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Establishing a Data Collection Methodology, Common Metrics and the Lighting Energy Code Comparison for Lighting Control Systems Research

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EXECUTIVE SUMMARY

New Buildings Institute (NBI) has managed two commercial office lighting controls research field studies – one through the Office of the Future Consortium (OTF) and another funded by the Northwest Energy Efficiency Alliance (NEEA). Additional NBI work with the California PIER program provided insights for the research metrics and key performance indicators. Office of the Future provided data from 7 retrofit and tenant improvement sites, each uniquely designed with advanced controls. These sites were located throughout the US/Canada. The NEEA field study looked at the retrofit application of the Enlighted brand wireless control system, which provided 3 additional data sets from sites located in the Pacific Northwest.

These studies were commissioned because utilities are facing higher mandates to save through energy efficiency. Energy codes provide tighter Lighting Power Densities (LPD) with every round and continue to require basic control strategies. In addition, EISA 2007 measures banned the manufacture and import of the standard T12 lamp in July 2012, which leaves the energy-lucrative T12-T8 retrofit market in question. One thing is known - at some point those widget replacement programs will end. Forward-thinking utilities are looking for new ways to incentivize large energy savings.

Lighting systems with advanced lighting controls are thought to offer a pathway to high savings. However they also create challenges that the industry must address. These include:

1. How to compare against code (W/SF) when installed capacity is less an indicator of energy performance
2. How to compare lighting systems to examine which approaches work best

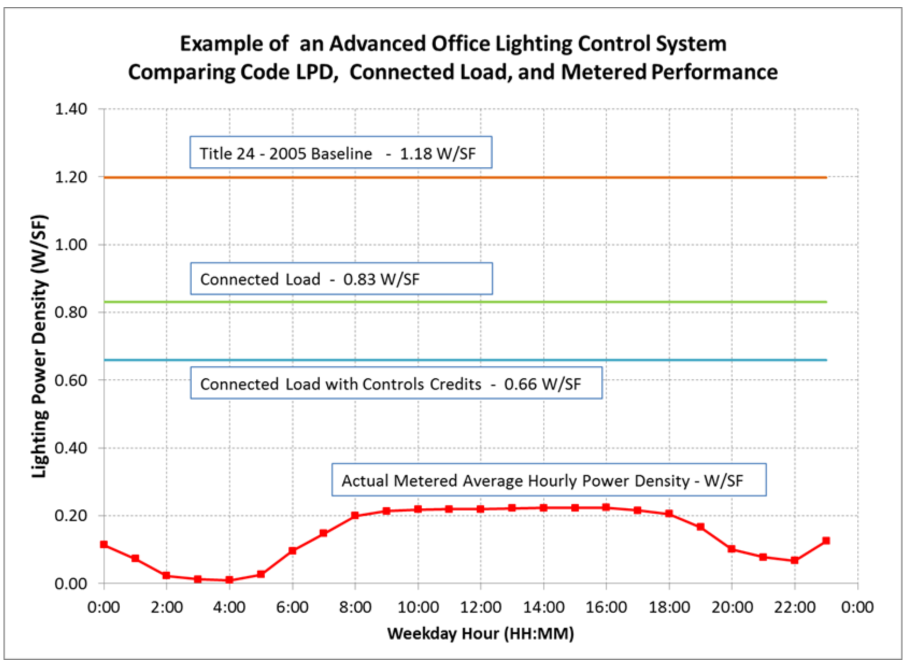

Figure 1. Actual metered use of an advanced lighting system with controls (in red) as compared to a static Lighting Power Density allowed by code and actual connected power of the system

As shown in Figure 1, the code baseline and the connected load metric (W/SF) do not take into consideration the occupancy and use of the space as they relate to actual energy consumed. To respond to this challenge, NBI developed a standardized method for translating the measured energy in an office (kWh) to a code basis in W/SF. By using established occupancy weighting data from the California DEER metrics, it allows the NBI research (labeled as Lighting Energy Code Comparison, or LECC) to better represent the savings of advanced lighting systems as compared to a code baseline, as in Figure 2.

