Getting Over the Hump: Leveraging Multi-Year Site-Specific Impact Evaluation to Derive C&I Lighting Parameters

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ABSTRACT

The objective of this paper is to highlight a successful method for developing lighting metering values for use in high-rigor evaluation. The evaluation team developed annual hours-of-use (HOU), utility and PJM-specific coincidence factors (CFs), and customer self-report ratio (CSRR)[1] space-level lighting parameters as part of this study.

In partnership with the EmPOWER utilities in the state of Maryland[2], the evaluation team sought to develop a rigorous set of lighting parameters to meet multiple objectives. The solution had to meet PJM requirements for summer metering of program installations to bid into the PJM forward capacity market and had to be flexible for application to future program years, all while minimizing long-term evaluation and metering costs by eliminating the need for yearly site-specific metering.

Based on previous evaluation work in Maryland, the team found that lighting retrofits often experience variability in lighting fixture installations between space-types from year-to-year. For lighting metering results to be applicable to future program years with variable distributions of installations by building-space type, the evaluation team needed to characterize the lighting parameters based on these unique building-space types.

Ultimately, the evaluation team leveraged four years of site-specific metering to develop building and space-level combinations for C&I lighting parameters. This approach improved the flexibility for use in future programs years as participation changes within the C&I building stock. PJM agreed with this approach and allows the application of space-level coincidence factor results for savings in future program years.

Introduction

The overarching objective of the EmPOWER Maryland C&I evaluation, from which this research is drawn, was to produce the most accurate verified energy and demand savings estimates at the portfolio-level. Additionally, the evaluation team sought to reduce long-term evaluation costs. Historically, lighting efficiency measures have contributed to the majority of program savings across the entire C&I portfolio. Therefore, the team explored several options to evaluate lighting measures, including:

- Site-specific measurement and verification of lighting equipment
- Lighting parameter-based research, including:
    - Equipment-type parameters (aggregated to the equipment or fixture-level)
    - Building-type parameters (aggregated to the building-level)
    - Space-type parameters (aggregated to building-space combinations)

[1] Customer self-report ratio = HOU_{Logged} / $HOU_{Customer\text{-}Reported}$

[2] EmPOWER utilities include: Baltimore Gas and Electric (BGE), Potomac Electric Power Company (Pepco), Delmarva Power & Light Company (DPL), Potomac Edison (PE), and Southern Maryland Electric Cooperative (SMECO)

In addition, the evaluation approach had to meet the following objectives:

- The portfolio-level demand savings had to meet PJM confidence and precision targets to bid into the PJM forward capacity market.
- Maintain flexibility to apply lighting metering results to future program years, therefore reducing long-term evaluation and metering costs. Ideally, the approach had to reduce or eliminate the need for yearly lighting metering studies.

The first evaluation option, site-specific measurement and verification, involves calculation of an energy and demand savings estimate for each individual site or project in the evaluation sample. This provides an accurate site-specific savings estimate by conducting lighting metering and verification to produce overall hours-of-use and coincidence factors for lighting equipment at the individual site. The evaluation team then uses the site-level savings results to calculate the overall savings for the entire program using ratio analysis. The drawback to this approach is that the evaluation team must perform site-specific lighting metering for each program year; the metering results from previous years are not applicable to newly sampled sites.

The second evaluation option, parameter-based research, involves calculating average overall HOU and CF values to apply to the entire population of energy efficiency projects within a particular utility or geographic area. Instead of calculating these parameters on a site-specific basis, evaluators use metering studies of several sites to calculate aggregate parameter values to apply to the entire population of lighting projects. There are several options to categorize these parameter values, including at the equipment-level, building-level, or space-level.

The evaluation team believes that space-level, or building-space combinations, are the ideal way to categorize HOU and CF lighting parameters for the EmPOWER evaluation. This is because:

- Building-space lighting metering results are flexible in application, because:
  - Lighting retrofit projects are frequently performed in different space types each year.
  - Different geographic regions may see a varying mixture of space-types within a particulat building type.
- Building-space parameters improve the overall relative precision of program savings estimates. Space-level parameters provide a better match to customer-reported hours, which can vary widely based on installation location.

