PREPARED BY
Seventhwave

Light Level Analysis in Buildings

A market characterization study

October 31, 2018

The project was funded by the Environmental & Economic Research and Development (EERD) Program under Focus on Energy, the Wisconsin statewide energy efficiency and renewable resource program funded by Wisconsin utilities.

{blank page}

Light Level Analysis in Buildings

October 31, 2018

Authors

Scott Schuetter, Seventhwave

749 University Row, Suite 320

Madison, WI 53705

608.210.7120

www.seventhwave.org

Project Manager

Scott Schuetter

Acknowledgements

Seventhwave staff who contributed to this project include Doug Ahl, Mikhaila Calice, Scott Hackel, Jennifer Li, Melanie Lord, and Leith Nye.

TABLE OF CONTENTS

FIGURES

TABLES

EXECUTIVE SUMMARY

On behalf of Focus on Energy's Environmental and Economic Research and Development Program (EERD), Seventhwave collected information from Wisconsin businesses on their light levels and associated lighting system characteristics. This information will help Focus on Energy address savings opportunities from optimizing light levels by identifying appropriate program offerings and resources.

The characterization study was comprised of both primary and secondary research. We reviewed studies germane to this project, conducted a segmentation of Wisconsin lighting based on U.S. Energy Information Administration data, interviewed Focus on Energy program staff and a select group of stakeholders, and visited a sample of Wisconsin businesses. We used the results from the site visits of Wisconsin businesses and data gleaned from our literature review to quantify the potential for energy savings from optimizing light levels (often referred to as illuminance). We distilled lessons learned to clarify effective approaches for Focus on Energy programs to reach this market segment.

Lighting Segmentation in Wisconsin

Commercial buildings in Wisconsin use approximately 4.29 billion kWh of lighting energy annually. Five building types comprise nearly three-quarters of the lighting energy. Office (22%) and Retail (21%) are the two largest market segments, with Education (12%), Healthcare (10%) and Warehouse (9%) also comprising significant components. Although Manufacturing facilities are not included in this segmentation, they comprise a significant portion of lighting energy consumption in Wisconsin, using approximately 1.4 billion kWh annually.[1]

Within the major building types, **the predominant and overlapping space types are open and private offices, conference rooms, storage areas, warehouse areas, and corridors (including hallways and stairwells). We also included classrooms as they were of interest to the Focus on Energy program staff.** Open plan offices are ideal for adjusting light levels, since the light levels and electrical power of a significant amount of lighting power can be affected with one adjustment. This minimizes the time and associated cost of achieving savings. Other good candidates are space types with many similar spaces such as private offices and classrooms. In these situations, the amount of adjustment can be determined in one space and quickly applied to the other similar spaces. Our space types of interest comprise the majority of the area in each of the major building types.

LEDs are inherently dimmable, meaning their light output and corresponding lighting energy could easily be reduced in overlit spaces. LEDs are rapidly increasing their share of the new and replacement lighting market. The DOE estimates that in 2012, LEDs comprised only 1% of the market. However, this increased to 3% in 2014 and 12.6% in 2016.[6] The DOE further projects that by 2020, LEDs will comprise 48% of the lighting market.[7] Using this information, we estimated the portion of commercial spaces in Wisconsin served by LEDs in 2018. **Across all the major building types, LEDs serve 3.9% of the total area.**

Task tuning, or high-end trim, is the adjustment of electric light levels by limiting the maximum light output and power of lighting systems. This control allows for the adjustment of light levels in existing overlit spaces, thereby saving electrical energy. **There is currently a low penetration of high-end trim in Wisconsin buildings, with only 0.4% of the major building types having implemented this control.**

Reviewing Focus on Energy Programs

[1] From analysis of 2017 U.S. Manufacturing Energy Consumption Survey data

We interviewed Focus on Energy program staff and a select group of stakeholders for their insights on lighting in Wisconsin businesses.

Key takeaways from Focus on Energy Business Incentive, Agriculture Schools and Government, and Large Energy User program staff include:

- Focus lighting programs serve the building types that comprise most of the lighting energy consumption in Wisconsin.
- Prescriptive measures make up most of the projects for all three programs.
- Retrofit projects account for most of savings in all three programs and they are seeing a significant and growing number of LED retrofits.
- Capital cost remains the primary barrier to lighting replacement and interest in energy efficiency is primarily motivated by reduction of operating costs.
- Program staff neither get involved with setting illuminance targets, nor in follow-up verification of actual light levels, leaving it to Trade Allies to provide appropriate illuminance for their projects.

Beneficial information for lighting program managers includes:

- Information on appropriate light levels for space types (including industrial spaces)
- Lighting metrics including min-max ratios and color temperatures
- Light levels by building type and customer type
- Strategies for moving customers toward optimal light levels
- Life cycle cost analysis education for owners and facility managers, etc.

Key takeaways from program stakeholders include:

- Program stakeholders (trade allies, manufacturers) are involved, to some degree, in multiple facets of implementing high efficiency lighting projects: there are no rigid boundaries around their services.
- They consider light levels on most projects but rarely measure light levels. There is a sense that spaces are overlit.
- Incentives, cost savings and simple payback are the most important strategies for promoting energy efficiency
- First cost is the primary barrier to implementing more efficient lighting but institutional, market and knowledge barriers also exist
- All were familiar with Focus on Energy and had worked with the program, primarily with the prescriptive lighting incentive offerings.

Stakeholder suggestions for improving the Focus on Energy lighting offerings included:

- Make program easier to understand and the forms clearer; make literature available before the program year begins; redesign the website to improve navigation and differentiate the programs; pay incentives in a timely manner to avoid cash flow issues for small businesses and trade allies
- Offer bigger incentives, especially for controls; offer financing
- Bring back the whole building lighting program; extend the lighting power reduction program beyond new construction projects
- Provide education and training to local trade allies

Site Visits

We visited a total of 40 buildings across Wisconsin. Within these buildings, we quantified the mean illuminance for our sample by space type (Table 1).

Table 1: Mean, standard deviation, and relative precision by space type.

Space Type	Average Illuminance (fc)		
	Mean	Standard Deviation	Relative Precision at 90% CI
Open Office	41.7	17.7	5.6
Private Office	37.4	16.3	4.4
Conference Room	44.0	17.0	5.5
Storage	25.3	14.3	4.5
Warehouse	28.0	13.6	5.9
Corridor	24.1	11.0	3.5
Classroom	53.1	21.5	8.9

We then calculated the degree to which the mean illuminance differed from the Illuminating Engineering Society (IES) recommendation for each space type, expressed as the percent reduction needed to bring the mean into agreement with the recommendation (Table 2).

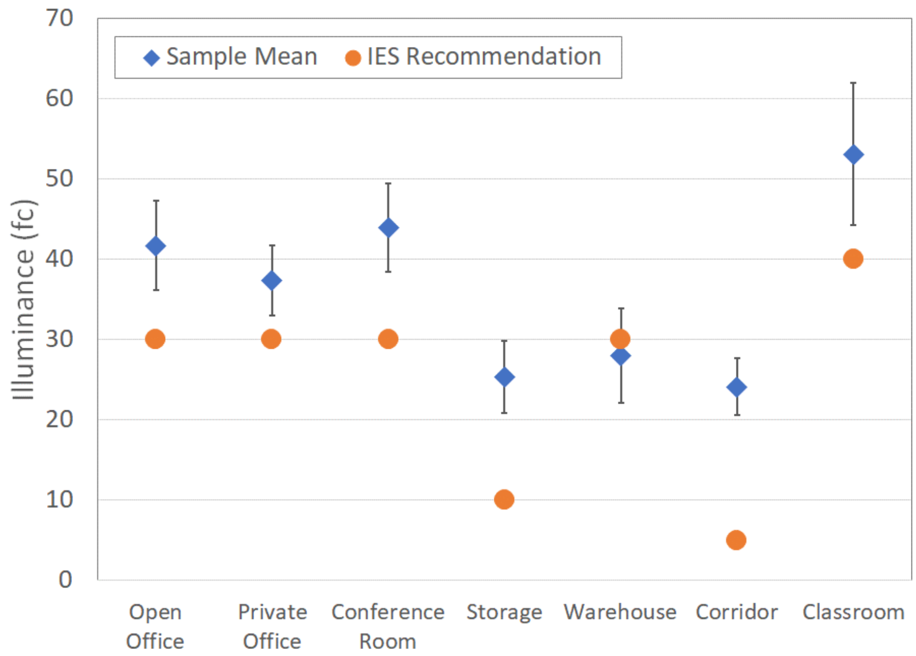
Table 2: Mean, IES recommendation, and percent reduction by space type.

Space Type	Average Illuminance (fc)		% Reduction
	Mean	IES Recommendation	
Open Office	41.7	30	28%
Private Office	37.4	30	20%
Conference Room	44.0	30	32%
Storage	25.3	10	61%
Warehouse	28.0	30	-7%
Corridor	24.1	5	79%
Classroom	53.1	40	25%

For all space types except Warehouse, the mean illuminance was higher than the IES recommendation. This means that energy savings could be captured by bringing the two into agreement. In Open Offices, Private Offices and Classrooms, this reduction was 28%, 20%, and 25%, respectively. This reduction is substantial, considering the large quantity of these space types in Wisconsin. Conference Rooms were even more overlit, needing a reduction of 32% to bring their mean illuminance into agreement with the IES recommendation. Storage (61%) and Corridor (79%) spaces were the most overlit, but there is less opportunity for aggregate energy savings in these spaces due to their smaller portion of overall building area. Warehouse was the only space type with a mean illuminance below the IES recommendation.

When the mean illuminance and IES recommendations are presented visually (Figure 1), the difference between the two is more striking.

Figure 1: Mean versus IES recommended illuminance.



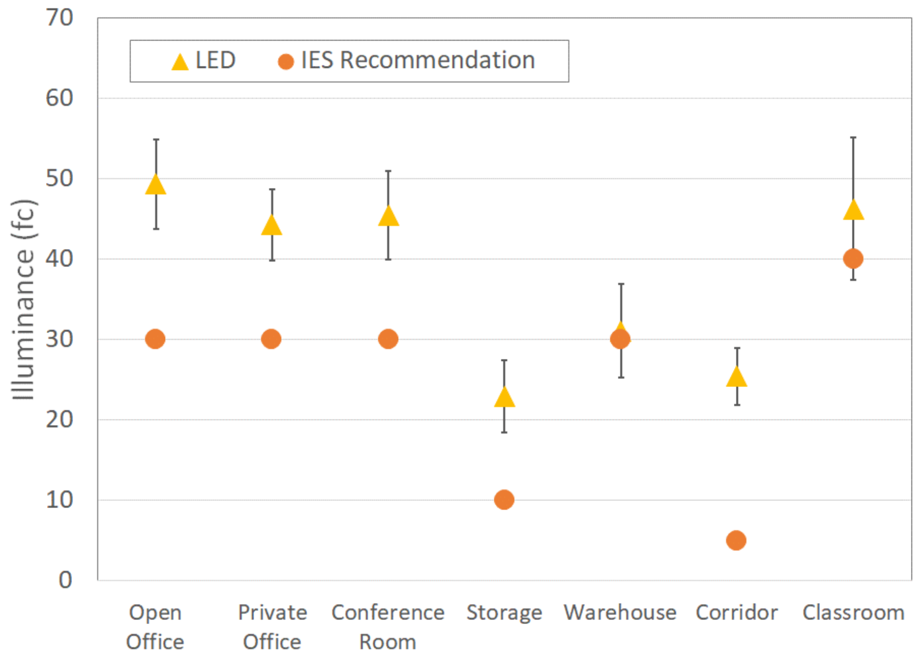
LEDs are the only primary lighting type with inherent dimming capabilities, and therefore represent the greatest opportunity for easily adjusting light levels. Since we tracked the primary lighting type of each of our spaces, we also quantified the mean illuminance for spaces lit by LEDs (Table 3).

Table 3: Mean, IES recommendation, and percent reduction by space type for LED-lit spaces.

Space Type	Average Illuminance (fc)		% Reduction
	Mean	IES Recommendation	
Open Office	49.4	30	39%
Private Office	44.3	30	32%
Conference Room	45.5	30	34%
Storage	23.0	10	56%
Warehouse	31.1	30	4%
Corridor	25.5	5	80%
Classroom	46.3	40	14%

Surprisingly, LEDs were the dominant primary lighting type, serving 54% of the total area we characterized. This is disproportionately high as compared to our segmentations estimate of approximately 4% of the total commercial building area in Wisconsin. This discrepancy is likely due to a combination of sample and response bias, as facility staff with high performance lighting were more likely to respond to our recruitment survey. For LED-lit spaces, all space types are overlit as compared to IES recommendations. As before, Warehouse is the only space type for which the IES recommendation lies within the confidence interval (Figure 2).

Figure 2: Mean versus IES recommended illuminance for LED-lit spaces.



The degree to which the LED mean illuminance differs from the overall mean illuminance is likely due to the nature of LED retrofit projects. These projects traditionally are one-for-one replacements of existing fluorescent lighting due to the prohibitive cost of modifying existing electrical infrastructure and/or drop ceilings. With little-to-no flexibility to adjust the fixture spacing, the LED light level is determined by the LED fixture's output. When multiple lumen packages exist for LED replacements fixtures, lighting professionals and Trade Allies tend to default to higher lumen packages to minimize the chance of customer dissatisfaction from low light levels. This default position is made even more reasonable given the replacement fixtures will still yield significant energy savings. **This systematic over-lighting of LED retrofit spaces represents a significant opportunity for programs to address.**

Expected Savings Estimates

The final estimated achievable savings potential from light level adjustment incentive programs in Wisconsin are shown in Table 4.

Table 4: Achievable potential savings from light level adjustment in Wisconsin.

Building Type	Estimated electricity savings (MWh)	Annual dollar savings ($)	Avoided GHG emissions (tCO2 eq.)
Office	1,735	$168,283	1,577
Healthcare	309	$30,017	281
Education	1,252	$121,430	1,138
Retail	544	$52,742	494
Warehouse	151	$14,612	137
Total	***3,991***	***$387,084***	***3,627***

In total, we estimate that adjusting light levels could potentially save Wisconsin 3,991 megawatt hours annually, with the majority of these savings coming from the Office and Education sector. This energy savings is equivalent to 371 typical Wisconsin household's annual electric consumption,[2] reducing greenhouse gas emissions by 3,627 tons of carbon dioxide equivalent, or the equivalent of taking 764 passenger vehicles off the road for a year.[3] This annual energy savings equates to nearly $390 thousand cost savings to Wisconsin businesses. The *Methodology* section contains more detail regarding the calculation approach for these estimates.

Cost Effectiveness

We estimated cost effectiveness under two scenarios: a new system associated with a new construction or major renovation project or an existing system. Using these scenarios, we calculated simple paybacks as outlined in Table 5.

Table 5: Simple paybacks for task tuning LED systems.

Space Type	Cost Savings ($/ft2)	Simple Payback (yr)	
		New Construction	Existing
Office	$0.092	0.6	1.2
Conference	$0.086	0.6	1.3
Warehouse	$0.005	11.3	22.5
Storage	$0.075	0.7	1.5
Corridor	$0.114	0.5	1.0
Classroom	$0.035	1.6	3.2

With the exception of Warehouse spaces, the cost savings and associated simple payback of task tuning LED systems are very good. For these cases, we calculate a cost savings of between $0.035 and $0.114 per square foot, resulting in a simple payback of between 0.5 and 1.6 years for the new construction and between 1.0 and 3.2 years for existing system cases, respectively. For Warehouse spaces though, the lower lighting power density and light level reduction lead to long simple paybacks. **Due to these short payback periods, we recommend that task tuning be implemented in new construction projects or major renovations in which a dimming system is already planned as part of the design requirements. For the same reason, if a dimming system already exists in a facility, task tuning should be strongly considered as a way to achieve cost-effective energy savings.**

Occupant Comfort

Task tuning is essentially a tradeoff between energy consumption of a lighting system and light levels in a space. When performing task tuning, it is important to balance energy savings with occupant visual comfort, as tuning that is too aggressive may result in high energy savings at the expense of occupant satisfaction.

