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FILE

DUKE ENERGY OHIO EXHIBIT__________

**BEFORE**

**THE PUBLIC UTILITIES COMMISSION OF OHIO**

| | | |
|---|---|---|
| In the Matter of the Application of Duke Energy Ohio, Inc., for Recovery of Program Costs, Lost Distribution Revenue and Performance Incentives Related to its Energy Efficiency and Demand Response Programs. | ) ) ) ) ) | Case No. 13-753-EL-RDR |

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**DIRECT TESTIMONY OF**

**ASHLIE J. OSSEGE**

**ON BEHALF OF**

**DUKE ENERGY OHIO, INC.**

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**VOLUME 2 OF 3**

March 28, 2013

Final Report

# Evaluation of the 2009 – 2011 Smart $aver Non-Residential Custom Incentive Program in Ohio

Results of an Impact Evaluation

**Prepared for**
**Duke Energy**
139 East Fourth Street
Cincinnati, OH 45201

September 13, 2012

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# Executive Summary

## Key Findings and Recommendations

The key findings and recommendations identified through this evaluation are presented below.

### Engineering Impact Estimates: Key Findings

1. The overall realization rate across all projects was 1.03, indicating that the program evaluation results matched the expected kWh savings very closely. On an individual project basis, the realization rates ranged from 0.37 to 3.23, indicating a wide variation in the evaluated vs. expected kWh savings on any individual project.
2. The cool roof project did not perform to program expectations. The calculations done for the project application used roofing system vendor estimates that overstated savings. Future cool roof projects should be more thoroughly screened. Project savings estimates prepared with vendor-supplied software should be independently verified, including comparisons to unit savings estimates (kWh/SF and kW/SF) from the Ohio TRM. Projects with pre-existing roof insulation levels at or near code should be carefully reviewed.
3. About 33% of the total program savings come from lighting. Based on our review, it appears there is enough data to support moving some measures to the Prescriptive Program by expanding the list of eligible fixtures. This will reduce application burden on customers and reduce the application review burden on Duke Energy staff. Candidates for inclusion in the prescriptive lighting program include interior and exterior induction lighting fixtures, high-bay fluorescent lighting in refrigerated spaces, exterior LED fixtures, and exterior metal halide fixtures.
4. Several HVAC systems were observed to have no mechanical ventilation. This situation can potentially cause indoor air quality problems, although buildings may have adequate ventilation due to infiltration. Enabling mechanical ventilation will increase energy consumption, but will bring buildings into compliance with ASHRAE Indoor Air Quality standards for commercial buildings.
5. The age of the equipment in one of the projects deemed to be early replacement was well past normal industry values for effective useful life. The customer was interviewed and asserted that they would have continued to operate and maintain the existing equipment in the absence of the program, including questions about the remaining useful life of existing equipment in the application is an industry best practice, and will reduce the risk of lifetime savings erosion in projects with equipment that is near the end of its service life. This information should be collected for early replacement projects, and include documentation to justify the claimed value. The justification and documentation of remaining useful life for early replacement projects should be examined as a normal component of the application review process.
6. Several of the new construction projects claimed savings for measures that were required by code. Application reviewers should screen new construction projects carefully to make sure measures exceed code minimum requirements.
7. One lighting project participant installed additional lighting measures without applying for a rebate from either the prescriptive or custom programs. This action could represent additional savings caused by the program due to customer "spillover." The impacts of

customer spillover at this site were not calculated, thus the net savings are likely conservative.

**Table 1: Evaluated Savings Estimate Breakdown by Customer**

| Customer | kWh | NCP kW[1] | CP kW[2] | MMBtu[3] |
|---|---|---|---|---|
| Site 1 | 258,169 | 42.00 | 42.00 | N/A |
| Site 2 | 399,610 | 226.00 | 70.00 | N/A |
| Site 3 | 3,378,176 | 483.00 | 483.00 | N/A |
| Site 4 | 4,798 | 13.40 | 8.20 | N/A |
| Site 5 | 3,775,031 | 588.00 | 588.00 | N/A |
| Site 6 | 5,591,557 | 603.26 | 603.00 | N/A |
| Site 7 | 360,188 | 56.00 | 56.00 | N/A |
| Site 8 | 587,214 | 61.30 | 0.00 | N/A |
| Site 9 | 247,604 | 24.50 | 28.20 | N/A |
| Site 10 | 329,359 | 64.40 | 0.00 | N/A |
| Site 11 | 52,653 | 13.70 | 13.70 | N/A |
| Site 12 | 449,297 | 21.00 | 21.00 | N/A |
| Site 13 | 1,813,844 | 768.00 | 384.00 | N/A |
| Site 14 | 161,110 | 5.10 | 27.70 | N/A |
| Site 15 | 347,394 | 28.60 | 28.60 | N/A |
| Site 16 | 237,527 | 319.20 | 22.00 | N/A |
| Site 17 | 22,341 | 9.90 | 2.60 | N/A |
| Site 18 | 719,314 | 75.00 | 75.00 | N/A |
| Site 19 | 113,766 | 0.00 | 0.00 | N/A |
| Site 20 | 470,380 | -99.20 | -52.00 | N/A |
| Site 21 | 95,107 | 22.80 | 0.00 | N/A |
| Site 22 | 287,240 | 28.90 | 28.90 | N/A |
| Site 23 | 203,477 | 76.70 | 65.40 | N/A |
| Site 24 | 130,149 | 161.30 | 199.20 | N/A |
| Site 25 | 657,570 | 117.85 | 69.33 | N/A |
| Site 26 | 39,340 | 6.20 | 6.20 | N/A |
| Site 27 | 194,606 | 21.90 | 21.90 | N/A |
| Site 28 | 75,476 | 7.80 | 7.80 | N/A |

**Table 2. Summary of Evaluated Gross Savings by Measure Type**

| Measure Type | Partici-pation Count | Evaluated Per unit kWh impact | Evaluated Per unit NCP kW impact | Evaluated Per unit CP kW impact | Evaluated kWh Savings | Evaluated NCP kW Savings | Evaluated CP kW Savings |
|---|---|---|---|---|---|---|---|
| Lighting | 7 | 154,387 | 26 | 13 | 1,080,709 | 185 | 94 |
| HVAC | 13 | 940,065 | 211 | 143 | 12,220,840 | 2,737 | 1,858 |
| Process | 8 | 962,594 | 103 | 106 | 7,700,749 | 825 | 847 |

[1] NCP kW is an abbreviation for non-coincident peak kW
[2] CP kW is an abbreviation for coincident peak kW
[3] The study evaluated electricity savings only.

**Table 3. Summary of Ex Ante Savings by Measure Type**

| Measure Type | Partici-pation Count | Ex Ante Per unit kWh impact | Ex Ante Per unit NCP kW impact | Ex Ante Per unit CP kW impact | Ex Ante kWh Savings | Ex Ante NCP kW Savings | Ex Ante CP kW Savings |
|---|---|---|---|---|---|---|---|
| Lighting | 7 | 162,417 | 24 | 23 | 1,136,918 | 166 | 159 |
| HVAC | 13 | 873,117 | 184 | 131 | 11,350,519 | 2,391 | 1,705 |
| Process | 8 | 978,612 | 121 | 116 | 7,828,897 | 969 | 926 |

**Table 4. Ex-Ante Savings Estimates by Customer[4]**

| Customer | Ex Ante kWh Savings | Ex Ante NCP kW Savings | Ex Ante CP kW Savings |
|---|---|---|---|
| Site 1 | 167,454 | 44.10 | 41.66 |
| Site 2 | 479,209 | 108.28 | 80.58 |
| Site 3 | 1,284,468 | 233.77 | 182.36 |
| Site 4 | 10,100 | 4.16 | 3.10 |
| Site 5 | 4,832,346 | 552.00 | 462.50 |
| Site 6 | 5,991,963 | 686.14 | 686.14 |
| Site 7 | 190,343 | 34.18 | 9.56 |
| Site 8 | 698,742 | 62.55 | 62.55 |
| Site 9 | 191,139 | 21.92 | 21.92 |
| Site 10 | 528,652 | 60.30 | 60.50 |
| Site 11 | 40,915 | 15.40 | 15.40 |
| Site 12 | 632,527 | 86.17 | 106.37 |
| Site 13 | 1,910,023 | 610.85 | 528.37 |
| Site 14 | 106,952 | 12.19 | 16.67 |
| Site 15 | 252,206 | 38.64 | 11.13 |
| Site 16 | 148,014 | 80.00 | 17.65 |
| Site 17 | 60,259 | 9.17 | 9.17 |
| Site 18 | 716,028 | 81.69 | 77.90 |
| Site 19 | 217,522 | 73.53 | 0.00 |
| Site 20 | 463,752 | 105.58 | 31.94 |
| Site 21 | 61,296 | 5.32 | 0.00 |
| Site 22 | 271,999 | 76.73 | 85.38 |
| Site 23 | 63,041 | 14.00 | 14.00 |
| Site 24 | 103,510 | 188.90 | 13.67 |
| Site 25 | 507,265 | 271.47 | 202.03 |
| Site 26 | 43,578 | 7.49 | 7.49 |
| Site 27 | 255,828 | 31.84 | 31.83 |
| Site 28 | 87,203 | 10.27 | 10.27 |

[4] Savings shown for entire project as unit savings are not applicable for custom projects.

# Introduction and Purpose of Study

## Summary of the Evaluation

This report presents the results of an impact evaluation of the Ohio Smart $aver Non-Residential Custom Incentive Program, herein referred to as the "Custom Program".

## Evaluation Objectives

An impact analysis was performed utilizing an M&V plan that was developed following the International Performance Measurement and Verification Protocol (IPMVP)[5]. The projects were separated into lighting, HVAC, and process categories, and samples were drawn from each category. The goal of the impact analysis was to estimate a savings realization rate for each category that can be projected into the full program participant population, and then could be applied to each new application Duke Energy Ohio receives by category.

This report is structured to provide program energy impact estimations via the engineering analysis. The impact tables reporting total savings are based on the savings identified from 28 surveyed participants extrapolated to the program's total participants through December 31, 2011. The engineering estimates were calculated using data from the sample of participants using the date range of January 2009 through April 2011.

## Researchable Issues

The evaluation issues researched in this study are listed below:

1. Estimate kWh, non-coincident peak (NCP) kW and coincident peak (CP) kW savings for each project in the sample
2. Calculate kW and kWh realization rates for each project
3. Calculate average kW and kWh realization rates by lighting, HVAC, and process projects
4. Calculate confidence intervals around the realization rates
5. Identify causes for differences between evaluated savings and ex-ante savings estimates

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

# Description of Program

The Duke Energy Custom Program is intended to supplement the Smart $aver® Non-Residential Prescriptive Incentive Program, which provides prescriptive rebates on pre-selected measures. Customers who want to install measures not on the Smart $aver Non-residential Prescriptive Incentive Program list are provided the opportunity to apply for a rebate through the Custom Program. The number of project applications that were reviewed and approved is shown below.

**Table 5. Program Participation Count**

| Program | Participation Count for January 2009 through April 2011 |
|---|---|
| Smart $aver Non-Residential Custom Incentive Program | 77 |

# Methodology

## Overview of the Evaluation Approach

This impact evaluation was performed using an engineering analysis of a sample of 28 out of 77 projected[6] total program participants.

### Study Methodology

The impact methodology consisted of engineering analysis following the International Performance Measurement and Verification Protocol (IPMVP)[7]. The projects were separated into lighting, HVAC, and process categories, and samples were drawn from each category. An M&V plan was developed following the IPMVP. Site surveys and metering equipment were installed to gather data according to the M&V plan. Pre and post installation measurements were taken whenever possible. Energy and demand savings estimates were developed for each sampled project. The goal of the impact analysis was to estimate a savings realization rate for each category that can be prospectively projected into the full program participant population.

### Data collection methods, sample sizes, and sampling methodology

Based on the projected participation of 77 projects, an initial sample of 31 projects was chosen to meet a sampling error of +/- 10% at 90% confidence.

[6] Projected participation included projects at the contract approval stage (where the incentive offer was accepted by the customer), along with projects that were completed and paid. It was possible that some of the projects at the contract approval stage may not be completed, hence the total participation count was a projection.

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

Site surveys were conducted and metering equipment was installed to gather data according to the M&V plan. Pre and post installation measurements were taken whenever possible. Energy and demand savings estimates were developed for each sampled project.

### Number of completes and sample disposition for each data collection effort

The sample disposition for the impact study is shown in Table 6.

**Table 6. Status of 2009-2011 Sample**

| Group | Sample Size | Completed | Notes |
|---|---|---|---|
| Lighting | 7 | 7 | Sample completed |
| HVAC | 15 | 13 | Construction not completed in time for post-period monitoring |
| Process | 9 | 8 | Construction not completed in time for post-period monitoring |
| **Total** | **31** | **28** | |

### Expected and achieved precision

The sample design was expected to return a sampling error of +/- 10% at 90% confidence. Due to sample dropout and actual sample variability, the achieved precision was +/- 11.1% at 90% confidence.

### Description of baseline assumptions, methods and data sources

For early replacement projects, the baseline assumption was the existing equipment. For normal replacement projects where the equipment is covered by state or federal energy standards, the minimally code compliant efficiency is the baseline. For normal replacement projects not covered by state or federal energy standards, industry common practice is the baseline.

### Description of measures and selection of methods by measure(s) or market(s)

The custom program encompasses a wide variety of measures. Current applications include a variety of lighting, HVAC, and industrial process projects. Lighting projects include fixture types not currently covered under the Smart $aver Non-Residential Prescriptive Incentive Program. HVAC projects include HVAC controls, equipment upgrades, and cool roof projects. Process projects include refrigeration systems, compressed air, and injection molding machines.

All projects were evaluated in compliance with the IPMVP. All projects were evaluated under either IPMVP Option A[8] or IPMVP Option D[9].

### Use of TRM values and explanation if TRM values not used

The study relied on primary data collection, engineering algorithms, building energy simulation modeling, and statistical regression modeling. Since this is a custom program, TRM algorithms and values do not apply.

[8] IPMVP Option A – Partially Measured Retrofit Isolation. See impact section below for more information.
[9] IPMVP Option D – Calibrated Simulation. See impact section below for more information.

### Threats to validity, sources of bias and how those were addressed

The study utilized a pre/post M&V protocol when feasible. Due to project timing, post-only measurements were made for some projects. The use of post-only measurements for these projects is not expected to significantly bias the results. Early sites were studied systematically before moving to a random selection process. The systematic selection of early projects could introduce some bias in the sample, but the project selection seems representative of the overall program participation. State of the art engineering modeling techniques, including building energy simulation modeling were employed to reduce engineering bias.

### Snapback and Persistence

The theoretical additional energy and capacity used by customers that may occur from implementing an energy efficiency product, often called "snapback" is not factored into this evaluation. In addition, TecMarket Works does not believe that snapback is an issue in evaluations of Custom programs. This is because of two key reasons: First, customers participating in the Custom Programs do not typically base energy-intensive investment decisions on the degree of savings being achieved from previous installed energy efficiency measures. Instead, these customers tend to base energy efficient investment decisions on the benefits and costs associated with a single project requiring an investment decision. Second, the very concept of snapback is theoretical in nature. There has yet to be an evaluation conducted of an energy efficiency program that has reliably documented a snapback effect. Studies of snapback based on the last 20-plus years of California's well-funded and aggressive energy efficiency portfolio demonstrate that snapback does not exist. California's per person energy consumption has remained flat for 20 years with energy efficiency programs; while other states not offering aggressive portfolios of energy efficiency programs over that period (more than 20 years) have increased per-person energy consumption. If snapback existed to any degree, per-person energy consumption in California would have increased at the same rate as states that have not offered a long history of energy efficiency programs. TecMarket Works does not believe that snapback exists for the Duke Energy Custom program and does not incorporate approaches to adjust savings for theoretical and unproven concepts.

The evaluation did not address how long these savings are likely to persist over time because the time span of the available data was not sufficient to address this issue.

# Impact Evaluation Findings

## Engineering-Based Impact Analysis

The impact evaluation employed a tracking system review, sample design and selection, an engineering review of the custom program applications, field measurement and verification (M&V) of selected projects, data analysis and reporting. Tracking data obtained from Duke Energy from January 2009 through April, 2011 shows the following breakdown of ex-ante energy savings by measure:

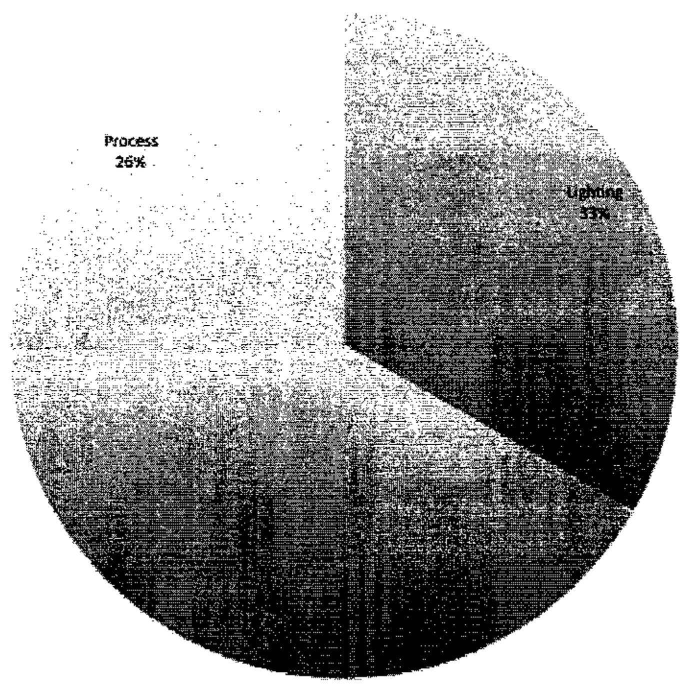



**Figure 1. Energy Savings by Project Type**

## Sample Design

The program evaluation started in June of 2009. Program participation was light in the early stages of the program, but program managers were interested in getting early feedback. Thus, the initial projects were evaluated as they were approved. As program participation increased, projects were studied on a sample basis. The projects were assigned as the program developed to one of three categories: Lighting, HVAC, and Process. The projects were grouped into similar technology categories to minimize the variation in the realization rates across projects and provide better precision in the overall program results. The realization rates across the technology categories also provided an idea of which types of projects are performing closer to original expectations.

The program tracking system is based on the Sales Force customer relationship management tool. Project leads are entered into the Sales Force system, and tracked as they progress in the system. In general, the process is as follows:

1. ***Initial Application.*** Customer submits an application for the project, including a project description and energy savings calculations.
2. ***Application Review.*** Applications are reviewed by a Duke Energy contractor for program eligibility and reasonableness. Modifications are made to the savings estimates as necessary. Project cost effectiveness is calculated and the incentive offer is determined.
3. ***Proposal to Customer.*** A rebate proposal based on the reviewed and adjusted (as necessary) savings estimate and incentive offer is presented to the customer.
4. ***Contract Approval.*** The customer has accepted the incentive and plans to move forward with the project.
5. ***Project Completion.*** The customer has completed the project, and requested and received their incentive.

Projects that are at the Proposal to Customer stage are put in a list of potential candidates. Once the project proceeds to Contract Approval, it is eligible for sampling. The intention is to capture as many projects in the contract approval phase before construction begins in order to obtain pre-installation data.

The sampling plan incorporates a stratified random sample approach, where the projects are stratified according to technology type (lighting, HVAC, or process), and sampled randomly within each stratum. Early projects were evaluated systematically to satisfy the needs for early feedback. As program participation increased, a random sample approach was introduced.

The total sample size is calculated from the following equation[10]:

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

where:

n = total sample size required
$kWh_k$ = estimated savings from group k
$cv_k$ = assumed coefficient of variation for group k

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

P = desired precision
KWh = total kWh savings
Z = z statistic (1.645 at 90% confidence)
$N_k$ = population size of group k

Samples are allocated to each group based on the following equation:

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

The Ohio participation at the time of sample selection is summarized in Table 7. This projection assumed all projects in the Contract Approval stage would complete construction and would be paid in this evaluation cycle.

**Table 7. Sample Selection for Custom Component of Ohio Custom Program**

| Group | kWh | cv | Total Projects | Sample Size |
|---|---|---|---|---|
| Lighting | 13,881,282 | 0.3 | 20 | 7 |
| HVAC | 17,044,128 | 0.5 | 42 | 15 |
| Process | 10,803,126 | 0.5 | 15 | 9 |
| Total | | | 77 | 31 |

Since lighting projects are generally more predictable, an initial assumption of 0.3 was used for the coefficient of variation. Otherwise, a coefficient of variation of 0.5 was used, consistent with sampling criteria in the IPMVP for projects where previous variability data are not available. A sample of 31 projects was used in the program evaluation, split across lighting, HVAC, and Process projects.

## Sample Status

At the conclusion of the evaluation, three of the projects in the sample did not complete and thus were eliminated from the sample. The achieved sample is shown in the table below.

**Table 8. Status of 2009-2011 Sample**

| Group | Sample Size | Completed | Notes |
|---|---|---|---|
| Lighting | 7 | 7 | Sample completed |
| HVAC | 15 | 13 | Construction at 2 sites not completed in time for post-period monitoring |
| Process | 9 | 8 | Construction at 1 site not completed in time for post-period monitoring |
| | 31 | 28 | |

The completed projects are summarized in Table 9 below.

**Table 9. Summary of Completed Projects**

| Site Number | Facility Type | Project Type | Expected kWh savings | Expected NCP kW savings | Expected CP kW savings |
|---|---|---|---|---|---|
| Site 1 | School | Lighting | 167,454 | 44.10 | 41.66 |
| Site 2 | Healthcare | HVAC | 479,209 | 108.28 | 80.58 |
| Site 3 | Hotel | HVAC | 1,284,468 | 233.77 | 182.36 |
| Site 4 | Gymnasium | HVAC | 10,100 | 4.16 | 3.10 |
| Site 5 | Convenience Store | HVAC | 4,832,346 | 552.00 | 462.50 |
| Site 6 | Grocery | Process | 5,991,963 | 686.14 | 686.14 |
| Site 7 | Grocery | Process | 190,343 | 34.18 | 9.56 |
| Site 8 | School district | HVAC | 698,742 | 62.55 | 62.55 |
| Site 9 | Refrigerated Warehouse | Lighting | 191,139 | 21.92 | 21.92 |
| Site 10 | Convenience Store | Lighting | 528,652 | 60.30 | 60.50 |
| Site 11 | Refrigerated Warehouse | Lighting | 40,915 | 15.40 | 15.40 |
| Site 12 | Hospital | HVAC | 632,527 | 86.17 | 106.37 |
| Site 13 | School | HVAC | 1,910,023 | 610.85 | 528.37 |
| Site 14 | Industrial | Process | 106,952 | 12.19 | 16.67 |
| Site 15 | Industrial | Process | 252,206 | 38.64 | 11.13 |
| Site 16 | School | HVAC | 148,014 | 80.00 | 17.65 |
| Site 17 | Gymnasium | Lighting | 60,259 | 9.17 | 9.17 |
| Site 18 | Industrial | Process | 716,028 | 81.69 | 77.90 |
| Site 19 | Industrial | HVAC | 217,522 | 73.53 | 0.00 |
| Site 20 | Office | HVAC | 463,752 | 105.58 | 31.94 |
| Site 21 | Prison | Lighting | 61,296 | 5.32 | 0.00 |
| Site 22 | Industrial | Process | 271,999 | 76.73 | 85.38 |
| Site 23 | Office | HVAC | 63,041 | 14.00 | 14.00 |
| Site 24 | School | HVAC | 103,510 | 188.90 | 13.67 |
| Site 25 | Hotel | HVAC | 507,265 | 271.47 | 202.03 |
| Site 26 | Industrial | Process | 43,578 | 7.49 | 7.49 |
| Site 27 | Industrial | Process | 255,828 | 31.84 | 31.83 |
| Site 28 | Office | Lighting | 87,203 | 10.27 | 10.27 |

## Application Review

The customer application for each site was obtained from Duke Energy, along with any supporting documentation. Each application was reviewed to gain an understanding of the measures included and the expected savings. The Duke Energy Business Relations Manager (BRM) associated with each sampled site was contacted to secure customer participation in the evaluation. Once contact was established with the customer, follow-on phone calls and emails were exchanged to better understand the facility, the measures, and the construction schedule.

## M&V Plan Development

An M&V plan was developed by Architectural Energy Corporation for each sampled site. The M&V plan covered the following topic areas:

***Introduction.*** The project and the measures installed were described in sufficient detail to understand the M&V project scope and methodology. Savings by measure were shown and the M&V priorities for measures within the project were listed. The project baseline assumptions were also described.

***Goals and Objectives.*** The overall goals and objectives of M&V activity were listed.

***Building Characteristics.*** An overview of the building, with a summary table of relevant building characteristics, such as building size (square footage), number of stories, building envelope, lighting system, HVAC system type, etcetera, was provided.

***Data Products and Project Output.*** Specific end products – kWh savings, coincident and noncoincident kW savings, and therm savings were listed. Raw and processed data to be supplied at the conclusion of the study were identified.

***M&V Option.*** The M&V Option according to the International Performance Measurement and Verification Protocol (IPMVP) was described. The options are summarized below:

- ***Option A - Partially Measured Retrofit Isolation.*** Savings under Option A are determined by partial field measurement of the energy use of the system(s) to which an energy conservation measure (ECM) was applied separate from the energy use of the rest of the facility. Measurements may be either short-term or continuous. Partial measurement means that some parameter(s) affecting the building's energy use may be stipulated, if the total impact of possible stipulation error(s) is not significant to the resultant savings. Savings are estimated from engineering calculations based on stipulated values and spot, short-term and/or continuous post-retrofit measurements.
- ***Option B - Retrofit Isolation.*** Savings under Option B are determined by field measurement of the energy use of the systems to which the ECM was applied separate from the energy use of the rest of the facility. Savings are estimated directly from measurements. Stipulated values are not allowed.
- ***Option C - Whole Facility.*** Savings under Option C are determined by measuring energy use at the whole-facility level. Short-term or continuous measurements are taken throughout the post-retrofit period and compared to 12 to 24 months of pre-retrofit data. Savings are estimated from analysis of whole-facility utility meter or sub-meter data using techniques ranging from simple comparison of utility bills to regression analysis.
- ***Option D - Calibrated Simulation.*** Savings under Option D are determined through building energy simulation[11] of the energy use of components or the whole facility, calibrated with hourly or monthly utility billing data, and/or end-use metering.

***Data Analysis.*** The engineering methods and/or equations used to generate the data products identified above were listed. The data sources, either measurements or stipulated values from secondary data sources, were identified.

[11] DOE-2 is a commonly used building energy simulation program.

***Field Data Points.*** Specific field data points collected through the M&V plan were listed. The field data were a combination of survey data, one-time measurements, and time series data collected from data loggers installed for the project or trend data collected from the site energy management system (EMS).

***Data Accuracy.*** Meter and sensor accuracy for each field measurement point was listed.

***Verification and Quality Control.*** The steps taken to validate the accuracy and completeness of the raw field data were listed.

***Recording and Data Exchange Format.*** The format of the raw and processed data files used in the analysis and supplied as data products were listed.

The M&V plans, along with the processed data summary and project results are shown in Appendix B. A summary of the M&V plan for each site is shown in Table 10.

**Table 10. M&V Plan Summary**

| Customer | Project Type | IPMVP Option | M&V Plan Summary |
|---|---|---|---|
| Site 1 | Lighting | A | Spot measurements of lighting fixture power combined with stipulated operating hours |
| Site 2 | HVAC | A | Engineering analysis combined with post installation monitoring |
| Site 3 | HVAC | A | Pre/post measurements of packaged terminal air conditioner (PTAC) current combined with spot kW |
| Site 4 | HVAC | D | DOE-2 model based on post-installation survey |
| Site 5 | HVAC | A | Pre/post measurements of HVAC and condensing unit current combined with spot kW |
| Site 6 | Process | A | Post only measurements of LED case lighting and occupancy sensors |
| Site 7 | Process | A | Pre/post measurements of refrigeration compressor amps combined with spot kW |
| Site 8 | HVAC | A | Fixture count verification at a sample of 9 schools; monitoring at a sample of 2 |
| Site 9 | Lighting | A | Post only monitoring of a sample of lighting circuits. Field verification of installed fixture count and type |
| Site 10 | Lighting | A | Post-only spot watts of lighting fixtures; log lighting circuit current to verify operating hours |
| Site 11 | Lighting | A | Time series current logging on a sample of lighting circuits |
| Site 12 | HVAC | A | Load from one-time gpm (from energy management system) and measured chilled water loop temperature difference. Post only time series kW. Pre kW estimated from chilled water temperature, condenser water temperature, outdoor wetbulb temperature and typical chiller performance curves |

| Customer | Project Type | IPMVP Option | M&V Plan Summary |
|---|---|---|---|
| Site 13 | HVAC | A | Short term post only monitoring of a sample of lighting circuits across the 10 schools. |
| Site 14 | Process | A | Post only monitoring of variable frequency drive equipped compressor combined with vendor monitoring of existing compressor plant |
| Site 15 | Process | A | Post only monitoring of variable frequency drive equipped compressor combined with vendor monitoring of existing compressor plant |
| Site 16 | HVAC | D | Onsite survey of building characteristics combined with energy management system trend logs of measure operation |
| Site 17 | Lighting | A | Post only monitoring of a sample of lighting circuits |
| Site 18 | Process | A | Vendor measurements of existing system kWh combined with Post measurements of compressor kW |
| Site 19 | HVAC | A | Post measurements of humidifier kW and latent humidification load. Pre estimated from load and steam generator efficiency. |
| Site 20 | HVAC | D | Building onsite survey used to develop DOE-2 model. Short term trend logs from a sample of 16 heat pumps used to verify measure operation. |
| Site 21 | Lighting | A | Spot measurements of lighting circuit kW and current combined with time series current measurements |
| Site 22 | Process | A | Post time series logging of new and backup compressors |
| Site 23 | HVAC | D | Onsite survey of treated and untreated floors. Data logging of treated and non-treated HVAC equipment |
| Site 24 | HVAC | D | Onsite survey of building characteristics data to build DOE-2 model. |
| Site 25 | HVAC | D | Onsite survey of a sample of guest rooms. Trend data showing occupancy and setpoints. Survey hotel personnel to establish baseline control strategies. |
| Site 26 | Process | A | Time series measurements of pump kW |
| Site 27 | Process | A | Spot watt measurement of existing compressor kW combined with vendor measurements of compressor operating hours. Post installation time series kW monitoring of variable frequency drive equipped compressor. |
| Site 28 | Lighting | A | Lighting circuit logging of a sample of circuits |

## Measurement and Verification

Field data were collected by Duke Energy contractors according to the M&V plan. The Duke Energy contractors were trained by personnel from Architectural Energy Corporation and BuildingMetrics Incorporated. In addition to the training, meter installations were observed by contractors representing the Public Utility Commission of Ohio (PUCO). Metering equipment consisted of a combination of light loggers, portable data acquisition equipment (capable of measuring temperature, relative humidity, electric current, etc.), as well as true electric power meters. The specific instrumentation used at each site is described in Appendix B and summarized below. Survey data and spot measurements were obtained during meter installation. The metering equipment was installed for a period ranging from 2 weeks to 6 weeks, depending on the nature and variability of the energy consumption of the metered equipment. The metering duration used in each site is also described in Appendix B and summarized in Table 11 below.

**Table 11. M&V Approach Summary**

| Customer | Project Type | Measurements Taken | Monitoring Duration |
|---|---|---|---|
| Site 1 | Lighting | Spot measurements of post-installation fixture power | One-time |
| Site 2 | HVAC | True electric power measurements of air handling unit (AHU) fans, AHU and outdoor temperatures and relative humidity. | 5+ weeks post only |
| Site 3 | HVAC | Pre/post PTAC current | 3+ weeks pre/ 2+ weeks post |
| Site 4 | HVAC | Comprehensive onsite survey for DOE-2 model development | N/A |
| Site 5 | HVAC | Spot watt and time series current for Rooftop air conditioners, refrigeration system condensing units, display cases, water heater | 4 weeks pre and 4 weeks post |
| Site 6 | Process | Light logger on occupancy sensor controlled case lighting | 3 weeks post only |
| Site 7 | Process | Spot watt and time series current for refrigeration compressors | 3 weeks pre/post |
| Site 8 | HVAC | Outdoor fixture circuit current | 3 weeks |
| Site 9 | Lighting | Time series lighting circuit current and spot circuit kW measurements | 3 weeks |
| Site 10 | Lighting | Spot watts and time series current on sample of lighting circuits | 3 weeks |
| Site 11 | Lighting | Post-only time series current measurements on sample of lighting circuits. Spot watt measurements of circuit power and current | 3 weeks |
| Site 12 | HVAC | Chiller kW, chilled water loop temperature difference, condenser water temperature, outdoor temperature and relative humidity. | 4 weeks |
| Site 13 | HVAC | Spot watt measurements of lighting circuit power and current, time series current measurements on a sample of lighting circuits | 3 weeks |
| Site 14 | Process | Compressor kW | 3 weeks |
| Site 15 | Process | Time series true electric power for variable frequency drive equipped compressor | 3 weeks |
| Site 16 | HVAC | Outdoor temperature, Air hander supply air, mixed air and return air temperatures, CO2 concentration, energy recovery ventilator entering and leaving air temperature. | 3 weeks |
| Site 17 | Lighting | Spot measurements of lighting circuit kW and current. Time series current measurements | 3 weeks |
| Site 18 | Process | Existing Compressor kW, new compressor kW, air dryer current | 3 weeks |

| Customer | Project Type | Measurements Taken | Monitoring Duration |
|---|---|---|---|
| Site 19 | HVAC | Humidifier kW, humidifier entering temperature and relative humidity humidifier leaving temperature and relative humidity, outdoor temperature and relative humidity. | 3 weeks |
| Site 20 | HVAC | Heat pump current, supply air temperature, outdoor air temperature and relative humidity. | 3 weeks |
| Site 21 | Lighting | Lighting circuit current, spot kW and current | 3 weeks |
| Site 22 | Process | True electric power for new and backup compressors | 3 weeks |
| Site 23 | HVAC | Comprehensive onsite data collection for DOE-2 model development plus time series data on air handers, cooling tower, pneumatic controls compressor, outdoor temperature and relative humidity. | 3 weeks |
| Site 24 | HVAC | Comprehensive onsite data collection for DOE-2 model development plus time series data on lighting circuits to verify daylighting controls operation | 3 weeks |
| Site 25 | HVAC | Trend data on a sample of guest rooms | 1 week |
| Site 26 | Process | Time series measurements of injection molding machine | 4 weeks |
| Site 27 | Process | Compressor kW pre (one time) and post (time series) | 3 weeks |
| Site 28 | Lighting | Spot kW and time series current | 3 weeks |

## Calculations and Reporting

Pre and post installation data were collected by Duke Energy contractors and forwarded to Architectural Energy Corporation for analysis. The data were analyzed according to the M&V plan developed for each project. Data analysis consisted of pre / post comparisons of monitored data extrapolated to annual consumption and demand using simple engineering models or linear regression techniques as described in the M&V plan. A site report was developed for each completed project. The reports are attached in Appendix B. The calculations and analysis techniques are summarized in Table 12.