Figure 1 shows an example of space-type participation changes from Period 1 to Period 2 within the school building type[3]. Period 1 saw a majority of lighting retrofit installations in school classrooms, while Period 2 saw less retrofit activity in classrooms and more activity in other school space types, including offices, dining areas, restrooms, and the library area. These space types have significantly different HOU and CF values than classrooms, as shown in this study. If the evaluation team were to develop overall building-level lighting parameters based on metering performed in retrofit areas during Period 1, the results may not be applicable to later years if the retrofit areas change significantly within a particular building type, such as in Period 2.

[3] The team collected this data from evaluation work performed in 2013 and 2014 program years.

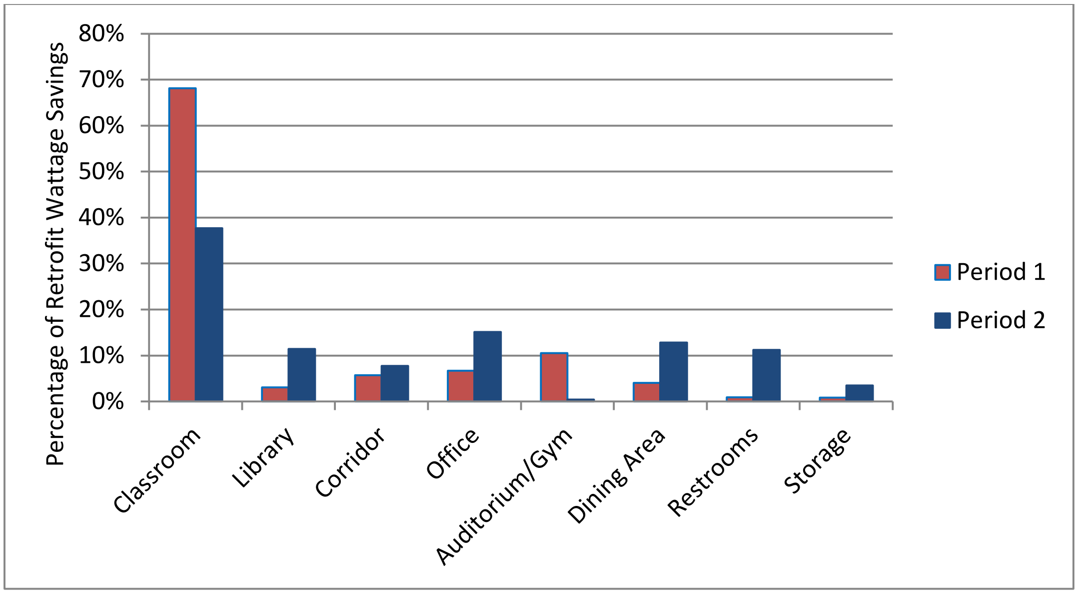

Figure 1: Comparison of Space-Type Contribution to Overall Building Lighting Retrofit Wattage, Period 1 (June 2012 through May, 2013) and Period 2 (June 2013 through May 2014)

Methodology

The following section describes the methods used to develop building and building-space level lighting parameters. Navigant prioritized this analysis for building types that account for the largest portion of lighting savings in the EmPOWER efficiency programs.

Sample Design

The evaluation team selected measurement and verification (M&V) methods in accordance with the requirements of PJM Manual 18B[4] for this study.

In order to reach an overall portfolio confidence and precision target of 90/10 one-tailed, Navigant targeted a 90/20 one-tailed confidence and precision target and a CV of 0.7 for the three most common building types in the EmPOWER programs: Office, Retail, and Warehouse/Industrial. For the School, Health, and Grocery building types, the team used a target of 90/25 one-tailed, with a CV of 0.7. These building-level metering targets were chosen so that when they are combined with annual verification uncertainty, 90/20 uncertainty would be obtained at the utility program level. The “Other” building type encompasses buildings that do not fall into the other six building categories. Navigant used a large sample size for the “Other” building category because of the high variance inherent due to the inclusion of multiple building types. Table 1 summarizes the number of sampled sites in each building-type category.

