Pop Quiz! LED Lighting Can Generate Significant Energy Savings in Nonresidential Buildings?

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ABSTRACT

Over the past several years, light-emitting diode (LED) technologies have contributed an increasing share of statewide portfolio level claimed savings for three California investor owned utilities[1] (IOU). While the technology itself is not new, it is a relatively new component of California energy efficiency programs and the underlying assumptions regarding the claimed energy savings benefits that derive from the technology remain uncertain. These assumptions include the baseline wattage of replaced equipment relative to the installed wattage, the space types and building types that these technologies are being installed within, the lamp life and performance of the equipment. This paper will discuss the results from a recently completed evaluation study of the California Statewide Nonresidential Programs that focused on developing estimates of key impact parameters for indoor LED A-lamps and reflector lamps. More specifically, this paper will discuss the approach taken to develop estimates of these impact parameters – operating hours, baseline wattages, installed wattages and installation rates. Evaluators will benefit from understanding the methods and results of this evaluation as LED lighting continues to generate a significant impact in the nonresidential downstream lighting market.

Introduction

Over the past several years, rebated light-emitting diode (LED) technologies have contributed an increasing share of statewide portfolio level claimed savings for California IOUs. Successes in marketing, cost reductions and customer education about perceived energy savings benefits have increased the market share of LED lighting throughout California. These successes have also led, in part, to a significant increase in utility program rebates of LED measures. In 2013, LED A-lamp and reflector lamp measures represented roughly 5% and 4%, respectively, of statewide portfolio level claimed ex-ante kWh savings for nonresidential downstream deemed lighting measures. This represented a significant increase from 2012 levels. In 2014, the share of claimed kWh savings from LED A-lamps tripled to 15% and the share of reflector lamps increased marginally (to 5%).

While indoor LED lamps have been available on the market for some time now, the rebated measures are fairly new and the underlying assumptions regarding the claimed energy savings benefits that derive from the measure remain uncertain. This paper will examine some of those assumptions by presenting the results from a recently completed evaluation study of the California Statewide Nonresidential Programs. The study focused on developing ex-post estimates of key impact parameters for indoor LED A-lamps and reflector lamps. This paper will also discuss the approach taken to develop estimates of these impact parameters – installation rates, operating hours, baseline wattages and installed wattages.

Evaluators will benefit from understanding the methods and results of this evaluation as LED lighting continues to generate a significant impact in the lighting market. The on-site verification and monitoring process provided invaluable information regarding where LED A-lamps and reflectors are being installed in

[1] These utilities include Southern California Edison (SCE), San Diego Gas and Electric (SDG&E) and Pacific Gas and Electric (PG&E)

nonresidential buildings and the lighting schedules of those space types, as well as which lighting technologies these measures are replacing. Furthermore, qualitative information garnered from the phone survey and on-site visit provide more information regarding customer satisfaction with the lighting levels, integrity and longevity of the equipment as well as levels of free ridership in the market.

Background

The analysis for this study was completed using data collected for the recently released *Nonresidential Deemed Energy Savings and Performance Incentive (ESPI) Lighting Impact Evaluation*, prepared by Itron, Inc., for the California Public Utilities Commission (Itron 2015). The primary objective of that evaluation was to perform a measure and/or measure-parameter impact evaluation, utilizing existing evaluation data as well as new primary data, in order to update gross and net savings estimates and inform future savings values for specific lighting measures identified in the 2013 Efficiency Savings and Performance Incentive (ESPI) decision[2]. This decision identified indoor LED lamps and reflector lamps as measures that required some level of ex-post evaluation for the 2013 program year. The new primary data that was collected for the ESPI evaluation included 2013 and 2014 program participants and the existing evaluation data was collected from three prior studies, *Small Commercial Contract Group Direct Impact Evaluation Report* (Itron et al. 2010), *Nonresidential Downstream Lighting Impact Evaluation Report* (Itron 2014a) and *LED Impact Evaluation Report* (Itron 2014b).

Data Sources

The ex-post gross and net impacts associated with LED lamp and reflector measures were generated from a number of data sources. The three main sources of data were participant phone surveys, on-site data collection and time-of-use metering.

Phone surveys were conducted to recruit for the on-site visit, as well as to collect data useful for the net-to-gross analysis. In total, over 600 phone surveys were completed, which led to roughly 400 on-site recruitments.

