Just When You Thought It Was Safe to Turn the Lights Out: Trials, Tribulations, and Results of a Pre-/Post-Retrofit Occupancy Sensor Evaluation

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ABSTRACT

Lighting occupancy sensors are widely accepted as an effective energy-efficiency measure and are promoted as such through commercial energy-efficiency programs across the nation. A pre-/post-retrofit metering study of occupancy sensor installations proved otherwise, with one-third of the studied installations showing little or negative impact on lighting time-of-use and an overall savings realization rate less than 50%.

Energy savings from lighting controls are driven by a reduction in the system hours of use compared to the baseline operation, but little research had been done to directly measure that reduction. To improve their program offerings, program administrators must understand the actual impacts of occupancy sensors and guide their program implementers to improve the selection and savings estimates for lighting controls projects. The Massachusetts Program Administrators sought to analyze this issue through a pre-/post-retrofit metering study of occupancy sensors installed on lighting systems in the small commercial sector.

This paper presents the data and findings from pre-/post-retrofit metering of over 200 occupancy sensor installation across 69 buildings. We compare the pre-/post-retrofit lighting operating profiles, discuss some unexpected study findings, and provide recommendations to improve the performance of controls for energy efficiency. In addition, we discuss the process of conducting a pre-/post-retrofit metering study for a direct-install program that included recruitment, data collection, and potential biases. We share the challenges we faced in collecting pre-retrofit data and discuss strategies for future pre/post impact evaluation.

Introduction

The Massachusetts Program Administrators (PAs)—Cape Light Compact, National Grid, NSTAR, Unitil, and Western Massachusetts Electric Company—commissioned a pre-/post-retrofit metering study to assess the energy and demand impacts of occupancy sensors that have been installed through the PAs' Small Business Direct Install (SBDI) program. The study, completed in fall 2012 (Reynolds, Mattison, Korn & Haselhorst 2012), collected pre-/post-retrofit operating data for 203 occupancy sensors in 69 buildings in the small commercial market (businesses with an average electric demand less than 300 kW).

The SBDI program is implemented by approved program vendors who perform these turn-key services: recruit participants, identify and install energy-efficiency measures, and provide project tracking data to the PAs.

In 2011, the SBDI program achieved 11% of the total statewide annual electric energy reductions and 17% of the summer peak demand reductions (Reynolds et al. 2013). The majority (89%) of these energy savings are from upgrades to participants' lighting systems, with about 7% of these savings from the implementation of lighting controls (Reynolds et al. 2013).

As program savings goals have increased over the past decade, so too have the energy and demand savings achieved through installation of occupancy sensors. The increasing savings values from occupancy sensor installations has motivated the PAs to conduct an evaluation to isolate the impact of lighting controls by directly measuring the system's operating hours before and after installation of the occupancy sensors.

Historically, the Massachusetts PAs have used billing analysis to evaluate the SBDI program. A billing analysis compares whole facility consumption data for program participants before and after measure installations to identify changes in consumption due to a particular energy-efficiency measure (Ozog & Klos 2007, RLW Analytics 2004). When combined with program tracking data, a billing analysis allows an assessment of the aggregate energy impacts of program activities; however, it does not provide the data to analyze the performance of energy-efficiency installations at the measure or building level. The PAs sought to investigate the actual performance of lighting controls installations, since their performance could not be confirmed through billing analysis alone.

In 2005, National Grid completed an impact evaluation for lighting controls measures that were installed for both small and large commercial markets; the evaluation used only post-retrofit metering data (RLW Analytics 2007). Since no pre-retrofit metering was performed, the study estimated the baseline system operation using various methods, such as logging the operation of systems without controls in similar spaces and estimating baseline profiles based on the post-retrofit load profiles. Neither of these methods produced an accurate assessment of both occupancy and baseline behavior in the spaces impacted by lighting controls.

This study directly measures the reduction in system operating hours by metering lighting time-of-use both before and after installation of occupancy sensors.

Savings from Lighting Controls

Lighting controls save energy by reducing the total operating hours of the connected lighting load. Therefore, the potential for savings is related to the number of hours the lighting system is operating unnecessarily and can instead be turned off. The potential to reduce lighting runtime depends on two factors: (1) the space occupancy (i.e., how frequently is the space occupied) and (2) the baseline control behavior (i.e., are the lights typically left on or turned off when the space is unoccupied). For lighting controls with occupancy sensors, a third factor is also important: the occupancy sensor delay setting (i.e., how long must the space be unoccupied before the lights are automatically switched off?).

Figure 1 shows a qualitative assessment of the potential impact of occupancy sensors for different combinations of occupancy rates, baseline behavior, and sensor-delay settings.