[4] Manual 18B defines the evaluation requirements for energy efficiency resources bid into the PJM forward capacity market. The allowed methods are comparable to IPMVP options a, b, c, and d. In addition, the manual requires both verification of installations on an annual basis and measurement during the PJM summer peak period, defined as 2 PM-6PM Eastern daylight time, non-holiday weekdays during June, July, and August. The manual also lays out a prescribed method for extrapolating weather-sensitive variability to a typical year.

Table 1: Lighting Metering Sample Sizes for Each Building Type

Building Type	Total Sample Size (Completed Sites)
Warehouse/Industrial	38
Office	25
Retail	21
School	10
Health	7
Grocery	10
Other*	61

*The “Other” building category refers to all projects that do not fall in the six defined building categories, including projects that have no specified building type.

The evaluation team conducted on-site visits during four metering period over the course of four years (2010 through 2013). Each metering period lasted four to ten weeks and the majority of loggers collected at least four weeks of data during the PJM peak period for each site. Field crews followed a thorough on-site protocol to determine the number and type of lighting circuits to meter. This protocol used the electrical load that each unique fixture/lighting control combination encompassed relative to the total retrofit load of the activity area in which it was located. The protocol required installation of meters on up to four switched circuits per space type for up to six different spaces per site. The team collected meter data with lighting and current state loggers.

Data Analysis

Navigant performed a thorough review and cleaning process for all collected logger data. Next, the evaluation team extrapolated the logger data and calculated lighting parameter values by building and space-type.

Review of Meter Data. Navigant analysts uploaded all on-site data and logger files to an online data collection system. The team reviewed all data for quality control purposes, including a thorough inspection of each site’s building characteristic inputs, operating schedules, measure-level in-service rates, and switched-circuit descriptions.

Navigant analysts reviewed all logger files deployed across the sampled sites and triaged each file as usable or unusable. Unusable logger files included loggers that had not been launched, loggers that failed in the field, and loggers that had been lost or stolen.

Navigant cleaned and analyzed the usable logger files with R, a statistical software package. First, the logger files were plotted and visually inspected for reasonableness. Next, the team converted all meter data to percent ON per hour. All meter data outside of and including the installation and retrieval dates were removed from the analysis. Any logger file deemed questionable at any point during this multi-step process was removed from the analysis.

Extrapolation of Meter Data. The cleaned logger files were extrapolated to provide percent ON per hour for the entire year (8760 hours), taking into account site-level data, including reported normal business hours, holidays, and seasonal schedules. The analyst used averages for each hour of the day, day type (weekday, weekend, and holiday), and customer-reported season to extrapolate to non-metered months.

Calculation of Logger-Level Parameters. Navigant calculated operating hours and coincidence factors for each logger, as follows:

- Operating Hours: percent ON per hour values were summed across all 8760 hours to calculate total annual operating hours.
- Utility CF: percent ON per hour values were averaged for the 4-5 PM period for all non-holiday weekdays in July and August to calculate the utility coincidence factor.
- PJM CF: percent ON per hour values were averaged for the 2-6 PM period for all non-holiday weekdays in June, July and August to calculate the PJM coincidence factor.

The customer self-report ratio is the ratio of logged operating hours to customer-reported operating hours:

$$CSRR = \frac{Operating\ Hours_{Logged}}{Operating\ Hours_{Customer-Reported}}$$

Where,

$Operating\ Hours_{Logged}$ = annual operating hours from logger, as discussed above.

$Operating\ Hours_{Customer\text{-}Reported}$ = annual operating hours listed in the customer application associated with the logged fixture(s).