The data gathered throughout the on-site verification process supported a number of the gross impact parameters. Measures were verified to support installation rates, storage rates, replacement rates, etc., as well as to confirm post-retrofit wattages. When the actual baseline equipment was not present, site contacts also provided self-reported data on the wattage of pre-existing equipment to help support estimates of pre-retrofit wattages. Likewise, the on-site surveyor also collected lighting equipment usage schedules to aid in the development of pre- and post-retrofit load shapes. Since different activity areas within a building generally have different lighting usage schedules, the site contact was asked to estimate the operating schedules for each of the activity areas where rebated LED lamps were installed. These self-reported operating hours represented the percent of time "ON" per hour for each hour of each day of the week. Business hours were also collected. If a business kept a separate set of business hours for holidays or seasonal operations, that information was collected as well.

The time-of-use data were obtained through the installation of lighting loggers. As part of the on-site visit, surveyors attempted to log every representative activity area where rebated LED lamps were installed. These loggers were generally in the field for several months in order to capture any potential variability associated with seasonality.

[2] D.13.09.023, Decision Adopting Efficiency Savings and Performance Incentive Mechanism. http://docs.cpuc.ca.gov/PublishedDocs/Published/G000/M076/K775/76775903.PDF

Logger data were also leveraged to develop factors that could be used to adjust the self-reported operating hour schedules garnered from the on-site visit and develop usage rates based on business hours. The on-site verification effort for 2013 and 2014 program participants revealed that LED measures were often replacing incandescent and halogen lighting and, in some cases, compact fluorescent lamps (CFL), so the logger data from Itron (2014b) was combined with the CFL logger data from Itron (2012, 2014a) to aid in the adjustment process. The adjustments were made at the technology, building type and activity area level. Only building type-activity area combinations for which at least 6 sites were monitored were used in the analysis to ensure reliability of the estimates. For building type-activity area combinations that were not well-represented, adjustments were also created at the building type level and the technology level alone. In total, over 3,000 loggers representing 900 sites were used in the adjustment process.

Impact Analysis

This section discusses the installation rate, operating hour and wattage analyses in more detail and briefly describes the approach used for estimating each of the parameters. As part of the on-site visit, business and building characteristics were collected and the customer was classified into a building type based on that information. This building type classification is referred to as an "analysis" building type and each of the impact parameters that are discussed below are also presented at that building type level.

Installation Rates

The installation rate represents the percentage of rebated equipment found to be installed and operable at the time of the on-site verification. In addition, the auditor also attempted to identify the disposition of all the rebated equipment that was not installed and in working condition. This analysis included identifying storage rates, removal rates and failure rates as well. Table 1 and Table 2 present the results from the installation rate analysis for LED A-lamps and LED reflector lamps, respectively. The tables include the number of sites that were used in the analysis along with the dispositions. The received rate represents the percentage of rebated measures that were actually received by the customer.

Table 1. Disposition of Lighting Verification for LED A-Lamps by Building Type

Building Type	Sites	Received Rate	Failure Rate	Storage Rate	Removal Rate	Installation Rate
Lodging	22	99%	0%	4%	2%	93%
Office - Small	48	91%	2%	0%	6%	83%
Other	6	85%	0%	0%	0%	85%
Restaurant - Fast Food	31	95%	1%	0%	7%	87%
Restaurant - Sit Down	42	97%	3%	0%	9%	85%
Retail - Small	46	94%	1%	0%	1%	92%
All Building Types	**195**	**98%**	**0%**	**3%**	**3%**	**91%**

Table 2. Disposition of Lighting Verification for LED Reflector Lamps by Building Type

Building Type	Sites	Received Rate	Failure Rate	Storage Rate	Removal Rate	Installation Rate
Office - Small	42	96%	7%	0%	0%	90%
Other	10	91%	5%	0%	0%	86%
Restaurant - Fast Food	39	98%	0%	0%	0%	98%
Restaurant - Sit Down	41	98%	1%	4%	9%	85%
Retail - Large	8	97%	0%	0%	0%	97%
Retail - Small	46	99%	1%	0%	1%	98%
All Building Types	**186**	**97%**	**1%**	**1%**	**2%**	**93%**

Reasons for why the installation rates were not 100% at the time of the on-site inspection vary among measures and building types. For LED A-lamps, the overall installation rate was 91%, but at the building type level, higher removal rates in the restaurant (7% and 9%) and small office (6%) segments contributed most significantly to lower installation rates. Failure rates contributed as well, but to a lesser extent. For the lodging sector, 4% of rebated A-lamps were put in storage. Overall, removal rates by building type were lower for LED reflector lamps compared to A-lamps, except for sit down restaurants (9%).