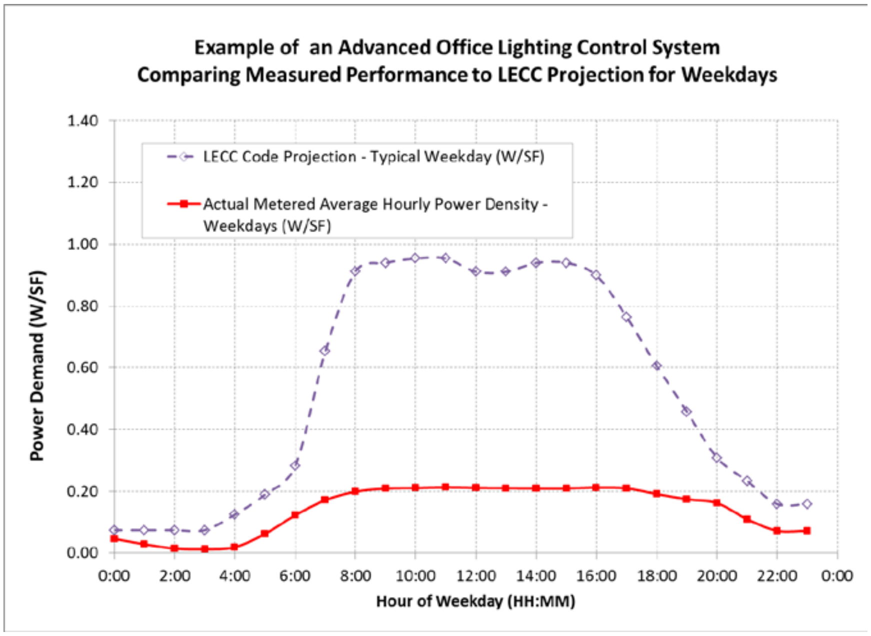

Figure 2. Daily Consumption Profiles showing the projected code comparison of a metered highly controlled office lighting system

Below are examples of the three primary metrics NBI has identified to quantify and compare the value of lighting systems with controls in office spaces. These include a Daily Consumption Profile, an Average Lighting Power Density that compares performance (in W/SF) during presumed occupied and non-occupied hours, and an Annualized Energy Consumption that compares to the LECC. Each is illustrated with a different NBI research project.

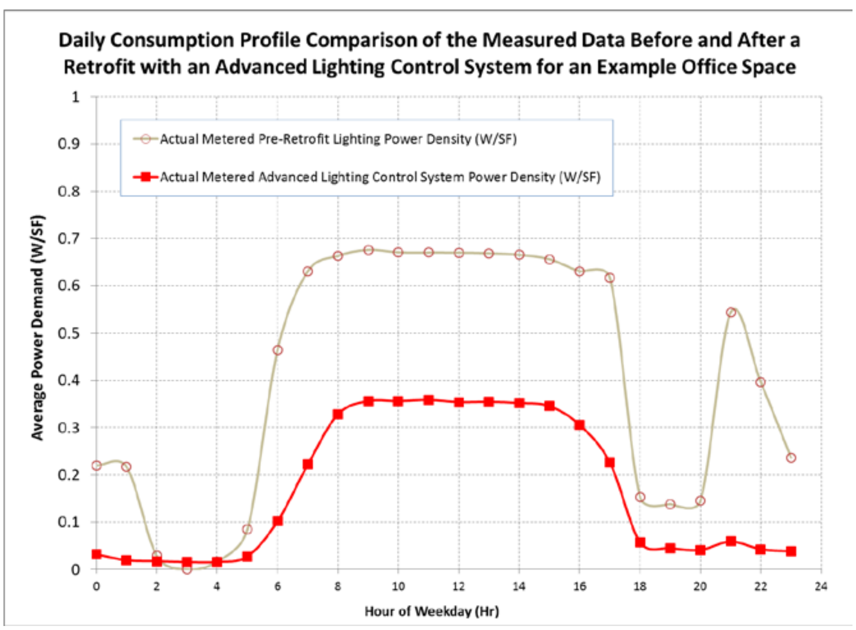

Figure 3. Daily Consumption Profiles before and after lighting system renovation

Table 1. Average Lighting Power Density Analysis comparing Existing and Retrofit Performance

