2 levels were not trended because the sensors were not installed.*
    - *The HVAC condensing units were not monitored; their operation is not trendable in the EMS, but they are always available to provide cooling when needed.*
- Trended EMS data for three weeks.
- Constructed and calibrated the building energy model.
- Evaluated the energy impacts of the building retrofit in the energy model.

Field Data Points

Survey data

- Nameplate data and quantity for HVAC all equipment.
- Pre-retrofit and post-retrofit sequences of operation for all controlled equipment.
- All other information in the AEC Survey-IT data form. This form includes detailed information about all building systems, including:
    - Building wall, window and floor area
    - Space types and uses
    - HVAC zoning
    - Occupancy schedules and operations (daily, weekly, annually, holidays)
    - Lighting loads and schedules
    - Equipment loads and schedules

- Temperature setpoints/schedules, Energy Management Systems
- HVAC system controls
- Fan and pump operation
- Shading and blinds
- Chillers, cooling towers, boilers, central air handlers, and water heating
- Building envelope, including windows, walls, areas, and construction types

Spot-Measurements

- For each AHU (qty = 4: Central Building Basement AHU plus Trane Packaged AHU-1, AHU-2 and AHU-3), measured the total unit electrical parameters including power (volts, amps, power factor and kW).
  - *Notes: The "Central Building AHU" is actually the only air handling unit at the site. References to "Trane Packaged AHU's" in the application documents apparently refer to the outdoor condensing units. These compressor-condenser packages (a.k.a. condensing units) are not air handlers, but provide compressed refrigerant to DX coils in the central AHU.]*
  - *One condensing unit was spot-measured; the other was not operating as one unit alone was satisfying the building cooling load at the time of the site visit.*
- Hot Water pump electrical parameters (volts, amps, power factor and kW).
  - *One HW pump was spot-measured; the other was not operating as one pump was enough to satisfy the reheat load at the time of the site visit.*

Time series data on controlled equipment

Trend logs were established in the EMS to monitor the points defined below.

General points:

- Outdoor air temperature and relative humidity

For the central AHU:

- Supply air temperature
- Return air temperature
- Mixed air temperature
- Return air CO2 sensor reading *(Not available – no sensor)*
- Supply fan VSD speed *(SF amps and kW were not available in the EMS)*
- Supply air CFM *(Not available – no flow station)*
- Supply air static pressure
- OA damper position.

For VAV boxes

- For (6) VAV boxes without reheat plus (10) with HW reheat:
  - Space temperature
  - Supply air volume CFM *(Not available in EMS)*
  - VAV terminal discharge air temperature

Data Analysis

Reviewed and summarized all EMS trend data.

Entered all data into eQUEST and constructed the building energy model.

Ran the model with pre-retrofit input parameters and operational sequences to determine annual pre-retrofit energy consumption. Calibrated with past utility bills to within 10% on a monthly basis. Only those parameters that were not known with a high level of uncertainty were modified. These parameters included plug loads, certain schedules, and infiltration, among others. Any parameters which are directly affected by the retrofit and have been explicitly monitored during data collection were NOT modified during model calibration.

Revised the model with the post-retrofit changes in parameters and sequences of operations.

Ran the model to determine annual post-retrofit energy consumption. Calibrated with past utility bills.

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

Verification and Quality Control

- Visually inspected logger data for consistent operation. Sort by day type and remove invalid data. Looked for data out of range and data combinations that are physically impossible.
- Verified pre-retrofit and post retrofit equipment specifications, quantities, and schedules are consistent with the application. If they are not consistent, record discrepancies.
  - *Note: "AHU" equipment inconsistencies have been noted above: the "Central Building AHU" is the only air handling unit at the site.*

Recording and Data Exchange Format

1. Survey forms and notes.
2. Energy Management System (EMS) data files

3. Excel spreadsheets
4. DOE-2 energy model data files

Results

BUILDING PARAMETERS

Listed below are a few of the model parameters obtained from information included in the application documents. Most of these parameters are common to both the pre-upgrade and post- upgrade models.

- The building walls are brick plus face brick, with an overall U-value = 0.20 (R-5)
- Roof construction is single-ply membrane over metal deck
- Windows are double-pane
- The building is fully occupied M-F from 7 AM – 6 PM, 20% occupied on Saturdays from 9 AM – 2 PM, and closed on Sundays.
- Six holidays are observed during the year
- Lighting is 4-lamp recessed fluorescent fixtures with no automatic control such as occupancy or daylighting sensors.
- Lighting operation is 100% on M-F from 6 AM – 7 PM, then 40% on until 9 PM, then off; 20% on Saturdays from 9 AM – 2 PM, and all of on Sundays.
- Exterior Lighting:

Garage:	(30) MH-250W = 7.5 kW
Parking lot:	(8) MH-500W = 4.0 kW
Bldg ext.:	(12) MH-250W = 3.0 kW
Schedule:	Timeclock, On at 9 PM, Off at 8 AM.

- Each floor has a 40-gallon electric WH.
- There are 3 elevators.
- The space heating fuel is natural gas; the boiler efficiency is 85%.
- Heating water (HW) distribution is provided by two 5-HP pumps
- The energy input for the HVAC condensing units is 1.12 kW/ton.
- The central AHU's air volume capacity is 75,000 CFM
- The central AHU's fan motor power is 100 HP
- Minimum outside air fraction (OAF) was 15%
- Before the EMS upgrade, the central building air handler had a dry-bulb economizer that functioned poorly and broken relief dampers on the roof that stayed open, continuously relieving conditioned air.

DATA REVIEW

With the cooperation of the customer contact, a considerable amount of HVAC system operational data was obtained from the building's own EMS trending capability. A review of this data, along with discussion of what the data reveals about the operation of the new EMS, follows. Each bullet point in the ECM will be addressed.