		Space Occupancy		
		Space Rarely Occupied	Space Frequently Occupied, Short Delay	Space Frequently Occupied, Long Delay
Baseline Behavior	Lights Typically Left On	Savings	Savings	No Savings
	Lights Typically Turned Off	No Savings	No Savings / Increase Usage	Increase Usage

Figure 1. Pre-/Post-Retrofit Lighting Profiles

These various combinations indicate the following:

- Energy savings from occupancy sensors rely on a baseline behavior in which the lighting systems are typically left on. If the baseline behavior is to turn the lights off when not needed, or to not use the lights at all, then there is no potential for the occupancy sensors to reduce system operation.
- Energy savings from occupancy sensors rely on low occupancy rates and improve with shorter delay settings. If the space has high occupancy rates and long delays, there is less potential for the occupancy sensors to reduce system operation.

- Given the wrong combination of baseline behavior and occupancy rates, occupancy sensors may increase the energy consumption of lighting systems. In spaces that are frequently occupied and for which the baseline behavior minimizes lighting system operation, occupancy sensors that operate the lighting systems whenever occupancy is detected may increase system operation and energy consumption compared to the baseline.

Evaluation Methods

Our approach in this study was to install meters to characterize the operation of lighting circuits before and after occupancy sensors were installed through the SBDI program. We analyzed these pre-/post-retrofit meter data to develop daily operating profiles and estimate the annual lighting hours of operation and energy consumption with and without occupancy sensors. We then calculated site-level and program realization rates using evaluation results and program tracking data for lighting control retrofits. This section discusses the evaluation methods, the challenges of collecting pre-/post-retrofit data, and the overall levels of project attrition from lead identification to the capture of a complete pre-/post-retrofit data set.

Sampling

The first challenge to conducting a pre-/post-retrofit metering study is to develop a sampling strategy. Since the population under study is unknown (because metering must be performed during the development of the population), the sample is typically based on historical program data and assumes that the evaluation year will be similar to the previous year(s). Following discussion with the PAs, Cadmus' final sampling plan aimed to conduct pre-/post-retrofit metering at 70 lighting controls sites selected from a prioritized list of prominent building types from the PY 2010 program population: offices, retail facilities, industrial facilities, restaurants, schools, health facilities, and warehouses. With 70 sites, we hoped to reach 90% confidence and 10% relative precision for the statewide program.

Participant Recruitment

The six direct-install vendors (DIV) operating at the time of the study installed about 5,000 projects during the year-long data collection effort using a process designed for speed and efficiency. A typical project is installed within three weeks of contract signature, often beginning within a week of agreement. The process moves automatically, with no extra decision points or delays. Multiple electrical subcontractors are responsible for scheduling work with the customer and installing the product at the site with no additional direct intervention by the DIV.

The DIVs made a good faith effort to provide leads to the evaluation team; however, the pre-retrofit logging did not fall naturally within the installation cycle and took additional DIV resources to set up. This required persistent attention by the evaluator and the cooperation of the DIV coordinators to successfully receive good leads.

Table 1 shows the challenges of coordinating and integrating a pre-/post-retrofit evaluation into the existing program process. The request for DIV assistance was first made at a regular meeting of PAs and DIVs, with a strong endorsement from the PAs. Each DIV was asked to send project leads to the evaluator at the end of each week. This lead could be a fax or scans of a project signed by a customer, with information about the occupancy controls, room-by-room inventories, proposed installations, and customer contact information. This project also had to have sufficient time to deploy loggers for at least a week. For this study, we were given 153 project leads.

Once the lead was identified, customer recruitment proceeded normally with one difference: the customer had to be recruited twice, once before and once after the installation. Customers were offered incentives, which were moderately helpful and probably a deciding factor at only a couple of sites.

Table 1. Logger Deployment Coordination and Challenges

	Customer Sign-up	Week 1	Week 2	Week 3	Week 4+	Week 5-8
DIV	Prepare product order Assign job to electrical subcontractor Send lead list to evaluator	Let electrical subcontractor know if site was selected for evaluation Package and prepare product for shipment	Product shipped to customer site		Let evaluator know when sensor installation is complete	
Electrical Subcontractor		Schedule work with customer		Install sensors		
Evaluator	Receive lead list	Recruit customer for study Install pre-retrofit loggers within 3 days	Remove pre-retrofit loggers		Schedule post-retrofit logger installation	Install post-retrofit loggers
Challenges	DIV does not send lead list No good candidates on lead list	Customer declines participation Not enough time before sensor installation Cannot meet the schedule	Sensors installed before loggers are removed Bad logger data	Sensors are not installed (site drops out of program) Sensors are not installed on logged circuit	Customer declines post-install logging	Bad logger data

Data Collection

As sites were recruited for participation in this study, we collected the list of proposed measures from the project contractors. For each planned lighting controls installation, the list included the controlled fixture type and quantity, estimated hours reduced, and measure location. Initially, we randomly selected up to five measures for logging at each site. However, on our first few post-retrofit visits, we found that not all of the proposed measures were installed, including some that had been selected for logging. To maximize the available data for each evaluated site, we began to install loggers on up to 10 randomly selected measures at each site.