**Table 12. Calculation Approach Summary**

| Site Number | Project Type | Calculations |
|---|---|---|
| Site 1 | Lighting | Engineering equations |
| Site 2 | HVAC | Engineering equations and regression model expanded using bin data. |
| Site 3 | HVAC | Regression model expanded using bin data. |
| Site 4 | HVAC | DOE-2 building energy simulation |
| Site 5 | HVAC | Engineering equations and regression model expanded using bin data. |
| Site 6 | Process | Engineering equations |
| Site 7 | Process | Regression model expanded using bin data |
| Site 8 | HVAC | Engineering calculations with short term monitoring (STM) of lighting hours. HVAC measures passed through. |
| Site 9 | Lighting | Engineering calculations supported by monitored lighting power. Interactions with refrigeration system included |
| Site 10 | Lighting | Short term measurements adjusted for nighttime hours across the year. Standard values used for baseline lighting fixtures. Measure values used for efficient fixtures. |

| Site Number | Project Type | Calculations |
|---|---|---|
| Site 11 | Lighting | Engineering calculations using standard baseline wattage assumptions, mfg. catalog post watt and monitored lighting hours. |
| Site 12 | HVAC | Regression model used to project STM into annual kWh |
| Site 13 | HVAC | Engineering calculations of lighting savings. |
| Site 14 | Process | Pre/post analysis of time series data by daytype |
| Site 15 | Process | Engineering calculations of pre/post kWh by daytype projected to annual savings |
| Site 16 | HVAC | Whole building analysis using ASHRAE Standard 90.1-2004 baseline |
| Site 17 | Lighting | Engineering calculations of lighting savings using monitored lighting hours |
| Site 18 | Process | Pre post kWh comparison adjusted for cfm differences |
| Site 19 | HVAC | Humidification energy estimated from AHU cfm and entering and leaving conditions. Pre kWh estimated from latent heat addition from an electric resistance heat source. Regression model applied to daily kWh estimates pre and post |
| Site 20 | HVAC | Short term data processed to inform DOE-2 model inputs. Model calibrated to billing data |
| Site 21 | Lighting | Engineering calculations of lighting savings |
| Site 22 | Process | Pre/post kWh comparisons, adjusted for no loss drains and leak sealing. Pre-monitoring conducted by vendor. |
| Site 23 | HVAC | DOE-2 building energy simulation, inputs derived from treated and untreated equipment |
| Site 24 | HVAC | Building energy simulation using DOE-2. ASHRAE Standard 90.1-2004 used as baseline |
| Site 25 | HVAC | DOE-2 building energy simulation, inputs derived from trend data |
| Site 26 | Process | *True electric power measurements of injection molding machine input power* |
| Site 27 | Process | Adjust Pre kW for reduction in system pressure |
| Site 28 | Lighting | Engineering calculations of lighting savings. One of two buildings upgraded. Untreated building used as baseline. |

## Results

The results of the evaluation are reported in this section. Annual savings for kWh and kW are reported along with their realization rates for each project. These data are summarized by project type. An independent assessment of the project life is also reported.

### Annual Savings

A summary of the annual savings from each project is shown in Table 14. The average annual realization rate by project type is shown in Table 15.

The estimated sampling precision in the realization rates is shown in Table 13.

**Table 13. Realization Rate Achieved Sampling Precision**

| Project Type | Population Size | Sample Size | Actual Sample cv | Relative Precision |
|---|---|---|---|---|
| Lighting | 20 | 7 | 0.42 | +/- 23% |
| HVAC | 42 | 13 | 0.54 | +/- 20% |
| Process | 15 | 8 | 0.15 | +/- 6% |
| Total | 77 | 28 | | +/- 11.1% |

**Table 14. Annual Results Summary**

| Site | Project Type | kWh Savings | | | NCP kW Savings | | | CP kW Savings | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Evaluated | Expected | RR | Evaluated | Expected | RR | Evaluated | Expected | RR |
| Site 1 | Lighting | 258,169 | 167,454 | 1.54 | 42.00 | 44.10 | 0.95 | 42.00 | 41.66 | 1.01 |
| Site 2 | HVAC | 399,610 | 479,209 | 0.83 | 226.00 | 108.28 | 2.09 | 70.00 | 80.58 | 0.87 |
| Site 3 | HVAC | 3,378,176 | 1,284,468 | 2.63 | 483.00 | 233.77 | 2.07 | 483.00 | 182.36 | 2.65 |
| Site 4 | HVAC | 4,798 | 10,100 | 0.48 | 13.40 | 4.16 | 3.22 | 8.20 | 3.10 | 2.65 |
| Site 5 | HVAC | 3,775,031 | 4,832,346 | 0.78 | 588.00 | 552.00 | 1.07 | 588.00 | 465.50 | N/A |
| Site 6 | Process | 5,591,557 | 5,991,963 | 0.93 | 603.26 | 686.14 | 0.88 | 603.00 | 686.14 | 0.88 |
| Site 7 | Process | 360,188 | 190,343 | 1.89 | 56.00 | 34.18 | 1.64 | 56.00 | 9.56 | 5.86 |
| Site 8 | HVAC | 587,214 | 698,742 | 0.84 | 61.30 | 62.55 | 0.98 | 0.00 | 62.55 | 0.00 |
| Site 9 | Lighting | 247,604 | 191,139 | 1.30 | 24.50 | 21.92 | 1.12 | 28.20 | 21.92 | 1.29 |
| Site 10 | Lighting | 329,359 | 528,652 | 0.62 | 64.40 | 60.30 | 1.07 | 0.00 | 60.50 | 0.00 |
| Site 11 | Lighting | 52,653 | 40,915 | 1.29 | 13.70 | 15.40 | 0.89 | 13.70 | 15.40 | 0.89 |
| Site 12 | HVAC | 449,297 | 632,527 | 0.71 | 21.00 | 86.17 | 0.24 | 21.00 | 106.37 | 0.20 |
| Site 13 | HVAC | 1,813,844 | 1,910,023 | 0.95 | 768.00 | 610.85 | 1.26 | 384.00 | 528.37 | 0.73 |
| Site 14 | Process | 161,110 | 106,952 | 1.51 | 5.10 | 12.19 | 0.42 | 27.70 | 16.67 | 1.66 |
| Site 15 | Process | 347,394 | 252,206 | 1.38 | 28.60 | 38.64 | 0.74 | 28.60 | 11.13 | 2.57 |
| Site 16 | HVAC | 237,528 | 148,014 | 1.60 | 319.20 | 80.00 | 3.99 | 22.00 | 17.65 | 1.25 |
| Site 17 | Lighting | 22,341 | 60,259 | 0.37 | 9.90 | 9.17 | 1.08 | 2.60 | 9.17 | 0.28 |
| Site 18 | Process | 719,314 | 716,028 | 1.00 | 75.00 | 81.69 | 0.92 | 75.00 | 77.90 | 0.96 |
| Site 19 | HVAC | 113,766 | 217,522 | 0.52 | 0.00 | 73.53 | 0.00 | 0.00 | 0.00 | |
| Site 20 | HVAC | 470,380 | 463,752 | 1.01 | -99.20 | 105.58 | -0.94 | -52.00 | 31.94 | -1.63 |
| Site 21 | Lighting | 95,107 | 61,296 | 1.55 | 22.80 | 5.32 | 4.29 | 0.00 | 0.00 | N/A |
| Site 22 | Process | 287,240 | 271,999 | 1.06 | 28.90 | 76.73 | 0.38 | 28.90 | 85.38 | 0.34 |
| Site 23 | HVAC | 203,477 | 63,041 | 3.23 | 76.70 | 14.00 | 5.48 | 65.40 | 14.00 | 4.67 |
| Site 24 | HVAC | 130,149 | 103,510 | 1.26 | 161.30 | 188.90 | 0.85 | 199.20 | 13.67 | 14.57 |
| Site 25 | HVAC | 657,570 | 507,265 | 1.30 | 117.85 | 271.47 | 0.43 | 69.33 | 202.03 | 0.34 |
| Site 26 | Process | 39,340 | 43,578 | 0.90 | 6.20 | 7.49 | 0.83 | 6.20 | 7.49 | 0.83 |
| Site 27 | Process | 194,606 | 255,828 | 0.76 | 21.90 | 31.84 | 0.69 | 21.90 | 31.83 | 0.69 |
| Site 28 | Lighting | 75,476 | 87,203 | 0.87 | 7.80 | 10.27 | 0.76 | 7.80 | 10.27 | 0.76 |

**Table 15. Average Annual Realization Rate by Project Type**

| Project Type | kWh Savings | | | NCP kW Savings | | | CP kW Savings | | |
|---|---|---|---|---|---|---|---|---|---|
| | Evaluated | Expected | RR | Evaluated | Expected | RR | Evaluated | Expected | RR |
| Lighting | 1,080,709 | 1,136,918 | 0.95 | 185 | 166 | 1.11 | 94 | 159 | 0.59 |
| HVAC | 12,220,840 | 11,350,519 | 1.08 | 2,737 | 2,391 | 1.14 | 1,858 | 1,705 | 1.09 |
| Process | 7,700,749 | 7,828,897 | 0.98 | 825 | 969 | 0.85 | 847 | 926 | 0.91 |
| Overall | 21,002,298 | 20,316,334 | 1.03 | 3,747 | 3,527 | 1.06 | 2,800 | 2,790 | 1.00 |

A summary of the specific findings from each project are shown in Table 16. See Appendix B for more information on each sampled project.

**Table 16. Findings Summary**

| Site Number | Project Type | Notes |
|---|---|---|
| Site 1 | Lighting | Additional operating hours verified |
| Site 2 | HVAC | Initial savings estimate provided by vendor with little detail, but realization rate was above 80% |
| Site 3 | HVAC | Occupancy controls along with heat pumps replacing PTACs with electric heat were very effective |
| Site 4 | HVAC | Cool roof savings less than simplified vendor calculations. |
| Site 5 | HVAC | All roof top unit outdoor air dampers shut off. No mechanical ventilation or outdoor air economizers. |
| Site 6 | Process | Limited savings from occupancy sensors |
| Site 7 | Process | Old compressor near end of effective useful life. Remaining life unknown. |
| Site 8 | HVAC | Site assigned to HVAC category, but is majority lighting. Not all projects are complete; savings based on projected completion of remaining projects. |
| Site 9 | Lighting | Straightforward lighting project that performed well. |
| Site 10 | Lighting | Additional non-rebated lamps observed during field work. Application based on 24/7 operation of lighting. Some override of photocell controls noticed. |
| Site 11 | Lighting | Combination of LVD (induction) and T8 fixtures. Original application showed only induction fixtures. |
| Site 12 | HVAC | Chiller sequencing changed, reducing effect of variable frequency drive on chiller compressor. Limits on minimum condenser water temperature due to other chillers in the plant also reduced savings. |
| Site 13 | HVAC | Assigned to HVAC stratum, but measures were mostly lighting. HVAC measures denied by Duke, with the exception of window replacements. Some exterior lighting photocells malfunctioned. Some planned fixture replacements did not occur. Several projects are planned but not completed. Savings based on completion of remaining projects. |
| Site 14 | Process | Straightforward compressed air project. Comprehensive analysis conducted by vendor provided sound technical basis for project. |
| Site 15 | Process | Straightforward compressed air project. Comprehensive analysis conducted by vendor provided sound technical basis for project. |
| Site 16 | HVAC | Savings claimed for economizers and heating system setback thermostats that are required by code. Lighting savings higher than expected. |
| Site 17 | Lighting | Occupancy sensors installed by owner outside of project reduced lighting operating hours |
| Site 18 | Process | Straightforward compressed air project. Comprehensive analysis conducted by vendor provided sound technical basis for project. |
| Site 19 | HVAC | Ultrasonic humidifiers only; ECM 1 (boiler replacement) not implemented |
| Site 20 | HVAC | Off-hour controls of a series of zone level water loop heat pumps. Return from off hour control caused a start-up peak, thus increasing non-coincident peak demand. Other measures denied by Duke. |
| Site 21 | Lighting | Observed operating hours less than application. Savings claim based on 76 fixtures; 145 fixtures verified. |
| Site 22 | Process | Straightforward air compressor project |
| Site 23 | HVAC | Project in progress; savings extrapolated from observed work to whole building. No savings assigned to thermostat calibration or AC compressor rebuilds. Claim reduced by 65% from value in application. |

| Site Number | Project Type | Notes |
|---|---|---|
| Site 24 | HVAC | Whole building new construction project assigned to HVAC stratum. Savings observed across lighting and HVAC end-uses. Lighting controls operating correctly. |
| Site 25 | HVAC | Setpoint schedules for Rented & Occupied, Rented & Unoccupied, Unrented (but available) and Unavailable (Off) modes projected into annual occupancy. Savings due primarily to fan energy reductions at room fan-coil units. |
| Site 26 | Process | VFD on injection molding machine performed to expectations. Machine throughput difficult to predict due to economy. |
| Site 27 | Process | Straightforward compressed air project. Comprehensive analysis conducted by vendor provided sound technical basis for project. |
| Site 28 | Lighting | Savings based on completion of one of two projects totaling 74 fixtures. Claim based on 79 fixtures. |

## Project Life

An independent assessment of the project life was conducted and compared to the project life estimates prepared by Wisconsin Energy Conservation Corporation[12] (WECC), in consultation with Duke Energy program managers. The WECC project life estimates were used to set incentive levels, and calculate the lifecycle savings and benefits of each project. The project life estimates for each project are shown in Table 17.

**Table 17. WECC Project Life Estimates**

| Site Number | Project Type | WECC Project Life |
|---|---|---|
| Site 1 | Lighting | 10.0 |
| Site 2 | HVAC | 2.0 |
| Site 3 | HVAC | 10.0 |
| Site 4 | HVAC | 15.0 |
| Site 5 | HVAC | 5.5 |
| Site 6 | Process | 8.0 |
| Site 7 | Process | 20.0 |
| Site 8 | HVAC | 10.0 |
| Site 9 | Lighting | 10.0 |
| Site 10 | Lighting | 7.0 |
| Site 11 | Lighting | 10.0 |
| Site 12 | HVAC | 10.0 |
| Site 13 | HVAC | 10.4 |
| Site 14 | Process | 10.0 |
| Site 15 | Process | 15.0 |
| Site 16 | HVAC | 10.0 |
| Site 17 | Lighting | 10.0 |

[12] WECC is a contractor hired by Duke Energy to assist in program implementation and application review.

| | | |
|---|---|---|
| Site 18 | Process | 15.0 |
| Site 19 | HVAC | 7.0 |
| Site 20 | HVAC | 7.0 |
| Site 21 | Lighting | 7.0 |
| Site 22 | Process | 10.0 |
| Site 23 | HVAC | 7.0 |
| Site 24 | HVAC | 20.0 |
| Site 25 | HVAC | 10.0 |
| Site 26 | Process | 10.0 |
| Site 27 | Process | 7.0 |
| Site 28 | Lighting | 10.0 |

An independent assessment of the project life was conducted by examining the measures making up each project and assigning an effective useful life (EUL) to each measure. EUL estimates were obtained from the Draft Ohio Technical Reference Manual (TRM), the California Database for Energy Efficiency Resources (DEER) EUL table or California IOU workpapers developed for new measures not yet incorporated into DEER. A project level EUL was calculated as the weighted average of the measure EULs. The results of this assessment are shown in Table 18.

**Table 18. Evaluated Project Life Estimates**

| Site No. | Project Type | Measures | EUL | Wt | Wt EUL | Source |
|---|---|---|---|---|---|---|
| Site 1 | Lighting | Induction Lighting | 16 | 100% | 16.0 | 2006 PG&E Workpaper |
| Site 2 | HVAC | HVAC Controls | 15 | 33% | 12.0 | DEER, Energy Management System |
| | | Peak Energy Reduction Through HVAC Controls | 11 | 34% | | DEER, HVAC Controls |
| | | Stack Effect Control System | 10 | 33% | | DEER, Reducing Over ventilation. |
| Site 3 | HVAC | 7000 Btuh Heat Pump | 15 | 25% | 15.0 | Ohio TRM |
| | | 12000 Btuh Heat Pump | 15 | 25% | | Ohio TRM |
| | | Wireless Thermostats and Energy management system | 15 | 50% | | DEER, EMS |
| Site 4 | HVAC | Cool Roof | 15 | 100% | 15.0 | Ohio TRM |
| Site 5 | HVAC | Energy Management System | 15 | 85% | 14.0 | DEER TRM, Energy management System |
| | | LED Refrigerated Case Lighting | 8 | 15% | | Ohio TRM |
| Site 6 | Process | LED Refrigerated Case Lighting | 8 | 100% | 8.1 | Ohio TRM |
| Site 7 | Process | Refrigeration Compressor Update | 15 | 100% | 15.0 | DEER Refrigeration Upgrades |
| Site 8 | HVAC | Exterior Induction Lighting | 16 | 78% | 15.9 | 2006 PGE Workpaper |
| | | Ventilation Controls | 15 | 23% | | DEER, EMS |
| Site 9 | Lighting | Refrigerated Lighting | 15 | 70% | 12.9 | Ohio TRM |
| | | Occupancy Sensors | 8 | 30% | | Ohio TRM |
| Site 10 | Lighting | Outdoor LED Lighting | 16 | 100% | 16.0 | 2006 PGE Workpaper |
| Site 11 | Lighting | High Bay Induction Lamps | 16 | 82% | 15.8 | 2006 PGE Workpaper |
| | | High Bay Fluorescent Lamps | 15 | 18% | | Ohio TRM |
| Site 12 | HVAC | Chiller | 20 | 53% | 17.7 | Ohio TRM |
| | | Chiller VFD | 15 | 47% | | Ohio TRM, HVAC VFD |
| Site 13 | HVAC | Linear Fluorescent | 15 | 87% | 14.5 | Ohio TRM |
| | | Pulse Start Metal Halide | 8 | 7% | | Ohio TRM |
| | | LED | 16 | 4% | | 2006 PGE Workpaper |
| | | Induction | 16 | 2% | | 2006 PGE Workpaper |
| Site 14 | Process | Air Compressor with VFD | 15 | 100% | 15.0 | Ohio TRM |
| Site 15 | Process | Air Compressor with VFD | 15 | 100% | 15.0 | Ohio TRM |
| Site 16 | HVAC | Lighting | 15 | 82% | 15.0 | Ohio TRM, linear fluorescent |
| | | Demand Controlled Ventilation | 15 | 18% | | DEER EMS |
| Site 17 | Lighting | Induction | 16 | 86% | 15.4 | 2006 PGE Workpaper |
| | | Hardwired CFL | 12 | 14% | | Ohio TRM |
| Site 18 | Process | Air Compressor with VFD | 15 | 100% | 15.0 | Ohio TRM |

| Site No. | Project Type | Measures | EUL | Wt | Wt EUL | Source |
|---|---|---|---|---|---|---|
| Site 19 | HVAC | Ultrasonic Humidifier | 7 | 100% | 7.0 | Independent estimate not available; Duke project life used |
| Site 20 | HVAC | EMS | 15 | 50% | 15.0 | DEER, EMS |
| | | Tstat Recalibration and Relocation | 15 | 50% | | DEER, EMS |
| Site 21 | Lighting | Ceramic Metal Halide | 15 | 100% | 15.0 | Ohio TRM |
| Site 22 | Process | Compressors | 15 | 100% | 15.0 | Ohio TRM |
| Site 23 | HVAC | Digital Control System | 15 | 100% | 15.0 | DEER, EMS |
| Site 24 | HVAC | HVAC | 20 | 41% | 17.1 | Ohio TRM |
| | | Linear Fluorescent | 15 | 59% | | Ohio TRM |
| Site 25 | HVAC | EMS Upgrades | 15 | 100% | 15.0 | DEER, EMS |
| Site 26 | Process | PLC-controlled AC inverter drive system | 15 | 100% | 15.0 | Ohio TRM, HVAC VFD |
| Site 27 | Process | Air Compressor with VFD | 15 | 100% | 15.0 | Ohio TRM |
| Site 28 | Lighting | Induction Lighting | 16 | 80% | 14.4 | 2006 PGE Workpaper |
| | | Photo Sensors: | 8 | 20% | | DEER, Timeclock with or without photosensors |

The WECC estimated project life and the independent project life estimates were weighted by the expected kWh savings and the evaluated kWh savings respectively, and a weighted average project life was calculated for each project type. The realization rate on project life was calculated as the ratio of the evaluated EUL to the WECC project life estimate. These results are shown in Table 19.

**Table 19. Summary of Project Life Estimates by Project Type**

| Project Type | WECC Project Life | Evaluated EUL | Realization Rate |
|---|---|---|---|
| Lighting | 8.4 | 15.1 | 1.79 |
| HVAC | 7.7 | 14.5 | 1.88 |
| Process | 9.2 | 14.1 | 1.53 |

Note, the evaluated project life estimates for Lighting, HVAC, and Process were 78%, 88%, and 53% higher, respectively, than the WECC estimates, indicating WECC and Duke Energy used a conservative approach to establishing project lifetimes for these types of projects.

# Appendix A: Required Savings Tables

| Project | Ex Ante kWh Savings | Ex Ante NCP kW Savings | Ex Ante CP kW Savings |
|---|---|---|---|
| Site 1 | 167,454 | 44.10 | 41.66 |
| Site 2 | 479,209 | 108.28 | 80.58 |
| Site 3 | 1,284,468 | 233.77 | 182.36 |
| Site 4 | 10,100 | 4.16 | 3.10 |
| Site 5 | 4,832,346 | 552.00 | 462.50 |
| Site 6 | 5,991,963 | 686.14 | 686.14 |
| Site 7 | 190,343 | 34.18 | 9.56 |
| Site 8 | 698,742 | 62.55 | 62.55 |
| Site 9 | 191,139 | 21.92 | 21.92 |
| Site 10 | 528,652 | 60.30 | 60.50 |
| Site 11 | 40,915 | 15.40 | 15.40 |
| Site 12 | 632,527 | 86.17 | 106.37 |
| Site 13 | 1,910,023 | 610.85 | 528.37 |
| Site 14 | 106,952 | 12.19 | 16.67 |
| Site 15 | 252,206 | 38.64 | 11.13 |
| Site 16 | 148,014 | 80.00 | 17.65 |
| Site 17 | 60,259 | 9.17 | 9.17 |
| Site 18 | 716,028 | 81.69 | 77.90 |
| Site 19 | 217,522 | 73.53 | 0.00 |
| Site 20 | 463,752 | 105.58 | 31.94 |
| Site 21 | 61,296 | 5.32 | 0.00 |
| Site 22 | 271,999 | 76.73 | 85.38 |
| Site 23 | 63,041 | 14.00 | 14.00 |
| Site 24 | 103,510 | 188.90 | 13.67 |
| Site 25 | 507,265 | 271.47 | 202.03 |
| Site 26 | 43,578 | 7.49 | 7.49 |
| Site 27 | 255,828 | 31.84 | 31.83 |
| Site 28 | 87,203 | 10.27 | 10.27 |

**Table 20. Evaluated Savings Estimate Breakdown by Customer**

| Customer | kWh | NCP kW | CP kW | MMBtu[13] |
|---|---|---|---|---|
| Site 1 | 258,169 | 42.00 | 42.00 | N/A |
| Site 2 | 399,610 | 226.00 | 70.00 | N/A |
| Site 3 | 3,378,176 | 483.00 | 483.00 | N/A |
| Site 4 | 4,798 | 13.40 | 8.20 | N/A |
| Site 5 | 3,775,031 | 588.00 | 588.00 | N/A |
| Site 6 | 5,591,557 | 603.26 | 603.00 | N/A |
| Site 7 | 360,188 | 56.00 | 56.00 | N/A |
| Site 8 | 587,214 | 61.30 | 0.00 | N/A |
| Site 9 | 247,604 | 24.50 | 28.20 | N/A |
| Site 10 | 329,359 | 64.40 | 0.00 | N/A |
| Site 11 | 52,653 | 13.70 | 13.70 | N/A |
| Site 12 | 449,297 | 21.00 | 21.00 | N/A |
| Site 13 | 1,813,844 | 768.00 | 384.00 | N/A |

[13] The study evaluated electricity savings only.

| Customer | kWh | NCP kW | CP kW | MMBtu[13] |
|---|---|---|---|---|
| Site 14 | 161,110 | 5.10 | 27.70 | N/A |
| Site 15 | 347,394 | 28.60 | 28.60 | N/A |
| Site 16 | 237,528 | 319.20 | 22.00 | N/A |
| Site 17 | 22,341 | 9.90 | 2.60 | N/A |
| Site 18 | 719,314 | 75.00 | 75.00 | N/A |
| Site 19 | 113,766 | 0.00 | 0.00 | N/A |
| Site 20 | 470,380 | -99.20 | -52.00 | N/A |
| Site 21 | 95,107 | 22.80 | 0.00 | N/A |
| Site 22 | 287,240 | 28.90 | 28.90 | N/A |
| Site 23 | 203,477 | 76.70 | 65.40 | N/A |
| Site 24 | 130,149 | 161.30 | 199.20 | N/A |
| Site 25 | 657,570 | 117.85 | 69.33 | N/A |
| Site 26 | 39,340 | 6.20 | 6.20 | N/A |
| Site 27 | 194,606 | 21.90 | 21.90 | N/A |
| Site 28 | 75,476 | 7.80 | 7.80 | N/A |

# Appendix B: Site M&V Reports – Customer Detail Redacted

[redacted]

# Site 1

# M&V Plan Results Summary

PREPARED FOR:
Duke Energy
Ohio

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

PREPARED ON:
March 2011

## Introduction

Architectural Energy Corporation was hired to evaluate the Duke Energy custom incentive program for the lighting retrofit of the interior hallway lights at [redacted]. The original proposal called for a one-for-one replacement of 21 fixtures at each [redacted], an existing 1000 Watt Metal Halide lamp, with a 200 Watt High-bay Induction lamp.

Energy savings were estimated at $8,340 annually for this upgrade at each [redacted], totaling $16,680 for the measure. The M&V portion of the project involved conducting post-installation spot measurements of the lighting circuits. Annual lamp runtime hours were determined from staff interviews prior to installation and are found in a brief explanation included with the application.

## Goals and Objectives

The project goal was electric use savings of 166,800 kWh annually and demand savings of 41 kW annually, or approximately $16,680, as noted in the M&V Plan. The specific objective of this M&V project was to complete a pre and post implementation site survey of the affected lighting in order to determine the true power reduction. Then apply the pre-installation counts to the new fixtures and interviewed operating hours to determine the actual annual energy savings and realization rate.

## Project Contacts

Approval shall be requested from the two Duke Energy contacts listed below prior to making direct contact with the Customer or undertaking work on this M&V Plan.

| | | |
|---|---|---|
| **Duke Energy M&V Administrator** | Frankie Diersing | [redacted] |
| **Duke Energy BRM** | Mike Harp | [redacted] |
| **Customer Contact** | | |
| **Site Locations** | [redacted] | |

## Data Products and Project Output

- Count post fixtures to verify quantity installation.
- Annual energy savings and verification of calculations.

## M&V Option

IPMVP Option A

## Verification and Quality Control

1. Verify pre and post-retrofit lighting fixture specifications and quantities are consistent with the application. If they are not consistent, record discrepancies.
2. Verify pre-retrofit lighting fixtures are removed from the project. If they are abandoned in place, please note if the wiring is removed or not. If the fixtures have been removed, check to see if the existing lighting fixture lamps and ballasts have been stored on site.
3. Verify electrical voltage of pre and post lighting circuits.
4. Visually inspect pre/post lighting data sheets for correlation to incentive plan savings.
5. Verify lighting data and correlate to incentive plan savings.

## Recording and Data Exchange Format

1. Pre-installation Lighting Survey Form and notes.
2. Post-installation Lighting Survey Form and notes.
3. CT logger data files.

## Results Summary

### Data Analysis

1. Verify Proposed Measures Were Implemented:

The 21 new fixtures were installed as planned at each site. There were increased annual hours of operation found compared to those deduced from the application calculation, based on an explanatory note included in the application. The calculation originally assumed that lighting would operate 4,000 hours annually. However, this note specifies a lighting operation time of 6:00 am through 10:00 pm each day (16 hours per day, or 4160 annually, with the assumption of Monday-Friday operation only).

2. Verify Lighting Control:

Lighting control was not part of this application.

3. Calculation Methodology:

Since the lighting is specified as being on through the peak demand period, kW savings should be included in this measure. However, a rate of $0.10 per kWh was used in the proposal calculation and is not clear where it was derived from. This value is close to the kWh rate published by the utility, thus does not appear to include demand savings. For this reason, and to maintain consistency, the same cost per kWh ($0.10) was also used to determine the realized post-install savings based on a kWh reduction only.

Annual lighting electric energy is calculated as follows:

$$kWh / year = a \times b \times c$$

Where:
a = Number of fixtures, counted during site visit, for replacement
b = kW per fixture, often from manufacturer specification
c = Total estimated annual "hours on"

4. Savings Verification and Realization Rate:

Compare Pre/Post values to obtain total lighting kWh/year savings. Once the savings are calculated, the realization rate is calculated by the following formula:

Realization Rate = $kWh_{actual} / kWh_{application}$

## Calculation Output

The following Excel Tables demonstrate real achieved lighting savings and summarize the results of the lighting retrofit application. For additional details, see included post-retrofit measurement and calculation spreadsheets.

**Reported in Application:**

| Baseline | | |
|---|---|---|
| kW per Fixture | | 1.200 |
| Fixture Count | | 42 |
| Run Hours (annual) | | 4,000 |
| Annual Energy (kWh) | | 201,600 |
| Electric Rate ($/kWh) | $ | 0.10 |
| Demand Rate ($/kW) | $ | - |
| Operating Cost | $ | 20,160 |

| Proposed | | |
|---|---|---|
| kW per Fixture | | 0.207 |
| Fixture Count | | 42 |
| Run Hours (annual) | | 4,000 |
| Annual Energy (kWh) | | 34,776 |
| Electric Rate ($/kWh) | $ | 0.10 |
| Demand Rate ($/kW) | $ | - |
| Operating Cost | $ | 3,478 |

**Savings:**
kWh: 166,824
Cost: $16,682

**Adjustments Based on Duke Energy Project Review:**

The Duke Energy project review adjusted the savings from 166,824 to 167,454. The incentive offer was based on a savings of 167,454 kWh.

**Reported Following Installation:**

| Baseline | |
|---|---|
| kW per Fixture | 1.200 |
| Fixture Count | 42 |
| Run Hours (annual) | 5,840 |
| Annual Energy (kWh) | 294,336 |
| Peak demand (kW) | 50.4 |
| Electric Rate ($/kWh) | $ 0.10 |
| Demand Rate ($/kW) | $ - |
| Operating Cost | $ 29,434 |

| Installed | |
|---|---|
| kW per Fixture | 0.207 |
| Fixture Count | 42 |
| Run Hours (annual) | 4,160 |
| Annual Energy (kWh) | 36,167 |
| Peak demand (kW) | 8.7 |
| Electric Rate ($/kWh) | $ 0.10 |
| Demand Rate ($/kW) | $ - |
| Operating Cost | $ 3,617 |

**Savings:**

kWh: 258,169
kW: 41.7
Cost: $25,817

### Project Savings Summary

The evaluated savings were compared to the final savings estimates from the DSMore runs. This comparison is shown in the Table below:

**Final Project Savings and Realization Rate**

| Evaluated kWh Savings | Expected kWh Savings | kWh RR | Evaluated NCP kW Savings | Expected NCP kW Savings | NCP kW RR | Evaluated CP kW Savings | Expected CP kW Savings | CP kW RR |
|---|---|---|---|---|---|---|---|---|
| 258,169 | 167,454 | 1.54 | 42 | 44 | 0.95 | 42 | 44 | 0.95 |

*Notes:

Lighting fixture power values were taken from the M&V Plan document.
Proposed savings were back calculated from the Application.
Electric Rate used was derived from the rebate application savings.

# M&V Summary

# Site 2

[redacted] – [redacted] – Stack Effect Control
Prepared by Dan Bertini
April, 2011

## Introduction

This document summarizes the third-party M&V activities for a Non-Residential Custom Incentive application for the first phase of an energy improvement project administered by [redacted] at their [redacted] location.

The project is being carried out in phases at three hospitals:

- [redacted]

Throughout the phases of the project there will be three measures implemented overall:

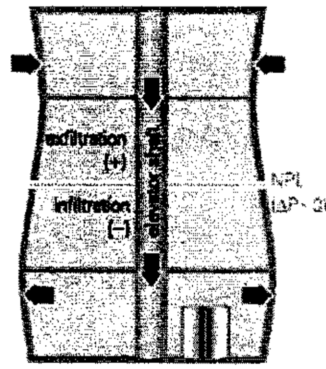
1. Stack Effect Control
2. Control System Optimization
3. Peak Load Shedding

The first measure was implemented at the three hospitals during the first phase of the project. The other two measures will be implemented in future phases. This document summarizes the M&V findings related only to the implementation of the Stack Effect Control measure at the [redacted] location.

The description of the measure is copied verbatim from [redacted] application as follows in *italics*:

*"Stack Effect Control:*

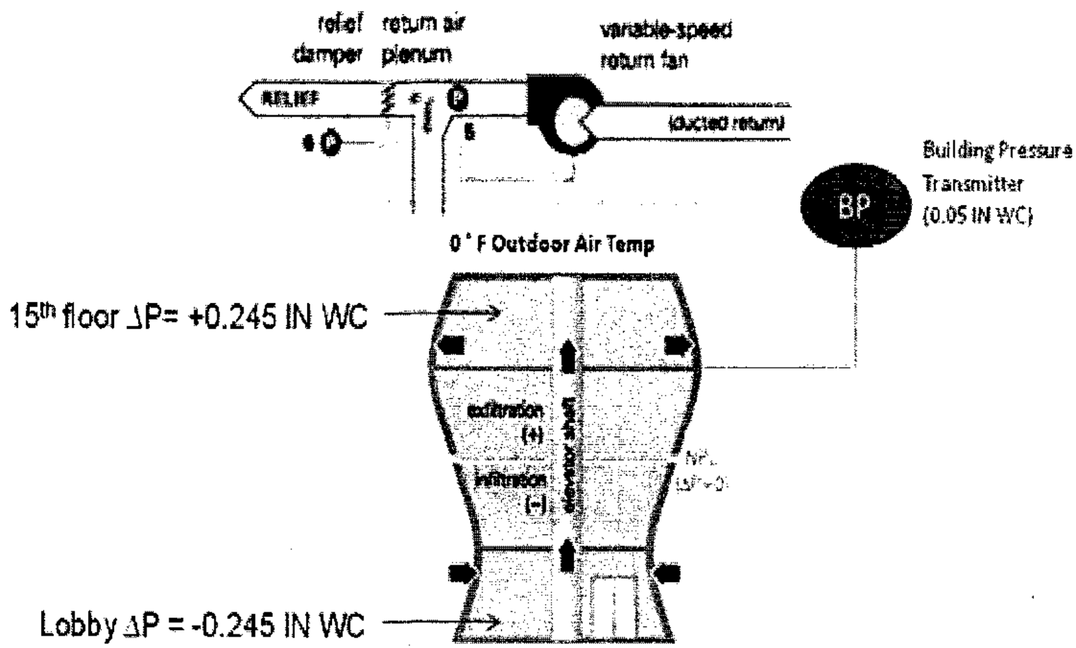
*"Stack Effect is a phenomenon that creates differential air pressure forces between the upper and lower floors of tall buildings. In the winter, the forces pressurize the upper floors of the building and make the lower floors negative. The opposite is true for the summer. See below:*




**Summer (reverse) stack effect**

- Outward-swinging doors may stand open
- Infiltrating outdoor air drives moisture into building envelope

*"In the case of the* [redacted] *hospital, at zero degree outside air temperature, the building is affected as follows:*




15th Story Building
**Winter (normal) stack effect**

- Inward-swinging doors may not latch
- Exfiltrating indoor air drives moisture into building envelope

*"The total stack effect pressure exerted on the building is almost 0.5 IN WC at zero degrees, which is 10 times the building pressure setpoint of 0.05 IN WC. This causes the HVAC control*

*systems to exhaust air needlessly out of the building. The more air the HVAC system exhausts, the worse the problem gets and the building becomes a chimney as the conditioned air is exhausted out of the building.*

*"To correct the problem, all the HVAC primary air handling units must be reprogrammed and exhaust air dampers of the air handlers need to be retrofitted to operate independently of other control dampers in the building. In addition, several VFD drives will need to be installed. Savings from this project are estimated at 2% of the total energy use of the facility and are based on field observations at the hospitals. The exception is [redacted] off peak kWh estimates are 10%. They are higher because we are installing more VFD's at this facility and heating kWh will be impacted as a result."*

## Goals

For the Stack Effect Control measure at [redacted] the following savings are expected:

- 479,208 Gross kWh
- 84 On-Peak kW

## Project Contacts

| | | |
|---|---|---|
| Duke Energy M&V Administrator | Frankie Diersing | [redacted] |
| Duke Energy BRM | Nick Beck | |
| Duke Energy BRM (alternate) | Mike Harp | |
| [redacted] (Customer) Contact | [redacted] | |
| [redacted] (Project Engineer) Contact | [redacted] | |

## Data Products and Project Output

- Average pre/post load shapes for controlled equipment
- Model predicting pre/post kWh as a function of outdoor temperature
- Summer peak demand savings
- Annual Energy Savings
- Miscellaneous diagnostics (cooling delta T, supply air temperature)
- Outdoor air fraction; economizer operation (if equipped).