ECM-1 – New Direct Digital Control System Installation

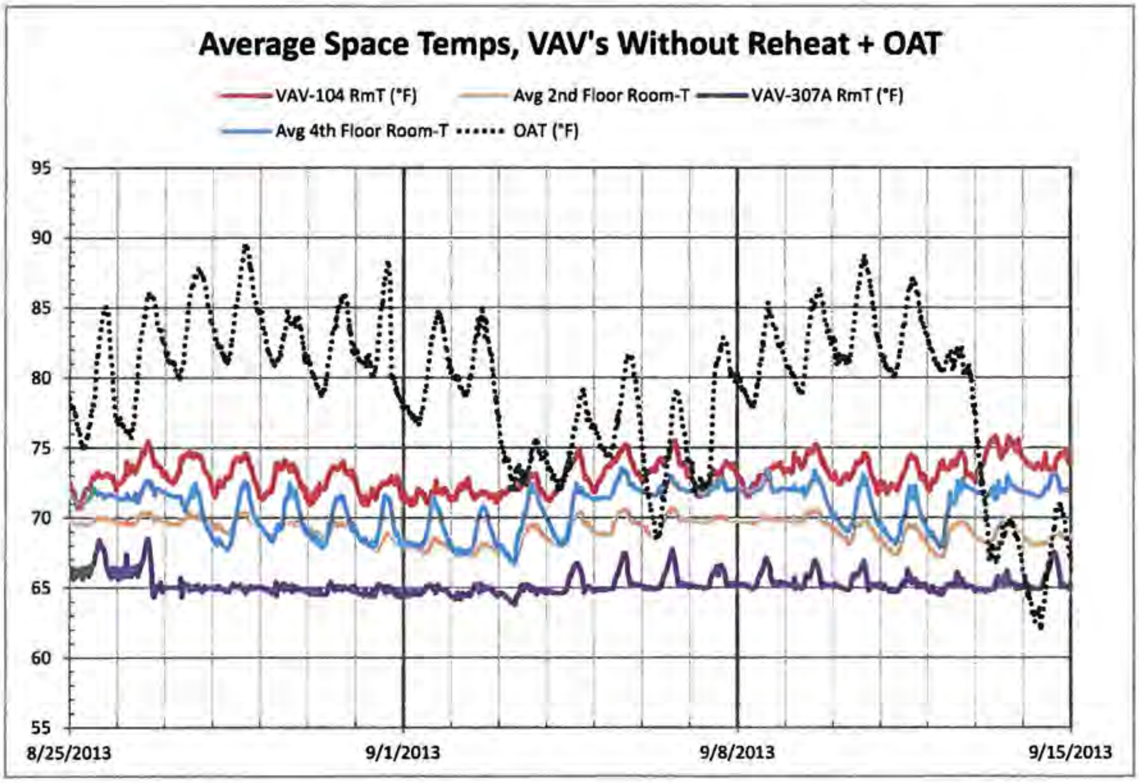
- Replacement of existing pneumatic building controls with a digital control system.
- Provide and install a new EMS (DD controls, wiring and conduit as required, computer, software, control valves and motors, communication infrastructure, low-voltage power trunks, etc.).

The above items address the physical hardware and software upgrades and, by themselves, do not affect the building energy usage.

- Implement a functional night setback system.

EMS trend data was obtained for sixteen randomly-selected spaces served by the VAV system. The data included the room temperatures for all sixteen of the zones, plus the VAV terminal discharge temperature for ten of the zones for which there was reheat capability.

A chart of the reported room temperatures for the six zones without reheat capability is shown below (the second and fourth floors zones are averaged). This is post-upgrade data. The outside air temperature history for the monitoring period is also presented.



In a system where night setback is enabled during the cooling season, a typical approach would be to control the HVAC system to maintain a "comfortable" space temperature (say, 72 - 74°F) during the daytime occupied hours, and then change, or "set back," the space temperature setpoint to a five- or ten-degree higher temperature (say, 78 - 80°F) during the night-time, unoccupied hours. (This is also sometimes referred to as "night set-up" when discussing cooling.) This control scheme reduces the temperature difference between the cool building interior and the warmer outside air, and thus reduces the cooling load on the air-conditioning equipment.

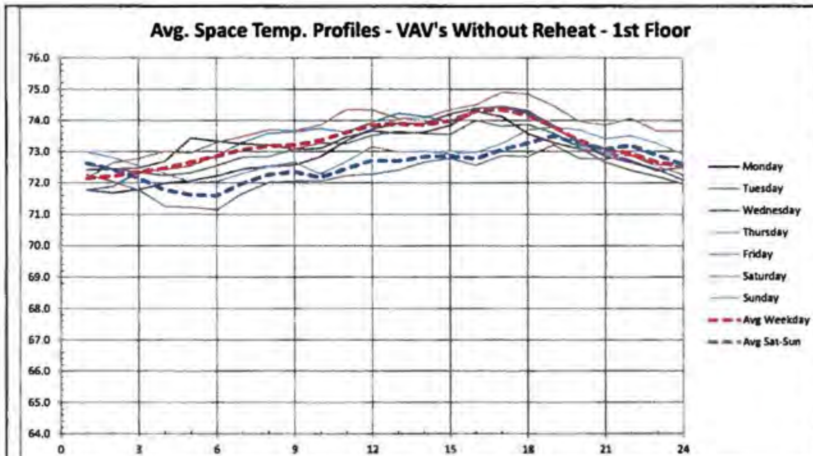
In this scenario, one would typically expect to see space temperatures increase somewhat, up to the higher setpoint, as the building is allowed to warm up. This condition would persist until the next occupied day, when the occupied setpoints would be again enacted. At that point, the space temperatures would be driven down to comfort conditions.

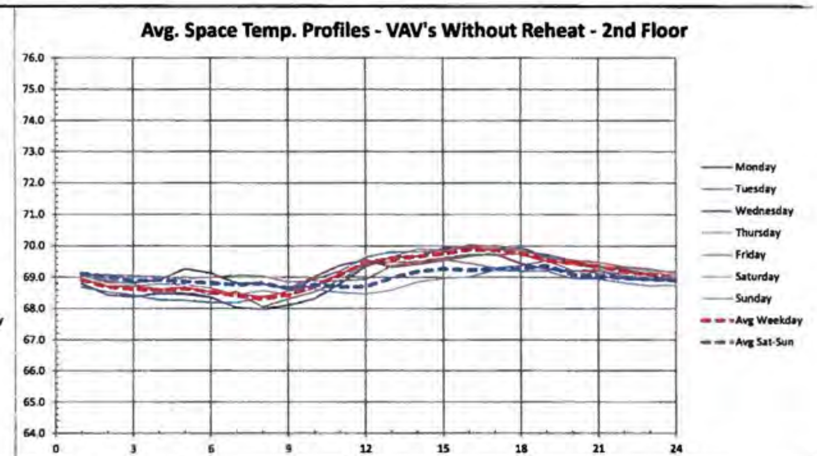
In the chart above, one can see that the room temperatures do fluctuate from daytime to night-time hours diurnal cycle. However, the pattern is inverted from that of a successful night setback control scheme: At night, temperatures in zones without reheat *drop* by 1 to 5 F. This is not indicative of night set-up during the cooling season. Zones without reheat are typically interior zones. The temperature patterns are typical of zones that have a constant low setpoint that is achieved only at night; during the day, when interior loads increase, the temperature rises. Thus these zones do not appear to have night set-up implemented.

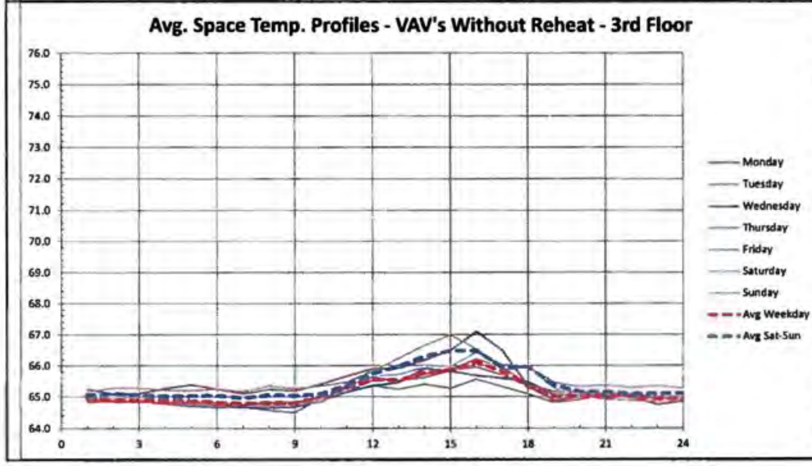
It is possible that the first floor interior zones' temperature behavior is influenced by the surrounding first floor exterior spaces (zones with reheat), as those zones are cooler than the interior. However, this is not true of the upper three floors.

