Final Report

Impact Evaluation of the Non-Residential Smart $aver® Prescriptive Program in Ohio and Kentucky

Results of an Impact Evaluation for
Linear Fluorescent Lighting, Occupancy Sensors, and VFDs

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

November 21, 2013

Submitted By:

Nick Hall, Brian Evans, and Johna Roth
TecMarket Works
165 West Netherwood Road
Oregon, Wisconsin 53575
(608) 835-8855

Pete Jacobs
BuildingMetrics, Inc

Stuart Waterbury
Architectural Energy Corporation

Table of Contents

Executive Summary

Key Findings and Recommendations

This Executive Summary provides an overview of the key findings identified through this evaluation. This evaluation was conducted for both Ohio and Kentucky. The M&V was conducted on Ohio projects, however, all findings are applicable to the Kentucky projects (where there was not enough projects for a representative sample).

Significant Impact Evaluation Findings for Linear Fluorescent Measures

- Energy and coincident peak demand savings realization rates for kWh and coincident peak kW for linear fluorescent lighting were 1.89 (energy) and 1.61 (demand) respectively, indicating the program planning estimates were conservative estimates of linear fluorescent lighting savings.
- Measurement and verification (M&V) activities conducted for this study produced an estimate of 5,155 lighting equivalent full load hours (EFLH), compared to a program planning estimate of 4,144 EFLH.
- M&V activities estimated a coincidence factor (CF) of 0.80, compared to a program planning estimate of 0.77.
- Although there were some small differences between the quantity of fixtures recorded in the Duke Energy program tracking database versus the number of fixtures in the field, the overall installation verification rate was 1.00.
- Program planning and M&V estimates of baseline fixture wattage were within 1%. M&V estimates of efficient fixture watts were an average of about 7% lower than program planning estimates, indicating conservative values of fixture watts were used during program design.

Significant Impact Evaluation Findings for Occupancy Sensor Measures

- Energy and coincident peak demand savings realization rates for kWh and kW for occupancy sensor measures were 0.56 and 1.21 respectively, indicating the program planning estimates were conservative estimates of occupancy sensor coincident peak kW savings, but overestimated occupancy sensor kWh savings.
- M&V activities conducted for this study produced an estimate of 3,078 lighting equivalent full load hours (EFLH) before the installation of occupancy sensors, compared to a program planning estimate of 4,144 EFLH.
- M&V activities produced an estimate of connected lighting kW per occupancy sensor that was 31% lower than the program assumption. Many of the occupancy sensors in the study were controlling a single fixture, which contributed to the reduced connected watts per sensor.
- M&V activities estimated an average kWh savings of 54% of the uncontrolled consumption and an average kW savings of 46% of the uncontrolled demand, compared to the program estimate of 30% for both kWh and kW. Although the kW savings as a percentage of the baseline estimated from M&V was higher, the connected load per

sensor was less, thus the overall demand savings per sensor from M&V was less than the program estimate.

Significant Impact Evaluation Findings for VFD Measures

- VFD energy and coincident peak demand savings realization rates were lower than program planning estimates. On average, the realization rates for energy, non-coincident peak, and peak demand savings were about 62, 46, and 43% respectively. HVAC fans had the highest realization rates, and process pumping had the lowest realization rates.

A summary of the impact findings is presented in the standardized Duke Energy Program Impact Metrics Tables below.

Table 1. Summary of Program Savings by Measure

Measure	Measure Count	Gross Ex Post (Adjusted) Per unit kWh impact	Gross Ex Post (Adjusted) Per unit kW impact	Gross Ex Post (Adjusted) kWh Savings	Gross Ex Post (Adjusted) kW Savings
HPT8 4ft 2 lamp, T12 to HPT8	4,878	191.6	0.033	934,625	161.0
HPT8 4ft 2 lamp, T8 to HPT8	2,705	72.4	0.012	195,842	32.5
Low Watt T8 lamps, 4ft	174,488	35.0	0.006	6,107,080	1,046.9
LW HPT8 4ft 2 lamp, replace T8	7,237	86.0	0.015	622,382	108.6
LW HPT8 4ft 4 lamp, replace T8	4,267	154.8	0.027	660,532	115.2
LW HP T-8 4ft 1L replace T-8 4ft 1L	1,032	60.2	0.010	62,126	10.3
LW HP T-8 4ft 2L replace T-8 4ft 2L	26,249	86.0	0.015	2,257,414	393.7
LW HP T-8 4ft 4L replace T-8 4ft 4L	6,768	154.8	0.027	1,047,686	182.7
T8 2ft 2 lamp	2,161	206.3	0.036	445,814	77.8
T8 4ft 2 lamp	24,674	111.8	0.019	2,758,553	468.8
T8 4ft 4 lamp	21,648	275.1	0.047	5,955,365	1,017.5
T8 8ft 2 lamp	3,553	120.4	0.021	427,781	74.6
Occupancy Sensors under 500 W	28,904	273.5	0.123	7,905,244	3,555.2
Occupancy Sensors over 500 W	10,968	684.8	0.302	7,510,886	3,312.3
VFD HVAC Fan	602	1011.7	0.070	609,043	42.1
VFD HVAC Pump	54	1558.0	0.207	84,132	11.2
VFD Process Pump 1-50 HP	9	270.6	0.033	2,435	0.3

Table 2. Program Impact Metrics Summary for Ohio and Kentucky

Metric	Result
Number of Program Participants from 1-1-2009 to 2-29-2012	2439 Projects (OH) 228 Projects (KY)
Gross Coincident Peak kW per unit	kW/unit
HPT8 4ft 2 lamp, T12 to HPT8	0.033
HPT8 4ft 2 lamp, T8 to HPT8	0.012
Low Watt T8 lamps, 4ft	0.006
LW HPT8 4ft 2 lamp, replace T8	0.015