Calculation of Space and Building-Level Parameters. Navigant used the weighting scheme shown in Table 2 to combine the data points from individual loggers into final space and building-level parameters.

Table 2: Lighting Parameter Analysis Steps and Weighting Scheme

Parameter Value Result	Analysis Step
Average HOU, CF, and CSRR for building-space combination at an individual site	Weight the individual logger parameters for each building-space combination. If greater than 75% of controlled circuits are logged at an individual site, use weighted average based on delta Watts attributable to each logger. Otherwise, use simple average.
*If stratification is used (e.g. by project size), calculate **strata-wide** building-space values using simple average*	
Average HOU, CF, and CSRR for building-space combination at the overall sample-level	Calculate **building-space values** using simple average of individual building-space results.
*Space-type values consolidated into **space-type groups** based on relative precision target**	
Average HOU, CF, and CSRR for building-type at the sample-level	Calculate **building-type values.** Weight the results using total sample-wide delta Watts for each building-space category for each unique building type.

* Navigant used a rough guideline of 30% relative precision at the 90% confidence interval as a cutoff value for all four lighting parameters (HOU, CSRR, CF-Utility, CF-PJM).

The evaluation team used a rough threshold of 30 percent overall relative precision for each calculated space-type parameter. Space types that met the threshold are presented as stand-alone space types. Space types that did not meet that threshold were grouped with other space types based on similar usage patterns. Space types that did not fit in to any other specific group were assigned to the "Other" group. See Table 3 for the relative precision of each grouping. It should be noted that this step has no impact on the overall results or confidence and precision on the total program, but it does impact how accurately the results can be extrapolated.

The final step of the weighting scheme combined the mapped space-type parameters for a given building type into a single building-type parameter. The building-type parameter values can be used in situations where building space-type is not available. The evaluation team used the delta Watts for each mapped space type as weighting factors in the analysis.[5] The delta Watts weighting factors for space type, *s*, within building type, *b*, were calculated as follows:

$$\Delta QW_{s,b} = \sum_{All\ sites\ of\ bldg\ type\ b\ with\ fixtures\ in\ s} Q_{Base} \times Watts_B - Q_{EE} \times Watts_{EE}$$

Where:

Q_{EE} = Efficient fixture quantity (field-verified)

$Watts_{EE}$ = Efficient fixture wattage (field-verified)

Q_{Base} = Baseline fixture quantity (from customer application, adjusted proportionally to Q_{EE} if necessary)

$Watts_{Base}$ = Baseline fixture wattage (from customer application)

Table 3 presents the relative precision for each of the four lighting parameters by building-space combination, as well as the quantities of sites and loggers represented in each category.

[5] The evaluation team used field data from all four evaluation years to develop the space-type weighting factors (2010-2013). Building-level parameters are derived using weightings of delta Watts for each building-space category in the metering study sample. Building-level results would therefore differ temporally or geographically based on space-type participation within a particular time period or geographic region.