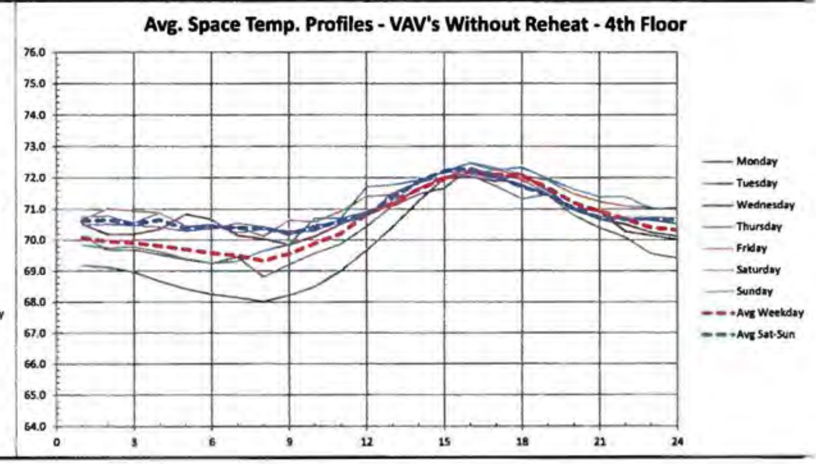
A cooling trend at night sometimes indicates night flushing (pre-cooling of the building overnight with cool OA); however, for the monitored data, the night-time OAT dropped below the warmest space temperature only on three occasions (out of 21), and one cannot cool the building with air that is warmer than the building.

Average space temperature profiles for the zones without reheat on the four floors appear on the next page. Some of the spaces, particularly on the third floor, are kept very cool most of the time.


Avg. Space Temp. Profiles - VAV's Without Reheat - 1st Floor
76.0
75.0
74.0
73.0
72.0
71.0
70.0
69.0
68.0
67.0
66.0
65.0
64.0
0
3
6
9
12
15
18
21
24
Monday
Tuesday
Wednesday
Thursday
Friday
Saturday
Sunday
Avg Weekday
Avg Sat-Sun


Avg. Space Temp. Profiles - VAV's Without Reheat - 2nd Floor
76.0
75.0
74.0
73.0
72.0
71.0
70.0
69.0
68.0
67.0
66.0
65.0
64.0
0
3
6
9
12
15
18
21
24
Monday
Tuesday
Wednesday
Thursday
Friday
Saturday
Sunday
Avg Weekday
Avg Sat-Sun


Avg. Space Temp. Profiles - VAV's Without Reheat - 3rd Floor
76.0
75.0
74.0
73.0
72.0
71.0
70.0
69.0
68.0
67.0
66.0
65.0
64.0
0
3
6
9
12
15
18
21
24
Monday
Tuesday
Wednesday
Thursday
Friday
Saturday
Sunday
Avg Weekday
Avg Sat-Sun

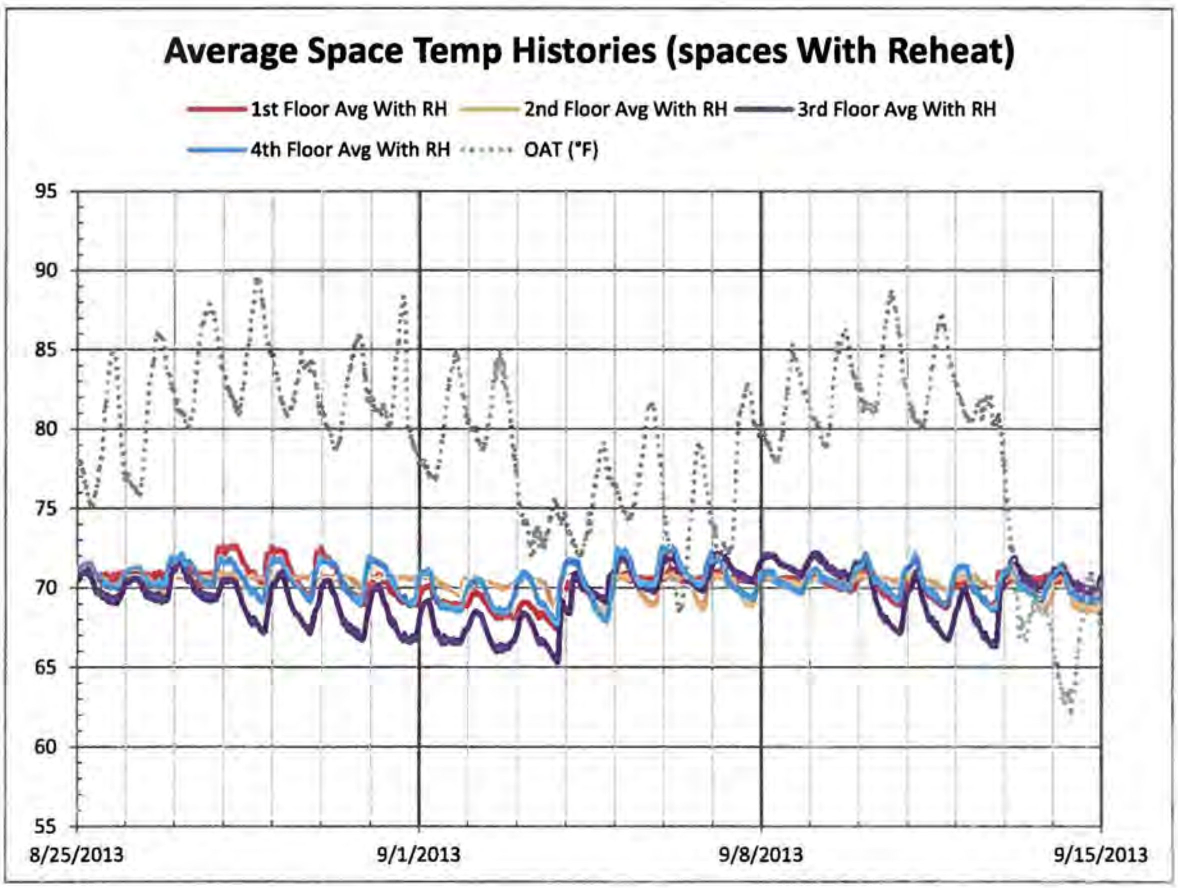

Avg. Space Temp. Profiles - VAV's Without Reheat - 4th Floor
76.0
75.0
74.0
73.0
72.0
71.0
70.0
69.0
68.0
67.0
66.0
65.0
64.0
0
3
6
9
12
15
18
21
24
Monday
Tuesday
Wednesday
Thursday
Friday
Saturday
Sunday
Avg Weekday
Avg Sat-Sun

For zones without reheat, the table below shows the average, minimum and maximum daily average space temperatures on each floor. Also shown are the ranges, or spread, between the minimum and maximum temperatures. The ranges are very tight, averaging only 2.0 F.