Metric	Result
LW HPT8 4ft 4 lamp, replace T8	0.027
LW HP T-8 4ft 1L replace T-8 4ft 1L	0.010
LW HP T-8 4ft 2L replace T-8 4ft 2L	0.015
LW HP T-8 4ft 4L replace T-8 4ft 4L	0.027
T8 2ft 2 lamp	0.036
T8 4ft 2 lamp	0.019
T8 4ft 4 lamp	0.047
T8 8ft 2 lamp	0.021
Occupancy Sensors under 500 W	0.123
Occupancy Sensors over 500 W	0.302
VFD HVAC Fan	0.070
VFD HVAC Pump	0.207
VFD Process Pump 1-50 HP	0.033
Gross kWh per unit	kWh/unit
HPT8 4ft 2 lamp, T12 to HPT8	191.6
HPT8 4ft 2 lamp, T8 to HPT8	72.4
Low Watt T8 lamps, 4ft	35.0
LW HPT8 4ft 2 lamp, replace T8	86.0
LW HPT8 4ft 4 lamp, replace T8	154.8
LW HP T-8 4ft 1L replace T-8 4ft 1L	60.2
LW HP T-8 4ft 2L replace T-8 4ft 2L	86.0
LW HP T-8 4ft 4L replace T-8 4ft 4L	154.8
T8 2ft 2 lamp	206.3
T8 4ft 2 lamp	111.8
T8 4ft 4 lamp	275.1
T8 8ft 2 lamp	120.4
Occupancy Sensors under 500 W	273.5
Occupancy Sensors over 500 W	684.8
VFD HVAC Fan	1011.7
VFD HVAC Pump	1558.0
VFD Process Pump 1-50 HP	270.6
Gross therms per unit	N/A
Freeridership rate (program wide)	38.40%
Spillover rate	6.60%
Self Selection and False Response rate	0.00%
Total Discounting to be applied to Gross values	68.20%

Metric	Result
Net Coincident Peak kW per unit	kW/unit
HPT8 4ft 2 lamp, T12 to HPT8	0.023
HPT8 4ft 2 lamp, T8 to HPT8	0.008
Low Watt T8 lamps, 4ft	0.004
LW HPT8 4ft 2 lamp, replace T8	0.010
LW HPT8 4ft 4 lamp, replace T8	0.018
LW HP T-8 4ft 1L replace T-8 4ft 1L	0.007
LW HP T-8 4ft 2L replace T-8 4ft 2L	0.010
LW HP T-8 4ft 4L replace T-8 4ft 4L	0.018
T8 2ft 2 lamp	0.025
T8 4ft 2 lamp	0.013
T8 4ft 4 lamp	0.032
T8 8ft 2 lamp	0.014
Occupancy Sensors under 500 W	0.084
Occupancy Sensors over 500 W	0.206
VFD HVAC Fan	0.048
VFD HVAC Pump	0.141
VFD Process Pump 1-50 HP	0.023
Net kWh per unit	kWh/unit
HPT8 4ft 2 lamp, T12 to HPT8	130.7
HPT8 4ft 2 lamp, T8 to HPT8	49.4
Low Watt T8 lamps, 4ft	23.9
LW HPT8 4ft 2 lamp, replace T8	58.7
LW HPT8 4ft 4 lamp, replace T8	105.6
LW HP T-8 4ft 1L replace T-8 4ft 1L	41.1
LW HP T-8 4ft 2L replace T-8 4ft 2L	58.7
LW HP T-8 4ft 4L replace T-8 4ft 4L	105.6
T8 2ft 2 lamp	140.7
T8 4ft 2 lamp	76.2
T8 4ft 4 lamp	187.6
T8 8ft 2 lamp	82.1
Occupancy Sensors under 500 W	186.5
Occupancy Sensors over 500 W	467.0
VFD HVAC Fan	690.0
VFD HVAC Pump	1062.6
VFD Process Pump 1-50 HP	184.5

Metric	Result
Net therms per unit	N/A
Measure Life	12yr (linear fluorescent) 10yr (occupancy sensor)

Net to Gross

The net to gross analysis is based on participant self-reports in Ohio and Kentucky and complies with standard evaluation practices and protocols, including the California Evaluation Protocols (TecMarket Works, April 2006). The program-wide net to gross analysis (freeridership = 38.4%+spillover = 6.6%) produced a net to gross ratio of 0.682 at the program level. That is, the program saved 31.8% less than the measures installed via the program incentive because freeridership was particularly high and the program did not induce participants to take many additional energy efficiency actions beyond those incented by the program.

Recommendations

Based on the results of the impact evaluation, the TecMarket Works team has the following recommendations:

1. Conservative estimates of lighting EFLH should be updated with M&V results.
2. The weighted average self-reported operating hours were 4,944 EFLH, which represents a better estimate of lighting EFLH than the standard estimate of 4,144 EFLH. Consider including the self-reported operating hours in the ex-ante estimates of measure savings.
3. The measured coincidence factor of 0.80 was slightly higher than the program planning estimate of 0.77. Consider revising the coincidence factor assumption to 0.80 for future program planning activities.
4. The M&V savings for VFDs was significantly lower than program estimates, especially for HVAC pumps and process pumps. Consider reducing the annual savings estimates to the M&V results.

Introduction and Purpose of Study

This report presents the results of an impact evaluation of the Non-Residential Smart $aver® Prescriptive Program in Ohio and Kentucky. The focus of this study is on linear fluorescent lighting fixtures, occupancy sensors, and VFDs on HVAC fans, HVAC pumps, and process pumping. A previous report examined high-bay lighting fixtures, which were and still are the dominant measure adopted by program participants. As the program has matured, linear fluorescent lighting, occupancy sensors, and VFD savings have increased as a percentage of total program savings. This report was prepared in response to the emergence of these measure types as significant measures in the overall program portfolio.

Summary Overview

Summary of the Evaluation

This report presents the results of an impact evaluation of linear fluorescent lighting, occupancy sensor, and VFD measures offered through Duke Energy's Non-Residential Smart $aver Program in Ohio and Kentucky. The Smart $aver Program provides incentives to customers to upgrade to energy efficient lighting and commercial equipment. The study focuses on participants from January 2009 through February 29, 2012.

The impact evaluation employed a tracking system review, onsite surveys, and short term Measurement and Verification (M&V) of selected lighting fixtures, occupancy sensors, and variable frequency drives (VFD) using portable data loggers.

Evaluation Objectives

The goal of the impact analysis was to estimate program level energy (kWh) and demand (kW) savings. Secondary objectives included estimates of unit energy savings for sampled measures, and overall energy and demand savings realization rates for the three measure groups studied: linear fluorescent lighting, occupancy sensors, and variable frequency drives.