Participant Attrition

Each coordination point presented an “opportunity” for loss of a data point. Due to the challenging field conditions, there was substantial attrition in the potential participation group. Table 2 presents this attrition of data points with reasons for the losses. We completed pre-/post-retrofit data collection at 69 (45%) of the initial 153 sites. Sixty-one (40%) of the 153 initial leads were lost due to inability to recruit the customer for participation in the study, insufficient measures to warrant inclusion in the study, and installation of occupancy sensors before the loggers could be deployed. Twenty-three

(25%) of the remaining 92 sites with at which pre-retrofit loggers were set up were lost from the study because the project was discontinued and the customer did not install lighting controls, the customer refused a return visit for post-retrofit metering, or the lighting controls were installed immediately so that pre-retrofit data could not be completed.

Table 2. Attrition of Sites and Measures

Attrition of Sites and Measures	Running Sample Size	Deducts	Running Logger Deployment	Deducts
Sites entered into lead database	153			
Fail to recruit, insufficient number of controls or not enough time		61		
Pre-install logger deployment	92		~600	
Completed pre-install visit only. Sites subsequently dropped.		23		~100
Sites with both pre-/post-retrofit logger deployment	69			
Deployed for pre-/post-retrofit			250/250	
Logger failed, was lost, or pulled by electrical contractor				~30
Pre but no post data				12
Sites and circuits with good pre-/post-retrofit data	69		208/208	
Insufficient representation		11		38/38
Sites and circuits included in realization rate	58		170/170	

Data Collection Periods

One challenge with pre-/post-retrofit impact evaluations is collecting sufficient pre-retrofit data. Figure 2 shows the distribution of sites by the duration of the pre-/post-retrofit logging periods. The pre-retrofit logging periods were generally shorter than the post-retrofit periods because both contractor and customer were eager to complete the installation. Sites were recruited for evaluation only after customer agreements were signed, and contractors often had an installation schedule to meet. Post-retrofit metering was less constrained because contractor tasks had been completed and less coordination was required with the customer and contractors.

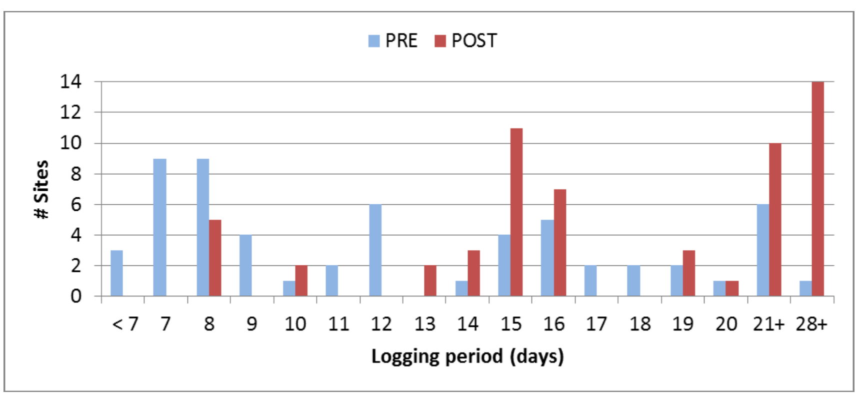

Figure 2. Pre-/Post-Retrofit Data Logging Periods

Data Analysis

After data collection, the pre-/post-retrofit lighting logger data must be analyzed and screened for appropriateness given the short data collection windows. This section describes the screening process to eliminate bad or non-representative data, the final data set, and the logger data attrition rate resulting from the measure and project screening.

Develop and quality control (QC) logger data. We processed the raw logger data into hourly operation and conducted an hour-by-hour review of the results. Figure 3 is an excerpt of logged daily profiles from the pre-retrofit period (Case B) for occupancy sensors installed in a school classroom. The profiles show that before the occupancy sensors were installed the lights were typically off all weekend and overnight on weekdays. The two logged weekdays that showed no lighting operation were identified as snow days and assigned to the Sundays/Holidays day type for the final analysis.