Summary of Space Temperature Data -
For VAV Zones Without Reheat

	1st Floor		2nd Floor		3rd Floor		4th Floor	
	Avg Weekday	Avg Sat-Sun	Avg Weekday	Avg Sat-Sun	Avg Weekday	Avg Sat-Sun	Avg Weekday	Avg Sat-Sun
Average Room Temp.	73.3	72.6	69.1	69.0	65.2	65.4	70.6	71.0
Max	74.4	73.5	69.9	69.4	66.1	66.5	72.2	72.3
Min	72.1	71.6	68.3	68.6	64.8	65.0	69.3	70.2
Range	2.2	1.9	1.6	0.7	1.3	1.5	2.9	2.1

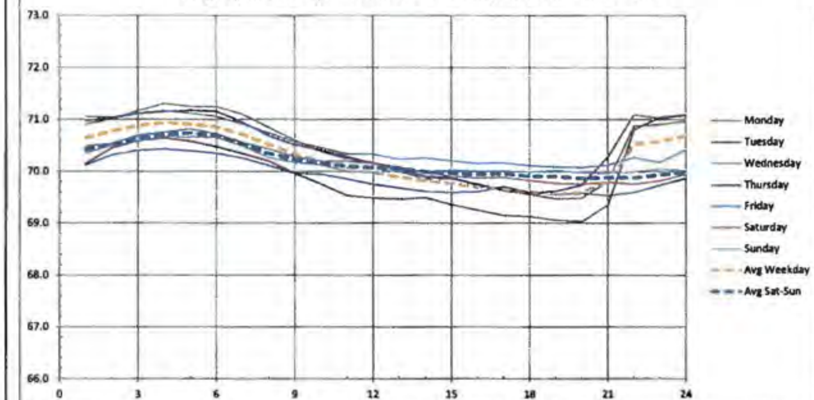
A chart of the reported room temperatures for the ten zones <u>with</u> reheat capability is shown below, averaged by floor. Again, this is post-upgrade data. The outside air temperature history for the monitoring period is also repeated for reference.



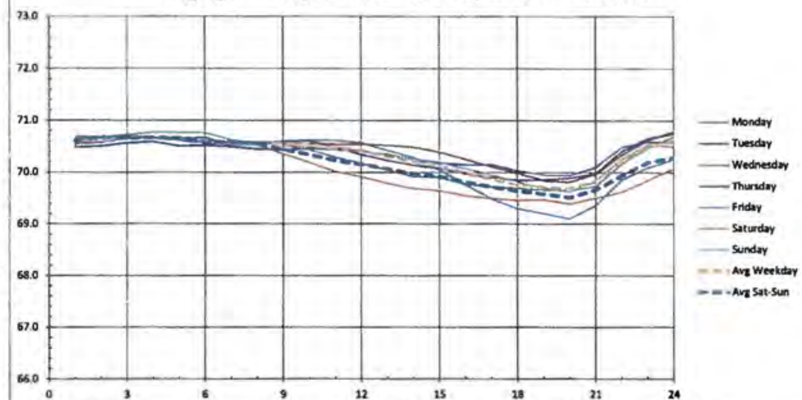
Here, the pattern is correct for successful night setback control. At night, temperatures in the zones increase by up to 5 F. Thus, these zones do appear to have night set-up implemented.

Average space temperature profiles for the zones with reheat on the four floors appear on the next page.

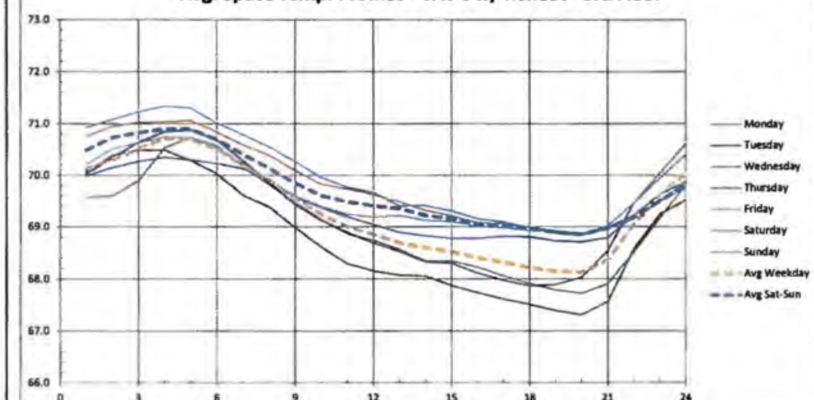
Avg. Space Temp. Profiles - VAV's w/ Reheat - 1st Floor



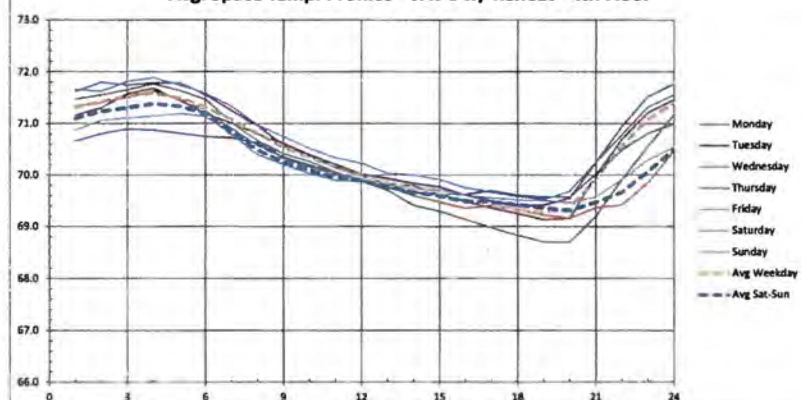
Avg. Space Temp. Profiles - VAV's w/ Reheat - 2nd Floor



Avg. Space Temp. Profiles - VAV's w/ Reheat - 3rd Floor



Avg. Space Temp. Profiles - VAV's w/ Reheat - 4th Floor



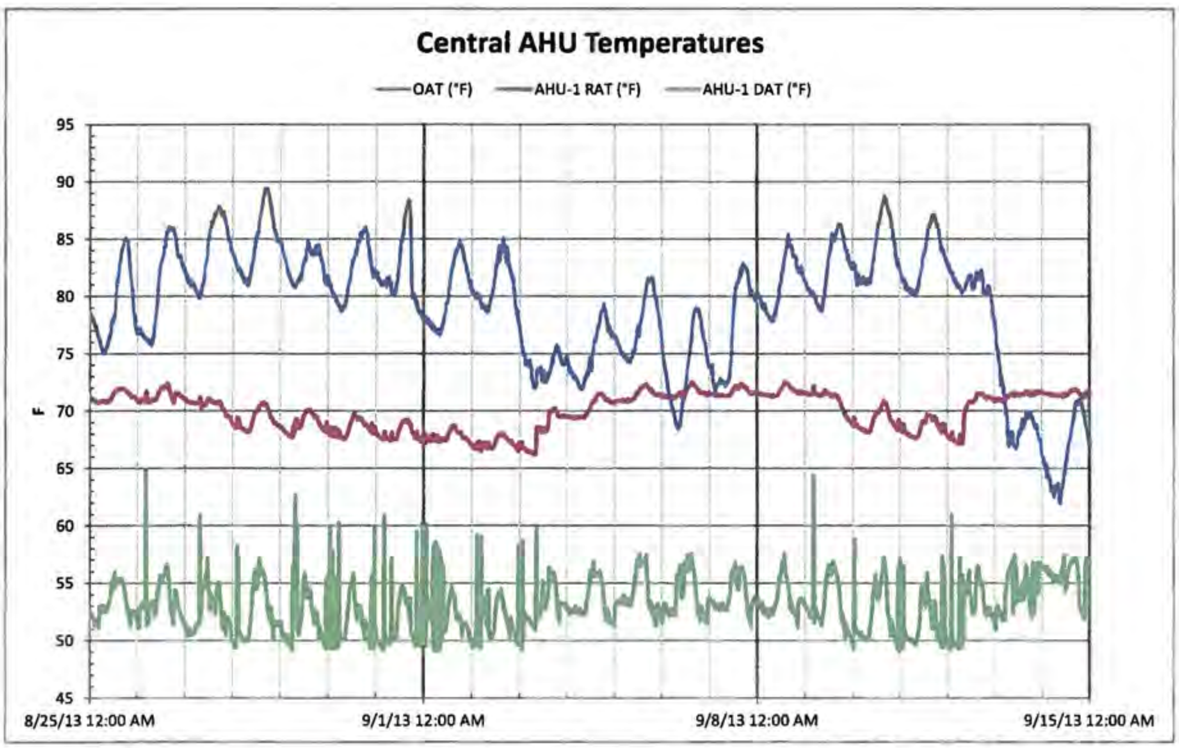
For zones with reheat, the table below shows the average, minimum and maximum daily average space temperatures on each floor. Also shown are the ranges, or spread, between the minimum and maximum temperatures. As for the interior zones, the ranges are very tight, averaging only 2.0 F, but here the minimum and maximum temperatures occur at the correct time of day, as noted above.