The participating customers reported three main reasons why LED A-lamps and reflector lamps had been removed: 1) the lighting they provided was not aesthetically pleasing; 2) the lighting was too strong; or 3) the lighting was too directional. Failure rates also contributed to lower installation rates in some segments, especially in offices and restaurants. On average, site contacts that had self-reported LED lamp failures claimed that the A-lamps or reflector lamps burned out within 6 to 8 months of installation.

Operating Hours

Operating hours were developed using lighting logger data and adjusted self-report data. As mentioned above, lighting loggers not only provided data to support the development of 8,760 load shapes for each site-specific activity area that the measure was installed within, but those data were also combined to generate proxy hours of use for measures where no logging had been done or logger data had been compromised in some way.

For customers that were monitored, the evaluation team compared their actual lighting usage to both their self-reported lighting usage and their business operating hours. These comparisons were made at the technology-building type-activity area level. Furthermore, comparisons in the data were made for four different use periods – the open shoulder, open, closed shoulder and closed periods. The open and closed shoulders represented the two hours before opening and after closing, respectively, and the closed period represented all the hours in which the business was closed outside of the shoulder periods. For the open period, the evaluation team compared actual logger data to the self-reported data collected from the site contact for each activity area of installation. The ratio of actual logger data to the self-reported estimates, or adjustment factors, were then applied to the self-reported schedule for each LED measure at the building type and activity area level. For the closed and shoulder periods, the evaluation team developed average usage rates instead, since site contacts often claimed no usage throughout these periods – a zero value cannot be adjusted by a multiplicative factor. A constant factor was generated for these periods, which represented the actual average usage found in the logger sample for those use periods, by building type and activity area.

Table 3 and Table 4 present the distribution of measure installations for LED A-lamps and reflector lamps by building type and activity area. The activity area field represents the total unique site-level activity area combinations where measure installations were found. The "Other" building type and "Other Miscellaneous" category represent all the unique building type or building type-activity areas where there were less than 6 sites represented in the sample. Outdoor lighting installations are the only areas that would not be represented in the "Other Miscellaneous" category as these areas were not monitored.

It is also important to note that the site counts presented in the installation rate section are higher than those reported in this section. If all the measures had been either removed or had failed prior to the on-site inspection, they were included in the lighting disposition, but would have no bearing on the operating hour analysis.

Table 3. Sites and Distribution of Installations for LED A-Lamps by Building Type and Activity Area

Building Type Activity Area	Site/Activity Areas	Distribution of Site/Activity Areas
Lodging		
Guest Rooms	22	96%
Hallway/Lobby	10	43%
Other Miscellaneous	12	52%
Outdoor	7	30%
Total Lodging	**23**	
Office - Small		
Hallway/Lobby	12	26%
Office	8	17%
Other Miscellaneous	5	11%
Outdoor	5	11%
Restrooms	35	76%
Storage	8	17%
Total Office - Small	**46**	
Other		
Other Miscellaneous	3	75%
Outdoor	1	25%
Total Other	**4**	
Restaurant - Fast Food		
Dining	15	56%
Other Miscellaneous	8	30%
Restrooms	14	52%
Storage	11	41%
Total Restaurant - Fast Food	**27**	
Restaurant - Sit Down		
Dining	26	63%
Hallway/Lobby	6	15%
Kitchen/Break Room	6	15%
Other Miscellaneous	5	12%
Outdoor	1	2%
Restrooms	22	54%
Storage	13	32%
Total Restaurant - Sit Down	**41**	
Retail - Small		
Other Miscellaneous	8	19%
Outdoor	3	7%
Restrooms	31	72%
Retail Sales	8	19%
Storage	9	21%
Total Retail - Small	**43**	

Table 4. Sites and Distribution of Installations for LED Reflectors by Building Type and Activity Area