	Installed LPD W/SF	Mon-Fri Occupied W/SF	Mon-Fri Night W/SF	Off Hours Ratio	Sat-Sun-Holiday W/SF	Weekend Ratio	Peak W/SF
Existing Baseline	1.23	0.85	0.35	41%	0.08	9%	1.07
Retrofit Condition	0.60	0.39	0.07	18%	0.02	5%	0.60

It is expected that the studied site could be compared to a variety of data, such as same building type, alternate floor within the same building, historical references, etc.

Table 2. Savings Metrics – Annualized Energy Consumption

SAVINGS METRICS	Example Office		
Location	CA		
Size (SF)	8328		Days
Performance Period	1/3/2011	10/1/2011	271
Exisitng Baseline Period	8/28/2010	10/31/2010	64

Comparison to Code		Title24 - 2005	Example Office	Savings over Code	Percent
Based on Code Installed Cap.	W/SF	1.18	0.83	0.35	30%
Annualized Energy	kWh/Yr	28872	8212	20659.9	72%
Annualized Energy per SF	kWh/SF/Yr	3.47	0.99	2.48	72%
Peak Demand	kW/Yr	7.9	3.6	4.34	55%
Peak Demand per SF	W/SF/Yr	0.95	0.43	0.52	55%

Table 2 extrapolates yearly energy use based on the measurements taken, provides generalized usage and makes comparisons to the presiding code. The “code” column is an LECC computation based on Title 24.

NBI has developed these standardized metrics for office space lighting to facilitate comparisons between office spaces, between pre- and post-retrofits of lighting systems, between code baselines, and between different modes of operation in highly complex lighting control systems.

The desire at NBI is to circulate this paper within lighting control stakeholder groups and begin a dialogue regarding the need for a code comparison energy method. Ultimately we want feedback on this approach, to be used as a catalyst to gain support for a method. The integration of a projected code comparison method into the proper research channels is imperative. It offers a pathway for better understanding of lighting controls, a standardized research method and a way to rate the use of advanced lighting control systems. Only then can controls be valued properly, allowing programs to correctly discuss and incentivize their use.

THE TWO PRIMARY CHALLENGES

In working with measured performance of highly controlled lighting systems in office spaces, NBI developed procedures to respond to the request to assess their efficacy. This advanced approach resulted in the recognition of a few key issues that need to be addressed, including:

1. **Metrics** - Researchers, both independent and utility researchers who study advanced lighting systems, use many different approaches when reporting results. An aligned approach and set of reporting metrics will allow for greater leverage of the combined work. In addition, highly controlled lighting solutions can now track energy usage themselves; requiring these vendors use the same metrics will promote a common measured performance language in the industry.
2. **Methodology** - Energy code relies on installed capacity (W/SF) comparisons to determine compliance. There is no generally accepted code methodology for assessing an *energy* comparison (kWh). Further, NBI data shows that installed capacity comparisons of connected load to code, even with adjustments, may underestimate savings from highly integrated, well-controlled, lighting systems. The table below shows a simplified representation of how NBI seeks to address the lack of a code energy comparison.

Table 3. Proposal for standard methodology to project code energy use

	Actual	Code	Unit
Installed Capacity	Observed	Power Demand Limits (LPD)	W/SF
Energy Use	Measured	***Proposal to use LECC**	kWh/SF/Year

In this paper NBI is proposing a consistent set of metrics along with a methodology to establish a code energy baseline for industry consideration. While commercial office spaces provide a worthwhile first building type for a proposal of standardized metrics, it is clear that differences between specific applications (i.e. schools, retail, etc.) must be acknowledged. Lighting use and occupancy patterns will obviously vary for these non-office space types. Application-specific metrics for these spaces are likely necessary. It is NBI's hope that this methodology might provide a starting point in commercial offices to begin to leverage the work of researchers nationwide to greatly expedite the assessment of integrated lighting control systems.