Complicating this balance is the fact that occupants perceive light levels differently both amongst individuals and under varying situations. Because of this complication, **we recommend that task tuning**

[2] Annual electricity consumption of typical Wisconsin household of 10,766 kWh/yr. U.S. Energy Information Administration (2012). "Average monthly residential electricity consumption, prices, and bills by state." http://www.eia.gov/tools/faqs/faq.cfm?id=97&t=3

[3] Annual greenhouse gas emissions from passenger vehicles of 4.75 tCO2. U.S. Environmental Protection Agency (2011). "Greenhouse Gas Equivalencies Calculator." https://www.epa.gov/energy/greenhouse-gas-equivalencies-calculator

be conducted with occupant feedback in order to balance energy savings and occupant visual comfort. Although this may result in lower immediate energy savings, it would increase energy savings persistence, as facility managers would be less likely to override tuned controls based on occupant complaints.

Program Approaches

There is growing potential in Wisconsin to capture energy savings from lighting control strategies. LEDs are gaining market share for a range of interior applications and this year's update to the building code in Wisconsin will help drive the market for dimmable lighting systems. Even when dimmable lighting systems are installed, tuning the system is not standard practice and many spaces are over lit as a result. We suggest three approaches to take advantage of the potential savings from advanced lighting controls, ranging from a simpler, lower cost prescriptive program to a more complex, higher cost program. We also recommend establishing the incentive on a per square foot basis for the following reasons:

- It is a number that building owners understand and are familiar with using in the decisions they make regarding their building
- It more clearly shows the degree to which the incentive offsets incremental costs
- It can be readily incorporated into project budgeting
- It sends a consistent, upfront signal in contrast to performance incentives which can't be determined until there is a completed project scope and some initial engineering calculations

Table 6: Program approaches for advanced lighting controls

Program	Description	Incentive	Delivery
Prescriptive	Tier 1: install dimmable lighting power and associated controls	per sq. ft.	Use qualified Trade Allies
	Tier 2: tune dimmable lighting	per sq. ft.	
Retrocommissioning	Tune existing dimmable systems	per kWh saved	Use qualified energy service representative or controls representative
Enhanced Lighting	Comprehensive approach from design through commissioning	per sq. ft.	Use qualified lighting designers/Trade Allies

The prescriptive program approach allows flexibility for building owners who might be considering a lighting system retrofit. The program provides an incentive for them to install dimmable lighting systems and associated controls. We then suggest offering a larger incentive for actually tuning the system in addition to installing it. This encourages building owners to take advantage of the additional savings possible from these systems. The tuning itself should be performed by a lighting controls manufacturer or trade ally who has participated in a utility program approved training on lighting controls. Trainings currently exist and a list of applicable programs can be found in the *Recommended Program Improvements* section.

A retrocommissioning program is a more comprehensive approach and would target buildings that already have dimmable lighting systems. The current retrocommissioning program could include adjusting scheduling, photo sensors and occupancy sensors as well as tuning. The tuning itself should be conducted by a trained Energy Service Representative. Alternately, an approved individual, similar to the prescriptive offering, could conduct the tuning.

The enhanced lighting program would target new construction or major retrofits and offer a comprehensive approach that would include professional lighting design and commissioning. When dimming already exists in a building, the program could stand alone as task tuning specific. Alternately, when dimming does not already exist, the tuning could be layered onto an existing program, such as a lighting retrofit program. This would be a good situation to offer an additional incentive for tuning.

INTRODUCTION

On behalf of Focus on Energy's Environmental and Economic Research and Development Program (EERD), Seventhwave collected information from Wisconsin businesses on their light levels and associated lighting system characteristics. This information will help Focus on Energy address savings opportunities from optimizing light levels by identifying appropriate program offerings and resources.

BACKGROUND

Lighting in commercial buildings has been the target of energy efficiency programs for years, with the primary strategy being one-for-one fixture replacement. However, recent changes to federal standards for fluorescent lamps and more stringent building and product codes, have begun to erode these program savings. Market changes are forcing energy efficiency programs to look beyond efficacy-based, per-product incentives. Research suggests that significant savings potential exists through task tuning of light levels and redesign of overlit spaces. However, the average light level (often called illuminance) in typical spaces in Wisconsin, as well as associated lighting system characteristics, is not well understood. A light level characterization, including site visits to accurately measure light levels, will fill this knowledge gap and lead to opportunities for increased energy savings. Seventhwave designed and conducted this research study to provide Focus on Energy with data that will help push customers to implement more comprehensive lighting upgrades that could include controls, lower wattage fixtures, and task tuning.

METHODOLOGY

The characterization study was comprised of both primary and secondary research. We reviewed studies germane to this project (summarized in *Appendix A: Literature Review*), conducted a segmentation of Wisconsin lighting, interviewed Focus on Energy program staff and a select group of stakeholders, and visited a sample of Wisconsin businesses. We used the results from the site visits of Wisconsin businesses and data gleaned from our literature review to quantify the potential for energy savings from optimizing light levels. We distilled lessons learned to clarify effective approaches for Focus on Energy programs to reach this market segment.

LIGHTING SEGMENTATION IN WISCONSIN

We began by conducting a literature review to assess previous studies focused on light levels and associated controls and to discern the applicability of those studies to the Wisconsin market. We also reviewed best practices of other utility advanced lighting programs.

We followed the literature review with a segmentation of lighting in Wisconsin. The goal of the segmentation was to better understand indoor lighting in Wisconsin commercial buildings. This segmentation provided clarity and direction to the remainder of the project, as well as quantified the lighting energy and relevant characteristics for programmatic planning. The U.S. Energy Information Administration's (EIA) Commercial Building Energy Consumption Survey (CBECS)[4] microdata includes characteristics about lighting types, lighting controls and the buildings they serve. In order to make this preliminary analysis specific to Wisconsin, we aggregated the data within Wisconsin's census division, East North Central, which also includes Illinois, Indiana, Ohio and Michigan. To understand Wisconsin's portion of this region's lighting, we used population prorating. Specifically, we prorated the census division's lighting energy down to 12%. Finally, the latest CBECS survey was completed in 2012. To

[4] http://www.eia.gov/consumption/commercial/

understand the scale of lighting in 2018, we assumed a 2% growth rate in agreement with EIA data for the growth of commercial building area.[5] We further used DOE estimates for the penetration of LEDs from 2012 to 2018 to adjust the total lighting energy and the overall percentage of LEDs.[6,7]

REVIEWING FOCUS ON ENERGY PROGRAMS

Seventhwave conducted interviews with Focus on Energy program staff from the Business Incentive Program (BIP), Agriculture, School and Government Program (AgSG) and the Large Energy Users (LEU) program. These interviews focused on collecting information on lighting-specific programs and projects to provide insight and barriers to implementing lighting efficiency measures.

STAKEHOLDER INTERVIEWS

Working with lighting designers, electrical engineers, electrical Trade Allies and manufacturers is required in order to have an influence on the implementation of improved efficiency in Wisconsin lighting systems. We identified stakeholders working with lighting in Wisconsin. Through in-depth interviews, we determined how they currently make decisions, whether they consider light levels in their projects, and how program offerings might use communications and outreach strategies to influence them. The results of these interviews helped us define needs in the market for adopting lighting efficiency measures.

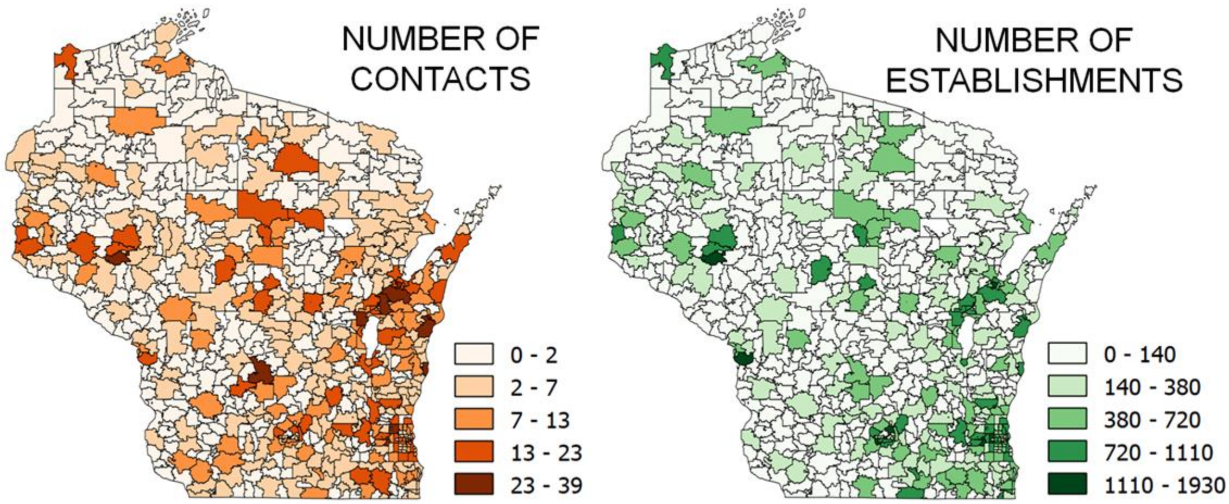
SITE VISITS

The site-visit sample was drawn from the results of a short online screening survey (*Appendix B: Screening Survey*). Email invitations to the screening survey were sent to contacts from Focus on Energy's SPECTRUM database. The statistical inference from our study is limited to the scope of this database and the method used to collect the data. Our results are therefore specific to buildings that have previously participated in Focus on Energy business programs.

We checked the geographic distribution of the email sample's contacts to ensure its relative agreement with Wisconsin's commercial establishment population distribution (Figure 3). We used the latest commercial building census data for the comparison.[8]

[5] http://buildingsdatabook.eren.doe.gov/ChapterIntro3.aspx
[6] Navigant, "Adoption of Light-Emitting Diodes in Common Lighting Applications", July 2017.
[7] Navigant, "Energy Savings Forecast of Solid-Sate Lighting in General Illumination Applications", August 2014
[8] https://www.census.gov/newsroom/press-releases/2016/cb16-tps102.html

Figure 3: Number of contacts and number of establishments by county.



Note the relative agreement between the counties with the most contacts and the ones with the most commercial establishments.

The screening survey gathered information pertaining to each respondent's building characteristics. The following high-level information was gathered:

- Building location
- Building type (Retail, Education, Office, Outpatient Healthcare or Warehouse)
- Building area
- Number of businesses in the building
- Primary lighting type (Fluorescent, Compact Fluorescent, Incandescent, Halogen, High-intensity discharge, Light-emitting diode)

Note that the screening survey focused on the five building types comprising over two-thirds[9] of Wisconsin commercial building lighting energy; office, retail, education, warehouse, and outpatient healthcare (no inpatient facilities). Based on the results from the screening survey, we attempted to identify equal numbers of buildings from each of the major building types as targets for site visits. However, we didn't get many survey responses from Retail or Outpatient Healthcare facilities, so these two building types are underrepresented in our site visit sample.

The predominant and overlapping space types of our building categories are open and private offices, conference rooms, storage areas, warehouse areas, and corridors (including hallways and stairwells). We additionally included classrooms as they were of interest to the Focus on Energy program staff. Underlying this is the assumption that space types are similar across building types.

In order to determine a target sample size, we assumed a mean average illuminance in agreement with the IES recommendations for each space type.[10] We additionally assumed a standard deviation of 57% of the

[9] From analysis of 2012 U.S. Commercial Building Energy Consumption Survey microdata
[10] DiLaura et al., "The Lighting Handbook", Tenth Edition, 2011.

mean average illuminance based on measurements from a similar study in Minnesota.[11] Sample size is then estimated by:

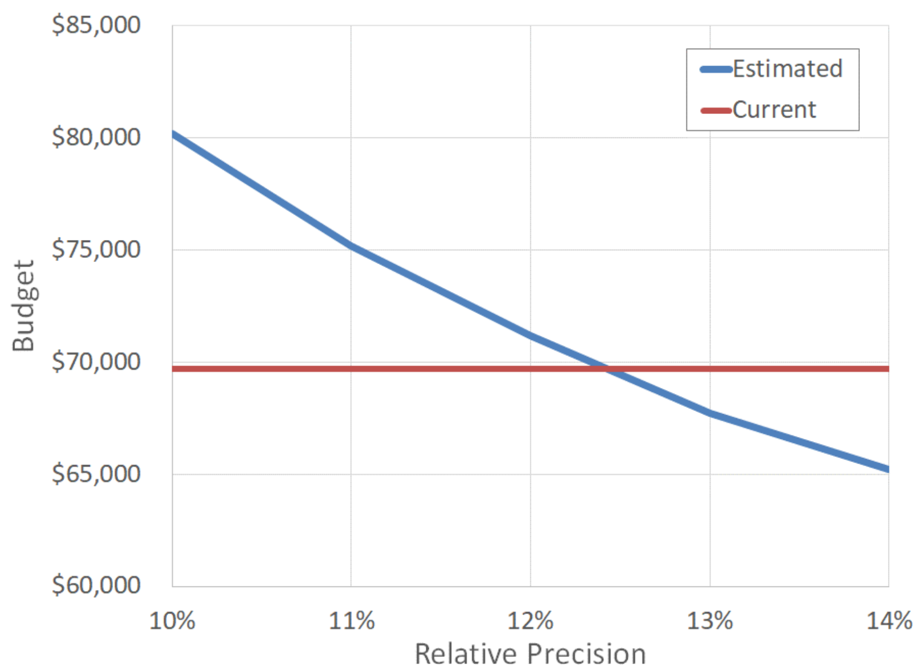
$$n = \left(\frac{Z * \sigma}{RP * \hat{x}}\right)^2$$

Where

n is the sample size,
Z is the z statistic,
σ is the standard deviation
RP is the relative precision, and
$\hat{x}$ is the sample mean.

The number of site visits and the corresponding time and budget associated with each is highly dependent on the relative precision target. Figure 4 illustrates the relationship between relative precision and estimated project budget.

Figure 4: Estimated and current budget versus relative precision at 90% confidence interval.



Within the project budget, our relative precision target is 12.5% at a 90% confidence interval. Using the stated assumptions, we estimated a target sample size of 56 unique spaces for each space type as the minimum sample needed. Typically, some spaces will be dropped from the final analysis for a variety of reasons, such as data corruption or facility staff changing their mind about participation. Therefore, we increased the sample by 5 percent to 59 to account for attrition.

Table 7 summarizes the assumed mean average illuminance, assumed standard deviation, and target relative precision, as well as the resulting target sample, for each space.

[11] Schuetter, et al., "Adjusting Lighting Levels in Commercial Buildings", prepared for the Minnesota Department of Commerce, COMM-2013-05-1-72743, August, 2015.

Table 7: Assumed mean, assumed standard deviation, target relative precision and target sample by space type.

Space Type	Average Illuminance (fc)			Target Sample
	Assumed Mean	Assumed Standard Deviation	Target Relative Precision at 90% CI	
Open Office	30	17.1	3.75	56
Private Office	30	17.1	3.75	56
Conference Room	30	17.1	3.75	56
Storage	10	5.7	1.25	56
Warehouse	30	17.1	6.29[12]	20[12]
Corridor	5	2.9	0.63	56
Classroom	40	22.8	8.39[12]	20[12]

Although our sampling plan requires measuring the average illuminance in 59 of each space type, we did not set out to visit 59 different buildings for each space type. We assumed that we would find an average of 1.5 unique spaces of each space type at each building we visited, equating to 40 total site visits. Note that we define a unique space as one that has a unique light level due to a unique lighting layout or fixture type. The assumption underlying this definition is that it would not improve statistical significance to include very similar spaces in our sample (i.e., identical private offices). The space types of interest are common to all major building types. So, it was likely that we would find at least one of each in a given building. However, in many buildings, such as multi-tenant buildings, buildings with additions or buildings with varying lighting approaches, we could find many more unique spaces. The exceptions to this are warehouse and classroom spaces. These space types are specific to the Warehouse and Education building category. Thus, our target sample is smaller for these, resulting in a higher relative precision.