Researchable Issues

Additional researchable issues in this evaluation include:

- Verification of measures as recorded in the Duke Energy program tracking database with field observations.
- Identification of ineligible measures.
- Estimation of average operating hours for commercial lighting fixtures
- Estimation of unit energy savings for VFDs
- Percent energy savings and connected load parameters for occupancy sensors

Program Description

The Non-Residential Smart $aver® Prescriptive program influences business customer decisions for saving energy by providing incentives to install qualifying high-efficiency measures such as lighting, HVAC, and motors. Duke Energy's commercial and industrial customers fund this program by paying an energy efficiency rider based upon their kWh usage. The program has a Custom component as well as the Prescriptive component. This evaluation study looks at the Prescriptive program only. The Custom program will not be evaluated here, but it works hand in hand with the Prescriptive program. In the Prescriptive program, customers may install selected energy efficient measures and then send in an application for rebates, up to 90 days after the installation. Energy efficiency measures that are not part of the Prescriptive program may still earn a rebate, but the installation of these Custom measures must first be approved by Duke Energy through an application process.

Program Participation

Program	OH Measure Count for 1/1/09 – 2/28/12	KY Measure Count for 1/1/09 – 2/28/12
Non-Residential Smart $aver Prescriptive	835,342	121,653

Methodology

Overview of the Evaluation Approach

Study Methodology

The impact methodology consisted of engineering analysis following the International Performance Measurement and Verification Protocol (IPMVP). The projects were separated into linear fluorescent, occupancy sensor, and variable frequency drives (VFDs) measure groups, and samples were drawn from each category. Site surveys and metering equipment were installed to gather data according to an M&V plan developed for each measure category [1]. Energy and demand savings estimates were developed for each sampled project.

Data collection methods, sample sizes, and sampling methodology

The impact evaluation employed a tracking system review, onsite surveys, and short term Measurement and Verification (M&V) of selected lighting fixtures, occupancy sensors, and variable frequency drives (VFD) using portable data loggers.

For the lighting measures, the sample design specified a minimum sample of 12 linear fluorescent and 13 occupancy sensor projects. A target sample of 25 projects representing 38 individual measures was selected for the study. The sampling plan incorporated a stratified random sample approach, where the projects were stratified according to technology type (linear fluorescents, occupancy sensors), and sampled randomly within each stratum.

VFDs were sampled by measure, not by project since more than one VFD measure is often included in a single project. The target sample included a total of 18 sites comprising 53 VFDs: 37 VFD fans, 9 VFD pumps, and 7 VFD process pumps.

Each sampled site was recruited for the M&V study by TecMarket Works contractors.

Number of completes and sample disposition for each data collection effort

Last minute customer refusals eliminated five of the 25 sites from the final sample lighting resulting in a total of 20 sites, ten each for linear fluorescents and occupancy sensors. Due to oversampling, the achieved sample met or exceeded the minimum sample requirements. For VFDs, total of 18 sites and 44 measures were monitored. The achieved sample exceeded both the minimum and target sample size. The final sample disposition is shown below:

[1] An overall M&V plan was developed for each measure category, with site-specific addenda to address measurement issues at each sampled site.

Table 3. Final Sample Disposition

Group	Minimum Required Sample Size	Target Sample Size	Achieved Sample Size
Linear Fluorescent	8 sites	12 sites	10
Occupancy Sensor	10 sites	13 sites	10
VFD-Fan	15 measures	20 measures	29
VFD-Process	1 measure	3 measures	6
VFD-Pump	4 measures	6 measures	9

Expected and achieved precision
A sample meeting +/- 10% relative precision at 90% confidence at the program level was selected. Due to higher than expected variability in the savings in the M&V sample relative to the program planning values, the achieved relative precision was +/- 23.1%. Planned and sample coefficients of variance are shown below.

Table 4. Planned and Sample Coefficients of Variance

Project Type	Target cv	Actual Sample cv
Linear Fluorescent	0.3	0.94
Occupancy Sensor	0.3	0.61
VFD-Fan	0.5	1.65
VFD-Process	0.5	0.41
VFD-Pump	0.5	0.32
Total		

Description of baseline assumptions, methods and data sources
For linear fluorescent measures, the baseline was the existing lighting system prior to the retrofit. Due to the nature of prescriptive rebate programs, it was not possible to observe the baseline lighting system. The baseline lighting system description was obtained by interviewing the site contacts at each sampled site. Occupancy sensor measures are an "add-on" measure, so the baseline assumption is the observed lighting fixtures without occupancy sensor controls. VFD baseline assumptions were obtained by interviewing site contacts to define the flow control strategy prior to installation of the VFD.

Description of measures and selection of methods by measure(s) or market(s)
The focus of this study is on linear fluorescent lighting fixtures and occupancy sensors, as well as VFDs on HVAC fans, pumps, and process pumping. All projects were evaluated in compliance with the International Performance Measurement and Verification Protocols (IPMVP) Option A – Partially measured, retrofit isolation protocol.

Use of TRM values and explanation if TRM values not used
Engineering algorithms from the Draft Ohio TRM were used to calculate lighting savings. The study relied on primary data collection, so deemed parameters from the TRM were unnecessary.

Building energy simulation modeling was used to calculate HVAC interactive effects multipliers based on the observed HVAC system characteristics. The VFD analysis used primary data collection and regression analysis; deemed values from the TRM were not used.

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

There is the possibility for extrapolation error going from short term measurement to annualized savings. To address this, industry standard protocols were followed in the selection of the duration of the monitoring period in order to capture sufficient workday and weekend operation and also to avoid anomalous operation periods. For weather dependent measures, data were collected during a portion of the year with sufficient temperature variation to establish trends and allow the projection of short term monitored data to annual savings. State of the art engineering analysis techniques, including building energy simulation modeling were employed to reduce engineering bias.

Evaluation Findings

The impact evaluation employed a tracking system review, an engineering review of the lighting and VFD measure savings calculations, and field measurement and verification (M&V) of selected lighting and VFD measures.