THE METRICS – HOW WE ANALYZE

The most commonly discussed metric for installed lighting power demand is Lighting Power Density (LPD). Historically there was no limit to the amount of power a lighting system could consume. As energy consumption in buildings became a target for energy efficiency (following the early 1970's energy crisis), building energy codes have used the allowed LPD to control the amount of connected power (in Watts/SF) in commercial buildings. Many agree that current code has reached a low-end threshold for connected power based on the efficiencies of incumbent sources/auxiliaries.

Although LPDs will surely continue to decline as new, more efficient technologies prove viable, lighting controls and dimming ballast systems can reduce lighting use (beyond connected load) even further. However, lighting code is represented in the power density (W/SF) associated with the connected load, and performance data is measured in energy (kWh). Therefore new methods and metrics are required to compare performance. The following outlines the approach that NBI took when confronted with these challenges, starting with the definitions and followed by some standard protocols.

Table 4. Definitions associated with proposed office space lighting metrics

Name	Unit	Definition
Occupied Power Density	W/SF	Average power per SF for non-holiday weekdays between 6AM – 6PM
Nighttime Power Density	W/SF	Average power per SF for non-holiday weekdays between 6PM – 6AM
Off Hours Ratio	%	Ratio of average power density for non-holiday weekdays between Nighttime and the Occupied Power Density
Weekday Power Density	W/SF	Average power per SF for non-holiday weekdays in 24-hour day
Sat/Sun/Holiday Power Density	W/SF	Average power per SF for weekends and holidays in 24-hour day
Weekend Ratio	%	Ratio of Sat/Sun/Holiday Power Density and Weekday Power Density
Peak Demand Density	W/SF	Absolute maximum demand density (at smallest interval available) seen in period
Annualized Energy	kWh/SF/yr.	A calculated number that uses weekdays and Sat/Sun/Hol energy usage to project the annual energy usage for a year. Allows less than a year of data to create annual data.

Metering

In order to quantify the effectiveness of the lighting control system, NBI analyzed 15-minute interval measurements of the average true power and energy[1] on the lighting circuit. Metering was installed at the panel serving the office space to measure the energy use of the entire lighting system serving that space, including any computers used for central control. This metering approach does not account for the potential transfer of the lighting load to task lights. Task lighting is often included in the plug load circuit and is not accounted for with this particular metering approach.

[1] Hourly energy and power data may also be used but the usefulness of any higher level of granularity is limited.

Office Space Square Footage

The denominator in all the metric analysis is square footage (SF) of the office space studied. Naturally there should be a standard for calculating office space square footage to avoid bias based on square footage assessments. Luckily ANSI/BOMA has authored standards for the calculation of square footage in leased spaces that would serve as a fine basis for calculation.

Day Types for Offices

Weekdays are defined as Monday through Friday and exclude holidays. Holidays are frequently the same for most office spaces, but some differ in their use of holidays so each office must be examined to ensure there are no incorrectly categorized days. Weekdays are distinguished from Saturdays, Sundays and the applicable holidays.

Hour-Starting Attribution

In the NBI metrics we use the beginning of the hour when reporting usage and power demand density. This means that the average power demand density at 10PM represents the average power demand density from 10PM to 10:59PM.

Monitoring Period Length

Ideally as large a time as possible is used for any period in which the metrics are calculated. Occupancy variations are averaged out as the length of time increases. When measuring the contribution of daylighting, seasonal variations matter. Therefore, measurements taken in winter may not be representative of the same space, used the same way, during summer months when daylighting contribution is greater. This should be taken into consideration.

Office Space Lighting Metrics

NBI uses three primary metrics to quantify and compare the value of controls in office space lighting systems. These are the Daily Consumption Profile, the Average Lighting Power Density and the Annualized Energy Consumption. These are illustrated with examples from various NBI research projects.

Daily Consumption Profile

The Daily Consumption Profile illustrates the average lighting power density, in W/SF, at each hour of the day during weekdays only in the measurement period. It graphically shows how occupancy use patterns impact lighting power levels throughout the course of a typical daytime/occupied and nighttime office weekday. Increased availability from daylighting may also impact the Daily Consumption Profile, and it is assumed to contribute during the hours of peak energy use, although it is difficult to determine the magnitude of this contribution.