Table 3: Sample Size and Relative Precision of Metering Parameters by Space-Type

Building Type	Space-Type Group	Qty of Sites	Qty of Loggers	Relative Precision			
				Op Hours	CF-Utility	CF-PJM	CSRR
All	Other	55	151	0.11	0.12	0.11	0.09
	Auto Repair Workshop	15	24	0.18	0.12	0.11	0.16
	Classroom/Lecture	11	30	0.21	0.26	0.22	0.20
	Commercial/Industrial Work	22	66	0.15	0.14	0.11	0.13
	Corridor/Hallways	42	105	0.10	0.09	0.08	0.14
	Kitchen/Break room & Food Prep	19	23	0.22	0.25	0.24	0.19
	Library	9	13	0.31	0.25	0.23	0.41
	Lobby (Main Entry and Assembly)	11	12	0.20	0.13	0.14	0.18
	Lobby (Office Reception/Waiting)	5	8	0.37	0.08	0.06	0.30
	Mechanical/Electrical Room	15	31	0.27	0.27	0.27	0.46
	Medical Offices/Exam & Patient Rm	5	11	0.26	0.17	0.17	0.33
	Office (Executive/Private)	23	41	0.19	0.20	0.17	0.17
	Office (General)	38	99	0.14	0.08	0.08	0.14
	Office(Open Plan)	13	25	0.19	0.21	0.19	0.29
	Restrooms	21	35	0.34	0.31	0.29	0.36
	Retail Sales/Showroom	42	129	0.08	0.04	0.04	0.09
	Storage	47	125	0.14	0.11	0.10	0.13
Grocery	Retail Sales/Showroom	10	39	0.08	0.03	0.03	0.08
Health	Corridor/Hallways/Lobbies	5	11	0.34	0.05	0.07	0.26
	Offices and Exam Rooms	5	12	0.21	0.16	0.16	0.28
Office	Corridor/Hallways/Lobbies	12	27	0.27	0.20	0.21	0.25
	Offices - General/Open	18	60	0.10	0.07	0.07	0.19
Retail	Corridor/Hallways/Lobbies	4	5	0.23	0.01	0.00	0.23
	Retail Sales/Showroom	20	70	0.10	0.05	0.05	0.07
	Storage (Conditioned)	5	11	0.36	0.24	0.24	0.29
School	Other	10	34	0.26	0.18	0.18	0.31
	Classroom/Lecture/Conference Rooms	5	18	0.24	0.25	0.18	0.25
	Corridor/Hallways	6	12	0.15	0.02	0.03	0.23
Warehouse/ Industrial	Workspace	23	68	0.14	0.11	0.09	0.12
	Offices - General/Open	11	25	0.19	0.21	0.21	0.16
	Storage	20	68	0.21	0.17	0.13	0.17

Lastly, it is important to examine the prevalence of "emergency" lighting in the logged sample. The evaluation team made an adjustment to four of the building-space categories, due to the fact that there were disproportionately large fractions of loggers installed on emergency circuits, which are set to be always ON.[6] The adjustment was made to correct for an artificially high representation of fixtures that stay on throughout the year. Table 4 shows the adjustments made to the fractions of loggers always ON for each of the four categories, based on National Fire Protection Association (NFPA) code requirements.

Table 4: Adjustment for "Always ON" Loggers

Building Type	Space-Type Group	Verified Fraction of Loggers Always ON	Adjusted Fraction of Loggers Always ON
All	Library	0.12	0.10
All	Office (General)	0.14	0.10
All	Office(Open Plan)	0.15	0.10
School	Corridor/Hallways	0.24	0.20

Application of Building-Space Parameters to Calculate Savings

The evaluation team performed site-specific measurement and verification of lighting savings during previous evaluation years, spanning 2010 through 2013. After completion of the building-space lighting metering study in 2013, the team was able to eliminate the need for lighting metering activities during the 2014 program year. During on-site verification, the team collected unique space-type information for all retrofit lighting equipment. The team then applied the building-space parameters to calculate overall site-level energy and demand savings.

During the on-site visit, Navigant verified the claimed building type for the project as well as the installed quantity and operating Wattage of the retrofit lighting equipment. Additionally, Navigant collected space-type and heating/cooling-type data for all lighting equipment.

Navigant calculated verified energy and demand savings for each unique combination of lighting equipment and space-type using the equations below. Total project savings is the summation of the individual savings for all unique fixture types and space-level combinations.

$$kWh_v = \frac{Q_V \times \Delta W_V \times HOU_{space-type} \times IF_E}{1000}$$

$$kW_v = \frac{Q_V \times \Delta W_V \times CF_{space-type} \times IF_D}{1000}$$

Where,

Q_V = on-site-verified fixture quantity
ΔW_V = on-site-verified load reduction in Watts
$HOU_{space\text{-}type}$ = building-space hours of operation based on verified space-type
$CF_{space\text{-}type}$ = building-space coincidence factor based on verified space-type
IF_E = lighting/HVAC energy interaction factor
IF_D = lighting/HVAC demand interaction factor

[6] Loggers were considered to be always ON if they had annual operating hours greater than 8,000 hours.