Tracking Data Analysis

The tracking system review revealed that a few measures were responsible for the majority of the savings. Tracking data obtained from Duke Energy from January 2009 through February 2012 show the following breakdown of energy savings by measure:

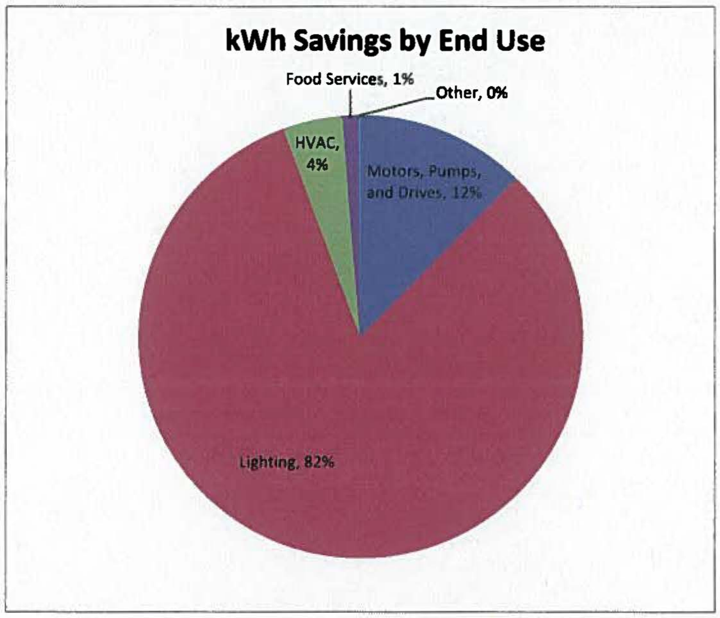

Figure 1. Measure Contribution to C&I Program Savings

Note lighting measures made up 82% of the total reported savings. Lighting was dominated by high-bay applications, making up 47% of the total lighting savings.

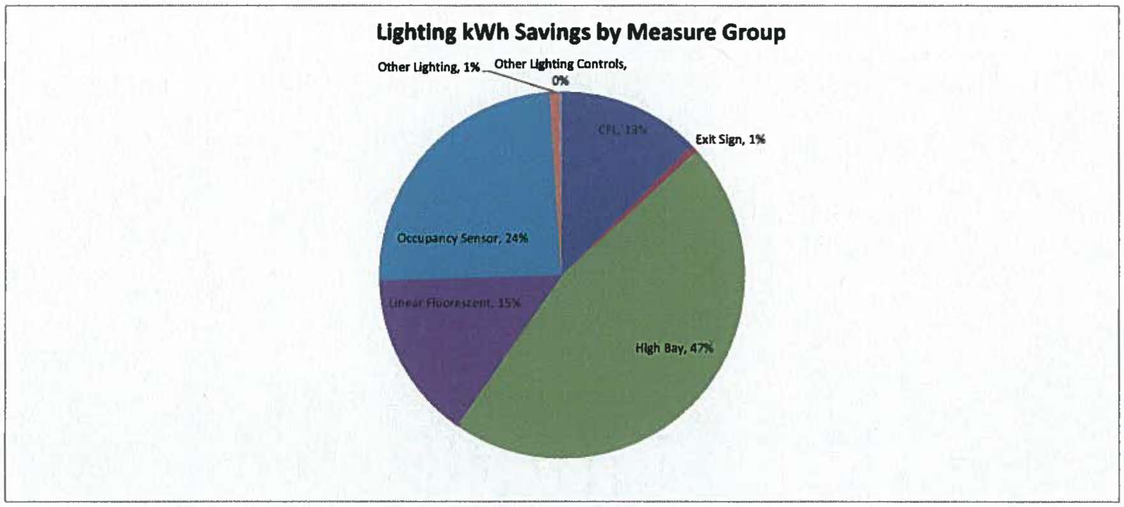

Figure 2. Lighting Measure Savings Distribution

The next largest measure group was Motors, Pumps, and Drives. This group is dominated by variable frequency drives (VFD), comprising over 99% of the energy savings. The breakdown of the VFD applications is shown in Figure 3. Over 96% of the VFD savings were attributed to HVAC Fan and Pump applications.

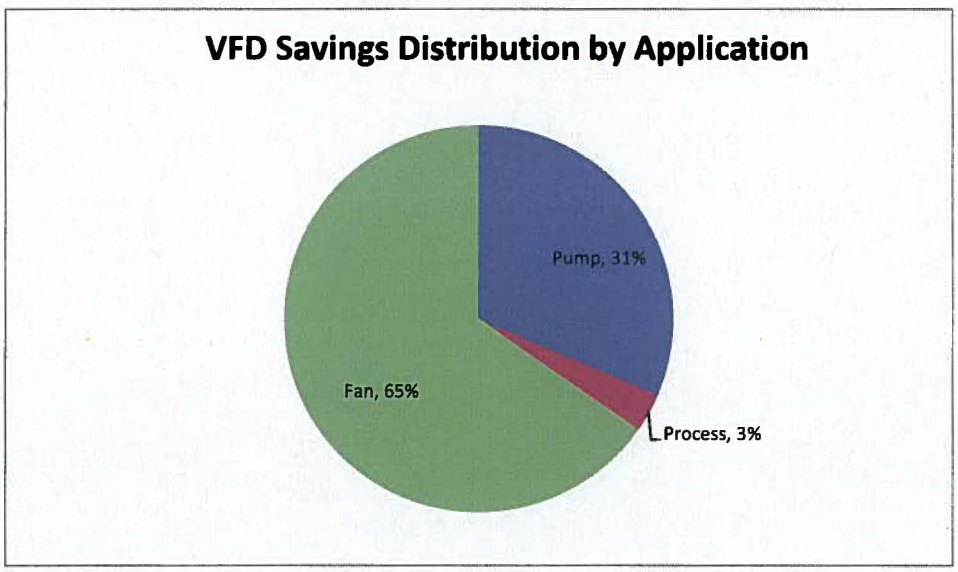

Figure 3. VFD Measure Savings Distribution

The Smart $aver Non-Residential Prescriptive program evaluation report[2] dated August 29, 2010 focused on the high bay applications. For this study, we focused on linear fluorescent lighting, occupancy sensors, and VFDs.

[2] Evaluation of the Non-Residential Smart $aver Prescriptive Program in Ohio, August 29, 2010.

The evaluation team conducted field M&V on a sample of linear fluorescent lighting, occupancy sensor, and VFD participants to estimate savings for these measures. The field M&V for lighting and occupancy sensors consisted of a site visit, verification of the quantity and type of incented lighting fixtures, verification of fixture wattage assumptions against manufacturers' catalog data, interviews with customers to identify the type and quantity of the replaced fixtures, and short-term monitoring of lighting system operation using light loggers to measure operating hours. The field M&V for VFD participants consisted of a site visit, verification of the quantity and type of incented VFDs, verification of VFD capacity, and short-term monitoring of VFDs to measure their performance. The field M&V activities were conducted by TecMarket Works' sub-contractors and the results were forwarded to Architectural Energy Corporation for analysis. The field M&V activities were compliant with the International Performance Measurement and Verification Protocols (IPMVP) Option A – Partially measured, retrofit isolation protocol.

