Impact Evaluation of 2010 Prescriptive Lighting Installations

FINAL REPORT

Massachusetts Energy Efficiency Program Administrators
Massachusetts Energy Efficiency Advisory Council
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1. Executive Summary

This document summarizes the work performed by DNV KEMA Energy and Sustainability (DNV KEMA) between 2011 and 2013 to quantify the actual energy and demand savings due to the installation of 56 Prescriptive Lighting projects installed through the Massachusetts Energy Efficiency Program Administrator's (PAs) C&I New Construction & Major Renovation and C&I Large Retrofit programs in 2010. Note that this document presents the final results following 12 months of metering for the four Prescriptive Lighting categories of interest, Systems, Controls, Advanced Lighting Design and Refrigerated LED Case Lighting.

1.1 Purpose of Study

The objective of this impact evaluation is to provide verification or re-estimation of electric energy and demand savings estimates and new savings factors for 56 Prescriptive Lighting retrofit and new construction projects through site-specific inspection, monitoring, and analysis. The final study results, produced following 12 months of monitoring, will be used to determine the final realization rates for Prescriptive Lighting energy efficiency projects installed in 2012. This report presents realization rates for gross energy savings and savings factors at the statewide level using 12 months of metered data collected from each site. It also provides realization rates for on-peak and seasonal summer and winter demand savings. A listing of all results and savings factors with descriptions is presented in Appendix A. These savings factors should be applied to future Technical Reference Manual (TRM) updates. The evaluation sample for this study was designed in consideration of the 90% confidence level for energy (kWh) and the 80% confidence level for coincident peak summer demand (kW).

This report also provides a comparison of the 12 month metering results to the interim results that were based on approximately three months of metering in the winter of 2011/2012.[1] The purpose of this comparison is to help PAs determine the value of long versus shorter term data collection, and to inform the most representative time of year to perform short term metering in any future impact evaluations of their Prescriptive Lighting programs.

1.2 Scope

The scope of work of this impact evaluation covered the 2010 Prescriptive Lighting end-use, which includes all lighting systems and controls, Advanced Lighting Design (ALD) or performance lighting, and refrigerated LED case lights. This impact evaluation includes only measures which primarily reduce electricity consumption. The presentation of 2010 findings in 2013 is due to the extended metering

[1] Impact Evaluation of 2010 Prescriptive Lighting Installations, Interim Results Memo, August 17, 2012, Prepared by DNV KEMA

period. Projects were contacted and meter installation began in late 2011; in order to complete a full year of metering, the meters were removed in late 2012 and early 2013, informing this report.

1.3 Sample

The Prescriptive Lighting sample was designed to allow DNV KEMA to estimate realization rates for a number of savings parameters (annual kWh, connected kW, summer and winter on-peak and seasonal coincidence factors, and HVAC interactive effects factor) with statistical precisions that meet PA requirements in two areas. The target for annual kWh was set at the traditional ±10% at 90% confidence, while the target for summer kW was set at ±10% precision at 80% confidence.

The PAs were interested in results for each of the four following groups:

- Lighting Systems
- Lighting Controls
- Advanced Lighting Design (Performance Lighting)
- Refrigerated Case Lighting (LED)

After running several scenarios based on different sample sizes and allocations, the team decided on a Prescriptive sample comprised of 57 sites split between measure types as indicated in Table 1. This table also includes estimates of the precisions that were anticipated at the time of this design, assuming an error ratio of 0.4.

Table 1: Prescriptive Lighting Sample Design

Measure Type	Accounts	Total Savings	Assumed Error Ratio	Confidence Level	Planned Sample Size	Anticipated Relative Precision
Systems & Controls	1,095	92,442,396	0.4	90%	37	±11.03%
Advanced Lighting Design	72	5,670,723	0.4	90%	10	±14.44%
Refrigerated Case Lighting	61	2,664,459	0.4	90%	10	±19.28%
Total	1,228	100,777,578	0.4	90%	57	±10.16%

This allocation by PA was further stratified by total savings, and sample sites were selected. After the sample selection, several adjustments were required based on observations made during initial file reviews and early site visits. In some cases, alternate sites were used, but in other cases there were no additional sites to select. In the end, a total of 56 sites were included in the Prescriptive Lighting sample.

1.4 Description of Methodology

Data collection included physical inspection and inventory, interview with facility personnel, observation of site operating conditions and equipment, and long-term metering of usage. At each site, the DNV KEMA team performed a facility walk-through that focused on verifying the post-retrofit or installed conditions of each Prescriptive Lighting measure. For pre-retrofit, or baseline hours and equipment, evaluators used a combination of facility interview and tracking estimates. Instrumentation such as power/current recorders, Time-Of-Use (TOU) lighting loggers, and TOU current loggers were installed to monitor the usage of the installed lighting equipment.

An 8,760 hourly spreadsheet analysis was used to estimate hourly energy use and diversified coincident peak demand for all Prescriptive Lighting sites. A typical meteorological year (TMY3) dataset of ambient temperatures for Worcester, MA was used for all savings analyses.

A full description of the methodology is provided in Section 3.2, Measurement, Verification and Analysis Methodology.

1.5 12 Month Monitoring Results

The results presented in the following section include statewide level realization rates (and associated precision levels) for annual kWh savings, percent on-peak kWh savings, and on-peak and seasonal demand (kW) coincidence factors at the times of the winter and summer peaks, as defined by the ISO New England Forward Capacity Market (FCM). All coincident summer and winter peak reductions were calculated using the following FCM definitions:

- Coincident Summer On-Peak kW Reduction is the average demand reduction that occurs over all hours between 1 PM and 5 PM on non-holiday weekdays in June, July and August.
- Coincident Winter On-Peak kW Reduction is the average demand reduction that occurs over all hours between 5 PM and 7 PM on non-holiday weekdays in December and January.
- Seasonal Peak: Non-holiday week days when the Real-Time System Hourly Load is equal to or greater than 90% of the most recent “50/50” System Peak Load Forecast for the summer and winter seasons.

Also included in the results are savings factors for summer and winter on-peak and seasonal coincidence factors, summer and winter kW HVAC interactive effect factors, kWh HVAC interactive effect factor and percent of energy savings during on-peak periods. Relative precision levels and error bounds are calculated at the 80% confidence level for demand savings factors and values. For all MWh realization rates, the standard 90% confidence level is used.

A detailed discussion of these results is presented in Section 4, Results. A summary of site level results are also presented in Appendix C.

1.5.1 Lighting Systems

Table 2 summarizes the statewide results of this analysis. In the case of annual kWh savings, the realization rate for Lighting Systems was found to be 112.3% with HVAC interactive effects included. Note that gross tracking savings do not generally include HVAC interactive effects. The error ratio was found to be 0.3.

Table 2 also shows the results for the connected kW realization rate. The overall realization rate was 99.7%, with a relative precision of ±2.6% at a 90% confidence level.

Table 2: Summary of Lighting Systems Realization Rates

Lighting Systems	Energy		Connected kW	
	kWh	% Gross	kW	% Gross
Gross Savings (Tracking)	79,439,316		17,236	
Documentation Adjustment	-376,857	0%	-130	-1%
Technology Adjustment	466,552	1%	9	0%
Quantity Adjustment	-2,755	0%	75	0%
Operational Adjustment	5,168,634	7%	N/A	N/A
HVAC Interactive Adjustment	4,531,719	6%	N/A	N/A
Adjusted Gross Savings	89,226,609	112%	17,190	100%
Gross Realization Rate	112.3%		99.7%	
Relative Precision	±7.9%		±2.6%	
Confidence Interval	90%		90%	
Error Ratio	29%		10%	

Table 3 summarizes the statewide savings factors resulting from this analysis. All relative precisions were calculated at the 90% confidence level. The on-peak summer coincidence factor was 72.2%, with a relative precision of ±11.1%. The seasonal summer coincidence factor was 73.6%, with a relative precision of ±10.9%. The on-peak winter coincidence factor was 65.9%, with a relative precision of ±12.2%. The seasonal winter coincidence factor was 66.9%, with a relative precision of ±12.6%. The table also provides savings factors for on-peak and seasonal summer and winter kW HVAC interactive effects, kWh HVAC interactive effect, hours of use realization rate and percent on-peak kWh.

Table 3: Summary of Lighting Systems Savings Factors

Savings Factors and Realization Rates at 90% Confidence	Systems	
	Value	Precision
Connected kW Realization Rate	99.7%	±2.6%
Summer Coincidence Factor		
On Peak Hours	72.2%	±11.1%
Seasonal Hours	73.6%	±10.9%
Winter Coincidence Factor		
On Peak Hours	65.9%	±12.2%
Seasonal Hours	66.9%	±12.6%
Summer kW HVAC Interactive Effect		
On Peak Hours	114.6%	±2.7%
Seasonal Hours	114.8%	±2.8%
Winter kW HVAC Interactive Effect		
On Peak Hours	99.8%	±0.4%
Seasonal Hours	99.8%	±0.3%
KWh Factors		
Connected kWh Realization Rate	100.1%	±3.1%
KWh HVAC Interactive Effect	105.4%	±1.3%
Hours of Use Realization Rate	106.5%	±7.4%
% On Peak KWh	63.88%	±5.6%
Non-Electric		
Heating HVAC Interaction Effect (MMBtu/kWh)	-0.000691	

1.5.2 Lighting Controls

Table 4 summarizes the statewide results of this analysis, which was based on 26 sample sites. In the case of annual kWh savings, the realization rate for Lighting Controls was found to be 72.0% with HVAC interactive effects included. The relative precision for this estimate was found to be ±23.2% at the 90% level of confidence. The error ratio was found to be 0.66.

Table 4 also shows the results for the connected kW realization rate. The overall realization rate was 93.8%, with a relative precision of ±6.0% at a 90% confidence level.

Table 4: Summary of Lighting Controls Realization Rates

Lighting Controls	Energy		Connected kW	
	kWh	% Gross	kW	% Gross
Gross Savings (Tracking)	12,805,436		10,313	
Documentation Adjustment	-131,240	-1%	-140	-2%
Technology Adjustment	-55,494	0%	-9	0%
Quantity Adjustment	-1,137,164	-9%	-489	-8%
Operational Adjustment	-2,537,753	-20%	N/A	N/A
HVAC Interactive Adjustment	281,840	2%	N/A	N/A
Adjusted Gross Savings	9,225,625	72%	9,675	94%
Gross Realization Rate	72.0%		93.8%	
Relative Precision	±23.2%		±6.0%	
Confidence Interval	90%		90%	
Error Ratio	66%		15%	

Table 5 summarizes the statewide savings factors resulting from this analysis. All relative precisions were calculated at the 90% confidence level. The on-peak summer coincidence factor was 13.8%, with a relative precision of ±23.6%. The seasonal summer coincidence factor was 13.0%, with a relative precision of ±20.9%. The on-peak winter coincidence factor was 13.4%, with a relative precision of ±46.3%. The seasonal winter coincidence factor was 14.0%, with a relative precision of ±43.3%. The table also provides savings factors for on-peak and seasonal summer and winter kW HVAC interactive effects, kWh HVAC interactive effect, hours of use reduced realization rate and percent on-peak kWh.

Table 5: Summary of Lighting Controls Savings Factors

Savings Factors and Realization Rates at 90% Confidence	Controls	
	Value	Precision
Connected kW Realization Rate	93.8%	±6.0%
Summer Coincidence Factor		
On Peak Hours	13.8%	±23.6%
Seasonal Hours	13.0%	±20.9%
Winter Coincidence Factor		
On Peak Hours	13.4%	±46.3%
Seasonal Hours	14.0%	±43.3%
Summer kW HVAC Interactive Effect		
On Peak Hours	109.3%	±3.8%
Seasonal Hours	110.2%	±3.7%
Winter kW HVAC Interactive Effect		
On Peak Hours	99.6%	±0.6%
Seasonal Hours	99.6%	±0.6%
KWh Factors		
Connected kWh Realization Rate	89.7%	±8.7%
KWh HVAC Interactive Effect	103.2%	±1.5%
Hours of Use Realization Rate	77.9%	±24.5%
% On Peak KWh	58.86%	±22.6%
Non-Electric		
Heating HVAC Interaction Effect (MMBtu/kWh)	-0.002728	

1.5.3 Advanced Lighting Design

Table 6 summarizes the statewide results of this analysis. In the case of annual kWh savings, the realization rate for ALD was found to be 124.6% with HVAC interactive effects included. The relative precision for this estimate was found to be ±7.6% at the 90% level of confidence. The error ratio was found to be 0.18.

Table 6 also shows the results for the connected kW realization rate. The overall realization rate was 101.2%, with a relative precision of ±1.7% at an 90% confidence level.

Table 6: Summary of ALD Realization Rates

	Energy		Connected kW	
Advanced Lighting Design	**kWh**	**% Gross**	**kW**	**% Gross**
Gross Savings (Tracking)	5,670,723		1,178	
Documentation Adjustment	619	0%	-6	-1%
Technology Adjustment	542,983	10%	64	5%
Quantity Adjustment	-228,228	-4%	-44	-4%
Operational Adjustment	639,442	11%	N/A	N/A
HVAC Interactive Adjustment	438,395	8%	N/A	N/A
Adjusted Gross Savings	7,063,933	125%	1,192	101%
Gross Realization Rate	124.6%		101.2%	
Relative Precision	±7.6%		±1.7%	
Confidence Interval	90%		90%	
Error Ratio	18%		3%	

Table 7 summarizes the statewide savings factors resulting from this analysis. All relative precisions were calculated at the 90% confidence level. The on-peak summer coincidence factor was 42.8%, with a relative precision of ±31.1%. The seasonal summer coincidence factor was 39.1%, with a relative precision of ±38.5%. There were two schools in this sample, and both had very low summer coincidence factors. This is likely the driver for the lower summer coincidence factors as compared to lighting systems. The on-peak winter coincidence factor was 46.7%, with a relative precision of ±15.2%. The seasonal winter coincidence factor was 46.6%, with a relative precision of ±17.5%. The table also provides savings factors for on-peak and seasonal summer and winter kW HVAC interactive effects, kWh HVAC interactive effect, hours of use realization rate and percent on-peak kWh.

Table 7: Summary of ALD Savings Factors

Savings Factors and Realization Rates at 90% Confidence	Advanced Lighting Design	
	Value	Precision
Connected kW Realization Rate	101.2%	±1.7%
Summer Coincidence Factor		
On Peak Hours	42.8%	±31.1%
Seasonal Hours	39.1%	±38.5%
Winter Coincidence Factor		
On Peak Hours	46.7%	±15.2%
Seasonal Hours	46.6%	±17.5%
Summer kW HVAC Interactive Effect		
On Peak Hours	122.6%	±2.9%
Seasonal Hours	123.2%	±3.0%
Winter kW HVAC Interactive Effect		
On Peak Hours	94.1%	±8.3%
Seasonal Hours	93.9%	±8.5%
KWh Factors		
Connected kWh Realization Rate	105.6%	±4.6%
KWh HVAC Interactive Effect	106.6%	±2.4%
Hours of Use Realization Rate	110.7%	±7.2%
% On Peak KWh	65.67%	±7.8%
Non-Electric		
Heating HVAC Interaction Effect (MMBtu/kWh)	-0.000175	

1.5.4 Refrigerated LED Case Lighting

An initial review of the Refrigerated LED sample found that some PAs were treating these measures differently between 2010 and 2011. The sample of Refrigerated LED projects were pulled from 2010, when some PAs were not applying refrigeration interactive savings to their tracking estimates, while other PAs were using different assumptions for refrigeration system efficiency.

It was found that NSTAR was not yet applying refrigeration interactive savings to their savings estimates in 2010. Evaluators also found that National Grid was using a refrigeration system efficiency of 1.6 kW/ton for most of their 2010 projects. The MA TRM[2] assumes a refrigeration system efficiency of 1.3 kW/ton. By applying the TRM assumptions to the NSTAR sample from 2010, this would have increased their savings estimates. Applying the TRM refrigeration system efficiency assumption to the National Grid sample from 2010 would have decreased their savings estimates.

In 2011, the PAs began applying refrigeration interactive savings to their tracking estimates using the MA TRM assumptions. For this reason, the use of realization rates and savings factors resulting from the

[2] Massachusetts Technical Reference Manual, 2011 Program Year – Plan Version, October 2010

2010 population is not applicable to 2011 programs and beyond. Therefore, DNV KEMA recommended, and the PAs and EEAC agreed to calculate realization rates relative to the TRM estimates, rather than the 2010 tracking savings. By applying the TRM savings algorithms to the 2010 sample projects, which includes refrigeration interactive savings, a valid comparison can be made so that results may be applied retrospectively as well as prospectively.

Table 8 summarizes the statewide results of this analysis relative to the TRM savings algorithm. In the case of annual kWh savings, the realization rate for Refrigerated LEDs was found to be 97.5% with HVAC interactive adjustments included. The relative precision for this estimate was found to be ±8.8% at the 90% level of confidence. The error ratio was found to be 0.19.

Table 8 also shows the results for the connected kW realization rate. The overall realization rate was 100.7%, with a relative precision of ±0.9% at a 90% confidence level.

Table 8: Summary of Refrigerated LED Realization Rates

	Energy		Connected kW	
Refrigerated LED	kWh	% Gross	kW	% Gross
Gross Savings (Tracking)	2,702,650		476	
Documentation Adjustment	0	0%	0	0%
Technology Adjustment	0	0%	0	0%
Quantity Adjustment	16,942	1%	3	1%
Operational Adjustment	-170,249	-6%	N/A	N/A
HVAC Interactive Adjustment	85,357	3%	N/A	N/A
Adjusted Gross Savings	2,634,701	97%	479	101%
Gross Realization Rate	97.5%		100.7%	
Relative Precision	±8.8%		±0.9%	
Confidence Interval	90%		90%	
Error Ratio	19%		2%	

Table 9 summarizes the statewide savings factors resulting from this analysis. All relative precisions were calculated at the 90% confidence level. The on-peak summer coincidence factor was 99.4%, with a relative precision of ±0.5%. The seasonal summer coincidence factor was 99.7%, with a relative precision of ±0.5%. The on-peak winter coincidence factor was 99.5%, with a relative precision of ±0.5%. The seasonal winter coincidence factor was 99.9%, with a relative precision of ±0.2%. The coincidence factors are all close to 100%, which is appropriate for this measure type, which tends to be installed in grocery stores. The business hours of these facilities typically coincide with the summer and winter peak periods. The table also provides savings factors for on-peak and seasonal summer and winter kW refrigeration interactive effects, kWh refrigeration interactive effect, hours of use realization rate and percent on-peak kWh.

Note that the kW and kWh refrigeration interactive effect factors included in this table are in addition to the refrigeration savings estimated in the TRM. As stated above, the TRM referenced in this study, used 1.3 kW/ton as the refrigeration system efficiency, while the evaluation found that 1.9 kW/ton is more

applicable to this application. This is why the refrigeration interactive effects are greater than one. This factor should only be applied to tracking savings that were developed using the 1.3 kW/ton refrigeration efficiency. If PAs begin applying the 1.9 kW/ton efficiency to future TRMs, the refrigeration factor should be one, or not used at all.