Summary of Space Temperature Data - For VAV Zones WITH Reheat

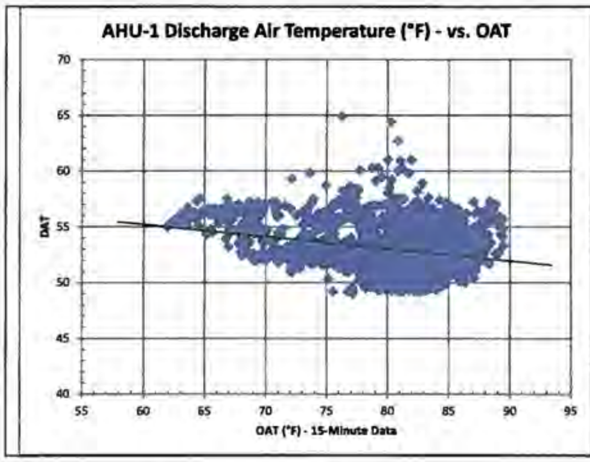
	1st Floor		2nd Floor		3rd Floor		4th Floor	
	Avg Weekday	Avg Sat-Sun	Avg Weekday	Avg Sat-Sun	Avg Weekday	Avg Sat-Sun	Avg Weekday	Avg Sat-Sun
Average Room Temp.	70.3	70.2	70.3	70.2	69.3	69.7	70.4	70.2
Max	70.9	70.7	70.7	70.7	70.7	70.9	71.6	71.4
Min	69.6	69.9	69.7	69.5	68.1	68.9	69.3	69.3
Range	1.4	0.9	1.0	1.2	2.6	2.0	2.3	2.1

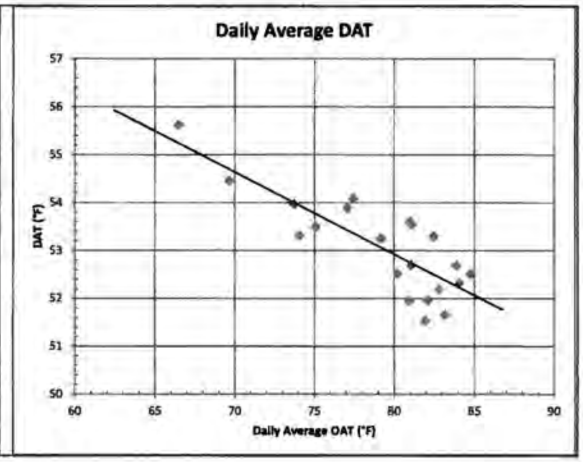
- Reset supply air temp based on actual building load.

The history of the central air handling unit (AHU-1) supply and return air temperatures is shown here:



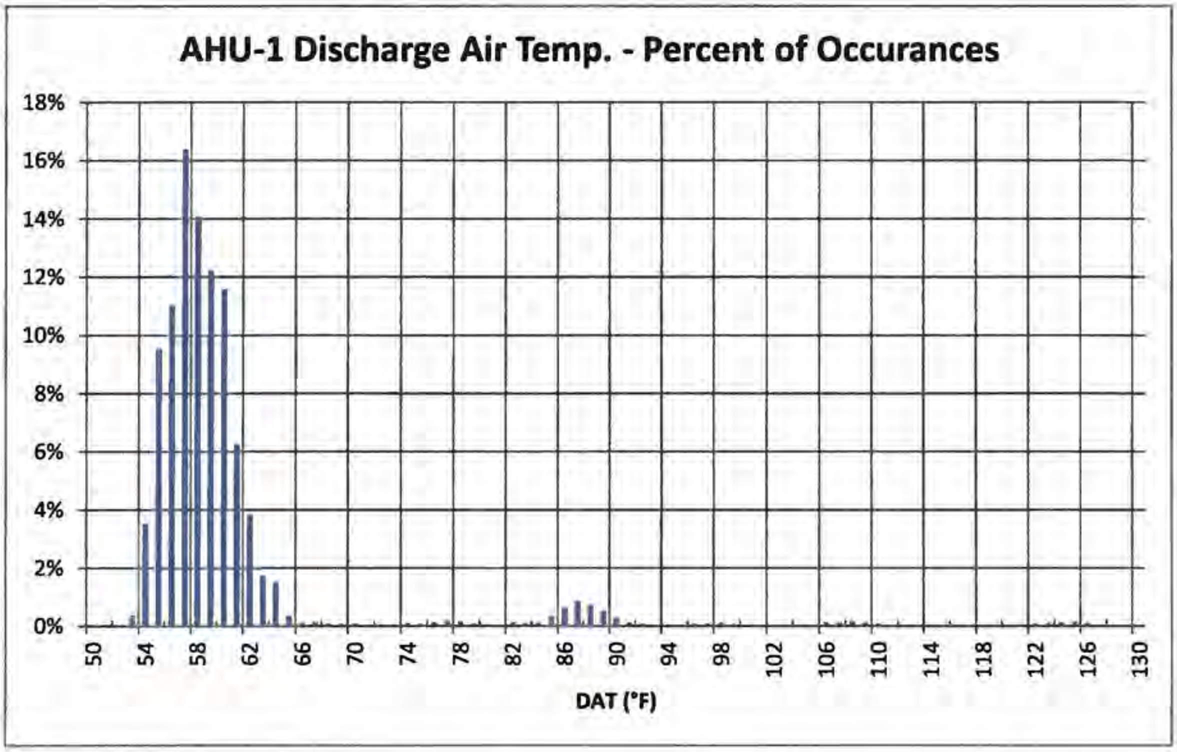
The post-upgrade DAT's observed coming from the central AHU are mostly in the range of 49 - 58°F, with a handful of instances of temperatures up to 65°F. There is a slight correlation with OAT using the 15-minute data, and a somewhat better correlation on a daily average basis (see charts below). However, the stated control intent was to reset DAT based on building load, not OAT, and while OAT contributes to building load it is not the only factor (internal gains from occupants and equipment being the other major factors).