## M&V Option

IPMVP Option A – Stipulated and Measured

# Field Data

## Pre-Implementation

Historical 15 minute interval data was obtained from the site's two utility meters for a roughly 2.5 year period starting January 1st, 2008 and ending June 8th, 2010. Unfortunately, since M&V activities were not scheduled prior to the implementation of the measure, other than the old T&B reports obtained during the post-implementation site survey, this historical site data represents the only actual pre-implementation operating data available to the investigation.

## Post-Implementation

Survey Data

- Copy of engineer's notebook containing equipment schedules, existing control strategies, and implementation plans for respective equipment
- Copy of owners working AHU equipment schedule
- Screen captures from control system front-end graphics
- Miscellaneous photos
- Copies of selected equipment schedules from original construction
- Copies of selected T&B reports from original construction
- Interview with the engineer who designed and commissioned the measure

One-time Measurements

- Spot measurements of supply and return fan kW at selected AHUs
- Spot measurements of supply and return fan % Speed at those selected AHUs that were VFD-driven
- Spot measurements of supply, return and mixed air temperatures at selected AHUs

Time series data on selected equipment

- While there are (37) AHUs in the hospital, the Stack Effect Control measure was implemented only on the (27) AHUs that at the time were under the control of the Siemens automation system. Of those (27) AHUs, (10) were randomly selected to be monitored for M&V purposes, representing roughly 60% of the overall designed CFM capacity of the (27)

- Loggers were deployed to record data at 5 minutes intervals for 40 full days starting on midnight June 12th and ending on midnight July 22nd, 2010 on the following (10) AHUs: 3,9,27,28,32,35,36,37,40,43
    - Dent Elite Pro loggers measured supply and return fan kW
    - Onset Hobo U-12s measured supply, return and mixed air temperatures
    - Onset Hobo U-10s measured OA, supply, return and mixed air temperature and relative humidity

# Data Accuracy

| Measurement | Sensor | Accuracy | Notes |
|---|---|---|---|
| Temperature | thermistor | ±0.5° | |
| Amps | current transducer | ±1% | 10% of rating < Amps < 130% of rating |
| %RH | capacitive element | ±3.5% | 25% < RH < 85% |
| kW | Elite Pro (7.28 kHz) | <1% | exclusive of current transducer |

# Verification and Quality Control

6. Visually inspect time series data for gaps
7. Compare readings to nameplate values; identify out of range data
8. Look for physically impossible combinations e.g. Tsupply > Tmix when AC unit is cooling

# Recording and Data Exchange Format

4. Dent and Hobo binary files
5. Excel spreadsheets

# Data Analysis Summary

## Approach

### Energy Savings

Discussions with the engineer established that the new Stack Effect Control sequence operates at each AHU essentially as follows:

- Supply Fan modulates to maintain downstream duct static pressure setpoint as downstream VAV dampers modulate to maintain space temperature
- Return Fan modulates to maintain return plenum static pressure setpoint

- Exhaust Damper modulates to maintain average building static pressure per patent-pending algorithm

For this evaluation it is assumed that the Stack Effect Control measure, by virtue of maintaining positive pressure entirely throughout the inside of the building, impacts the selected AHUs by essentially reducing to zero the infiltration component of their respective cooling loads, which in turn has the effect of reducing the overall fan and chiller plant load in the summer, but in winter, when the "free cooling" of infiltration is eliminated, may have the opposite effect. The objective of the analysis then is to calculate the amount by which the overall hourly electrical demand is reduced over the course of a year as a result of the change in fan and chiller plant demand, as shown in Equation 1:

**Equation 1 – *Annual kWh Savings***

$$Annual\ kWh\ Savings = \frac{\sum_{i=1}^{8760\,hrs}\left(kW_{plant\_pre_i} - kW_{plant\_post_i} + kW_{fans\_pre_i} - kW_{fans\_post_i}\right)}{S}$$

where

$kW_{plant\_pre}$ = *pre-implementation hourly kW of chiller plant resulting from coil load on (10) AHUs*
$kW_{plant\_post}$ = *post-implementation hourly kW of chiller plant resulting from coil load on (10) AHUs*
$kW_{fans\_pre}$ = *pre-implementation hourly kW of fans on (10) AHUs*
$kW_{fans\_post}$ = *post-implementation hourly kW of fans on (10) AHUs*
$S$ = *ratio of total CFM of (10) sampled AHUs to total CFM of (27) site AHUs*

## Demand Reduction

From the hourly set of demand derived in Equation 1 is also found the following two key measures:

1. Maximum on-peak kW reduction
2. Minimum grid-coincident-peak kW reduction

### $kW_{fans\_post}$

The last term in the numerator of Equation 1, $kW_{fans\_post}$, is the hourly kW of all the fans in the (10) sampled AHUs. This is calculated through the use of the regression model shown in Equation 2. The parameters $m1_T$ and $b1_T$ are calculated using the logged data by regressing total daily logged AHU fan kWh against average daily logged outdoor air temperature.

**Equation 2 - $kW_{fans\_post}$**

$$kW_{fans\_post} = \frac{\left(m1_T T_{a_i} + b1_T\right)}{24}$$

where

$T_a$ = *hourly outdoor drybulb*
$m1_T$ = *slope of daily total AHU fan kWh regressed against average daily outdoor drybulb*
$b1_T$ = *intercept of daily total AHU fan kWh regressed against daily outdoor drybulb*

### $kW_{fans\_pre}$

The third term in the numerator of Equation 1, $kW_{fans\_pre}$, is the sum of broken out as follows in Equation 3:

**Equation 3 - $kW_{fans\_pre}$**

$$kW_{fans\_pre} = kW_{sf\_pre} + kW_{rf\_pre}$$

where

$kW_{sf\_pre}$ *pre implementation hourly total supply fan kW*

$kW_{rf\_pre}$ *pre implementation hourly total return fan kW*

Equation 3 requires hourly values for $kW_{sf\_pre}$ and $kW_{rf\_pre}$. The former is found in Equation 4:

**Equation 4 - $kW_{sf\_pre}$**

$$kW_{sf\_pre} = \frac{(m_Q \dot{Q}_{pre} + b_Q)}{24}$$

where

$\dot{Q}_{pre}$ *pre implementation average hourly coil load of (10) AHUs (tons)*

$m_Q$ *slope of daily total supply fan kWh regressed against daily average coil load*

$b_Q$ *intercept of daily total supply fan kWh regressed against daily average coil load*

Equation 4 represents the total supply fan kW required to satisfy the total pre-implementation coil load, $\dot{Q}_{pre}$ and requires knowledge of $\dot{Q}$ not only in its solution but also in the formulation of the regression parameters. The regression parameters are calculated using logged data by regressing the daily average logged post-implementation coil load of all (10) AHUs against the corresponding daily total logged supply fan kWh. It is assumed that the coil load is zero whenever the calculated value for $\dot{Q}_{pre}$ is less than or equal to zero.

In general, since ducted returns connect to all AHUs in the hospital, it is assumed that all infiltration is seen by the AHUs as an adjustment in space load, which implies that $\dot{Q}_{pre}$ is equal to $\dot{Q}_{post}$ plus (or minus) an adjustment to offset a proportion, $S$, of the total building infiltration load, $\dot{Q}_{inf}$, as shown in Equation 5.

**Equation 5 - $\dot{Q}_{pre}$**

$$\dot{Q}_{pre} = \dot{Q}_{post} + S\dot{Q}_{inf}$$

where

$\dot{Q}_{post}$ *post implementation total hourly coil load (tons)*

$\dot{Q}_{inf}$ *pre implementation hourly infiltration load (tons)*

$S$ *ratio of total CFM of (10) sampled AHUs to total CFM of (27) site AHUs*

The first term in Equation 5, $\dot{Q}_{post}$, is found in Equation 6 as follows:

**Equation 6 - $\dot{Q}_{Post}$**

$$\dot{Q}_{Post} = c_u \rho \left(\overline{h_{ma} - h_{sa}}\right) \sum_{i=1}^{\#\ Supply\ Fans} CFM_{sf\_post_i}$$

where

$c_u$ = units conversion of $60\left(\frac{min}{hr}\right) / 12000\left(\frac{btu}{ton}\right)$

$CFM_{sf\_post}$ = post implementation supply fan airflow (CFM)

$\overline{h_{ma} - h_{sa}}$ = CFM weighted average coil enthalpy drop $\left(\frac{btu}{lbm}\right)$

The post-implementation supply fan airflow that is required in Equation 6 for each supply fan, $CFM_{sf\_post}$, is found implicitly in the flow ratio, $f$, of the Englander-Norford equation for a VFD-driven fan, which is shown below in Equation 7:

**Equation 7 - $H_{sf\_post}$**

$$H_{sf\_post} = a + bf + df^3$$

where

$f = \frac{CFM_{sf\_post}}{CFM_{sf\_max}}$ = supply fan airflow ratio

$H_{sf\_post} = \frac{kW(f)}{kW_{sf\_max}}$ = supply fan power ratio

$a = \left(\frac{1-p_0}{2}\right)^{1.5}$

$p_0$ = ratio of static pressure setpoint of the controller to the static pressure at the fan discharge

$b = p_0(1 - a)$

$d = 1 - a - b$

$kW_{sf\_max}$ = supply fan full load kW

$CFM_{sf\_max}$ = supply fan full load CFM

Note that when $p_0 = 1$, as is the case for a return fan controlling the static pressure immediately downstream, Equation 7 reduces to the familiar cubic relation in Equation 8:

**Equation 8 - $H$**

$$H = f^3$$

Two of the critical parameters called out in Equation 7 for each fan, $CFM_{max}$ and $kW_{max}$, are presumed to be equal to those values given in the T&B reports if available or alternately from the design BHP and CFM found in the equipment schedules. However, in this investigation it is assumed instead that $kW_{max}$ for each fan is approximately equal to the maximum kW measured during the investigation, which occurred during what was perhaps the hottest time of the year. Furthermore, $CFM_{max}$ is then assumed to be approximately equal to the following shown in Equation 9.

**Equation 9 - $CFM_{max}$**

$$CFM_{max} = CFM_{max}^{*}\left(\frac{kW_{max}}{kW_{max}^{*}}\right)^{\frac{1}{3}}$$

where

$CFM_{max}^{*}$ *maximum CFM presumed from T&B or design documents*

$kW_{max}^{*}$ *maximum of measured kW and kW presumed from T&B or design documents*

The second term in Equation 5 includes $\dot{Q}_{inf}$, which is a function of the total building infiltration airflow, $CFM_{inf}$. For this analysis $CFM_{inf}$ is calculated following the ASHRAE enhanced method, which seeks to combine the effects of both ambient wind and internal stack pressures as shown in Equation 10:

**Equation 10 - $CFM_{inf}$**

$$CFM_{inf} = \sqrt{(CFM_w)^2 + (CFM_s)^2}$$

The wind and stack effect components are defined, respectively, in Equation 11 and Equation 12:

**Equation 11 - $CFM_w$**

$$CFM_w = cC_w(sfV_w)^{2n}$$

**Equation 12 - $CFM_s$**

$$CFM_s = cC_s(|T_o - T_i|)^n$$

where

$c$ *flow coefficient* $\left(\frac{CFM}{in\,wc^n}\right)$

$C_w$ *wind coefficient* $\left(\left(\frac{in\,wc}{mph^2}\right)^n\right)$

$C_s$ *stack coefficient* $\left(\left(\frac{in\,wc}{°F}\right)^n\right)$

$sf$ *shelter factor*

$V_w$ *outdoor windspeed (mph)*

$n$ *pressure coefficient*

$T_o$ *outdoor ambient drybulb temperature (°F)*

$T_i$ *typical indoor drybulb temperature (°F)*

The hourly infiltration load, $\dot{Q}_{inf}$, is then found by inserting the result from Equation 10, $CFM_{inf}$, into Equation 13:

**Equation 13 - $\dot{Q}_{inf}$**

$$\dot{Q}_{inf} = c_u\rho(h_o - h_i)CFM_{inf}$$

where

$c_u$ – *units conversion of* $60\left(\frac{min}{hr}\right)/12000\left(\frac{btu}{ton}\right)$

$\rho$ *nominal air density* $\left(\frac{lbm}{ft^3}\right)$

$h_o$ $\quad$ *enthalpy of outdoor ambient air* $\left(\frac{btu}{lbm}\right)$

$h_i$ $\quad$ *enthalpy of typical indoor air* $\left(\frac{btu}{lbm}\right)$

$CFM_{inf}$ $\quad$ *total building infiltration (CFM)*

It is significant that $\dot{Q}_{inf}$ can be positive or negative, thereby increasing or decreasing the pre-implementation coil load.

Having now calculated $\dot{Q}_{Post}$ in Equation 6 and $\dot{Q}_{inf}$ in Equation 13, the sum of the two provides the solution to Equation 5, $\dot{Q}_{Pre}$, which is then applied to Equation 4 to give the pre-implementation supply fan kW, $kW_{sf\_pre}$, which is one of the two variables required in Equation 3 to solve for $kW_{fans\_pre}$.

Note however that Equation 6, as presented thus far, can only be solved using logged data. To extrapolate over 8760 hours in a year requires creating another regression model from the logged data as shown in Equation 14.

**Equation 14 - $\dot{Q}_{Post}$ Regression**

$$\dot{Q}_{Post} \quad (m2_T T_a + b2_T)$$

where

$\dot{Q}_{Post}$ $\quad$ *post implementation total hourly coil load (tons)*

$T_a$ $\quad$ *hourly outdoor drybulb*

$m2_T$ $\quad$ *slope of daily total coil load regressed against average daily outdoor drybulb*

$b2_T$ $\quad$ *intercept of daily total coil load regressed against average daily outdoor drybulb*

The regression parameters $m2_T$ and $b2_T$ are calculated using logged data by regressing the daily average logged post-implementation coil load of all (10) AHUs against the corresponding daily average logged outdoor air temperature. It is assumed that the post-implementation coil load is zero whenever the calculated value for $\dot{Q}_{post}$ is less than or equal to zero.

The second variable required by Equation 3, $kW_{rf\_pre}$, is obtained through the application of Equation 8 as shown in Equation 15:

**Equation 15 - $kW_{rf\_pre}$**

$$kW_{rf\_pre} \quad kW_{totalrf\_max}(f_{rf\_pre})^{3}$$

where

$f_{rf\_pre}$ $\quad$ *total pre implementation return fan airflow ratio*

$kW_{totalrf\_max}$ $\quad$ *total return fan full load kW*

The survey reveals that the pre-implementation return fans generally were intended to maintain a fixed airflow differential with respect to the supply fans in order to continuously return from the spaces only the balance of the volume not exhausted by the building exhaust fans nor required to maintain building pressurization. In this case then $f_{rf\_pre}$ is assumed to be as shown in Equation 16:

**Equation 16 – Pre-Implementation Return Fan Airflow Ratio**

$$f_{rf\_pre} = \frac{CFM_{totalsf\_pre} - t}{CFM_{totalrf\_max}}$$

where

$t$ = return fan airflow tracking differential (CFM)
$CFM_{totalsf\_pre}$ = total pre-implementation supply fan airflow
$CFM_{totalrf\_max}$ = total return fan full load airflow

The solution of Equation 16, however, requires knowing the total pre-implementation supply airflow, $CFM_{totalsf\_pre}$, which is found implicitly via the application of the Englander-Norford equation for a VFD-driven fan as shown in Equation 17:

**Equation 17 - $H_{totalsf\_pre}$**

$$H_{totalsf\_pre} = a + b(f_{sf\_pre}) + d(f_{sf\_pre})^3$$

where

$f_{sf\_pre} = \frac{CFM_{totalsf\_pre}}{CFM_{totalsf\_max}}$ = total pre-implementation supply fan airflow ratio
$H_{totalsf\_pre} = \frac{kW_{sf\_pre}(\eta_i)}{kW_{totalsf\_max}}$ = total pre-implentation supply fan power ratio
$kW_{totalsf\_max}$ = total supply fan full load kW
$a = \left(\frac{p_0}{2}\right)^{1.5}$
$p_0$ = ratio of static pressure setpoint of the controller to the static pressure at the fan discharge
$b = p_0(1-a)$
$d = 1-a-b$

Solving Equation 17 for $CFM_{totalsf\_pre}$ and inserting it into Equation 16 gives $f_{rf\_pre}$, which, when applied to Equation 15, returns $kW_{rf\_pre}$.

Inserting $kW_{sf\_pre}$ and $kW_{rf_{pre}}$ into Equation 3 finally enables the calculation of $kW_{fans\_pre}$.

### $kW_{plant\_post}$

The second term in the numerator of Equation 1, $kW_{plant\_post}$, is obtained by inserting the solution to Equation 6, $\dot{Q}_{Post}$, into Equation 18:

**Equation 18 - $kW_{plant\_post}$**

$$kW_{plant\_post} = \frac{\varepsilon_{Plant}\dot{Q}_{Post}}{S}$$

where

$\dot{Q}_{Post}$ post implementation total hourly coil load (tons)

$\varepsilon_{Plant}$ overall plant efficiency $\left(\frac{kW}{ton}\right)$

$S$ ratio of total CFM of (10) sampled AHUs to total CFM of (27) site AHUs

### $kW_{plant\_pre}$

With ducted returns connected to all the AHUs in the hospital, it is assumed that all infiltration must be met with a corresponding increase or decrease in load on the chilled water plant, depending on whether the outdoor ambient enthalpy is greater or less than the typical indoor enthalpy. The first term in the numerator of Equation 1, $kW_{plant\_pre}$, is therefore obtained by inserting $\dot{Q}_{Post}$ and the solution to Equation 13, $\dot{Q}_{inf}$, into Equation 19:

**Equation 19 - $kW_{plant\_pre}$**

$$kW_{plant\_pre} = \varepsilon_{Plant}\left(\dot{Q}_{Post} + \dot{Q}_{inf}\right)$$

## Summary of Required Parameters and Independent Variables

The overall set of numbers required to solve all the equations described above are summarized below in
Table 1 and Table 2. Required hourly independent variables are from logged data and/or TMY. Required parameters are derived by one of three means:

1. Survey
2. Stipulation
3. Regression of logged data

**Table 1 – Required Parameters**

| Parameter | Description | Source |
|---|---|---|
| $m1_T$ | slope of daily total AHU fan kWh regressed against daily average outdoor drybulb (sampled supply and return fans) | regression of logged data |
| $b1_T$ | intercept of daily total AHU fan kWh regressed against daily average outdoor drybulb (sampled supply and return fans) | regression of logged data |
| $S$ | ratio of total CFM of (10) sampled AHUs to total CFM of (27) site AHUs | survey |
| $m_{\dot{Q}}$ | slope of daily total supply fan kWh regressed against daily total coil load (sampled AHUs) | regression of logged data |
| $b_{\dot{Q}}$ | intercept of daily total supply fan kWh regressed against daily total coil load (sampled AHUs) | regression of logged data |
| $\rho$ | nominal air density | stipulated |
| $p_{ll}$ | ratio of controlled static pressure setpoint to static pressure at fan discharge | stipulated |
| $CFM_{sf\_max}$ | full load CFM of individual supply fan | survey |
| $kW_{sf\_max}$ | full load kW of individual supply fan | survey |
| $\varepsilon_{m}$ | nominal efficiency of fan motors | stipulated |
| $\varepsilon_{drive}$ | nominal efficiency of VFD drives | stipulated |

| | | |
|---|---|---|
| $c$ | flow coefficient | stipulated |
| $c_s$ | stack coefficient | stipulated |
| $c_w$ | wind coefficient | stipulated |
| $sf$ | shelter factor | stipulated |
| $n$ | flow exponent | stipulated |
| $T_i$ | typical indoor drybulb | survey |
| $h_i$ | typical indoor enthalpy | survey |
| $m2_T$ | slope of daily average coil load regressed against daily average outdoor drybulb (sampled supply and return fans) | regression of logged data |
| $b2_T$ | intercept of daily average coil load regressed against daily average outdoor drybulb (sampled supply and return fans) | regression of logged data |
| $CFM_{totalsf\_max}$ | sum of full load CFM of all (10) supply fans | survey |
| $CFM_{totalrf\_max}$ | sum of full load CFM of all (10) return fans | survey |
| $kW_{totalrf\_max}$ | sum of full load kW of all (10) supply fans | survey |
| $kW_{totalsf\_max}$ | sum of full load kW of all (10) return fans | survey |
| $t$ | return fan airflow tracking differential | survey |
| $\varepsilon_{plant}$ | overall plant efficiency | stipulated |

**Table 2 – Required Independent Hourly Variables**

| Variable | Description | Source |
|---|---|---|
| $kW_{fans\_post}$ | post-implementation kW of all fans sampled | logged |
| $T_o$ | outdoor drybulb temperature | logged and TMY |
| $\overline{\Delta h}$ | post-implementation CFM-weighted overall average coil enthalpy drop | logged |
| $V_w$ | outdoor windspeed | TMY |
| $h_o$ | outdoor enthalpy | psychrometrics applied to TMY |

## Surveyed Parameters

The values assigned for maximum $CFM$ and $kW$ for each fan, as well as the total $CFM$ and $kW$ for the full set of supply and return fans, respectively, are shown below in Table 3. Values assigned to the remaining surveyed parameters are shown in Table 4:

**Table 3 –Fan Full Load CFM and kW**

| Fan | $CFM_{sf\_max}$ | $kW_{sf\_max}$ | $CFM_{rf\_max}$ | $kW_{rf\_max}$ |
|---|---|---|---|---|
| AHU-3 | 5823 | 9.2 | 5028 | 2.0 |
| AHU-9 | 40515 | 33.5 | 40480 | 11.3 |
| AHU-27 | 64000 | 54.6 | 60000 | 35.0 |
| AHU-28 | 13682 | 10.6 | 11562 | 2.3 |
| AHU-32 | 7744 | 10.8 | 5608 | 2.5 |
| AHU-35 | 53743 | 48.7 | 40760 | 33.7 |
| AHU-36 | 56161 | 55.6 | 45308 | 46.2 |
| AHU-37 | 57692 | 60.2 | 33210 | 18.2 |

| | | | | |
|---|---|---|---|---|
| AHU-40 | 17760 | 5.6 | 13422 | 1.7 |
| AHU-43 | 42501 | 22.7 | 26422 | 5.0 |
| | **359,620** | **312** | **281,800** | **158** |
| | $CFM_{totalsf\_max}$ | $kW_{totalsf\_max}$ | $CFM_{totalrf\_max}$ | $kW_{totalrf\_max}$ |

**Table 4 - Other Surveyed Parameters**

| Parameter | Nominal Value |
|---|---|
| $T_i$ | 72 |
| $h_i$ | 26.3 (RH=50%) |
| $S$ | 0.6 |
| $t$ | $CFM_{totalsf\_max}$ $CFM_{totalrf\_max}$ |

## Stipulated Parameters

The stipulated parameters, shown below in Table 5, are based on engineering standards.

**Table 5 – Stipulated Parameters**

| Parameter | Nominal Value |
|---|---|
| $p_o$ | 0.4 |
| $\varepsilon_{drive}$ | 0.95 |
| $\varepsilon_m$ | 0.85 |
| $\varsigma$ | 400,000 |
| $\varsigma_s$ | 0.005 |
| $\varsigma_w$ | 0.0025 |
| sf | 1 |
| $\eta$ | 0.65 |
| $\rho$ | 0.075 |
| $\varepsilon_{Fault}$ | 0.75 |

## Logged Variables and Regression Parameters

The logged kW, temperature and humidity data are used only to create the (6) regression parameters shown in Table 1 that are required to find the extrapolated hourly results for Equation 2, $kW_{fans\_post}$, Equation 3, $kW_{fans\_pre}$, and Equation 14, $\dot{Q}_{post}$, as further described below.

## TMY Variables

Hourly Typical Meteorological Year (TMY) data for Cincinnati are applied for purposes of extrapolating annual savings results, as described below. Only three TMY values are required:

1. $V_w$, outdoor windspeed
2. $T_o$, outdoor drybulb temperature
3. $RH_o$, outdoor relative humidity

A standard psychrometric formula applied to the latter two variables gives the hourly variable, $h_o$, outdoor enthalpy, which is required in Equation 13.

# TMY Annual Extrapolation

All the necessary equations and data are now in place to solve Equation 1 for each hour of a typical meteorological year (TMY). This hourly extrapolation is performed as follows for each of the terms in Equation 1.

$kW_{fans\_post}$

1. TMY drybulb, $T_a$, is applied directly to Equation 2 to calculate the hourly value for $kW_{fans\_post}$.

$kW_{fans\_pre}$

1. TMY drybulb, $T_a$, and wind speed, $V_w$, are applied to Equation 10 to calculate hourly infiltration, $CFM_{inf}$, which is combined with TMY $h_a$ in Equation 13 to obtain hourly infiltration load, $\dot{Q}_{inf}$.
2. TMY drybulb, $T_a$, is also applied to Equation 14 to obtain hourly average overall post-implementation coil load, $\dot{Q}_{post}$.
3. The values for $\dot{Q}_{inf}$ and $\dot{Q}_{post}$ calculated above are applied to Equation 5 to obtain hourly $\dot{Q}_{pre}$, which, when inserted into Equation 4 gives $kW_{sf\_pre}$. $kW_{sf\_pre}$ is then plugged into Equation 17, the result of which is plugged into Equation 15 to give $kW_{rf\_pre}$. Combining $kW_{sf\_pre}$ and $kW_{rf\_pre}$ in Equation 3 gives the hourly value for $kW_{fans\_pre}$.

$kW_{plant\_post}$

1. The value $\dot{Q}_{post}$ calculated above is applied directly to Equation 18 to obtain the hourly value for $kW_{plant\_post}$.

$kW_{plant\_pre}$

1. The value $\dot{Q}_{pre}$ calculated above is applied directly to Equation 19 to obtain the hourly value for $kW_{plant\_pre}$.

## Sensitivity Analysis

The partial variation in overall annual savings with respect to various parameters is identified by adjusting, alone and in turn, each of the selected parameters shown below in Table 6.

**Table 6 - Sensitive Parameters**

| Parameter | Nominal Value |
|---|---|
| $p_s$ | 0.4 |
| $\varepsilon_m$ | 0.85 |
| $c$ | 400,000 |
| $c_s$ | 0.005 |

| | |
|---|---|
| $c_w$ | 0.0025 |
| $sf$ | 1 |
| $\eta$ | 0.65 |
| $\varepsilon_{Plant}$ | 0.75 |
| $T_i$ | 75 |
| $RH_i$ | 50 |
| $S$ | 0.6 |
| $CFM_{totalsf\_max}$ | 359,620 |
| $CFM_{totalrf\_max}$ | 281,800 |
| $kW_{totalsf\_max}$ | 312 |
| $kW_{totalrf\_max}$ | 158 |
| $\tau$ | 77,821 |

# Results Summary

## Regressions

Logged data yielded the required regression parameters shown in Table 7 and depicted in Figure 1- Logged Daily AHU kWh and Coil Load v Average Daily Outside Air Temperature" and Figure 2 – Logged Daily Supply Fan kWh v Daily Average Coil Load".

**Table 7 - Regression Parameters**

| Parameter | Description | Value |
|---|---|---|
| $m1_T$ | slope of daily total AHU fan kWh regressed against daily average outdoor drybulb (sampled supply and return fans) | 44.6 |
| $b1_T$ | intercept of daily total AHU fan kWh regressed against daily average outdoor drybulb (sampled supply and return fans) | 3254 |
| $m_{\dot{Q}}$ | slope of daily total supply fan kWh regressed against daily total coil load (sampled AHUs) | 2.0 |
| $b_{\dot{Q}}$ | intercept of daily total supply fan kWh regressed against daily total coil load (sampled AHUs) | 3798 |
| $m2_T$ | slope of daily average coil load regressed against daily average outdoor drybulb (sampled supply and return fans) | 12.7 |
| $b2_T$ | intercept of daily average coil load regressed against daily average outdoor drybulb (sampled supply and return fans) | 400 |

**Figure 1- Logged Daily AHU kWh and Coil Load v Average Daily Outside Air Temperature**

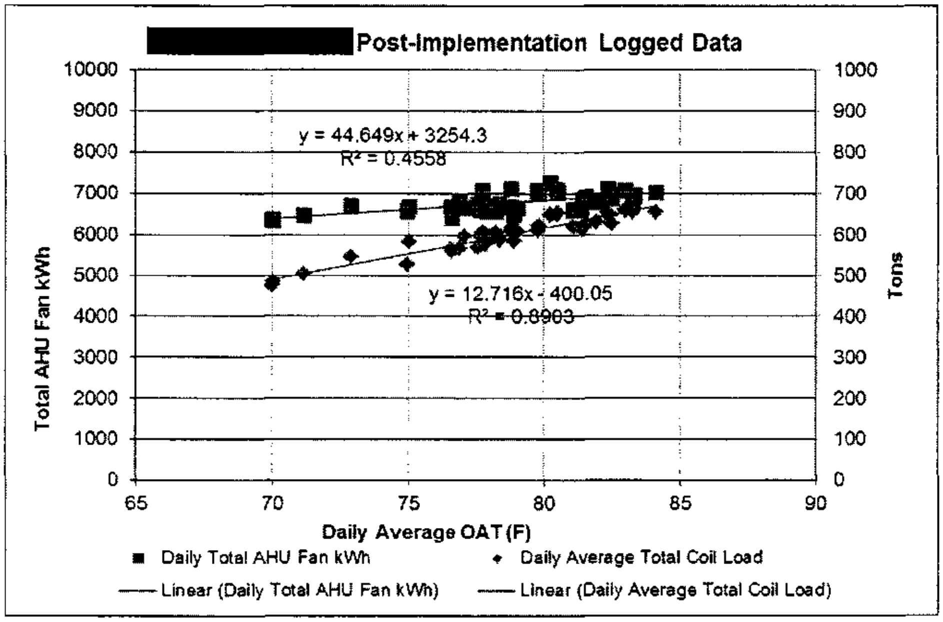
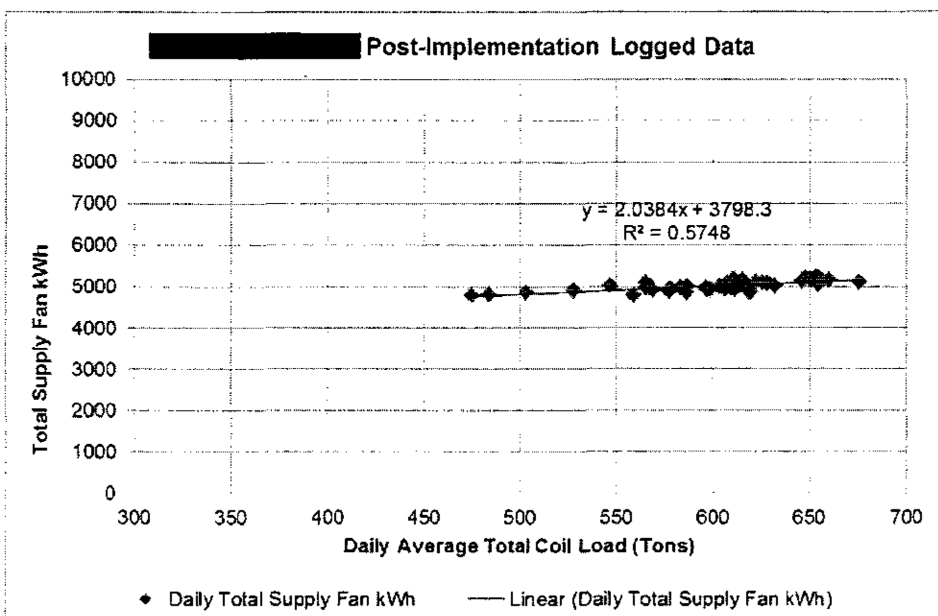



**Figure 2 – Logged Daily Supply Fan kWh v Daily Average Coil Load**




## Energy Use and Savings

Applying the parameters given in Tables 3, 4 and 5, the solution to Equation 1 – ***Annual kWh Savings*** is given below in

Table 8. This represents the estimated savings associated with implementing the Stack Effect Control measure on (27) AHUs in the hospital. Annual energy savings amount to almost 400,000 kWhs, which is equal to ~6% of the pre-implementation energy use associated with the (27) AHUs. Note that in post-implementation while overall return fan energy drops dramatically, overall supply fan and plant energy actually rises. The drop in return fan energy is expected considering that the return fans work much less to maintain return plenum static pressure than they did to maintain airflow differential. On the other hand, the increase in work by the supply fans and chiller plant may indicate that the respective AHU economizers have not compensated for the loss of the "free cooling benefit" associated with infiltration. It is expected that this effect will be remedied in Phase 2 of the project.

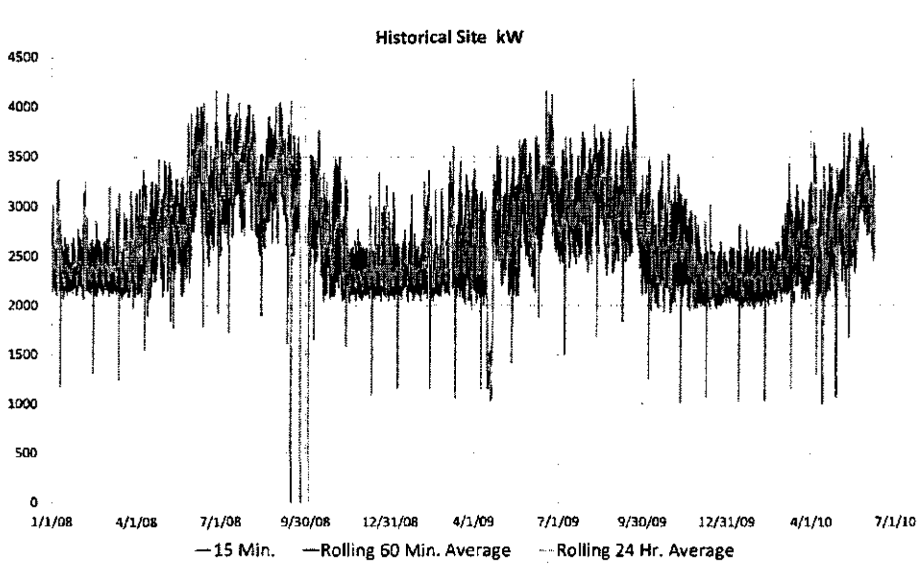
**Table 8 – Annual Energy Savings**

| | kWhs Pre | kWhs Post | kWh Savings |
|---|---|---|---|
| **Supply Fans** | 2,668,225 | 2,696,164 | -27,938 |
| **Return Fans** | 1,330,933 | 754,269 | 576,664 |
| **Plant** | 3,149,007 | 3,298,122 | -149,115 |
| **Total** | **7,148,165** | **6,748,555** | **399,610** |

## Demand Savings

The historical 15 minute demand data obtained from the site's two utility meters is shown in Figure 3 – Historical Site Interval Data". In 2008 the on-peak maximum demand of 4152 kW occurred on Thursday, June 26th at 12:15 pm. In 2009 the on-peak maximum of 4282 kW occurred on Monday, September 20th at 1:00 pm.

**Figure 3 – Historical Site Interval Data**



Integrating this data for the years 2008 and 2009 shows average annual consumption during that time to be ~23,700,000 kWh. The savings associated with the Stack Effect Control measure therefore amounts to ~1.7% of the whole site.