Lighting and VFD program participation records covering the period from January 2009 through the end of February 2012 were obtained from Duke Energy. The data, delivered as an Excel spreadsheet flat file, contained customer name and address, installing vendor contact information, measure descriptions, unit energy savings estimates, number of measures installed, lighting operating hours, installed fixture watts, VFD horsepower, rebate amounts, etc. These data were examined to identify which of the measures promoted by the program were adopted by program participants and in what numbers, and the availability of any customer description data that could be used in the analysis.

Customers indicated the annual operating hours of their lighting systems on the incentive applications. These self-reported lighting system hours of operation are entered into the program tracking database. A tabulation of the average self-reported operating hours for linear fluorescent, CFL and High Bay measures by building type are shown in Table 5. These data do not include occupancy sensor measures. It is worth noting that 4219 average operating hours per year across all building types compares favorably to the estimate of 4144 average operating hours per year used in the program design workpapers[3].

[3] 4,144 average operating hours per year across all building types, from the Ohio Technical Reference Manual: Technical Reference Manual (TRM) for Ohio Senate Bill 221"Energy Efficiency and Conservation Program" and 09-512-GE-UNC, October 15, 2009.

Table 5. Self-Reported Lighting Operating Hours by Building Type

Building Description	Operating hour report frequency by building type	Average self-reported operating hours from program application
Big Box Retail	59	4,788
Education	436	3,219
Grocery	30	6,712
Healthcare	150	4,662
Industrial	804	5,354
Lodging	67	4,809
Office	455	3,743
Other	422	3,134
Public Assembly	263	3,084
Public Order/Safety	254	4,074
Restaurant	47	5,465
Small Box Retail	312	3,691
Warehouse	468	4,158
All Buildings	3767	4,219

The distribution of the self-reported operating hours by building type and fixture type is shown in Table 6.

Table 6. Self-Reported Lighting Operating Hours by Building and Fixture Type

Building Type	CFL	Linear fluorescent	High Bay
Big Box Retail	6,766	5,428	3,948
Education	3,661	2,691	2,997
Grocery	8,068	7,340	5,985
Healthcare	6,118	4,102	5,332
Industrial	6,559	4,969	5,417
Lodging	5,005	3,419	
Office	3,797	3,853	4,146
Other	2,221	3,272	3,741
Public Assembly	2,891	3,083	3,354
Public Order/Safety	4,480	3,991	3,689
Restaurant	5,580	4,436	
Small Box Retail	3,863	4,832	3,203
Warehouse	3,504	3,600	4,201
All Buildings	3,571	4,029	4,617

Sample Design

The sampling plan incorporates a stratified random sample approach, where the projects are stratified according to technology type (linear fluorescent and occupancy sensors), and sampled randomly within each stratum. The total sample size is calculated from the following equation[4]:

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

where:

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

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

A sample meeting +/- 10% relative precision at 90% confidence at the program level was selected. A coefficient of variation of 0.3 was assumed for the lighting measure population, and 0.5 for the VFD measure population. The Ohio participation (at the time of sample selection) and the resulting sample sizes are summarized in Table 7.

Samples were selected by address to maximize the effectiveness of the M&V field efforts. This often allowed multiple measures to be sampled at a single address (site). The sample design is shown in Table 7 below. Note that the VFDs are sampled by measure, not by address since more than one VFD technology is often located at a single address.

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

Table 7. Sample Selection by Measure or Site for Linear Fluorescent, Occupancy Sensor, and VFD

Group	kWh	cv	Total Measures or Sites	Minimum Required Sample Size	Target Sample Size
Linear Fluorescent	20,966,845	0.3	925 sites	8 sites	12 sites
Occupancy Sensor	26,311,741	0.3	672 sites	10 sites	13 sites
VFD-Fan	23,902,375	0.5	195 measures	15 measures	20 measures
VFD-Process	675,467	0.5	14 measures	1 measures	3 measures
VFD-Pump	5,450,294	0.5	54 measures	4 measures	6 measures

VFDs were sampled throughout the duration of the program, including a total of 18 sites comprising 53 VFDs: 37 VFD fans, 9 VFD pumps, and 7 VFD process pumps during 2009 - 2010[5].

A sample of 18 lighting projects and 44 VFD measures were selected for the study. The allocation of the projects across the different technology measures is shown in Table 7 above. Sites were randomly selected within each group. Each sampled site was recruited for the M&V study by TecMarket Works contractors. Backup sites were used when it was not possible to successfully recruit customers in the primary sample.

At the conclusion of the evaluation, several sites were not included in the lighting and occupancy sensor study. Last minute customer refusals and logger failures eliminated five of the sites from the sample. However, the achieved sample met or exceeded the minimum required sample size, as shown in the table below.

Table 8. Status of 2009-2012 Linear Fluorescent and Occupancy Sensor Sample

Group	Minimum Required Sample Size (Sites)	Target Sample Size (Sites)	Completed (Sites)	Notes
Linear Fluorescent	8	12	10	Customer refusal. 1 site dropped.
Occupancy Sensor	10	13	10	Customer refusal, loggers did not record any data. 3 sites dropped.

The achieved sample met or exceeded the target for the VFD measures as shown in Table 9.

[5] Sampling of VFDs within the sites resulted in a total of 44 monitored VFDs.

Table 9. Status of 2009-2012 VFD Sample

Group	Minimum Required Sample Size (Measures)	Target Sample Size (Measures)	VFDs Monitored (Measures)	Notes
VFD-Fan	15	20	**29**	Monitored VFDs exceeded the Target Sample
VFD-Process	1	3	**9**	Monitored VFDs exceeded the Target Sample
VFD-Pump	4	6	**6**	Monitored VFDs equals the Target Sample

A summary of the characteristics of the 10 customers that participated in the linear fluorescent M&V study is shown in Table 10.