Table 9: Summary of Refrigerated LED Savings Factors

Savings Factors and Realization Rates at 90% Confidence	Refrigerated LED	
	Value	Precision
Connected kW Realization Rate	100.7%	±0.9%
Summer Coincidence Factor		
On Peak Hours	99.4%	±0.5%
Seasonal Hours	99.7%	±0.5%
Winter Coincidence Factor		
On Peak Hours	99.5%	±0.5%
Seasonal Hours	99.9%	±0.2%
Summer kW Refrigeration Interactive Effect		
On Peak Hours	105.8%	±1.1%
Seasonal Hours	105.9%	±1.0%
Winter kW Refrigeration Interactive Effect		
On Peak Hours	105.8%	±1.1%
Seasonal Hours	106.0%	±1.0%
KWh Factors		
Connected kWh Realization Rate	100.6%	±0.8%
KWh Refrigeration Interactive Effect	103.3%	±2.6%
Hours of Use Realization Rate	93.7%	±6.1%
% On Peak KWh	63.53%	±3.9%
Non-Electric		
Heating HVAC Interaction Effect (MMBtu/kWh)	0.000000	

1.6 Comparison of 12 Month and 3 Month Monitoring Results

Table 10 through Table 13 presents some of the results of both the three month interim analysis, and the 12 month analysis. These comparison tables are provided to highlight the differences between the two monitoring periods.

As shown in Table 10 below, the annual energy savings and summer demand savings dropped between the three and 12 month analyses. The annual energy savings were about 5% less in the 12 month analysis. A review of the individual site results showed that schools, libraries and offices had lower annual hours of operation as compared to the three month analysis. Annual hours of use for these three building types went down approximately 8% as compared to the three month analysis. These building types represented 11 of the 34 sites in the Lighting Systems sample. The annual operating hours for the remaining building types, including manufacturing, retail, exercise facilities, and other, were nearly 100% of the predicted three month analysis.

Likewise, there was a drop in the summer coincidence factors, and as a result, in the summer kW realization rates. These drops were mostly driven by schools (54% three month summer CF, 39% 12 month summer CF) and offices (89% three month summer CF, 81% 12 month summer CF). This is significant because the interim three month monitoring period covered the winter season, and the summer period was extrapolated from logger data and adjusted based on discussions with facility personnel. For schools in particular, it is difficult to predict summer usage based on this method. This is explained by the reduced and inconsistent summer usage typical of schools. For offices, it is possible that occupants use their lights less often during the day if they have windows that provide sufficient sunlight. Additionally, vacations are also more frequent during the summer period, which could play a role in these reductions.

Table 10: Comparison of 3 vs. 12 Month Results – Lighting Systems

Lighting Systems	3 Month Analysis			12 Month Analysis		
Savings Realization Rate/Factor	Confidence Interval	Realization Rate/Factor	Relative Precision	Confidence Interval	Realization Rate/Factor	Relative Precision
Annual kWh Realization Rate	90%	118.1%	±8.54%	90%	112.3%	±7.89%
Connected kW Realization Rate	80%	99.7%	±2.05%	90%	99.7%	±2.64%
Summer On-Peak Coincidence Factor	80%	77.3%	±7.36%	90%	72.2%	±11.11%
Winter On-Peak Coincidence Factor	80%	65.8%	±10.13%	90%	65.9%	±12.15%
Summer On-Peak kW HVAC Interactive Effect Factor	80%	114.7%	±2.10%	90%	114.6%	±2.74%
Winter On-Peak kW HVAC Interactive Effect Factor	80%	99.8%	±0.18%	90%	99.8%	±0.37%
kWh Interactive Effect Factor	80%	105.8%	±1.03%	90%	105.4%	±1.27%
% On-Peak kWh	80%	63.1%	±4.42%	90%	63.9%	±5.62%

Table 11 presents the same comparison for Lighting Controls. Similar to Lighting Systems, controls savings also went down between the three month and 12 month analyses. However, there was no particular pattern to the reductions. In fact, 21 of the 26 Lighting Controls sites showed lower hours reduced as compared to the three month analysis.

Table 11: Comparison of 3 vs. 12 Month Results – Lighting Controls

Lighting Controls	3 Month Analysis			12 Month Analysis		
Savings Realization Rate/Factor	Confidence Interval	Realization Rate/Factor	Relative Precision	Confidence Interval	Realization Rate/Factor	Relative Precision
Annual kWh Realization Rate	90%	84.0%	±20.72%	90%	72.0%	±23.23%
Connected kW Realization Rate	80%	93.8%	±4.67%	90%	93.8%	±5.99%
Summer On-Peak Coincidence Factor	80%	19.6%	±15.94%	90%	13.8%	±23.62%
Winter On-Peak Coincidence Factor	80%	15.4%	±44.25%	90%	13.4%	±46.34%
Summer On-Peak kW HVAC Interactive Effect Factor	80%	111.5%	±2.20%	90%	109.3%	±3.79%
Winter On-Peak kW HVAC Interactive Effect Factor	80%	99.9%	±0.10%	90%	99.6%	±0.59%
kWh Interactive Effect Factor	80%	103.1%	±1.08%	90%	103.2%	±1.52%
% On-Peak kWh	80%	60.1%	±15.51%	90%	58.9%	±22.58%

Table 12 presents the comparison of results for Advanced Lighting Design. Savings in this category also dropped from the three month analysis to the 12 month analysis. Two of the 10 sampled sites had hours of use reductions that were less than 90% of the three month estimate. One of these was a school, and the other an office building.

Table 12: Comparison of 3 vs. 12 Month Results – Advanced Lighting Design

Advanced Lighting Design	3 Month Analysis			12 Month Analysis		
Savings Realization Rate/Factor	Confidence Interval	Realization Rate/Factor	Relative Precision	Confidence Interval	Realization Rate/Factor	Relative Precision
Annual kWh Realization Rate	90%	135.1%	±12.31%	90%	124.6%	±7.60%
Connected kW Realization Rate	80%	104.5%	±4.68%	90%	101.2%	±1.73%
Summer On-Peak Coincidence Factor	80%	68.7%	±19.84%	90%	42.8%	±31.12%
Winter On-Peak Coincidence Factor	80%	59.0%	±24.87%	90%	46.7%	±15.25%
Summer On-Peak kW HVAC Interactive Effect Factor	80%	123.9%	±1.65%	90%	122.6%	±2.88%
Winter On-Peak kW HVAC Interactive Effect Factor	80%	95.2%	±5.41%	90%	94.1%	±8.33%
kWh Interactive Effect Factor	80%	108.7%	±1.69%	90%	106.6%	±2.42%
% On-Peak kWh	80%	69.3%	±4.42%	90%	65.7%	±7.78%

Table 13 shows the results of the Refrigerated LED Case Lights. As highlighted below, there were no large differences between the two analyses. Since this technology is found in grocery and other retail stores, hours of use tend to be very predictable. In many cases, these lights are controlled by remote energy management systems, and do not vary much throughout the year.

Table 13: Comparison of 3 vs. 12 Month Results – Refrigerated LED Case Lighting

Refrigerated LED Case Lighting	3 Month Analysis			12 Month Analysis		
Savings Realization Rate/Factor	Confidence Interval	Realization Rate/Factor	Relative Precision	Confidence Interval	Realization Rate/Factor	Relative Precision
Annual kWh Realization Rate	90%	97.3%	±8.72%	90%	97.5%	±8.80%
Connected kW Realization Rate	80%	100.7%	±0.67%	90%	100.7%	±0.87%
Summer On-Peak Coincidence Factor	80%	99.5%	±0.28%	90%	99.4%	±0.46%
Winter On-Peak Coincidence Factor	80%	99.5%	±0.34%	90%	99.5%	±0.45%
Summer On-Peak kW HVAC Interactive Effect Factor	80%	105.8%	±0.84%	90%	105.8%	±1.06%
Winter On-Peak kW HVAC Interactive Effect Factor	80%	105.8%	±0.84%	90%	105.8%	±1.06%
kWh Interactive Effect Factor	80%	103.7%	±1.96%	90%	103.7%	±2.61%
% On-Peak kWh	80%	60.3%	±2.96%	90%	63.5%	±3.88%

1.7 Conclusions and Recommendations

Overall, Massachusetts' Prescriptive Lighting programs are performing quite well. With the exception of lighting controls, each of the other three lighting measures is producing more savings than expected.

In the case of lighting systems, energy realization rates are somewhat higher than previous lighting impact evaluations, which are typically in the 100 to 110% range. There could be several reasons for this increase in lighting savings. First, the mix of building and fixture type could have an effect on the increased hours of use, which drive the higher savings. We found several manufacturing facilities with high hours of operation relative to tracking estimates. It is also possible that the economy could have played a role in under predicting the hours of use in 2010 when these projects were installed.

Lighting controls under performed with a realization rate of 74% on energy savings. The lower realization rate is somewhat consistent with a recently completed small business lighting controls impact evaluation[3], which resulted in a 43% realization rate.

The following are some conclusions and recommendations for all measures, and some specific to each measure analyzed. More details around these recommendations are provided in Section 0, Conclusions and Recommendations.

1.7.1 All Prescriptive Lighting Measures

- **Evaluation Monitoring.** For future lighting impact evaluations, three month data collection should be sufficient to estimate annual energy savings. The three month period that was most representative of the entire year was between September and November. However, all combinations of three month monitoring periods were within 5% of the annual savings when annualized. Therefore, it is recommended that the PAs consider monitoring for a minimum of three months. Also consider including a winter or summer month in that period if possible.
- **HVAC Interactive Effects.** If HVAC savings are being claimed as part of the gross tracking savings, the PAs should apply the Annual kWh Realization Rate. Otherwise, the Annual kWh with HVAC Realization Rate should be applied. Likewise, the Summer and Winter HVAC Interactive Effect Factors and the kWh HVAC Interactive Effect Factor should only be applied if HVAC savings are not being claimed as part of the tracking savings.

1.7.2 Lighting Systems

- **Update the TRM.** It is recommended that the Lighting Systems component of the TRM be updated to reflect these new results, which are mostly based on 12 months of metering.
- **Lighting Hours of Use.** It is recommended that the PAs continue to use site specific data when estimating lighting hours of use. Also consider additional operation that may not be captured in the typical business hours for spaces such as stairwells, corridors and large open areas that may

[3] Small Business Direct Install Program: Pre/Post Lighting Occupancy Sensor Study, Prepared by: The Cadmus Group and Energy & Resource Solutions, Inc., October 23, 2012

not go dark until the last person leaves for the day. Also be sure to consider potential day lighting effects, which could limit the hours of operation.

1.7.3 Lighting Controls

- **Consider a Pre/Post Lighting Controls Study.** Depending on the outcome of the current lighting controls market study, it may be recommended that a pre/post metering lighting controls study be conducted in the future.
- **Consider Pre-Installation Monitoring.** To help implementation vendors and TAs produce more reliable estimates of hours reduced, it is recommended that the PAs consider requiring pre-installation metering to establish an estimate of baseline hours. This could be done as part of the vendors' walkthrough of a facility when trying to determine where lighting controls will be installed. A minimum of two weeks of data would be ideal for this type of effort.
- **Update the TRM.** Until a new pre/post lighting controls impact evaluation is done, it is recommended that the lighting controls component of the TRM be updated to reflect these new results, which are based on 12 months of post-installation only metering.

1.7.4 Advanced Lighting Design

- **Collect Final Lighting As-Builts.** It is recommended that for all Advanced Lighting Design projects, the PAs try to collect the final lighting as-built, which would be used to adjust the proposed connected kW savings.
- **Update the TRM.** It is recommended that the PAs and EEAC consider updating the TRM using these realization rates and savings factors.

1.7.5 Refrigerated LED Case Lighting

- **Update the TRM.** This report recommends that the TRM be updated to utilize a refrigeration system efficiency of 1.9 kW/ton. This value is based on a larger proportion of lower temperature freezer cases than cooler cases found in these applications. Please note that the refrigeration interactive factor developed for this study is based on the tracking assumption of 1.3 kW/ton. This means that if the TRM is updated to reflect the 1.9 kW/ton recommendation, the refrigeration interactive factor would no longer be applied.
- **Consider Lighting Controls.** It is recommended that in all future freezer/cooler case LED lighting applications, lighting controls be considered.

2. Introduction

This document summarizes the work performed by DNV KEMA Energy and Sustainability (DNV KEMA) between 2011 and 2013 to quantify the actual energy and demand savings due to the installation of 56 Prescriptive Lighting projects installed through the Massachusetts Energy Efficiency Program Administrator's (PAs) C&I New Construction & Major Renovation and C&I Large Retrofit programs in 2010. Note that this document presents the final results following 12 months of metering for the four Prescriptive Lighting categories of interest, Systems, Controls, Advanced Lighting Design and Refrigerated LED Case Lighting.

2.1 Purpose of Study

The objective of this impact evaluation is to provide verification or re-estimation of electric energy and demand savings estimates and new savings factors for 56 Prescriptive Lighting retrofit and new construction projects through site-specific inspection, monitoring, and analysis. The final study results, produced following 12 months of monitoring, will be used to determine the final realization rates for Prescriptive Lighting energy efficiency projects installed in 2012.

This report presents the following realization rates at the statewide level using 12 months of metered data collected from each site:

- **Annual KWh** – This result is the gross annual kWh realization rate including additional savings due to HVAC interactive effects. This realization rate is the evaluation gross annual kWh savings divided by the tracking gross annual kWh savings.
- **Connected KW** – This result is the gross connected kW realization rate, which includes any documentation, quantity, and technology adjustments. This realization rate is the evaluation gross connected kW savings divided by the tracking gross connected kW savings.
- **Connected kWh** – This result is the gross connected kWh realization rate, which includes only the documentation, quantity, and technology adjustments. This realization rate is the evaluation gross connected kWh savings divided by the tracking gross connected kWh savings.
- **Hours of Use** – This result is the hours of use realization rate, which represents the evaluation estimate of hours of use divided by the tracking estimate of hours of use.

This report also provides the following savings factors:

- **Summer Coincidence Factor**

- **On Peak Hours** – Diversity x Coincidence. This is the percentage of the connected kW savings coincident with the summer on-peak period.
- **Seasonal Hours** – Diversity x Coincidence. This is the percentage of the connected kW savings coincident with the summer seasonal peak period.

- **Winter Coincidence Factor**
  - **On Peak Hours** – Diversity x Coincidence. This is the percentage of the connected kW savings coincident with the winter on-peak period.
  - **Seasonal Hours** – Diversity x Coincidence. This is the percentage of the connected kW savings coincident with the winter seasonal peak period.
- **Summer kW HVAC Interactive Effect**
  - **On Peak Hours** – This is the percentage of gross connected kW savings that are due to interactive effects during the summer on-peak period.
  - **Seasonal Hours** – This is the percentage of gross connected kW savings that are due to interactive effects during the summer seasonal peak period.
- **Winter kW HVAC Interactive Effect**
  - **On Peak Hours** – This is the percentage of gross connected kW savings that are due to interactive effects during the winter on-peak period.
  - **Seasonal Hours** – This is the percentage of gross connected kW savings that are due to interactive effects during the winter seasonal peak period.
- **KWh HVAC Interactive Effect** – This is the percentage of the gross kWh savings that are due to interactive effects.
- **% On Peak KWh** – This is the percentage of energy savings that occur during on-peak hours.

A listing of all realization rates and savings factors with descriptions and algorithms is presented in Appendix A. The savings factors presented in this report are developed so that they may be applied to future TRM updates.

The evaluation sample for this study was designed in consideration of the 90% confidence level for energy (kWh) and the 80% confidence level for coincident peak summer demand (kW).

This report also provides a comparison of the 12 month metering results to the interim results that were based on approximately three months of metering in the winter of 2011/2012.[4] The purpose of this comparison is to help PAs determine the value of long versus shorter term data collection, and to inform the most representative time of year to perform short term metering in any future impact evaluations of their Prescriptive Lighting programs.

2.2 Scope

The scope of work of this impact evaluation covered the 2010 Prescriptive Lighting end-use, which includes all lighting systems and controls, Advanced Lighting Design (ALD) or performance lighting, and refrigerated LED case lights. This impact evaluation includes only measures which primarily reduce electricity consumption. The presentation of 2010 findings in 2013 is due to the extended metering period. Projects were contacted and meter installation began in late 2011; in order to complete a full year of metering, the meters were removed in late 2012 and early 2013, informing this report.

3. Evaluation Approach

3.1 Sample Design

The Prescriptive Lighting sample was designed to allow DNV KEMA to estimate realization rates for a number of savings parameters (annual kWh, connected kW, summer and winter on-peak and seasonal coincidence factors, and HVAC interactive effects factor) with statistical precisions that meet PA requirements in two areas. The target for annual kWh was set at the traditional ±10% at 90% confidence, while the target for summer kW was set at ±10% precision at 80% confidence.

The PAs were interested in results for each of the four following groups:

- Lighting Systems
- Lighting Controls
- Advanced Lighting Design (Performance Lighting)
- Refrigerated Case Lighting (LED)

After running several scenarios based on different sample sizes and allocations, the team decided on a Prescriptive sample comprised of 57 sites split between measure types as indicated in Table 14. This table also includes estimates of the precisions that were anticipated at the time of this design, assuming an error ratio of 0.4.

[4] Impact Evaluation of 2010 Prescriptive Lighting Installations, Interim Results Memo, August 17, 2012, Prepared by DNV KEMA

Table 14: Prescriptive Lighting Sample Design

Measure Type	Accounts	Total Savings	Assumed Error Ratio	Confidence Level	Planned Sample Size	Anticipated Relative Precision
Systems & Controls	1,095	92,442,396	0.4	90%	37	±11.03%
Advanced Lighting Design	72	5,670,723	0.4	90%	10	±14.44%
Refrigerated Case Lighting	61	2,664,459	0.4	90%	10	±19.28%
Total	1,228	100,777,578	0.4	90%	57	±10.16%

This allocation by PA was further stratified by total savings, and sample sites were selected. After the sample selection, several adjustments were required based on observations made during initial file reviews and early site visits. In some cases, alternate sites were used, but in other cases there were no additional sites to select. In the end, a total of 56 sites were included in the Prescriptive Lighting sample.

3.2 Measurement, Verification and Analysis Methodology

A key task in the on-site engineering assessment is the installation of measurement equipment to aid in the development of independent estimates of savings. The type of measure influences the measurement strategy used. Time-of-use loggers, electrical current loggers, and multi-channel three-phase power loggers may all be utilized to inform the savings calculations with a direct measurement of electrical usage and/or hours of operation. For the interim study, three months of data was typically used for all sites. For this report, 12 months of logger data were collected at all sites, and used to update the estimated operation from the interim report.

In the context of an energy analysis, most efficiency measures can be characterized as either time-dependent or load-dependent. Time-dependent equipment typically runs at constant load according to a time-of-day operating schedule. Mathematically, hour-of-day and day-of-week are usually the most relevant variables in the energy savings analysis of these measures. Lighting is the most prevalent time-dependent measure.