	A	D	G	H	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	AA	AB	AC	AD	AE	AF	AG	AH	AI	AJ
1	File	Ca	tim	date	wd/we	u	comment																								
1119	20_226_B	B	13.00	1/26/11	weekday	1									88%	100%	100%	82%	78%	40%	100%	100%	100%	97%	0%	0%	81%	100%	71%	0%	0%
1120	20_226_B	B	13.00	1/27/11	weekday	1	snow day	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
1121	20_226_B	B	13.00	1/28/11	weekday	1		0%	0%	0%	0%	0%	0%	0%	44%	100%	66%	62%	26%	32%	100%	100%	100%	100%	100%	100%	100%	100%	95%	0%	0%
1122	20_226_B	B	13.00	1/29/11	Saturday	1		0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
1123	20_226_B	B	13.00	1/30/11	Sunday	1		0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
1124	20_226_B	B	13.00	1/31/11	weekday	1		0%	0%	0%	0%	0%	0%	1%	38%	100%	100%	100%	100%	38%	100%	97%	66%	100%	5%	0%	71%	100%	68%	0%	0%
1125	20_226_B	B	13.00	2/1/11	weekday	1		0%	0%	0%	0%	0%	0%	1%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
1126	20_226_B	B	13.00	2/2/11	weekday	1	snow day	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
1127	20_226_B	B	13.00	2/3/11	weekday	1		0%	0%	0%	0%	0%	0%	0%	0%	0%	75%	100%	100%	87%	18%	64%	100%	1%	0%	0%	74%	100%	75%	0%	0%
1128	20_226_B	B	13.00	2/4/11	weekday	1		0%	0%	0%	0%	0%	0%	0%	66%	100%	100%	85%	24%	34%	100%	100%	100%	100%	100%	100%	100%	100%	76%	0%	0%
1129	20_226_B	B	13.00	2/5/11	Saturday	1		0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
1130	20_226_B	B	13.00	2/6/11	Sunday	1		0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
1131	20_226_B	B	13.00	2/7/11	weekday	1		0%	0%	0%	0%	0%	0%	1%	63%	100%	100%	86%	100%	47%	100%	90%	0%	0%	0%	0%	0%	49%	100%	13%	0%
1132	20_226_B	B	13.00	2/8/11	weekday	1		0%	0%	0%	0%	0%	0%	0%	0%	19%															
1133	20_226_A	A	33.06	5/27/11	weekday	1											44%	100%	10%	100%	83%	80%	0%	0%	20%	60%	30%	43%	3%	0%	0%
1134	20_226_A	A	33.06	5/28/11	Saturday	1		0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
1135	20_226_A	A	33.06	5/29/11	Sunday	1		0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
1136	20_226_A	A	33.06	5/30/11	weekday	0	Holiday- Memorial Day	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
1137	20_226_A	A	33.06	5/31/11	weekday	1		0%	0%	0%	0%	0%	0%	43%	100%	100%	57%	83%	27%	73%	50%	0%	30%	0%	0%	33%	57%	13%	13%	0%	0%
1138	20_226_A	A	33.06	6/1/11	weekday	1		0%	0%	0%	0%	0%	0%	43%	100%	100%	60%	73%	13%	100%	67%	33%	77%	0%	0%	33%	60%	40%	0%	0%	0%
1139	20_226_A	A	33.06	6/2/11	weekday	1		0%	0%	0%	0%	0%	33%	43%	100%	100%	70%	100%	13%	100%	90%	87%	0%	0%	33%	30%	57%	7%	13%	0%	0%

Figure 3. Pre/Post Hourly Profiles by Measure

Develop and QC hourly average profiles. Once the hourly profiles were cleaned and screened, we created the average pre-/post-retrofit weekday, weekend, and holiday profiles for each measure. The average profiles were cleaned and screened again, this time pairing pre-/post-retrofit profiles together. By reviewing the comparisons of average pre-/post-retrofit operating profiles, we flagged measures for which the profiles were unexpected. The data for all flagged measures were sent to the engineer who performed the logger installations to verify that the data made sense and to explain the unexpected behavior.

Since occupancy levels were not measured as part of the evaluation, the comparison of pre-/post-retrofit profiles was an important step in the QC process to ensure that data appropriately represented similar space conditions, such as occupancy. For multiple measures, we identified scenarios in which the comparison of pre-/post-retrofit profiles suggested different occupancy levels in the space. We reviewed the conditions with the field engineer who installed and removed those loggers and could confirm that lights were frequently off even when the space was occupied, the space had good daylighting, or the space was under construction and unoccupied during the data collection period. This feedback helped determine if the logger data were retained for the analysis.

Estimate Annual Operating Hours. We used daily operating profiles from logger data and customer-reported information on seasonal operating hours to estimate the pre-/post-retrofit annual operating hours, similar to the approach used in the previous meter-based lighting impact evaluation (Reynolds, Mattison, Huang, Haselhorst & Ioan 2012). For each logger, we estimated the daily hours by day-type in each season by adjusting the measured daily hours in the logged season by the ratio of the customer-estimated seasonal hours to the customer-estimated hours in the logged season.

Although longer metering periods are preferable to analyze how well customer-reported seasonal hours reflect hours when occupancy controls are in place, this approach accounts for important seasonal adjustments such as summer periods for schools or extended hours for seasonal retail facilities and restaurants. Only nine of the 58 final evaluation sites required seasonal adjustments. The majority (85%) of the evaluation sites reported the same operating hours during all seasons.

Site Analysis

After developing the pre-/post-retrofit profiles and annual operating hours for each measure, Cadmus matched the evaluation data to the final population of projects from the PAs' program tracking data in order to review the *ex ante* savings estimates and assess measure, project, and program realization rates.

Matching to Tracking Data. We matched all projects and all but 14 measures from the evaluation sample to the corresponding projects and measures reported in the PA tracking data. The 14 unclaimed lighting controls measures represent occupancy sensor installations we verified and for which we collected pre-/post-retrofit time-of-use data; however, these were not listed as claimed lighting controls measures in the PA tracking data.