Table 10. Linear Fluorescent Lighting M&V Study Participants

Site	Customer Name	Building Type	Total fixtures rebated	Installed Fixture(s)	Baseline Fixture(s)
LF-1	[redacted]	Office	40	T-8 8ft 2 lamp	T-12 8ft 2 lamp
			11	T-8 3ft 4 lamp	T-12 3ft 4 lamp
			9	HP T-8 4ft 2 lamp	T-8 4ft 2 lamp
			32	HP T-8 4ft 2 lamp	T-12 4ft 2 lamp
			52	HP T-8 4ft 2 lamp	T-12 4ft 2 lamp
LF-2	[redacted]	Warehouse	410	T-8 4ft 4 lamp	T-12 4ft 4 lamp
LF-3	[redacted]	Public Assembly	538	LW T-8 4ft (per-lamp replacement)	4 ft 6L F32 high bay (per lamp repl)
LF-4	[redacted]	Office	56	LW T-8 4ft 1 lamp	T-8 4ft 1 lamp
			200	LW T-8 4ft 2 lamp	T-8 4ft 2 lamp
			276	LW T-8 4ft 2 lamp	T-8 4ft 4 lamp
LF-5	[redacted]	Public Order Safety / Institutional	83	HP T-8 4ft 2 lamp	T-8 4ft 2 lamp
			4 (none installed)	High performance low watt lamp T8 fluorescent	Standard T8 fluorescent
			40	T-8 4ft 2 lamp	T-12 4ft 2 lamp
LF-6	[redacted]	Healthcare	15	T-8 4ft 4 lamp	T-12 4ft 4 lamp
LF-7	[redacted]	Industrial	10	LW T-8 4ft 1 lamp	T-8 4ft 1 lamp
			356	LW T-8 4ft 2 lamp	T-8 4ft 2 lamp
			409	LW T-8 4ft 4 lamp	T-8 4ft 4 lamp
LF-8	[redacted]	Office	34	T-8 4ft 4 lamp	T-12 8ft 2 lamp

Site	Customer Name	Building Type	Total fixtures rebated	Installed Fixture(s)	Baseline Fixture(s)
LF-9	[redacted]	Warehouse	6	T-8 4ft 2 lamp	T-12 4ft 2 lamp
			9	Not present	T-12 4ft 4 lamp
LF-10	[redacted]	Small Box Retail	922	LW T-8 4ft (per lamp)	T-8 4ft 2 lamp (per lamp)

The characteristics of the ten sites that participated in the occupancy sensor study are shown in Table 11.

Table 11. Occupancy Sensor M&V Study Participants

Site	Customer Name	Business Type	Number of Occupancy Sensors Rebated	Occupancy Sensor Type
OS-1	[redacted]	Education	29	Occupancy Sensors over 500 W
			54	Occupancy Sensors under 500 W
OS-2	[redacted]	Public Order/Safety	7	Occupancy Sensors under 500 W
OS-3	[redacted]	Warehouse	88	Occupancy Sensors under 500 W
OS-4	[redacted]	Industrial	19	Occupancy Sensors under 500 W
OS-5	[redacted]	Small Box Retail	8	Occupancy Sensors under 500 W
OS-6	[redacted]	Office	2	Occupancy Sensors under 500 W
OS-7	[redacted]	Education	3	Occupancy Sensors under 500 W
			9	Occupancy Sensors under 500 W
OS-8	[redacted]	Education	41	Occupancy Sensors over 500 W
			30	Occupancy Sensors under 500 W
OS-9	[redacted]	Education	33	Occupancy Sensors under 500 W
			40	Occupancy Sensors over 500 W
OS-10	[redacted]	Office	45	Occupancy Sensors under 500 W

The characteristics of the 18 sites that participated in the VFD study are shown in Table 12 below. These sites represent 53 VFDs in the tracking database. 44 of these 53 VFDs were monitored.

Table 12. VFD M&V Study Participants

Site	Customer Name	Building Type	VFDs Monitored				
			VFDs Rebated	VFD HVAC Fan	VFD HVAC Pump	VFD Process Pump 1-50 HP
VFD-1	[redacted]	Healthcare	3	3	0	0
VFD-2	[redacted]	Education K-12	2	2	0	0
VFD-3	[redacted]	Education K-12	2	2	0	0
VFD-4	[redacted]	Healthcare	1	1	0	0
VFD-5	[redacted]	Healthcare	3	0	3	0
VFD-6	[redacted]	Church	5	3	0	0
VFD-7	[redacted]	Office	1	1	0	0
VFD-8	[redacted]	Office	2	2	0	0
VFD-9	[redacted]	Other	6	2	0	4
VFD-10	[redacted]	Office	2	2	0	0
VFD-11	[redacted]	Healthcare	1	1	0	0
VFD-12	[redacted]	Office	2	0	2	0
VFD-13	[redacted]	Grocery	1	0	1	0
VFD-14	[redacted]	Grocery	1	0	1	0
VFD-15	[redacted]	Education	10	3	2	0
VFD-16	[redacted]	Education	2	2	0	0
VFD-17	[redacted]	Office	6	2	0	2
VFD-18	[redacted]	Office	3	3	0	0
	Total		53	29	9	6

Gross Savings Analysis – Linear Fluorescents and Occupancy Sensors

Paper file applications and supporting documentation were obtained for each site. The data in the application files were reviewed and compared to the program tracking database and onsite survey observations. Discrepancies were noted and corrected for the impact evaluation. These discrepancies are reported in Table 13.

Table 13. Tracking System and Paper File Discrepancies

Measure	Site	Discrepancy
Linear Fluorescent	1	3-foot fixtures were installed in lieu of 2-foot fixtures.
	4	4-lamp fixtures were replaced by 2-lamp fixtures
	5	63 fixtures were installed instead of 83 in app
	5	No 4-ft 4-lamp HPT8s were found in monitored building
	14	Rebate provided to replace standard 32W T8 lamps with 28W lamps. Program calcs used lamp watts; A fixture watts value that includes the observed ballast factor was used, normalized per lamp replaced.

Fixture watts reported in the manufacturer's catalogs (where available) were averaged and compared to the standard assumptions used in program design for several popular fixture types. This comparison is shown in Figure 4.