The following section outlines the methodology for time-dependent lighting measures. A more detailed description of the calculation methodology is presented in Appendix B.

3.2.1 Monitoring

Time-dependent measures typically call for the installation of time-of-use (TOU) loggers to measure hours of use. These small devices use specialized sensors – photocells in the case of lighting measures – to sense and record the dates and times that a device turns on and off. This TOU data will be used to support the evaluation in two key ways:

1. To develop peak coincidence factors, and

2. To develop annual hours of use.

The measure scope influences the appropriate number of loggers and systems monitored for each site. Factors that drive the number of installed loggers include the number of unique schedules at the site, and the anticipated level of variation among the schedules within a particular space type.

Clamp-on time-of-use, current, or power loggers may also be used in selective situations such as high-bay lighting, or exterior fixtures where traditional time-of-use lighting loggers may be impractical due to installation height or accessibility.

During the retrieval of the first round (three month) loggers, new loggers were installed in their place to continue monitoring operation throughout the remainder of the metered year.

It was expected that with a logger study of this length, there were likely to be some gaps in the 8,760 hour data resulting from lost or moved loggers, bad data, dead loggers or loggers that exceeded the maximum number of records. To plan for this, DNV KEMA used new batteries in each logger that was deployed, and used redundant loggers in areas with significant savings. Additionally, most loggers were swapped again after approximately six more months to help improve the odds of collecting good data. Evaluators based this decision to swap loggers again on a couple factors, including how many on/off transitions the loggers recorded during the first round (maximum of 8,000 transitions), and buildings/locations that may lose loggers (i.e. schools, hospitals and retail). In the end, evaluators used 2,054 lighting loggers to monitor 766 spaces between the 56 sites. In addition, evaluators used a handful of clamp-on CT loggers and power loggers.

3.2.2 Verification

A detailed inventory was performed for each installed measure. This inventory included a verification of the quantity and technologies installed from the program, as well as customer reported operating hours for specific equipment and locations. For pre-retrofit, or baseline hours and equipment, evaluators used a combination of facility interview and tracking estimates. Methods of control were also examined and inventoried at this time. Other variables that were analyzed include the types of heating and cooling systems serving the areas of the installed measure for the calculation of interactive HVAC effects.

3.2.3 Site Analysis

3.2.3.1 Three Month Logger Data

The project team was responsible for data entry and analysis of all information gathered during the evaluation. On and off transition data was downloaded from each logger. The data was then analyzed using computer software, which develops time-of-use load profiles and estimates of percentage on-times during the monitoring period. For the interim results memo, evaluators extrapolated the three months of captured operation data out to 12 months to achieve annual hours of operation.

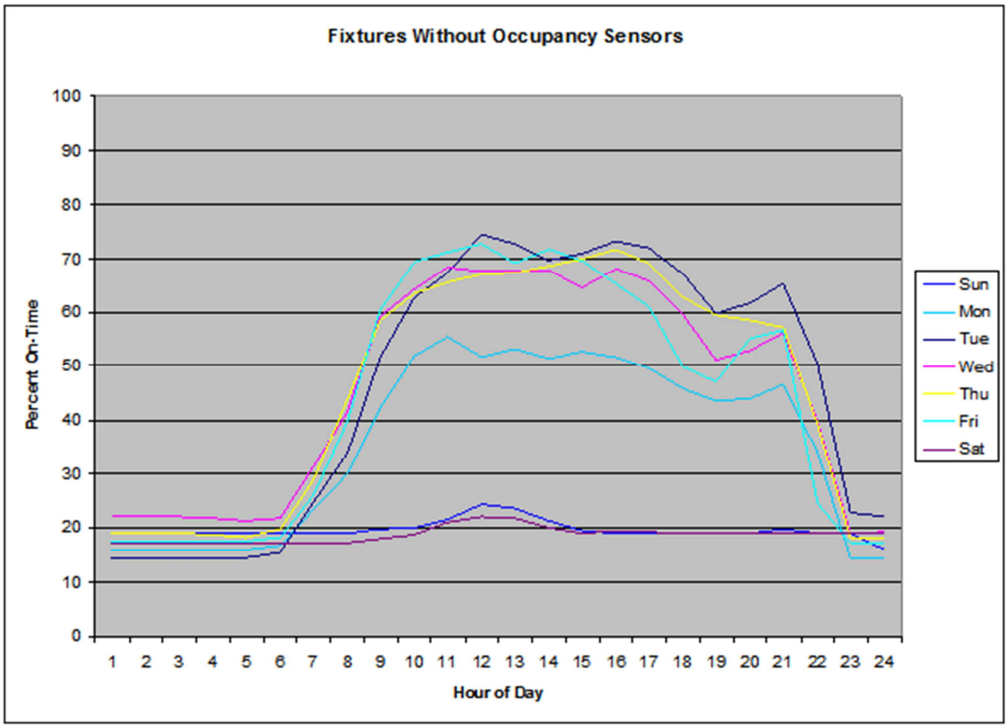

Figure 1: Measured Hourly Lighting Profiles by Day-of-Week

Time-of-use data from each logger, such as in Figure 1, was reviewed to identify the influence on annual trends such as seasonal effects (e.g., daylight savings), production, and occupancy swings (e.g., vacations). Detailed review of time-of-use data was expected to reveal explicable patterns that agree with other data sources, such as on-site interviews or equipment control schedules. The time-of-use profiles were combined with these other data sources to extrapolate the three month logger data to an entire year.

3.2.3.2 12 Month Logger Data

Following the completion of a full 12 months of metering, logger data were processed and combined using a computer program. This program was designed to retrieve the two or three logger data streams for each space monitored, and combine them into one 8,760 hourly profile of actual operation.

As expected, there were some gaps in the 8,760 hour despite our efforts to avoid these circumstances. The program utilized a method as a first pass to fill these gaps. In the cases where the data gap occurred in one season, the program filled these gaps with average logger data from the same hour, day of week, and season from the good data. This occurred in 9% of the loggers, but the gaps represented only 2.5% of the total annual hours. In cases where loggers were considered bad or were missing over multiple seasons (2% of loggers, 2% of annual hours), evaluators performed more manual adjustments. In some cases, logger data from redundant loggers were used in place of the missing data. In other cases, average logger data from the same hour and day of week from the same space were used to fill in the missing data. On

average, missing data accounted for approximately two weeks of the year, per site, which did not overly influence the results.

Annualized logger data and field verified equipment and quantities were entered into an 8,760 hour analysis spreadsheet. Massachusetts program values were used for fixture wattages with site verified modifications as needed. The spreadsheet calculates annual kW and kWh savings for the installed system as compared with the baseline equipment, which was mostly based on tracking estimates and verified, as best possible, through discussions with facility staff.

3.2.4 Lighting Controls

The key variable in estimating savings due to the installation of lighting controls is the difference in operating hours for occupancy sensors, or the difference in average lighting wattage for dimming controls. In the case of occupancy sensors, the installed condition of the system was metered. Since no pre-installation metering was conducted, the baseline operating hours needed to be estimated. The DNV KEMA team employs several different methodologies to determine these baseline hours depending on the site and usage of the space, and apply them according to information gathered on-site as illustrated below.

The most frequent method applied by evaluating engineers is to establish operating thresholds utilizing operating profiles of the monitored lights. This method is performed by determining when the lights come on in the morning and when they go off at night. This period is defined as the first hour of the day when the operating profile shows an apparent increase in lighting usage from the overnight usage, to the last hour of the day where this level of increased usage is observed. Between these hours, the baseline operation is set at a certain fixed percentage. This percentage is usually less than 100%, though not always, and is inferred from the maximum hourly operation observed during the monitoring period of the controlled fixture.

In some cases, lighting controls were installed to shut off lighting that would have otherwise been on 100% of the time during business hours. Typically, this situation occurs in warehouses or large open spaces, which are occupied continuously throughout the day. Occupancy sensors may be installed on individual fixtures, or rows of fixtures, to reduce energy if sections of the space are unoccupied. Typically, facility staff is confident in their estimate of baseline operating hours in these specific cases. In these cases, evaluators will discuss the baseline operating hours with facility personnel, and assess the reasonableness of these hours.

One other method used to estimate baseline operating hours is to utilize lighting logger data from a similar space type in the facility that is not being controlled. This type of proxy space is sometimes difficult to find in facilities because similar space types typically are treated the same when lighting controls are installed. However, in some circumstances, evaluators may be able to monitor some uncontrolled spaces, and apply the operating profiles, as baseline schedules, to similar space types that did receive occupancy sensors. In these cases, logger data from the uncontrolled space is compared to logger

data from the controlled spaces to determine if the operating profiles match. For example, the magnitude of the operation may be different between the two profiles, but the operating profiles tend to have the same start and stop times.

3.2.5 HVAC Interactive Effects

When lighting equipment converts electrical energy to light, a significant amount of that energy is dissipated in the form of heat. Energy efficient lighting measures convert more electrical energy to light and less to heat. Since installing energy efficient lighting adds less heat to a given space, a complete estimation of energy savings considers the associated impacts on the heating and cooling systems or "interactive effects."

The interactive effects take into account the effect of the energy efficient lighting measures on their corresponding heating and cooling systems. Energy efficient lighting serves to reduce the heat gain to a given space and accordingly reduces the load on cooling equipment. But this reduced heat gain has the added consequence of increasing the load on the heating system.

As part of the on-site methodology, evaluators interviewed facility personnel to ascertain the cooling and heating fuel, system type, and other information with which to approximate the efficiency of the HVAC equipment serving the space of each lighting installation. The DNV KEMA team expresses HVAC system efficiency in dimensionless units of Coefficient of Performance (COP), which reflects the ratio of work performed by the system to the work input of the system. Table 15 details the COP assumptions for general heating and cooling equipment types encountered in this study. Where site specific information yields improved estimates of system efficiency, these were used in place of the general assumptions below.

Table 15: General Heating and Cooling COP Assumptions

Cooling System Type	COP
Packaged DX	2.9
Window DX	2.7
Chiller <200 Ton	4.7
Chiller >200 Ton	5.5
Air to Air Heat Pump	3.9
Water to Air Heat Pump	4.4
Refrigerated Area (high temp)	1.4
Refrigerated Cases (low temp)	1.9

Heating System Type	COP
Air to Air Heat Pump	1.5
Electric Resistance	1
Water to Air Heat Pump	2.8

Interactive effects are calculated only at sites where heating or cooling systems are in use. Leveraging the 8,760 profile of hourly demand impacts, the DNV KEMA team computes electric interactive effects during the hours that lighting and HVAC are assumed to operate in unison.

DNV KEMA utilizes Typical Meteorological Year 3 (TMY3) hourly dry-bulb temperatures for Worcester, Massachusetts as the balance point criteria in this analysis. For each hour in a typical year, DNV KEMA computes HVAC interaction according to the following equations:

Cooling kW Effects = 80% * Lighting kW Savings / Cooling System COP

Heating kW Effects = -80% * Lighting kW Savings / Heating System COP

The 80% values represent the assumed percentage of the lighting energy that translates to heat which either must be removed from the space by the air conditioning system or added to the space by the heating system during the aforementioned HVAC hours. This assumption is consistent with those established and employed in previous impact evaluations of custom lighting measures. Also, heating factors are negative because heating interaction erodes gross lighting savings, while cooling interactive boosts it.

4. Results

The results presented in the following section include statewide level realization rates (and associated precision levels) for annual kWh savings, percent on-peak kWh savings, and on-peak and seasonal demand (kW) coincidence factors at the times of the winter and summer peaks, as defined by the ISO New England Forward Capacity Market (FCM). All coincident summer and winter peak reductions were calculated using the following FCM definitions:

- Coincident Summer On-Peak kW Reduction is the average demand reduction that occurs over all hours between 1 PM and 5 PM on non-holiday weekdays in June, July and August.
- Coincident Winter On-Peak kW Reduction is the average demand reduction that occurs over all hours between 5 PM and 7 PM on non-holiday weekdays in December and January.
- Seasonal Peak: Non-holiday week days when the Real-Time System Hourly Load is equal to or greater than 90% of the most recent “50/50” System Peak Load Forecast for the summer and winter seasons.

The adjusted gross energy savings and connected kW demand reduction are presented with their associated realization rate and relative precision for each lighting measure. These tables present results as adjustments to tracking savings. Each of these adjustments, or discrepancies, is described below:

- **Documentation Adjustment**: The Documentation Adjustment reflects any change in savings due to discrepancies in project documentation. Evaluators recalculated the tracking estimates of savings using all quantities, fixture types/wattages, and hours documented in the project file. All tracking system discrepancies and documentation errors are reflected in this adjustment.

- **Technology Adjustment**: The Technology Adjustment reflects the change in savings due to the identification of a different lighting technology (fixture type and wattage) at the site than represented in the tracking system estimate of savings.

- **Quantity Adjustment**: The Quantity Adjustment reflects the change in savings due to the identification of a different quantity of lighting fixtures at the site than presented in the tracking system estimate of savings.

- **Operational Adjustment**: The Operational Adjustment reflects the change in savings due to the observation or monitoring of different lighting operating hours at the site than represented in the tracking system estimate of savings.

- **HVAC Interactive Adjustment**: The HVAC Interactive Adjustment reflects changes in savings due to interaction between the lighting and HVAC systems among the sampled sites. Generally, these impacts cause a heating penalty and a cooling credit. This adjustment reflects impacts from electric heating and/or cooling, not other fuels.

Also included in the results are savings factors for summer and winter on-peak and seasonal coincidence factors, summer and winter kW HVAC interactive effect factors, kWh HVAC interactive effect factor and percent of energy savings during on-peak periods. Relative precision levels and error bounds are calculated at the 90% confidence level for demand savings factors and values. For all kWh realization rates, the standard 90% confidence level is used.

A summary of site level results are also presented in Appendix C.

4.1 Lighting Systems

Figure 2 presents a scatter plot of evaluation results for Lighting Systems for annual energy savings using all 34 PA sample points. The dashed line in this graph represents a realization rate of 100%. The slope of the solid line in this graph is an indication of the overall realization rate, and can be seen to be greater than 100%. These sample data are arranged closely around the trend line, which supports the estimate made during the design process that the error ratio would be relatively low.

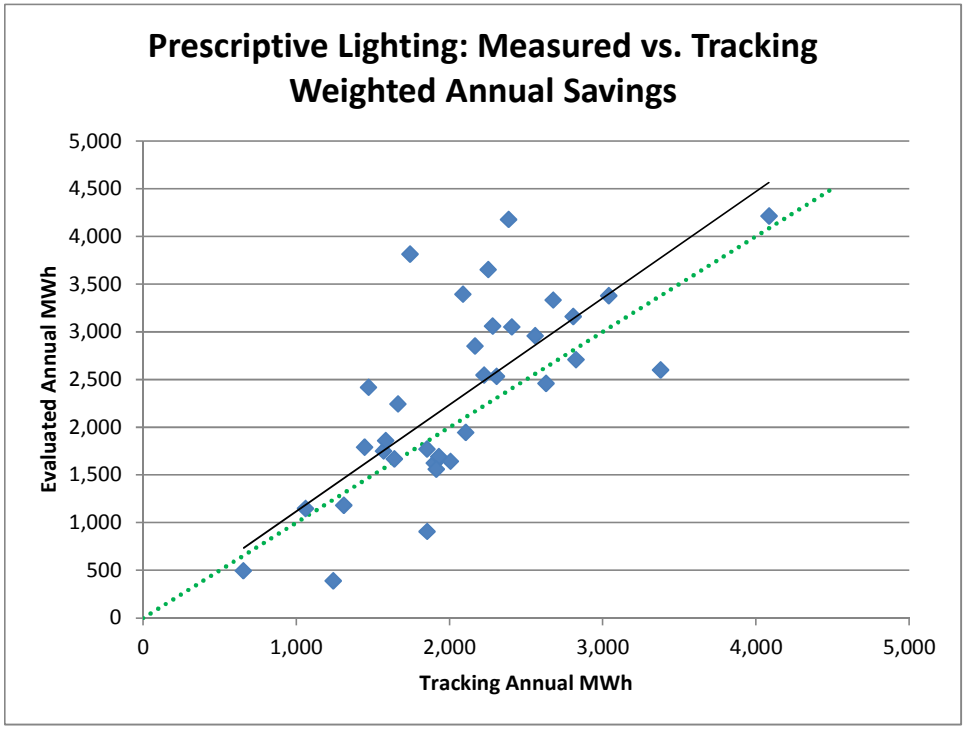

Figure 2: Scatter Plot of Evaluation Results for Systems for Annual MWh Savings

Table 16 summarizes the statewide results of this analysis. In the case of annual kWh savings, the realization rate for Lighting Systems was found to be 112.3% with HVAC interactive effects included. The relative precision for this estimate was found to be ±7.9% at the 90% level of confidence. Note that gross tracking savings do not generally include HVAC interactive effects. The error ratio was found to be 0.29.

Table 16 also shows the results for the connected kW realization rate. The overall realization rate was 99.7%, with a relative precision of ±2.6% at a 90% confidence level.

Table 16: Summary of Lighting Systems Realization Rates

Lighting Systems	Energy		Connected kW	
	kWh	% Gross	kW	% Gross
Gross Savings (Tracking)	79,439,316		17,236	
Documentation Adjustment	-376,857	0%	-130	-1%
Technology Adjustment	466,552	1%	9	0%
Quantity Adjustment	-2,755	0%	75	0%
Operational Adjustment	5,168,634	7%	N/A	N/A
HVAC Interactive Adjustment	4,531,719	6%	N/A	N/A
Adjusted Gross Savings	89,226,609	112%	17,190	100%
Gross Realization Rate	112.3%		99.7%	
Relative Precision	±7.9%		±2.6%	
Confidence Interval	90%		90%	
Error Ratio	29%		10%	

Table 17 summarizes the statewide savings factors resulting from this analysis. All relative precisions were calculated at the 90% confidence level. The on-peak summer coincidence factor was 72.2%, with a relative precision of ±11.1%. The seasonal summer coincidence factor was 73.6%, with a relative precision of ±10.9%. The on-peak winter coincidence factor was 65.9%, with a relative precision of ±12.2%. The seasonal winter coincidence factor was 66.9%, with a relative precision of ±12.6%. The table also provides savings factors for on-peak and seasonal summer and winter kW HVAC interactive effects, kWh HVAC interactive effect, hours of use realization rate and percent on-peak kWh.