Once identified, the site-visit sample was recruited through follow-up phone calls. To minimize self-selection sampling bias when calling our building contacts, we made three attempts to contact a small set of sampled buildings before moving on to another set of buildings. However, some sampling bias may persist as buildings with more energy efficiency motivated staff are more likely to respond.

For these site visits, we used a protocol we developed in previous research we've conducted on lighting levels in businesses. The protocol allows us to collect information on light levels, light level uniformity, lighting system parameters, control parameters, space geometry, and architectural properties for each space. We followed IES's procedure for carefully selecting measurement locations to calculate average illuminance and determine the approximate maximum and minimum values of each space.[10] This data allowed us to quantify both the light level and uniformity relative to IES recommendations. Data was collected using a tablet-based form as outlined in *Appendix C: Site Visit Protocol*.

ANLYSIS

Our data analysis began by ensuring data accuracy. Data accuracy assures that results are admissible for utility program design, calculations, and evaluation. Our first level of quality control involved training our field technicians to ensure they gathered quality data. This training included the following steps:

- Lighting basics including different lighting types, fixture types and control options.

[12] Note that warehouse and classroom spaces will likely only be present in Warehouse and Education building types, respectively. We therefore adjusted the target sample and associated relative precision to reflect a reasonable number of spaces in the buildings we would be visiting.

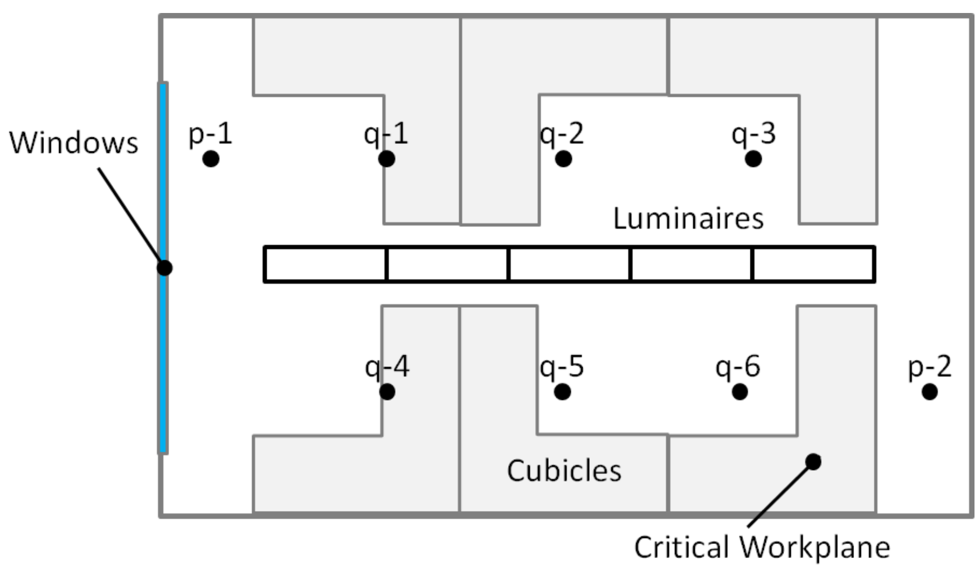
- IES light level measurement approach including identifying the applicable luminaire configuration and light level measurement locations.
- Proper light level measurement technique. This included waiting for the lighting system to warm up such that the light it provided was at steady-state, as well as minimizing the researcher's effect on the reading by utilizing a tripod and standing back from the light meter. We further minimized the effect of daylight on our readings by pulling any blinds and taking readings with the lights on followed immediately by readings with the lights off. The difference in these two readings was used for the electric light component of the measured illuminance.
- Two practice site visits with both field technicians to ensure consistent measurements techniques across the team. These preliminary site visits identified gaps in our protocol and pointed to ways of improving data gathering accuracy.

The use of the tripod also allowed for consistent, horizontal readings at the workplane. We further ensured that the Extech EA30 light meter was calibrated traceable to National Institute of Standard and Technologies. Once data was in hand, our quality control checks for data accuracy included high level tabulations to identify and address:

- Significant gaps in data
- Data outliers that exceed reasonable limits of minimum and maximum measured illuminance

Once a quality data set was established, we used the measured illuminance data to calculate the average illuminance of each space. One method for calculating average illuminance is to take readings on a 2' × 2' grid throughout the entire space and then average the measurements. However, this method is time-intensive, requiring a large number of readings for even relatively small spaces. We therefore followed the IES Lighting Handbook's procedure for calculating average illuminance.[10] This procedure is more focused, defining key positions for illuminance readings based on a given lighting system's luminaire configuration type. Figure 5 shows one luminaire configuration type: the Regular Area with Single Row of Continuous Luminaires.

Figure 5: Light meter measurement points for Regular Area with Single Row of Continuous Luminaires.



Note that the measurement points (i.e. p-1, p-2, q-1…) are specific to the luminaire configuration type, and the number of total points is greatly reduced when compared to a regular 2' × 2' grid. The average illuminance, E_{ave}, for this specific luminaire configuration is given by:

$$E_{ave} = \frac{Q(N_{lum} - 1) + P}{N}$$

Where:

E_{ave} is the average illuminance in a given space in fc,
N_{lum} is the number of luminaires in the space,
Q is the average of the illuminance measurements taken at the q-labeled points in fc, and
P is the average of the illuminance measurements taken at the p-labeled points in fc.

Other luminaire configurations have different key measurement points and different equations for finding the average illuminance.

We further calculated each space's lighting power, lighting power density and percentage of lighting power controlled by occupancy and photosensors. The lighting power for each space was calculated by:

$$P_{tot} = \sum_{i=1}^{n_{fixtype}} \sum_{j=1}^{m_{fix}} P_{i,j}$$

Where:

P_{tot} is the lighting power of a given space in W,
$P_{i,j}$ is the fixture power of fixture type *i* and fixture *j* in W,
$n_{fixtype}$ is the number of fixture types in a given space, and
m_{fix} is the number of fixtures of a given fixture type in a given space.

The lighting power density for each space was calculated by:

$$LPD = \frac{P_{tot}}{A}$$

Where:

LPD is the lighting power density of a given space in W/ft^2,
A is the area of a given space in ft^2.

The percentage of lighting power controlled by occupancy sensors was calculated by:

$$\%_{occ} = \frac{\sum_{i=1}^{n_{fixtype}} \sum_{j=1}^{m_{fix}} \left(P_{i,j} * \%_{occ,i,j}\right)}{P_{tot}}$$

Where:

$\%_{occ}$ is the percentage of lighting power that is occupancy-controlled in a given space, and
$\%_{occ,i,j}$ is the percentage of fixture type *i* and fixture *j* that is occupancy-controlled in a given space.

The percentage of lighting power controlled by photosensors was calculated by:

$$\%_{photo} = \frac{\sum_{i=1}^{n_{fixtype}} \sum_{j=1}^{m_{fix}} \left(P_{i,j} * \%_{photo,i,j}\right)}{P_{tot}}$$

Where:

$\%_{photo}$ is the percentage of lighting power that is photocontrolled in a given space, and
$\%_{photo,i,j}$ is the percentage of fixture type *i* and fixture *j* that is photocontrolled in a given space.

We performed a quality check on these estimates and either corrected issues that were identified or developed reasonable explanations for them. These quality checks included:

- Average illuminance deviation from IES recommendations
- Lighting power density deviation from code requirements
- Aggregate occupancy and photosensor controlled percentages compared to typical market penetration rates as summarized in the *Lighting Segmentation in Wisconsin* results section.

Overall mean illuminance for each space type was calculated as:

$$E_{mean} = \frac{\sum_{k=1}^{n_{spaces}} E_{ave,k}}{n_{spaces}}$$

Where:

E_{mean} is the mean illuminance for a given space type in fc, and
n_{spaces} is the number of spaces for a given space type,

Once we determined the mean illuminances, we calculated the percentage that a given space type's light levels could be reduced to bring it in agreement with IES recommendations:

$$\%_{reduction} = \frac{E_{mean} - E_{recommended}}{E_{recommended}}$$

Where:

$\%_{reduction}$ is the percentage reduction of a given space type,
$E_{recommended}$ is the IESNA illuminance recommendation for a given space type in fc, and
E_{mean} is the mean average illuminance for a given space type in fc.

In order to quantify Wisconsin's statewide potential for energy savings from task tuning we extended the findings from our study to the population of studied commercial buildings within the state. We used data from CBECS, the U.S. Census and our measured results, to understand lighting energy use and potential savings from task tuning for the five building types studied as part of this project; Office, Healthcare, Education, Retail and Warehouse. From our segmentation, we had previously quantified the total amount of lighting energy attributable to each building type in Wisconsin, the percentage that could be tuned, as well as the percentage of each building type's floor area (and therefore lighting energy) from each of our space types.

We assumed that a program would bring the measured mean average illuminance into agreement with the IES recommended illuminance for each of the space types, capturing a proportionate amount of energy savings. Note that we used the LED-lit space illuminance results when establishing the percent to which the light levels could be reduced by. We applied these savings to the lighting energy consumption, scaled to our buildings types via the space breakouts discussed in the subsequent *Lighting Segmentation in Wisconsin* section. This calculation represented the technical potential of lighting energy savings from task tuning. We finally assumed an achievability factor of 9%, meaning Focus on Energy programs could capture only this portion of the technical potential.[13] Note that these estimates are conservative as savings could additionally be captured from other building sectors.

[13] The Cadmus Group, "Focus on Energy 2016 Energy Efficiency Potential Study", June 2017.

Achievable electricity savings was converted to dollar savings using an average electric utility rate of $0.1092/kWh.[14] We used conversions outlined in ASHRAE Standard 105-2014 to estimate greenhouse gas emissions saved in metric tons CO_2 equivalent.[15]

RESULTS

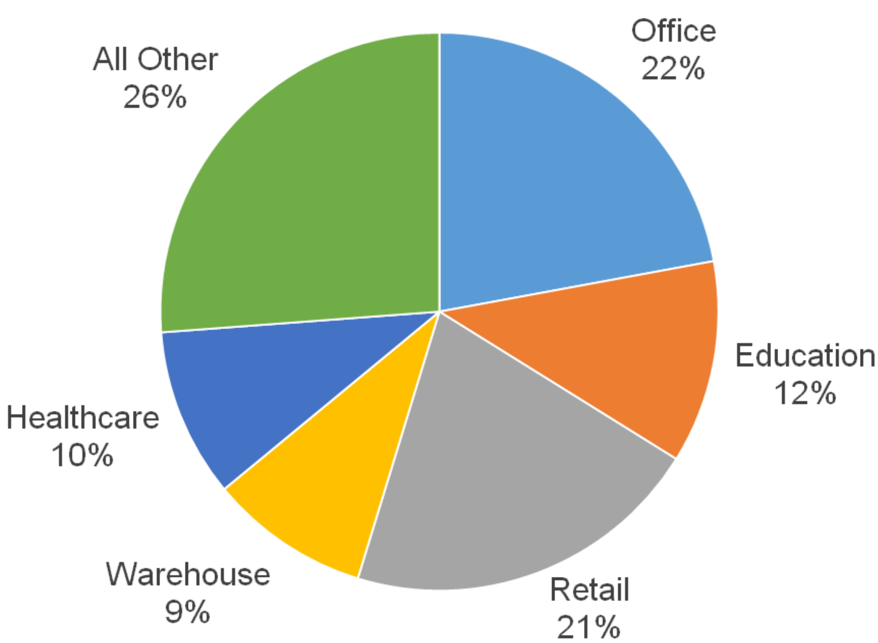
The results from this study are presented as follows: first we describe the demographics of lighting in Wisconsin. This section is followed by a review of Focus on Energy's current programs and the results of stakeholder interviews. We conclude with a summary of the primary data collected from the site visits. These results lead to our recommendations for program design and a discussion of the barriers that need to be overcome to make a program successful.

LIGHTING SEGMENTATION IN WISCONSIN

Market Segments

Commercial buildings in Wisconsin use approximately 4.29 billion kWh of lighting energy annually. Five building types comprise nearly three-quarters of the lighting energy (Figure 6).

Figure 6. Lighting energy in commercial buildings in Wisconsin.



Office (22%) and Retail (21%) are the two largest market segments, with Education (12%), Healthcare (10%) and Warehouse (9%) also comprising significant components. Note that although Manufacturing facilities are not included in this segmentation, they comprise a significant portion of lighting energy

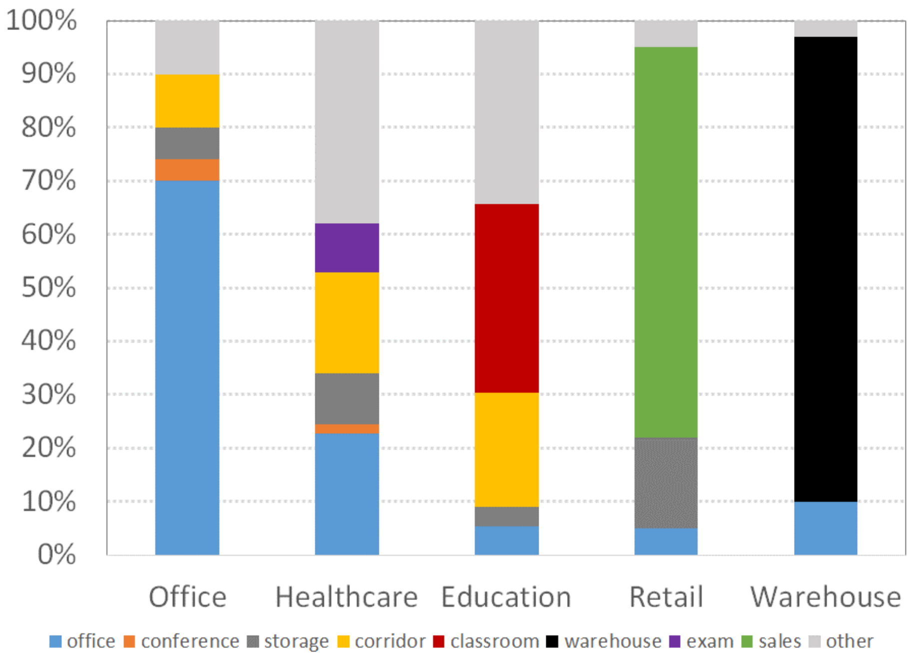
[14] U.S. Energy Information Administration, Electric Power Monthly, May 2018, Table 5.6.B. Average Retail Price of Electricity to Ultimate Customers by End-Use Sector. http://www.eia.gov/electricity/monthly/epm_table_grapher.cfm?t=epmt_5_06_b
[15] American Society of Heating, Refrigeration and Air Conditioning Engineers. "Standard 105-2014, Standard Methods of Determining, Expressing and Comparing Building Energy Performance and Greenhouse Gas Emissions", Table J2-D, pg. 23.

consumption in Wisconsin, using approximately 1.4 billion kWh annually.[1] Additionally, these facilities have space types included in this study, and a corresponding opportunity for optimizing light levels.

Space Types

Within the major building types, the predominant and overlapping space types are open and private offices, conference rooms, storage areas, warehouse areas, and corridors (including hallways and stairwells). We also included classrooms as they were of interest to the Focus on Energy program staff. Open plan offices are ideal for adjusting light levels, since the light levels and electrical power of a significant amount of lighting power can be affected with one adjustment. This minimizes the time and associated cost of achieving savings. CBECS data indicates that 38% of Office buildings have open plan offices. Other good candidates are space types with many similar spaces such as private offices and classrooms. In these situations, the amount of adjustment can be determined in one space and quickly applied to the other similar spaces. Using building energy modeling prototypes, we can estimate the approximate proportion of each building type comprised by these space types (Figure 7).[16,17]

Figure 7. Proportion of area for significant space types in commercial buildings in Wisconsin.