The results of Equation 1 are shown by equipment type in annual profile in Figure 4, and then specifically for January (winter) and July (summer) in Figure 5 and Figure 6, respectively. Peak values are shown in

**Table 9 – Demand Savings**

| | kW | Time and Date |
|---|---|---|
| On-Peak Max Demand Savings | 226 | Wednesday August 8, 1:00 PM |
| Grid-Coincident Min Demand Savings | 70 | Thursday August 2, 3:00 PM |
| Grid-Coincident Max Demand Savings | 150 | Monday August 20, 3:00 PM |

**Figure 4 – TMY Annual Demand Savings Profile**

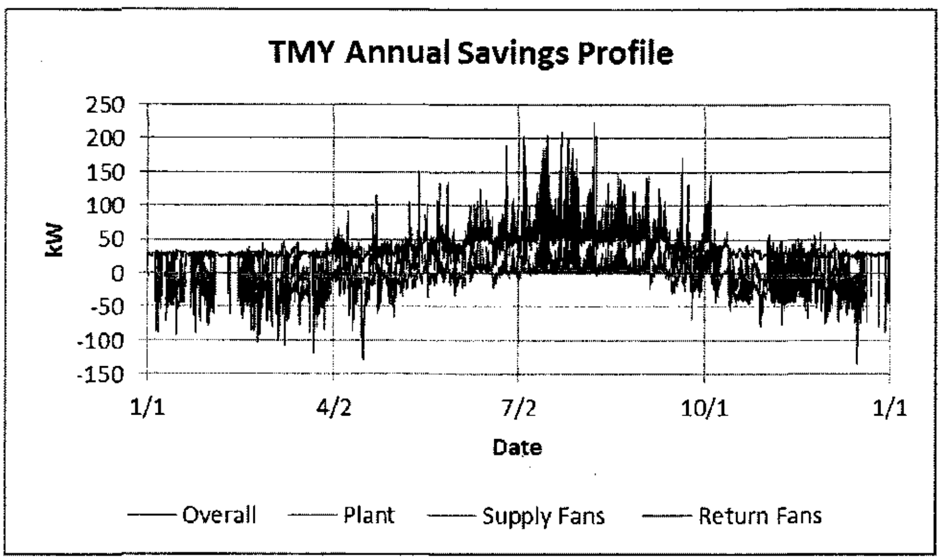


**Figure 5 – January Demand Savings Profile**

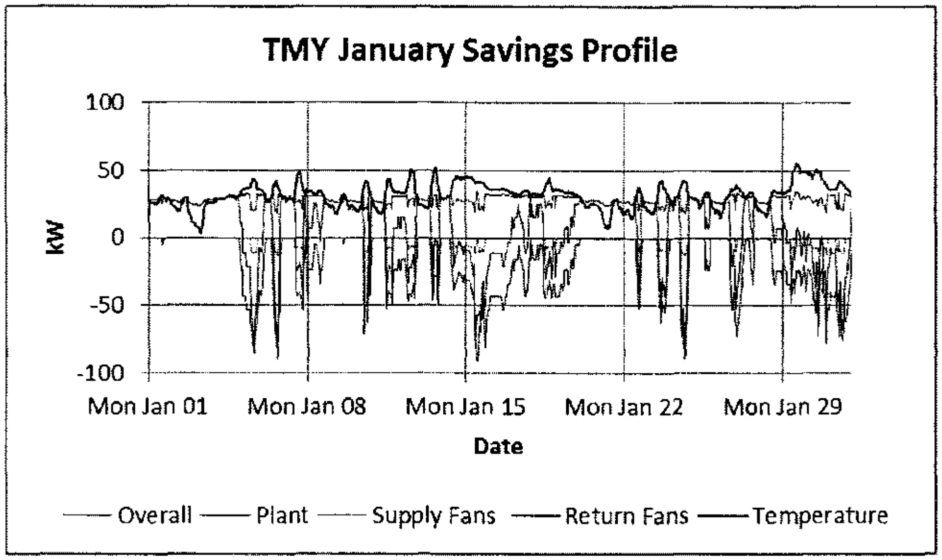



**Figure 6 – July Demand Savings Profile**

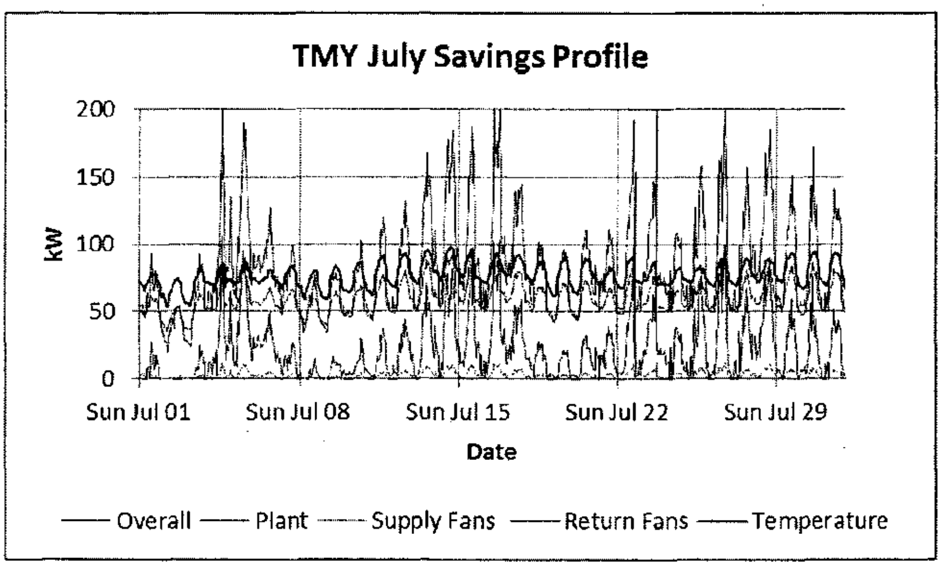
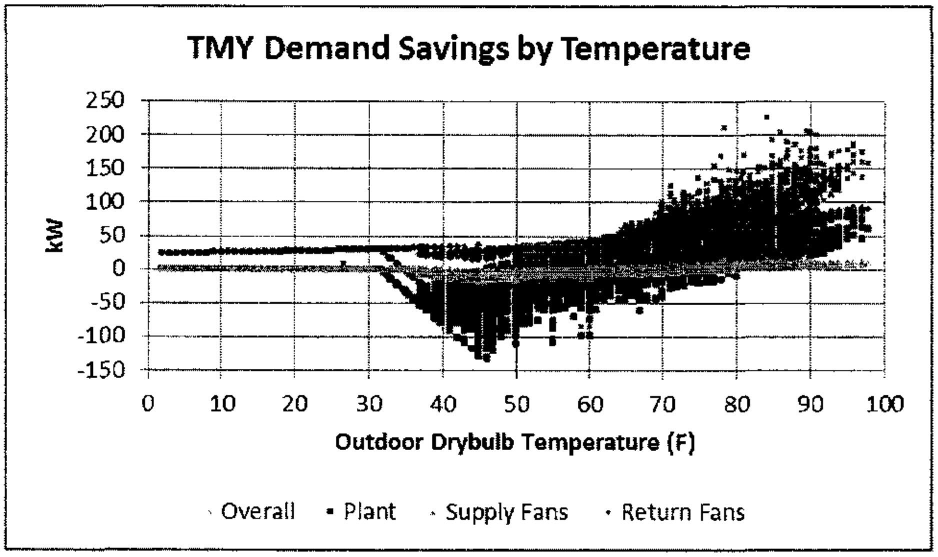



Figure 7 below depicts the respective demand savings according to outdoor temperature rather than date. As mentioned above, note the penalty associated with the plant in the range of "swing" temperatures, between ~35F to ~65F, when the economizers should be working to provide free cooling. Below ~30F the difference between pre and post electrical use appears to be limited to the return fans (humidification impacts are not addressed here).

**Figure 7 – Demand Savings by Temperature**




## Realization Rate

Savings realizations rates are shown in Table 10.

**Table 10 – Realization Rates**

| | Predicted | Measured | Realization Rate |
|---|---|---|---|
| Energy Consumption (kWh) | 479,208 | 399,610 | 83% |
| Coincident Peak Demand (kW) | 108 | 70 | 65% |

## Sensitivity

The partial variation in overall annual savings with respect to various parameters is identified by adjusting within Equation 1, alone and in turn, each of the selected parameters shown in Table 6. Shown below in Table 11 are the results presented as the ratio of the %variation in savings to the %variation in parameter. For example, a 1% increase in $CFM_{total\_sf\_max}$ will result in a 12.5% increase in savings. Conversely, a 1% increase in $CFM_{total\_rf\_max}$ will result in a 9.4% decrease in savings.

**Table 11 - Sensitive Parameters**

| Parameter | Nominal Value | Sensitivity |
|---|---|---|

| | | |
|---|---|---|
| $CFM_{totalsf\_max}$ | 359,620 | 12.5 |
| $kW_{totalsf\_max}$ | 312 | -9.4 |
| $CFM_{totalrf\_max}$ | 281,800 | -9.4 |
| $T_t$ | 75 | -5.0 |
| $kW_{totalrf\_max}$ | 158 | 3.1 |
| $\tau$ | 77,821 | -3.1 |
| $p_0$ | 0.4 | 1.5 |
| $S$ | 0.6 | -1.3 |
| $RH_t$ | 50 | -1.0 |
| $\eta$ | 0.65 | -0.7 |
| $\varepsilon_{Fload}$ | 0.75 | -0.4 |
| $\zeta$ | 400,000 | -0.3 |
| $\zeta_s$ | 0.005 | -0.2 |
| $\varepsilon_m$ | 0.85 | -0.2 |
| $sf$ | 1 | -0.1 |
| $\zeta_w$ | 0.0025 | -0.1 |

**Site Savings Summary**

The evaluated savings were compared to the final savings estimates from the DSMore runs. This comparison is shown in the Table below:

**Final Project Savings and Realization Rate**

| Evaluated kWh Savings | Expected kWh Savings | kWh RR | Evaluated NCP kW Savings | Expected NCP kW Savings | NCP kW RR | Evaluated CP kW Savings | Expected CP kW Savings | CP kW RR |
|---|---|---|---|---|---|---|---|---|
| 399,610 | 479,209 | 0.83 | 226 | 108 | 2.1 | 70 | 81 | 0.87 |

# Site 3

[redacted]

# M&V Plan Results Summary

PREPARED FOR:
Duke Energy
OHIO

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

PREPARED IN:
March 2011

# INTRODUCTION

Architectural Energy Corporation was hired to evaluate the Duke Energy custom incentive evaluation program for [redacted] in downtown Cincinnati. The energy conservation measures (ECM) were provided by [redacted] and AEC designed the plan to measure and quantify the results. The ECM measures include:

1. Replace 163 existing 15,000 BTU McQuay Dx and electric resistance heating PTACs with GE Zoneline 7,000 BTU heat pumps and add wireless thermostats.
2. Replace 179 existing 15,000 BTU McQuay Dx and electric resistance heating PTACs with GE Zoneline 12,000 BTU heat pumps and add wireless thermostats.
3. Implement a wireless thermostat mesh-network that is monitored and controlled by an energy management control system.

Measures #1 and #2 will involve removing and replacing existing HVAC equipment with a more efficient technology and adding thermostatic control. The two new models have dramatically different energy results and thus are reflected as separate measures.

Measure #3 will tie the new thermostats into a wireless mesh network and control them by the energy and demand management software. With the direct integration to the property management software at the front desk, the "unsold" rooms will be deeply setback. The system will allow [redacted] to perform demand forecasting and reduction as well as monitor the energy use of each PTAC.

# GOALS AND OBJECTIVES

Gross kWh and peak kW savings

- Total kiloWatt hour forecasted reduction is 1,821,204 kWh
- Total peak kiloWatt reduction is 266 kW

The specific objective of this M&V project is to create a realization rate based on [redacted] applications. The realization rate is the actual savings, based on monitored data, versus the projected savings presented in the applications.

# BUILDING CHARACTERISTICS

The building characteristics of the building are summarized below:

Table 1: Building Characteristics

| Characteristic | Value |
|---|---|
| Building size | 180,000 SF |

| | |
|---|---|
| Number of stories | 17 |
| Age | 27 years old |
| HVAC system | 2 15,000 BTU PTAC in each suite |
| Thermostat | Integral to unit |

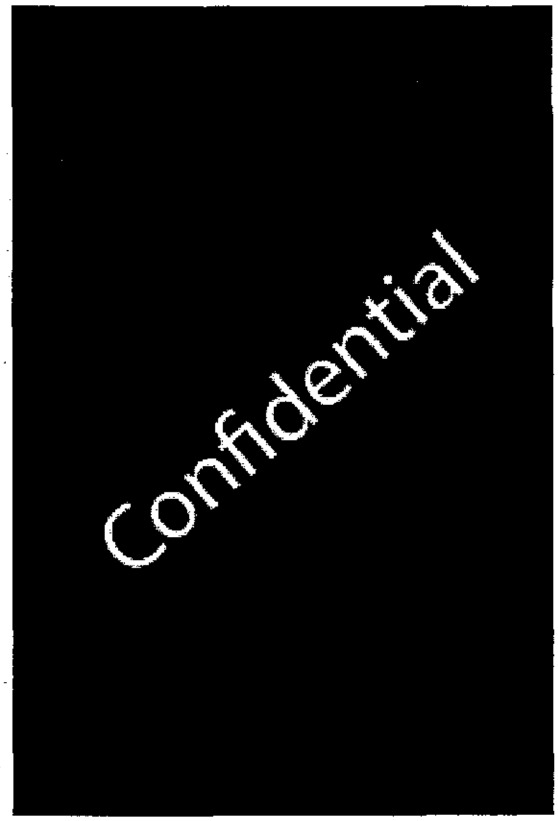


Figure 1: Building site photo

## Data Products and Project Output

- Measured data used to model annual Pre/Post load shapes
- Verify heating/cooling runtime hrs reduced through occupancy controls
- Peak demand savings verification
- Annual Energy Savings verification

## M&V Option

IPMVP Option A

# Data Analysis

Two sets of data were recorded. "Pre" data refers to data recorded with the original equipment. "Post" data was recorded after the energy conservation measures (ECM) are applied. In this study the Pre data was recorded during the cooling season and the Post data was recorded during the heating season. This left the challenge of using the data to verify the energy saving under different conditions. The Pre and Post units operate differently when either heating or cooling, however, from the data there is a lot of information and the following steps were used to show that our analysis concludes that [redacted] did meet their predicted realization rate.

There are two main aspects to the energy savings on this project. The first is the installation of efficient equipment and second, occupancy controls that will setback thermostats in unsold rooms.

# Field Data

Field procedures are repeated as written for both the Pre measurement period and Post measurement period.

Survey data

- PTAC unit(s) make and model

One-time measurements

- PTAC kW with logger installed and compressor running. This measurement is used to correlate the recorded PTAC amps to kW

Time series data on controlled equipment

- PTAC unit power (Amps)
- PTAC return and Supply temperatures (F)

Set up loggers for 5 minute instantaneous readings. The loggers were deployed for 3 weeks. The data that was retrieved was reviewed for quality. Any data that appeared to be inaccurate was removed. The actual time period for the usable data was 25.5 days Pre retrofit, during the cooling season, and 15.5 days of data after the retrofit during the heating season.

# Data Accuracy

Table 2: Data accuracy by sensor

| Measurement | Sensor | Accuracy | Notes |
|---|---|---|---|

| | | | |
|---|---|---|---|
| Temperature | MDL thermistor | ±0.5° | |
| Current | Magnelab CT | ±1% | > 10% of rating |

## Verification and Quality Control

9. Visually inspect time series data for gaps
10. Compare readings to data sheet values; identify out of range data
11. Look for physically impossible combinations e.g. supply << Return air and no current draw (unit is cooling)

## Recording and Data Exchange Format

6. MDL binary files
7. Excel spreadsheets

## Results Summary

### Data Analysis

Two sets of data were recorded. "Pre" data refers to data recorded with the original equipment. "Post" data is recorded after the energy conservation measures (ECM) are applied. In this study the Pre data was recorded during the cooling season and the Post data was recorded during the heating season. This left the challenge of using the data to verify the energy saving under different conditions. The Pre and post units operate differently when either heating or cooling, however, from the data there is a lot of information and the following steps were used to show that our analysis concludes that [redacted] did meet their predicted realization rate.

There are two main aspects to the energy savings on this project. The first is the installation of efficient equipment and second, occupancy controls that will setback thermostats in unsold rooms.

### Unoccupied Room setback

The first step was to determine the Pre and post run time percentages of the units in the room. Setbacks are programmed from the main office; this and more accurate thermostats installed in the rooms contribute to runtime savings.

- Convert raw Amp data to kW using spot measurements

$$kW_{measured} = A_{measured} \times \frac{kW_{spot}}{A_{spot}}$$

- The kW data for each room was charted
- A function was written to count points with kW > .2
- The total number of points greater than .2 kW was converted to hrs and divided by the number of hrs that the MDLs logged. The result was hrs/day that each unit ran

$$\frac{ON_{Total}}{12} = HRS$$

$$\frac{HRS}{TotalHRS\,{}^{12}\!/_{24}} = {HRS}/{DAY}$$

*Assumption: kW measurements less than .2 represent a unit that is not running*

- This process was repeated for the Post data
- The final answer is the Post divided by the Pre

$$\%Runtime = \frac{Post\ {HRS}/{DAY}}{\Pr e\ {HRS}/{DAY}}$$

*Assumption: The hrs/day that the PTAC runs is representative of occupancy and thermostat control savings. The occupancy rate of the hotel would affect this value, however, it is not considered in our model.*

## Efficient Equipment

The Pre data was recorded during the cooling season and the Post data during the heating season. This situation allowed us to use each set of measured data as a baseline for our annual model. The baseline was adjusted for the changes in equipment to model the projected use before and after the retrofit.

Cooling

- Data was plotted, separated by Bedroom and Living Room units. The value for each room type was averaged to find the per unit energy average and then multiplied by the number of rooms of that type. That data was again averaged per hour and summed daily. This was graphed. From the graph a regression line was plotted that represented average daily kWh vs OAT.

$$kW_{total} = avgkW_{bedroom} \times 179 + avgkW_{LivingRoom} \times 163$$

*Assumption: Bedroom units use more energy therefore they are the larger PTAC unit. 179 12,000 BTU units and 163 7,000 BTU units are being installed*

- The formula for the regression line was multiplied by TMY3 to model the cooling kWh in a typical year. This value represents daily kWh and TMY3 data is given in hours. The results must be divided by 24.

$$kWh = (m \times (TEMP) + b) \Big/ 24$$

Where: *m & b are values from the regression line*

*Assumption: The regression line crossed the x axis at 55 deg, this temperature was used as the cut off for the cooling data*

- The first stage in the model is to compare the energy use for the same conditions based on the improved efficiency of the new equipment. This is done by multiplying each type of equipment by the ratio of the new and old EERs. EER stands for Energy Efficiency Ratio.

$$kWh_{EER} = kWh_{pre} \times \frac{EER_{post}}{EER_{pre}}$$

$$EER = \frac{BTU/Hr_{output}}{Watt_{input}}$$

- The final improvement in energy saving will be made by multiplying the above value by the run time ratio calculated earlier. With improved run time and efficiency the final number will represent Post cooling values.

$$kWh_{post} = kWh_{EER} \times \%runtime$$

<u>Heating</u>

- Post data was plotted, as before, separated by Bedroom and Living Room units. The value for each room type was averaged to find the per unit energy average and then multiplied by the number of rooms of that type. That data was again averaged per hour and then summed daily. This was graphed. From the graph a regression line was plotted that represented average daily kWh vs OAT.

- The formula for the regression line was multiplied by TMY3 to model the heating kWh in a typical year. This value represents daily kWh and TMY3 data is given in hours so the results must be divided by 24.

$$kWh = (m \times (TEMP) + b) \Big/ 24$$

Where: *m & b are values from the regression line*

*Assumption: 55 deg was used as the upper limit of the heating data.*

- The original equipment used electric resistance heating, the new equipment will attempt to control temperature with the heat pump first and utilize resistance heating as a backup. Resistance heat has a Coefficient of Performance (COP) of 1, while the heat pumps have COPs of 3.6 and 3.4 for the Bedroom and Living Room units respectively. This model is done in a similar way to the cooling EER calculations except in reverse.

$$kWh_{COP} = kWh_{Post} \times \frac{COP_{pre}}{COP_{post}}$$

$$COP = \frac{Watt_{output}}{Watt_{input}}$$

- Because the new units have resistance heat as a back up this has to be accounted for. The data can be graphed as kW vs time, from this two distinct bands can be seen in the power. The first band is roughly 200 – 1000 W and the second band is between 2500-3500 W. The first band is the heat pump and the second is made when the resistance heat kicks in. A statement was written to distinguish values between 200 and 1000 W. If the data fell in this range it was multiplied by the COP to model a unit with only resistance heating.

*Assumption: Data that falls between .2 – 1.0 kW is heat Pump Data*

- As in the Cooling model the final step was to reapply the % runtime ratio.

$$kWh_{pre} = kWh_{COP} \div \%runtime$$

## Savings Verification and Realization Rate:

- Compare Pre/Post values to obtain total kWh/year savings. Once the savings are calculated, the realization rate is calculated by the following formula:

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

### CALCULATION OUTPUT

The following Table summarizes energy savings as the results of this energy conservation measure.

Table 3: Data analysis results and realization rate

| Criteria | Bedroom | Living Room | | |
|---|---|---|---|---|

| | | | | |
|---|---|---|---|---|
| | | | Adjusted Total | |
| PRE - Running hrs/day (Power > 200W) | 20.1 | 19.1 | | |
| POST - Running Hrs/Day (Power > 200W | 3.9 | 4.9 | | |
| % run time difference based on Pre and Post run hrs/day | 19% | 25% | 22% | |
| Cooling Regression | PRE kWh (measured) | KWh adjusted for EER | Runtime (kWh based on occupancy control) | |
| Total kWh | 1,032,059 | 791,566 | 175,681 | |
| Peak kW | 258 | 199 | N/A | |
| Heating Regression | Adjusted for occupancy | Adjusted for Heat Pump COP | Post install (measured) | |
| Total kWh | 2,788,599 | 618,905 | 266,800 | |
| Peak kW | N/A | 767 | 284 | |
| Total | Pre | | Post | savings |
| Energy kWh | 3,820,657 | | 442,482 | 3,378,175.81 |
| Peak kW | 767 | | 284 | 483 |
| Dollars | $343,859.16 | | $39,823.34 | $304,035.82 |
| | | Application | Modeled | |
| Realization rate (%) | | 1,821,204 | 3,378,175.81 | 185.49% |

**Site Savings Summary**

The evaluated savings were compared to the final savings estimates from the DSMore runs. This comparison is shown in the Table below:

**Final Project Savings and Realization Rates**

| Evaluated kWh Savings | Expected kWh Savings | kWh RR | Evaluated NCP kW Savings | Expected NCP kW Savings | NCP kW RR | Evaluated CP kW Savings | Expected CP kW Savings | CP kW RR |
|---|---|---|---|---|---|---|---|---|
| 3,378,176 | 1,284,468 | 2.63 | 483 | 234 | 2.07 | 483 | 182 | 2.65 |

# Site 4

[redacted]

## - Cool Roof Retrofit -

# M&V Plan Results Summary

PREPARED FOR:
Duke Energy
Ohio

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

PREPARED IN:
April 2011

## Introduction

Architectural Energy Corporation was hired to evaluate the Duke Energy custom incentive program addressing upgrades to the roof of the [redacted]. The measures were to replace the existing roof with a white membrane "cool roof" to reduce the heat gain on by the building envelope, as well as add insulation to the roof deck providing for better space conditioning retention.

Energy savings were estimated at 36,983 kWh, or near $3,300 annually. These calculations were initially completed by the roofing contractor to complete the installation.

## Goals and Objectives

The project goal was electric use savings of 36,983 kWh annually. The specific objective of this M&V project was to complete a post-implementation site survey of the existing building systems and new roof to determine the energy reduction in heating and cooling needs of the building. Ultimately, a realization rate can be determined to validate the intended energy savings.

## Project Contacts

Approval shall be requested from the two Duke Energy contacts listed below prior to making direct contact with the Customer or undertaking work on this M&V Plan.

| | | |
|---|---|---|
| **Duke Energy M&V Administrator** | Frankie Diersing | [redacted] |
| **Duke Energy Account Manager** | Ira Poston | [redacted] |
| **Customer Contact** | [redacted] | |
| **Site Location** | [redacted] | |

## Data Products and Project Output

- SurveyIT model output comparison of existing 'black' and retrofit 'white' roof systems.

## M&V Option

IPMVP Option D

## DATA ANALYSIS

Survey Form data entry into SurveyIT program provides DOE2 analysis output of improved building performance.

## FIELD DATA

These are examples of the data collected to obtain a complete picture of the building operation.

Completion of Building Survey Form:

1. General Information
   - Size, building type
   - Areas included
2. Areas
   - Occupancy schedules, holidays
   - Lighting schedules, plug loads
   - Thermostat setpoints
3. HVAC Systems
   - Make/model, type, capacity, efficiency
   - Quantity, location, control method
4. Zones
   - Exterior surfaces (if applicable)
   - Roof (if applicable)
   - Window types and geometry (if applicable)
5. Spaces
   - Occupancy style
   - Lighting, miscellaneous equipment
6. Important Details
   - Domestic water heating, kitchen equipment
   - Exterior lighting and other schedules
   - Meters serving the building
   - Space/Zone/Area assignment and association

## VERIFICATION AND QUALITY CONTROL

12. Review Error Logs for critical issues or unintended data omission.
13. Review size and type of building for reliable reduction proposal.

## RECORDING AND DATA EXCHANGE FORMAT

8. DOE2 text output files.

# Results Summary

## Data Analysis

1. Verify Proposed Measures Were Implemented:

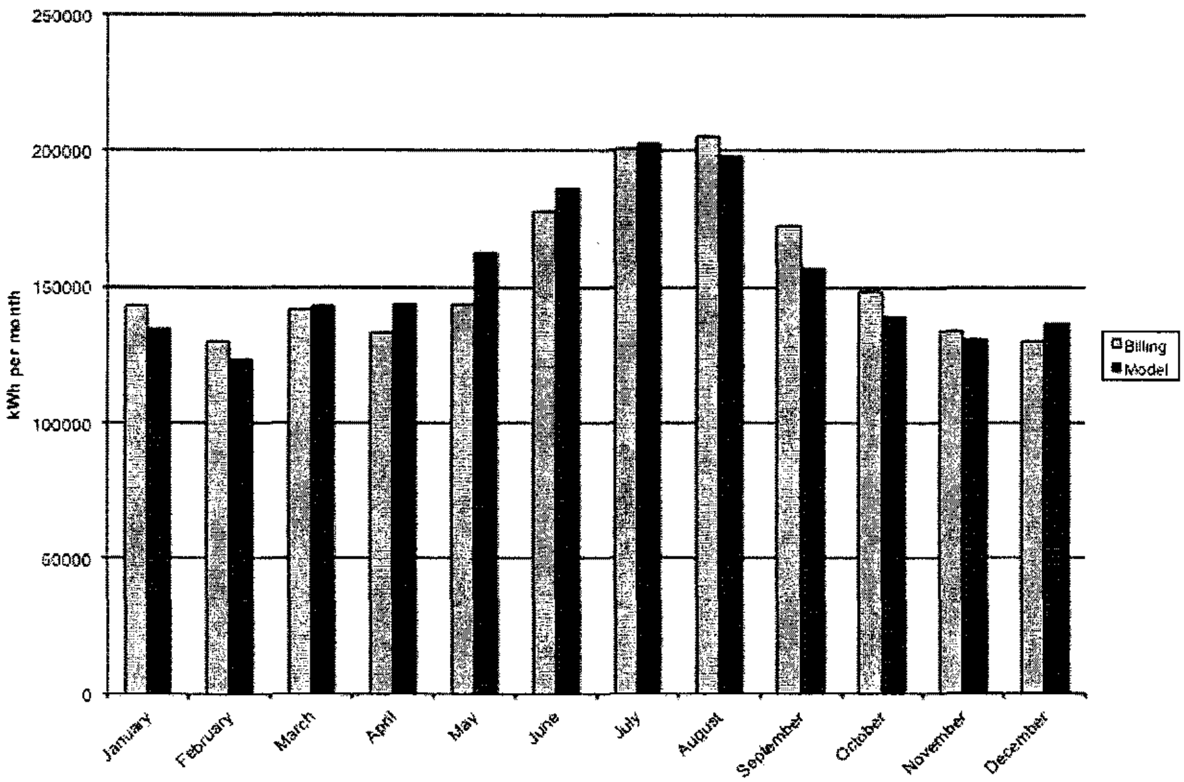
   The "cool roof" was installed on the [redacted] per the scope intended.

2. Calculation Methodology:

   A Survey Form was filled out for the building during a site walk following the roof install. The information requested by the form helps attain a complete picture of the facility operation and equipment necessary to determine annual energy use. This form was then transferred directly to a MS Access Database (SurveyIT) that runs DOE2 (Department of Energy) software to calculate the building energy performance and a host of other information. From these outputs, the necessary annual energy use in kWh and Therms can be compared to determine the savings attributed to the roofing retrofit performed for this measure.

3. Model Calibration

   Once the inputs were defined, as-built model was calibrated to billing data. A comparison of the simulated monthly kWh from the calibrated model and the monthly utility bills is shown below:




The calibration statistics are summarized below. Note, the calibration statistics are better than the targets established by ASHRAE Guildeline 14 - Measurement of Energy and Demand Savings.

| Parameter | Calibration Result | ASHRAE Guideline 14 Target |
|---|---|---|
| RMS Error | 0.5% | +/- 15% |
| Mean Bias Error | 0.1% | +/- 5% |
| Maximum monthly deviation | -13.5% | Not addressed |

4. Savings Verification and Realization Rate:

Pre/Post values are compared to obtain annual kWh and Therm savings for the facility. Once the savings are calculated, the realization rate is calculated by the following formula:

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

## CALCULATION OUTPUT

Below are two tables that demonstrate achieved savings based on the DOE2 calculation through ModelIT. Only electricity savings was included here due to only that commodity being included on the Rebate Application.

**Savings reported in Application:**

| Commodity | Value |
|---|---|
| Electricity | 36,983 |
| Natural Gas | 0 |
| Cost | $ 3,328 |

**Following Installation of 'Cool Roof':**

| Annual Energy Savings | | |
|---|---|---|
| Electricity | 4,798 | kWh |

| Approximate Annual Cost Savings | |
|---|---|
| Electricity | $ 432 |

Realization Rate: 4,798 / 36,983 = 13%

*Notes:
- A rate of $0.09 per kWh was used to estimate cost savings, taken from the Application breakout of cost per kWh.

### Site Savings Summary

The evaluated savings were compared to the final savings estimates from the DSMore runs. This comparison is shown in the Table below:

**Final Project Savings and Realization Rate**

| Evaluated kWh Savings | Expected kWh Savings | kWh RR | Evaluated NCP kW Savings | Expected NCP kW Savings | NCP kW RR | Evaluated CP kW Savings | Expected CP kW Savings | CP kW RR |
|---|---|---|---|---|---|---|---|---|
| 4,798 | 10,100 | 0.48 | 13 | 4 | 3.22 | 8 | 3 | 2.65 |

# M&V Summary

## Site 5

Prepared by Architectural Energy Corporation
February, 2011

## Introduction

Architectural Energy Corporation was hired by TecMarket Works to evaluate the Duke Energy custom incentive evaluation program for *n* [redacted] stores in the Cincinnati area. Of the population, 5 specific stores were selected for sampling and data-logging. The following ECM measures were the target of the data analysis:

1. Emerson E-2 Energy Management System
   - System provides remote control of:
     a. HVAC
     b. Milk cooler
     c. Display freezer
     d. Walk-in freezer
     e. Water heater
     f. Ice storage
   - The E-2 system implements the following control strategies:
     a. Space temperature setpoints and setback
     b. Case temperature reset
     c. Anti-sweat heater controls
     d. HVAC and lighting scheduling
     e. Peak demand limiting
     f. Rotational load shedding
2. LED case lighting for milk cooler and freezer
   - Replace T12 case lighting for GE LED case lighting

## Goals and Objectives

The projected savings goals identified in the application are:

- Total population (*n* stores) reduction of 4,900,840 kWh.

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

- Annual gross kWh savings
- Summer peak kW savings (at actual peak and grid peak)
- kWh and kW realization rates

## Building Characteristics

The building characteristics of each store are summarized below:

| Characteristic | Value |
|---|---|
| Building size | 3200 SF |
| Number of stories | 1 |
| Age | Varies from 23 – 69 years old |
| HVAC system | 1-2 rooftop units |
| Refrigeration system | 1 walk-in cooler with remote condensing unit |
| | 1 walk-in freezer with remote condensing unit |
| | 1 ice chest |
| Water heater` | 1 electric water heater |
| | |

## Data Products and Project Output

- Model predicting pre/post kWh as a function of outdoor temperature
- Summer peak demand savings
- Annual Energy Savings

## M&V Option

1. IPMVP Option A

## Field Data Points

1.. Survey existing equipment and note the following information:

- Refrigerated case lighting survey
- Refrigerated case make and model
- Thermostat type and setpoints
- Canopy lighting survey
- RTU make and model
- Condensing unit(s) make and model
- Water heater make and model

2. Data loggers were installed to trend amperage for the following equipment at 5 minute intervals over the course of 1 month (each pre and post ECM implementation) for each of the 5 selected locations. Supply and return temperatures for each RTU were also logged.

- HVAC unit(s)
- Milk cooler

- Hardening freezer
- Ice chest
- Domestic hot water heater
- Ice cream display case(s)

3. Spot watt measurements were taken for all logged equipment during data logger installation. The following readings were taken at a single point in time and simultaneously compared to instantaneous data logger readings:

- Kilowatts
- Amperage
- Voltage
- Power factor

## Data Accuracy

| Measurement | Sensor | Accuracy | Notes |
|---|---|---|---|
| Temperature | MDL thermistor | ±0.5° | |
| Current | Magnelab CT | ±1% | > 10% of rating |

## Verification and Quality Control

14. Visually inspect time series data for gaps
15. Compare readings to nameplate values; identify out of range data

## Recording and Data Exchange Format

9. MDL binary files
10. Excel spreadsheets

## Data Analysis Summary

**EMS Data Analysis**

1. The following calculations were performed for each piece of logged equipment for both the pre and post logged interval data:

- Find ratio of kW to amps for each piece of equipment from spot watt measurements.
- Multiply Logged amperage interval data by kW/amp ratio to obtain 5 minute interval kW.
- Convert 5 minute interval kW to kWh by multiplying by 5/60.
- Sum 5 minute kWh values per day to obtain kWh/day.
- Average daily outside air temperatures.

- Regress HVAC and refrigeration kWh/day into a temperature dependent load model. Form of the regression equation is:

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

  where:

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

- Average daily TMY3 outside air temperature data.
- Extrapolate each equipment regression by plugging in average daily TMY3 outside air temperature data to obtain kWh/day for the year.
- Sum kWh/day extrapolations to obtain kWh/year.
- Compare Pre/Post kWh/year to show kWh decrease/increase due to ECM implementation.

**Refrigerated Case Anti-sweat heater control (Deemed Savings)**

1. A deemed savings of 1674 kWh/year per door of each refrigerated case was included in the sample savings estimation. This value was obtained from the Duke Energy measure savings database, which is derived from DOE-2 simulations of anti-sweat heater control performance in prototypical grocery stores. A deemed savings approach was used because it was not cost-effective to monitor the power going to the anti-sweat heaters given the relatively small savings expected from the anti-sweat heater controls.

**Refrigerated Case LED Lighting Data Analysis**

1. A survey which included lighting fixture type, count and wattage was conducted for each of the 5 sampled locations.

2. The following calculations were performed for each piece of logged equipment for both the pre and post logged interval data:

   - Use the following formula to obtain total fixture kW:

     $$kW_{total} = a \times \frac{b}{1000}$$

     Where:

     a = Number of fixtures
     b = Fixture wattage

- Determine direct kWh/year (kWh consumed by lighting) by using the following equation:

  $$kWh/year_{direct} = kW_{total} \times 8760$$

- Determine indirect kWh/year (kWh converted to heat) by using the following equations:

  $$kWh/year_{indirect(milkcooler)} = a \times 0.37 \times \frac{3.413}{b}$$

  Where:

  a = kWh/year$_{direct}$
  b = Equipment energy efficiency ratio (EER)

  $$kWh/year_{indirect(selfserve)} = a \times \left(\frac{1}{b}\right) \times \left(0.37 \times \frac{3.413}{c}\right) + 0.63$$

  Where:

  a = kWh/year$_{direct}$
  b = RTU coefficient of performance (COP)
  c = Equipment energy efficiency ratio (EER)

- Sum direct and indirect values to obtain total kWh/year

- Compare Pre/Post values to obtain total lighting kWh/year savings.