Table 17: Summary of Lighting Systems Savings Factors

Savings Factors and Realization Rates at 90% Confidence	Systems	
	Value	Precision
Connected kW Realization Rate	99.7%	±2.6%
Summer Coincidence Factor		
On Peak Hours	72.2%	±11.1%
Seasonal Hours	73.6%	±10.9%
Winter Coincidence Factor		
On Peak Hours	65.9%	±12.2%
Seasonal Hours	66.9%	±12.6%
Summer kW HVAC Interactive Effect		
On Peak Hours	114.6%	±2.7%
Seasonal Hours	114.8%	±2.8%
Winter kW HVAC Interactive Effect		
On Peak Hours	99.8%	±0.4%
Seasonal Hours	99.8%	±0.3%
KWh Factors		
Connected kWh Realization Rate	100.1%	±3.1%
KWh HVAC Interactive Effect	105.4%	±1.3%
Hours of Use Realization Rate	106.5%	±7.4%
% On Peak KWh	63.88%	±5.6%
Non-Electric		
Heating HVAC Interaction Effect (MMBtu/kWh)	-0.000691	

Overall, lighting systems appear to be performing better than expected. The significant increase in the annual kWh realization rate is primarily due to higher than predicted operation of the lighting systems. The main discrepancy factors that can be used to highlight the high realization rate are the connected kW adjustment, operation adjustment and the HVAC interactive adjustment.

The connected kW adjustment, or connected kW realization rate encompasses any documentation errors, quantity and fixture discrepancies. As found in this evaluation, the connected kW realization rate of 99.7% indicates that the programs are seeing the correct quantities and fixture types being installed.

The operation adjustment of 112.6% was the largest adjustment factor. A review of the site level results in Appendix C show that seven of the 34 sample projects with lighting systems installed showed hours of operation that were more than 125% of the proposed estimates. Of these eight sites, two were manufacturing facilities. The other six sites were a dormitory, movie theater, school, retail store and a library. With such a range of building types, this doesn't appear to be the driver for the hours increase. In the case of the manufacturing facilities, it appears that they are operating more shifts than expected. It is likely that in most of these situations, the proposed hours were the expected business hours, while the lighting hours, especially those in common areas, tend to operate more.

The HVAC interactive adjustment of 105.5% represents the additional savings associated with the space cooling and heating.

4.2 Lighting Controls

Figure 3 presents a scatter plot of evaluation results for Lighting Controls for annual energy savings using all 26 PA sample points. The slope of the solid line in this graph is an indication of the overall realization rate, and can be seen to be less than one. These sample data spread from the trend line, which is indicative of a higher error ratio. Site level realization rates ranged from 4% to 353% in this measure category. The evaluation found that majority of the discrepancies between the tracking and evaluated savings estimates were due to miscalculation of the hours reduced. In the case of the 353% realization rate site, hours reduced were found to be almost four times as much as tracking estimates. This is one reason why a pre/post metering lighting controls study is being considered as a separate effort.

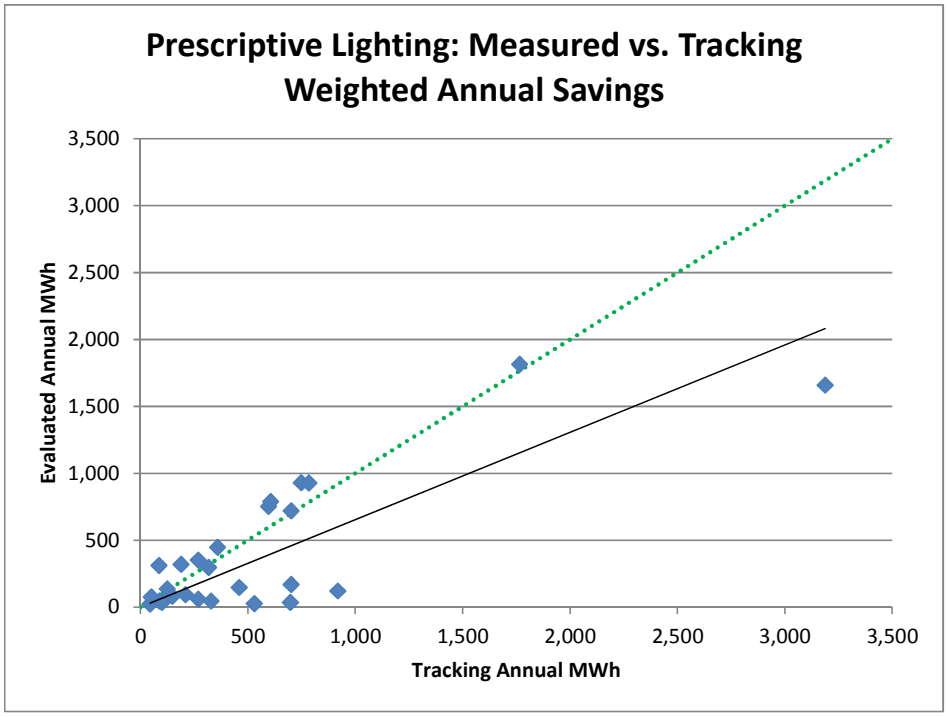

Figure 3: Scatter Plot of Evaluation Results for Controls for Annual MWh Savings

Table 18 summarizes the statewide results of this analysis. In the case of annual kWh savings, the realization rate for Lighting Controls was found to be 72.0% with HVAC interactive effects included. The relative precision for this estimate was found to be ±23.2% at the 90% level of confidence. The error ratio was found to be 0.66.

Table 18 also shows the results for the connected kW realization rate. The overall realization rate was 93.8%, with a relative precision of ±6.0% at a 90% confidence level.

Table 18: Summary of Lighting Controls Realization Rates

Lighting Controls	Energy		Connected kW	
	kWh	% Gross	kW	% Gross
Gross Savings (Tracking)	12,805,436		10,313	
Documentation Adjustment	-131,240	-1%	-140	-2%
Technology Adjustment	-55,494	0%	-9	0%
Quantity Adjustment	-1,137,164	-9%	-489	-8%
Operational Adjustment	-2,537,753	-20%	N/A	N/A
HVAC Interactive Adjustment	281,840	2%	N/A	N/A
Adjusted Gross Savings	9,225,625	72%	9,675	94%
Gross Realization Rate	72.0%		93.8%	
Relative Precision	±23.2%		±6.0%	
Confidence Interval	90%		90%	
Error Ratio	66%		15%	

Table 19 summarizes the statewide savings factors resulting from this analysis. All relative precisions were calculated at the 90% confidence level. The on-peak summer coincidence factor was 13.8%, with a relative precision of ±23.6%. The seasonal summer coincidence factor was 13.0%, with a relative precision of ±20.9%. The on-peak winter coincidence factor was 13.4%, with a relative precision of ±46.3%. The seasonal winter coincidence factor was 14.0%, with a relative precision of ±43.3%. The table also provides savings factors for on-peak and seasonal summer and winter kW HVAC interactive effects, kWh HVAC interactive effect, hours of use realization rate and percent on-peak kWh.

Table 19: Summary of Lighting Controls Savings Factors

Savings Factors and Realization Rates at 90% Confidence	Controls	
	Value	Precision
Connected kW Realization Rate	93.8%	±6.0%
Summer Coincidence Factor		
On Peak Hours	13.8%	±23.6%
Seasonal Hours	13.0%	±20.9%
Winter Coincidence Factor		
On Peak Hours	13.4%	±46.3%
Seasonal Hours	14.0%	±43.3%
Summer kW HVAC Interactive Effect		
On Peak Hours	109.3%	±3.8%
Seasonal Hours	110.2%	±3.7%
Winter kW HVAC Interactive Effect		
On Peak Hours	99.6%	±0.6%
Seasonal Hours	99.6%	±0.6%
KWh Factors		
Connected kWh Realization Rate	89.7%	±8.7%
KWh HVAC Interactive Effect	103.2%	±1.5%
Hours of Use Realization Rate	77.9%	±24.5%
% On Peak KWh	58.86%	±22.6%
Non-Electric		
Heating HVAC Interaction Effect (MMBtu/kWh)	-0.002728	

4.3 Advanced Lighting Design

Figure 4 presents a scatter plot of evaluation results for ALD for annual energy savings using all ten PA sample points. The slope of the solid line in this graph is an indication of the overall realization rate, and can be seen to be greater than one. These sample data are arranged closely around the trend line, which supports the estimate made during the design process that the error ratio would be relatively low.

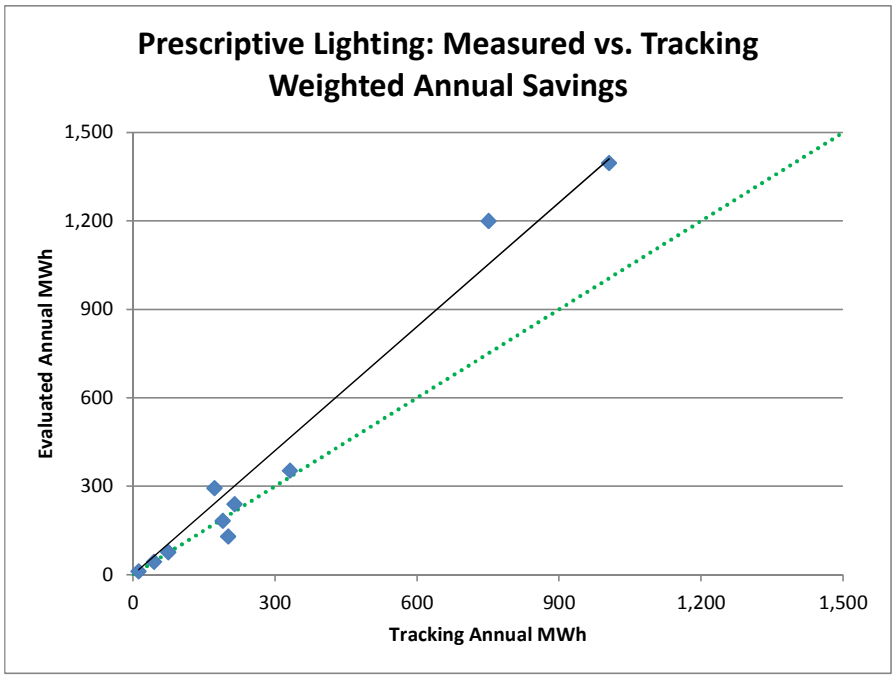

Figure 4: Scatter Plot of Evaluation Results for ALD for Annual MWh Savings

Table 20 summarizes the statewide results of this analysis. In the case of annual kWh savings, the realization rate for ALD was found to be 124.6% with HVAC interactive effects included. The relative precision for this estimate was found to be ±7.6% at the 90% level of confidence. The error ratio was found to be 0.18.

Table 20 also shows the results for the connected kW realization rate. The overall realization rate was 101.2%, with a relative precision of ±1.7% at a 90% confidence level.

Table 20: Summary of ALD Realization Rates

	Energy		Connected kW	
Advanced Lighting Design	kWh	% Gross	kW	% Gross
Gross Savings (Tracking)	5,670,723		1,178	
Documentation Adjustment	619	0%	-6	-1%
Technology Adjustment	542,983	10%	64	5%
Quantity Adjustment	-228,228	-4%	-44	-4%
Operational Adjustment	639,442	11%	N/A	N/A
HVAC Interactive Adjustment	438,395	8%	N/A	N/A
Adjusted Gross Savings	7,063,933	125%	1,192	101%
Gross Realization Rate	124.6%		101.2%	
Relative Precision	±7.6%		±1.7%	
Confidence Interval	90%		90%	
Error Ratio	18%		3%	

Table 21 summarizes the statewide savings factors resulting from this analysis. All relative precisions were calculated at the 90% confidence level. The on-peak summer coincidence factor was 42.8%, with a relative precision of ±31.1%. The seasonal summer coincidence factor was 39.1%, with a relative precision of ±38.5%. There were two schools in this sample, and both had very low summer coincidence factors. This is likely the driver for the lower summer coincidence factors as compared to lighting systems. The on-peak winter coincidence factor was 46.7%, with a relative precision of ±15.2%. The seasonal winter coincidence factor was 46.6%, with a relative precision of ±17.5%. The table also provides savings factors for on-peak and seasonal summer and winter kW HVAC interactive effects, kWh HVAC interactive effect, hours of use realization rate and percent on-peak kWh.

Table 21: Summary of ALD Savings Factors

Savings Factors and Realization Rates at 90% Confidence	Advanced Lighting Design	
	Value	Precision
Connected kW Realization Rate	101.2%	±1.7%
Summer Coincidence Factor		
On Peak Hours	42.8%	±31.1%
Seasonal Hours	39.1%	±38.5%
Winter Coincidence Factor		
On Peak Hours	46.7%	±15.2%
Seasonal Hours	46.6%	±17.5%
Summer kW HVAC Interactive Effect		
On Peak Hours	122.6%	±2.9%
Seasonal Hours	123.2%	±3.0%
Winter kW HVAC Interactive Effect		
On Peak Hours	94.1%	±8.3%
Seasonal Hours	93.9%	±8.5%
KWh Factors		
Connected kWh Realization Rate	105.6%	±4.6%
KWh HVAC Interactive Effect	106.6%	±2.4%
Hours of Use Realization Rate	110.7%	±7.2%
% On Peak KWh	65.67%	±7.8%
Non-Electric		
Heating HVAC Interaction Effect (MMBtu/kWh)	-0.000175	

4.4 Refrigerated LED Case Lighting

An initial review of the Refrigerated LED sample found that some PAs were treating these measures differently between 2010 and 2011. The sample of ten Refrigerated LED projects were pulled from 2010, when some PAs were not applying refrigeration interactive savings to their tracking estimates, while other PAs were using different assumptions for refrigeration system efficiency.

It was found that NSTAR was not yet applying refrigeration interactive savings to their savings estimates in 2010. Evaluators also found that National Grid was using a refrigeration system efficiency of 1.6

kW/ton for most of their 2010 projects. The MA TRM assumes a refrigeration system efficiency of 1.3 kW/ton. By applying the TRM assumptions to the NSTAR sample from 2010, this would have increased their savings estimates. Applying the TRM refrigeration system efficiency assumption to the National Grid sample from 2010 would have decreased their savings estimates.

In 2011, the PAs began applying refrigerating interactive savings to their tracking estimates using the MA TRM assumptions. For this reason, the use of realization rates and savings factors resulting from the 2010 population is not applicable to 2011 programs and beyond. Therefore, DNV KEMA recommended, and the PAs and EEAC agreed to calculate realization rates relative to the TRM estimates, rather than the 2010 tracking savings. By applying the TRM savings algorithms to the 2010 sample projects, which includes refrigeration interactive savings, a valid comparison can be made so that results may be applied retrospectively as well as prospectively.

Figure 5 presents a scatter plot of evaluation results for Refrigerated LEDs for annual energy savings using all PA sample points. The slope of the solid line in this graph is an indication of the overall realization rate, and can be seen to be close to one. These sample data are arranged closely around the trend line, which supports the estimate made during the design process that the error ratio would be relatively low.

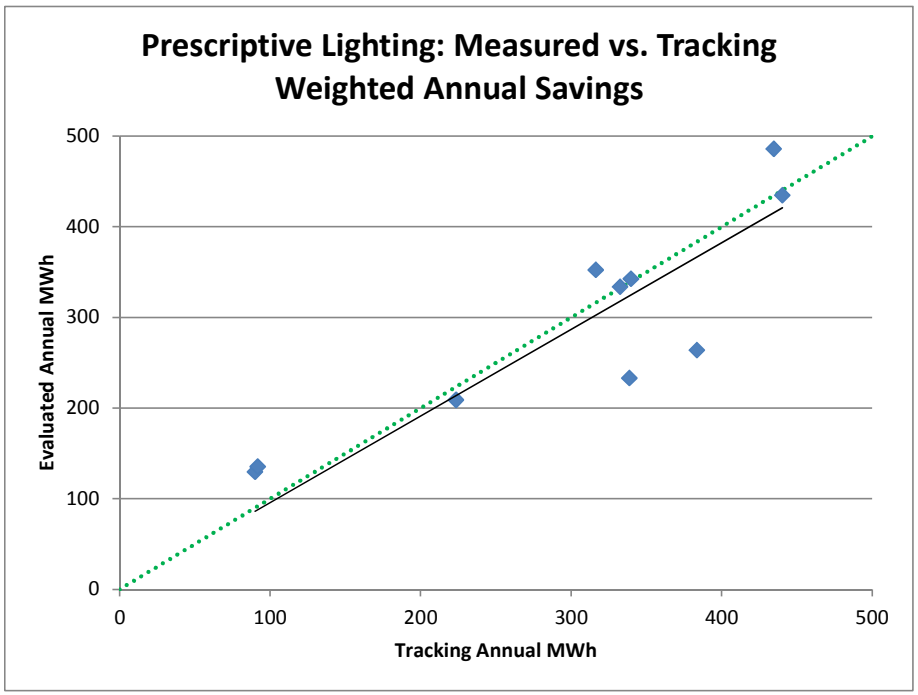

Figure 5: Scatter Plot of Evaluation Results for Refrigerated LEDs for Annual MWh Savings

Table 22 summarizes the statewide results of this analysis relative to the TRM savings algorithm. In the case of annual kWh savings, the realization rate for Refrigerated LEDs was found to be 97.5% with

HVAC interactive adjustments included. The relative precision for this estimate was found to be ±8.8% at the 90% level of confidence. The error ratio was found to be 0.19.

Table 22 also shows the results for the connected kW realization rate. The overall realization rate was 100.7%, with a relative precision of ±0.9% at a 90% confidence level.

Table 22: Summary of Refrigerated LED Realization Rates

	Energy		Connected kW	
Refrigerated LED	kWh	% Gross	kW	% Gross
Gross Savings (Tracking)	2,702,650		476	
Documentation Adjustment	0	0%	0	0%
Technology Adjustment	0	0%	0	0%
Quantity Adjustment	16,942	1%	3	1%
Operational Adjustment	-170,249	-6%	N/A	N/A
HVAC Interactive Adjustment	85,357	3%	N/A	N/A
Adjusted Gross Savings	2,634,701	97%	479	101%
Gross Realization Rate	97.5%		100.7%	
Relative Precision	±8.8%		±0.9%	
Confidence Interval	90%		90%	
Error Ratio	19%		2%	

Table 23 summarizes the statewide savings factors resulting from this analysis. All relative precisions were calculated at the 90% confidence level. The on-peak summer coincidence factor was 99.4%, with a relative precision of ±0.5%. The seasonal summer coincidence factor was 99.7%, with a relative precision of ±0.5%. The on-peak winter coincidence factor was 99.5%, with a relative precision of ±0.5%. The seasonal winter coincidence factor was 99.9%, with a relative precision of ±0.2%. The coincidence factors are all close to 100%, which is appropriate for this measure type, which tends to be installed in grocery stores. The business hours of these facilities typically coincide with the summer and winter peak periods. The table also provides savings factors for on-peak and seasonal summer and winter kW refrigeration interactive effects, kWh refrigeration interactive effect, hours of use realization rate and percent on-peak kWh.