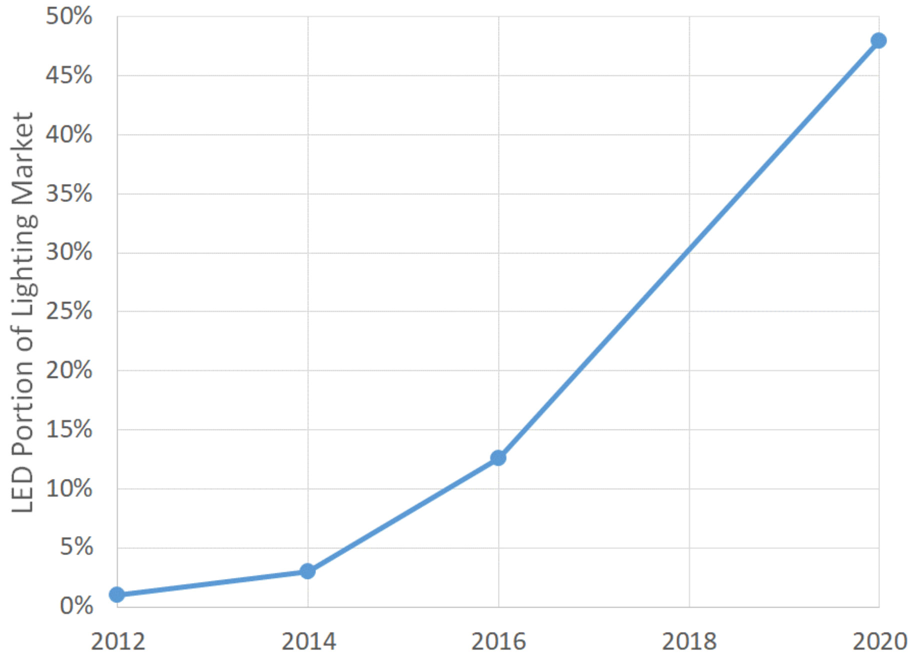
Our space types of interest comprise the majority of the area in each of the major building types with the exception of Retail. In Retail buildings, sales areas are the predominant space type. This space type is unique to this building type. From our experience working with lighting design in retail establishments, it is often very difficult to convince owners to reduce light levels. This is due to their perception that reducing light level will affect sales. This barrier would be difficult to overcome programmatically. The Other space category comprises copy rooms, break rooms, mechanical and electrical rooms and other ancillary spaces.

LEDs and Dimmable Ballasts

[16] Deru et al., "U.S. Department of Energy Commercial Reference Building Models of the National Building Stock", NREL/TP-5500-46861, February 2011.
[17] eQuest 3-64 Design Development Wizard

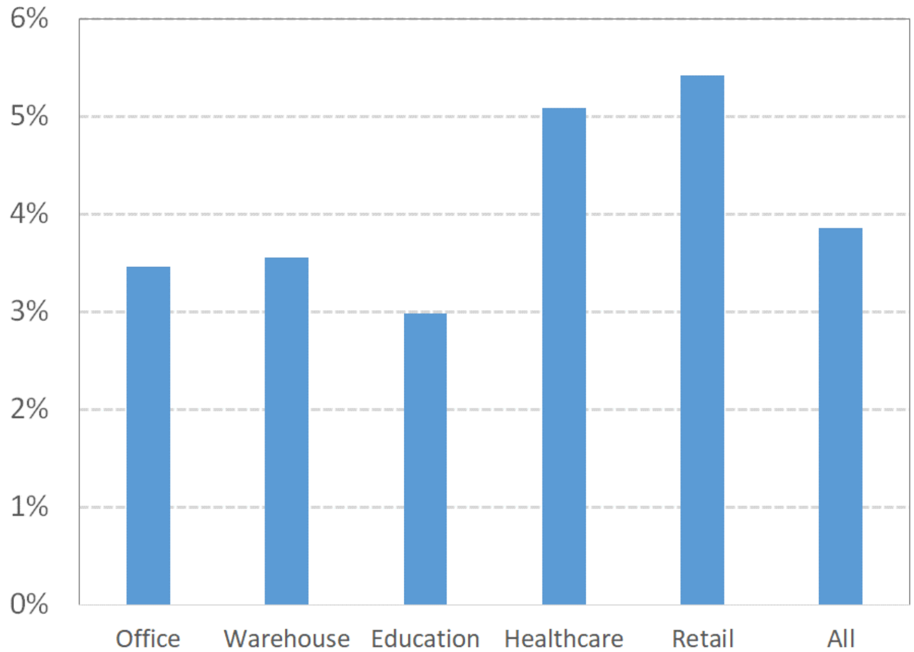
LEDs are inherently dimmable, meaning their light output and corresponding lighting energy could easily be reduced in overlit spaces. LEDs are rapidly increasing their share of the new and replacement lighting market. The DOE estimates (Figure 8) that in 2012, LEDs comprised only 1% of the market. However, this increased to 3% in 2014 and 12.6% in 2016.[6] The DOE further projects that by 2020, LEDs will comprise 48% of the lighting market.[7]

Figure 8. LED portion of new and replacement lighting market.



Using this information, we estimated the portion of commercial spaces served by LEDs in 2018. LEDs currently serve a small portion of the area of each of the major building types (Figure 9).

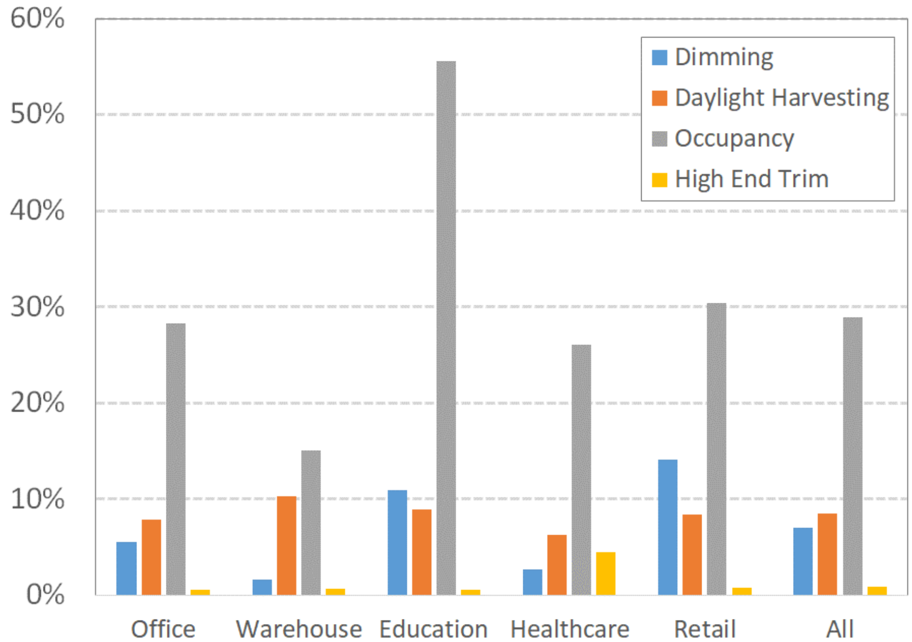
Figure 9. Proportion of area served by LEDs in commercial buildings in Wisconsin.



Across all the major building types, LEDs serve 3.9% of the total area in Wisconsin. Slightly higher penetration rates exist in Healthcare and Retail buildings.

LEDs are not the only type of dimmable lighting. Electronic, dimmable ballasts allow more common fluorescent fixtures to be adjustable as well. Across all major building types (Figure 10), 9.4% of buildings have some amount of dimmable or multi-level lighting. Retail and Education have higher penetrations, while Warehouse and Healthcare have lower penetrations of dimming.

Figure 10. The proportion of commercial buildings in Wisconsin with differing advanced lighting controls.



Lighting Controls

Daylight harvesting is an advanced lighting control strategy that automatically adjusts the electric lighting levels when sufficient natural light is detected. This is important since the photosensor setpoint may be easily reduced in overlit spaces, thereby reducing the electric light levels during daylit periods. Figure 10 illustrates the varying penetrations of daylight harvesting by market segment. The highest penetration of daylight harvesting is in Warehouses presumably in combination with toplighting. On average, 8.5% of the major building types have some amount of daylight harvesting. This proportion will continue to increase due to energy code requirements for this control in spaces with natural light.

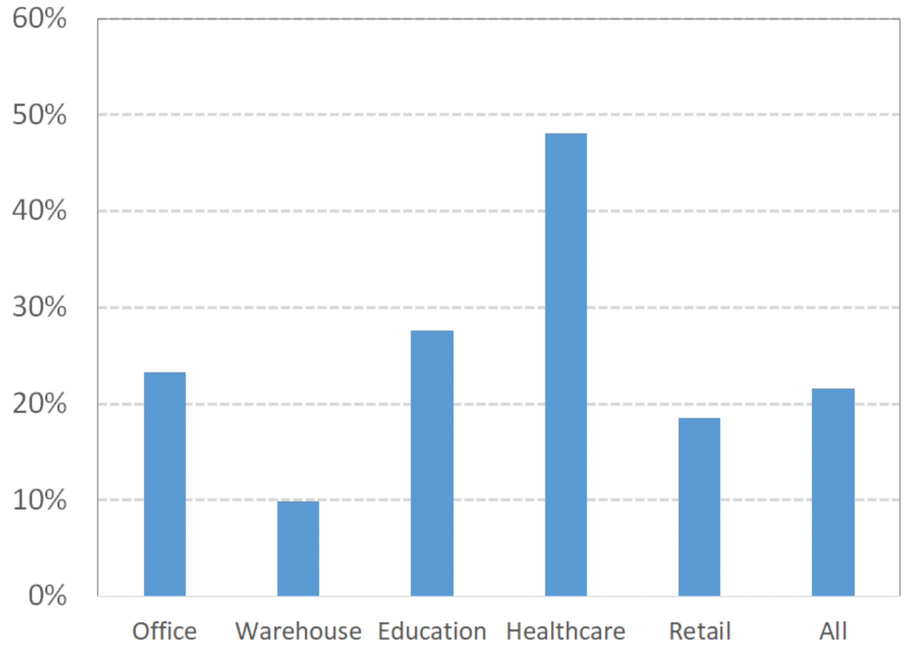
Another form of advanced lighting controls is occupancy and/or vacancy sensing. Although these controls do not allow for simple adjustment of light levels, they will likely reduce any savings that may be achieved by reducing light levels. It is important therefore to understand their penetration across Wisconsin buildings. Figure 10 illustrates the varying penetrations of occupancy sensing by market segment. Of the advanced lighting controls, occupancy sensing has the highest penetration, averaging 28.9% across the major building types. This control is most prevalent in Education and least prevalent in Warehouse.

Task tuning, or high-end trim, is the adjustment of electric light levels by limiting the maximum light output and power of lighting systems. This control allows for the adjustment of light levels in existing overlit spaces, thereby saving electrical energy. Figure 10 illustrates the varying penetrations of high end trim by market segment. **There is currently a low penetration of high-end trim in Wisconsin buildings, with only 0.4% of the major building types having implemented this control.** Healthcare facilities are an outlier with over 4% implementing high-end trim.

Lighting Retrofits

It is also interesting to understand the proportion of existing buildings that have received a lighting upgrade. This metric highlights the types of buildings that are more amenable to lighting upgrades and those that tend to turn over their lighting less frequently. Figure 11 illustrates the proportion of Wisconsin buildings that report having a lighting upgrade. Across all major building types, 21.6% of buildings report receiving some kind of lighting upgrade, with Healthcare having the highest penetration and Warehouses the lowest penetration of lighting upgrades.

Figure 11. Proportion of commercial buildings in Wisconsin with lighting upgrades and older than typical EUL.



REVIEWING FOCUS ON ENERGY PROGRAMS

We conducted three interviews with staff from the Business Incentive Program (BIP); Agriculture, School and Government Program (AgSG); and the Large Energy Users (LEU) Program. Following are the key takeaways from these interviews:

General program information

- Current LED market share is estimated at under 10%
- Prescriptive measures make up most of the projects for all three programs. Largely, these have been one-for-one replacements of existing fixtures.
- Some LEU projects are custom (larger lighting projects) but most LEU projects are prescriptive.
- There have been approximately 15 projects through the networked controls offering since its inception in 2017.
- Retrofit projects account for most of the savings in all three programs
- Program staff neither get involved with setting illuminance targets, nor in follow-up verification of actual light levels, leaving it to Trade Allies to provide appropriate illuminance for their projects.
- Program staff engagement with light levels only occurs in instances where the AgSG uses the delamping incentive or if a plant in the LEU program changes a process or space use.

Dominate building types for each program

- BIP: offices
- AgSG: offices, K-12 schools and higher education
- LEU: manufacturing and warehouses

Lighting project characteristics

- Majority of AgSG projects are LED replacements for 2'x4' fluorescent troffers
- BIP and AgSG are still seeing some T12 fluorescent fixtures
- BIP reports fixtures to be "older than typical estimated useful life" of between 13 and 15 years.
- The LEU reports HIDs in the 10- to 20-year age range and somewhat newer fluorescents

Program participants involvement in lighting projects

- People most involved in lighting projects vary across programs, ranging from building owners and facility staff to Trade Allies and distributors and occasionally even IT and financial staff.
- Level of engagement in the program varies: all three programs report a high level of engagement with facility maintenance staff.

Motivations and barriers

- Reducing operating costs and maintenance are the primary motivations for pursuing energy efficiency.
- Capital cost remains the primary barrier to lighting replacement and simple payback is the key metric for most lighting projects.
- Other barriers include: accurately quantifying savings, need to shut down operations to complete a lighting project, and scheduling.

Sources of information for new lighting approaches or technologies

- Associations such as DesignLights Consortium, Illuminating Engineering Society (IES), and the Association of Energy Engineers
- Publications such as the IES LD+A magainze
- Webinars
- Conferences such as the IES Lightfair
- Manufactures such as Acuity Brands, Cree, and Philips

Program managers wish list

- Information on appropriate light levels for space types (including industrial spaces)
- Lighting metrics including min-max ratios and color temperatures
- Light levels by building type and customer type
- Strategies for moving customers toward optimal light levels
- Life cycle cost analysis education for owners and facility managers, etc.

STAKEHOLDER INTERVIEWS

We interviewed staff from seven businesses involved with lighting projects in Wisconsin for their insights on lighting in the businesses they serve. We conducted interviews with staff from Upper 90 Energy, PKK Lighting, Cree, Spectrum, US Lamp, Mlazgar Associates and Elan Lighting. These businesses represent lighting manufacturers (Cree and Spectrum), sales representatives (US Lamp, Mlazgar Associates and

Elan Lighting) and electrical Trade Allies (Upper 90 Energy and PKK Lighting). These organizations provide lighting primarily for offices, schools, healthcare facilities, manufacturing and warehouses. Four of these organizations mainly serve the retrofit market while three have more new construction projects than retrofit projects.

Following are the key takeaways from these interviews:

Business characteristics

- Program stakeholders are involved, to some degree, in multiple facets of implementing high efficiency lighting projects: there are no rigid boundaries around their services (i.e., Trade Allies do not just install lighting, manufacturers do not just create products).
- These organizations work for a range of clients including building facility staff and owners as well as lighting designers/specifiers, such as Trade Allies, engineers, and architects.
- All of the organizations we spoke to try to influence energy-related decisions. These efforts include:
  - Upsell controls
  - Calculate savings and provide information on new products
  - Design systems with proper light levels, use most efficient lighting and include controls
  - Talk about energy use and efficiency
- Strategies for selling energy efficiency include (in descending order of importance):
  - Use incentives as a selling point, talk about cost savings and simple payback
  - Provide savings calculations
  - Discuss maintenance reduction aspect of LEDs
  - Educate owners and designers on the intricacies of the various energy efficient light sources and control technologies
- Energy efficiency is important to design engineers, maintenance staff and ESCOS while Trade Allies and sales representatives are motivated by sales. Therefore, they are more focused on associated incentives.