**Outdoor Lighting Data Analysis**

1. Outdoor lighting calculations were based on an assumed "time on." Store hours for non-24 hr stores was assumed to be 5 am to 1 am.

2. "Pre" calculations were done assuming the timer was set for the worst case during the year or the winter solstice and operated at that time for the entire year.

3. "Post" calculations were done based on actual sunrise/sunset times during the year to simulate the photocell operation.

   - Calculate "hours on" by determining hours from store open to sunrise and from sunset to store close.
   - Calculate kWh savings per year by using the following equation:

$$kWh / year = a \times b \times c$$

Where:

a = Number of fixtures
b = kW per fixture
c = Total estimated "hours on"

- Compare Pre/Post values to obtain total lighting kWh/year savings.

**Population Extrapolation**

Sample kWh/year savings were extrapolated to the population of *n* stores by using the following equation:

$$kWh / year_{totalsavings} = \frac{a \times b}{c}$$

Where:

a = Total Sample Savings
b = Total kWh/year for entire population (actual billing usage)
c = Total sample kWh/year (actual billing usage)

## Results Summary

The following results account for benefits of the EMS retrofit and the case lighting LED retrofit. The estimated savings attributable to the EMS retrofit reflect the new on/off scheduling at those stores that close at night as well as the rotational load shedding for all stores.

Savings attributable to the LED retrofit are assumed to be constant regardless of outdoor air temperature. The retrofitted case lights were not trended during either the Pre or Post survey period and are assumed to be energized 24/7, regardless of store operating schedule.

During data analysis, it was noted that outside air dampers on all sampled RTU's were shut and not operating.

A summary of the estimated annual savings from the 5 sampled stores is shown in the Table 1, broken out by the HVAC and refrigeration savings expected from the EMS system and the refrigeration LED case lighting.

**Table 1**

| Realization Rates | | | |
|---|---|---|---|
| Site | EMS Realization Rate | Case LED Lighting Realization Rate | Total Realization Rate |
| Site 1 | 68% | 106% | 108% |
| Site 2 | 27% | 108% | 74% |
| Site 3 | 67% | 103% | 84% |
| Site 4 | 99% | 68% | 76% |
| Site 5 | 56% | 106% | 99% |

Average Sample RR = 88%

Realization rates for the EMS and refrigerated case LED ECM's at the sampled stores are noted in Table 2. On average, the sampled stores achieve a realization rate of 88%.

**Table 2**

| Realization Rates | | | |
|---|---|---|---|
| Site | EMS Realization Rate | Case LED Lighting Realization Rate | Total Realization Rate |
| Site 1 | 68% | 106% | 108% |
| Site 2 | 27% | 108% | 74% |
| Site 3 | 67% | 103% | 84% |
| Site 4 | 99% | 68% | 76% |
| Site 5 | 56% | 106% | 99% |

Average Sample RR = 88%

When extrapolated to the entire population of *n* stores, the realization rate dropped slightly to 77%. The overall population realization rate was determined by dividing the estimated population savings by the total expected kWh savings. A summary of the estimated annual savings for all UDF stores is shown in Table 3.

**Table 3**

| UDF Total Savings | | |
|---|---|---|
| Sample Total Savings | 237381 | kWh |
| Sample Total Usage | 1729120 | kWh |
| Population Total Usage | 27497949 | kWh |
| **Population Savings** | **3775031** | **kWh** |
| **Total Population RR** | **77%** | |

Evidence of peak demand reduction is shown in Table 4. Peak demand from actual billing data was compared from 2009 to 2010 in the months of June, July, and August. The greatest peak demand reductions were noted in the month of July.

**Table 4**

| Billing Peak Demand Reduction (2009 to 2010) | | | |
|---|---|---|---|
| | June (kW) | July (kW) | August (kW) |
| Site 1 | 2.4 | **7.2** | 6 |
| Site 2 | 8 | **9.6** | 5.6 |
| Site 3 | 9.6 | **10.4** | 8 |
| Site 4 | **2.97** | 2.9 | 1.98 |
| Site 5 | 2.2 | **2.2** | 0.8 |

The average peak demand reduction is 6.46 kW per store. Total peak demand savings over the *n* store project is 588 kW.

Figures 1-5 depict graphs of energy consumption and savings for the metered equipment (HVAC and refrigeration) in each of the sampled stores over the course of 1 year.

**Figure 1**

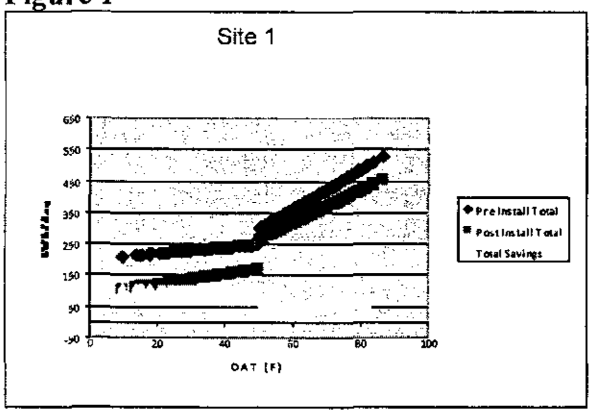



**Figure 2**

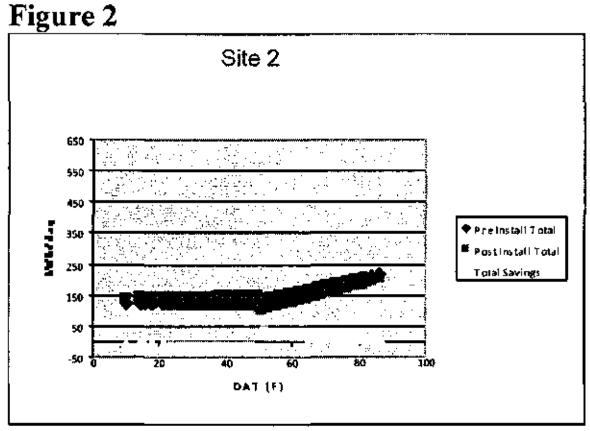



**Figure 3**

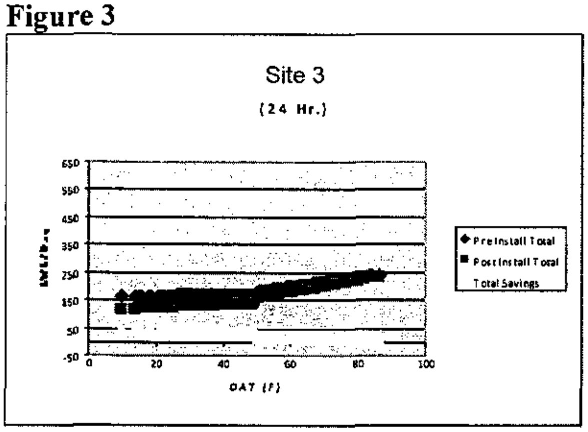



**Figure 4**

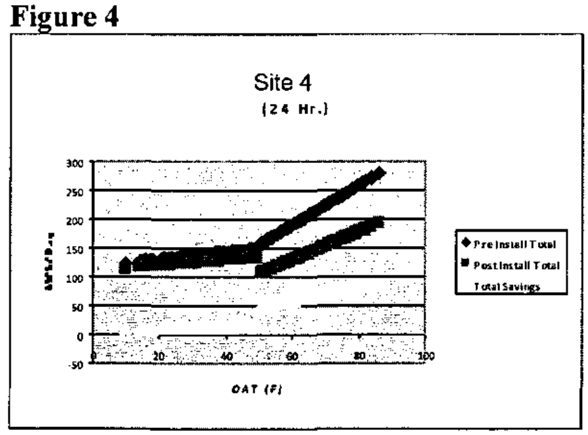
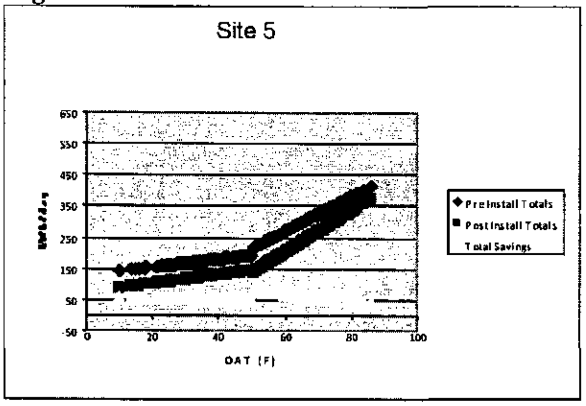


**Figure 5**




Figures 6-16 depict kWh/day vs. average daily outside air temperature for the 5 sampled stores. The rooftop units were the only load that showed a strong temperature dependence. The RTU loads were separated from the r kWh/day were then extrapolated for the year by substituting TMY3 outside air temperatures into the linear regression equations for both pre and post ECM install.

**Figure 6**

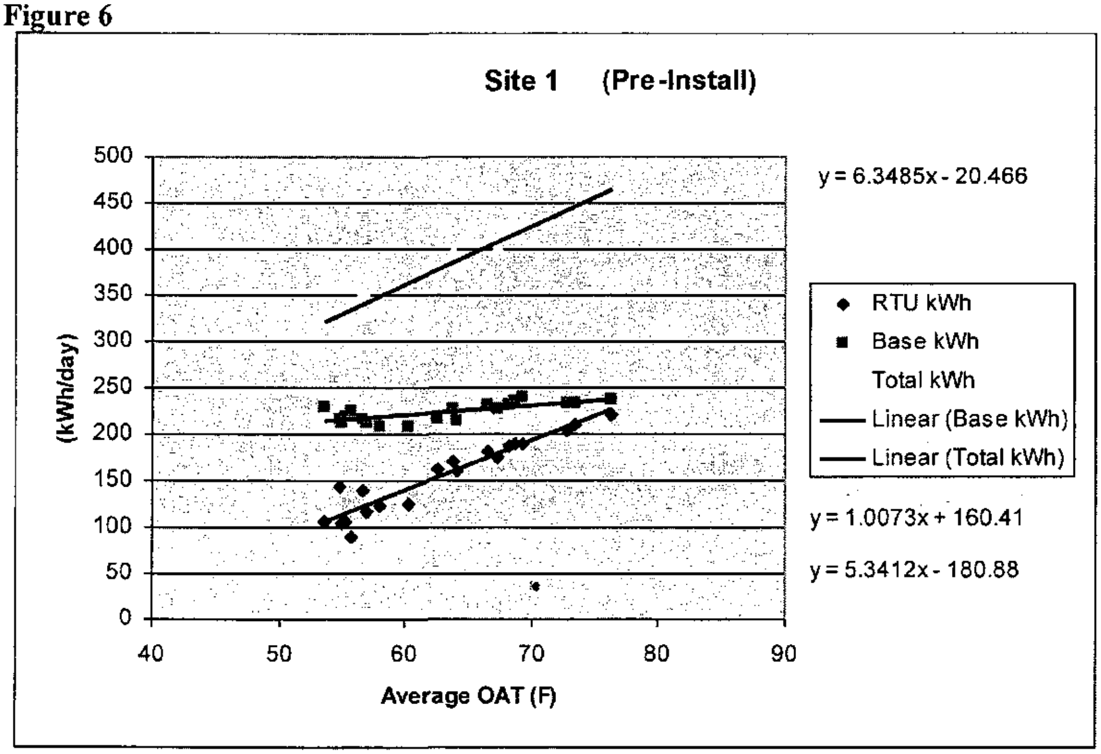


**Figure 7**

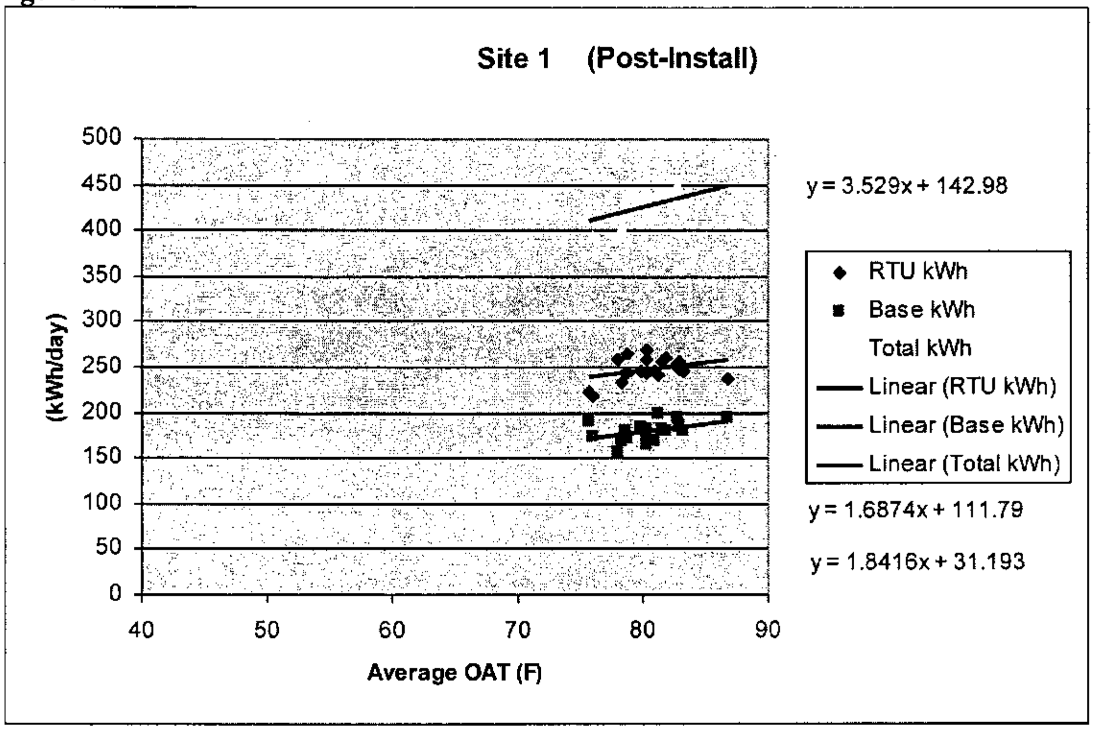



**Figure 8**

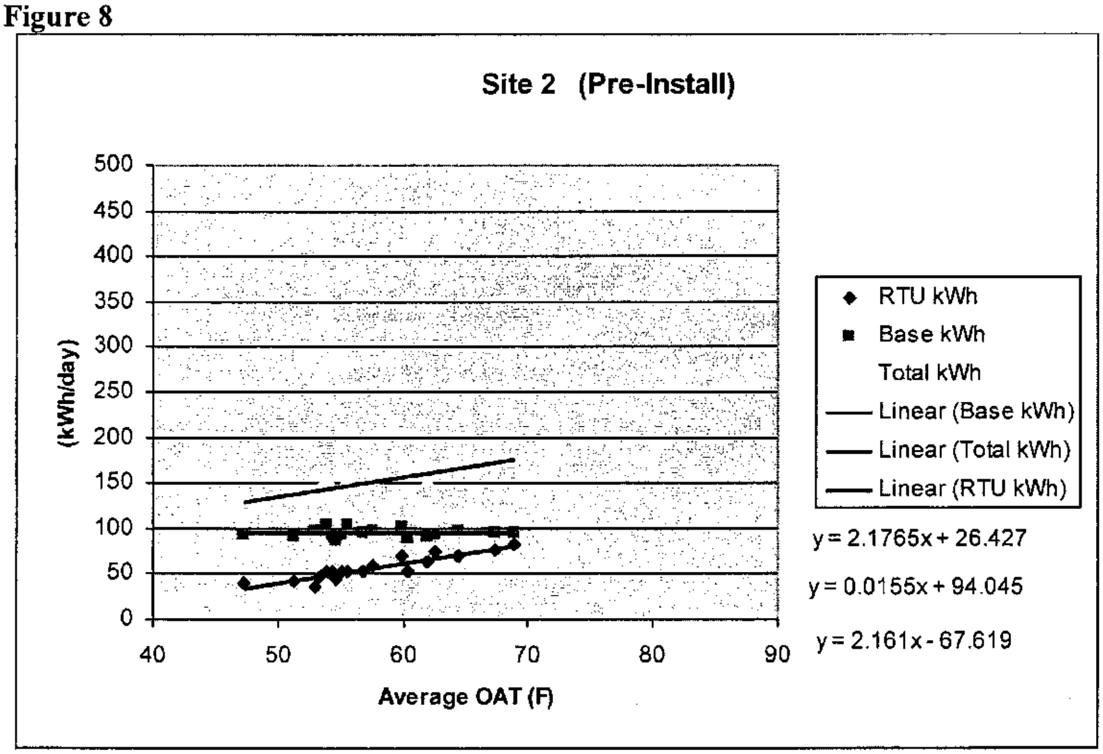


**Figure 9**

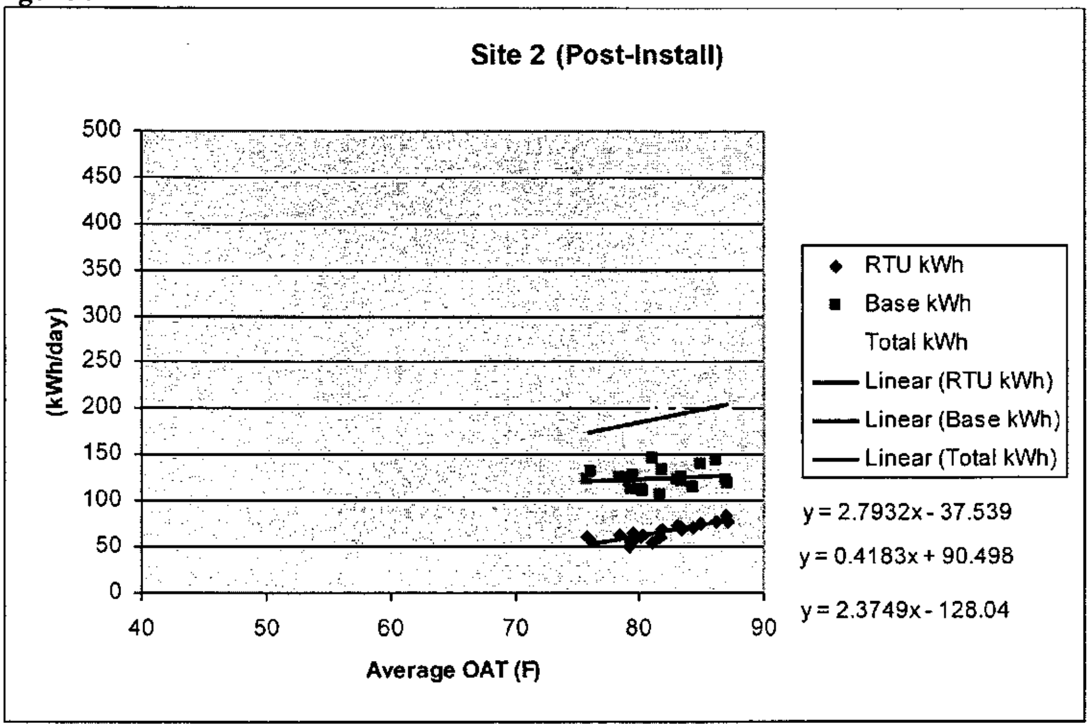



**Figure 10**

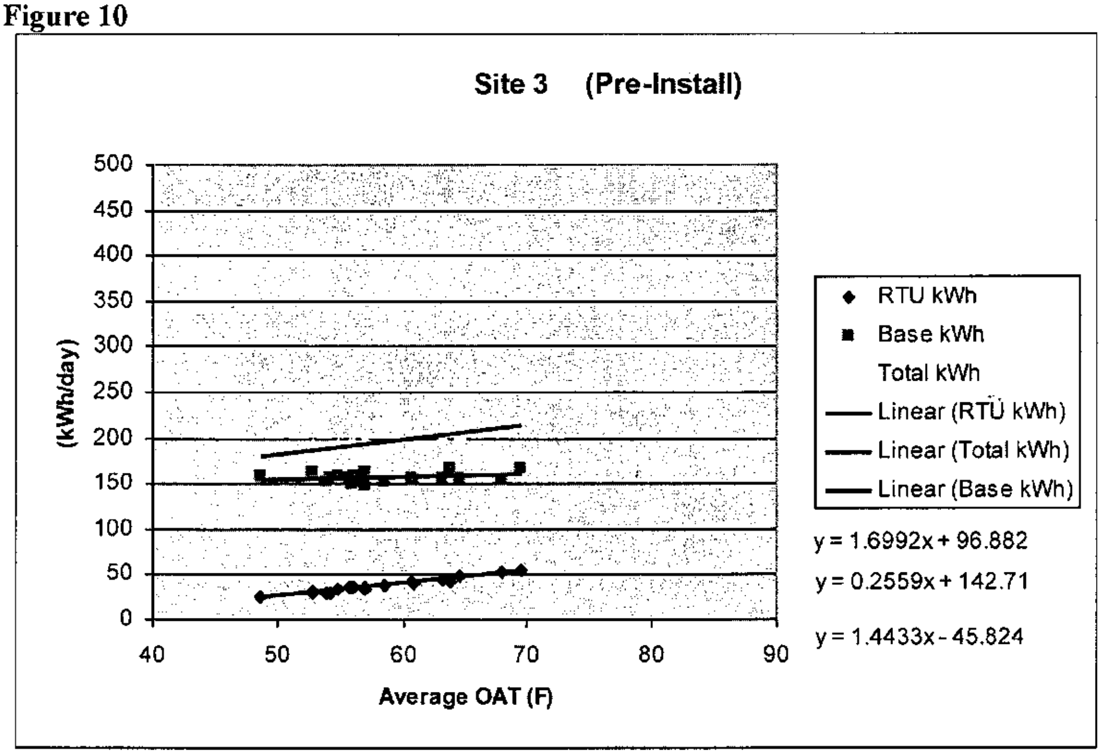


**Figure 11**

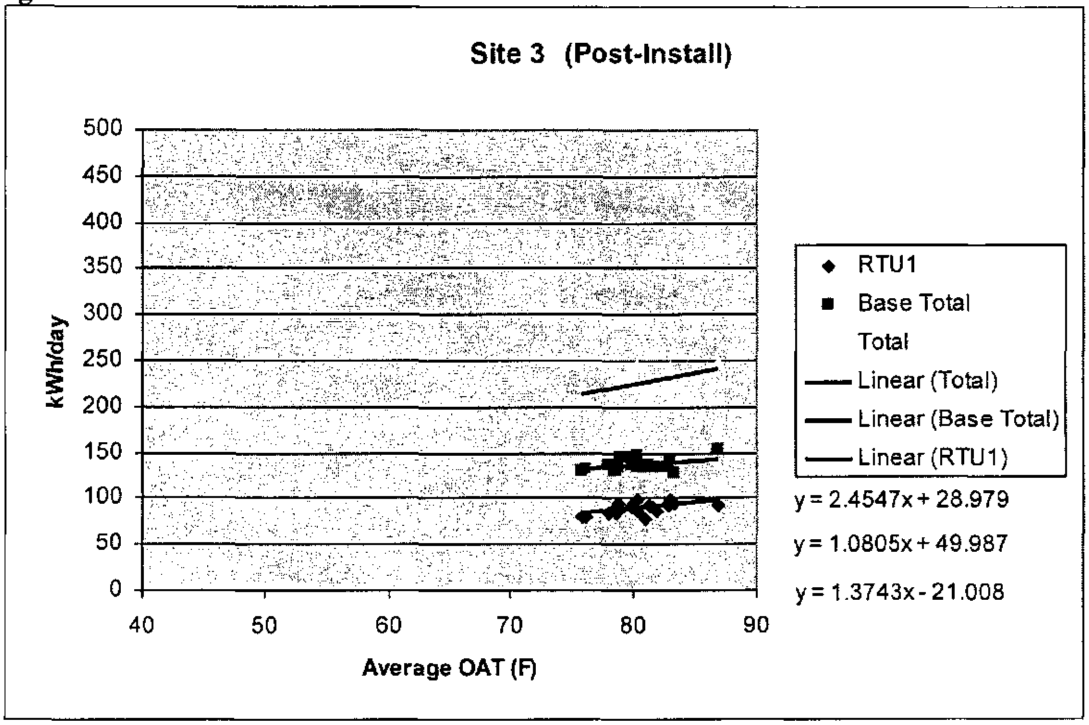



**Figure 12**

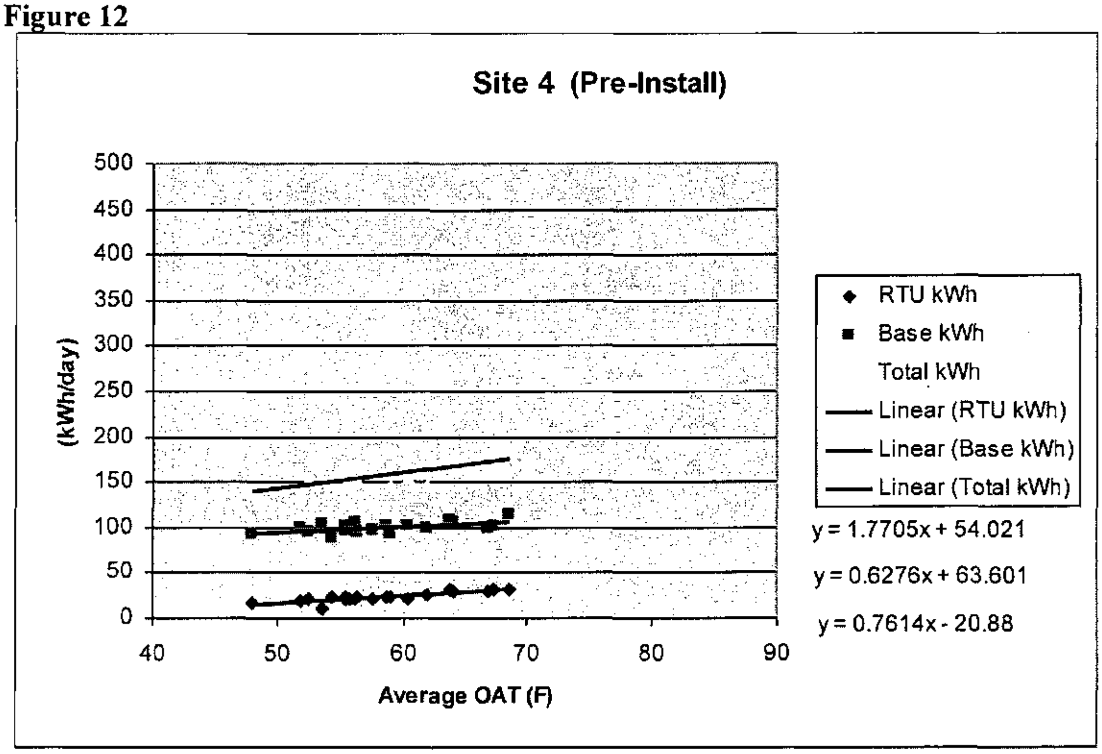


**Figure 13**

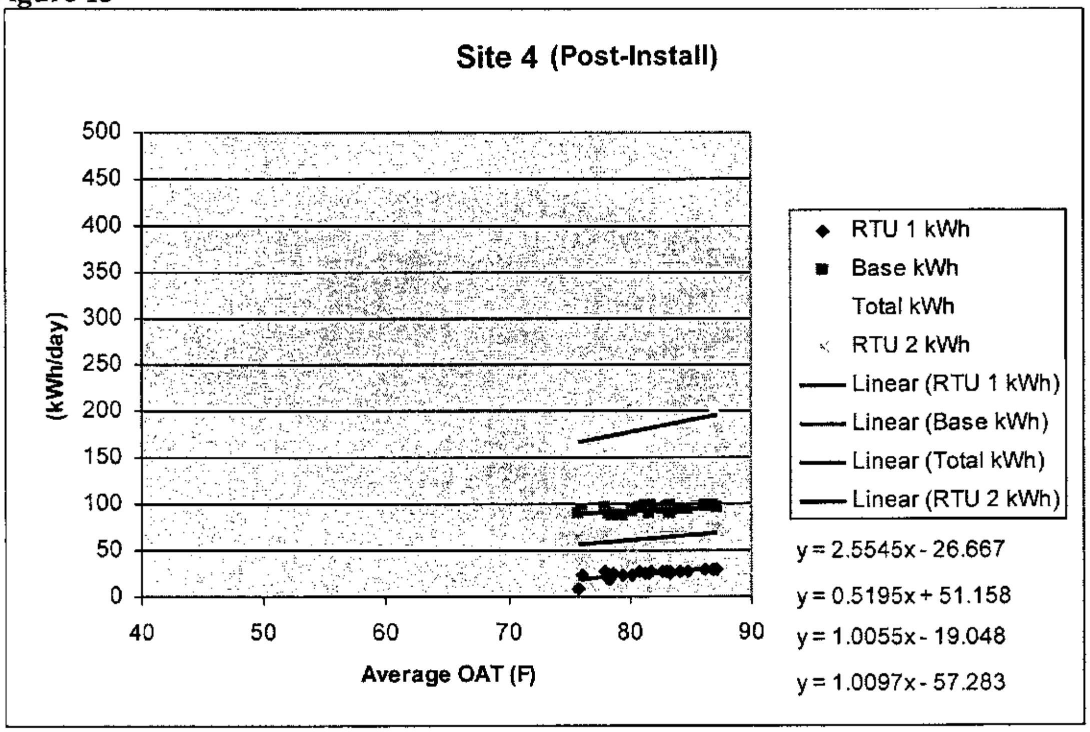



**Figure 14**

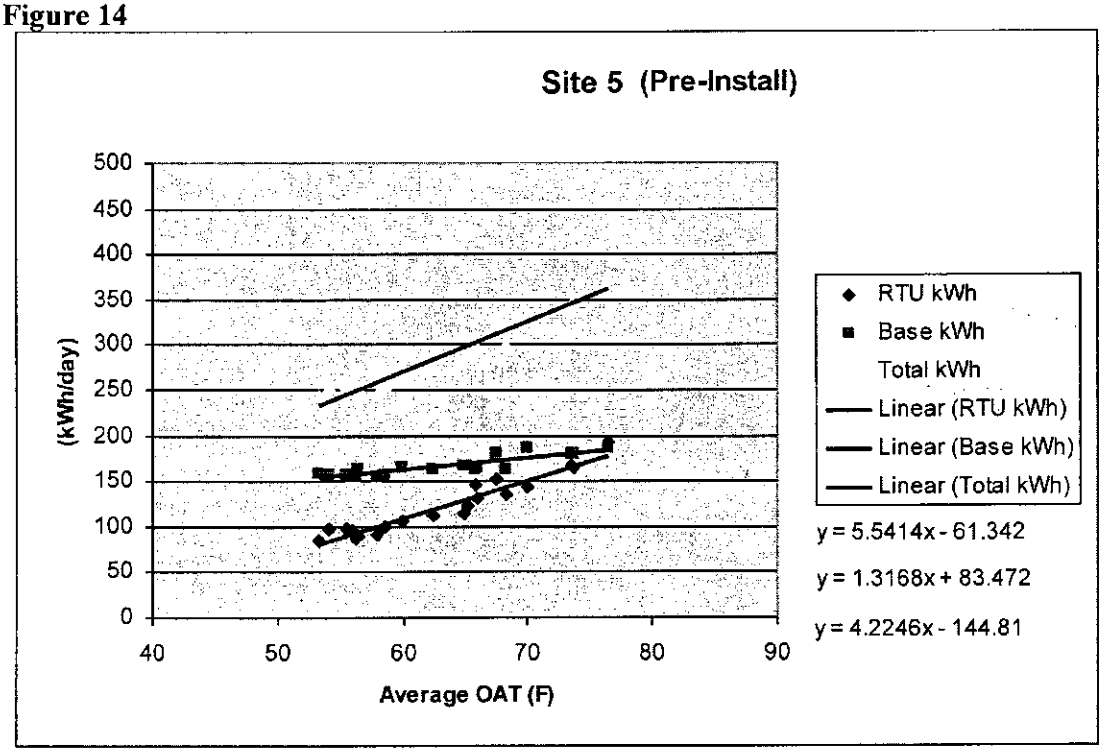
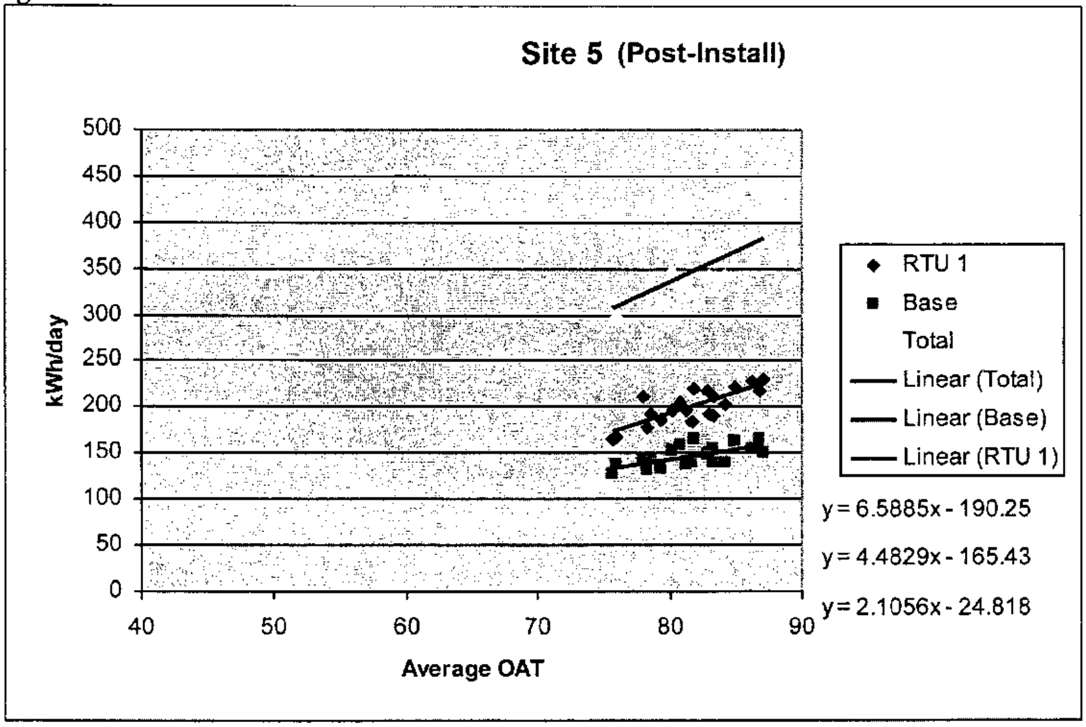


**Figure 15**




**Site Savings Summary**

The evaluated savings were compared to the final savings estimates from the DSMore runs. This comparison is shown in the Table below:

**Final Project Savings and Realization Rate**

| Evaluated kWh Savings | Expected kWh Savings | kWh RR | Evaluated NCP kW Savings | Expected NCP kW Savings | NCP kW RR | Evaluated CP kW Savings | Expected CP kW Savings | CP kW RR |
|---|---|---|---|---|---|---|---|---|
| 3,775,031 | 4,832,346 | 0.78 | 588 | 552 | 1.07 | 588 | 0 | N/A |

# Site 6

[redacted]

## Refrigerated Case Lighting Retrofits

# M&V Plan Results Summary

PREPARED FOR:
Duke Energy
Ohio

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

PREPARED IN:
March 2011

## Introduction

Architectural Energy Corporation was hired by TecMarket Works to evaluate the Duke Energy custom incentive evaluation program for 60 [redacted] stores in the Cincinnati area. Of the population, five specific stores were selected for sampling and data-logging. The following ECM measures were the target of the data analysis:

LED refrigerated case lighting was the target of the data analysis. Fluorescent case lighting was replaced by LED case lighting, controlled by motion sensors.

## Objectives

The specific objectives of this M&V project were to verify the actual annual gross kWh savings, as well as the summer peak kW savings associated with the lighting retrofits.