Table 23: Summary of Refrigerated LED Savings Factors

Savings Factors and Realization Rates at 90% Confidence	Refrigerated LED	
	Value	Precision
Connected kW Realization Rate	100.7%	±0.9%
Summer Coincidence Factor		
On Peak Hours	99.4%	±0.5%
Seasonal Hours	99.7%	±0.5%
Winter Coincidence Factor		
On Peak Hours	99.5%	±0.5%
Seasonal Hours	99.9%	±0.2%
Summer kW Refrigeration Interactive Effect		
On Peak Hours	105.8%	±1.1%
Seasonal Hours	105.9%	±1.0%
Winter kW Refrigeration Interactive Effect		
On Peak Hours	105.8%	±1.1%
Seasonal Hours	106.0%	±1.0%
KWh Factors		
Connected kWh Realization Rate	100.6%	±0.8%
KWh Refrigeration Interactive Effect	103.3%	±2.6%
Hours of Use Realization Rate	93.7%	±6.1%
% On Peak KWh	63.53%	±3.9%
Non-Electric		
Heating HVAC Interaction Effect (MMBtu/kWh)	0.000000	

Refrigeration System Interactive Savings

Note that the HVAC interactive effects in the table above are greater than 100%. The primary reason for the increase is difference in refrigeration efficiency employed in the evaluation as compared to the TRM[5] estimate. In the TRM, the interactive refrigeration savings attributed to the reduction of waste-heat loads at the compressor is calculated using a 1.3 kW/ton system efficiency. This value was obtained from a report prepared for National Grid in March 2007[6]. The refrigeration measures included in that report consisted of replacing existing shaded pole evaporator fan motors with electrically commutated motors. The sites included three liquor stores, a convenience store, and a restaurant. The fans were installed in six walk-in beverage coolers and one small walk-in freezer. All of the beverage coolers are higher-temperature applications. The average 1.3 kW efficiency stated in this report refers to the average efficiency of the sites and equipment in this small business analysis.

The LED lighting fixtures installed in the Large C&I prescriptive lighting program were found in facilities and equipment that are significantly different from what was reported in the 2007 Small

[5] Massachusetts Technical Reference Manual, 2011 Program Year – Plan Version, October 2010

[6] RLW Analytics (2007). Small Business Services Custom Measure Impact Evaluation. Prepared for National Grid.

Business report. Most of the lighting fixtures were installed in reach-in freezers. Product included frozen vegetables, ice, frozen seafood, ice cream, and other frozen product. Case temperatures ranged from ±20°F to temperatures well below 0°F. These refrigeration units are linked to the low temperature side of the supermarket rack systems. The efficiencies at these temperatures are less than higher temperature applications. R-22 was the only refrigerant used in the higher temperature applications, while the low temperatures supermarket systems use R-22 and other refrigerants in their systems. Medium and high temperature units include reach-in deli multi-decks, cheese coffins, deli showcases, beverage coolers, and other units that were not included in the lighting retrofit.

As part of this evaluation, the refrigeration systems were reviewed at each location. Evaluators were unable to find documentation at the sites that would provide design specifications or operational efficiencies of the units. Nameplate data was taken from several compressors, but performance data could not be located. It was also noted that rack systems had different components with different ages. Systems consisted of compressors from the original installation as well as new compressors, installed over time, to replace failed units. The efficiency of the system is then the interactive composite of components of different age and efficiency. Also, the condition and accuracy of controls, valves, and other components was not known.

To estimate refrigeration system efficiency, evaluators utilized a combination of ASHRAE estimates and manufacturer's specifications for new equipment. ASHRAE rates the main load at an 8 to 9 EER [1.5 kW/ton and 1.3 kW/ton]. The chapter (2010 ASHRAE Refrigeration Handbook, Chapter 47, Retail Food Store Refrigeration and Equipment) also noted that low-temperature frozen food units ranged from 3.4 kW/ton to 2.4 kW/ton. However, these efficiencies included -30°F to -40°F temperatures for ice cream freezers. Temperatures that low were not noted at the stores. That temperature range applied to walk-in bulk storage and not the reach-in retail cases.

Compressor data from three manufacturers was obtained for new equipment. Average performance data was calculated across multiple compressor sizes focusing for R-22, R-507, and R-404 units. The review focused on Saturated Suction Temperatures (F) 0°F, 10°F, and 20°F for R-22 units at Saturated Discharge Temperatures (F) of 100°F, 110°f, and 120°F. For other refrigerants, the SST range was 10°F, 0°F, -10°F, and -20°F at the same SDT. However, this data represents new equipment, and the refrigeration in the field consisted of units of various ages and conditions. The condition of controls, defrosts, evaporator fan operation, and other maintenance factors was unknown. Therefore, the average efficiencies were increased by a 15% maintenance diversity factor to account for aged units and deferred maintenance. The result was an average efficiency of 1.9 kW/ton. This should provide a more accurate estimate of refrigeration efficiency for the types of refrigerated cases where these fixtures are being installed.

5. Comparison of 12 Month and 3 Month Monitoring Results

Table 24 through Table 25 presents some of the results of both the three month interim analysis, and the 12 month analysis. These comparison tables are provided to highlight the differences between the two monitoring periods.

As shown in Table 24, the annual energy savings and summer demand savings dropped between the three and 12 month analyses. The annual energy savings were about 5% less in the 12 month analysis.

Table 24: Comparison of 3 vs. 12 Month Results – Lighting Systems

Lighting Systems	3 Month Analysis			12 Month Analysis		
Savings Realization Rate/Factor	Confidence Interval	Realization Rate/Factor	Relative Precision	Confidence Interval	Realization Rate/Factor	Relative Precision
Annual kWh Realization Rate	90%	118.1%	±8.54%	90%	112.3%	±7.89%
Connected kW Realization Rate	80%	99.7%	±2.05%	90%	99.7%	±2.64%
Summer On-Peak Coincidence Factor	80%	77.3%	±7.36%	90%	72.2%	±11.11%
Winter On-Peak Coincidence Factor	80%	65.8%	±10.13%	90%	65.9%	±12.15%
Summer On-Peak kW HVAC Interactive Effect Factor	80%	114.7%	±2.10%	90%	114.6%	±2.74%
Winter On-Peak kW HVAC Interactive Effect Factor	80%	99.8%	±0.18%	90%	99.8%	±0.37%
kWh Interactive Effect Factor	80%	105.8%	±1.03%	90%	105.4%	±1.27%
% On-Peak kWh	80%	63.1%	±4.42%	90%	63.9%	±5.62%

Table 25 presents the un-weighted average lighting hours of use and summer coincidence factors for both analyses by facility type. A review of these results showed that schools, libraries and offices had lower annual hours of operation as compared to the three month analysis. Annual hours of use for these three building types went down approximately 8% as compared to the three month analysis. These building types represented 11 of the 34 sites in the Lighting Systems sample. The annual operating hours for the remaining building types, including manufacturing, retail, exercise facilities, and other, were nearly 100% of the predicted three month analysis.

Likewise, there was a drop in the summer coincidence factors, and as a result, in the summer kW realization rates. These drops were mostly driven by schools (54% three month summer CF, 39% 12 month summer CF) and offices (89% three month summer CF, 81% 12 month summer CF). This is significant because the interim three month monitoring period covered the winter season, and the summer period was extrapolated from logger data and adjusted based on discussions with facility personnel. For schools in particular, it is difficult to predict summer usage based on this method. This is explained by the reduced and inconsistent summer usage typical of schools. For offices, it is possible that occupants use their lights less often during the day if they have windows that provide sufficient sunlight.

Additionally, vacations are also more frequent during the summer period, which could play a role in these reductions.

Table 25: Facility Type Comparison – Lighting Systems

Facility Type	Count of Facility Type	3 Month Hours of Use	12 Month Hours of Use	12 Month/ 3 Month	3 Month Summer CF	12 Month Summer CF	12 Month/ 3 Month
Manufacturing Facility	6	5,898	5,730	97%	88%	88%	100%
Office	5	4,079	3,759	92%	89%	81%	91%
Retail	5	5,727	5,473	96%	91%	91%	100%
School/University	4	3,114	2,839	91%	54%	39%	72%
Exercise Center	2	6,541	6,604	101%	89%	91%	102%
Library	2	2,129	1,990	93%	58%	58%	101%
Other	10	6,054	5,965	99%	81%	79%	98%
Average All Lighting Systems	**34**	**5,140**	**4,963**	**97%**	**81%**	**77%**	**96%**

Figure 6 presents the site-by-site comparison of hours of use for both the three month analysis (green) and the 12 month analysis (blue) for Lighting Systems. This chart highlights the differences between the estimated annual hours in the three month analysis and the actual annual hours in the 12 month analysis. As shown below, most sites had similar estimates of hours in both analyses. Of the 34 sites in this sample, 27 had a 12 month hours of use estimate within 10% of their 3 month hours of use estimate. The largest difference between the two was site 58, an office building.

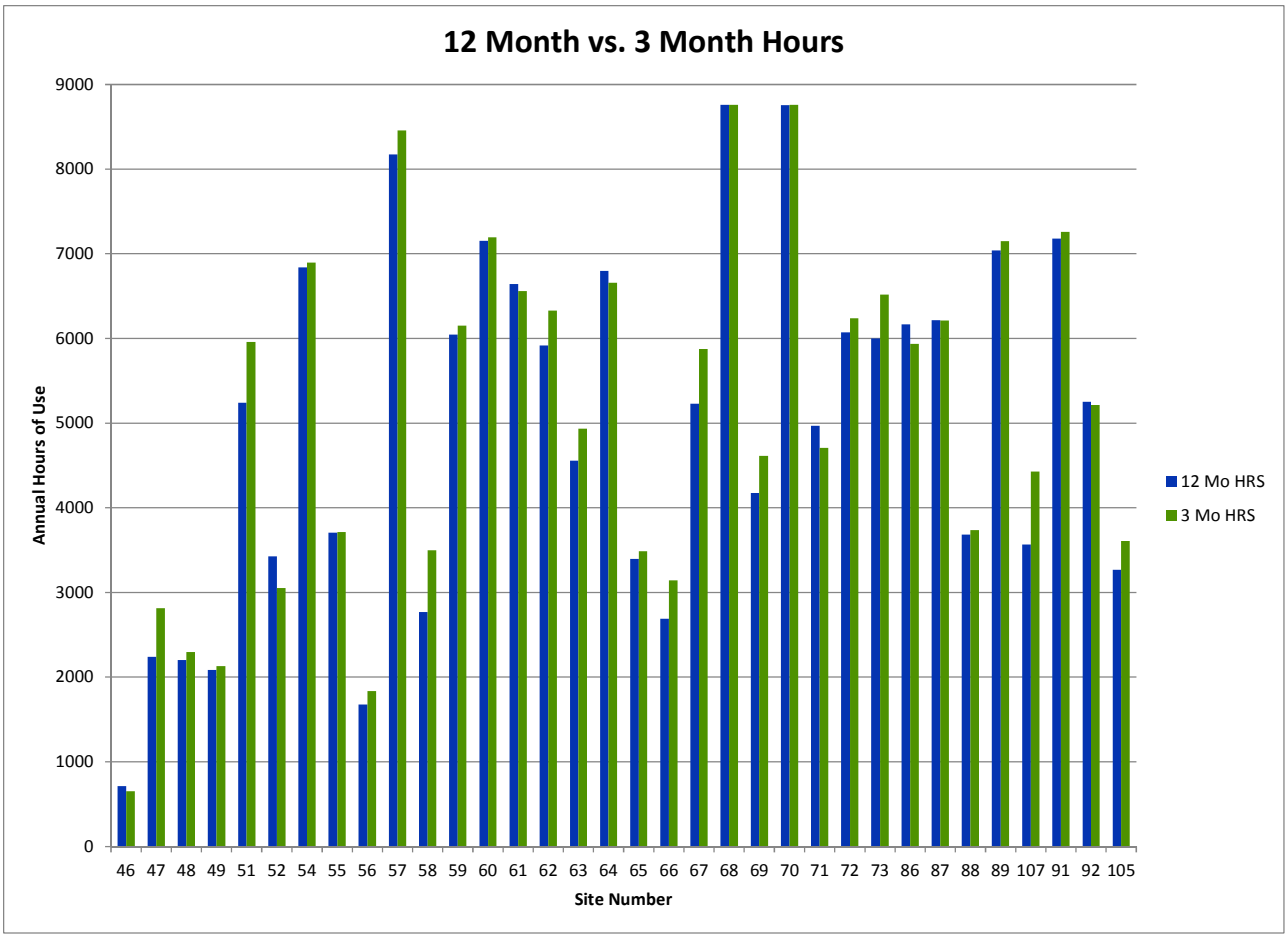

Figure 6: Site Level Hours of Use Comparison – Lighting Systems

The evaluation team also analyzed the 12 month savings results to try to determine the most representative one, two and three month metering periods for lighting systems. Table 26 presents the annualized weighted monthly average site savings, and how well they match the actual annual site savings. As shown below, January, March, July and September were the best matches when compared to the actual annual savings.

Table 26: Annualized Weighted Monthly Average Savings

Month	Annualized Weighted Monthly Average Savings (kWh)	Percent of Actual Annual Savings (kWh)
January	80,290	99.2%
February	73,070	90.2%
March	81,594	100.8%
April	77,647	95.9%
May	87,266	107.8%
June	83,707	103.4%
July	82,374	101.7%
August	84,269	104.1%
September	81,926	101.2%
October	84,732	104.6%
November	75,723	93.5%
December	79,136	97.7%
Actual Annual Savings	80,978	100.0%

Table 27 presents the annualized weighted two-month average site savings, and how well they match the actual annual site savings. As shown below, October/November and March/April appear to best represent the entire year.

Table 27: Annualized Weighted 2-Month Average Savings

Two Month Period	Annualized Weighted 2-Month Average Savings (kWh)	Percent of Actual Annual Savings (kWh)	Two Month Period	Annualized Weighted 2-Month Average Savings (kWh)	Percent of Actual Annual Savings (kWh)
Jan-Feb	76,680	94.7%	Dec-Jan	79,713	98.4%
Mar-Apr	79,621	98.3%	Feb-Mar	77,332	95.5%
May-Jun	85,487	105.6%	Apr-May	82,456	101.8%
Jul-Aug	83,321	102.9%	Jun-Jul	83,041	102.5%
Sept-Oct	83,329	102.9%	Aug-Sept	83,097	102.6%
Nov-Dec	77,430	95.6%	Oct-Nov	80,228	99.1%
Actual Annual Savings	80,978	100.0%	Actual Annual Savings	80,978	100.0%

Table 28 presents the annualized weighted three-month average site savings, and how well they match the actual annual site savings. As shown below, the three-month monitoring period between September and November best represented the entire year.

Table 28: Annualized Weighted 3-Month Average Savings

Three Month Period	Annualized Weighted 3-Month Average Savings (kWh)	Percent of Actual Annual Savings (kWh)	Three Month Period	Annualized Weighted 3-Month Average Savings (kWh)	Percent of Actual Annual Savings (kWh)	Three Month Period	Annualized Weighted 3-Month Average Savings (kWh)	Percent of Actual Annual Savings (kWh)
Jan-Mar	78,318	96.7%	Dec-Feb	77,499	95.7%	Nov-Jan	78,383	96.8%
Apr-Jun	82,873	102.3%	Mar-May	82,169	101.5%	Feb-Apr	77,437	95.6%
Jul-Sept	82,856	102.3%	Jun-Aug	83,450	103.1%	May-Jul	84,449	104.3%
Oct-Dec	79,864	98.6%	Sept-Nov	80,794	99.8%	Aug-Oct	83,642	103.3%
Actual Annual Savings	80,978	100.0%	Actual Annual Savings	80,978	100.0%	Actual Annual Savings	80,978	100.0%

Table 29 presents the same comparison for Lighting Controls. Similar to Lighting Systems, controls savings also went down between the three month and 12 month analyses. However, there was no particular pattern to the reductions. In fact, 21 of the 26 Lighting Controls sites showed lower hours reduced as compared to the three month analysis.

Table 29: Comparison of 3 vs. 12 Month Results – Lighting Controls

Lighting Controls	3 Month Analysis			12 Month Analysis		
Savings Realization Rate/Factor	Confidence Interval	Realization Rate/Factor	Relative Precision	Confidence Interval	Realization Rate/Factor	Relative Precision
Annual kWh Realization Rate	90%	84.0%	±20.72%	90%	72.0%	±23.23%
Connected kW Realization Rate	80%	93.8%	±4.67%	90%	93.8%	±5.99%
Summer On-Peak Coincidence Factor	80%	19.6%	±15.94%	90%	13.8%	±23.62%
Winter On-Peak Coincidence Factor	80%	15.4%	±44.25%	90%	13.4%	±46.34%
Summer On-Peak kW HVAC Interactive Effect Factor	80%	111.5%	±2.20%	90%	109.3%	±3.79%
Winter On-Peak kW HVAC Interactive Effect Factor	80%	99.9%	±0.10%	90%	99.6%	±0.59%
kWh Interactive Effect Factor	80%	103.1%	±1.08%	90%	103.2%	±1.52%
% On-Peak kWh	80%	60.1%	±15.51%	90%	58.9%	±22.58%

Table 30 presents the comparison of results for Advanced Lighting Design. Savings in this category also dropped from the three month analysis to the 12 month analysis. Two of the 10 sampled sites had hours of use reductions that were less than 90% of the three month estimate. One of these was a school, and the other an office building.

Table 30: Comparison of 3 vs. 12 Month Results – Advanced Lighting Design

Advanced Lighting Design	3 Month Analysis			12 Month Analysis		
Savings Realization Rate/Factor	Confidence Interval	Realization Rate/Factor	Relative Precision	Confidence Interval	Realization Rate/Factor	Relative Precision
Annual kWh Realization Rate	90%	135.1%	±12.31%	90%	124.6%	±7.60%
Connected kW Realization Rate	80%	104.5%	±4.68%	90%	101.2%	±1.73%
Summer On-Peak Coincidence Factor	80%	68.7%	±19.84%	90%	42.8%	±31.12%
Winter On-Peak Coincidence Factor	80%	59.0%	±24.87%	90%	46.7%	±15.25%
Summer On-Peak kW HVAC Interactive Effect Factor	80%	123.9%	±1.65%	90%	122.6%	±2.88%
Winter On-Peak kW HVAC Interactive Effect Factor	80%	95.2%	±5.41%	90%	94.1%	±8.33%
kWh Interactive Effect Factor	80%	108.7%	±1.69%	90%	106.6%	±2.42%
% On-Peak kWh	80%	69.3%	±4.42%	90%	65.7%	±7.78%

Table 31 shows the results of the Refrigerated LED Case Lights. As highlighted below, there were no large differences between the two analyses. Since this technology is found in grocery and other retail stores, hours of use tend to be very predictable. In many cases, these lights are controlled by remote energy management systems, and do not vary much throughout the year.