To create this plot, interval measurements of average lighting power density, at a particular hour on a weekday, are averaged for all of the weekdays in the monitoring period. This is repeated for every hour, and these results are plotted over the 24-hour occupied/nighttime period to graphically show the average weekday profile, as shown in Figure 4.

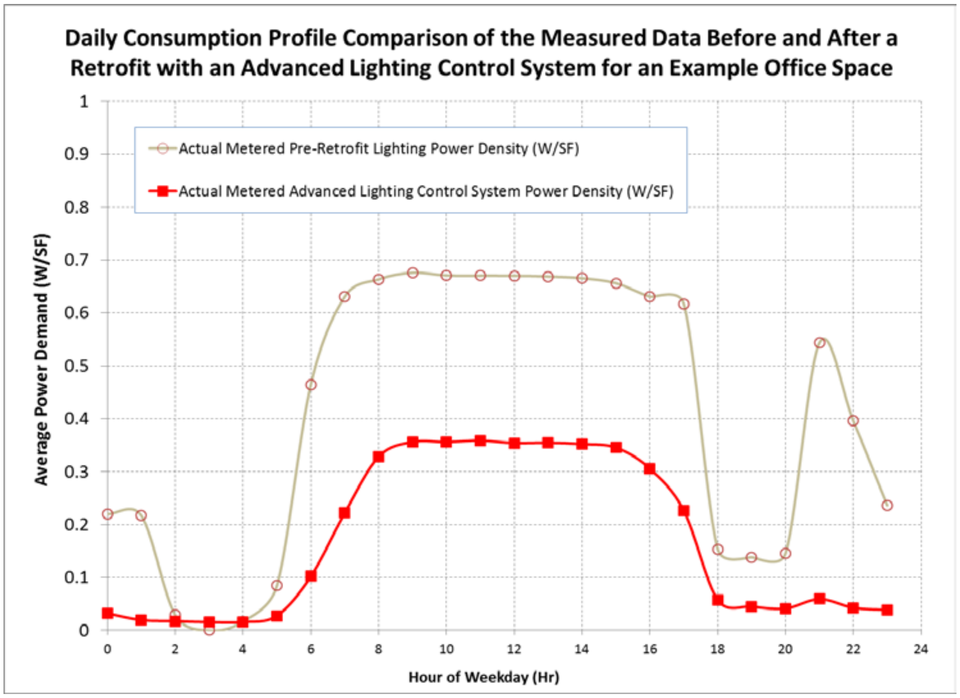

Figure 4. Example comparison of a lighting retrofit project using the Daily Consumption Profile

Average Lighting Power Density (in W/SF)

The Average Lighting Power Density analysis separately examines daytime and nighttime power demand and compares these LPDs within a table. The defined 12-hour period for occupied daytime period is the hours of 6:00AM and 6:00PM with the nighttime then from 6:00PM to 6:00AM. The daytime time period is referred to as the 'occupied hours' since it is the time the office space is most likely to be in use.