Post data was obtained from the following 5 stores:

| Store | Suburb | Address | City |
|---|---|---|---|
| 1 | [redacted] | [redacted] | [redacted] |
| 2 | [redacted] | [redacted] | [redacted] |
| 3 | [redacted] | [redacted] | [redacted] |
| 4 | [redacted] | [redacted] | [redacted] |
| 5 | [redacted] | [redacted] | [redacted] |

## Data Products and Project Output

- Average pre/post load shapes by daytype for controlled equipment
- Summer peak demand savings
- Annual Energy Savings

## M&V Option

IPMVP Option A

## Data Analysis

5. Convert time series data on logged equipment into post average load shapes by daytype. Estimate peak demand savings.

## Field Data Points

Calendar schedule:

- Post data should be gathered during a time period when the store is expected to operate under normal conditions (i.e., not during the holidays)

Store survey data:

- [redacted] Store #
- Survey all cases and condensing units that are part of the retrofit project for store
  - Case lighting survey
    - number of LED sticks or fluorescent lamps
  - Case lighting on/off schedule (PRE only)
- Record locations of installed loggers by logger number and case name or number
- Photos
  - store front
  - typical case front and typical condensing unit
  - typical logger installation

Time series data on controlled equipment:

- Lighting status loggers on all cases that are part of the retrofit project (set up for 3 week deployment.)

## Verification and Quality Control

16. Visually inspect time series data for gaps
17. Compare readings to nameplate values; identify out of range data

## Recording and Data Exchange Format

11. Excel spreadsheets

## Data Analysis Summary

**Refrigerated Case LED Lighting Data Analysis**

3. A survey which included lighting fixture type, count and wattage was conducted for each of the 5 sampled locations.

4. The following calculations were performed for each piece of logged equipment for both the pre- and post-logged interval data:

   - Use the following formula to obtain total fixture kW:

     $$kW_{total} = a \times \frac{b}{1000}$$

     Where:

     a = Number of fixtures
     b = Fixture wattage

   - Determine direct kWh/year (kWh consumed by lighting) by using the following equation:

     $$kWh/year_{direct} = kW_{total} \times 8760 \times F$$

     Where:

     F= percentage of time that the lighting equipment is ON. For the PRE- measurements, this number is 100%. For POST- measurements, the number is less than 100%, and originates from the logger data collected.

   - Determine indirect kWh/year (kWh converted to heat) by using the following equations:

     $$kWh/year_{indirect(milkcooler)} = a \times COP$$

     Where:

     a = $kWh/year_{direct}$
     COP = Equipment energy efficiency (Coefficient of Performance)

   - Sum direct and indirect values to obtain total kWh/year

   - Compare Pre/Post values to obtain total lighting kWh/year savings.

**Population Extrapolation**

Sample kWh/year savings were extrapolated to the population of 60 stores by using the following equation:

$$kWh / year_{totalsavings} = \overline{a} \times b$$

Where:

$\overline{a}$ = Average kWh/year savings per sample LED stick
b = Total number of LED sticks installed

## RESULTS SUMMARY

The following results account for benefits of the case lighting LED retrofit. The estimated savings attributable to the LED retrofit are assumed to be constant regardless of outdoor air temperature. The retrofitted case lights were trended only during the Post survey period, as the schedules during the Pre period assumed to be energized 24/7, regardless of store operating schedule.

During data analysis, it was noted that outside air dampers on all sampled RTU's were shut and not operating.

A summary of the estimated annual savings from the 5 sampled stores is shown in the Table 1, broken out by the consumption and demand savings from the LED case lighting measure.

**Table 1**

| Store | Pre- Runtime | Post- Runtime | Total kWh Savings/Year | Peak Demand Savings (kW) |
|---|---|---|---|---|
| 1 | 8,760 | 7,936 | 120,607 | 13 |
| 2 | 8,760 | 5,825 | 146,175 | 15 |
| 3 | 8,760 | 8,716 | 132,830 | 15 |
| 4 | 8,760 | 8,699 | 143,045 | 16 |
| 5 | 8,760 | 6,517 | 133,327 | 14 |
| **Average** | **8,760** | **7,539** | **135,197** | **14.6** |

Figures 1 and 2 show example hours-of-operation profiles for the retrofitted LED case lighting, as controlled by motion sensors. Figure 1 is from the floral refrigeration case in Store 1, while Figure 2 is from one of the refrigerated cases in Store 2.

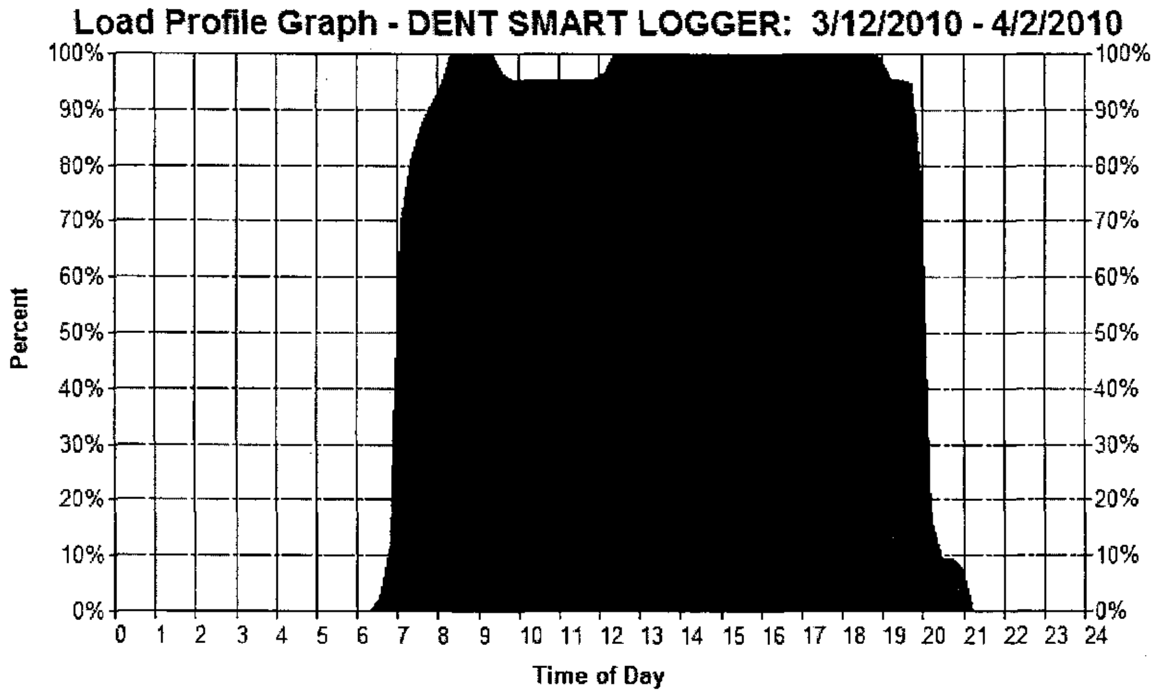



Figure 8: Lighting use profile, store 1

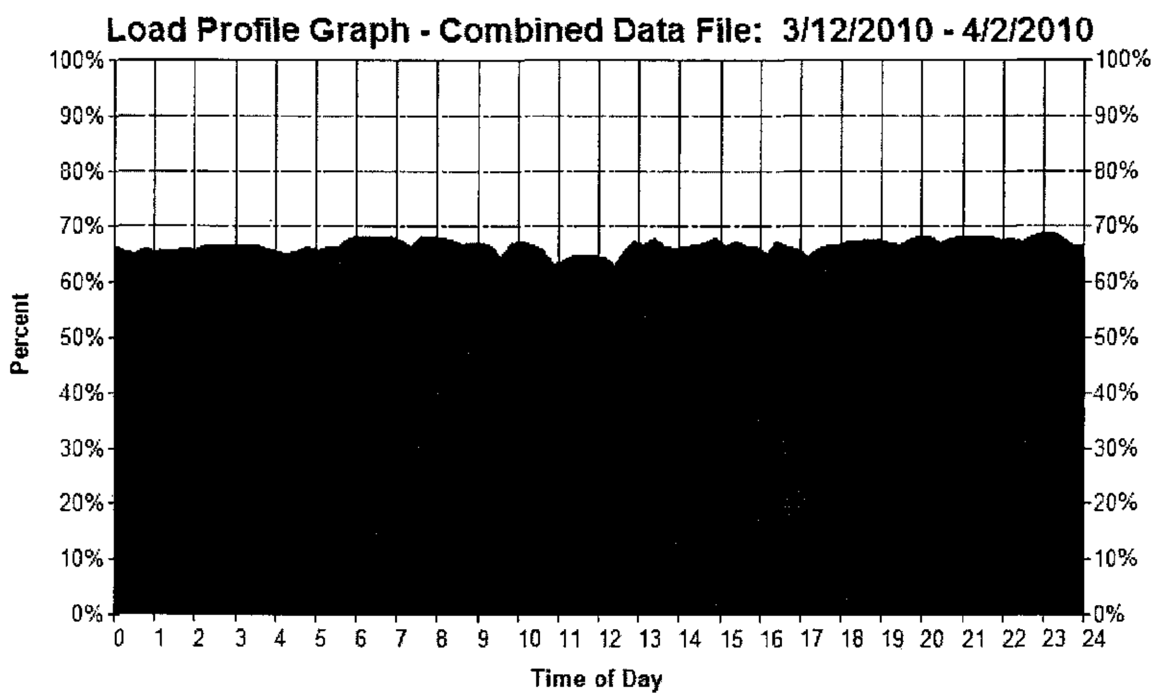



Figure 9: Lighting use profile, store 2

Figures 3, 4, and 5 display images of the lighting and data logging operations.


Figure 10: Mounting position of a light data logger.

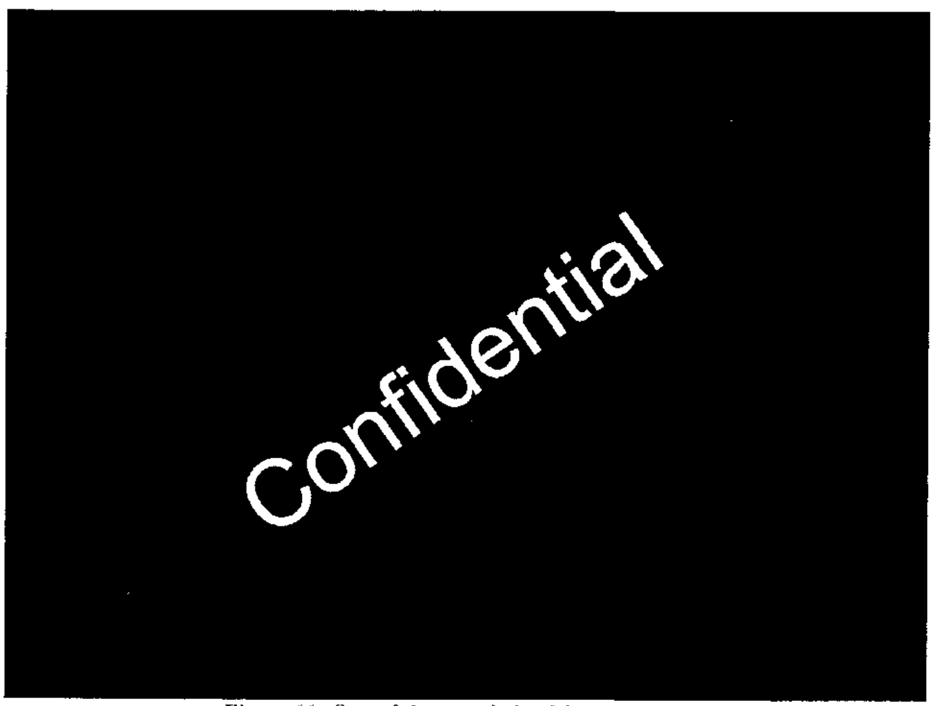



Figure 11: One of the sampled refrigerated cases.

[redacted]

Figure 12: [redacted] store.

# RESULTS

### Store 1

Knowns:

| | | | | |
|---|---|---|---|---|
| Compressor COP: | 0.35 | | | |
| Existing Florescent: | 248 lamps | 58 watts | 14.384 | Lighting only |
| Base runhours: | 8760 hours | | 19.42 | Lighting and refrigeration to remove heat |
| New LED: | 231 sticks | 20 watts | 4.62 | Lighting only |
| motion sensor savings: | 0.09404 % | of prior runhours | 6.24 | Lighting and refrigeration to remove heat |
| runtime of LED: | 7936 hours | | | |
| | | | 13.18 KW | 170105.184 KWH BEFORE |

**Existing Load of Florescent:**
Lamp wattage + Refrigeration load because of lamp wattage in the case:
[254 lamps * 58w/lamp * 8760 hours/year*1/1000 watts/kW] + {[254 lamps * 58w/lamp * 8760 hours/year*1/1000 watts/kW]*0.35 COP}
**170,105 kWh/year**

**New Load of LED:**
Stick wattage + Refrigeration load because of stick wattage in the case:
[224 sticks * 20w/stick *8760 hours/year * 1/1000 watts/kW *.7 ontime] + {[224 sticks * 20w/stick *8760 hours/year * 1/1000 watts/kW *.7 ontime] * 0.35 COP}
**49,498 kWh/year**

49498.1393 KWH AFTER

**Energy Savings from Florescent to LED Case Lighting:** **13.18 kW**
**170,105 - 49,498 = 120,607 kWh/year** 120,607 KWH SAVINGS

## Store 2

| | | | | |
|---|---|---|---|---|
| Knowns: | | | | |
| Compressor COP: | 0.35 | | | |
| Existing Florescent: | 267 lamps | 58 watts | 15.486 | Lighting only |
| Base runhours: | 8760 hours | | 20.91 | Lighting and refrigeration to remove heat |
| New LED: | 235 sticks | 20 watts | 4.7 | Lighting only |
| motion sensor savings: | 0.335 % | of prior runhours | 6.35 | Lighting and refrigeration to remove heat |
| runtime of LED: | 5825 hours | | | |
| | | | 14.56 KW | 183137.436 KWH BEFORE |

**Existing Load of Florescent:**
Lamp wattage + Refrigeration load because of lamp wattage in the case:
[254 lamps * 58w/lamp * 8760 hours/year*1/1000 watts/kW] + {[254 lamps * 58w/lamp * 8760 hours/year*1/1000 watts/kW]*0.35 COP}
**183,137 kWh/year**

**New Load of LED:**
Stick wattage + Refrigeration load because of stick wattage in the case:
[224 sticks * 20w/stick *8760 hours/year * 1/1000 watts/kW *.7 ontime] + {[224 sticks * 20w/stick *8760 hours/year * 1/1000 watts/kW *.7 ontime] * 0.35 COP}
**36,962 kWh/year**

36962.163 KWH AFTER

**Energy Savings from Florescent to LED Case Lighting:** **14.56 kW**
**183,137 - 36,962 = 146,175 kWh/year** 146,175 KWH SAVINGS

## Site 3

| | | | | |
|---|---|---|---|---|
| Knowns: | | | | |
| Compressor COP: | 0.35 | | | |
| Existing Florescent: | 276 lamps | 58 watts | 16.008 | Lighting only |
| Base runhours: | 8760 hours | | 21.61 | Lighting and refrigeration to remove heat |
| New LED: | 240 sticks | 20 watts | 4.8 | Lighting only |
| motion sensor savings: | 0.005 % | of prior runhours | 6.48 | Lighting and refrigeration to remove heat |
| runtime of LED: | 8716 hours | | | |
| | | | 15.13 KW | 189310.608 KWH BEFORE |

**Existing Load of Florescent:**
Lamp wattage + Refrigeration load because of lamp wattage in the case:
[254 lamps * 58w/lamp * 8760 hours/year*1/1000 watts/kW] + {[254 lamps * 58w/lamp * 8760 hours/year*1/1000 watts/kW]*0.35 COP}
**189,311 kWh/year**

**New Load of LED:**
Stick wattage + Refrigeration load because of stick wattage in the case:
[224 sticks * 20w/stick *8760 hours/year * 1/1000 watts/kW *.7 ontime] + {[224 sticks * 20w/stick *8760 hours/year * 1/1000 watts/kW *.7 ontime] * 0.35 COP}
**56,481 kWh/year**

56480.976 KWH AFTER

**Energy Savings from Florescent to LED Case Lighting:** **15.13 kW**
**189,311 - 56,481 = 132,830 kWh/year** 132,830 KWH SAVINGS

**Site 4**

| | | | | |
|---|---|---|---|---|
| Knowns: | | | | |
| Compressor COP: | 0.35 | | | |
| Existing Florescent: | 301 lamps | 58 watts | 17.458 | Lighting only |
| Base runhours: | 8760 hours | | 23.57 | Lighting and refrigeration to remove heat |
| New LED: | 270 sticks | 20 watts | 5.4 | Lighting only |
| motion sensor savings: | 0.007 % | of prior runhours | 7.29 | Lighting and refrigeration to remove heat |
| runtime of LED: | 8699 hours | | | |
| | | | 16.28 KW | 206458.308 KWH BEFORE |

**Existing Load of Florescent:**
Lamp wattage + Refrigeration load because of lamp wattage in the case:
[254 lamps * 58w/lamp * 8760 hours/year*1/1000 watts/kW] + {[254 lamps * 58w/lamp * 8760 hours/year*1/1000 watts/kW]*0.35 COP}
**206,458 kWh/year**

**New Load of LED:**
Stick wattage + Refrigeration load because of stick wattage in the case:
[224 sticks * 20w/stick *8760 hours/year * 1/1000 watts/kW *.7 ontime] + {[224 sticks * 20w/stick *8760 hours/year * 1/1000 watts/kW *.7 ontime] * 0.35 COP}
**63,413 kWh/year**

63413.3772 KWH AFTER

**Energy Savings from Florescent to LED Case Lighting:** **16.28 kW**
**206,458 - 63,413 = 143,045 kWh/year** 143,045 KWH SAVINGS

**Site 5**

| | | | | |
|---|---|---|---|---|
| Knowns: | | | | |
| Compressor COP: | 0.35 | | | |
| Existing Florescent: | 248 lamps | 58 watts | 14.384 | Lighting only |
| Base runhours: | 8760 hours | | 19.42 | Lighting and refrigeration to remove heat |
| New LED: | 209 sticks | 20 watts | 4.18 | Lighting only |
| motion sensor savings: | 0.256 % | of prior runhours | 5.64 | Lighting and refrigeration to remove heat |
| runtime of LED: | 6517 hours | | | |
| | | | 13.78 KW | 170105.184 KWH BEFORE |

**Existing Load of Florescent:**
Lamp wattage + Refrigeration load because of lamp wattage in the case:
[254 lamps * 58w/lamp * 8760 hours/year*1/1000 watts/kW] + {[254 lamps * 58w/lamp * 8760 hours/year*1/1000 watts/kW]*0.35 COP}
**170,105 kWh/year**

**New Load of LED:**
Stick wattage + Refrigeration load because of stick wattage in the case:
[224 sticks * 20w/stick *8760 hours/year * 1/1000 watts/kW *.7 ontime] + {[224 sticks * 20w/stick *8760 hours/year * 1/1000 watts/kW *.7 ontime] * 0.35 COP}
**36,778 kWh/year**

36777.9139 KWH AFTER

**Energy Savings from Florescent to LED Case Lighting:** **13.78 kW**
**170,105 - 36,778 = 133,327 kWh/year** 133,327 KWH SAVINGS

## Results Summary

The data from the five sampled stores were combined to obtain an average savings per LED stick installed. The results are summarized below:

| Store | kWh | kW | Sticks | kWh/stick | kW/stick |
|---|---|---|---|---|---|
| 1 | 120,607 | 13.2 | 231 | 522.1 | 0.057 |
| 2 | 146,175 | 14.6 | 235 | 622.0 | 0.062 |
| 3 | 132,830 | 15.1 | 240 | 553.5 | 0.063 |
| 4 | 143,045 | 16.3 | 270 | 529.8 | 0.060 |
| 5 | 133,327 | 13.8 | 209 | 637.9 | 0.066 |
| Total | 675,984 | 72.9 | 1,185 | 570.5 | 0.062 |

The sample produced an average savings of 570.5 kW and 0.062 kW per LED stick installed. The total project savings were based on a total of 9,802 LED sticks installed.

| | Expected | Evaluated |
|---|---|---|
| Number of Sticks | 9802 | 9802 |
| kWh per stick | 611.3 | 570.5 |
| kW per stick | 0.070 | 0.062 |
| Total kWh | 5,991,963 | 5,591,557 |
| Total kW | 686 | 603 |

**Project Savings Summary**

The evaluated savings were compared to the final savings estimates from the DSMore runs. This comparison is shown in the Table below:

**Final Project Savings and Realization Rate**

| Evaluated kWh Savings | Expected kWh Savings | kWh RR | Evaluated NCP kW Savings | Expected NCP kW Savings | NCP kW RR | Evaluated CP kW Savings | Expected CP kW Savings | CP kW RR |
|---|---|---|---|---|---|---|---|---|
| 5,591,557 | 5,991,963 | 0.93 | 603 | 686 | 0.88 | 603 | 686 | 0.88 |

# Site 7

[redacted]

Refrigeration Compressor Updates

# M&V Plan Results Summary

PREPARED FOR:
Duke Energy
Ohio

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

PREPARED IN:
March 2011

## INTRODUCTION

Architectural Energy Corporation was hired to evaluate the Duke Energy custom incentive program addressing upgrades to the [redacted] refrigeration equipment. The measures were to replace an old refrigeration compressor rack and condenser systems (Rack 'A' and Rack 'B') with two new more efficient systems.

Energy savings were estimated at 50% and 8% of current use, for Rack 'A' and 'B' respectively. Pre and post-retrofit power measurements on controlled equipment were conducted on a sample of the rack compressors to validate energy savings.

## GOALS AND OBJECTIVES

The project goal was electric use savings of 190,998 kWh annually. The specific objective of this M&V project was to complete a pre and post implementation site survey of the compressor racks in order to determine the true power reduction. Ultimately, a realization rate can be determined to validate the intended energy savings.

## PROJECT CONTACTS

Approval shall be requested from the two Duke Energy contacts listed below prior to making direct contact with the Customer or undertaking work on this M&V Plan.

| | | |
|---|---|---|
| **Duke Energy M&V Administrator** | Frankie Diersing | [redacted] |
| **Duke Energy Account Manager** | Ira Poston | [redacted] |
| **Customer Contact** | [redacted] | |
| **Site Location** | [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.
- Annual energy savings verification.

# M&V Option

IPMVP Option A

# Data Analysis

6. Convert time series data on logged equipment into pre/post average load shapes by day-type.

Refrigeration Rack and Condenser kW

7. Regress 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 (°F)
$a, b$ = Constants determined during regression development

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

9. Create diagnostic plots
   a) Plot time series fan and compressor kW; look for cycling

# Field Data

Applies to Pre and Post Installation:

7. Survey Data
   - Rack nameplate and photo
   - Condenser nameplate and photo
   - Compressor nameplate and photo
8. One-time Measurements
   - Compressor and condenser kW, amps and power factor (fan and fan plus compressor)
   - Case or walk-in temperatures
9. Time Series Data on Controlled Equipment
   - For each Rack A and B, obtain amps from a sample of the Rack compressors and the remote condensing unit.
   - Outside air temperature
10. Set up loggers for 5 minute instantaneous readings. Deploy for 3 weeks. Anticipate installing:
   - (1) Onset Weatherstation

- (1) U-12 with 4 CTs on Rack 'A'
- (1) U-12 with 4 CTs on Rack 'B'
- (1) U-12 with 1 CT on remote condensing unit serving Rack 'A'
- (1) U-12 with 1 CT on remote condensing unit serving Rack 'B' (if remote condensing units are in close proximity, then maybe can get away with a single U-12 for both)

## Data Accuracy

| Measurement | Sensor | Accuracy | Notes |
|---|---|---|---|
| Temperature | MDL thermistor | ±0.5° | |
| Current | Magnelab CT | ±1% | > 10% of rating |

## Verification and Quality Control

18. Visually inspect time series data for gaps.
19. Compare readings to nameplate values; identify out of range data.

## Recording and Data Exchange Format

12. Hobo U-12 binary files.
13. Excel spreadsheets.

## Results Summary

### Data Analysis

5. Verify Proposed Measures Were Implemented:

The compressor racks were installed as planned at [redacted] to operate the refrigeration system.

6. Calculation Methodology:

Power measurements were first collected and compared for the pre-install and post-install scenarios. A regression equation was determined for each case and they are shown here.

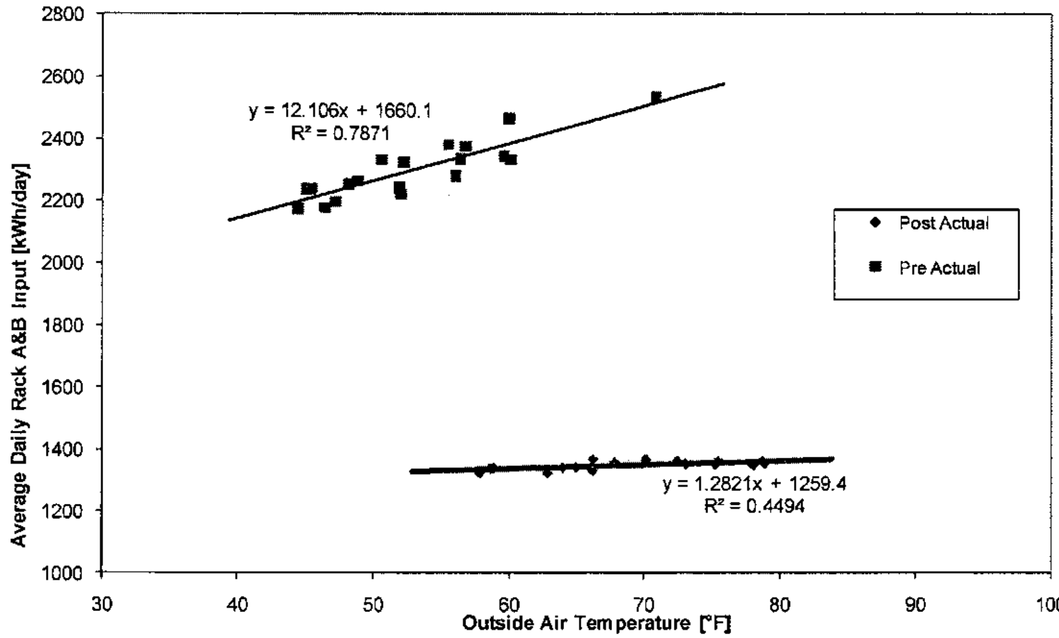



Figure 13: System Power Data Collected Before and After Measure Installation.

Making energy consumption (kWh) a function of outside air temperature allowed for an approximation the refrigeration system energy consumption for the entire year based on Version 3 of the Typical Meteorological Year (TMY3) weather data. An example of this TMY analysis is displayed in the table here.

Table 12: Daily Extrapolation of the Regression Equations in Figure 1.

| NOAA Date [M/D/Y] | NOAA Time [H:M] | NOAA Dry Bulb [C] | NOAA RH [%] | CALC Dry Bulb [F] | CALC PRE Input kWh/Day | CALC POST Input kWh/Day | CALC Input Savings kWh/Day |
|---|---|---|---|---|---|---|---|
| 1/1 | 12:30 | -2.4 | 67.8 | 27.6 | 1994.3 | 1294.8 | 699.5 |
| 1/2 | 12:30 | -5.7 | 69.4 | 21.7 | 1923.2 | 1287.2 | 636.0 |
| 1/3 | 12:30 | -7.7 | 70.5 | 18.2 | 1880.8 | 1282.7 | 598.0 |
| 1/4 | 12:30 | -1.4 | 72.8 | 29.4 | 2016.1 | 1297.1 | 719.0 |
| 1/5 | 12:30 | 3.1 | 64.4 | 37.6 | 2114.7 | 1307.5 | 807.2 |
| 1/6 | 12:30 | 0.5 | 68.6 | 32.9 | 2058.7 | 1301.6 | 757.1 |
| 1/7 | 12:30 | 1.7 | 73.7 | 35.1 | 2085.4 | 1304.4 | 781.0 |
| 1/8 | 12:30 | -0.5 | 59.2 | 31.2 | 2037.4 | 1299.3 | 738.1 |
| : | : | : | : | : | : | : | : |
| : | : | : | : | : | : | : | : |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 12/26 | 12:30 | 0.2 | 54.7 | 32.4 | 2052.5 | 1300.9 | 751.6 |
| 12/27 | 12:30 | -3.2 | 67.2 | 26.3 | 1978.7 | 1293.1 | 685.6 |
| 12/28 | 12:30 | -4.8 | 78.0 | 23.3 | 1942.7 | 1289.3 | 653.4 |
| 12/29 | 12:30 | 1.2 | 65.3 | 34.1 | 2073.0 | 1303.1 | 769.9 |
| 12/30 | 12:30 | 6.7 | 67.3 | 44.0 | 2192.8 | 1315.8 | 877.0 |
| 12/31 | 12:30 | 3.1 | 77.5 | 37.6 | 2115.7 | 1307.6 | 808.1 |
| **Totals** | | | | | **845,199** | **485,011** | **360,188** |

The figure below shows these extrapolated results in total.

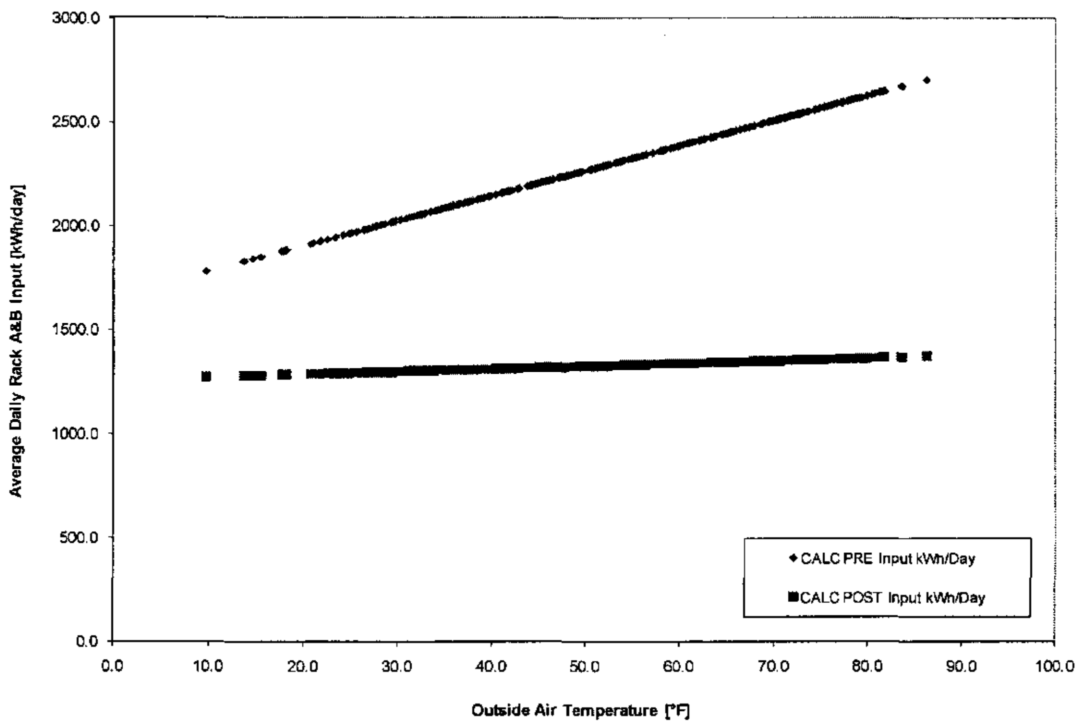



Figure 14: Annual Power Consumption Reduction from This Measure.

Cost savings rates applied to the energy savings reference the $0.10 per kWh mentioned in the rebate application PDF and it is also applied in the calculation to approximate cost savings.

Peak demand savings were estimated from the regression equations. According to the TMY3 dataset, the daily average temperature on the hottest day of the year is 88.1°F. Evaluating the pre and post regression equations at 88.1°F yields the following:

| Daily Average Temperature | kWh/day pre | kWh /day post | kWh/day Savings | Avg kW savings |
|---|---|---|---|---|
| 88.1 | 2726.6 | 1372. | 1354. | 56.4 |

Refrigeration compressor hourly load data are generally constant over the day, so the daily average demand savings is a reasonable estimate of the peak hourly savings. Note: the application did not claim any kW savings for this project.

7. Savings Verification and Realization Rate:

Compare Pre/Post values to obtain total kWh/year savings. Once the savings are calculated, the realization rate is calculated by the following formula:

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

## Calculation Output

The following Excel Tables demonstrate real achieved savings and summarize the results of the refrigeration system retrofit. For additional details, see included post-retrofit measurement and calculation spreadsheets.

**Reported in Application:**

| Description | Value | Units |
|---|---|---|
| Pre-install Annual Energy Use | 812,177 | kWh |
| Post-install Annual Energy Use | 621,179 | kWh |
| Expected Savings | 190,998 | kWh |
| Converted Cost Savings | $ 19,100 | |

**Reported Following Installation:**

| Description | Value | Units |
|---|---|---|
| Pre-install Annual Energy Use | 845,199 | kWh |
| Post-install Annual Energy Use | 485,011 | kWh |
| Realized Annual Energy Savings | 360,188 | kWh |
| Converted Cost Savings | $ 36,019 | |

kWh Realization Rate: 360,188 / 190,998 = 189%

*Notes:

- A rate of $0.10 per kWh was used to estimate cost savings, taken from the calculation Excel file and use at the time of the application. (See page 24-26 of the application PDF)

#### Final Project Savings Summary

The evaluated savings were compared to the final savings estimates from the DSMore runs. This comparison is shown in the Table below:

#### Final Project Savings and Realization Rate

| Evaluated kWh Savings | Expected kWh Savings | kWh RR | Evaluated NCP kW Savings | Expected NCP kW Savings | NCP kW RR | Evaluated CP kW Savings | Expected CP kW Savings | CP kW RR |
|---|---|---|---|---|---|---|---|---|
| 360,188 | 190,343 | 1.89 | 56 | 34 | 1.65 | 56 | 10 | 5.86 |

# Site 8

## M&V Summary

**[redacted] Schools "House Bill" Application**

**Replacement of Exterior Lighting Fixtures**

Prepared by Dan Bertini

December, 2011

## Introduction

This document summarizes the 3rd-party M&V activity and findings for a Non-Residential Custom Incentive application submitted by [redacted] Schools. Capital funding for the project was provided by the Ohio State Legislature. The application covers 21 schools in the [redacted] area. This report covers only the Exterior Lighting ECM, the second of the three measures covered in the application. The three measures in the application are:

**ECM-1 - Electrostatic "Dynamic" Filters**

- *Electrostatic "Dynamic" filters containing activated carbon media will reduce the required amount of ventilation air by code thereby reducing associated energy costs to condition outdoor air.*

**ECM-2 - Replacement of Exterior Lighting Fixtures**

- *Exterior lighting fixtures will be replaced with new lower wattage induction type incandescent fixtures.*

**ECM-3 - Summer Ventilation Controls**

- *Implementation of reduced summer outdoor air ventilation schedules via the DDC control system to reduce ventilation in select buildings during summer months when school is not in session, thereby reducing associated energy costs.*

## Goals and Objectives

The projected savings goals identified in the application are:

| ECM | Vendor Estimated | Duke Projected |
|---|---|---|
| 1 | 819 | - |
| 2 | 475,031 | - |
| 3 | 109,276 | - |
| **Total** | **642,515** | **699,752** |

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 Admin. | Frankie Diersing | [redacted] |
| Duke Energy BRM | Mike Harp | [redacted] |
| Customer Contact | [redacted] | |

## Site Locations/ECM's

| Site | Address | Sq. Footage/Age | ECM's Implemented |
|---|---|---|---|
| [redacted] | [redacted] | 62675/22 | 1,2,3 |
| [redacted] | [redacted] | 74652/18 | 1,2,3 |
| [redacted] | [redacted] | 64543/32 | 2 |
| [redacted] | [redacted] | 85197/32 | 2 |
| [redacted] | [redacted] | 76612/16 | 2,3 |
| [redacted] | [redacted] | 79612/16 | 2,3 |
| [redacted] | [redacted] | 76138/3 | 2,3 |
| [redacted] | [redacted] | 76138/3 | 2,3 |
| [redacted] | [redacted] | 60620/18 | 2,3 |
| [redacted] | [redacted] | 60070/20 | 2,3 |
| [redacted] | [redacted] | 66792/20 | 2,3 |
| [redacted] | [redacted] | 83903/48 | 2 |
| [redacted] | [redacted] | 75874/37 | 2 |
| [redacted] | [redacted] | 126903/2 | 2 |
| [redacted] | [redacted] | 22616/34 | 2 |
| [redacted] | [redacted] | 50600/49 | 2 |
| [redacted] | [redacted] | 113777/7 | 2 |
| [redacted] | [redacted] | 27000/7 | 2 |
| [redacted] | [redacted] | 90901/7 | 2 |
| [redacted] | [redacted] | 320551/13 | 2 |
| [redacted] | [redacted] | 320551/13 | 2 |

## M&V Option

IPMVP Option A

## Data Analysis

- **ECM-2**

Calculated kWh/year saved for each fixture type as follows:

$$kWh / year = a \times b \times c$$

where

a = fixture number
b = fixture wattage savings
c = yearly operating hours

## Results of Field Survey and Data Logging

- **ECM-2**

Fixture counts and their respective wattages were obtained at a sample of 9 of the 21 facilities identified in the project. Actual observed fixture counts and wattages matched the expected counts almost perfectly, the only exception being at [redacted], where 21 of the highest wattage pole fixtures were expected but only 17 were counted. The actual saved wattage therefore amounted to 98% of expected. However, replacement work has yet to be carried out at 2 of the 9 schools sampled. In fact, according to the vendor, as of this date work has yet to be carried out at 3 schools in all. Final completion is scheduled to be in January, 2011.