Lighting project characteristics

- Their lighting projects exceed code most of the time (from 75% to 100% of the time). However, this may change under IECC 2015 as the threshold for simply meeting code is more stringent.
- They consider light levels on nearly all of their projects. This primarily takes the form of photometric calculations. Trade Allies also often install a demonstration fixture so their customer can see the differences and provide feedback on light level and other performance metrics.
- While they do consider illuminance levels, they rarely measure them directly. There is a sense that spaces tend to be overlit.
- Other lighting quality metrics they use include: uniformity, color rendering index (particularly in retail), color temperature, zonal lumen density and glare control

Client engagement in lighting projects

- It is the decision maker who is most active on lighting projects. This person could be the building owner, property or maintenance manager, an ESCO, an engineer or architect or school administrator (or school board).

- Barriers to implementing more efficient lighting (beyond first cost) include:
    - Competing projects for dollars available (e.g, school projects)
    - Politics and logistics (schools may need to go to referendum for funding)
    - Product not available in the local market, lengthy wait time to get it
    - Lack of education/understanding on basic lighting topics. For instance, some occupants resist lighting controls because they do not understand that the lights are designed to be off when no one is in the space or sufficient natural light is present.

Sources of information for new lighting approaches or technologies

- Lightfair, the Illuminating Engineering Society's (IES) annual conference, was named as a trusted source of information as were manufacturers.
- IES
- Design Lights Consortium (DLC). Two organizations, however, expressed discontent with DLC (charges for approved products are too high, the process for approval takes too long making the list outdated, perhaps not needed anymore now that the LED market is mature and there is less risk of low quality products).

Familiarity with Focus on Energy

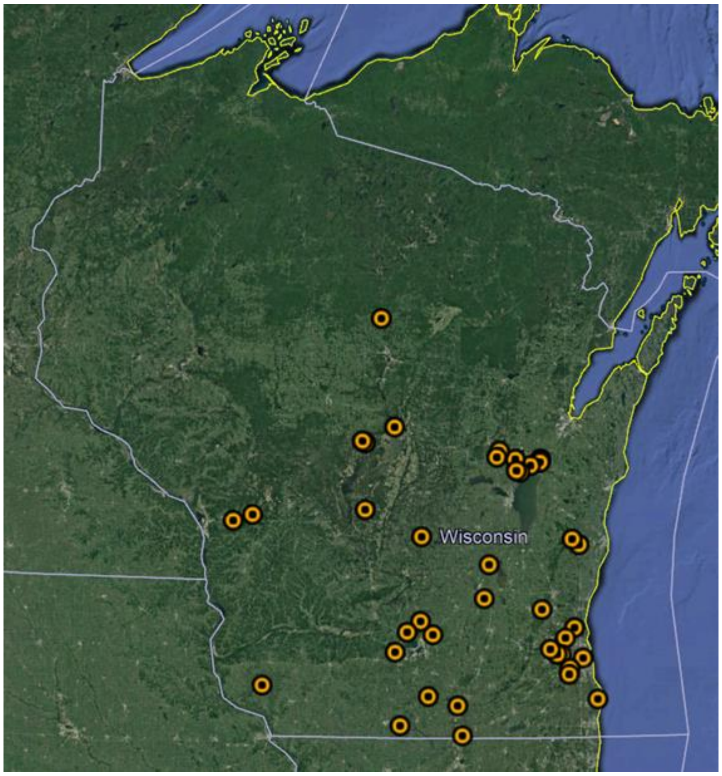
- All of the organizations were familiar with Focus on Energy and had worked with the program, primarily with the prescriptive lighting offerings. Custom projects and Comprehensive Lighting Initiative were also mentioned. This program provides incentives for upgrading to energy efficient fixtures, new LED technology and accompanying controls.
- Suggestions for improving the Focus on Energy lighting programs included:
    - Make program easier to understand
    - Make forms clearer
    - Provide education and training to local trade allies
    - Offer bigger incentives, especially for controls
    - Bring back the whole building lighting program
    - Extend the lighting power reduction program beyond new construction projects
    - Offer financing
    - Make program literature available before the program year begins. Include summary of substantial changes.
    - Pay incentives in a more timely manner. The long wait periods create cash flow issues for small businesses and trade allies.
    - Improve the website to more easily navigate and understand the different programs and associated offerings

SITE VISITS

Building and System Summary

We visited a total of 40 buildings across Wisconsin (Figure 12).

Figure 12: Map of visited buildings.



Similar to the contacts from Focus on Energy's SPECTRUM database, the sites were predominately clustered around population centers, such as Milwaukee, Appleton and Madison, with a number of additional sites in smaller towns.

Within the sites, we visited buildings from each of our target building types (Table 8).

Table 8: Number of buildings visited by building type.

Building Type	Number Visited
Office	11
Retail	4
Education	15
Warehouse	9
Outpatient Healthcare	1

Although we set out to visit a similar number of each building type, it proved difficult to schedule site visits with Retail and Outpatient Healthcare facilities. This is due to a low response rate of these building types to our recruitment survey. We did visit a significant number of Office, Education and Warehouse facilities. Although Manufacturing buildings were not originally included in the scope of the research design, they were prevalent in the email database and their facility staff had a high level of interest. These facilities additionally contain each of our space types of interest. Manufacturing buildings were therefore included in our study if they had a warehouse space. They were subsequently categorized under the Warehouse building type. Anecdotally, the Manufacturing facility staff were just as interested in the light levels of their manufacturing areas. While these areas were outside the scope of the project, this interest combined with the high lighting requirements of these spaces would indicate potential for a program to serve them.

Within these building types, we visited a number of each space type (Table 9).

Table 9: Number of spaces visited by space type.

Space Type	Number Visited	Target Sample
Open Office	41	56
Private Office	55	56
Conference Room	39	56
Storage	41	56
Warehouse	23	20
Corridor	40	56
Classroom	25	20

Note that we did not reach our sample target on all space types except Warehouse and Classroom. This is due to only averaging about 1 unique space per building, as opposed to our assumed 1.5.

For each space, we documented the primary lighting type allowing us to quantify the portion of each space type that was served by each lighting type (Table 10).

Table 10: Percentage of total floor area by primary lighting type for each space type.

Space Type	Fluorescent	LED	Other[18]
Open Office	71%	29%	0%
Private Office	52%	43%	5%
Conference Room	63%	34%	3%
Storage	53%	46%	1%
Warehouse	31%	69%	0%
Corridor	40%	57%	3%
Classroom	70%	30%	0%
Total	***45%***	***54%***	***1%***

Surprisingly, LEDs were the dominant primary lighting type, serving 54% of the total area we characterized. This is disproportionately high as compared to our segmentations estimate of approximately 4% of the total commercial building area in Wisconsin. This discrepancy is likely due to a combination of sample and response bias, as facility staff with high performance lighting were more likely to respond to our recruitment survey. This means that LEDs are disproportionately represented in our sample and corresponding results. However, LEDs are the most likely lighting type to be tunable, and their market share will be increasing rapidly over the coming years. We therefore will present results in terms of overall and LED-specific values. Fluorescent lighting served 45% of the total area we

[18] Compact Fluorescent, Incandescent, Halogen, or High-intensity discharge

characterized. This typically involved T8 troffers in most space types, and high or low bay fixtures in warehouses spaces.

For each space, we documented the lighting power allowing us to quantify the lighting power density of each space type (Table 11).

Table 11: Lighting power density by primary lighting type for each space type.

Space Type	Lighting Power Density (W/ft^2)		% Diff Fluor to LED
	Fluorescent	LED	
Open Office	1.12	0.58	48%
Private Office	1.58	0.68	57%
Conference Room	1.57	0.62	61%
Storage	0.80	0.33	59%
Warehouse	0.49	0.30	40%
Corridor	1.05	0.35	67%
Classroom	1.54	0.70	54%
Total	***0.98***	***0.81***	***62%***

The lighting power density reduction for LEDs as compared to Fluorescent lighting ranged from 40% to 67%. Across all of the characterized spaces, this reduction was 62%. This reduction is significant and illustrates the magnitude of potential energy savings solely from upgrading to LEDs from more traditional Fluorescent lighting systems.

For each space, we documented the amount of lighting power controlled by occupancy or photosensors. We then summarized the proportion of each space type's total lighting power with these controls (Table 12).

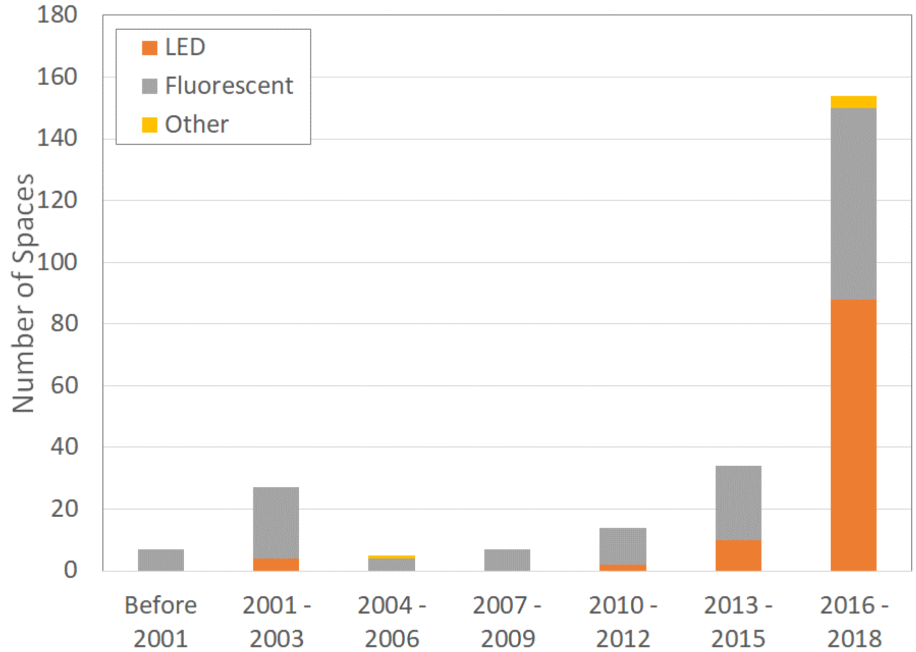
Table 12: Percentage of total lighting power controlled by occupancy or photosensors for each space type.

Space Type	Occupancy Sensor	Photosensor
Open Office	27%	8%
Private Office	33%	1%
Conference Room	24%	0%
Storage	21%	0%
Warehouse	74%	0%
Corridor	4%	0%
Classroom	29%	0%
Total	***48%***	***1%***

Occupancy sensors controlled 48% of the lighting power in the spaces we characterized. This proportion was highest in Warehouse spaces but was prevalent in all other space types except Corridors. Photosensors were much less prevalent, controlling only about 1% of the lighting power in the spaces we characterized. This proportion was highest in Open Office spaces. This information will be used when extrapolating the potential energy savings of tuning light levels in Wisconsin

For each space, we documented the year that the lighting system was installed or renovated (Figure 13).

Figure 13: Year of installation or renovation.



In the majority of characterized spaces (62%) the lighting systems were installed between 2016 and 2018. This large proportion is also likely due to sample bias of facility owners with newer systems being overrepresented in our email sample. The proportion of systems that were LEDs is clearly increasing over time.

A few other general lessons from our site visits included:

- We were able to conduct our site visits of Education facilities more easily because our site visits occurred in the summer. This is applicable to a potential program as they may want to focus outreach to this facility type during the summer months as well.
- Churches would typically be outside the scope of a light level adjustment program. However, many churches have associated schools and offices, making them candidates both for our study as well as a light level adjustment program.

Description of WI Commercial Building Light Levels

We quantified the mean illuminance for our sample by space type (Table 13)

Table 13: Mean, standard deviation, and relative precision by space type.

Space Type	Average Illuminance (fc)		
	Mean	**Standard Deviation**	**Relative Precision at 90% CI**
Open Office	41.7	17.7	5.6
Private Office	37.4	16.3	4.4
Conference Room	44.0	17.0	5.5
Storage	25.3	14.3	4.5
Warehouse	28.0	13.6	5.9
Corridor	24.1	11.0	3.5

Space Type	Average Illuminance (fc)		
	Mean	**Standard Deviation**	**Relative Precision at 90% CI**
Classroom	53.1	21.5	8.9

We then calculated the degree to which the mean illuminance differed from the IES recommendation for each space type, expressed as the percent reduction needed to bring the mean into agreement with the recommendation (Table 14).

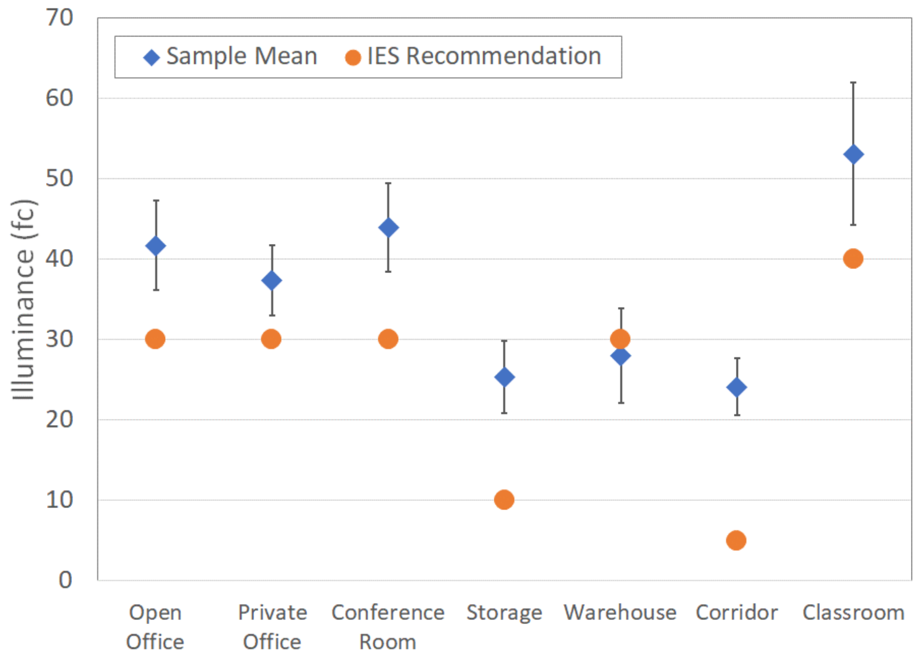
Table 14: Mean, IES recommendation, and percent reduction by space type.

Space Type	Average Illuminance (fc)		% Reduction
	Mean	**IES Recommendation**	
Open Office	41.7	30	28%
Private Office	37.4	30	20%
Conference Room	44.0	30	32%
Storage	25.3	10	61%
Warehouse	28.0	30	-7%
Corridor	24.1	5	79%
Classroom	53.1	40	25%

For all space types except Warehouse, the mean illuminance was higher than the IES recommendation. This means that energy savings could be captured by bringing the two into agreement. In Open Offices, Private Offices and Classrooms, this reduction was 28%, 20%, and 25%, respectively. This reduction is significant, considering the quantity of these space types in Wisconsin. Conference Rooms were even more overlit, needing a reduction of 32% to bring their mean illuminance into agreement with the IES recommendation. Storage (61%) and Corridor (79%) spaces were the most overlit. There is less opportunity for aggregate energy savings in these spaces due to their smaller portion of overall building area. In addition, the IES recommendation of 5 fc for corridor spaces may be considered too aggressive of a reduction by facility staff and building occupants, thereby reducing the energy savings potential. Warehouse was the only space type with a mean illuminance below the IES recommendation. This may be due to a higher focus by lighting designers to properly illuminate the racked aisles of a Warehouse space.

When the mean illuminance and IES recommendations are presented visually (Figure 14), the difference between the two is more striking.

Figure 14: Mean versus IES recommended illuminance.



The error bars on the mean illuminance represent the 90% confidence interval. With the exception of Warehouse, all of the IES recommendations fall outside of these bounds. This indicates that our estimated mean illuminance is statistically different than the IES recommended illuminance and that those spaces were all overlit.[19] Since the Warehouse recommendation falls within these bounds, we cannot be as certain whether this space type is over or underlit.

LEDs are the only primary lighting type with inherent dimming capabilities, and therefore represent the greatest opportunity for easily adjusting light levels. Since we tracked the primary lighting type of each of our spaces, we also quantified the mean illuminance for spaces lit by LEDs (Table 15).