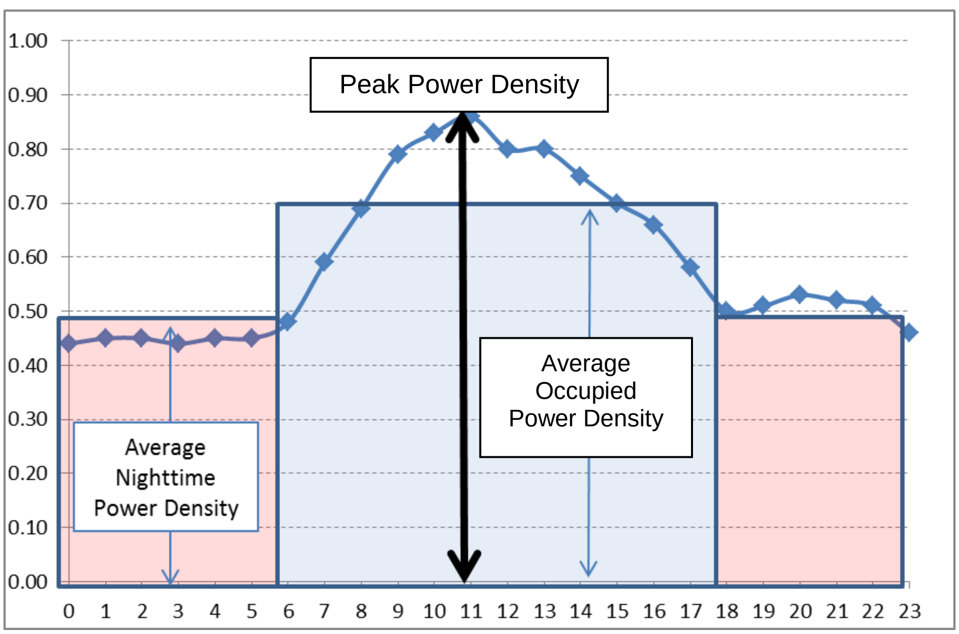

Figure 5: Average Lighting Power Density Representation

To create the Average Lighting Power Density table, start with the connected load/installed capacity of the site, then list comparison columns for the average Occupied and Nighttime Weekdays, the Sat/Sun/Holiday average and the Peak for the monitoring period. This allows easy comparison of energy savings due to controls/usage patterns.

Table 5. Example of a comparison of the average lighting power density (demand) metrics between a pre- and post- retrofit of a lighting control system

	Installed LPD W/SF	Mon-Fri Occupied W/SF	Mon-Fri Night W/SF	Off Hours Ratio	Sat-Sun-Holiday W/SF	Weekend Ratio	Peak W/SF
Existing Baseline	1.23	0.85	0.35	41%	0.08	9%	1.07
Retrofit Condition	0.60	0.39	0.07	18%	0.02	5%	0.60

Annualized Energy Consumption

The average Annualized Energy Consumption estimates the annual energy use that would be expected given the measurements taken. The estimated annual consumption is calculated based on the average 24-hour weekday kWh/day multiplied by 251 weekdays plus the average 24-hour weekend kWh/day x 114 weekend/holiday days. This estimated annual consumption is also normalized by the size of the office to allow for easy comparisons among the sites.

Table 6. Example of a report for a lighting retrofit that compares metrics including annualized energy

Comparison to Existing		Existing or Baseline	Advanced Control System	Savings over Existing	Percent
Lights					
Annualized Energy	kWh/Yr	17971	6095	11876	66%
Annualized Energy per SF	kWh/SF/Yr	4.28	1.45	3	66%
Occupied Power Density	W/SF	0.86	0.40	0.46	53%
Off-Hours Ratio		46%	18%		
Peak Demand Density	W/SF	1.07	0.60	0.47	44%
Avg Weekday Power Density	W/SF	0.63	0.24	0.39	62%
Avg Sat/Sun/Hol Power Density	W/SF	0.18	0.01	0.17	95%
Weekend Ratio		29%	4%		

However, since predicted code energy consumption is not readily available, NBI created the Lighting Energy Code Comparison (LECC) method to estimate what code would have predicted given particular office occupancy patterns, space types and lighting characteristics. This methodology is outlined in the next section.

THE METHOD – HOW WE COMPARE TO CODE

NBI, working with the Office of the Future Consortium (OTF), developed a methodology for projecting code-level energy usage in office spaces. This approach presumes "what would have happened" from a code standpoint for an office space with certain space types and lighting installed capacities. This methodology addressed the shortcomings of using one-time installed capacity comparisons when evaluating highly controlled lighting systems.

The methodology, which we call the Lighting Energy Code Comparison, uses lighting data from energy modeling software, used in code projection for whole buildings, to project the lighting-specific energy usage for a subject space. The energy modeling data is taken from the support data for the California Database of Energy Efficiency Resources (DEER). DEER uses building prototypes and batch modeling runs with DOE2 software to create a database of the whole building impact of particular measures. Within these prototypes there are usage fraction schedules for lighting space types. When projecting code energy usage the software uses these fractions to account for the lighting component of energy use. The DEER fractions were derived from metered data and represent the most accurate data set available for lighting energy projections in office spaces.