Results

This section presents the results of Navigant's space-level lighting metering study. Table 5 shows hours of operation, coincidence factors (utility and PJM) and customer self-report ratios by space-type group for each of the main building types in this study.

Table 5: Lighting Parameters by Space-Type

Building Type	Space-Type Group	Annual Operating Hours	CF-Utility	CF-PJM	Customer Self-Report Ratio
Other	Auto Repair Workshop	4,498	0.88	0.88	1.05
	Classroom/Lecture	1,707	0.34	0.33	0.69
	Commercial/Industrial Work	3,667	0.66	0.69	0.92
	Corridor/Hallways	5,604	0.79	0.80	1.24
	Kitchen/Break room & Food Prep	3,694	0.55	0.57	0.92
	Library	3,287	0.70	0.66	1.38
	Lobby (Main Entry and Assembly)	5,518	0.87	0.85	1.24
	Lobby (Office Reception/Waiting)	4,401	0.93	0.94	1.04
	Mechanical/Electrical Room	4,163	0.55	0.55	0.83
	Medical Offices/Exam & Patient Rm	2,678	0.75	0.75	0.63
	Office (Executive/Private)	1,960	0.49	0.51	0.66
	Office (General)	3,092	0.69	0.68	0.85
	Office(Open Plan)	2,494	0.59	0.61	0.88
	Other	5,199	0.66	0.67	0.95
	Restrooms	3,494	0.47	0.48	1.00
	Retail Sales/Showroom	5,247	0.92	0.92	1.05
	Storage	3,584	0.61	0.62	0.88
Grocery	Retail Sales/Showroom	7,149	0.96	0.96	1.14
Health	Corridor/Hallways/Lobbies	4,834	0.95	0.93	1.10
	Offices and Exam Rooms	2,852	0.78	0.78	0.67
Office	Corridor/Hallways/Lobbies	3,068	0.68	0.66	0.81
	Offices - General/Open	2,585	0.73	0.72	0.75
Retail	Corridor/Hallways/Lobbies	6,986	1.00	1.00	1.48
	Retail Sales/Showroom	4,951	0.97	0.95	1.05
	Storage (Conditioned)	5,232	0.84	0.84	1.20
School	Classroom/Lecture/Conf Rooms	2,257	0.48	0.49	0.97
	Corridor/Hallways	5,827	0.95	0.94	2.08
	Other	2,110	0.39	0.38	0.96
Warehouse/ Industrial	Offices - General/Open	2,414	0.61	0.62	0.68
	Storage	3,726	0.62	0.65	0.94
	Workspace	4,486	0.80	0.82	1.20

Based on the results of this study, some of the building types have large differences in lighting parameters at the space-level. For example, school buildings have relatively low HOU and CF in classrooms as compared to hallways and corridors. In general, private spaces with intermittent lighting usage show lower HOU compared to customer-reported hours (quantified as CSRR), including private offices, exam rooms, and classrooms. Corridors, hallways, and lobby areas show higher CSRRs, likely due to always-on emergency lighting fixtures and lights left on after hours.

Navigant used these space-level values to create weighted building-type values. Table 6 shows the building-type parameter results for all of the major building types studied. The parameters for the office, retail, and warehouse/industrial building categories are split into two subcategories, prescriptive and small business, using only the logger results from prescriptive and small business sampled sites, respectively. These building types have greater contrast in lighting schedules between prescriptive and small business participants. The remaining building type categories have one set of parameters for both prescriptive and small business projects.