While it is unclear why these 14 measures were not claimed, we included them in the program impact analysis after verifying they were part of project installations claimed in PY 2011 and confirming with the PAs that they were unlikely to be claimed in a customer spillover survey. Because the measures were implemented at the same time and by the same vendor as other measures verified and claimed in the PA tracking data, it is unlikely the customer is aware that some measures were not claimed, much less be able to differentiate which measures were and were not claimed. Therefore, it is probable that the customer would not indicate on a spillover survey that any additional measures were installed than what was claimed in the tracking data.

Where possible, for each matched measure we compared savings parameters from the tracking system—lighting fixture type, lighting fixture wattage, lighting fixture quantity, estimated hours before and after or estimated hours reduced, total gross kW savings, and total gross kWh savings—to data collected during the evaluation. We then used these data to recalculate and verify the tracked energy and demand savings for each evaluated measure.

Site Screening. Of the 69 sites sampled, 11 sites were removed from the analysis because the final pre-/post-retrofit logged measures did not represent the final list of lighting control measures in the PA tracking data. Causes for this shortage of pre-/post-retrofit logged data at these sites included:

- Pre-/post-retrofit logger data did not pass quality analysis/quality control (QA/QC).
- The final set of tracked lighting controls measures did not match the planned set of lighting controls measures.
- Planned measures logged in the pre-retrofit condition were not implemented.
- Some pre-/post-retrofit logged measures were not claimed in the tracking data.

Results

Comparison of the pre-/post-retrofit logger data showed varied impacts of the occupancy sensors. These varied impacts were also observed in the wide range of project realization rates and contributed to poor relative precision values. This section describes the comparison of pre-/post-retrofit system operating profiles, the final realization rates for evaluated projects, and the issues that affect the desired precision for occupancy sensor savings.

Pre-/Post-Retrofit Load Profiles

Our review of the pre-/post-retrofit profiles for each measure showed that installed occupancy sensors had positive, negligible, and adverse impacts on the lighting system operation. Figure 4 presents the average pre-/post-retrofit operating and savings profiles for four unique occupancy sensor installations. The operating profiles are developed from light logger data collected before and after installation of the occupancy sensors. The savings profiles are the difference between the pre-/post-retrofit load profiles. A positive value on the savings profile indicates a reduction in system operating hours due to the occupancy sensors; a negative value indicates increased system operation after installation of the controls.

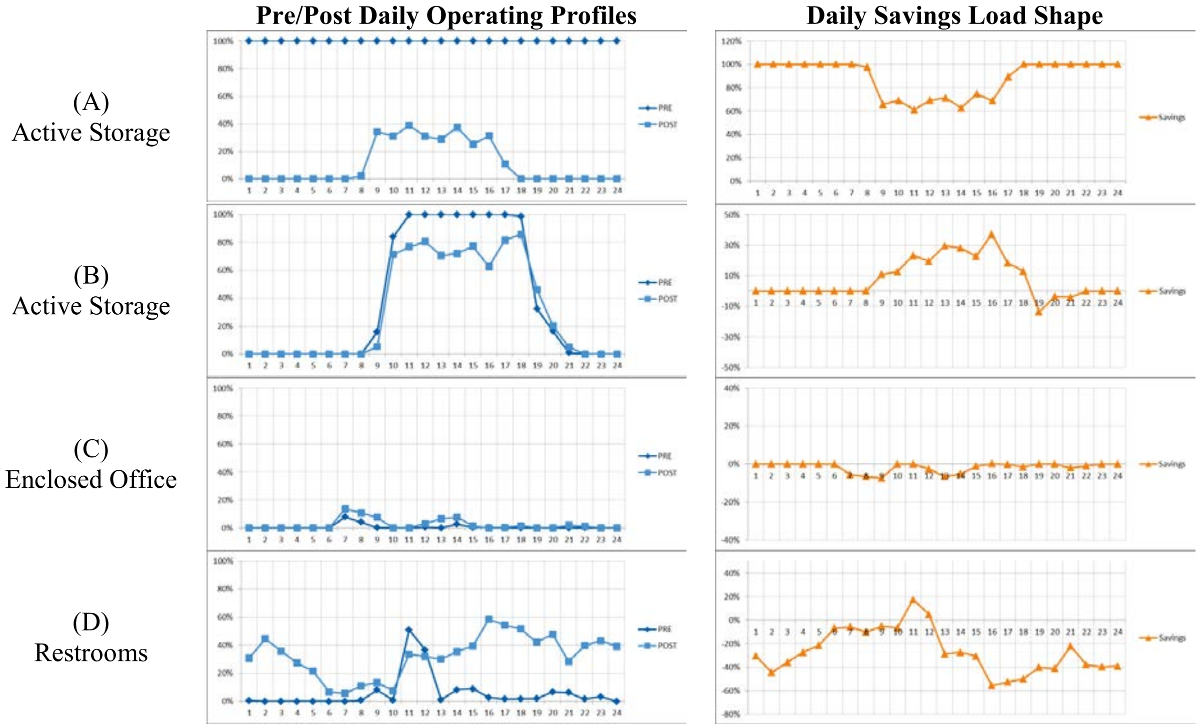

Figure 4. Pre-/Post-Retrofit Lighting Profiles

Measure (A) shows the ideal application for lighting controls. The baseline behavior, indicated in the PRE profile, shows continuous lighting system operation. The POST profile indicates infrequent space occupancy—with no occupancy between 5 p.m. and 7 a.m. (Hours 18 through 7)—enabling large savings during the day and overnight due to occupancy sensor controls.