Table 31: Comparison of 3 vs. 12 Month Results – Refrigerated LED Case Lighting

Refrigerated LED Case Lighting	3 Month Analysis			12 Month Analysis		
Savings Realization Rate/Factor	Confidence Interval	Realization Rate/Factor	Relative Precision	Confidence Interval	Realization Rate/Factor	Relative Precision
Annual kWh Realization Rate	90%	97.3%	±8.72%	90%	97.5%	±8.80%
Connected kW Realization Rate	80%	100.7%	±0.67%	90%	100.7%	±0.87%
Summer On-Peak Coincidence Factor	80%	99.5%	±0.28%	90%	99.4%	±0.46%
Winter On-Peak Coincidence Factor	80%	99.5%	±0.34%	90%	99.5%	±0.45%
Summer On-Peak kW HVAC Interactive Effect Factor	80%	105.8%	±0.84%	90%	105.8%	±1.06%
Winter On-Peak kW HVAC Interactive Effect Factor	80%	105.8%	±0.84%	90%	105.8%	±1.06%
kWh Interactive Effect Factor	80%	103.7%	±1.96%	90%	103.7%	±2.61%
% On-Peak kWh	80%	60.3%	±2.96%	90%	63.5%	±3.88%

6. Conclusions and Recommendations

Overall, Massachusetts' Prescriptive Lighting programs are performing quite well. With the exception of lighting controls, each of the other three lighting measures is producing more savings than expected.

In the case of lighting systems, energy realization rates are somewhat higher than previous lighting impact evaluations, which are typically in the 100 to 110% range. There could be several reasons for this increase in lighting savings. First, the mix of building and fixture type could have an effect on the increased hours of use, which drive the higher savings. We found several manufacturing facilities with high hours of operation relative to tracking estimates. It is also possible that the economy could have played a role in under predicting the hours of use in 2010 when these projects were installed.

Lighting controls under performed with a realization rate of 74% on energy savings. The lower realization rate is somewhat consistent with a recently completed small business lighting controls impact evaluation[7], which resulted in a 43% realization rate.

The following are some conclusions and recommendations for all measures, and some specific to each measure analyzed.

6.1 All Prescriptive Lighting Measures

- **Evaluation Monitoring.** This study produced and compared results of monitoring periods of three months and 12 months in length. The three month metering study was more typical of a lighting impact evaluation, while the 12 month study was more comprehensive and costly. In consideration of study costs of performing 12 months of metering, the two analyses were compared. In general, the typical, three month study did a good job of estimating annual energy savings using shorter term monitoring. There were cases such as schools and offices in which it proved to be more difficult to estimate summer usage using only three months of winter data. Additionally, it was difficult to estimate summer coincidence factors for schools since these facilities tend to be closed, or have inconsistent usage in the summer. The three month period that was most representative of the entire year was between September and November. However, all combinations of three month monitoring periods were within 5% of the annual savings when annualized. Therefore, it is recommended that the PAs consider monitoring for a minimum of three months. Also consider including a winter or summer month in that period if possible.

- **HVAC Interactive Effects.** This study produced realization rates for energy and demand savings with HVAC interactive effects. Additionally, this report provides individual realization rates and savings factors that are multiplicative, and can be used to estimate savings going forward. However, caution is advised when applying these realization rates and savings factors so that savings involving HVAC interactive effects are not duplicated. It was found that some PAs are including HVAC interactive effects in some lighting systems projects, but the majority of

[7] Small Business Direct Install Program: Pre/Post Lighting Occupancy Sensor Study, Prepared by: The Cadmus Group and Energy & Resource Solutions, Inc., October 23, 2012

projects did not. If HVAC savings are being claimed as part of the gross tracking savings, the PAs should apply the Annual kWh Realization Rate. Otherwise, the Annual kWh with HVAC Realization Rate should be applied. Likewise, the Summer and Winter HVAC Interactive Effect Factors and the kWh HVAC Interactive Effect Factor should only be applied if HVAC savings are not being claimed as part of the tracking savings.

6.2 Lighting Systems

- **Update the TRM.** The current TRM[8] includes realization rates and savings factors that are specific to individual PAs. This impact evaluation was designed to produce statewide results for prescriptive lighting savings. This study produces results for energy and demand realization rates, and summer and winter coincidence factors that had relative precisions at or better than +/- 10%. It is recommended that the Lighting Systems component of the TRM be updated to reflect these new results, which are mostly based on 12 months of metering.

- **Lighting Hours of Use.** The primary reason for the increase in savings was the underestimated annual operating hours. On average, lighting hours of use were found to be approximately 12% greater than predicted in the tracking savings. Lighting operation is the most difficult parameter to predict when developing lighting savings. The Massachusetts PAs typically base this parameter on building specific data rather than a deemed value. Usually, this estimate is based on a facilities actual operating hours. However, it is likely that some lighting within a facility operates longer than the general business hours. It is recommended that the PAs continue to use site specific data when estimating lighting hours of use. Also consider additional operation that may not be captured in the typical business hours for spaces such as stairwells, corridors and large open areas that may not go dark until the last person leaves for the day. Also be sure to consider potential day lighting effects, which could limit the hours of operation

6.3 Lighting Controls

- **Consider a Pre/Post Lighting Controls Study.** A concurrent study is being done to examine the Massachusetts market for lighting controls. In recent years, the MA PAs have seen a decrease in lighting controls installations. This market study is expected to be completed in the summer of 2013, and will provide much needed information on the status of lighting controls in MA. Since lighting controls savings are completely dependent on a change in operation, the best way to evaluate them would be to perform pre-installation metering. Depending on the outcome of the

[8] Massachusetts Technical Reference Manual, Three-Year Plan 2013-2015, October 31, 2012

current lighting controls market study, it may be a recommended that a pre/post metering lighting controls study be conducted in the future.

- **Consider Pre-Installation Monitoring.** Occupancy sensors represent the largest component of lighting controls program savings in MA. Savings for these measures are driven by the vendor or TA estimate of hours reduced. In most cases, this value is based on the difference between site specific estimates for baseline or pre-existing and the proposed hours of use. As found in this study, as well as previous lighting controls studies, tracking estimates of hours reduced are generally overestimated. It tends to be more difficult to estimate hours reduced than hours of use, which is why lighting systems savings are more stable. To help implementation vendors and TAs produce more reliable estimates of hours reduced, it is recommended that the PAs consider requiring pre-installation metering to establish an estimate of baseline hours. This could be done as part of the vendors' walkthrough of a facility when trying to determine where lighting controls will be installed. A minimum of two weeks of data would be ideal for this type of effort. It is likely that this strategy would help improve lighting controls savings estimates going forward.

- **Update the TRM.** The current TRM includes realization rates and coincidence factors that are specific to individual PAs. This impact evaluation was designed to produce statewide results for prescriptive lighting savings. However, this study had relatively poor precisions for energy and demand savings and savings factors due to the high variability (error ratio of 0.6) between tracking and evaluation estimates. Until a new pre/post lighting controls impact evaluation is done, it is recommended that the lighting controls component of the TRM be updated to reflect these new results, which are based on 12 months of post-installation only metering. Although the relative precision of these results are poor, the methodology is similar to previous lighting controls impact evaluations, which makes these results just as reliable as previous studies.

6.4 Advanced Lighting Design

- **Collect Final Lighting As-Builts.** Annual energy savings were significantly higher than tracking savings for this group. The primary reason was a large increase in annual hours. However, there was about a 5% increase in connected kW savings due to lower connected wattage in the as-built condition as compared to the proposed condition. Since the baseline for these types of new construction lighting project remain fixed relative to the square footage, savings can swing significantly with any changes to the proposed condition. It is recommended that for all Advanced Lighting Design projects, the PAs try to collect the final lighting as-built, which would be used to adjust the proposed connected kW savings.

- **Update the TRM.** The current TRM includes realization rates and coincidence factors that are specific to individual PAs. This impact evaluation was designed to produce statewide results for prescriptive lighting savings. This study produces results for energy realization rates that had relative precisions at or better than +/-11%. However, the realization rates for summer and winter demand savings and the savings factors were not quite as good. It is recommended that the PAs and EEAC consider updating the TRM using these realization rates and savings factors.

6.5 Refrigerated LED Case Lighting

- **Update the TRM.** The 2013-15 TRM currently includes interactive refrigeration savings as part of the savings algorithm. The refrigeration system efficiency used in this version of the TRM is 1.6 kW/Ton. This evaluation found that the majority of the LED lights were being installed in freezer cases, which indicates that a higher value for refrigeration system efficiency be used. This report recommends that the TRM be updated to utilize a refrigeration system efficiency of 1.9 kW/Ton. This value is based on a larger proportion of lower temperature freezer cases than cooler cases found in these applications. Please note that the refrigeration interactive factor developed for this study is based on the tracking assumption of 1.3 kW/ton. This means that if the TRM is updated to reflect the 1.9 kW/ton recommendation, the refrigeration interactive factor would no longer be applied.

- **Consider Lighting Controls.** Lighting controls on freezer and cooler cases were seen in one or two custom lighting applications as part of the Impact Evaluation of 2010 Custom Lighting Installations in Massachusetts, completed in May, 2012. This appears to be a good application for lighting controls, and an opportunity for deeper savings when the reduction in refrigeration energy is considered. It is recommended that in all future freezer/cooler case LED lighting applications, lighting controls be considered.

A. Description of Results and Factors

This section presents a listing of realization rate and savings factors that were produced as part of this study. Each entry contains a description of that savings variable.

A.1 Realization Rates

Annual KWh – This result is the gross annual kWh realization rate including additional savings due to HVAC interactive effects. This realization rate is the evaluation gross annual kWh savings divided by the tracking gross annual kWh savings.

Connected KW – This result is the gross connected kW realization rate, which includes any documentation, quantity, and technology adjustments. This realization rate is the evaluation gross connected kW savings divided by the tracking gross connected kW savings.

Connected kWh – This result is the gross connected kWh realization rate, which includes only the documentation, quantity, and technology adjustments. This realization rate is the evaluation gross connected kWh savings divided by the tracking gross connected kWh savings.

Hours of Use – This result is the hours of use realization rate, which represents the evaluation estimate of hours of use divided by the tracking estimate of hours of use.

A.2 Savings Factors

Summer Coincidence Factor

On Peak Hours – Diversity x Coincidence. This is the percentage of the connected kW savings coincident with the summer on-peak period.

Seasonal Hours – Diversity x Coincidence. This is the percentage of the connected kW savings coincident with the summer seasonal peak period.

Winter Coincidence Factor

On Peak Hours – Diversity x Coincidence. This is the percentage of the connected kW savings coincident with the winter on-peak period.

Seasonal Hours – Diversity x Coincidence. This is the percentage of the connected kW savings coincident with the winter seasonal peak period.

Summer kW HVAC Interactive Effect

On Peak Hours – This is the percentage of gross connected kW savings that are due to interactive effects during the summer on-peak period.

Seasonal Hours – This is the percentage of gross connected kW savings that are due to interactive effects during the summer seasonal peak period.

Winter kW HVAC Interactive Effect

On Peak Hours – This is the percentage of gross connected kW savings that are due to interactive effects during the winter on-peak period.

Seasonal Hours – This is the percentage of gross connected kW savings that are due to interactive effects during the winter seasonal peak period.

KWh HVAC Interactive Effect – This is the percentage of the gross kWh savings that are due to interactive effects.

% On Peak KWh – This is the percentage of energy savings that occur during on-peak hours.

Table 32: Summary of Results and Factors

Tracking System Values		**Evaluation Values**	
(a)	Annual kWh	(j)	Annual kWh
(b)	kWh HVAC Factor	(k)	kWh HVAC Factor
(c)	On-Peak % Annual kWh	(l)	On-Peak % Annual kWh
(d)	Connected kW	(m)	Connected kW
(e)	Summer kW Coincidence Factor	(n)	Summer kW Coincidence Factor
(f)	Summer kW HVAC Factor	(o)	Summer kW HVAC Factor
(g)	Winter kW Coincidence Factor	(p)	Winter kW Coincidence Factor
(h)	Winter kW HVAC Factor	(q)	Winter kW HVAC Factor
(i)	Average Hours of Use	(r)	Average Hours of Use

Realization Rates	
(s)	Annual kWh
(t)	Connected kW
(u)	Connected kWh
(v)	Hours of Use

Savings Algorithms	
Evaluated Annual kWh Savings	(a) x (s) or (a) x (u) x (v) x (k)
Evaluated Connected kW	(d) x (t)
Evaluated Summer Peak kW Reduction	(d) x (t) x (n) x (o)
Evaluated Winter Peak kW Reduction	(d) x (t) x (p) x (q)

B. Calculation Methods

This section serves as a detailed example that illustrates the calculation of all savings and adjustment factors. DNV KEMA modified a single line item from one of the actual customers involved in the evaluation to serve as an example of the calculation methods. Table 33 presents a summary of all savings parameters for this particular example.

Table 33: Calculation Example Result Summary

Parameter	Annual KWH	Difference %	Connected kW	Difference %
Gross (TRACKING) kWh/Connected kW Savings	3,690	N/A	0.74	N/A
Adjustment - Documentation Change	0	0%	0.00	0%
Adjustment - Technology Change	0	0%	0.00	0%
Adjustment - Quantity Change	-410	-11%	-0.08	-11%
Adjustment - Operation Change	543	15%	N/A	N/A
Non-Interactive Savings	3,823	104%	0.66	89%
Adjustment - Cooling Interaction	314	9%		
Adjusted Gross (ONSITE) Savings	4,136	112%		

Parameter	On-Peak Summer kW	Difference %	On-Peak Winter kW	Difference %
Connected Demand Savings	0.66	N/A	0.66	N/A
Adjustment - On-Peak Coincidence	-0.12	-18%	0.00	0%
Non-Interactive Savings	0.54	82%	0.66	100%

Parameter	On-Peak Summer kW	Difference %	On-Peak Winter kW	Difference %
Non-Interactive Savings	0.54	N/A	0.66	N/A
Adjustment - HVAC Interaction	0.14	27%	0.00	0%
Adjusted Gross (ONSITE) Savings	0.68	127%	0.66	100%

Table 34 presents the pre-retrofit condition for this space as outlined in the application documentation. The pre-retrofit condition included (18) 2F40SSS fixtures rated at 94 watts each. The application also assumed 5,000 annual operating hours.

Table 34: Tracking Pre-Retrofit Condition

Qty	Lighting Fixture Code	Fixture Type	Fixture Description	W/Fixt	Hours of Operation per Year
18	2F40SSS	2L4' STD/STD	Four Foot T12 Systems	94	5,000

Table 35 represents the proposed condition according to the tracking system. In this case, the pre-retrofit fixtures were to be replaced with (18) 2F32EEE fixtures rated at 53 watts each. The hours of operation in the proposed condition were also 5,000 annual operating hours.

Table 35: Tracking Proposed Condition

Qty	Lighting Fixture Code	Fixture Description	Fixture Type	W/Fixt	Hours of Operation per Year
18	2F32EEE	2L4' T8EE/ELEE	Four Foot T8 HP/RW Systems	53	5,000

The first step of the savings analysis was to recreate the savings calculations based upon project documentation. This was done to isolate any documentation adjustments.

Documentation Adjustments

Documentation adjustments reflect any change in savings due to discrepancies in project documentation. Evaluators recalculated the tracking estimates of savings using all quantities, fixture types/wattages, and hours documented in the project file. All tracking system discrepancies and documentation errors are reflected in this adjustment. The documentation adjustments are calculated according to the following formulae:

DOC KWH ADJ = Recreated Tracking kWh Savings – Tracking kWh Savings = 3,690 - 3,690 = 0 kWh

DOC KW ADJ = Recreated Tracking kW Savings – Tracking kW Savings = 0.74 – 0.74 = 0 kW

Hours of Use and Coincidence

The first on-site task was establishing the customer's holiday and vacation/shutdown schedule. Table 36 shows the input for the site holiday analysis. In this particular case, the site contact informed the evaluating engineer that the facility was closed during 6 major holidays. He also stated that the facility does not have any long shutdowns.

Table 36: Input for Site Specific Holidays

Holiday	Date	Site Observed Holidays
New Year's Day	1/1/2012	Y
Martin Luther King Day	1/16/2012	N
Presidents Day	2/20/2012	N
Good Friday	4/6/2012	N
Memorial Day	5/28/2012	Y
Independence Day	7/4/2012	Y
Labor Day	9/3/2012	Y
Columbus Day	10/8/2012	N
Veteran's Day	11/11/2012	N
Thanksgiving Day	11/22/2012	Y
Day After Thanksgiving	11/23/2012	N
Christmas Eve	12/24/2012	N
Christmas Day	12/25/2012	Y

To determine the annual operating hours from monitoring lighting logger data, engineers examine the hourly percent run time across the entire monitoring period. For this study, lighting logger data was adjusted for the daylight savings time change that occurred within the monitoring period.

For the three month logger data analysis, an 8x24 profile (Monday through Friday plus Holiday by hour-of-day) is generated using a computer program to represent the average percentage of time that the fixture operated during the monitoring study. Table 37 presents the profile of the logger used for this example.

Table 37: Logger Profile Summary

Hour Ending	Sun	Mon	Tue	Wed	Thu	Fri	Sat	Hol
1	33.4	36.0	48.5	45.4	45.5	52.7	44.8	57.3
2	33.9	36.0	41.8	47.0	41.4	49.3	45.8	50.9
3	32.0	36.0	49.5	38.6	41.8	38.9	40.5	50.0
4	32.0	36.3	41.1	35.6	35.3	37.1	36.5	50.0
5	57.1	39.4	39.7	36.2	33.5	37.4	49.4	50.0
6	33.8	56.7	54.1	52.8	83.6	49.7	35.3	50.0
7	33.6	75.3	89.1	66.3	94.3	65.9	38.6	50.0
8	35.0	98.7	99.8	99.5	99.0	98.8	46.9	51.7
9	36.6	100.0	100.0	99.9	100.0	100.0	51.1	56.8
10	37.9	100.0	100.0	100.0	100.0	100.0	58.2	50.0
11	34.7	100.0	100.0	100.0	99.8	100.0	52.8	50.0
12	36.6	99.6	100.0	100.0	99.9	100.0	53.3	50.0
13	35.7	98.4	100.0	100.0	99.5	100.0	44.7	50.0
14	34.6	99.1	100.0	100.0	98.8	99.9	42.7	50.0
15	33.5	100.0	100.0	100.0	100.0	100.0	47.8	50.0
16	36.6	94.1	91.6	94.0	91.9	90.2	42.6	50.0
17	34.2	71.7	66.2	64.2	65.5	61.0	41.8	50.0
18	36.1	80.6	83.8	83.3	80.1	83.3	36.8	50.0
19	37.2	94.4	95.2	95.5	95.1	94.8	35.3	50.0
20	33.7	94.7	88.9	92.9	93.6	96.6	34.5	50.0
21	32.0	98.3	96.2	94.5	96.5	96.5	36.9	50.0
22	33.1	95.6	91.5	88.4	86.9	73.0	34.8	50.0
23	32.2	76.5	70.6	67.7	60.7	65.3	34.0	50.0
24	32.7	51.2	48.4	46.1	46.2	54.9	42.2	50.0

For the 12 month logger data analysis, the actual 8,760 hourly percentage of time that the fixture operated during the monitoring study was used directly. This analysis concluded that this fixture operates 5,827 hours per year, of which 67% of these operating hours occur coincide with the defined on-peak period definition. The on-peak summer and winter coincidence factors are 82% and 100%, respectively.