In the application all the lights were assumed to operate 4004 hours per year. By contrast, actual operating hours of 2913 and 3630 were logged at 2 of the facilities, respectively. By weighting them equally, since the two schools' lighting wattages are equal, the actual operating hours are therefore assumed to be 3272 hrs, or 82% of expected.

ECM-1 and ECM-3.

Savings for ECM-1 are small (0.1%) compared to the total project savings, thus the evaluation team accepts the vendor estimated savings. Savings for ECM-3 represent about 19% of the savings. Since the savings for ECM-3 occur over the summer, it was not possible to evaluate this measure. The vendor estimated savings were accepted.

## Realization Rate and Annual Savings

- **ECM-2**
    - **380,928 kWh/yr**
    - **Realization rate: 80%**

The savings for all measures at the nine sites where M&V was conducted are summarized below:

**Savings Estimates from M&V Sample**

| ECM | Vendor Estimated | Evaluated |
|---|---|---|
| 1 | 819 | 819 |
| 2 | 475,031 | 380,928 |
| 3 | 109,276 | 109,276 |
| Total | 585,126 | 491,023 |
| Realization Rate | | 0.84 |

The savings from the evaluated sites are extrapolated to the full project as shown below:

**Full Project Savings**

| Parameter | kWh | Non-coincident kW |
|---|---|---|
| Total project estimated savings | 699,752 | 63 |
| Realization rate from M&V sample | 0.84 | 0.98 |
| Total project evaluated savings | 587,214 | 61 |

Note: since the ECM-2 savings occur at night, the coincident peak savings are zero. ECM-1 peak savings are negligible. It was not possible to evaluate the peak demand savings associated with ECM-3.

**Project Savings Summary**

The evaluated savings were compared to the final savings estimates from the DSMore runs. This comparison is shown in the Table below:

**Final Project Savings and Realization Rate**

| Evaluated kWh Savings | Expected kWh Savings | kWh RR | Evaluated NCP kW Savings | Expected NCP kW Savings | NCP kW RR | Evaluated CP kW Savings | Expected CP kW Savings | CP kW RR |
|---|---|---|---|---|---|---|---|---|
| 587,214 | 698,742 | 0.84 | 61 | 63 | 0.98 | 0 | 63 | 0.00 |

# Site 9

[redacted]

## - Refrigerated Lighting Replacement -

# M&V Report

PREPARED FOR:
Duke Energy
Ohio

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

PREPARED IN:
December 2011

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

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

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

# Introduction

This report addresses M&V activities for a refrigerated case lighting retrofit at [redacted] that replaced existing lighting fixtures with more efficient fixtures.

### ECM-1 – Refrigerated Lighting

The project involves a replacement of (77) 400 watt metal halide lamps with (35) Orion ENCF6PSWS 6 lamp T8 Cooler fixtures and (41) Orion ENCF6PIDS 6 lamp T8 Freezer fixtures. All fixtures are equipped with occupancy sensors. Freezer fixtures are equipped with dual switching; leaving 3 of the 6 bulbs on at all times even after occupancy sensors are activated.

# Goals and Objectives

The projected savings goals identified in the application are:

| Application Proposed Annual savings (kWh) | Application Proposed Peak Savings (kW) | Duke Projected Annual Savings (kWh) | Duke Projected Peak Savings (kW) |
|---|---|---|---|
| 183,936 | 19 | 199,139 | 22 |

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

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

# Project Contacts

| | | |
|---|---|---|
| Duke Energy M&V Admin. | Frankie Diersing | [redacted] |
| Duke Energy BRM | Roshena Ham | [redacted] |
| Customer Contact | [redacted] | |

# Site Location

| Address |
|---|
| [redacted] |

## Data Products and Project Output

- Post retrofit survey of lighting fixtures
- Post retrofit time series data on logged equipment converted into average load shapes by day type
- Peak demand savings
- Coincident peak demand savings
- Annual Energy Savings

## M&V Option

IPMVP Option A

## M&V Implementation Schedule

- Monitoring period included both weekday and weekend periods.

## Field Survey Points

Post – installation

Survey data (for all equipment logged)

- Lighting survey
  - Fixture Type
  - Fixture Count
  - Fixture wattage
  - Current lighting on/off scheduling

- Conducted the Post retrofit survey after the customer performed the lighting retrofit.
- Spot measured the lighting load connected to the circuit by measuring the kW load and current of the circuit during the post retrofit survey. Spot measured the lighting load at the panel.
- Pre-retrofit operating hours and pre fixture information was recorded from the application. Interviewed the building owner/operator to verify pre fixture information in application is correct.
  - Mon-Sat; Half-day on Sunday (8,112 hours, pre-retrofit)
- Determined how lighting is controlled and recorded the controller settings

- During the post survey, verified that all existing fixture specifications and quantities are consistent with the application. Differences are noted below:
  - Cooling shipping area used five(5) 4-lamp versus five (5) 6-lamp fixtures. Remaining quantities and types are consistent
- During the post survey, verified that all pre (existing) fixtures were removed.
  - Yes
- During the post survey, verified that all post (new) fixture specifications and quantities are consistent with the application.
  - Yes
- Determine what holidays the building observes over the year, and if the lighting zones are disabled during the holidays.
  - 5 holidays per year; lighting not disabled during holidays

Collected one-time measurements for all equipment logged (to establish ratio of kW/amp and simultaneous logger amp/temperature readings)

- Lighting circuits volts, amps, kW and power factor

## .Data Accuracy

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

## Field Data Logging

- **ECM-1**

1. Deployed dataloggers during post survey to measure operating hours
   a. Deployed current measurement CT loggers to measure current at the panelboard, logging individual circuits.
2. Set up loggers for 5 minute instantaneous readings and allowed loggers to operate between October 11 to November 2, 2011.

## Logger Table

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

| Area | Hobo U-12 | 20 amp CT's | Post-Monitoring Notes | # of fixtures monitored |
|---|---|---|---|---|
| Cooler #1 | 1 | 1 | 1 chan | 8 |
| Cooler Shipping | | 1 | 1 chan | 4 |
| Cooler #2 | | | Not Monitored | |
| Freezer #1 (Dual Switched) | 1 | 2 | 2 chan | 6 |
| Freezer Shipping (Dual Switched) | | 2 | 2 chan | 5 |
| Freezer #2 (Dual Switched) | 1 | 2 | 2 chan | 8 |
| Cooler Meat | | | Not monitored | |
| **Total** | | **8** | | |

## Data Analysis

- **ECM-1**

1. "Synthesized" Pre time series data by using the following equation:

$$\frac{kWh}{year_{pre}} = No._{fixtures} * Watts_{fixture} * HoursOn_{year}$$

2. Converted time series data on logged equipment into pre/post average load shapes by day type.
3. The Post annual kWh was calculated using the following equations:

Weekdays:

$$\frac{kWh}{year_{post}} = \sum \left[ \frac{kW_{spot}}{Ampacity_{spot}} * Current_{time-measured} * \frac{5\,\text{min.}_{intervals}}{\frac{60\,\text{min.}}{hour}} * \frac{24hour}{day} * \frac{260days}{year} \div \frac{weekdays}{monitoringperiod} \right]$$

Weekends:

$$\frac{kWh}{year}_{post} = \sum \left[ \frac{kW_{spot}}{Ampacity_{spot}} * Current_{time-measured} * \frac{5\min \cdot_{int\,ervals}}{\frac{60\min.}{hour}} * \frac{24hour}{day} * \frac{104days}{year} \div \frac{WEdays}{monitoringperiod} \right]$$

Annual Total:

$$\frac{kWh}{year} = \sum \left[ \frac{kWh}{year}_{weekday} + \frac{kWh}{year}_{weekend} \right]$$

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

$$\frac{hWh_{saved}}{year} = \frac{kWh_{pre}}{year} - \frac{kWh_{post}}{year}$$

Interactive effects of lighting savings on refrigeration system were also included.

## Verification and Quality Control

20. Visual inspection of time series data identified no problems
21. Compared readings to nameplate and spot-watt values and identify no problems

## Recording and Data Exchange Format

14. Hobo logger binary files
15. Excel spreadsheets

## Post Data Results

The post-data results were based on three loggers deployed as shown in the lighting logger table above. The shipping cooler area had different fixtures than the other areas, being 4-lamp fixtures as opposed to the 6-lamp fixtures installed elsewhere. In summary a total of (77) 400watt metal halide fixtures were replaced with 71 high bay, 6 lamp T8 fixtures with occupant sensor control, and five 4 lamp T8 fixtures in the Cooler Shipping area. There are 35 new fixtures in cooler area and 41 fixtures in freezer area. The pre-install estimated savings for replacing the (77) metal halides is 183,936 kWh per year.

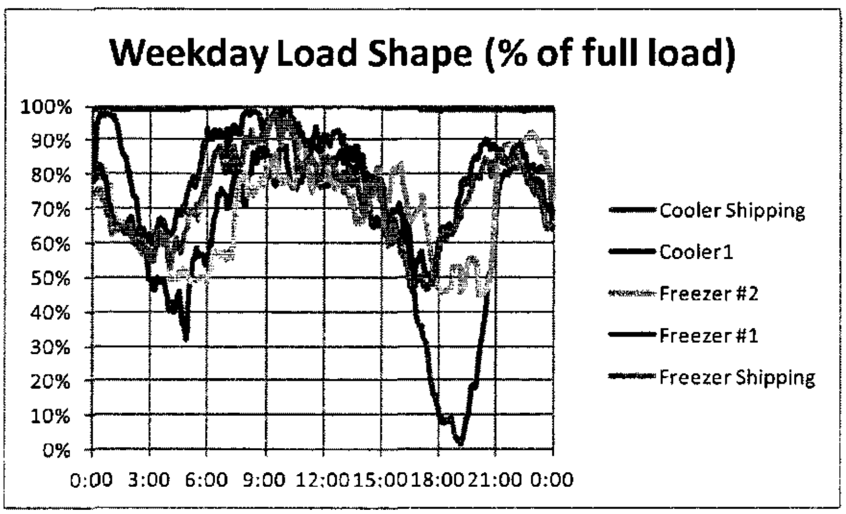
The following table summarizes the energy and demand savings resulting from these ECMs. The projected annual savings based on post install trend data is 196,398 kWh based on the lighting savings alone, and 247,604 kWh when the additional savings due to reducing the refrigeration load is included. The refrigeration load reduction was based on a chiller efficiency of 0.8 kW/ton for the coolers, and 1.0 kW/ton for the freezers.

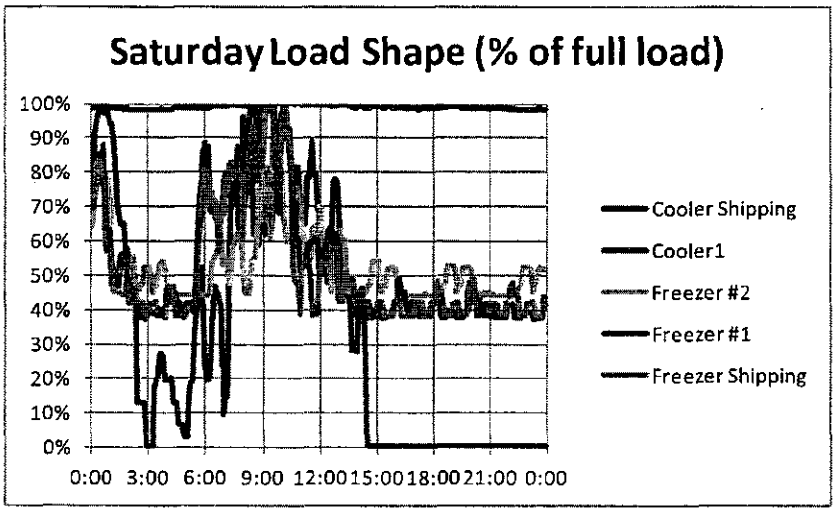
| Existing Fixtures Replaced | | | | | Post Retrofit Results | | | | Lighting Savings | | Refrigeration Savings | | Total Savings | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Area | Qty | Watts | Annual Hours | Annual kWh | Qty | Average Watt per Fixture | Equivalent Full Load Hours | Annual kWh | Energy savings (kWh) | Demand Savings (kW) | Energy savings (kWh) | Demand Savings (kW) | Total Energy Savings | Total Demand Savings |
| Cooler | 30 | 465 | 8112 | 113,162 | 29 | 221; 145 | 5,202 | **31,371** | **81,791** | **7.9** | **18,610** | **1.8** | **100,401** | **9.7** |
| Freezer | 47 | 465 | 8112 | 177,288 | 47 | 221 | 6,035 | **62,681** | **114,607** | **11.5** | **32,596** | **3.3** | **147,202** | **14.7** |
| Total | 77 | | | 290,450 | 76 | | | **94,053** | **196,398** | **19.4** | **51,206** | **5.1** | **247,604** | **24.5** |

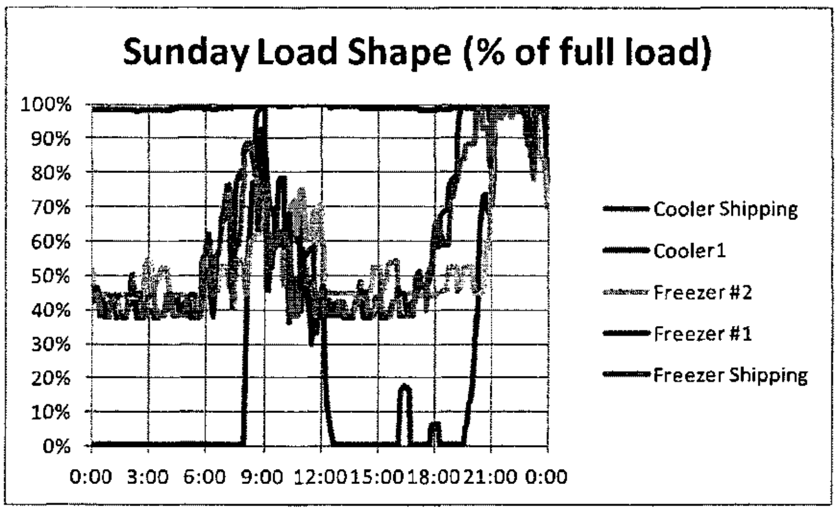
The realization rate for these ECMs relative to the savings claimed in the application is shown in the following table. The energy and demand savings exceed the projected savings.

| Realization Rate | Energy | Demand |
|---|---|---|
| Lighting only | 107% | 102% |
| Lighting and Refrigeration savings | 135% | 129% |

The graphs below show the average daily load shapes for the monitored areas. These plots average the entire monitoring period into the three day types shown. The lights in the Cooler Shipping area are on continuously. The occupancy sensors reduce the lighting load for the other areas throughout the three day types.






From the monitored load profiles above, the average % of full load at 2pm on a weekday in the cooler is 85.8%, while the average % of full load at 2pm on a weekday in the freezer is 77.4%. The coincident peak kW savings are summarized below:

**Coincident Peak Demand Savings**

| Area | % full load at 2pm | Lighting CP kW Savings | Refrigeration CP kW Savings | Total CP kW Savings |
|---|---|---|---|---|
| Cooler | 85.8% | 8.5 | 1.9 | 10.4 |
| Freezer | 77.4% | 13.8 | 4.0 | 17.8 |
| Total | | 22.3 | 5.9 | 28.2 |

**Project Savings Summary**

The evaluated savings were compared to the final savings estimates from the DSMore runs. This comparison is shown in the Table below:

**Final Project Savings and Realization Rate**

| Evaluated kWh Savings | Expected kWh Savings | kWh RR | Evaluated NCP kW Savings | Expected NCP kW Savings | NCP kW RR | Evaluated CP kW Savings | Expected CP kW Savings | CP kW RR |
|---|---|---|---|---|---|---|---|---|
| 247,604 | 191,139 | 1.30 | 25 | 22 | 1.12 | 28.2 | 22 | 1.29 |

# Site 10

[redacted]

## Parking Lot Lighting Replacement

# M&V Report

PREPARED FOR:
Duke Energy
Ohio

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

PREPARED IN:
December 2011
Version 1.0

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

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

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

# INTRODUCTION

This report addresses M&V activities for new LED parking lot lighting fixtures in 10 [redacted] stores in the Cincinnati area.

The net effect was a reduction in power consumption by the lighting fixtures.

**Note: ECM's have already been installed and implemented for this application. Data collection was for Post install only.**

The measures included:

### ECM-1 – Area Lighting

ECM-1 involves replacing lighting fixtures in the parking area of 10 [redacted] stores. Fixtures to be replaced are as follows:

(13) existing 250w MH fixtures will be replaced with 71w LED fixtures.
(82) existing 400w MH fixtures will be replaced with 71w LED fixtures.
(38) existing 1000w MH fixtures will be replaced with 138w LED fixtures.

# GOALS AND OBJECTIVES

The projected savings goals identified in the application are:

| Facility | Application Proposed Annual savings (kWh) | Application Proposed Peak Savings (kW) | Duke Projected savings (kWh) | Duke Projected savings (kW) |
|---|---|---|---|---|
| Store #58 | 66,576 | 7 | - | - |
| Store #63 | 74,854 | 9 | - | - |
| Store #65 | 43,231 | 5 | - | - |
| Store #67 | 31,702 | 4 | - | - |
| Store #71 | 34,584 | 4 | - | - |
| Store #74 | 24,624 | 3 | - | - |
| Store #75 | 37,063 | 5 | - | - |
| Store #550 | 87,074 | 11 | - | - |
| Store #551 | 52,200 | 6 | - | - |
| Store #552 | 91,743 | 11 | - | - |
| **Total** | **543,651** | **65** | **543,654** | **62** |

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

- Annual gross kWh savings

- Summer peak kW savings
- Summer Utility coincident peak kW savings
- kWh & kW Realization Rates

## Project Contacts

Approval has not yet been granted from the Duke Energy contacts listed below to plan and schedule the site visit with the Customer.

| | | |
|---|---|---|
| Duke Energy M&V Admin. | Frankie Diersing | [redacted] |
| Duke Energy BRM | Terry Holt | [redacted] |
| Customer Contact | [redacted] | [redacted] |

## Site Locations/ECM's

| Store | Address | Area | 250w (71w) | 400w (71w) | 1000w (138w) |
|---|---|---|---|---|---|
| a | [redacted] | 2960 | - | 10 | 5 |
| b | [redacted] | 2800 | 3 | 6 | 7 |
| c | [redacted] | 3500 | - | 15 | - |
| d | [redacted] | 2560 | - | 11 | - |
| e | [redacted] | 3040 | - | 12 | - |
| f | [redacted] | 2640 | 1 | 8 | - |
| g | [redacted] | 2640 | - | 5 | 3 |
| h | [redacted] | 4784 | 3 | 5 | 9 |
| i | [redacted] | 4784 | 3 | 6 | 4 |
| j | [redacted] | 4784 | 3 | 4 | 10 |

## Data Products and Project Output

- Post retrofit survey of lighting fixtures
- Summer peak demand savings
- Coincident peak demand savings
- Annual Energy Savings

## M&V Option

IPMVP Option A

## Field Survey Points

Post – installation

The following data was collected for all equipment logged:

- Lighting survey
    - Fixture Type
    - Fixture Count
    - Fixture wattage
    - Current lighting on/off scheduling

- Pre retrofit survey was conducted before the customer performed the lighting retrofit.
- The lighting load connected to the circuit was spot measured by measuring the kW load and current of the circuit during both the pre-retrofit and post retrofit survey.
- Lighting control settings were noted and recorded
- Verified that all existing fixture specifications and quantities are consistent with the application.
- Verified that all pre (existing) fixtures were removed
- Verified that all post (new) fixture specifications and quantities are consistent with the application
- Determined what holidays the building observes over the year

One-time measurements for all equipment logged (to establish ratio of kW/amp and simultaneous logger amp readings) were taken

## Field Data Logging

- **ECM-1**

3. Deployed dataloggers during pre survey to measure operating hours
    a. Installed one lighting logger at each lighting control zone.
4. Loggers were set up for 5 minute instantaneous readings and allowed to operate for a period of three weeks.

## Logger Table

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

| Store | Hobo U-12 | 20 amp CT's |
|---|---|---|
| a | 1 | 2 |
| b | 1 | 3 |
| c | 1 | 1 |
| d | 1 | 1 |
| e | 1 | 1 |
| f | 1 | 2 |
| g | 1 | 2 |
| h | 1 | 3 |
| i | 1 | 3 |
| j | 1 | 3 |
| **Total** | **10** | **21** |

Note: CT count based on 20 amp, 120v circuits. Field survey will need to be conducted to determine actual number and type of loggers/CT's needed.

# Data Analysis

- **ECM-1**

5. The Pre annual kWh was calculated using the following equation:

$$\frac{kWh}{year_{pre}} = Watts_{fixture} * No._{fixtures} * HoursOn_{day} * \frac{365days}{year}$$

6. The Post annual kWh was calculated using the following equation:

$$\frac{kWh}{year_{post}} = Watts_{fixture} * No._{fixtures} * HoursOn_{day} * \frac{365days}{year}$$

Annual Total:

$$\frac{kWh}{year} = \sum\left[\frac{kWh}{year_{weekday}} + \frac{kWh}{year_{weekend}}\right]$$

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

$$\frac{hWh_{saved}}{year} = \frac{kWh_{pre}}{year} - \frac{kWh_{post}}{year}$$

# Recording and Data Exchange Format

16. Survey Forms
17. Excel spreadsheets

# Results Summary

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

- The "Pre" and "Post" lighting hours run from sunrise to sunset, according to published sunrise-sunset times for Cincinnati, OH. Published hours were adjusted to account for differences in run hours as noted from the collected time-series data.
- The pre-retrofit lamp watts for each fixture is as noted:
    - Wall Packs – 250 watts
    - Canopy Lights – 400 watts
    - Parking Lot Pole Lights – 1000 watts
- The post-retrofit electrical demand for each fixture was taken from actual field measurements. Averages are as follows:
    - Wall Packs – 45 watts
    - Canopy Lights – 54 watts
    - Parking Lot Pole Lights – 112 watts
- It should be noted that only the lights listed in the application were included in this analysis. During the survey, it was discovered that more lights had been replaced than were listed in the application.

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

**Table 1. Estimated Annual Energy Savings**

| [redacted] kWh Savings | | | | | |
|---|---|---|---|---|---|
| Store # | Pre | Post | Savings | App. Realization Rate | Duke Realizaton Rate |
| a | 53082.7 | 5190.3 | 47892.4 | 71.9% | - |
| b | 48048.9 | 5036.8 | 43012.0 | 57.5% | - |
| c | 33782.5 | 3378.2 | 30404.2 | 70.3% | - |
| d | 28394.0 | 3265.3 | 25128.7 | 79.3% | - |
| e | 26741.3 | 4211.8 | 22529.5 | 65.1% | - |
| f | 13127.1 | 2714.6 | 10412.6 | 42.3% | - |
| g | 23232.2 | 3642.8 | 19589.4 | 52.9% | - |
| h | 57204.6 | 6893.8 | 50310.8 | 57.8% | - |
| i | 34963.6 | 3716.4 | 31247.2 | 59.9% | - |
| j | 55855.8 | 7023.8 | 48832.0 | 53.2% | - |
| | | | | | |
| **Total** | **374432.6** | **45073.8** | **329358.7** | **60.6%** | **60.6%** |

ON AVERAGE, THE SAVINGS FOR ALL 10 [redacted] STORES WAS 60.6%. THE CALCULATIONS INCLUDED WITH THE APPLICATION APPEAR TO HAVE MADE WITH THE ASSUMPTION THAT THE LIGHTING WAS ON 24 HOURS/DAY, 7 DAYS/WEEK. THE LIGHTING IS ACTUALLY CONTROLLED BY LIGHT LEVEL SENSORS, WHICH TURN THE LIGHTS ON AT SUNSET AND OFF AT SUNRISE.

A SUMMARY OF THE ESTIMATED ANNUAL PEAK KW SAVINGS IS SHOWN IN TABLE 2

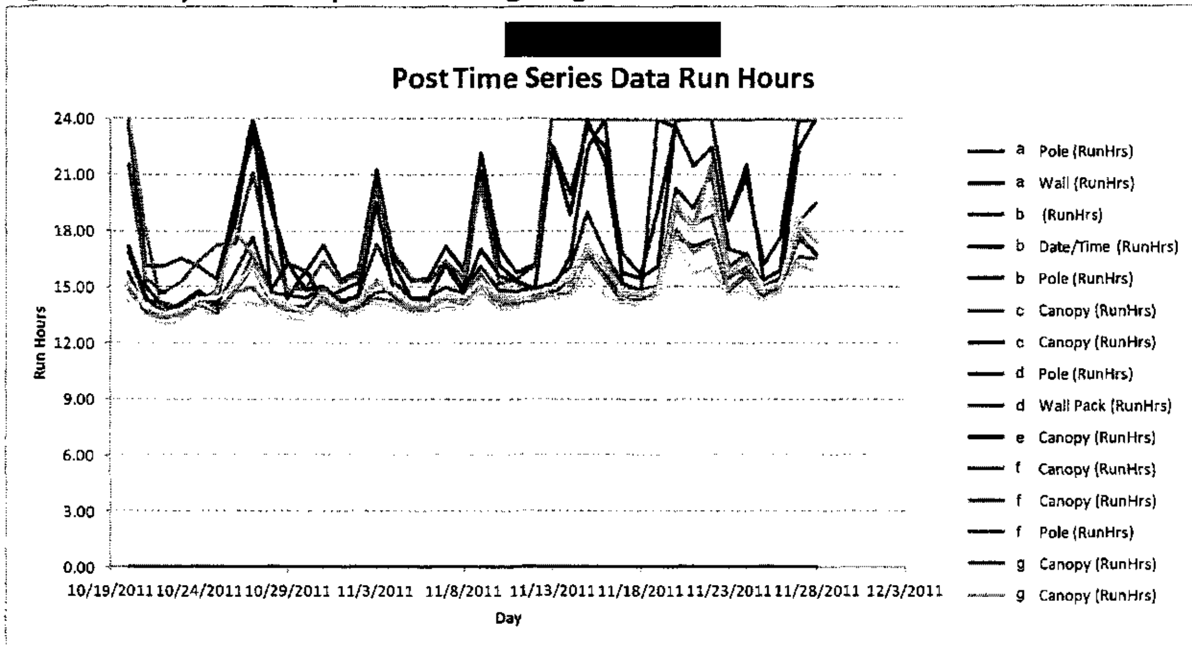
TABLE 2. ESTIMATED PEAK DEMAND SAVINGS

| [redacted] Peak kW Savings | | | | | |
|---|---|---|---|---|---|
| Store # | Pre | Post | Savings | App. Realization Rate | Duke Realizaton Rate |
| a | 9.0 | 0.9 | 8.1 | 116.0% | - |
| b | 10.2 | 1.1 | 9.1 | 101.0% | - |
| c | 6.0 | 0.6 | 5.4 | 108.0% | - |
| d | 4.4 | 0.5 | 3.9 | 97.4% | - |
| e | 4.8 | 0.8 | 4.0 | 101.1% | - |
| f | 2.7 | 0.5 | 2.1 | 70.1% | - |
| g | 5.0 | 0.8 | 4.2 | 84.3% | - |
| h | 11.8 | 1.4 | 10.3 | 93.9% | - |
| i | 7.2 | 0.8 | 6.4 | 106.5% | - |
| j | 12.4 | 1.6 | 10.8 | 98.2% | - |
| | | | | | |
| **Total** | **73.25** | **8.9** | **64.4** | **99.1%** | **103.8%** |

Note, since the lighting system is controlled off at 2pm on weekdays, the coincident peak kW savings are zero.

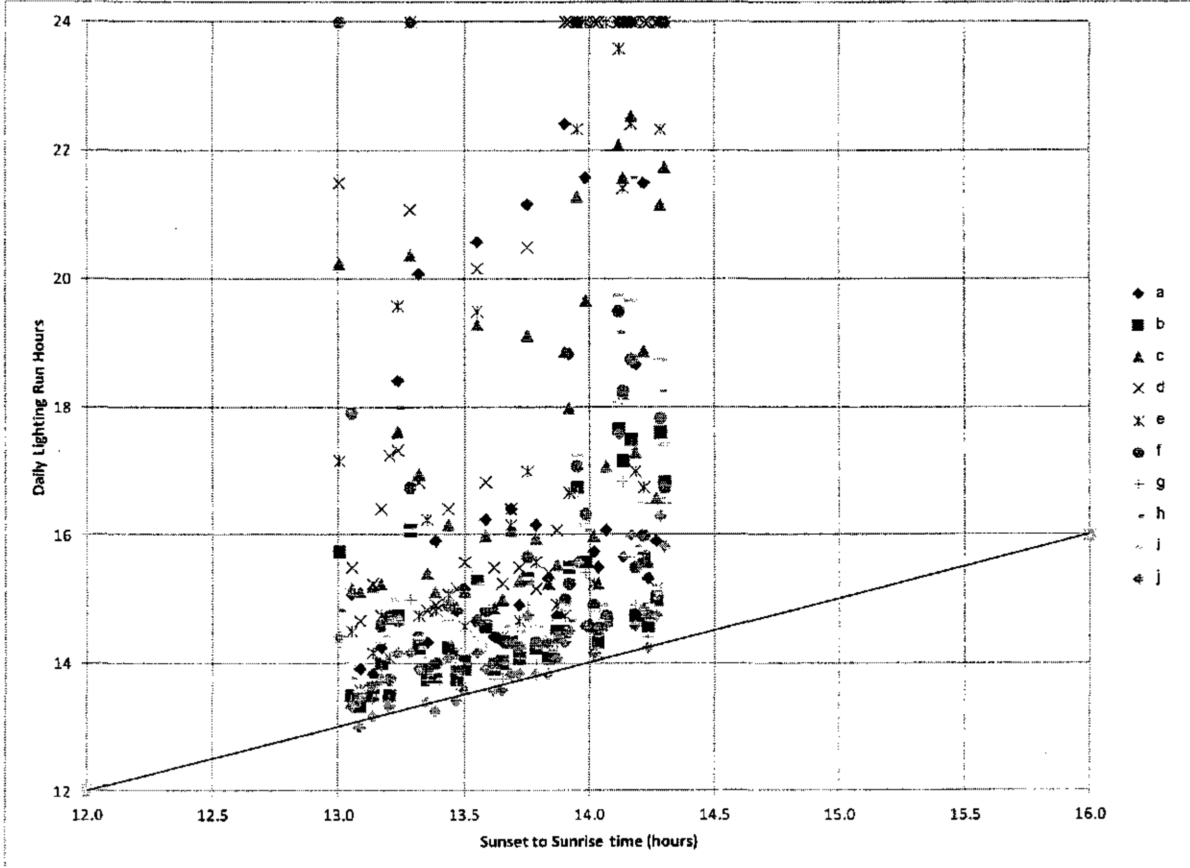
Figure 1 shows the daily run hours from the time-series data taken during the logging period. Discrepancies in daily run hours can be accounted for by the fact that there are two different types of light level sensors installed at these locations. One sensor is less accurate that the other and needs to be set when ambient light levels are appropriate for turning the lights on/off. The other sensor can be programmed digitally, and can be more accurate. Lighting override switches are also at all locations. If these switches are activated, the lights will stay on no matter the ambient light level. This accounts for the spikes in Figure 1 which show the lights on 24 hours/day.

**Figure 1. Daily run hours per outdoor lighting circuit**




Another representation of the lighting run hours is shown below, in Figure 2. This shows the average lighting hours per day for each store versus the time between sunset and sunrise. If the lights turned on exactly and sunset and turned off at sunrise, all of the data would follow the diagonal line. Data above the line indicate run hours longer than necessary. As was mentioned earlier, there are several days when the lights were on 24 hours a day.

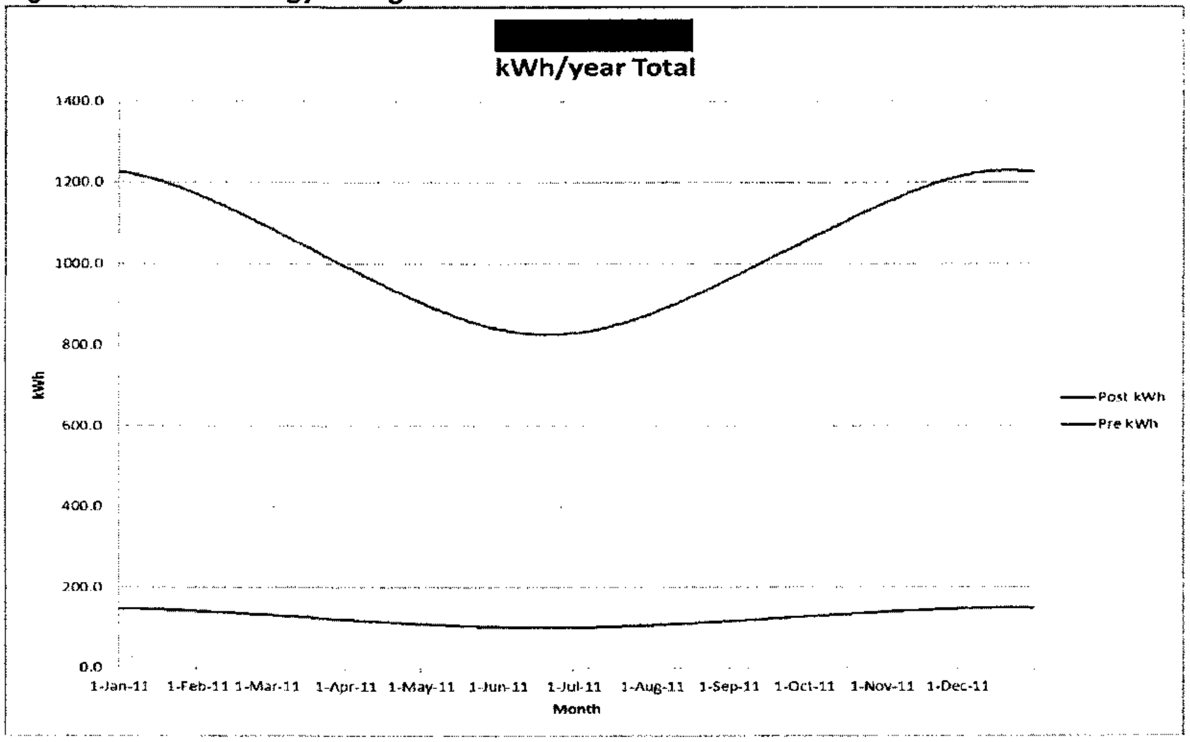
**Figure 2. Daily lighting run hours versus daily hours of darkness**




Run hours/day for each store were calculated and compared to actual sunset-sunrise times for the Cincinnati area during the logging period. Differences between these two values were calculated for each day of the year, and then averaged. The average difference for each location was added to the actual sunset-sunrise time for each day to adjust for the differences in run hours noted above.