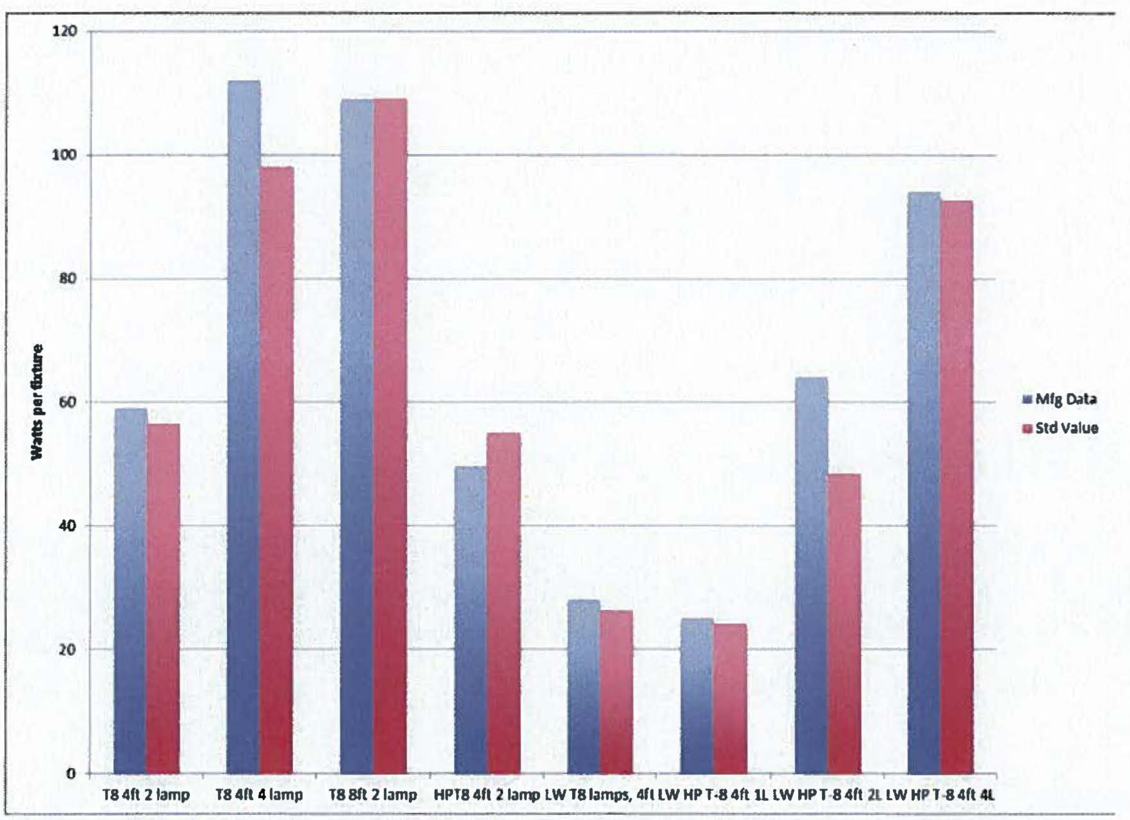

Figure 4. Comparison of Installed Fixture Watts from Manufacturers vs. Standard Assumptions

These data are also shown in Table 14.

Table 14. Comparison of Manufacturer's Fixture Watts with Standard Program Assumptions for Linear Fluorescent Fixtures

Fixture	n	Program Assumption	Mfg Cutsheets
T8 4ft 2 lamp	2	59	56.5
T8 4ft 4 lamp	3	112	98
T8 8ft 2 lamp	1	109	109
HPT8 4ft 2 lamp	3	49.7	55
LW T8 lamps, 4ft	2	28	26.3
LW HP T-8 4ft 1L	2	25	24.2
LW HP T-8 4ft 2L	3	64	48.3
LW HP T-8 4ft 4L	1	94	92.6

In many cases, the program standard assumption exceeds the manufacturers' cut sheet values, indicating conservative values were used in developing the program estimates of fixture savings. Where the M&V values exceed the program assumption, the M&V values are based on in-situ measurements, where ballast factors may be different than program assumptions.

The fixture quantities installed at the sampled sites along with the number of light loggers deployed are shown in Table 15 and Table 16. Light loggers were deployed to monitor the on/off behavior of the lighting systems based on the circuiting and switching of the lighting systems. At some sites, recording current loggers were installed to measure time series current on selected lighting circuits.

Table 15. Logger Installations at Linear Fluorescent M&V Study Sites

Site	Customer Name	Business Type	Total fixtures rebated	Loggers installed
LF-1	[redacted]	Office	144	11
LF-2	[redacted]	Warehouse	410	12 Current
LF-3	[redacted]	Public Assembly	538	6 Current
LF-4	[redacted]	Office	532	10
LF-5	[redacted]	Public Order Safety / Institutional	127	5 Current
LF-6	[redacted]	Healthcare	15	5
LF-7	[redacted]	Industrial	775	16
LF-8	[redacted]	Office	34	4 Current
LF-9	[redacted]	Warehouse	15	1 Current
LF-10	[redacted]	Small Box Retail	922	2 Current

Table 16. Logger Installations at Occupancy Sensor M&V Study Sites

Site	Customer Name	Business Type	Total Occupancy Sensors rebated	Loggers installed
OS-1	[redacted]	Education	83	7
OS-2	[redacted]	Public Order/Safety	7	6
OS-3	[redacted]	Warehouse	88	15
OS-4	[redacted]	Industrial	19	2
OS-5	[redacted]	Small Box Retail	8	7
OS-6	[redacted]	Office	2	2
OS-7	[redacted]	Education	12	8
OS-8	[redacted]	Education	71	18
OS-9	[redacted]	Education	73	19
OS-10	[redacted]	Office	45	8

The light logger data were downloaded by the TecMarket Works contractors. These data were processed by engineers from Architectural Energy Corporation. The results are summarized in Table 17 and Table 18. Average weekday and weekend load shapes for each site from the logger study are also shown in Appendix A: Load Shapes.

Table 17. Lighting Logger Study Results

Site	Customer Name	Business Type	Application self-reported annual operating hours	Logger study annual operating hours	Ratio logged / self report	Coincident demand factor[6]
LF-1	[redacted]	Office	4,199	7,103	1.69	1.00
LF-2	[redacted]	Warehouse	2,600	2,997	1.15	0.75
LF-3	[redacted]	Public Assembly	3,016	1,255	0.42	0.40
LF-4	[redacted]	Office	3,131	8,109	2.59	0.98
LF-5	[redacted]	Public Order Safety / Institutional	4,000	2,157	0.54	0.77
LF-6	[redacted]	Healthcare	2,480	4,072	1.64	0.89
LF-7	[redacted]	Industrial	8,760	2,852	0.33	0.57
LF-8	[redacted]	Office	2,080	2,081	1.00	0.48

[6] Coincidence factor is defined as the fraction of the total connected load operating at the coincident peak hour, which is defined as the hour between 4pm and 5pm on the hottest summer workday.