How Does the LECC Work?

This DEER data projects typical Weekday, Saturday and Sunday/Holiday hourly lighting usage fractions for different space types including different office space types, e.g. open office, private office, etc. The hourly usage fraction defines the amount of the installed capacity of lighting that is assumed to be on during a given hour of the day. Further, the usage profiles also differ for two different lighting types: LED/CFL and Fluorescent lighting.

Table 7. Example of lighting fraction data from the DEER database office building prototype for Weekdays by Hour and by Lighting Type (shows the weekday hours up to 8AM for open office spaces)

Private Office	Weekday Hour								
	1	2	3	4	5	6	7	8		24
DEER 2005	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.8		0.2
DEER 2008 CFL/LED	0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.5733333	...	0.306667
DEER 2008 T8/Other	0.055	0.055	0.055	0.055	0.11	0.18	0.28	0.45		0.1

NBI adopted these usage fraction profiles, an example of which is in Table 7, to attempt to reflect what the DEER energy modeling process would expect for energy consumption in a particular office space given that the installed capacity, space types and areas are known from the NBI data collection protocol.

Note that this does not represent prediction of expected behavior but a projection of what an energy model would expect for the office space. In this way it represents a model-based "code level" projection of energy use which can be compared with actual meter energy use to make a code comparison on an energy and peak demand basis.

To create a specific value for an office space the LECC first identifies the constituent office space types and square footages in the research site. These are:

- open office
- private office
- conference room

- corridor
- waiting/lobby
- mechanical/storage
- other

Note that there is no “kitchen” category which NBI combines into “other.”

Next the code-level installed capacity for each space type is taken from the applicable code. The code maximum permitted installed capacity (W/SF) for office space types are usually called out in a table in an energy code, in the lighting section space-by-space methodology.

Then the applicable usage fraction for each space type, LED/CFL or Fluorescent, is chosen from the DEER usage fraction profiles. This is based on the predominant type of lighting installed in each space.

The installed capacity for each space is then multiplied by its corresponding square footage and usage fraction for each of the three day types: Weekday, Saturday and Sunday/Holiday. The energy from each hour is summarized for each day type to create the three prototypical days[2].

Then the annualized energy is found by adding up the hourly energies to find the 24-hour energy for the day type. The day type 24-hour energy is then multiplied by the number of corresponding day types expected in a typical year monitored as an aggregate of all office lighting energy usage.

Table 8. Example of the LECC for a subject office space with a very highly controlled and low installed capacity lighting system

SAVINGS METRICS	Example Office				
Location	CA				
Size (SF)	8328		Days		
Performance Period	1/3/2011	10/1/2011	271		
Exisitng Baseline Period	8/28/2010	10/31/2010	64		
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Also shown in the Comparison column of Table 8 is the peak demand observed in the metered data with the peak demand predicted from the weekday model-based projection data. This analysis provides the utility with a sense of the demand reduction capabilities of the system.

[2] NBI day type quantities are: Weekdays (minus 10 holidays) = 241; and combined Saturday, Sunday + Holidays = 114. Therefore two day types versus DEERs use of three.

The weekday model-based profile also provides a useful visual comparison with metered data from weekdays. In Figure 6 below, we plotted the weekday model-based average power demand density (purple dashed diamonds) along with the measured data for the existing (pre-retrofit) lighting system (red squares). This provides a quick graphical qualitative appreciation for "how well did the site do vs. code" which can be quantified in a number of ways (i.e. annual energy, peak demand vs. installed capacity, or other metric).