Measure (B) shows an application for which the lighting occupancy sensors have a positive impact during the normal occupied hours but no impact during unoccupied hours due to baseline behavior that regularly turned the lights off at the end of each day.

Measure (C) shows an application for which occupancy sensors have no impact on the system operation. The PRE profile indicates that the lighting system was rarely operated prior to the installing occupancy sensors, and the POST profile indicates that the space was rarely occupied. Since the baseline operating hours are minimal, there is no opportunity for savings from the occupancy sensors.

Measure (D) shows an increase in the lighting system operation due to the installation of controls. The baseline profile shows minimal lighting operation throughout the day with most operation during the morning. The POST profile indicates lighting operation during all hours of the day, often at higher levels than without lighting controls. This appears to indicate that in the PRE profile, the occupants rarely turned on the lights when entering the restroom whereas, in the POST profile, each time an occupant entered the restroom, lights were automatically turned on.

Pre-/Post-Retrofit Hours by Space Types

We used the average pre-/post-retrofit load profiles and customer-reported information on annual operating hours for each building to estimate the annual pre-/post-retrofit system operating hours for each evaluated measure. Figure 5 shows these pre-/post-retrofit annual hours for selected space types. The blue bars show the estimated pre-retrofit operation hours and the red bars show the estimated post-retrofit operating hours. The installation of occupancy sensors reduced the operating hours (and achieved energy savings) for all measures for which the red bars are shorter than the blue bars.