From these results, it does appear that some reset is occurring.

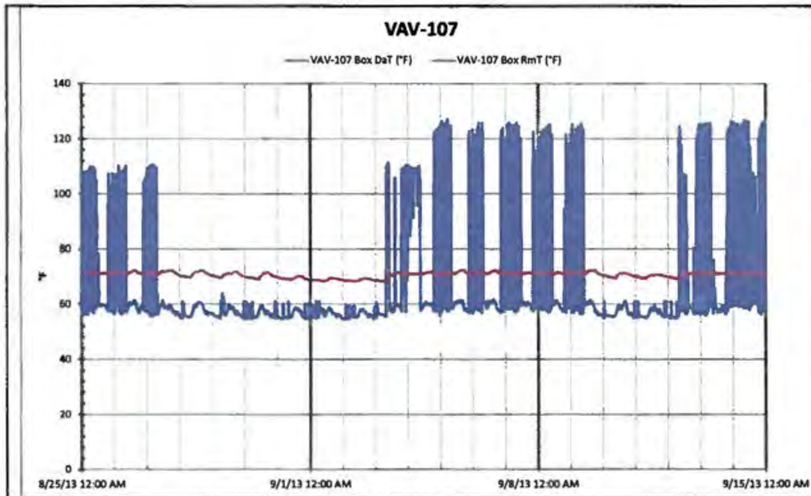
Discharge air temperature data was also obtained for the VAV's with reheat capability. There is again a variation in these DAT's; this is expected since the central AHU feeds air to the VAV terminals. The range of VAV DAT's is approximately 54 - 64°F when not reheating, or about 5 – 6 degrees warmer than the central AHU DAT. The higher DAT's observed at the VAV terminals may be due to heat gains to the air distribution system ductwork. The distribution of DATs from the VAV terminals is shown in the chart below.

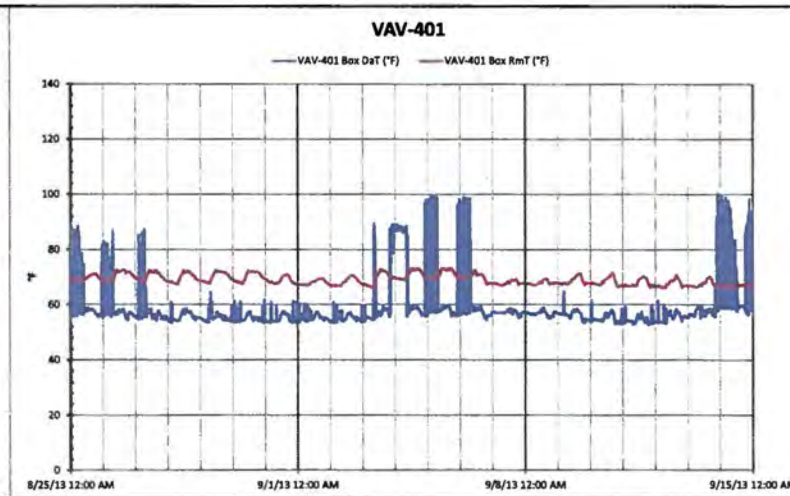


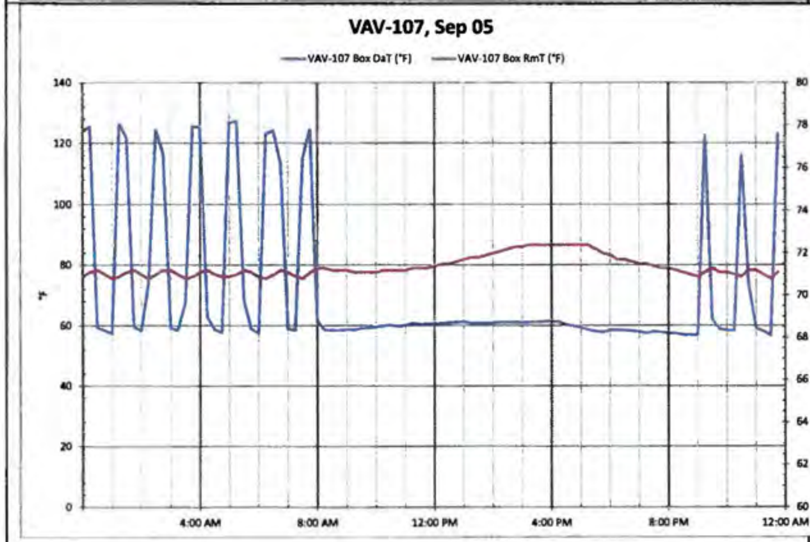
Little reheat was used during the monitoring period, with the most occurring on the third floor (16% of the time). When reheating, the average discharge temperature on the third floor was about 87°F. DAT's as high as 126°F occurred on the first floor, 106°F on the second floor, and 98°F on the fourth floor. These were minor occurrences; overall, the DAT's from the VAV's with reheat were in the range of 54 - 62°F over 90% of the time.

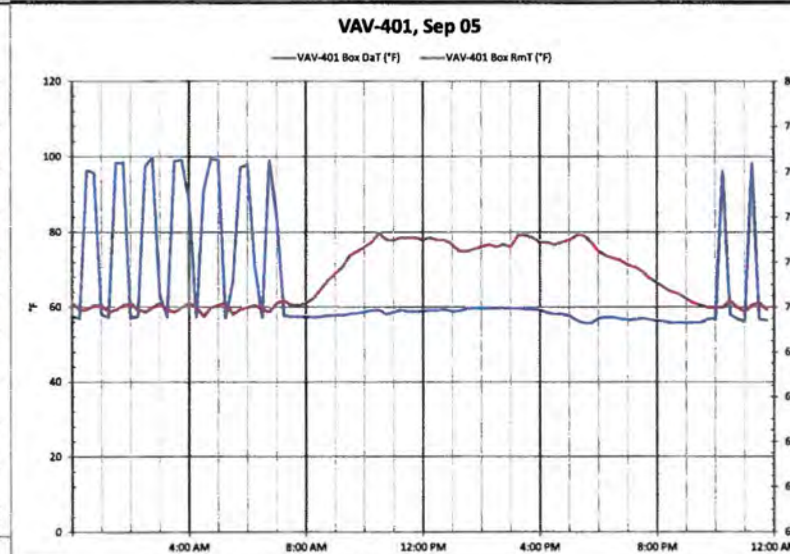
While the daily temperature swings in the exterior zones do indicate that cooling setback control is operating, there is an issue with how the nighttime temperature is controlled in some zones. Two examples are shown in the top row of the table on the next page; in the bottom row, we have zoomed in on one full day (in the bottom row, the space temperatures are indicated on the right axes of the charts). Note that there is a considerable amount of reheat energy being alternated with cooling energy to maintain the night temperature within a very tight tolerance. Although the reheat energy is provided by gas-fired hot water and is not a direct concern of this report, the additional cooling energy being used is a concern.