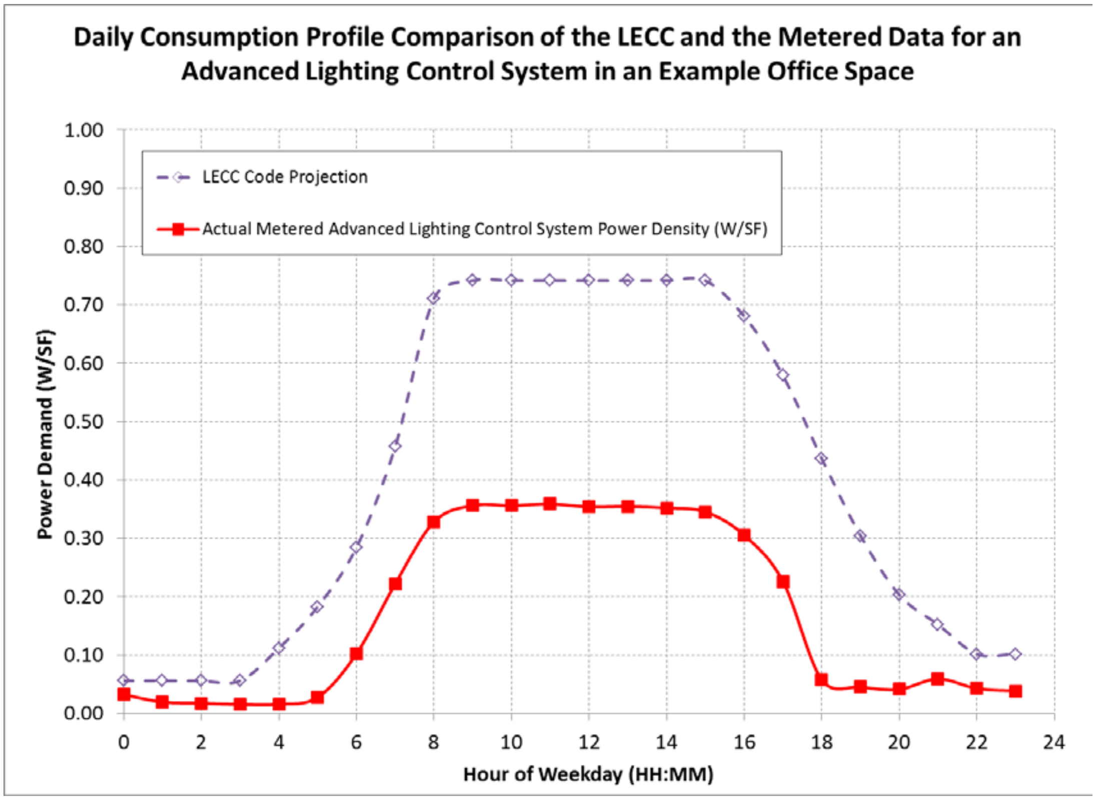

Figure 6. Example of the visual comparison of typical weekday average lighting power density between the model-based projection and the existing (pre-retrofit) lighting system

With the LECC we have tried to create a simple method for projecting code level energy use. We think this provides a good basis for incentivizing lighting control systems that may use complex integrated control approaches that exceed the capabilities of prescriptive codes.

NEXT STEPS

NBI feels strongly that a common analysis method and an agreed-upon list of standard metrics are necessary to propel the usability of advanced lighting systems with controls research to a position of valid action.

Lighting system controls investigative work is being planned and executed around the country. These pilot studies need consistent data collection to allow comparison and amassing of significant data for direction.

This paper characterizes a method framework, applied to office spaces, and is offered as a methodology and metrics combination concept to be leveraged by working groups in a position to educate and influence the lighting research milieu.

The DEER usage fraction profiles, used in this method framework, exist for other buildings types, such as schools and retail, and therefore provide an opportunity to expand the code projection research method to these building types.

Additional work needed to meet the goal of consistent methods includes:

1. Establishing a standardized measured performance language
2. Encouraging control system manufacturers to implement common metrics language
3. Addressing the challenge of an effective task light/plug load metering method
4. Establishing a consistent research methodology for utility program planners and regulators alike

The desire at NBI is to circulate this paper within lighting control stakeholder groups and begin a dialogue regarding the need for a code comparison energy method. Ultimately, we want feedback on this approach and will use it as a catalyst to gain support for a method. The integration of a projected code comparison method into the proper research channels is imperative. It offers a pathway for better understanding of lighting controls, a standardized research method and a way to rate the use of advanced lighting/control systems. Only then can controls be valued properly, allowing programs to correctly discuss and incentivize their use.