Building Type Activity Area	Site/Activity Areas	Total Observations
Office - Small		
Hallway/Lobby	11	29%
Office	18	47%
Other Miscellaneous	15	39%
Outdoor	4	11%
Restrooms	8	21%
Total Office - Small	**38**	
Other		
Other Miscellaneous	7	78%
Outdoor	2	22%
Total Other	**9**	
Restaurant - Fast Food		
Dining	22	58%
Kitchen/Break Room	7	18%
Other Miscellaneous	7	18%
Outdoor	5	13%
Retail Sales	6	16%
Total Restaurant - Fast Food	**38**	
Restaurant - Sit Down		
Dining	33	85%
Hallway/Lobby	12	31%
Other Miscellaneous	7	18%
Outdoor	6	15%
Restrooms	6	15%
Total Restaurant - Sit Down	**39**	
Retail - Large		
Other Miscellaneous	4	50%
Outdoor	1	13%
Retail Sales	8	100%
Total Retail - Large	**8**	
Retail - Small		
Office	7	16%
Other Miscellaneous	13	29%
Outdoor	6	13%
Retail Sales	34	76%
Total Retail - Small	**45**	

There was significant variability as to where customers were installing LED A-lamp measures (Table 3). The distribution of activity area installations was clearly predicated on the building type. For sites in the lodging sector, 22 of the 23 facilities had measures installed in guest rooms. For small office and retail customers, restrooms contributed to the greatest percentage of measure installation at 76% and 72%, respectively. Restaurants had more even distributions of LED A-lamp installations with dining areas representing the greatest percentage of measure installation, followed by restrooms and storage areas. These are important distinctions given the fact that dining and retail sales areas are generally higher occupancy areas than storage or restrooms and lighting operating hours are highly correlated with occupancy levels.

The distribution of activity area installations for LED reflectors (Table 4) was fairly similar to LED A-lamp installations for a couple of building types and significantly different for others. In the restaurant segments, reflectors were generally installed in higher usage areas like restaurant dining areas much like LED A-lamps, however restrooms and storage areas made up a significantly lower percentage of installations for reflectors than A-lamps. The most significant differences were with retail installations. While LED A-lamp installations in retail sales areas were only represented in 19% of small retail, LED reflector installations were represented in 76% of that building type/space type.

Annual operating hour estimates for each LED lamp type were created by aggregating each of the site-specific activity area load shapes to the building type level. Each load shape profile was weighted to represent the number of lamps in the population. Table 5 below presents those results.

Table 5. Annual Hours of Operation and Coincidence Factors (CF) by Building Type for LED A-Lamps and Reflectors

Building Type	LED A-Lamps			LED Reflectors		
	Sites	**Operating Hours**	**Coincidence Factor**	**Sites**	**Operating Hours**	**Coincidence Factor**
Lodging	23	882	8%			
Office - Small	46	1,024	27%	38	1,822	45%
Other	4	2,522	76%	9	3,655	52%
Restaurant - Fast Food	27	3,623	67%	38	3,908	70%
Restaurant - Sit Down	41	3,277	66%	39	3,625	67%
Retail - Large				8	3,682	98%
Retail - Small	43	883	22%	45	3,443	80%
All Building Types	**184**	**1,215**	**20%**	**177**	**3,294**	**64%**

For restaurants, the annual operating hours and coincidence factors associated with LED A-lamp and reflector measures were fairly similar, but for small office and retail, there were significant differences. Differences in operating hours and peak demand were a function of the random nature of the sampling process, but to a much greater extent, were predicated on differences in the distribution of activity area installations. As mentioned above, LED reflector lamps were installed in higher usage activity areas than LED A-lamps. While this had only a marginal effect on restaurants, the impacts on small office and retail installations were quite dramatic. As previously noted, the "Other" building type represents segments where less than six sites were represented in the sample. For example, the "Other" category for LED A-lamps includes two large retail sites and one lodging site for reflector lamps.

Pre- and Post-Wattage

Post-retrofit wattages were based on lamp information gathered by the on-site auditor. In limited cases, it was not possible to gather wattage information, because all the measures had been either removed or had failed prior to the on-site inspection. Pre-retrofit wattages were developed using a variety of sources. The first was to locate fixtures that were not retrofitted but were in the same area or area-type as retrofitted measures. The second approach was to look for spare baseline lamps in storage or maintenance areas. The third was to collect self-reported data from the contact or maintenance staff regarding what had been installed prior to the retrofit. If none of these data were available, average wattages were applied to the baseline case.

Table 6 presents the results of the wattage analysis. These wattages are displayed at the analysis building type level and are weighted by the number of lamps. Also shown is the wattage ratio which represents the baseline wattage divided by the wattage of the retrofit. It is important to note that the "n" represents unique site-level wattage observations and so the counts can be greater than those represented in the operating hour tables.