The situation could be mitigated in several ways; for example, reducing the HW supply temperature, reducing the VAV terminal supply temperature (which may require a modulating HW valve plus appropriate control), or reducing the minimum VAV terminal airflow. Additionally, the facility is working toward being able to turn off the HVAC system overnight and on weekends, but this had not yet been achieved at the time of the monitoring effort (more about this below).


VAV-107
VAV-107 Box DaT (°F)
VAV-107 Box RmT (°F)
°F
140
120
100
80
60
40
20
0
8/25/13 12:00 AM
9/1/13 12:00 AM
9/8/13 12:00 AM
9/15/13 12:00 AM


VAV-401
VAV-401 Box DaT (°F)
VAV-401 Box RmT (°F)
°F
140
120
100
80
60
40
20
0
8/25/13 12:00 AM
9/1/13 12:00 AM
9/8/13 12:00 AM
9/15/13 12:00 AM


VAV-107, Sep 05
VAV-107 Box DaT (°F)
VAV-107 Box RmT (°F)
°F
140
120
100
80
60
40
20
0
80
78
76
74
72
70
68
66
64
62
60
4:00 AM
8:00 AM
12:00 PM
4:00 PM
8:00 PM
12:00 AM

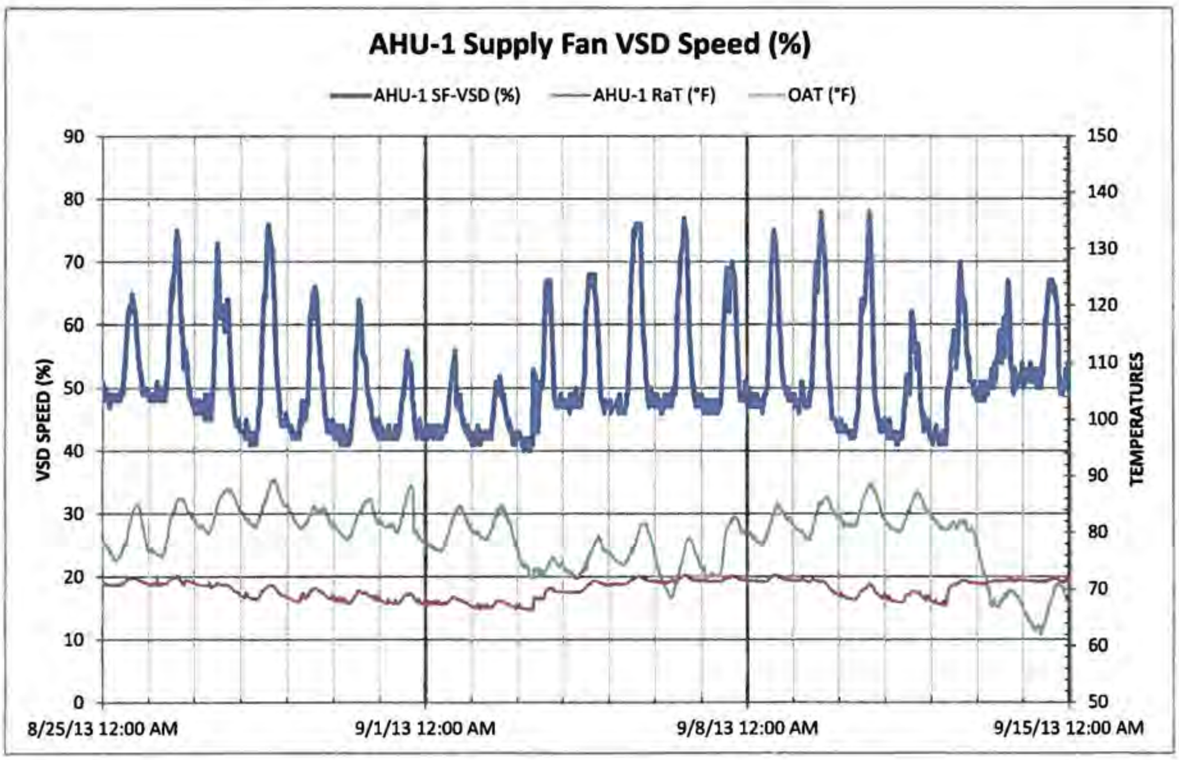

VAV-401, Sep 05
VAV-401 Box DaT (°F)
VAV-401 Box RmT (°F)
°F
120
100
80
60
40
20
0
80
78
76
74
72
70
68
66
64
62
60
4:00 AM
8:00 AM
12:00 PM
4:00 PM
8:00 PM
12:00 AM

- Convert all pneumatic VAV boxes to DDC for improved control, tenant scheduling, night setback/setup, and CFM volume reduction based on occupancy.

And:

- Retrofit obsolete VAV box piston dampers to blade type for improved control.

Other than the discharge air temperature monitoring as discussed previously, individual VAV boxes were not monitored directly for damper operation, schedule or CFM. However, monitored data for the central AHU's fan VSD frequency was collected. The VSD speed, and thus air flow, does decrease at night, to as low as 40%. The highest VSD speed observed in the monitored data was 78%. A chart of the fan behavior is presented here. The variation in speed indicates that the VSD is responding to VAV terminals collectively closing down in response to reduced occupancy and other space loads. (Duct static pressure data was also collected; it is essentially constant at 1.5 in-WC.)



Information collected during the site visit, and from the application documents, indicates that the facility is working toward being able to limit AHU fan operation to 13-14 hours per day on weekdays, and 8-12 hours on Saturdays, with Sundays off. The VSD speed chart above shows that this goal has not yet been achieved. At the time of the site visit, there was a customer in the building that was operating 24/7. This customer is trying to change its operation so the central AHU fan can shut down at night and on weekends.

- Install new outside air dampers

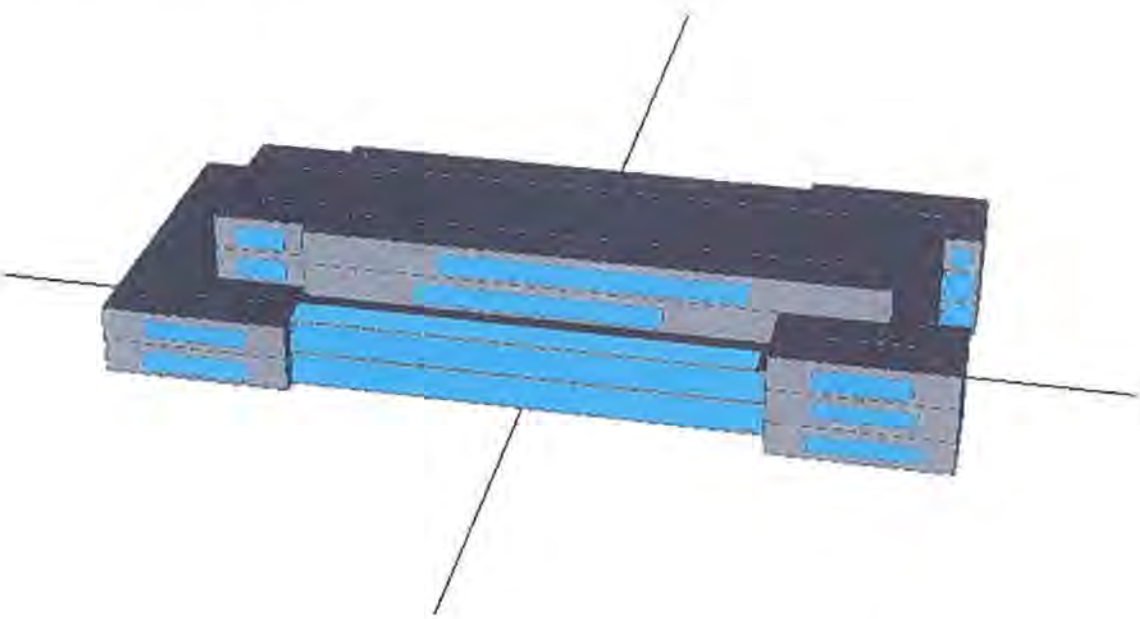
And:

- Repair defective relief dampers for an operational fresh air economizer and much improved building pressurization scheme.