Table 6: Lighting Parameters by Building-Type

Building Type	Sector	Annual Operating Hours	CF-Utility	CF-PJM	Customer Self-Report Ratio
Grocery	Prescriptive & Small Business	7,134	0.96	0.96	1.14
Health	Prescriptive & Small Business	3,909	0.80	0.79	0.88
Office	Prescriptive	2,969	0.70	0.69	0.79
	Small Business	2,950	0.67	0.67	0.80
Other	Prescriptive & Small Business	4,573	0.66	0.67	0.96
Retail	Prescriptive	4,920	0.96	0.94	1.05
	Small Business	4,926	0.86	0.85	1.03
School	Prescriptive & Small Business	2,575	0.50*	N/A**	1.04
Warehouse/Industrial	Prescriptive	4,116	0.70	0.72	1.04
	Small Business	3,799	0.68	0.70	0.99

* From NEEP Lighting Loadshape Study (NEEP 2011)/Mid-Atlantic TRM v4.0 (NEEP 2014). This metering study did not provide sufficient data during the summer schedule period to produce robust coincidence factors for schools from primary data.

** Navigant did not include PJM demand savings for schools in this evaluation due to the lack of primary data.

Figure 2 and Figure 3 show a comparison of the coincidence factors and annual operating hours from the metering study with those from the NEEP Lighting Loadshape Study (NEEP 2011). In general, the building-level results compare favorably between the two studies. In the Health and Retail building categories, the metering study produced higher coincidence factors than the NEEP Study. In all other categories, the CFs from the metering study fell in between the NEEP Utility CF and PJM CF. The metering study produced higher HOU for the Grocery, Retail, School, and "Other" building categories.

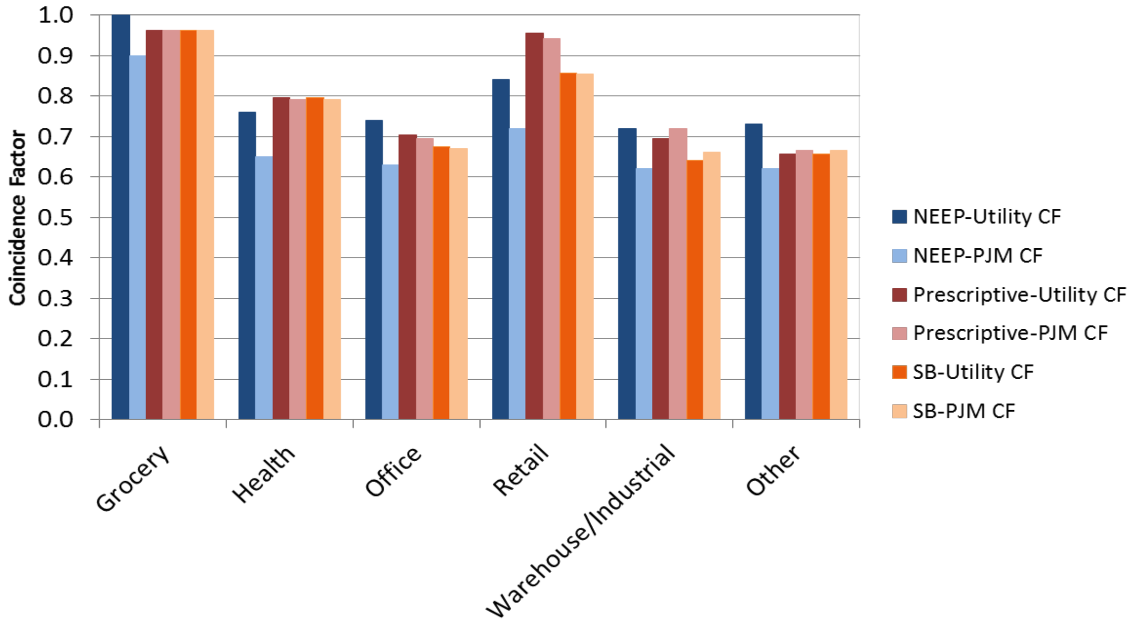

Figure 2: Comparison of NEEP and Navigant Coincidence Factors[7]