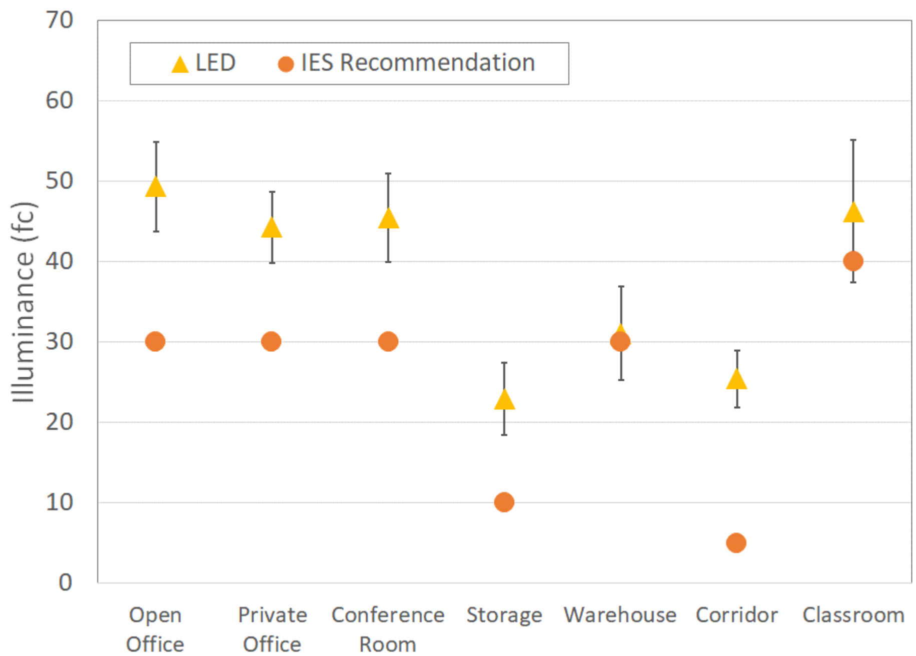
Table 15: Mean, IES recommendation, and percent reduction by space type for LED-lit spaces.

Space Type	Average Illuminance (fc)		% Reduction
	Mean	IES Recommendation	
Open Office	49.4	30	39%
Private Office	44.3	30	32%
Conference Room	45.5	30	34%
Storage	23.0	10	56%
Warehouse	31.1	30	4%
Corridor	25.5	5	80%
Classroom	46.3	40	14%

For LED-lit spaces, all space types are overlit as compared to IES recommendations. As before, Warehouse is the only space type for which the IES recommendation lies within the confidence interval (Figure 15).

[19] Alpha=0.1. Analysis of other influential effects on average illuminance in spaces was out of scope for the study. It is possible that unaccounted confounding effects would increase the uncertainty of estimated mean illuminance shown here. ***Error! Reference source not found.*** provides a short review of the difference among selected effects using linear mixed models.

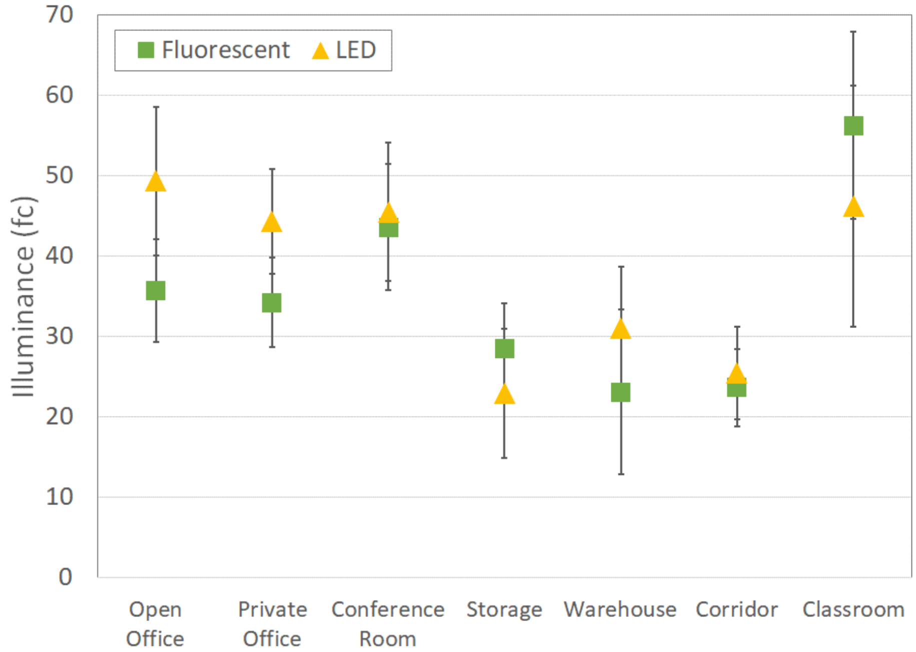
Figure 15: Mean versus IES recommended illuminance for LED-lit spaces.



The degree to which the LED mean illuminance differs from the overall mean illuminance is likely due to the nature of LED retrofit projects. These projects traditionally are one-for-one replacements of existing fluorescent lighting due to the prohibitive cost of modifying existing electrical infrastructure and/or drop ceilings. With little-to-no flexibility to adjust the fixture spacing, the LED light level is determined by the LED fixture's output. When multiple lumen packages exist for LED replacements fixtures, lighting professionals and Trade Allies tend to default to higher lumen packages to minimize the chance of customer dissatisfaction from low light levels. This default position is made even more reasonable given the replacement fixtures will still yield significant energy savings. **This systematic over-lighting of LED retrofit spaces represents a significant opportunity for programs to address.**

This phenomenon is more clearly seen by comparing the mean illuminance from LED and Fluorescent-lit spaces (Figure 16).

Figure 16: Mean illuminance for LED and Fluorescent-lit spaces.



Only Storage and Classroom spaces have a higher Fluorescent than LED mean illuminance. Conference Rooms and Corridors have essentially the same for each primary lighting type. The remaining space types (Open Office, Private Office, and Warehouses) all have higher LED than Fluorescent mean illuminances. However, the error bars for estimated Fluorescent and LED mean illuminance all overlap and therefore are not statistically different[20]. It is clear however that the overall trend is for LEDs to provide higher light levels than the fluorescent fixtures they replace.

Expected Savings Estimates

Following the assumptions outlined in the *Methodology* section, the final estimated achievable savings potential from light level adjustment incentive programs in Wisconsin are shown in Table 16.

Table 16: Achievable potential savings from light level adjustment in Wisconsin.

Building Type	Estimated electricity savings (MWh)	Annual dollar savings ($)	Avoided GHG emissions (tCO2 eq.)
Office	1,735	$168,283	1,577
Healthcare	309	$30,017	281
Education	1,252	$121,430	1,138
Retail	544	$52,742	494
Warehouse	151	$14,612	137
Total	***3,991***	***$387,084***	***3,627***

[20] alpha = 0.1

In total, we estimate that adjusting light levels could potentially save Wisconsin 3,991 megawatt hours annually, with the majority of these savings coming from the Office and Education sector. This energy savings is equivalent to 371 typical Wisconsin household's annual electric consumption,[21] reducing greenhouse gas emissions by 3,627 tons of carbon dioxide equivalent, or the equivalent of taking 764 passenger vehicles off the road for a year.[22] This energy savings equates to nearly $390 thousand cost savings to Wisconsin businesses.

On a project-by-project basis, the energy savings from tuning light levels of a lighting system without other controls may be estimated as:

$$\Delta Q_{tune} = \%_{reduction} * Q_{tot}$$

Where:

ΔQ_{tune} is the electricity savings from reducing light levels in kWh,
$\%_{reduction}$ is the percent reduction of maximum lighting power, and
Q_{tot} is the annual electricity consumption of the tuned lighting system in kWh.

Note that the percent reduction of maximum allowable lighting power, often called high end trim, is closely approximated by the percent reduction in light levels. Reasonable percent reductions by space type may be found in Table 14 for all lighting types and Table 15 for LED-lit spaces. The annual electricity consumption may be estimated as:

$$Q_{tot} = P * t$$

Where:

P is the connected lighting power in kW, and
t is the annual operating time in hrs.[23]

For systems with other controls, the energy savings from tuning light levels interacts with the savings from the other controls technologies. The two most prevalent controls are occupancy controls and photocontrols. The energy savings from tuning light levels of a lighting system with these controls may be estimated as:

$$\Delta Q_{tune,int} = f * \Delta Q_{tune}$$

Where:

$\Delta Q_{tune,int}$ is the interactive electricity savings from reducing light levels in kWh, and
f is the controls interactivity factor.

The controls interactivity factor may be approximated as:

$$f = 1 - \%_{oc} - \%_{pc} + (\%_{oc} * \%_{pc})$$

Where:

$\%_{oc}$ is the percent savings from occupancy controls, and
$\%_{pc}$ is the percent savings from photosensor controls.

---

[21] Annual electricity consumption of typical Wisconsin household of 10,766 kWh/yr. U.S. Energy Information Administration (2012). "[Average monthly residential electricity consumption, prices, and bills by state](http://www.eia.gov/tools/faqs/faq.cfm?id=97&t=3)." http://www.eia.gov/tools/faqs/faq.cfm?id=97&t=3

[22] Annual greenhouse gas emissions from passenger vehicles of 4.75 tCO2. U.S. Environmental Protection Agency (2011). "Greenhouse Gas Equivalencies Calculator." https://www.epa.gov/energy/greenhouse-gas-equivalencies-calculator

[23] Reasonable annual operating hours: The Cadmus Group, "Wisconsin Focus on Energy 2018 Technical Reference Manual", pg. 280.

Table 17 summarizes typical percent savings from occupancy and photosensor controls,[24] and the corresponding interactivity factors.

Table 17: Typical percent savings and interactivity factors for occupancy and photosensor controls.

Building Type	Typical Percent Savings		Interactivity Factor		
	Occupancy Control	Photosensor Control	Occupancy Control Only	Photosensor Control Only	Both
Office	23%	38%	0.77	0.62	0.48
Healthcare	23%	no data	0.77	no data	no data
Education	31%	49%	0.69	0.51	0.35
Retail	5%	29%	0.95	0.71	0.67
Warehouse	35%	28%	0.65	0.72	0.47

[24] Williams et al., "A Meta-Analysis of Energy Savings from Lighting Controls in Commercial Buildings", 2011, Lawrence Berkeley National Laboratory.

CONCLUSIONS AND RECOMMENDATIONS

RECOMMENDED PROGRAM IMPROVEMENTS

A few lighting efficiency programs have begun to crop up that are designed to reduce lighting energy consumption through the use of advanced lighting controls. These programs generally provide a performance-based incentive and/or an incentive for an advanced control system that, minimally, employs the following strategies:

- Task tuning
- Scheduling
- Daylight harvesting/photo sensing
- Occupancy sensing
- Variable load shedding (demand response)

We conducted an in-depth review of lighting programs in the Midwest that focus on advanced lighting controls, not just fixture replacement or upgrade. These programs tend to use incentives for adding controls when upgrading to energy efficient fixtures. One program, LiTES, is designed to increase awareness of the benefits of networked lighting controls through Trade Ally training and demonstration sites. A few examples of these programs are shown in Table 18.

Table 18: Examples of advanced lighting controls programs.

Program Administrator	Brief Program Description	Program	Incentives
Focus on Energy	Comprehensive Lighting Initiative. This program provides incentives for upgrading to energy efficient fixtures, new LED technology and accompanying controls.	AgSG	Incentive is $0.07/kWh. Bonus incentive of $0.03 for saving over 60% of baseline energy (kWh) usage.
Focus on Energy	Networked Lighting Controls *(NLC).* This program requires pre-approval and offers incentives for installing and/or upgrading space with a Design Lights Consortium listed networked lighting control system.	BIP	Range from $0.05/Square Foot to $0.25/Square Foot
Focus on Energy	New Construction Lighting Power Density Reduction. This program offers incentives for reducing LPD 20%, 30% or 40% below code requirements in new construction.	New Construction	Range from $0.08/Square Foot to $0.16/Square Foot
ComEd	Advanced Lighting and Controls. Provides incentives for energy-efficient lighting, including fixture replacements and retrofits,	ComEd Energy Efficiency Program for Businesses	Range from $0.07 kWh saved above baseline to $0.50 watt reduced + new lighting control

Program Administrator	Brief Program Description	Program	Incentives
	advanced lighting networked sensors and controls.		system @ $0.18 watt controlled
Xcel Energy – Minnesota	Lighting Efficiency Program. Provides incentives for advanced lighting controls on newly installed networked systems controlling LED lighting technology.	Business Lighting Efficiency	Custom incentives
AEP Ohio	Advanced Lighting and Controls. Provides cash incentives for adding networked lighting controls to LED lighting systems.	Efficient Products for Business	Range from $0.30 to $0.75/Square Foot
Consumers Energy	Business Lighting Program. Provides incentives for advanced lighting controls as one component of their efficient lighting program.	Business Lighting Savings	Range from $0.08 to $0.40 watt controlled
Lighting Technology Energy Solutions (LiTES)	NextEnergy partnered with the Department of Energy, the Michigan Advanced Lighting Controls Training Program, DTE Energy and Consumers Energy to launch this program in 2017. It is a three-year initiative designed to train Trade Allies about the latest networked lighting control solutions and their advantages as well as provide consumers with information about advanced lighting control solutions.	LiTES	Range from $0.12 to $0.25 kwh saved if selected to demonstrate controls technology

Program Approaches

There is growing potential in Wisconsin to capture energy savings from lighting control strategies. LEDs are gaining market share for a range of interior applications and this year's update to the building code in Wisconsin will help drive the market for dimmable lighting systems. Even when dimmable lighting systems are installed, tuning the system is not standard practice and many spaces are over lit as a result. We suggest three approaches to take advantage of the potential savings from advanced lighting controls, ranging from a simpler, lower cost prescriptive program to a more complex, higher cost program (Table 19).

Table 19: Program approaches for advanced lighting controls.

Program	Description	Incentive	Delivery
Prescriptive	Tier 1: install dimmable lighting power and associated controls	per sq. ft.	Use qualified Trade Allies

Program	Description	Incentive	Delivery
	Tier 2: tune dimmable lighting	per sq. ft.	
Retrocommissioning	Tune existing dimmable systems	per kWh saved	Use qualified energy service representative or controls representative
Enhanced Lighting	Comprehensive approach from design through commissioning	per sq. ft.	Use qualified lighting designers/Trade Allies

We also recommend establishing the incentive on a per square foot basis for the following reasons:

- It is a number that building owners understand and are familiar with using in the decisions they make regarding their building
- It more clearly shows the degree to which the incentive offsets incremental costs
- It can be readily incorporated into project budgeting
- It sends a consistent, upfront signal in contrast to performance incentives which can't be determined until there is a completed project scope and some initial engineering calculations

The prescriptive program approach allows flexibility for building owners who might be considering a lighting system retrofit. The program provides an incentive for them to install dimmable lighting systems and associated controls. We then suggest offering a larger incentive for actually tuning the system in addition to installing it. This encourages building owners to take advantage of the additional savings possible from these systems. The tuning itself should be performed by a qualified Trade Ally, lighting controls manufacturer or trade ally who has participated in a utility program approved training on lighting controls. More information on appropriate level of training is outlined subsequently in the *Analysis and Training* section.

A retrocommissioning program is a more comprehensive approach and would target buildings that already have dimmable lighting systems. The current retrocommisioning program could include adjusting scheduling, photo sensors and occupancy sensors as well as tuning. The tuning itself should be conducted by a trained Energy Service Representative. Alternately, an approved individual, similar to the Prescriptive program, could conduct the tuning.

The enhanced lighting program would target new construction or major retrofits and offer a comprehensive approach that would include professional lighting design and commissioning. When dimming already exists in a building, the program could stand alone as task tuning specific. Alternately, when dimming does not already exist, the tuning could be layered onto an existing program, such as a lighting retrofit program. This would be a good situation to offer an additional incentive for tuning.