Figure 3 shows the difference in kWh for the year as a result of the lighting change.

**Figure 3. Annual energy savings**




**Project Savings Summary**

The evaluated savings were compared to the final savings estimates from the DSMore runs. This comparison is shown in the Table below:

**Final Project Savings and Realization Rate**

| Evaluated kWh Savings | Expected kWh Savings | kWh RR | Evaluated NCP kW Savings | Expected NCP kW Savings | NCP kW RR | Evaluated CP kW Savings | Expected CP kW Savings | CP kW RR |
|---|---|---|---|---|---|---|---|---|
| 329,359 | 528,652 | 0.62 | 64 | 60 | 1.07 | 0 | 61 | 0.00 |

# Site 11

[redacted]

## High Bay Lighting Retrofit

# Report

PREPARED FOR:
Duke Energy
Ohio

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

PREPARED IN:
September 2011

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

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

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

# INTRODUCTION

This report summarizes M&V activities for [redacted] custom program application. The application covers a lighting retrofit at one 70,000 ft$^2$ warehouse in the Cincinnati area. The measure includes:

**ECM-1 – High bay light fixture retrofit**

- 70 existing metal halide light fixtures were replaced with 59 LVD high bay 200 TX200W/277 light fixtures and 13 T5/T8 high bay fluorescent fixtures. This resulted in a per-fixture energy reduction from 430W to 235W in the case of LVD replacements, and 430W to 192W in the case of high bay fluorescent replacements.

# GOALS AND OBJECTIVES

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

- Annual gross energy (kWh) savings
- Summer peak demand (kW) savings
- Coincident peak demand (kW) savings
- kWh & kW Realization Rates

# PROJECT CONTACTS

| | | | |
|---|---|---|---|
| Duke Energy M&V Admin. | Frankie Diersing | [redacted] | |
| Duke Energy BRM | Cory Gordon | | |
| Customer Contact | [redacted] | | |

# SITE LOCATIONS/ECM'S

| Site | Address | Sq. Footage | ECM's Implemented |
|---|---|---|---|
| [redacted] Warehouse | [redacted] | 70,000 | # 1 |

# DATA PRODUCTS AND PROJECT OUTPUT

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

## M&V Option

IPMVP Option A

## Data Accuracy

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

## Field Data Points

Pre-Installation

Survey data

- Fixture count and Wattage
    - Pre-retrofit, (70) 430-Watt metal halide light fixtures were in use.
- Determine how lighting is controlled and record controller settings
    - The pre-retrofit schedule was taken to be the same as the post-retrofit schedule. This was NOT 10.5 hours per weekday with no weekend and holiday operation, as listed in the application, but rather an average of 13.15 equivalent full-load hours per weekday and 4.63 equivalent full-load hours per weekend day and holiday.
- During the pre-retrofit survey, verify that all existing fixture specifications and quantities are consistent with the application
    - Pre-retrofit fixtures and quantities were consistent with the application.
- During the post survey, verify that all pre (existing) fixtures were removed.
    - All pre-retrofit fixtures were removed.
- During the post survey, verify that all post (new) fixture specifications and quantities are consistent with the application.
    - Post-retrofit fixture types and counts are NOT consistent with the application. The application claimed (70) 235-Watt induction fixtures, but the survey found (59) 235-Watt induction fixtures and (13) 192-Watt T8 high bay fluorescents.
- Determine what holidays the building observes over the year. Determine if the lighting zones are disabled during the holidays.
    - There are (8) holidays observed throughout the year, although it appears that lighting zones are NOT disabled, but rather approximate weekend operation.

One-time and time-series measurements

- Lighting circuit power when lights are on.
    - 14 individual lighting circuits were monitored during the three-week study period. Each of these circuits was also spot-checked for Volts, Amps, Watts, and Power Factor.

## Field Data Logging

- o Current measurement CT loggers were deployed to measure current at the panelboard
- o Original CT Instructions: Prepare to deploy current measurement CT loggers to measure current at the panelboard. If the panelboard is dedicated to the lighting being logged, log the panel board. If the panelboard is not dedicated to lights in question, but the circuit is, log the individual circuits. If both the panelboard and circuit layouts are unknown or involve additional loads such as other lighting or plug loads, install lighting loggers OR On/OFF CT loggers to measure light status at the fixture.
- o Set up loggers for 5 minute instantaneous readings and allow loggers to operate for a minimum period of three weeks.
- o Original spot measurement instructions: 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 must have only one fixture type on the circuit. If the circuit has more than one type, spot measure the lighting load at the fixture ballast for the fixture in question. It is likely that the current will be so low that it will require amplification for accurate measurement. Use a 'donut' approach and record the number of windings.

## Logger Table

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

| ECM | Hobo U-12 | 20A CT | Hobo Lighting Loggers (If circuits are not dedicated) |
|---|---|---|---|
| 1 | 14 | 14 | 14 |
| **Total** | **14** | **14** | **14** |

## Verification and Quality Control

22. Time series data was visually inspected for gaps.
23. Readings were compared to nameplate. Consequently, samples J and L were identified as out of range, and not included in the calculations. Sample J showed 0A readings at all times, while Sample L showed 20A readings at all times. These clearly did not match up with the total lighting wattage numbers of 1132W on each of these samples.
24. The data was examined for physically impossible combinations.
25. Pre-retrofit schedules were corrected to correspond to the actual schedules observed in the post-retrofit data. This measure was not a schedule modification measure.

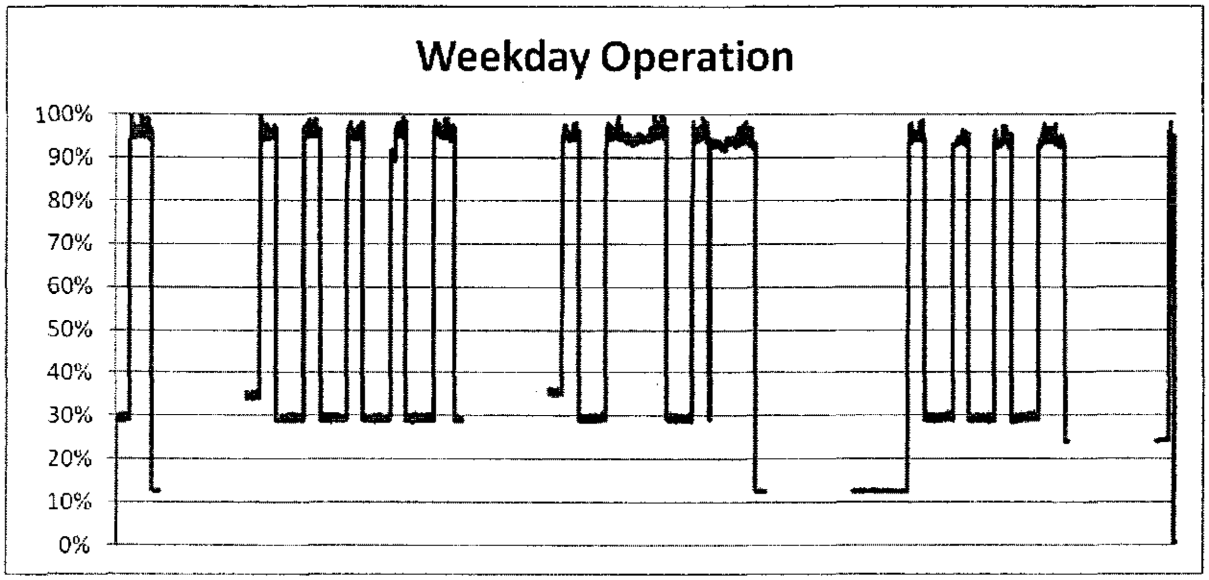
## Recording and Data Exchange Format

18. Pre-installation Lighting Survey Form and Notes.

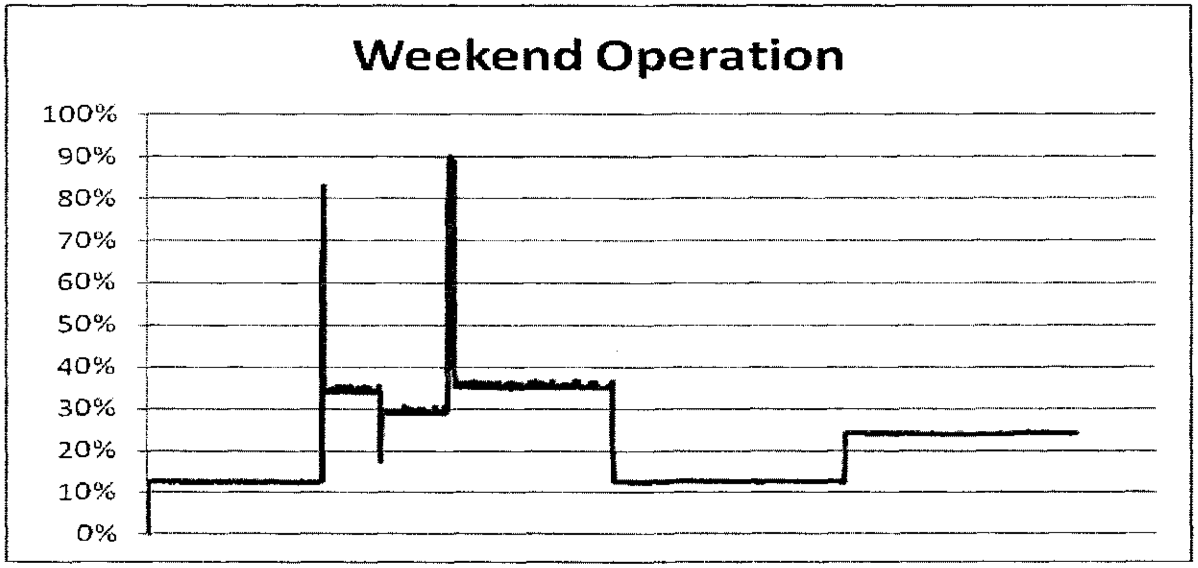
19. Post-installation Lighting Survey Form and Notes.
20. Hobo/Elite Pro logger binary files
21. Excel spreadsheets

## Data Analysis

Analysis of the combined data reveals that the light systems run for an average of 13.15 equivalent full load hours during each weekday. This compares to the 10.5 hours per weekday listed in the application. Data for all of the logged circuits was combined to provide a Watt-weighted overall lighting profile. The three week profile of all monitored lighting circuits can be seen below.




A similar analysis of weekend operation revealed that although the application listed zero lighting operation on weekends, the lights are in fact on for 4.63 equivalent full-load hours per weekend day and holiday. (Note: all weekend days are combined into a single data stream for this graph, and there are no gaps in the data, where weekdays would normally occur.)




These schedules, including the 13.15 hours per day on weekdays and 4.63 hours per day on weekend days and holidays, were used as the average schedules for both the pre-retrofit and post-retrofit cases. In addition, given the 8 holidays per year, the annual schedule amounts to 252 weekdays and 112 weekend days/holidays.

The overall lighting wattage in the pre-retrofit case was 30.1 kW (70 fixtures X 430 Watts). In the post-retrofit case, that figure decreased to 16.4 kW (59 fixtures X 235 Watts + 13 fixtures X 192 Watts).
Combining the annual equivalent full-load operating hours with the pre- and post-retrofit lighting wattage allows us to calculate annual energy (kWh) and demand (kW) savings. The following table illustrates all calculation details.

| Energy and Demand Savings Summary | | | |
|---|---|---|---|
| | Pre- | Post- | |
| Operating Hours Per Weekday | 13.15 | 13.15 | |
| Operating Hours Per Weekend Day | 4.63 | 4.63 | |
| Annual Operating Hours (Full Load) | 3832 | 3832 | |
| Lighting kW / Demand | 30.10 | 16.361 | |
| Annual Energy Consumption [kWh] | 115,354 | 62,701 | |
| | | | |
| | Expected | Evaluated | Realization Rate |
| Annual Energy Savings [kWh] | 42,070 | 52,653 | 125% |
| Building Peak Demand Savings [kW] | 15.0 | 13.7 | 92% |
| Coincident Peak Demand Savings [kW] | 15.0 | 13.7 | 92% |

Because lighting loads coincide with air conditioning loads (typically the most important driver of building and utility peak kW usage), the coincidence factor of the lighting demand reduction, and the utility coincident peak demand reduction, will both be 1.0. Therefore, the full amount of demand reduced by the lighting retrofit measure is counted toward both of these demand reduction metrics.

**Final Project Savings Summary**

The evaluated savings were compared to the final savings estimates from the DSMore runs. This comparison is shown in the Table below:

**Final Project Savings and Realization Rate**

| Evaluated kWh Savings | Expected kWh Savings | kWh RR | Evaluated NCP kW Savings | Expected NCP kW Savings | NCP kW RR | Evaluated CP kW Savings | Expected CP kW Savings | CP kW RR |
|---|---|---|---|---|---|---|---|---|
| 52,653 | 40,915 | 1.29 | 14 | 15 | 0.89 | 14 | 15 | 0.89 |

# Site 12

[redacted]

# M&V Report

PREPARED FOR:
Duke Energy
Ohio

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

PREPARED IN:
December 2011
Revision 1.1

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

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

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

# INTRODUCTION

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

The measures include:

**ECM-1 – Replace existing 750 Ton Chiller with new 400 Ton Chiller**

- Replace 23 year old CFC refrigerant based chiller with new 400 ton chiller. New chiller will have factory mounted VFD

**ECM-2 – Add VFD to 1100 Ton Chiller**

- Chiller #6

Note: ECM's have already been implemented. Only post measurements will be 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 Peak savings (kW) |
|---|---|---|---|---|
| 1 | 502,345 | 172 | - | - |
| 2 | 130,181 | 191 | - | - |
| **Total** | **632,526** | **363** | **679,536** | |

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

Approval has not yet been granted from the Duke Energy contacts listed below to plan and schedule the site visit with the Customer.

| | | |
|---|---|---|
| Duke Energy M&V Admin. | Frankie Diersing | [redacted] |
| Duke Energy BRM | Mike Heath | [redacted] |
| Customer Contact | [redacted] | [redacted] |

## Site Locations/ECM's

| Site | Address | Sq. Footage | Age | ECM's Implemented |
|---|---|---|---|---|
| [redacted] | [redacted] | | | 1,2 |

## Data Products and Project Output

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

## M&V Option

IPMVP Option A

## M&V Implementation Schedule

- ECM's dictate that this plan should be implemented during the summer months (peak cooling season).
- Post data will need to be collected for a thorough evaluation.
- Monitoring period should include both normal workday and weekend/holiday periods

## Field Survey Points

For ECM-1, survey/log the 400 ton chiller. For ECM-2, survey/log the 1100 ton chiller.

Survey data (for all equipment logged)

- 400 and 1100 ton Chiller make/model/serial number
- 400 and 1100 ton Chiller VFD make/model
- 400 ton chiller flow rate
- 1100 ton chiller flow rate

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

- 400 and 1100 ton Chiller volts, amps, kW and power factor
- OA Temperature

## Data Accuracy

| Measurement | Sensor | Accuracy | Notes |
|---|---|---|---|
| Temperature | Hobo thermistor | ±0.5° | |
| Current | Magnelab CT | ±1% | > 10% of rating |

## Field Data Logging

- **ECM-1&2**
  5. Install loggers to measure and record chiller kW in 5 minute intervals
  6. For ECM-1, log the 400 ton replacement chiller.
  7. For ECM-2, log the 1100 ton chiller.
  8. Log Chilled water supply and return temperatures for both chillers in 5 minute intervals.
  9. Log condenser water supply and return temperatures in 5 minute intervals.
  10. Log for 4 weeks post-measure installation.

  **Note: Chiller kW and chiller/condenser water temperatures must be logged at the same time.**

- **Outdoor Air**

  1. Install a weather logging station to record outside air temperature and relative humidity in 5 minute intervals. If BAS is capable of logging OA temperature and RH, set up trends in place of weather station installation. Log for 4 weeks pre-measure installation and 4 weeks post-measure installation. **Outdoor air readings must coincide with chiller kW readings for the post logging interval.**

## Logger Table

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

| ECM | Elite-Pro | Hobo U-12 (4 CH) | Temperature Probe | CT's | Weather Stations |
|---|---|---|---|---|---|
| 1 | 1 | 1 | 2 | (3) 450 amp | 1 |
| 2 | 1 | 1 | 2 | (3) 1200 amp | - |
| **Total** | **2** | **2** | **4** | **6** | **1** |

**Note: CT sizes are based on worst case scenario. Hobo logger count is based on four (4) channel loggers. Field survey will need to be conducted to verify actual breaker sizes.**

# Data Analysis

10. Convert time series data on logged equipment into pre/post average load shapes by day-type.
11. Develop pre/post regression model of total daily kWh as a function of average outdoor drybulb and wetbulb temperature,
12. Estimate peak demand savings by subtracting pre/post time series data during peak ambient temperatures. Find time series sequences that have equivalent temperatures. Calculate coincident peak savings by subtracting pre/post peak kW values at equivalent hot days at 4 pm local time.

- **ECM-1&2**

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

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

where

| | | |
|---|---|---|
| Tons | = | Chiller load |
| GPM | = | Chilled water flow rate |
| $\Delta$T | = | Chilled water supply/return temperature differential |

2. Use DOE-2 chiller curves to estimate Pre chiller operating conditions. Chiller load from equation above remains the same. Modify chiller curves for actual chilled water/condenser water temperatures realized during logging period.
3. Determine kWh for both Pre and Post operating conditions.
4. Convert time series data on logged equipment into pre/post average load shapes by daytype. Compare pre/post peak kW for evidence of peak demand limiting. Calculate peak demand savings
5. Regress data into a temperature dependent load model. Form of the regression equation is:

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

where

| | |
|---|---|
| kWh/day | = daily energy consumption |
| $T_{avg}$ | = Daily average drybulb or wetbulb temperature |

6. Apply equation above to TMY3 data processed into average drybulb and wetbulb temperature for each day of the year. Use correlation that gives the best fit.

## Verification and Quality Control

26. Visually inspect time series data for gaps
27. Compare readings to nameplate and spot-watt values; identify out of range data

## Recording and Data Exchange Format

22. Elite Pro logger and weather station binary files
23. Excel spreadsheets

## Results Summary

The following results account for benefits of the VFD retrofit/chiller replacement.

A summary of the estimated annual savings is shown in Table 1, broken out by each chiller's individual savings.

**Table 1**

| | kWh Summary | | | |
|---|---|---|---|---|
| | 750 to 400 ton | | 1100 ton; add VFD | |
| | Pre | Post | Pre | Post |
| | 854,839 | 616,152 | 1,860,574 | 1,649,965 |
| **Total Savings (kWh)** | **238688** | | **210609** | |
| **Application Realization Rate** | **48%** | | **162%** | |
| **Total Savings (kWh) for both chillers** | **449,297** | | | |
| **Duke Realization Rate** | **66%** | | | |

Realization rates varied between 48% for the 400 ton chiller replacement, to 162% for the 1100 ton chiller VFD implementation, with 66% for the Duke estimated kWh savings.

Evidence of peak demand reduction is shown in Table 2.

**Table 2**

| | Peak kW Summary | | | |
|---|---|---|---|---|
| | 750 to 400 ton | | 1100 ton; add VFD | |
| | Pre | Post | Pre | Post |
| | 261 | 253 | 490 | 476 |
| **Total Savings (Peak kW)** | **8** | | **13** | |
| **Application Realization Rate** | **5%** | | **7%** | |
| **Total kW Savings (both** | **21** | | | |

| | |
|---|---|
| chillers) | |
| Duke Realization Rate | N/A |

Figures 1 and 2 depict graphs of energy consumption and savings for the metered equipment (750/1100 ton chillers pre and 400/1100 ton chillers post) during the monitoring period.

**Figure 1**

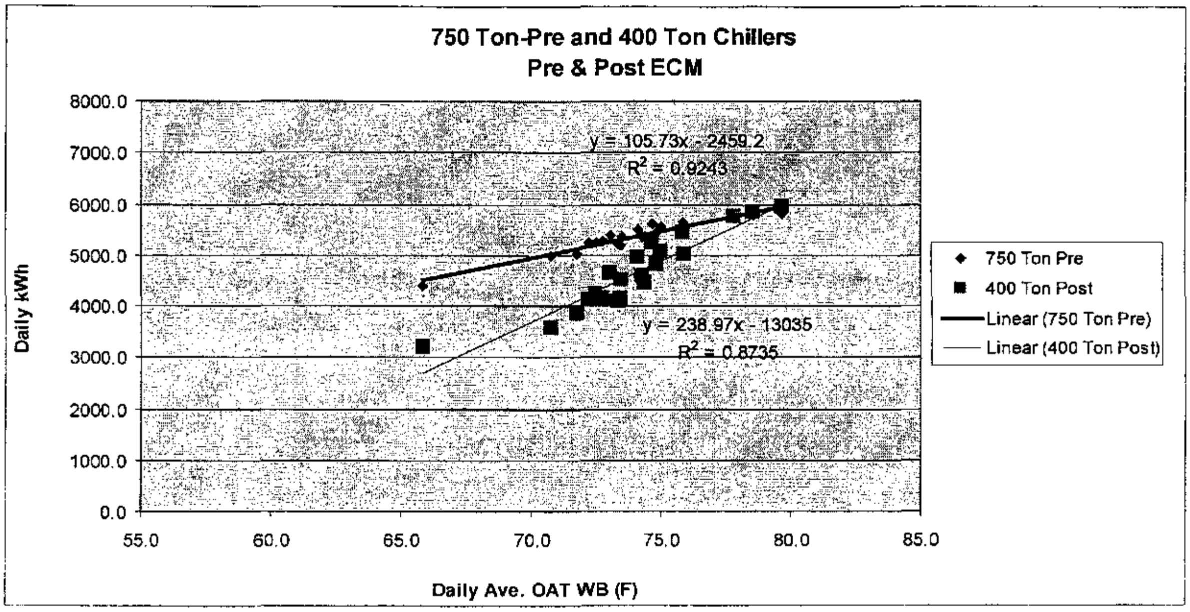
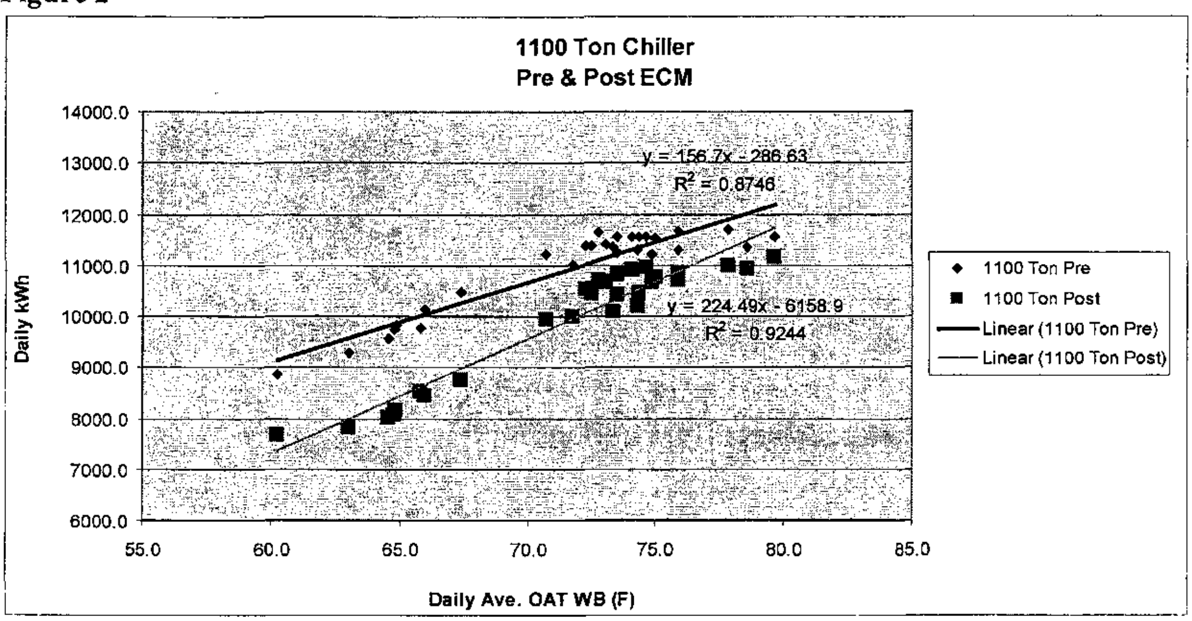



**Figure 2**



Figures 3 and 4 depict graphs of energy consumption and savings for the metered equipment extrapolated over the course of one year. kWh/day were extrapolated for the year by substituting TMY3 outside air temperatures (wet bulb) into the linear regression equations above for both pre and post ECM install. The chillers were assumed to run 100% under 34 OAT (DB). The chillers were assumed to be off between 34 and 64 OAT (DB), where the flat plate heat exchanger would be able to offer free cooling. Above 64 degrees, the chillers were assumed to follow the linear regressions noted above.

**Figure 3**

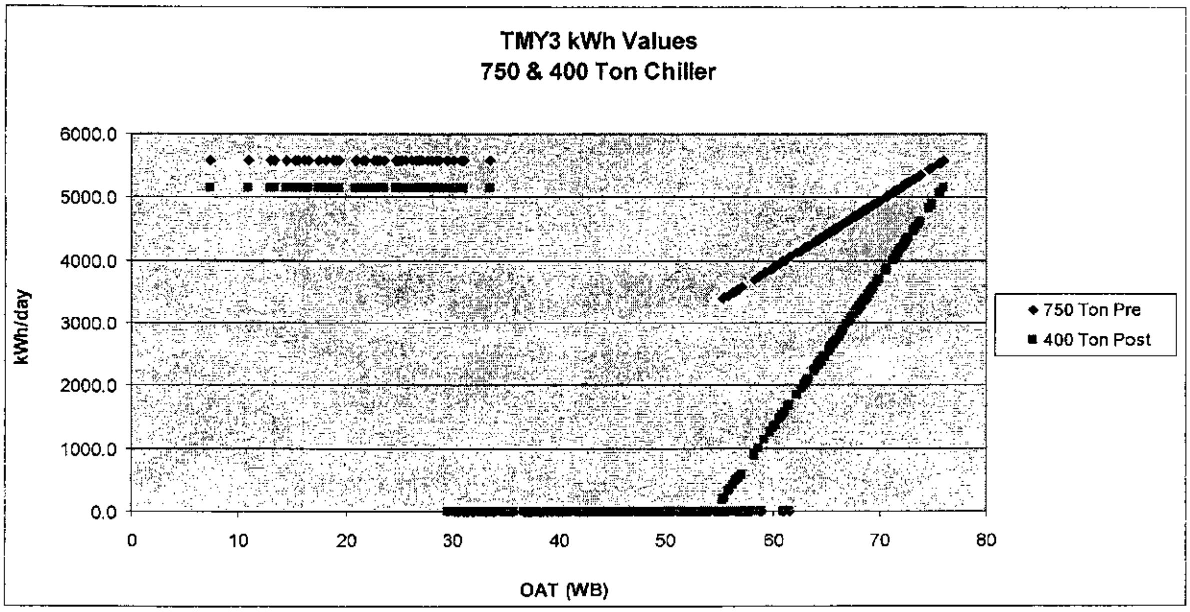
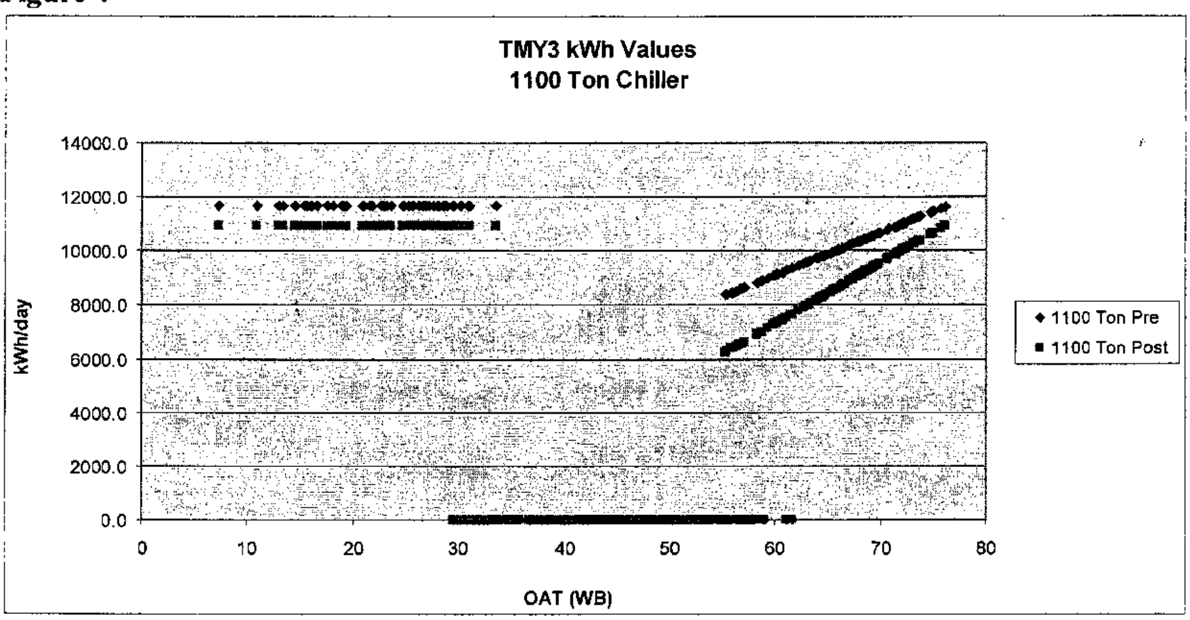



**Figure 4**



Although overall kWh savings were realized for this application, they were, overall, slightly lower than originally expected for the 400 ton chiller. Part of this may be due to the loading of the chillers post-retrofit. The 400 and 750-ton chillers were allocated similar loads, and so the 400-ton chiller was loaded at a higher part load ratio. The demand curves show that the demand of the two chillers at high wet bulb temperatures, and consequently high loads, is very similar, leading to having somewhat similar energy consumption at high ambient temperatures. The modeling of the two chillers resulted in somewhat similar annual energy reductions, about 210MWh to 240MWh each.

Figures 5 and 6 depict peak kW values for both Pre and Post ECM. The 400 ton Post as well as both Pre and Post 1100 ton regressions were noted to be change-point models. The 750 ton Pre regression was assumed to be linear. Similar to the kWh/day extrapolation, Peak kW/day were then extrapolated for the year by substituting TMY3 outside air temperatures (wb) into the linear regression equations which resulted in the highest kW value.

**Figure 5. 750 and 400 ton chiller demand**

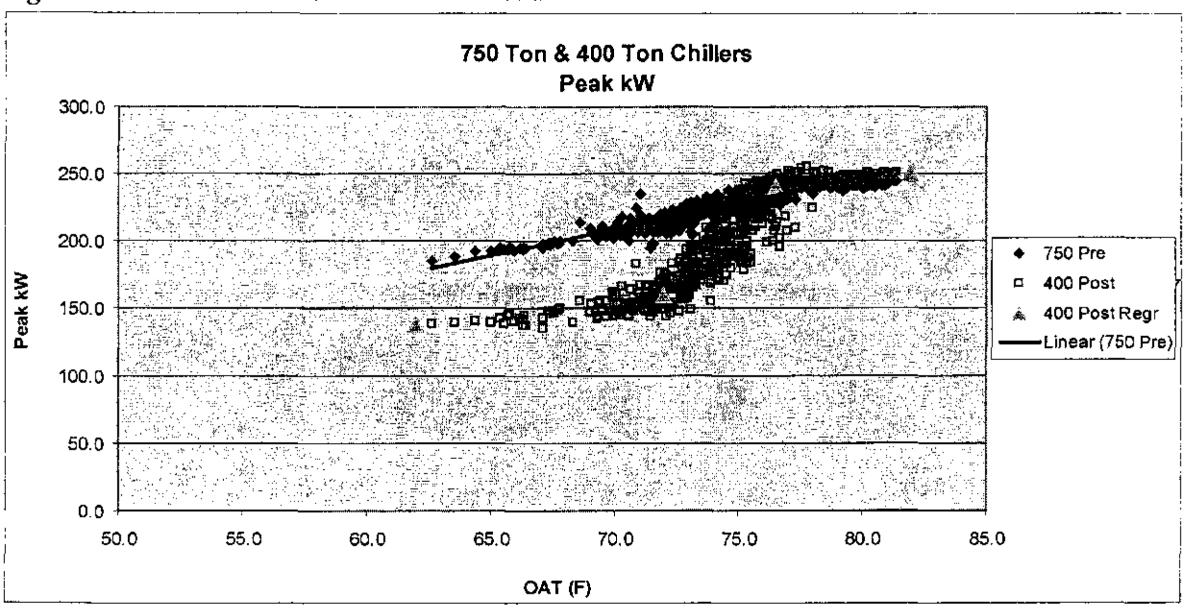
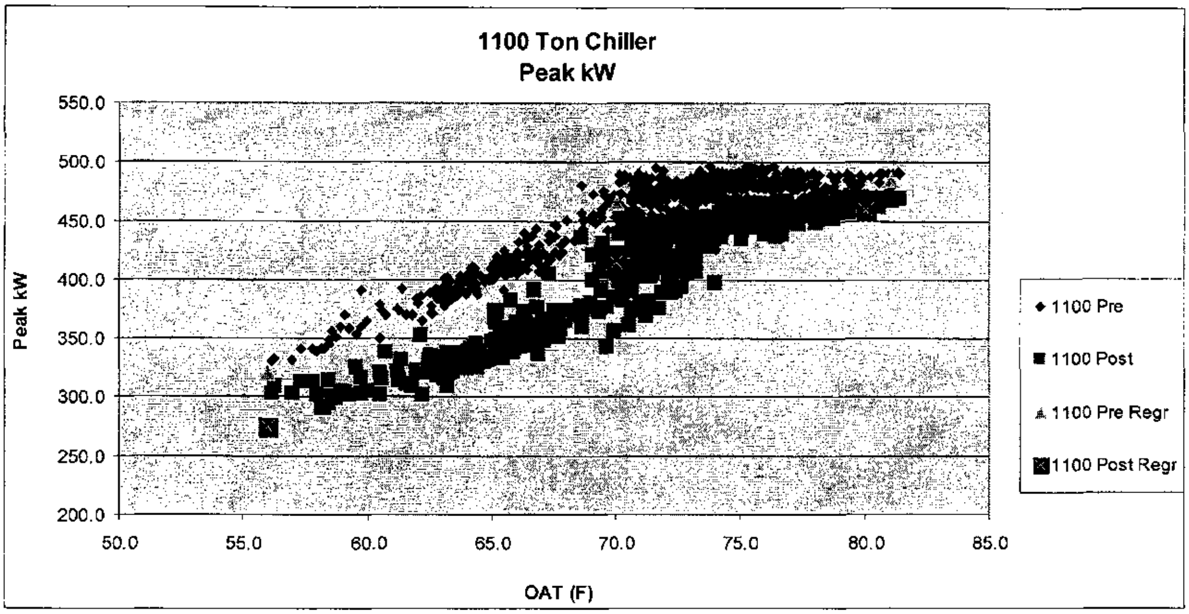



**Figure 6. 1100 ton chiller pre and post retrofit demand**




**Final Project Savings Summary**

The evaluated savings were compared to the final savings estimates from the DSMore runs. This comparison is shown in the Table below:

**Final Project Savings and Realization Rate**

| Evaluated kWh Savings | Expected kWh Savings | kWh RR | Evaluated NCP kW Savings | Expected NCP kW Savings | NCP kW RR | Evaluated CP kW Savings | Expected CP kW Savings | CP kW RR |
|---|---|---|---|---|---|---|---|---|
| 449,297 | 632,527 | 0.71 | 21 | 86 | 0.24 | 21 | 106 | 0.20 |

# Site 13

## [redacted] School District

## M&V Report

PREPARED FOR:
Duke Energy
Ohio

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

PREPARED IN:
January 2012

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

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