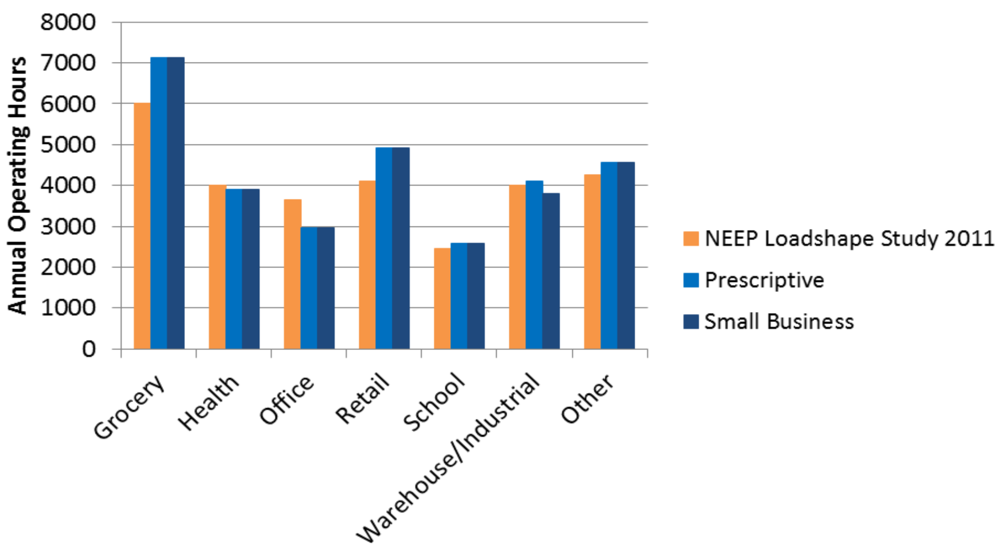

Figure 3: Comparison of NEEP and Navigant Annual Operating Hours

Conclusions and Recommendations

In summary, the evaluation team was able to leverage four years of lighting metering data in the EmPOWER Maryland service territory to develop building and space-level lighting parameters. This cost-

[7] The NEEP "Other" category shows the values for the "Other/Misc." category from the NEEP Lighting Loadshape Study/Mid-Atlantic TRM version 3. The value should not be compared directly with the results from this study, which include additional buildings in the "Other" category, including College, Lodging, and Restaurants.

effective approach allowed for greater flexibility - the results are applicable to future program years and do not require yearly lighting metering to provide evaluation results. PJM agreed with this approach, and the evaluation team has successfully applied space-type hours-of-use, coincidence factor, and customer self-report ratio parameters to support the EmPOWER C&I program evaluations in 2013 and 2014 program years. In the 2014 evaluation year, Navigant was able to forego lighting metering work altogether, and instead performed a verification-only study for sampled sites in the EmPOWER service territory, reducing evaluation costs. Navigant collected space-type information for retrofit areas at each site and was able to apply the space-type lighting metering parameters developed as part of this study. Other evaluation teams can explore similar methods with an optional nested sample of metered projects.

As part of this work, the evaluation team presents the following recommendations to program designers, evaluators, and implementation teams:

- The results of this study did not show significantly low HOU for any particular space-type category. The team recommends that program designers focus on whole-building, comprehensive lighting retrofits and do not use the results of this study to target specific space types for retrofit activity.
- Program implementation contractors should consider tracking lighting projects at the space-level. Space-level data can be used to improve savings estimates, reduce uncertainty, and lower overall evaluation costs by producing better confidence and precision using fewer evaluated sites.
- The team recommends that evaluators utilize customer self-report ratios (CSRRs) in combination with customer-reported lighting HOU to increase the accuracy of lighting savings estimates.

Future Work

The team is considering additional metering activities in school buildings to quantify the seasonal differences in lighting metering parameters. The summer break usage is especially difficult to meter and extrapolate, as schools experience high variability in summer usage within different space types. Evaluators should be careful to design their metering studies to use multiple time periods during summer breaks to capture differing usage.

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