Table 6. Pre- and Post-Retrofit Wattages by Building Type for LED A-Lamp and Reflectors

Building Type	LED A-Lamps				LED Reflectors			
	n	Pre Watts	Post Watts	Ratio	n	Pre Watts	Post Watts	Ratio
Lodging	22	44	10	4.5				
Office - Small	48	56	8	7.0	43	52	13	4.2
Other	6	18	14	1.3	9	73	13	5.7
Restaurant - Fast Food	27	49	9	5.5	53	58	13	4.5
Restaurant - Sit Down	43	68	10	7.1	52	66	12	5.6
Retail - Large					11	72	18	4.0
Retail - Small	43	65	8	7.9	66	55	11	4.9
All Building Types	**189**	**49**	**9**	**5.2**	**234**	**64**	**13**	**5.0**

For both LED A-lamps and reflectors, the post-retrofit wattages were fairly consistent across building types, except for the large retail reflectors which had an average post-retrofit wattage of 18. There was more substantial variability in the wattages of the baseline equipment across building types and across measures. For both A-lamps and reflector lamps, sit down restaurants were generally removing higher wattage baseline equipment than the fast food restaurants. Overall, the wattage ratios for each measure were fairly similar (5.2 for lamps and 5.0 for reflectors), but the ratios had significant variability at the building type level.

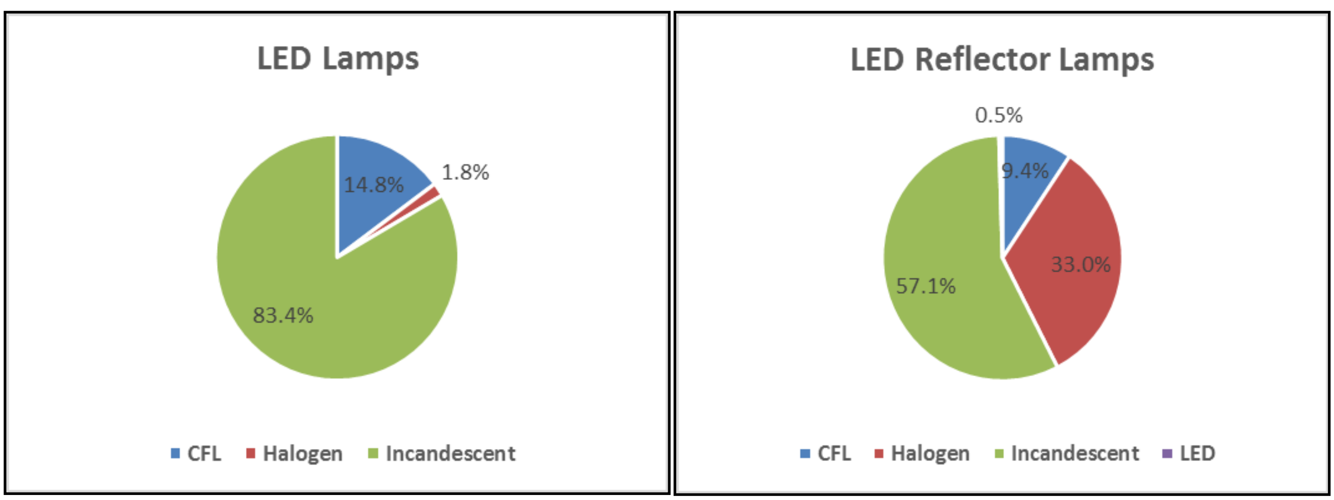

Figure 1. Distribution of Baseline Equipment Type for LED A-Lamps and Reflector Lamps

The on-site auditors also collected information regarding the type of equipment that the LED was replacing – incandescent, halogen or CFL (Figure 1). These data reveal that the vast majority of LED A-lamps were replacing incandescent lighting while the LED reflector lamps were mostly replacing incandescent lighting, but also a large share of halogens. These data also reveal that LED A-lamps and reflectors were replacing a small percentage of CFLs. Roughly 15% of LED A-lamp baseline equipment were CFLs with the majority of that equipment being retrofitted in lodging.