Although the OA damper EMS signal was trended, the data was all zeroes and is not useful. Because of the late-summer monitoring period and the relatively cool building temperatures, the OA temperature was nearly always higher than the central AHU return air temperature (see Central AHU Temperatures chart above), so the economizer function would not have been used anyway during this time period. For the purposes of this M&V effort, we will stipulate that the OA dampers were repaired and the relief dampers were repaired as planned.

BUILDING ENERGY MODEL

The building energy model was constructed in eQUEST using photographs and survey data. The above common parameters were also entered. The total floor area is 80,600 sqft. A rendering of the model is show here.



In addition to the model features noted previously, the inputs listed below, derived from the monitored data, were also included for the pre-retrofit model:

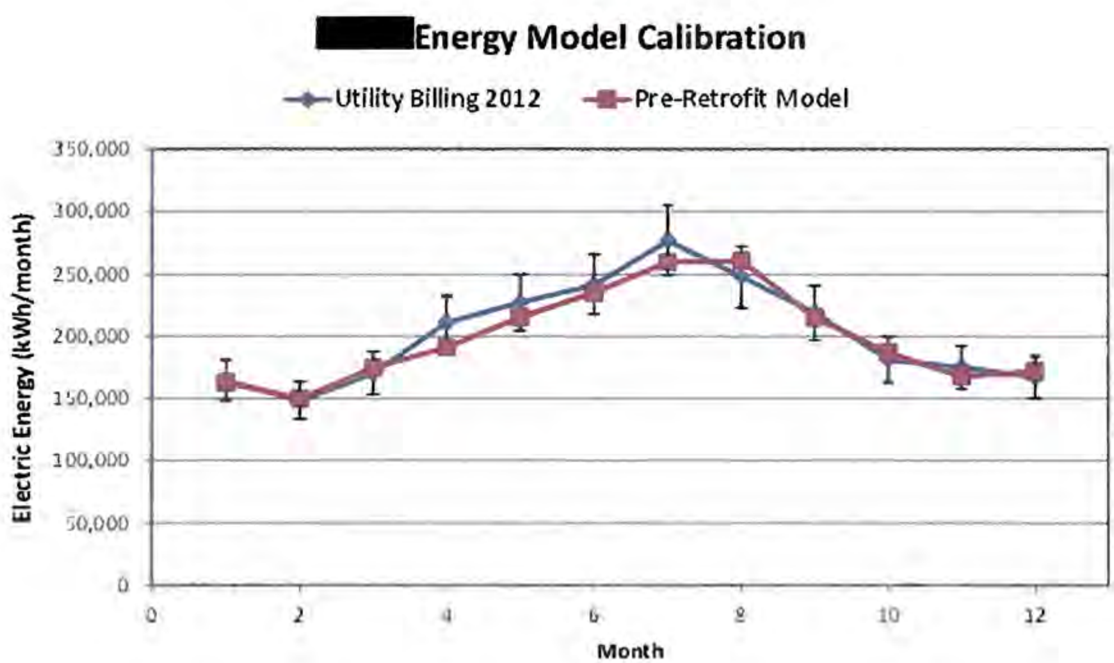
- Space temperature setpoints, based on reviewed data:

Interior zones:	1st Floor: 72°F	2nd Floor: 69°F	3rd Floor: 65°F	4th Floor: 70°F
Exterior zones:	1st Floor: 70°F	2nd Floor: 70°F	3rd Floor: 68°F	4th Floor: 69°F

- Interior zones Night Set-up (cooling): None
- Interior zones Night Setback (heating): None
- Exterior zones Night Set-up (cooling): None
- Exterior zones Night Setback (heating): None

- Fixed outside air fraction (OAF): 15%.
- Broken relief dampers on the roof that stayed open, continuously relieving conditioned air: Modeled as increased infiltration/outside air
- Poorly controlling VAV boxes: Modeled as a minimum airflow of 70% and zone temperature control of +/- 4 F
- Supply air temperature <u>not</u> reset: Fixed at 55°F

The pre-retrofit model was then run to determine the annual post-retrofit energy consumption. The model was calibrated against past utility bills to within 10% on a monthly basis. Only those parameters that were not known with a high level of uncertainty were modified. These parameters included plug loads and certain schedules, among others. Any parameters which are directly affected by the retrofit and have been explicitly monitored during data collection were NOT modified during model calibration. The annual energy usage calculated by the final pre-retrofit model is within 2% of the total of the utility bills. The month-by-month comparison is shown below.



	Electric Energy (kWh/month)		
Month	Utility Billing 2012	Pre-Retrofit Model	Model/Billing (%)
Jan	164,456	162,700	98.9%
Feb	148,335	149,800	101.0%
Mar	170,454	174,700	102.5%
Apr	211,091	191,000	90.5%
May	227,242	215,500	94.8%

Jun	241,551	235,100	97.3%
Jul	277,079	259,600	93.7%
Aug	247,931	260,800	105.2%
Sep	218,913	215,100	98.3%
Oct	181,253	186,800	103.1%
Nov	175,069	167,800	95.8%
Dec	167,327	171,700	102.6%
Total	2,430,701	2,390,600	98.4%

The model was then revised with the post-retrofit changes. These changes include the inputs listed below, also derived from the monitored data as discussed above. Because of the time of year when the M&V monitoring was conducted, heating setback control could not be verified.

- Space temperature setpoints: Same as pre-retrofit
- Interior zones Night Set-up (cooling): None
- Interior zones Night Setback (heating): None
- Exterior zones Night Set-up (cooling): None
- Exterior zones Night Setback (heating): None
- Full dry-bulb economizer function, minimum OAF: 15%
- Repaired relief dampers: Modeled as decreased infiltration
- Improved control of VAV boxes: Modeled as a minimum airflow of 40% and zone temperature control of +/- 2 F
- Central AHU supply air temperature reset: 49°F - 58°F based on warmest zone

ENERGY SAVINGS

The revised model was then run to calculate the annual post-retrofit demand and energy consumption. The table below presents the final energy and demand savings and realization rates for the [REDACTED] Custom Incentive Program project. For Ohio in 2013, the coincident peak demand is evaluated on July 17, for the hour between 4-5 PM.

Facility	[Redacted]		
	Annual Energy Usage (kWh)	**Summer Coincident Peak Demand (kW)**	**Summer Peak Demand (kW)**
Duke Projected Savings	244,110	18.6	25.9
Model Savings	462,143	29.1	32.5
Realization Rate	189%	156%	125%