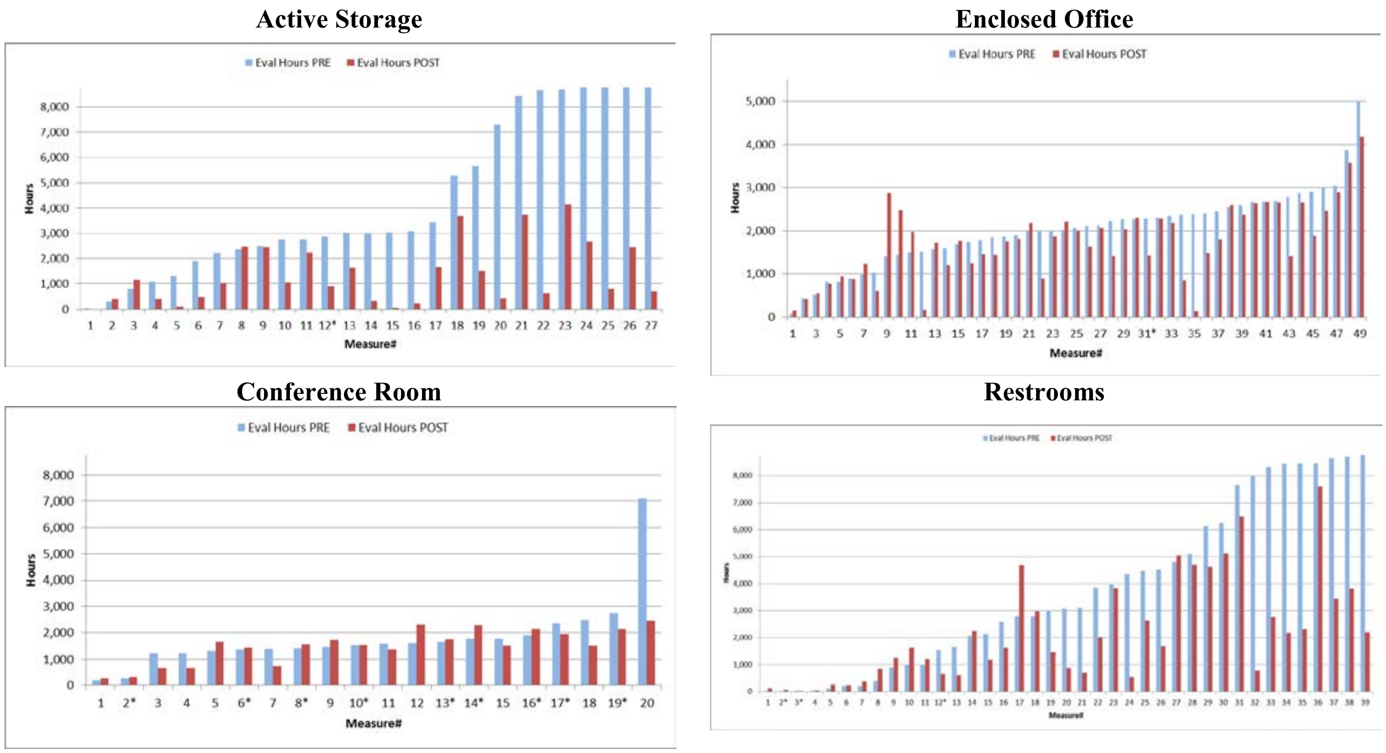

Figure 5. Pre-/Post-Retrofit Annual Hours by Space Type

Realization Rates and Precision

Based on pre-/post-retrofit logging of 170 measure installations at the 58 evaluated sites across Massachusetts, we estimated an average 43% realization rate for lighting controls installations. At the 90% confidence level, this realization rate has a relative precision of +/-55%, indicating large variations in the energy impacts of lighting controls installations among the studied sites.

Realization Rates. Figure 6 shows the gross energy realization rates for the 58 evaluated sites. The realization rates range from –127% to 1,173%. Thirteen (22% of the 58 sites) had a negative realization rate and increased lighting time-of-use for controlled measures. Twenty-four (41%) had a realization rate less than 100%, indicating the energy savings achieved were smaller than predicted by the program contractors. Only nineteen (33%) sites had a positive energy realization rate greater than 100%, showing energy savings higher than estimated by the program contractors.

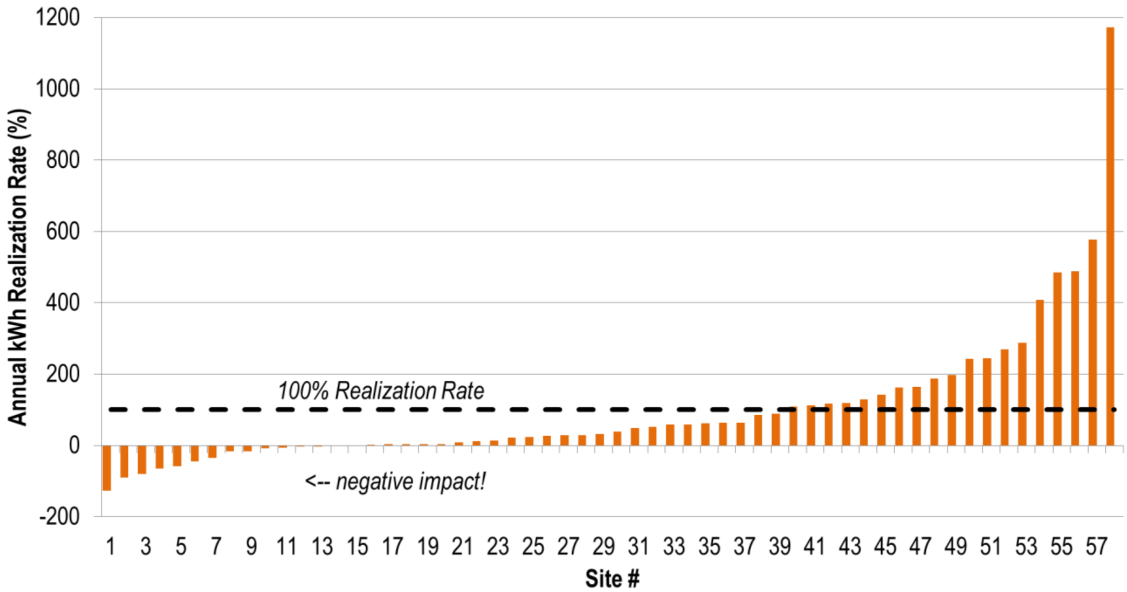

Figure 6. Energy Realization Rates for 58 Projects

Precision. In this study, we found poor correlation between *ex ante* and *ex post* kWh savings values, and this is reflected in several precision estimates. The origins of these values provide three reasons the deviations vary randomly (i.e., with no systematic pattern) from one site to the next:

- The *ex ante* values are based on contractor's estimates of hours of use, which may vary in precision and from one contractor to the next. There is no mechanism whereby the (logger-based) *ex post* values would reflect these varying methods.
- The *ex post* values are based on pre-/post-retrofit logging info. This rigorous approach provides a high degree of objectivity because it directly measures the actual change in hours of use (the delta) between the pre-/post-retrofit periods for each sampled site. These deltas vary greatly from one site to the next and among applications within each site. Our data show wide variation among verified hours of use times, both in absolute terms and relative to *ex ante* hours of use values. A surprising number of circuits showed negligible or even negative reductions in hours of use, even in applications where contractors had recorded large savings.
- In contrast, consider the case where an evaluation uses post-retrofit-only time-of-use logging, and each measure's verified savings value is obtained from a postulated baseline. This approach ensures positive and reasonable savings for each measure. The measure-level values obtained through engineering judgment or technical reference manual (TRM)-specified methods do not account for all site-level idiosyncrasies or human factors. As a result, *ex post* values based on post-retrofit-only metering with inferred baselines tend to be well-correlated with contractor estimates.