Non-Impact Analysis

The on-site survey process not only facilitated verification analyses and the development of impact parameter estimates for LED A-lamps and reflector lamps, it also served as a way of better understanding why individuals were installing LED equipment in the first place. As part of the on-site effort, site contacts were asked to state what the single-most important factor was in determining whether or not to retrofit their existing equipment with LED lighting. While a separate net-to-gross battery was administered as part of the larger phone survey effort, these results provide an additional qualitative understanding of the decision makers' rationale for retrofitting their existing equipment. Table 7 and 8 present the results from that analysis for LED A-lamps and LED reflector lamps, respectively.

Table 7. Reasons for LED A-Lamp Retrofit by Building Type for On-Site Sample

Retrofit Due to:	Lodging	Office Small	Other	Restaurant Fast Food	Restaurant Sit Down	Retail Small
Appearance	5%					
Contractor		4%		10%	17%	13%
Efficiency	14%		17%	3%	12%	
Energy Savings	9%	4%	17%	6%	7%	
Rebate	73%	90%	50%	74%	64%	78%
Unknown		2%	17%	3%		9%
n	**22**	**48**	**6**	**31**	**42**	**46**

Table 8. Reasons for LED Reflector Lamp Retrofit by Building Type for On-Site Sample

Retrofit Due to:	Office Small	Other	Restaurant Fast Food	Restaurant Sit Down	Retail Large	Retail Small
Appearance					13%	2%
Contractor	7%		23%	15%		20%
Efficiency	2%		8%	7%		
Energy Savings	7%	20%	8%	12%	25%	7%
Rebate	76%	60%	59%	59%	63%	65%
Unknown	5%	20%	3%	2%		4%
n	**42**	**10**	**39**	**41**	**8**	**46**

For both LED technologies, across all building types, the availability of a utility rebate was the primary reason that the lighting retrofit was performed. However, the input from a contractor played an important role in the decision, as well as the perceived efficiency and energy savings associated with the installation.

Conclusions

The gross energy savings associated with the installation of LED lamps have the potential of being quite significant. As discussed above, these technologies are being installed in a variety of different business types and the impacts associated with those installations vary significantly.

Failure and removal rates were the primary reasons that the installation rates were in the 91-93% range at the time of the on-site inspections. The main reasons for measures having been removed, which were garnered from the site contact, were that the light the LED lamps provided was too directional, the light was too bright or the light was not aesthetically pleasing. On average, lamps that had failed had done so within 6 to 8 months of installation.

The evaluation found that small offices, lodging and retail establishments had lower operating hours on average than other building types. These building types typically have shorter business hours, relative to other segments, and they were installing more LED measures (especially A-lamps) in lower usage areas within those segments. In contrast, restaurants tended to have much higher operating hours for both lamp types. This was generally due to the fact that restaurants are often open longer periods of time and LED lighting was being installed in high occupancy areas like dining areas.

These data reveal that the vast majority of LED A-lamps were replacing incandescent lighting, while LED reflector lamps were mostly replacing incandescent lighting, but also a larger share of halogens than LED A-lamps. These data also reveal that LED A-lamps and reflector lamps were replacing a small percentage of CFLs as well.

Recommendations

The following recommendations are provided to guide future evaluation efforts and market studies for LED measures:

- **On-site verification**: On-site verification will continue to provide essential information for any future impact evaluation or market study. On-site visits provide more information beyond just installation rates. Specifically, they provide information on where the measures are being installed, if they are being put in storage or if they are failing or being removed. Given the increasing contribution of LED measures to claimed ex-ante savings, these data are critical for future evaluation efforts.
- **Make and Model information:** Collection of make and model information on installed equipment should accompany the on-site verification process. These data, when looked up using manufacturer cut sheets, provide valuable lamp specifications. These data can also be used to target what specific technologies are failing or performing well in the market.
- **Baseline Lamp Characteristics:** Baseline lamp information should also be collected. Given the significant potential energy savings associated with low wattage LED measures replacing high wattage baseline equipment, it is important to collect as much information on what equipment is being replaced. This evaluation also found that LED lighting is replacing a small percentage of CFLs, which generally results in a smaller per unit impact savings than an incandescent or halogen retrofit.
- **Lighting Logger Data:** Lighting logger data should also continue to be collected in order to accurately estimate load shape profiles. Operating hours have a significant effect on the per unit energy savings of the measures as well as the effective useful life of the measure. Given the significant differences in operating schedules of LED installations, in terms of both activity areas and building types, additional logger data will help create a more robust catalog of load shapes and provide more value added to future program planning and unit energy savings calculations.

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