Outreach

Tuning lighting requires the lights to be dimmable. The outreach goal for a task tuning program should therefore be to find buildings with dimmable lights. In general, this entails buildings with daylighting controls (i.e. plenty of perimeter zones) or LEDs. Typical buildings types include:

- Office: Ideally, the project would include large open offices with high controlled power or many private offices in which you can apply the same tuning approach quickly by copying control settings.
- Education: Ideally, the project would include many similar classrooms in which you can apply the same tuning approach quickly by copying control settings.

- Institutional: Libraries and higher education facilities are great candidates, allowing program personnel to train a small number of facility staff who could then apply tuning to a number of buildings.
- Big Box Retail: Combining high lighting powers with increasing penetration of highbay LEDs means that there is significant potential for task tuning energy savings. However, programs will face obstacles in convincing owners to reduce light levels, as they often view this as potentially reducing product sales. However, there is a trend in retail lighting design towards lower ambient lighting paired with the use of more accent lighting to highlight the merchandise. As this trend continues, there is likely increasing potential for task tuning in retail applications.
- Light Manufacturing: Similar to big box retail, this sector has high lighting powers and increasing penetration of highbay LEDs. However, safety concerns around potentially dangerous manufacturing process may be an obstacle. Coupling task tuning with task lighting may be a way around this.
- Warehouse: New code requirements for skylights and associated daylight sensors coupled with higher penetrations of highbay LEDS will lead to increasing potential in this sector. Large areas of similarly controlled lights and low demand for light level targets help with cost effectiveness.
- Parking Garages: New code requirements for lighting controls in parking garages will lead to increasing potential in this sector. Large areas of similarly controlled lights and low demand for light level targets help with cost effectiveness.

Buildings with lighting designed by a Trade Ally and little to no commissioning are good candidates as well. Focus on Energy should partner with a variety of organizations to find potential projects:

- Multiple building owners: property management companies, higher education, government (state, county, city), retail chains
- Professions: electrical Trade Allies, lighting controls manufacturers, design firms
- Professional Organizations: IES, IFMA, USGBC, ASHRAE

Analysis and Training

Determining the energy savings associated with task tuning is outlined in the *Expected Savings Estimates* section of this report. We have developed a checklist that could be followed by program staff when undertaking task tuning of a given lighting system. This checklist may be found in Appendix D: Task Tuning Checklist.

In order to successfully implement task tuning, program staff or trade allies should be trained and proficient in a variety of lighting-related subjects.

1. ***Fundamentals of Lighting***: This course was developed by the Illumination Engineering Society and covers a range of lighting-specific subjects at an appropriate level for gaining proficiency in task tuning. The class is offered through local chapters of IES, such as the Milwaukee chapter and participants typically meet one night per week for two and a half hours. Relevant topics include:
    a. Basic Lighting Concepts, Vision, and Color
    b. Electric Light Sources and Ballasts
    c. Luminaires and Lighting Controls
    d. Photometry and Lighting Calculations
    e. Lighting for Interiors

2. ***Lighting Controls***: The Lighting Controls Association's Education Express[25] offers a variety of lighting control and dimming control classes.
3. ***How to use a light meter***: The documentation that accompanies a specific light meter will provide most of the detail needed to operate the light meter. However, proper placement of the light meter is necessary in order to get the most accurate readings. Light meters should be placed on the working surface or tripod when possible, and the person operating the meter should ensure that they are not blocking any light by stepping away from the meter during the reading. When taking readings while holding the meter, the light meter should be held away from the body as far as possible, and the person should endeavor to position themselves in such a way as to block as little of the light as possible.
4. ***Basics of major manufacturer control systems***: The biggest variable in any task tuning effort is understanding the nuances of the lighting control systems serving a given space. Efficiency program staff should work with control system manufacturers to develop training on the basics of their systems.

Verification and Persistence

There are several forms that a verification effort could take based on the program's needs. They may be grouped into two categories.

- Level 1: The first level of verification involves a high-level check that task tuning has been undertaken. This could entail a program representative measuring light levels in a representative sample of incentivized buildings or checking that lighting controls have indeed been adjusted from their factory defaults. This level is less time consuming and less costly but does not confirm actual energy savings.
- Level 2: The second level involves an effort similar to the Measurement and Verification process outlined in the International Performance Measurement and Verification Protocol[26] or ASHRAE Guideline 14.[27] This typically entails using power meters or current transducers to measure lighting system energy consumption both before and after the task tuning has occurred. The associated energy savings is then determined by comparing the normalized energy consumption from both periods. This level is more time consuming and costly but does confirm actual energy savings.

As with any efficiency program, energy savings persistence should be considered. Typically, savings from lighting control measures have a useful life of seven years. However, since there is a strong occupant comfort component to task tuning, the risk of shorter savings periods exists. This risk may be mitigated by involving the building occupants and facility staff in the task tuning process. Getting their feedback as to appropriate light levels is helpful in maximizing energy savings while maintaining a high level of occupant comfort. Further, educating only one point of contact, typically the facility manager, on how to use their lighting controls, and why task tuning is important helps with savings longevity.

An alternate approach to tuning that may result in a higher level of persistence is to task tune during unoccupied periods. This approach is in contrast to the previously outlined approach, in that it does not

---

[25] *Lighting Controls Association Education Express web site , (http://aboutlightingcontrols.org/Education_Express/welcome.php)*
[26] DOE. 2002. International Performance Measurement and Verification Protocol. http://www.nrel.gov/docs/fy02osti/31505.pdf
[27] ASHRAE. 2014. American Society of Heating, Refrigeration and Air Conditioning Engineers. "Standard 105-2014, Standard Methods of Determining, Expressing and Comparing Building Energy Performance and Greenhouse Gas Emissions", Table J2-D, pg. 23.

include occupant feedback. The intent of this approach is to make smaller incremental reductions in light levels that occupants will not notice, as they do not occur when the occupants are present. Care should be taken in this approach that the tuned light levels are conservatively high, to mitigate the possibility of visual discomfort.

COST EFFECTIVENESS

The most cost-effective task tuning programs would focus on buildings with large areas of similarly controlled lighting, such as large open offices or a number of classrooms for which the same level of tuning could quickly be applied. Regardless of the building, it is likely not cost effective to measure the light levels in all spaces. Rather, a sample of representative spaces should be identified and measured. The resulting lighting level reduction should then be applied to all similar spaces. Additionally, personal computer-based systems can be tuned quickly, even allowing tuning to occur remotely with a couple key strokes after measurement occurs. Stand-alone systems are more time consuming as the tuning has to occur on-site by going from system to system. Finally, higher program cost effectiveness is achieved when coupled with a lighting retrofit, since there is a high fixed cost in merely getting into the building, understanding the spaces, and associated lighting controls. Once this is done, the time associated with actually tuning the lights is relatively small. The tasks and associated time for task tuning a system are outlined below. These estimates do not include the outreach time associated with getting a building to apply to the program.

1. ***Preparation (2-4 hours):*** This task includes acquiring and reviewing building drawings, specifications, and lighting control documentation. In addition, time must be spent coordinating the site visit.
2. ***Measurement (6-8 hours)***
    - Site tour
    - Facility staff and occupant interviews: Any issues? Targets?
    - Measure pre-tuned light levels
    - Calculate pre-tuned average and critical light level
    - Determine recommended average light level
    - Calculate recommended critical light level
3. ***Controls adjustment (2-4 hours)***
    - Determine sequence for adjusting light levels
    - Adjust system to recommended working plane light level
    - Verify that critical light level meets recommendation

In order to understand the economics underlying task tuning, we performed a simple payback analysis. We assume for the purpose of this analysis that the cost of task tuning is specific to the time involved, and does not include equipment, maintenance or other costs.

For this analysis, we needed to develop typical utility costs savings and labor costs for task tuning. We therefore assumed that the dimmable lighting system had an average lighting power density and percent savings factor for each space type calculated from the LED-lit spaces that we characterized. We additionally assumed annual operating hours of 3,730 hours for all space types except classrooms. For classrooms, we assumed 3,239 annual operating hours.[28] Finally, we used an average electric rate of $0.1092/kWh.[14] Taken together, these assumptions allowed us to calculate the utility cost savings per square foot for each space type.

[28] The Cadmus Group, "Wisconsin Focus on Energy 2018 Technical Reference Manual", pg. 280.

The time associated with task tuning involves becoming familiar with the lighting control system, measuring average light levels, and adjusting the lighting system to provide recommended light levels. The time requirement varies considerably based on the tuner's level of familiarity with the lighting system. For example, it would take someone who is very familiar with the system (i.e. a lighting manufacturer representative or commissioning agent of a new system) much less time than someone who is not familiar with the system (i.e. an energy service representative trying to tune an existing system).

When estimating the labor costs, we assumed that the lighting system served 25,000 square feet at a labor cost of $86 per hour.[29] Note that labor costs scale with square footage, and that our assumed 25,000 square feet serves as a typical example.

We estimated labor costs under two scenarios: a new system associated with a new construction or major renovation project or an existing system. For new construction or major renovation, we assume that the experienced technician or Trade Ally would take about 16 hours, since they would already be familiar with the system because they participated in the design and commissioning process. For the existing system case, more time would be required to understand the system, learn how to adjust its controls, as well as understand the zoning of light fixtures. We therefore assumed that the same experienced technician or Trade Ally would need twice the time to tune the existing system (32 hours).

Using these assumptions, we calculated simple paybacks as outlined in Table 20.

Table 20: Simple paybacks for task tuning LED systems.

Space Type	Cost Savings ($/ft2)	Simple Payback (yr)	
		New Construction	Existing
Office	$0.092	0.6	1.2
Conference	$0.086	0.6	1.3
Warehouse	$0.005	11.3	22.5
Storage	$0.075	0.7	1.5
Corridor	$0.114	0.5	1.0
Classroom	$0.035	1.6	3.2

With the exception of Warehouse spaces, the cost savings and associated simple payback of task tuning LED systems are very good. For these cases, we calculate a cost savings of between $0.035 and $0.114 per square foot, resulting in a simple payback of between 0.5 and 1.6 years for the new construction and between 1.0 and 3.2 years for existing system cases, respectively. For Warehouse spaces though, the lower lighting power density and light level reduction lead to long simple paybacks **Due to these short payback periods, we recommend that task tuning be implemented in new construction projects or major renovations in which a dimming system is already planned as part of the design requirements. For the same reason, if a dimming system already exists in a facility, task tuning should be strongly considered as a way to achieve cost-effective energy savings.**

Although task tuning does not stand alone as a reason to purchase a dimming system, task tuning would help justify the installation of a more complex lighting control system than originally planned or prevent a dimming system that is part of a lighting design from being cut due to budget constraints.

[29] RSMeans Electrical Cost Data 2016; with inflation rates of 2.1% and 1.9% for 2017 and 2018, respectively

BEST PRACTICES AND LESSONS LEARNED

While the concept of task tuning is relatively simple—use the dimming capabilities and controls of the lighting system to reduce light levels to appropriate levels—there are a number of conditions that prevent it from being a cookie cutter solution to reducing lighting energy use. We compiled a list of the situations we encountered, and lessons learned from relevant past projects in Wisconsin, Minnesota and Illinois.

The primary functionality needed for task tuning is having the ability to reduce light levels within the lighting system's controls. This type of control first became available with dimming ballasts for fluorescent fixtures, mostly utilized in conjunction with photosensor controls. LEDs are inherently dimmable and quickly gaining market share in Wisconsin. However, not all LED systems also include the control needed to adjust light levels. Best practice is to include these controls, which are incrementally inexpensive, in LED retrofit and new construction applications.

Task tuning is essentially a tradeoff between energy consumption of a lighting system and light levels in a space. When performing task tuning, it is important to balance energy savings with occupant visual comfort, as aggressive tuning will result in high energy savings at the expense of occupant satisfaction.

Complicating this balance is the fact that occupants perceive light levels differently both between individuals and under varying situations. For instance, when tuning a lighting system some occupants may provide feedback that the tuned light levels are too low while others say they are just right. Additionally, if an occupant is present when the tuning occurs, they may provide immediate feedback that the tuned light levels are too low, simply because their eyes were adjusted to the previous, higher light levels. Had the tuning occurred without them present, the lower light levels may have gone unnoticed when the occupant first perceived them upon arrival into the space.

Because of these complexities, there are two general approaches to task tuning with respect to occupants: tuning when occupants aren't present (unoccupied periods) or tuning when occupants are present (occupied periods). Tuning during unoccupied periods occurs with no occupant feedback while tuning during occupied periods solicits occupant feedback either through formal pre/post surveys or informal conversations during tuning. The following tables highlight the pros and cons of each approach.

Table 21. Pros and cons of tuning during unoccupied periods

Pros	Cons
Without occupant feedback, the tuner can adjust the lights to a level that maximizes energy savings.	Increases risk of occupant visual discomfort and associated complaints.
Minimizes the chance of an occupant providing false feedback based on perceived relatively lower light levels.	Increases risk of lower rates of savings persistence, as facility managers respond to occupant complaints.
If tuned at night, the tuning process itself is less complicated as outlined in *Appendix D: Task Tuning Checklist*.	
Reduced complexity means tuning takes less time and is less costly.	

Table 22. Pros and cons of tuning during occupied periods.

Pros	Cons
Decreases risk of occupant discomfort and associated complaints.	Potential exists of an occupant providing false feedback based on perceived relatively lower light levels.
May result in increased energy savings, as occupants may be comfortable with light levels below IESNA recommendations.	Occupant feedback may result in reduced or no energy savings.
Increases savings persistence, as facility managers will not need to respond to occupant complaints.	If tuned during the day, the tuning process itself is more complicated as outlined in *Appendix D: Task Tuning Checklist*.
	Increased complexity means tuning takes more time and is more costly.

We recommend that task tuning be conducted with occupant feedback, due to the approach's balance of energy savings and occupant visual comfort. However, if including occupant feedback is too complex or costly, special care should be taken to not adversely affect occupant visual comfort. One method to ensure this would be to choose conservative light level reductions. For instance, if a space was found to have an average illuminance of 60 fc, but IESNA recommendations were 30 fc, a conservative reduction would be to reduce the average illuminance to 45 fc. Although this would result in lower immediate energy savings, it would increase energy savings persistence, as facility managers would be less likely to override tuned controls based on occupant complaints.

Another approach would be to lower light levels incrementally during unoccupied periods over the course of several weeks. For instance, if a space was to be tuned from 60 to 30 fc, a facility manager or other onsite personnel could reduce the light levels at night in 5 fc increments over the course of six weeks. In this way, the occupants would acclimate to each new light level, as opposed to having to adjust to the entire reduction at once. If an occupant does complain, the facility manager could simply raise the light levels to the previous increment before the complaint occurred. In this way, occupants could be indirectly polled without survey bias.

For both methods, there is also the risk that, even though the average tuned illuminance levels meet IESNA recommendations, a few areas or occupants are still not receiving enough light to perform their tasks. This is particularly prevalent in spaces with widely spaced lighting or tall cubicles or partitions. This situation can be avoided by checking that the illuminance at the critical workplane is not too low. The critical workplane is defined as the location where an occupant is performing a task that has the lowest light level. Polling the occupant at this location directly is the surest means of determining whether they are comfortable with the lower light levels. If the light levels are too low, the ambient light level may simply be increased, or task lighting may be added at this location. As discussed previously, requesting occupant feedback may be too complicated or not timely. A method for determining suitable critical workplane illuminance without occupant feedback involves the following. Note that this method deviates from the method we outline in Appendix D: Task Tuning Checklist, by tuning based on critical illuminance and not average illuminance:

1. Based on IESNA recommendations, determine the tuned average illuminance for the space
2. The ratio between the average and critical illuminance is defined as:

$$U_{ave/min} = \frac{Tuned\ Average\ Illuminance}{Tuned\ Critical\ Illuminance}$$

The IESNA Lighting Handbook recommends that this ratio be below 1.5.[10] For example, a space with an average illuminance of 30 fc should not have any workplane illuminance below 20 fc.