Sample-based studies typically summarize variation in the data in terms of a coefficient of variation (for simple mean-based estimators) or an error ratio (for ratio-based estimators). In many circumstances—generally, when there is reason to expect strong correlation between *ex ante* and *ex post* data—an error ratio of 0.5 may be used for planning purposes. (Lower error ratios indicate low variability in the data, which results in smaller sample size requirements to obtain a given precision level.) For this study, we obtained an error ratio of 2.01 in estimating total *ex post* kWh with reported kWh as *ex ante* data.

Bias. There are several possible sources of bias in this pre-/post-retrofit metering evaluation that are difficult to quantify but should be considered for both the study results and future pre-/post-retrofit impact evaluations. These include self-selection bias and the influence of evaluation activities on measure performance.

In the sampling analysis, we treated the sites as if they were randomly selected among program participants. This is a typical assumption for impact evaluations when the sample population is selected from a defined program population, even though there is some potential for bias when a customer can refuse to participate in on-site data collection. However, because this study required data collection during the program year (in order to collect pre-retrofit metering), sample sites were recruited throughout the year and relied on the opt-in participation of both the program contractor and the participating customer. As a result, for all evaluated sites, vendors and customers were willing to delay implementation of the lighting controls to allow installation of time-of-use loggers for a multi-week period. However, since savings for lighting controls are based on standard formulas and, as this study shows, the realized impact of installations is highly variable, it is unlikely that contractors biased the evaluation toward better performing projects.

Another potential source of bias is the influence of the evaluation activities on customer behavior. It is possible that visits by the data collection team and presence of installed loggers had an influence on the behavior of building occupants to control and thereby impact the operations of the lighting systems under study. Measure impacts are highly dependent on occupant behavior, and in a short pre-/post-retrofit logging period, small changes in occupant behavior may have large impacts on the measure results. Although it is difficult to measure changes in occupant behavior, this potential bias may be mitigated with longer monitoring periods that are more likely to represent regular user behavior.

Conclusions and Recommendations

The review of the final data, including review of the pre-/post-retrofit lighting system load profiles, showed clear cases of large, negligible, and negative energy impacts due to occupancy sensor installations. Discussion of these energy impacts was enlightening to the PAs and DIVs who, like many others, assumed that occupancy sensors always effect energy reductions. We offer the following conclusions from this pre-/post-retrofit data collection study:

- The energy and peak demand impacts of lighting controls are highly variable and may increase usage in certain applications. Post-retrofit metering showed that the installed lighting controls operate as expected; however, pre-retrofit metering showed that many lights were used less frequently than expected, diminishing the potential impact for controls.
- The energy impact of lighting controls depends on both user behavior and space type. The space type savings potential is based on its expected occupancy schedule—for example, an infrequently entered conference room may have more savings potential than a constantly occupied open office area—but the energy impact is determined by the baseline occupant behavior before controls were installed. There is no savings potential in any space types where occupants consistently manually control lighting circuits.
- Although time-of-use impacts varied even within space type groups, some space types showed higher and more consistent energy savings than others. Active storage, corridor/transition, and restrooms regularly showed high reductions in operating hours with installed lighting controls. Classrooms, conference rooms, dining areas, and enclosed offices showed irregular impacts and, on average, only modest reductions in annual operating hours.

To maximize future savings, we recommend the following for program implementers:

- DIVs should explore the use of portable occupancy/light sensors to predict savings with short-term monitoring. Vendors could deploy these loggers at the time of the audit and download the data when they arrive to install the fixtures. If the base usage warrants the installation of an occupancy sensor, the vendor can go ahead with the installation.

- PAs and program contractors should consider space types and occupancy patterns to identify appropriate locations. Frequently entered storage areas are a good candidate; classrooms tend to be a poor candidate unless lights are left on during unoccupied hours.
- PAs should work with contractors to set short delays on sensors, selecting dual-technology sensors to avoid unwanted shutoffs when occupants are still in the space (one reason why long delays may be set). Dual-technology sensors combine sensor technologies such as motion, infrared, ultrasonic, and microwave, rather than motion only.
- PAs should encourage the installation of vacancy controls that require manual switch operation to turn lights on, but use occupancy detection to turn lights off after a pre-determined delay. For several measures in this study, lighting operation increased after the installation of controls, likely because the lights switched on automatically when the space would not have previously used lighting (for example, when natural day lighting is sufficient). In these cases, vacancy controls should mimic pre-retrofit behavior.

The results of this study show that understanding the baseline, or un-controlled, lighting operating profile of a space is critical to estimating the impact of lighting controls. This study showed that baseline operation varies both within the same space types and within the same facility and is, therefore, difficult to predict without direct measurement before lighting controls are installed. Therefore, we recommend that future lighting controls impact evaluations continue to measure the pre-retrofit or un-controlled operating profiles of lighting systems to accurately assess energy and demand impacts for the small commercial sector. To mitigate the challenges we encountered in this study, future evaluators should consider the challenges and recommendations outlined in the previous section.

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