Non-Interactive On-Site Savings

Table 38 represents the on-site installed condition as found the evaluation team. For this example, the evaluator identified (16) 2F32EEE fixtures, which was two fewer fixtures than in the project documentation. A schedule identification number ("1" in this example) maps the hours of operation and the summer and winter coincidences into this spreadsheet.

Table 38: On-Site Installed Condition

Qty	Lighting Fixture Code	Fixture Description	Fixture Type	W/Fixt	Schedule Number	Hours of Operation per Year	On-Peak Summer Coincidence	On-Peak Winter Coincidence
16	2F32EEE	2L4' T8EE/ELEE	Four Foot T8 HP/RW Systems	53	1	5,827	82%	100%

The on-site pre-retrofit condition, presented in Table 39, was established through review of project documents, discussion with facility personnel, and observational inference. This lighting fixture savings analysis presumes that the operating hours did not change between the pre- and post-retrofit conditions.

Table 39: On-Site Pre-Retrofit Condition

Qty	Lighting Fixture Code	Fixture Description	Fixture Type	W/Fixt	Hours of Operation per Year
16	2F40SSS	2L4' STD/STD	Four Foot T12 Systems	94	5,827

Table 40 presents the adjusted gross on-site savings for this example.

Table 40: Adjusted Gross On-Site Savings

kW Savings	kW Summer Savings	kW Winter Savings	kWh Savings
0.656	0.536	0.656	3,823

Heating and Cooling Interaction

Heating and cooling interaction was calculated for each line item where applicable based on the specific HVAC systems serving the space. When lighting equipment converts electrical energy to light, a significant amount of that energy is dissipated in the form of heat. Energy efficient lighting measures convert more electrical energy to light and less to heat. Since installing energy efficient lighting adds less heat to a given space, a complete estimation of energy savings considers the associated impacts on the heating and cooling systems or "interactive effects."

The interactive effects take into account the effect of the energy efficient lighting measures on their corresponding heating and cooling systems. Energy efficient lighting serves to reduce the heat gain to a given space and accordingly reduces the load on cooling equipment. But this reduced heat gain has the added consequence of increasing the load on the heating system.

As part of the on-site methodology, evaluators interviewed facility personnel to ascertain the cooling and heating fuel, system type, and other information with which to approximate the efficiency of the HVAC equipment serving the space of each lighting installation. The DNV KEMA team expresses HVAC system efficiency in dimensionless units of Coefficient of Performance (COP), which reflects the ratio of work performed by the system to the work input of the system. Table 41 details the COP assumptions for general heating and cooling equipment types encountered in this study. Where site specific information

yields improved estimates of system efficiency, these were used in place of the general assumptions below.

Table 41: General Heating and Cooling COP Assumptions

Cooling System Type	COP
Packaged DX	2.9
Window DX	2.7
Chiller <200 Ton	4.7
Chiller >200 Ton	5.5
Air to Air Heat Pump	3.9
Water to Air Heat Pump	4.4
Refrigerated Area (high temp)	1.4
Refrigerated Cases (low temp)	1.9

Heating System Type	COP
Air to Air Heat Pump	1.5
Electric Resistance	1
Water to Air Heat Pump	2.8

Interactive effects are calculated only at sites where heating or cooling systems are in use. Leveraging the 8,760 profile of hourly demand impacts, the DNV KEMA team computes electric interactive effects during the hours that lighting and HVAC are assumed to operate in unison.

DNV KEMA utilizes Typical Meteorological Year 3 (TMY3) hourly dry-bulb temperatures for Worcester, Massachusetts as the balance point criteria in this analysis. For each hour in a typical year, DNV KEMA computes HVAC interaction according to the following equations:

Cooling kW Effects = 80% * Lighting kW Savings / Cooling System COP

Heating kW Effects = -80% * Lighting kW Savings / Heating System COP

The 80% values represent the assumed percentage of the lighting energy that translates to heat which either must be removed from the space by the air conditioning system or added to the space by the heating system during the aforementioned HVAC hours. This assumption is consistent with those established and employed in previous impact evaluations of custom lighting measures. Also, heating factors are negative because heating interaction erodes gross lighting savings, while cooling interactive boosts it.

C. Site Level Results

C.1 Lighting Systems

Table 42: Lighting Systems Tracking Estimates

Lighting Systems			Tracking								
			(a)	(b)	(c)	(d)	(e)	(f)	(g)	(h)	(i)
KEMA ID	Application ID	Facility Type	Annual kWh	kWh HVAC Factor	On-Peak % Annual kWh	Connected kW	Summer kW Coincidence Factor	Summer kW HVAC Factor	Winter kW Coincidence Factor	Winter kW HVAC Factor	Average Hours of Use
46	544262	Library	13,593	N/A	N/A	5.27	N/A	N/A	N/A	N/A	2,581
47	546599	Other	20,286	N/A	N/A	5.15	N/A	N/A	N/A	N/A	3,937
48	592612	Retail	21,109	N/A	N/A	7.72	N/A	N/A	N/A	N/A	2,736
49	544258	Police/Fire Station	20,795	N/A	N/A	8.32	N/A	N/A	N/A	N/A	2,500
51	581137	Office	7,175	N/A	N/A	1.44	N/A	N/A	N/A	N/A	5,000
52	621570	School/University	49,413	N/A	N/A	17.81	N/A	N/A	N/A	N/A	2,774
54	722811	Dormitory	76,952	N/A	N/A	18.39	N/A	N/A	N/A	N/A	4,184
55	660907	Office	115,333	N/A	N/A	22.53	N/A	N/A	N/A	N/A	5,119
56	546524	School/University	103,282	N/A	N/A	57.38	N/A	N/A	N/A	N/A	1,800
57	632684	Motion Picture Theatre	150,276	N/A	N/A	29.31	N/A	N/A	N/A	N/A	5,127
58	547042	Office	168,622	N/A	N/A	70.16	N/A	N/A	N/A	N/A	2,403
59	650917	Manufacturing Facility	98,837	N/A	N/A	18.02	N/A	N/A	N/A	N/A	5,484
60	621718	Other	161,148	N/A	N/A	26.01	N/A	N/A	N/A	N/A	6,195
61	576653	Manufacturing Facility	203,118	N/A	N/A	23.19	N/A	N/A	N/A	N/A	8,759
62	651249	Retail	233,568	N/A	N/A	38.93	N/A	N/A	N/A	N/A	6,000
63	658493	Manufacturing Facility	219,304	N/A	N/A	63.10	N/A	N/A	N/A	N/A	3,475
64	581008	Manufacturing Facility	132,726	N/A	N/A	17.50	N/A	N/A	N/A	N/A	7,584
65	694532	Office	213,150	N/A	N/A	67.58	N/A	N/A	N/A	N/A	3,154
66	591585	School/University	187,569	N/A	N/A	60.80	N/A	N/A	N/A	N/A	3,085
67	544486	Manufacturing Facility	176,410	N/A	N/A	63.04	N/A	N/A	N/A	N/A	2,798
68	606427	Warehouse	144,855	N/A	N/A	16.54	N/A	N/A	N/A	N/A	8,760
69	621710	Other	385,564	N/A	N/A	84.94	N/A	N/A	N/A	N/A	4,539
70	565829	Other	358,722	N/A	N/A	40.95	N/A	N/A	N/A	N/A	8,760
71	544468	Hospital	557,341	N/A	N/A	108.89	N/A	N/A	N/A	N/A	5,118
72	573018	Retail	383,028	N/A	N/A	63.84	N/A	N/A	N/A	N/A	6,000
73	573019	Retail	414,720	N/A	N/A	69.12	N/A	N/A	N/A	N/A	6,000

Lighting Systems			Tracking								
			(a)	(b)	(c)	(d)	(e)	(f)	(g)	(h)	(i)
KEMA ID	Application ID	Facility Type	Annual kWh	kWh HVAC Factor	On-Peak % Annual kWh	Connected kW	Summer kW Coincidence Factor	Summer kW HVAC Factor	Winter kW Coincidence Factor	Winter kW HVAC Factor	Average Hours of Use
86	BS8890	Exercise Center	54,117	N/A	N/A	9.34	N/A	N/A	N/A	N/A	5,797
87	BS8725	Other	71,289	N/A	N/A	12.01	N/A	N/A	N/A	N/A	5,935
88	BS8762	Office	65,336	N/A	N/A	15.46	N/A	N/A	N/A	N/A	4,225
89	BS8609	Exercise Center	151,659	N/A	N/A	25.24	N/A	N/A	N/A	N/A	6,009
107	644669	School/University	104,854	N/A	N/A	39.15	N/A	N/A	N/A	N/A	2,679
91	BS8667	Retail	143,693	N/A	N/A	28.18	N/A	N/A	N/A	N/A	5,100
92	BS9087	Manufacturing Facility	225,392	N/A	N/A	46.96	N/A	N/A	N/A	N/A	4,800
105	WM10L255	Library	16,111	N/A	N/A	7.26	N/A	N/A	N/A	N/A	2,220

Table 43: Lighting Systems Evaluation Estimates

Lighting Systems			Evaluation								
			(j)	(k)	(l)	(m)	(n)	(o)	(p)	(q)	(r)
KEMA ID	Application ID	Facility Type	Annual kWh	kWh HVAC Factor	On-Peak % Annual kWh	Connected kW	Summer kW Coincidence Factor	Summer kW HVAC Factor	Winter kW Coincidence Factor	Winter kW HVAC Factor	Average Hours of Use
46	544262	Library	4,210	108%	88%	5.50	27%	117%	10%	100%	712
47	546599	Other	9,894	100%	51%	4.42	25%	100%	51%	100%	2,238
48	592612	Retail	18,452	107%	79%	7.82	55%	117%	38%	100%	2,202
49	544258	Police/Fire Station	17,735	102%	69%	8.32	47%	108%	24%	100%	2,084
51	581137	Office	5,370	100%	75%	1.03	93%	100%	97%	100%	5,239
52	621570	School/University	61,018	100%	78%	17.81	47%	100%	56%	100%	3,426
54	722811	Dormitory	124,514	101%	48%	17.95	81%	104%	69%	100%	6,839
55	660907	Office	88,667	106%	92%	22.53	94%	114%	87%	100%	3,706
56	546524	School/University	104,747	109%	97%	57.38	24%	126%	19%	100%	1,675
57	632684	Motion Picture Theatre	262,904	111%	47%	29.05	92%	127%	92%	100%	8,175
58	547042	Office	209,674	107%	76%	70.52	43%	126%	53%	100%	2,769
59	650917	Manufacturing Facility	109,978	104%	50%	17.48	71%	114%	78%	100%	6,046
60	621718	Other	186,019	100%	50%	26.01	92%	100%	100%	100%	7,151
61	576653	Manufacturing Facility	165,896	108%	57%	23.19	88%	127%	84%	100%	6,641
62	651249	Retail	256,051	111%	62%	38.93	100%	127%	100%	100%	5,915
63	658493	Manufacturing Facility	288,028	100%	70%	63.08	85%	101%	49%	100%	4,555
64	581008	Manufacturing Facility	118,982	100%	58%	17.50	96%	100%	95%	100%	6,798
65	694532	Office	196,339	104%	75%	55.71	84%	110%	40%	100%	3,396
66	591585	School/University	178,870	109%	74%	60.75	48%	127%	51%	100%	2,689
67	544486	Manufacturing Facility	385,822	100%	69%	73.76	97%	100%	88%	100%	5,230
68	606427	Warehouse	155,936	108%	48%	16.54	100%	127%	100%	100%	8,760
69	621710	Other	369,097	104%	58%	84.81	69%	114%	55%	100%	4,174
70	565829	Other	334,668	100%	47%	38.23	99%	100%	100%	100%	8,755

Lighting Systems			Evaluation								
			(j)	(k)	(l)	(m)	(n)	(o)	(p)	(q)	(r)
KEMA ID	Application ID	Facility Type	Annual kWh	kWh HVAC Factor	On-Peak % Annual kWh	Connected kW	Summer kW Coincidence Factor	Summer kW HVAC Factor	Winter kW Coincidence Factor	Winter kW HVAC Factor	Average Hours of Use
71	544468	Hospital	574,037	106%	59%	109.10	83%	114%	65%	100%	4,970
72	573018	Retail	430,904	111%	61%	63.84	100%	127%	100%	100%	6,069
73	573019	Retail	460,369	111%	62%	69.12	100%	127%	100%	100%	5,997
86	BS8890	Exercise Center	63,318	110%	64%	9.34	99%	123%	99%	100%	6,168
87	BS8725	Other	115,770	98%	65%	18.95	100%	100%	99%	95%	6,216
88	BS8762	Office	53,182	106%	79%	13.63	89%	114%	71%	100%	3,683
89	BS8609	Exercise Center	191,941	110%	51%	24.83	83%	127%	97%	100%	7,039
107	644669	School/University	140,953	100%	63%	39.53	38%	100%	50%	100%	3,566
91	BS8667	Retail	192,446	111%	54%	24.15	100%	127%	100%	100%	7,179
92	BS9087	Manufacturing Facility	257,373	106%	68%	46.28	96%	114%	91%	100%	5,252
105	WM10L255	Library	26,390	111%	86%	7.26	90%	127%	67%	100%	3,268

Table 44: Lighting Systems Realization Rates and Primary Reasons for Discrepancies

Lighting Systems		Realization Rates				
		(s)	(t)	(w)	(ab)	
KEMA ID	Application ID	Annual kWh (Excluding HVAC)	Annual kWh (Including HVAC)	Connected kW	Average Hours of Use	Primary Reasons for Discrepancies
46	544262	29%	31%	104%	28%	Evaluated hours of use 28% of tracking estimates.
47	546599	49%	49%	86%	57%	Hours of use 57% of tracking estimates. Identified (24) 3F32T8 fixtures instead of 2F32T8 fixtures in one area.
48	592612	82%	87%	101%	80%	Reduction in average hours of use.
49	544258	83%	85%	100%	83%	Hours of use 83% of tracking estimate.
51	581137	75%	75%	71%	105%	Reduction due to quantity reduction and small increase in operation.
52	621570	123%	123%	100%	123%	Evaluated hours of use 23% higher than estimated in the tracking assumptions.
54	722811	159%	162%	98%	163%	Logged Hours were higher than tracking.
55	660907	72%	77%	100%	72%	Hours of use 72% of tracking estimates.
56	546524	93%	101%	100%	93%	Addition of HVAC interactive effects increased savings estimates.
57	632684	158%	175%	99%	159%	Increase in annual hours of use.
58	547042	116%	124%	101%	115%	Evaluated annual hours of use 15% higher than tracking estimates.
59	650917	107%	111%	97%	110%	Logged Hours of Use is higher than tracking estimates.
60	621718	115%	115%	100%	115%	Logged Hours of Use is higher than predicted.
61	576653	76%	82%	100%	76%	Evaluated annual hours of use 76% of tracking estimates.
62	651249	99%	110%	100%	99%	HVAC Interaction (11% increase)
63	658493	131%	131%	100%	131%	Hours of operation 31% higher than tracking estimates.
64	581008	90%	90%	100%	90%	Hours of use less than predicted in the tracking estimate.

Lighting Systems		Realization Rates				
		(s)	(t)	(w)	(ab)	
KEMA ID	Application ID	Annual kWh (Excluding HVAC)	Annual kWh (Including HVAC)	Connected kW	Average Hours of Use	Primary Reasons for Discrepancies
65	694532	89%	92%	82%	108%	Tracking system assumed that 139 of the replaced fixtures were 4LT8 when they were actually 2LT8. Logger hours were approximately 8% higher on average than was assumed in the tracking system. Tracking assumed a 6F32EEE fixture type for the warehouse for lighting reduction, but used a 6F32SSH fixture type for controls savings. Actual fixture installed was a 6F32SSH, which resulted in a 7% documentation change.
66	591585	87%	95%	100%	87%	HVAC interaction (8%) combined with decrease in annual hours of operation (-13%)
67	544486	219%	219%	117%	187%	Logged hours of use almost twice as much as estimated in the tracking savings. Additional increase in savings due to increase in fixture quantity.
68	606427	100%	108%	100%	100%	HVAC interaction increased savings by 8%.
69	621710	92%	96%	100%	92%	Combination of operation (-8%) and HVAC interaction (4%)
70	565829	93%	93%	93%	100%	Incorrect fixture type used in the tracking savings estimates.
71	544468	97%	103%	100%	97%	Reduced hours of use offset by increase due to HVAC interaction.
72	573018	101%	112%	100%	101%	HVAC interaction increased savings by 11%.
73	573019	100%	111%	100%	100%	HVAC Interaction (11% increase)
86	BS8890	106%	117%	100%	106%	Increased savings due to HVAC interactive effects.
87	BS8725	165%	162%	158%	105%	Savings increased due to a differing fixture types between the tracking and evaluation.
88	BS8762	77%	81%	88%	87%	Annual hours of use approximately 13% lower than proposed on average.
89	BS8609	115%	127%	98%	117%	Combination of HVAC Interaction (10% increase) and Annual hours (17% increase).

Lighting Systems		Realization Rates				
		(s)	(t)	(w)	(ab)	
KEMA ID	Application ID	Annual kWh (Excluding HVAC)	Annual kWh (Including HVAC)	Connected kW	Average Hours of Use	Primary Reasons for Discrepancies
107	644669	134%	134%	101%	133%	Annual hours of use higher than tracking estimate.
91	BS8667	121%	134%	86%	141%	All 805 program fixtures were found to be 52W 2L4'T8, while the tracking system assumed they were 47W. Logged HOU were 42% higher than assumed in the tracking system.
92	BS9087	108%	114%	99%	109%	Hours of use higher than tracking estimates. Additional savings due to HVAC interaction.
105	WM10L255	147%	164%	100%	147%	Annual hours of use higher than proposed. HVAC interactive savings included in evaluation.