LF-9	[redacted]	Warehouse	5,000	2,055	0.41	0.04
LF-10	[redacted]	Small Box Retail	8,736	8,183	0.94	0.97
	Wt. Average[7]		4,944	5,155	1.04	0.80

Table 18. Occupancy Sensor Logger Study Results

Site	Customer Name	Business Type	Connected kW	EFLH		DF[8]	
				Pre	Post	Pre	Post
OS-1	[redacted]	Education	19.01	3,063	1,767	0.88	0.37
OS-2	[redacted]	Public Order/Safety	1.04	5,384	3,720	0.73	0.56
OS-3	[redacted]	Warehouse	19.89	2,167	196	0.50	0.03
OS-4	[redacted]	Industrial	6.67	2,899	522	0.50	0.01
OS-5	[redacted]	Small Box Retail	2.95	2,176	989	0.51	0.25
OS-6	[redacted]	Office	0.67	3,862	2,131	1.00	0.65
OS-7	[redacted]	Education	3.66	3,399	2,008	1.00	0.67
OS-8	[redacted]	Education	33.75	2,611	1,445	0.90	0.42
OS-9	[redacted]	Education	36.38	3,147	2,138	0.87	0.44
OS-10	[redacted]	Office	6.62	6,571	4,345	1.00	0.73
	Wt. Average			3,078	1,547	0.81	0.36

On average, the light logger study predicted about 4% more operating hours for linear fluorescent measures than the customer self-reported values, and 24% more operating hours than the 4,144 EFLH assumption used in the program design estimates. The light logger study for occupancy sensors predicted about 25% fewer uncontrolled operating hours than the 4,144 EFLH assumption used in the program design estimates.

For linear fluorescent measures, the light logger results were combined with the verified fixture counts and verified installed fixture watts to estimate the actual energy and peak demand savings, using the equations shown below.

$kWh_{savings} = (Watts_{base} - Watts_{ee}) / 1000 \times EFLH_{post} \times (1+WHF_e)$

[7] Individual site operating hours were weighted by kWh savings per site to obtain kWh savings weighted average operating hours. Individual site coincidence factors were weighted by kW savings per site to obtain a kW savings weighted coincidence factor.

[8] The diversity factor is defined as the fraction of the total connected load operating at any particular hour. The diversity factor at the coincident peak hour is defined as the fraction of the total connected load operating during the hour between 4pm and 5pm on the hottest summer workday.

$kW_{savings} = (Watts_{base} - Watts_{ee}) / 1000 \times CF \times (1+WHF_d)$

where:

$Watts_{base}$ = baseline fixture watts
$Watts_{ee}$ = efficient fixture watts
$EFLH_{post}$ = equivalent full-load lighting operating hours after retrofit
CF = coincidence factor
= fraction of total connected load operating at the utility coincident peak hour
= defined as hour ending at 4pm
WHF_e = waste heat factor for energy
WHF_d = waste heat factor for demand

For occupancy sensor measures, the light logger results were combined with the verified fixture counts and verified installed fixture watts to estimate the actual energy and peak demand savings, using the equations shown below.

$kWh_{savings} = Watts_{controlled} \times (EFLH_{pre} - EFLH_{post}) / 1000 \times (1+WHF_e)$

$kW_{savings} = Watts_{controlled} / 1000 \times (DF_{pre} - DF_{post}) \times (1+WHF_d)$

where:

$Watts_{controlled}$ = controlled fixture watts
$EFLH_{pre}$ = equivalent full-load lighting operating hours without occupancy sensor
$EFLH_{post}$ = equivalent full-load lighting operating hours with occupancy sensor
DF_{pre} = diversity factor without occupancy sensor
= fraction of total connected load operating without occupancy sensor controls
DF_{post} = diversity factor with occupancy sensor
= fraction of total connected load operating once occupancy sensor controls have been installed

Waste heat factors were calculated using building energy simulation models derived from the commercial building prototypes used in the California Database for Energy Efficiency Resources (DEER) study[9], with adjustments made for local building practices and climate. The commercial prototypes were using long-term average weather data for Cincinnati. The results of the interactive effects simulations are shown in Appendix B: Results of HVAC Interactive Effects Simulations.

[9] Itron, 2005. "2004-2005 Database for Energy Efficiency Resources (DEER) Update Study, Final Report," Itron, Inc., J.J. Hirsch and Associates, Synergy Consulting, and Quantum Consulting. December, 2005. Available at http://eega.cpuc.ca.gov/deer.

Based on the observed building and HVAC system type, the interactive effects multipliers used for each of the sites in the study are shown below:

Site	Customer Name	Business Type	HVAC System Type	WHF_e	WHF_d
LF-1	[redacted]	Office	Office/DX no econ gas heat + Garage	0.061	0.111
LF-2	[redacted]	Warehouse	Lt Industrial/DX no econ gas heat	0.080	0.210
LF-3	[redacted]	Public Assembly	Assembly/DX no econ gas heat	0.154	0.246
LF-4	[redacted]	Office	Small Office/DX with econ gas heat	0.080	0.184
LF-5	[redacted]	Public Order Safety / Institutional	Office/DX no econ gas heat	0.104	0.136
LF-6	[redacted]	Healthcare	Office/Heat pump no econ	0.077	0.136
LF-7	[redacted]	Industrial	Office2/3 /DX with econ gas heat+ Manufacturing-heat only	0.053	0.122
LF-8	[redacted]	Office	Warehouse/DX no econ gas heat	0.085	0.317
LF-9	[redacted]	Warehouse	Warehouse/DX with econ gas heat	0.080	0.210
LF-10	[redacted]	Small Box Retail	Retail/DX with econ gas heat	0.076	0.268
OS-10	[redacted]	Education	School/AC econ gas heat	0.032	0.263
OS-2	[redacted]	Public Order/Safety	Office/AC no econ gas heat	0.080	0.184
OS-3	[redacted]	Warehouse	Warehouse/No AC Gas Heat	0.000	0.000
OS-4	[redacted]	Industrial	Warehouse/No AC Gas Heat	0.000	0.000
OS-5	[redacted]	Small Box Retail	Office/AC econ gas heat	0.103	0.136
OS-6	[redacted]	Office	Office/heat pump no econ	0.023	0.190
OS-7	[redacted]	Education	School/AC no econ gas heat	0.072	0.263
OS-8	[redacted]	Education	School/AC no econ gas heat	0.072	0.263
OS-9	[redacted]	Education	School/AC no econ electric heat	-0.808	0.266
OS-10	[redacted]	Office	Warehouse/no cool/Gas heat	0.000	0.000
	Wt. Average			0.003	0.164

Gross Impact Results – Linear Fluorescents and Occupancy Sensors

These results of the energy and demand savings calculations are shown in Table 19 and Table 20. These results were compared to the tracked savings based on the fixture counts and standard per fixture kW and kWh savings estimates from program design work papers. The ratio of the evaluated savings to the program planning estimated savings is expressed as a realization rate (RR) for kWh, non-coincident peak (NCP) kW, and coincident peak (CP) kW.