C.2 Lighting Controls

Table 45: Lighting Controls Tracking Estimates

Lighting Controls			Tracking								
			(a)	(b)	(c)	(d)	(e)	(f)	(g)	(h)	(i)
KEMA ID	Application ID	Facility Type	Annual kWh	kWh HVAC Factor	On-Peak % Annual kWh	Connected kW	Summer kW Coincidence Factor	Summer kW HVAC Factor	Winter kW Coincidence Factor	Winter kW HVAC Factor	Average Reduction in Hours of Use
47	546599	Other	7,632	N/A	N/A	4.35	N/A	N/A	N/A	N/A	1,756
48	592612	Retail	960	N/A	N/A	0.48	N/A	N/A	N/A	N/A	2,001
49	544258	Police/Fire Station	494	N/A	N/A	0.66	N/A	N/A	N/A	N/A	750
111	594528	Other	5,803	N/A	N/A	1.86	N/A	N/A	N/A	N/A	3,120
52	621570	School/University	26,782	N/A	N/A	21.54	N/A	N/A	N/A	N/A	1,244
54	722811	Dormitory	9,191	N/A	N/A	9.30	N/A	N/A	N/A	N/A	988
55	660907	Office	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
56	546524	School/University	13,223	N/A	N/A	24.49	N/A	N/A	N/A	N/A	540
58	547042	Office	17,002	N/A	N/A	19.85	N/A	N/A	N/A	N/A	856
59	650917	Manufacturing Facility	22,608	N/A	N/A	14.21	N/A	N/A	N/A	N/A	1,591
61	576653	Manufacturing Facility	32,124	N/A	N/A	12.17	N/A	N/A	N/A	N/A	2,640
63	658493	Manufacturing Facility	71,104	N/A	N/A	62.56	N/A	N/A	N/A	N/A	1,137
64	581008	Manufacturing Facility	93,052	N/A	N/A	37.21	N/A	N/A	N/A	N/A	2,501
65	694532	Office	8,794	N/A	N/A	18.59	N/A	N/A	N/A	N/A	473
66	591585	School/University	19,155	N/A	N/A	22.70	N/A	N/A	N/A	N/A	844
67	544486	Manufacturing Facility	60,354	N/A	N/A	58.03	N/A	N/A	N/A	N/A	1,040
68	606427	Warehouse	241,062	N/A	N/A	45.86	N/A	N/A	N/A	N/A	5,256
69	621710	Other	20,316	N/A	N/A	7.90	N/A	N/A	N/A	N/A	2,572
70	565829	Other	102,242	N/A	N/A	17.63	N/A	N/A	N/A	N/A	5,800
71	544468	Hospital	17,001	N/A	N/A	10.73	N/A	N/A	N/A	N/A	1,584
85	BS9009	School/University	108,838	N/A	N/A	139.53	N/A	N/A	N/A	N/A	780
86	BS8890	Exercise Center	11,233	N/A	N/A	5.65	N/A	N/A	N/A	N/A	1,989
87	BS8725	Other	20,725	N/A	N/A	9.97	N/A	N/A	N/A	N/A	2,079

Lighting Controls			Tracking								
			(a)	(b)	(c)	(d)	(e)	(f)	(g)	(h)	(i)
KEMA ID	Application ID	Facility Type	Annual kWh	kWh HVAC Factor	On-Peak % Annual kWh	Connected kW	Summer kW Coincidence Factor	Summer kW HVAC Factor	Winter kW Coincidence Factor	Winter kW HVAC Factor	Average Reduction in Hours of Use
88	BS8762	Office	15,700	N/A	N/A	10.07	N/A	N/A	N/A	N/A	1,560
89	BS8609	Exercise Center	6,387	N/A	N/A	4.89	N/A	N/A	N/A	N/A	1,307
107	644669	School/University	44,230	N/A	N/A	35.50	N/A	N/A	N/A	N/A	1,246
92	BS9087	Manufacturing Facility	5,221	N/A	N/A	3.11	N/A	N/A	N/A	N/A	1,681

Table 46: Lighting Controls Evaluation Estimates

Lighting Systems			Evaluation								
			(j)	(k)	(l)	(m)	(n)	(o)	(p)	(q)	(r)
KEMA ID	Application ID	Facility Type	Annual kWh	kWh HVAC Factor	On-Peak % Annual kWh	Connected kW	Summer kW Coincidence Factor	Summer kW HVAC Factor	Winter kW Coincidence Factor	Winter kW HVAC Factor	Average Reduction in Hours of Use
47	546599	Other	325	100%	56%	2.44	1%	100%	3%	100%	133
48	592612	Retail	441	107%	81%	0.42	22%	117%	29%	100%	970
49	544258	Police/Fire Station	192	117%	89%	0.63	2%	127%	0%	100%	261
111	594528	Other	236	113%	94%	0.20	41%	127%	17%	100%	1,064
52	621570	School/University	31,534	100%	60%	20.21	26%	100%	28%	100%	1,560
54	722811	Dormitory	11,878	107%	24%	9.14	5%	124%	14%	100%	1,218
56	546524	School/University	5,657	111%	97%	20.01	7%	126%	5%	100%	255
58	547042	Office	3,487	108%	86%	16.18	7%	120%	2%	100%	199
59	650917	Manufacturing Facility	27,932	104%	48%	15.45	14%	114%	11%	100%	1,742
61	576653	Manufacturing Facility	29,556	106%	38%	12.17	16%	127%	36%	100%	2,296
63	658493	Manufacturing Facility	72,464	100%	53%	62.37	13%	101%	10%	100%	1,160
64	581008	Manufacturing Facility	11,782	100%	51%	37.21	8%	100%	0%	100%	317
65	694532	Office	31,053	100%	82%	18.59	49%	100%	15%	100%	1,670
66	591585	School/University	31,846	109%	77%	21.02	22%	127%	30%	100%	1,396
67	544486	Manufacturing Facility	75,680	100%	61%	58.03	8%	100%	32%	100%	1,304
68	606427	Warehouse	247,132	106%	27%	45.86	17%	127%	33%	100%	5,080
69	621710	Other	10,686	103%	26%	7.87	-14%	114%	27%	100%	1,323
70	565829	Other	126,157	100%	45%	17.63	78%	100%	88%	100%	7,157
71	544468	Hospital	18,097	105%	92%	10.84	22%	114%	23%	100%	1,583
85	BS9009	School/University	56,534	106%	95%	139.85	12%	114%	6%	100%	380
86	BS8890	Exercise Center	1,365	111%	78%	3.12	8%	125%	7%	100%	395
87	BS8725	Other	26,826	98%	70%	6.05	69%	100%	73%	96%	4,509
88	BS8762	Office	4,837	105%	54%	10.06	6%	113%	4%	100%	459
89	BS8609	Exercise Center	1,909	111%	67%	7.91	4%	127%	3%	100%	217
107	644669	School/University	10,366	100%	97%	32.09	4%	100%	8%	100%	323
92	BS9087	Manufacturing Facility	7,114	104%	50%	6.07	9%	113%	15%	100%	1,130

Table 47: Lighting Controls Realization Rates and Primary Reasons for Discrepancies

Lighting Systems		Realization Rates				
		(s)	(t)	(w)	(ab)	
KEMA ID	Application ID	Annual kWh (Excluding HVAC)	Annual kWh (Including HVAC)	Connected kW	Average Reduction in Hours of Use	Primary Reasons for Discrepancies
47	546599	4%	4%	56%	8%	Combination of fewer controlled fixtures and a lower reduction in operating hours due to the controls.
48	592612	43%	46%	88%	48%	Documentation change due to incorrect fixture code (2F32SSE). Hours of use reduction differences.
49	544258	33%	39%	96%	35%	Hours of use reduction 35% of tracking estimate.
111	594528	4%	4%	11%	34%	Sensors installed on different fixtures than proposed. Sensors installed on (4) fixtures rather than (31) fixtures. Hours of use reduction also less than predicted.
52	621570	118%	118%	94%	125%	Evaluated hours of use reduction 25% higher than estimated in the tracking assumptions.
54	722811	121%	129%	98%	123%	Logged Hours were higher than sponsor's were assuming.
56	546524	39%	43%	82%	47%	Documentation adjustment due to incorrect fixture type used in tracking analysis affected connected kW reduction negatively. Hours of use reduction less than estimated in the tracking savings.
58	547042	19%	21%	81%	23%	Evaluated annual hours of use reduction 23% of tracking estimates.
59	650917	119%	124%	109%	109%	Hours of use reduction was higher than tracking estimates. Additional savings due to more fixtures with controls.
61	576653	87%	92%	100%	87%	Hours of use reduction 87% of tracking. HVAC interaction increased savings by 7%.
63	658493	102%	102%	100%	102%	Hours of operation reduction 2% greater than tracking estimates.
64	581008	13%	13%	100%	13%	Hours of use reduction approximately 13% of that predicted in the tracking estimate.
65	694532	353%	353%	100%	353%	The actual reduction in hours of use realized by the lighting controls was almost 4 times greater than assumed in the tracking system.
66	591585	153%	166%	93%	165%	Greater reduction in hours of use.
67	544486	125%	125%	100%	125%	Hours of use reduction 25% higher than estimated in the tracking savings.

Lighting Systems		Realization Rates				
		(s)	(t)	(w)	(ab)	
KEMA ID	Application ID	Annual kWh (Excluding HVAC)	Annual kWh (Including HVAC)	Connected kW	Average Reduction in Hours of Use	Primary Reasons for Discrepancies
68	606427	97%	103%	100%	97%	Hours of use reduction 97% of tracking estimate.
69	621710	51%	53%	100%	51%	Decrease in the average reduction in hours of use.
70	565829	123%	123%	100%	123%	Hours of use reduction greater than estimated in the tracking estimates.
71	544468	101%	106%	101%	100%	No significant adjustments.
85	BS9009	49%	52%	100%	49%	Hours of use reduction lower than estimated in the tracking savings.
86	BS8890	11%	12%	55%	20%	Connected kW approximately half of that estimated in the tracking. Hours of use reduction was also less than estimated in the tracking.
87	BS8725	132%	129%	61%	217%	Average reduction in hours of use more than twice those estimated in the tracking savings.
88	BS8762	29%	31%	100%	29%	Annual hours of use reduction approximately 71% lower than proposed on average.
89	BS8609	27%	30%	162%	17%	62% increase in controlled wattage. Partially offset by evaluated annual reduction in hours, which were 17% of tracking estimates, and 10% increase due to HVAC interaction.
107	644669	23%	23%	90%	26%	Annual hours of use reduction was less than half of tracking estimate.
92	BS9087	131%	136%	195%	67%	More fixtures being controlled than proposed.

C.3 Advanced Lighting Design

Table 48: ALD Tracking Estimates

Advanced Lighting Design			Tracking								
			(a)	(b)	(c)	(d)	(e)	(f)	(g)	(h)	(i)
KEMA ID	Application ID	Facility Type	Annual kWh	kWh HVAC Factor	On-Peak % Annual kWh	Connected kW	Summer kW Coincidence Factor	Summer kW HVAC Factor	Winter kW Coincidence Factor	Winter kW HVAC Factor	Average Hours of Use
74	550483	Healthcare-Clinic	138,185	N/A	89%	40.82	N/A	N/A	N/A	N/A	3,386
112	CS8294A	Parking Garage	89,687	N/A	N/A	10.24	N/A	N/A	N/A	N/A	8,758
76	528704	School/University	335,301	N/A	100%	152.30	N/A	N/A	N/A	N/A	2,202
95	CS8404	Office	675	N/A	N/A	0.21	N/A	N/A	N/A	N/A	3,214
96	CS8120	Office	2,502	N/A	N/A	0.78	N/A	N/A	N/A	N/A	3,208
97	CS8302	Office	4,154	N/A	N/A	1.30	N/A	N/A	N/A	N/A	3,195
98	S8286A	School/University	84,002	N/A	N/A	23.33	N/A	N/A	N/A	N/A	3,600
99	CS8104	Office	79,238	N/A	N/A	24.76	N/A	N/A	N/A	N/A	3,200
100	S8379A	Retail	250,593	N/A	N/A	53.95	N/A	N/A	N/A	N/A	4,645
114	CS8296	Retail	71,858	N/A	N/A	18.43	N/A	N/A	N/A	N/A	3,900

Table 49: ALD Evaluation Estimates

Advanced Lighting Design			Evaluation								
			(j)	(k)	(l)	(m)	(n)	(o)	(p)	(q)	(r)
KEMA ID	Application ID	Facility Type	Annual kWh	kWh HVAC Factor	On-Peak % Annual kWh	Connected kW	Summer kW Coincidence Factor	Summer kW HVAC Factor	Winter kW Coincidence Factor	Winter kW HVAC Factor	Average Hours of Use
74	550483	Healthcare-Clinic	146,367	106%	74%	40.98	78%	114%	47%	100%	3,360
112	CS8294A	Parking Garage	99,050	100%	47%	11.46	100%	100%	94%	100%	8,647
76	528704	School/University	465,058	111%	70%	149.88	42%	127%	34%	100%	2,807
95	CS8404	Office	518	104%	68%	0.21	72%	106%	36%	100%	2,362
96	CS8120	Office	2,347	104%	68%	0.78	78%	105%	58%	100%	2,895
97	CS8302	Office	4,180	106%	94%	1.30	95%	114%	85%	100%	3,026
98	S8286A	School/University	53,542	106%	91%	23.33	34%	116%	41%	100%	2,175
99	CS8104	Office	75,642	82%	75%	24.75	82%	127%	71%	20%	3,719
100	S8379A	Retail	399,260	108%	54%	67.51	32%	131%	99%	100%	5,487
114	CS8296	Retail	121,601	111%	66%	20.87	91%	127%	94%	100%	5,251

Table 50: ALD Realization Rates and Primary Reasons for Discrepancies

Advanced Lighting Design		Realization Rates					
		(s)	(t)	(v)	(w)	(ab)	
KEMA ID	Application ID	Annual kWh (Excluding HVAC)	Annual kWh (Including HVAC)	On-Peak % Annual kWh	Connected kW	Average Hours of Use	Primary Reasons for Discrepancies
74	550483	100%	106%	83%	100%	99%	Positive HVAC interactive effects.
112	CS8294A	110%	110%	N/A	112%	99%	Lower connected wattage installed than proposed. Higher savings when compared to the same base case of 0.3 watts/sqft.
76	528704	125%	139%	70%	98%	128%	Increase in annual operating hours plus positive HVAC interactive effects.
95	CS8404	74%	77%	N/A	100%	73%	Annual Hours of use were approximately 27% lower than proposed. HVAC interaction included in analysis.
96	CS8120	90%	94%	N/A	100%	90%	Annual hours of use were approximately 9% lower than proposed. HVAC interaction included in analysis.
97	CS8302	95%	101%	N/A	100%	95%	Annual hours of use were approximately 5% lower than proposed. HVAC interaction included in analysis.
98	S8286A	60%	64%	N/A	100%	60%	Annual hours of use were approximately 40% lower than proposed. HVAC interaction included in the analysis.
99	CS8104	116%	95%	N/A	100%	116%	Annual hours of use were approximately 16% higher than proposed. Electric heat resulted in negative HVAC interaction.
100	S8379A	148%	159%	N/A	125%	118%	Lower total wattage installed than proposed combined with higher operating hours and HVAC interaction resulted in increased savings.
114	CS8296	152%	169%	N/A	113%	135%	Baseline quantity was approximately 4% higher than proposed. Annual hours of use were approximtely 35% higher than proposed. HVAC interaction was included in the analysis.

C.4 Refrigerated Case LED Lighting

Table 51: Refrigerated Case LED TRM Savings Estimates

Prescriptive Refrigerated LED			Tracking								
			(a)	(b)	(c)	(d)	(e)	(f)	(g)	(h)	(i)
KEMA ID	Application ID	Facility Type	Annual kWh	kWh HVAC Factor	On-Peak % Annual kWh	Connected kW	Summer kW Coincidence Factor	Summer kW HVAC Factor	Winter kW Coincidence Factor	Winter kW HVAC Factor	Average Hours of Use
77	715718	Retail	9,427	N/A	N/A	1.51	N/A	N/A	N/A	N/A	6,249
78	542120	Retail	34,849	N/A	N/A	5.91	N/A	N/A	N/A	N/A	5,895
79	698459	Retail	9,240	N/A	N/A	1.48	N/A	N/A	N/A	N/A	6,249
80	690533	Retail	47,894	N/A	N/A	7.66	N/A	N/A	N/A	N/A	6,249
81	690750	Retail	162,810	N/A	N/A	26.05	N/A	N/A	N/A	N/A	6,249
82	690542	Retail	164,949	N/A	N/A	26.40	N/A	N/A	N/A	N/A	6,249
83	690544	Retail	118,555	N/A	N/A	18.97	N/A	N/A	N/A	N/A	6,249
102	CS8125	Retail	34,125	N/A	N/A	5.19	N/A	N/A	N/A	N/A	6,570
103	BS8958	Retail	82,159	N/A	N/A	9.38	N/A	N/A	N/A	N/A	8,760
104	BS8959	Retail	72,528	N/A	N/A	8.28	N/A	N/A	N/A	N/A	8,760

Table 52: Refrigerated Case LED Evaluation Estimates

Prescriptive Refrigerated LED			Evaluation								
			(j)	(k)	(l)	(m)	(n)	(o)	(p)	(q)	(r)
KEMA ID	Application ID	Facility Type	Annual kWh	kWh HVAC Factor	On-Peak % Annual kWh	Connected kW	Summer kW Coincidence Factor	Summer kW HVAC Factor	Winter kW Coincidence Factor	Winter kW HVAC Factor	Average Hours of Use
77	715718	Retail	13,864	114%	47%	1.51	100%	105%	100%	105%	8,084
78	542120	Retail	35,091	108%	71%	5.91	100%	111%	100%	111%	5,499
79	698459	Retail	13,250	113%	47%	1.48	93%	102%	100%	105%	7,924
80	690533	Retail	44,686	102%	63%	7.70	98%	105%	97%	104%	5,711
81	690750	Retail	181,894	107%	62%	26.65	100%	106%	100%	106%	6,395
82	690542	Retail	162,779	103%	67%	26.80	100%	106%	100%	106%	5,883
83	690544	Retail	131,867	107%	63%	19.61	98%	106%	100%	106%	6,310
102	CS8125	Retail	34,186	104%	61%	5.03	99%	104%	98%	103%	6,550
103	BS8958	Retail	56,400	92%	67%	9.38	100%	105%	100%	105%	6,536
104	BS8959	Retail	49,838	92%	68%	8.29	100%	105%	100%	105%	6,529

Table 53: Refrigerated Case LED Realization Rates and Primary Reasons for Discrepancies

Prescriptive Refrigerated LED		Realization Rates				
		(s)	(t)	(w)	(ab)	
KEMA ID	Application ID	Annual kWh (Excluding HVAC)	Annual kWh (Including HVAC)	Connected kW	Average Hours of Use	Primary Reasons for Discrepancies
77	715718	129%	147%	100%	129%	Increase in annual hours plus HVAC interaction
78	542120	93%	101%	100%	93%	Annual hours of use approximately 7% lower than proposed. HVAC interactive savings included in the evaluation.
79	698459	127%	143%	100%	127%	Increase in annual hours plus HVAC interaction
80	690533	92%	93%	100%	91%	Hours of use less than estimated in the tracking savings plus increased refrigeration interactive savings.
81	690750	105%	112%	102%	102%	A small increase in savings associated with refrigeration savings as refrigeration interaction was also accounted for in the tracking analysis.
82	690542	96%	99%	102%	94%	Hours of use less than estimated in the tracking savings. Also, only a small increase in savings associated with refrigeration savings as refrigeration interaction was also accounted for in the tracking analysis.
83	690544	104%	111%	103%	101%	Increase in annual hours plus additional refrigeration interaction
102	CS8125	97%	100%	97%	100%	Increase in savings due to the addition of refrigeration savings.
103	BS8958	75%	69%	100%	75%	Decrease in savings due to lower hours of operation than tracking estimate.
104	BS8959	75%	69%	100%	75%	Decrease in savings due to lower hours of operation than tracking estimate.