3. Given the recommended ratio between average and critical illuminance, calculate a tuned critical illuminance for the space.

$$tuned\ critical\ illuminance = \frac{tuned\ average\ illuminance}{1.5}$$

4. Perform task tuning on the space, such that the illuminance measured at the critical workplane by a light meter is equivalent to the calculated tuned critical illuminance above.

Within this method, the space's actual average illuminance is not required. In fact, for problematic spaces with high averaged-to-tuned illuminance ratios ($U_{ave/min}$ >1.5), the average illuminance after tuning will be much higher than that recommended by IESNA. However, the point of this approach is not to have the correct average illuminance, but rather to have a reasonable minimum illuminance.

As noted in Appendix D: Task Tuning Checklist, there are five types of spaces that could be tuned:

A: Spaces without daylight
B: Spaces with daylight, blinds and photosensor
C: Spaces with daylight, blinds and no photosensor
D: Spaces with daylight, no blinds and photosensor
E: Spaces with daylight, no blinds and no photosensor

The differentiating features between each is whether the space has daylight present, whether you can reduce the amount of daylight by adjusting blinds, and whether the lights are controlled by a photosensor. Spaces without daylight are the simplest to tune since there is no daylight to contend with or photosensor controls to adjust. These spaces may be tuned at any time. Having blinds in spaces with daylight allows the person tuning the system to reduce the available daylight to below the recommended average illuminance. Without blinds, the available daylight can be significantly higher than the recommended average illuminance, resulting in an inability to check through light meter measurements that the photosensor setpoint and high end trim are properly adjusted. Additionally, if the amount of daylight is too high, then occupants will not be able to give their feedback as to whether or not the light levels after tuning are appropriate. Ideally, tuning in spaces without blinds should be done during periods of low daylight such as under cloudy sky conditions.

Table 23 outlines additional lessons learned throughout relevant past projects.

Table 23: Lessons learned from implementing task tuning.

Topic	Issue	Lesson
Useful light and lumen output	Delivered light (illuminance) is a better metric for evaluating LEDs than lumen output since it discounts wasted light. LEDs waste less light than their conventional counterparts.	Evaluating LEDs primarily on the basis of lumen output can underestimate or distort its performance and suitability for a given application. Lighting designers may be inclined to over light spaces when specifying LEDs leading to greater opportunities for task tuning.

Topic	Issue	Lesson
Scenes	Lighting controls can be used to lower light levels to preset levels such as A/V mode in classrooms or conference rooms. These settings affect the amount of savings from task tuning.	Account for scene control in determining the amount of savings from task tuning.
Getting accurate readings	A number of conditions make it difficult to get accurate light level readings, e.g., spaces with a lot of daylight.	Never take readings in direct sunlight. Lower blinds or pick spots away from windows. Let lights warm up before taking measurements. Light output can change over several minutes. Use a light meter, current transducer, or power meter to know when a system has equilibrated.
Tuning daylit spaces	More complicated than tuning non-daylit spaces.	Be careful not to be too aggressive with tuning (i.e. reducing light levels below IESNA recommendations). While there is ample light during most occupied hours, the periods of dawn and dusk can be problematic.
Occupant satisfaction	While IESNA has established light levels for various tasks, individual's needs vary. Tuning all ambient lighting does not account for individual preference.	Add task lighting for individual control. This strategy allows for energy savings from task tuning, while satisfying the few individuals whose visual needs are not met by this strategy. See previous discussion for more detail.
Retrofit applications	While LEDs are growing rapidly, there are also opportunities to add dimming ballasts, and photosensor controls in retrofit applications. This will increase the potential for task tuning over time.	It is essential to properly pair ballasts and lamps—an incorrect pairing will lead to premature lamp failure.
Establishing light levels	It is difficult to determine the appropriate light level.	The IESNA Lighting Handbook publishes exhaustive tables of appropriate light levels by space type and task. For new construction, design intent may also be used. For existing buildings, similar spaces in the same building or another of the owner's facilities may also be used.
Value of commissioning	The benefits of commissioning may not be worth the expense and time commitment.	Yes, it ensures that light levels are correct, and catches other problems such as poor placement of photosensors or other issues with daylighting controls.

Topic	Issue	Lesson
Miscellaneous barriers	Perception that dimming ballasts are prohibitively expensive, need more maintenance and fail frequently. Perception that LEDs are prohibitively expensive. Disconnect between owner's needs and lighting designers vision. Lighting control systems not intuitive and differ by brand – steep learning curve just to figure them out.	

APPENDIX A: LITERATURE REVIEW

We conducted a literature search to establish a foundation for our light level analysis project. There is an abundance of information on how to measure light levels and recommendations for light levels for given tasks. There is also a growing body of work measuring energy savings from lighting controls. However, we found little that documents and establishes a baseline of existing light levels in work spaces.

A common theme among the reports we reviewed was the range of individual preference for light levels. Several studies recorded individual lighting preferences ranging from as low as 8 fc to as high as 148 fc. And, if given the opportunity, people will choose different illuminance levels even for the same task. Documenting light levels in Wisconsin buildings, and the extent to which spaces are over- or under-lit (compared to IES suggested levels) will lead to recommendations for program strategies that allow occupants to control their individual lighting while reducing overhead light levels to reduce energy use.

Following are a few reports/papers that present information on light levels and occupant satisfaction.

High Efficiency Office: Low Ambient/ Task Lighting Pilot Project. Howlett, Owen. 2009. Heschong Mahone Group (now TRC). Pacific Gas and Electric Company's Emerging Technologies Program.
This report presents the results of a study on the design, installation and monitoring of "low ambient / task lighting" in a small office building in Davis, CA. The project was designed to determine whether light levels could be significantly reduced to save energy, while preserving a comfortable and attractive office environment.

Lighting and the Living Lab: Testing Innovative Lighting Control Systems in the Workplace. Cordell, David et al. 2014. Perkins + Will Research Journal, vol. 06.01.
This research studied the role of smart lighting strategies and the use of lighting control systems in an office environment. They studied task tuning, variable load shedding and daylight harvesting. Each strategy was tested sequentially for twelve consecutive weeks to determine the ability of each approach to reduce the overall energy consumption, while incurring minimal consequences on productivity and comfort.

Lighting Quality and Office Work: A Field Simulation Study. Boyce, Peter et al. 2003. Pacific Northwest National Laboratory.
Two experiments were conducted in an office setting designed as an open plan workplace for nine people. The simulated workplace had perimeter windows for views but limited daylight penetration. The two experiments tested different lighting installations to study how office lighting affects the performance of office work and the health and well-being of employees.

Lighting quality perceived in offices. Zumtobel Research. 2014. Fraunhofer Institute for Industrial Engineering, Stuttgart, Germany.
The aim of this user study initiated by Zumtobel and implemented in cooperation with Fraunhofer IAO, was to describe the lighting situation in offices and to record the specific needs of various user groups in different work scenarios. An interactive component of the study allowed participants to choose illuminance levels to suit their needs: more than 60 percent chose levels of 800 lux (80 fc) or higher.

Light environment in Japanese office buildings after the 3.11 earthquake - field measurements on illuminance levels and occupants' satisfaction. Yoshizawa, N. et al. 2012. International Society of Indoor Air Quality and Climate Healthy Building Conference, Brisbane, Australia.
This study collected and analyzed basic data on light environments in Japanese office buildings after the March 2011 earthquake. Results from field measurements at 14 buildings suggest that workplace

dissatisfaction decreases until a desktop illuminance of approximately 400 lux (30 dx) is reached: the dissatisfaction rate remains nearly constant above this illuminance level.

Lighting preference profiles of users in an open office environment. Despenic, Marija et al. 2017. Building and Environment, 116 (2017) 89-107.
The authors propose a method for modelling lighting preference profiles based on users control behavior. These profiles can be used to address lighting issues in multi-user, open-space environments.

A Meta-Analysis of Energy Savings from Lighting Controls in Commercial Buildings. Williams, Alison et al. 2011. Lawrence Berkeley National Laboratory.
The authors conducted a meta study of available research on the energy savings associated with lighting controls. In total, they summarize 88 papers, comprising 240 savings estimates of 4 controls strategies; daylighting, occupancy sensors, personal tuning and institutional tuning.
Personal tuning is defined as an individual adjusting their own light levels to their personal preference using dimmers, wireless on/off switches, bi-level switches, computer-based controls or pre-set scene selection. On average, the lighting energy savings were 31 percent for personal tuning.

Advanced Lighting Control System (ALCS) in an Office Building. Beresini, Jeff. 2013. Pacific Gas and Electric Company’s Emerging Technologies Program.
This report summarizes an assessment project that studied the performance of an advanced lighting control system (ALCS) in a generic office setting. After relamping, reballasting, and adding wireless controls to the existing lighting fixtures, baseline measurements were taken. An initial energy savings of 26% resulted from the implementation of task tuning through the ALCS. A further energy savings of 44% resulted from the implementation of complete ALCS functionality, based on the results of the test at the Contra Costa County Office of Education ending in January 2013.

Evaluation of an LED Retrofit Project at Princeton University’s Carl Icahn Laboratory. Davis, Robert et al. 2015. U.S. Department of Energy, Commercial Building Integration Program.
To prepare for Princeton’s first building-wide interior LED project, facility engineers installed multiple samples of several lighting retrofit products and collected feedback from stakeholders on the appearance, perceived impacts on light levels and distribution, and potential glare. This process was used to determine which retrofit product to use.

APPENDIX B: SCREENING SURVEY

Dear Sir/Madam,

Focus on Energy's Environmental & Economic Research and Development Program (EERD) is sponsoring research to better understand light levels in Wisconsin businesses. This research, conducted by Seventhwave (seventhwave.org) will be used to inform Focus on Energy's energy efficiency program designs to better serve Wisconsin businesses in the future.

Please take 5 minutes to complete this survey to help us identify building sites to include in our research. If your building qualifies and you're willing to participate in our research, we'll follow up with you to schedule a site visit in the coming weeks. During this site visit, our field technician will measure light levels in your building's spaces. This assessment will conclude with a short discussion of any noteworthy findings, and we will follow up with a short summary of suggestions as to how to improve your lighting performance.

For more information about Focus on Energy, please visit our website (https://www.focusonenergy.com/).

All individual responses will be kept confidential with results reported in aggregated form only. Please respond by [DATE].

If you are not the appropriate contact, please forward this survey link to a building, facility or business manager for your Wisconsin location.

Thank you in advance for answering the survey questions. If you have questions or comments about this survey, please contact Scott Schuetter (sschuetter@seventhwave.org).

If you have any additional questions about Focus on Energy, the EERD program, or this project, they can be directed to Joe Fontaine (Joe.Fontaine@wisconsin.gov), Focus on Energy Performance Manager at the Public Service Commission of Wisconsin.

Questions

1. Are you knowledgeable about the lighting systems serving your organization's building? ***Yes/No***

   If No: If you are not the appropriate contact, please forward this survey link to a building, facility or business manager for your Wisconsin location. ***Thank and Terminate***

2. Is the building that you are responding about located in Wisconsin? ***Yes/No***

   If No: ***Thank and Terminate***

3. What is the approximate square footage of the space occupied by this building? If there are multiple tenants, we are looking for the size of the entire building.
   a. Record integer value
   b. Don't know

[ASK IF Q3=Don't know]

4. Would you say that this building occupies?
   a. Less than 1,000 square feet

b. 1,001 to 5,000 square feet
c. 5,001 to 10,000 square feet
d. 10,001 to 25,000 square feet
e. 25,001 to 50,000 square feet
f. 50,001 to 100,000 square feet
g. 100,001 to 200,000 square feet
h. 200,001 to 500,000 square feet
i. Over 500,000 square feet
j. Don't know

If Don't Know: ***Thank and Terminate***

5. Thinking about the Wisconsin building as a whole, what are the spaces primarily used for?

Key	**Building Type**	**Description**	**May Include**	**Does Not Include**
1.	RETAIL	Buildings used for the sale and display of goods other than grocery or convenience stores.	• retail store • beer, wine, or liquor store • rental center • dealership or showroom for vehicles or boats • studio/gallery • enclosed mall • strip shopping center	• grocery stores • convenience stores
2.	EDUCATION	Buildings used for academic or technical classroom instruction, such as elementary, middle, or high schools, and classroom buildings on college or university campuses.	• elementary or middle school • high school • college or university • preschool or daycare • adult education • career or vocational training • religious education	• Buildings on education campuses for which the main use is not classroom. For example, administration buildings, dormitories and libraries.

Key	Building Type	Description	May Include	Does Not Include
3.	OFFICE	Buildings used for general office space, professional office, or administrative offices.	• administrative or professional office • government office • mixed-use office • bank or other financial institution • medical office (see the next column) • sales office • Trade Ally's office (e.g., construction, plumbing, HVAC) • non-profit or social services • city hall or city center • religious office • call center	• Medical offices that use any type of diagnostic medical equipment. These would be categorized under Outpatient Healthcare
4.	OUTPATIENT HEALTHCARE	Buildings used as diagnostic and treatment facilities for outpatient care.	• medical office (see previous column) • clinic or other outpatient healthcare • outpatient rehabilitation • veterinarian	• Hospitals • Medical offices that DO NOT use any type of diagnostic medical equipment. These would be categorized under Office.
5.	WAREHOUSE AND STORAGE	Buildings used to store goods, manufactured products, merchandise, raw materials, or personal belongings (such as self-storage).	• refrigerated warehouse • non-refrigerated warehouse • distribution or shipping center	
6.	OTHER			
7.	DON'T KNOW			

If Other or Don't Know: ***Thank and Terminate***

6. How many different business or tenants occupy this building?
    a. Record integer value
    b. Don't know

[ASK IF Q6=Don't know]

7. Would you say that this building has?
    a. 1 business/tenant
    b. 2 to 5 businesses/tenants
    c. 6 to 10 businesses/tenants
    d. 11 to 20 businesses/tenants

e. 21 to 50 businesses/tenants
f. 51 to 100 businesses/tenants
g. More than 100 businesses/tenants
h. Don't know

If Don't Know: ***Thank and Terminate***

[ASK IF Q6 > 1 or Q7 != A]

8. What is the approximate square footage of the space occupied by your <u>business</u>? Note that this may be less than the total square footage of the building.
    a. Record integer value
    b. Don't know

[ASK IF Q8=Don't know]

9. Would you say that this <u>business</u> occupies?
    a. Less than 1,000 square feet
    b. 1,001 to 5,000 square feet
    c. 5,001 to 10,000 square feet
    d. 10,001 to 25,000 square feet
    e. 25,001 to 50,000 square feet
    f. 50,001 to 100,000 square feet
    g. 100,001 to 200,000 square feet
    h. 200,001 to 500,000 square feet
    i. Over 500,000 square feet
    j. Don't know

    If Don't Know: ***Thank and Terminate***

10. What lighting type serves the majority of your <u>business</u>?
    a. Fluorescent
    b. Compact fluorescent
    c. Incandescent
    d. Halogen
    e. High-intensity discharge (HID)
    f. Light-emitting diode (LED)
    g. Other

11. Would you be willing to participate in our research study? For more information on what to expect, please our FAQ
    a. Yes
    b. No

    If No: ***Thank and Terminate***

12. What is the address of the building that you are responding about?
    a. Street address
    b. City
    c. State
    d. Zip Code

13. What is your contact information?
    a. Name
    b. Organization
    c. Email
    d. Phone Number
    e. Job Title

APPENDIX C: SITE VISIT PROTOCOL

Pre Visit
pre-visit_intro
Fill out this section in the car prior to going into the business.

bldgid
Enter the building ID number
This will auto-populate survey data

researcher
Who are you?
1 Leith Nye
2 Mikhaila Calice
3 Andy Lick
4 Scott Schuetter
5 Jennifer Li

date_visit
Enter the date of the site visit

bldg_pic
Take a picture of the building

ID check
check_id_note
If the Building ID number was typed correctly, you should see the business name and address here:
[company_surv] at [address_surv]
If you don't see it, go back and double check the Business ID #. Be sure there aren't extra spaces at the end.

Interview

dwelling_intro
Upon entering the business, introduce yourself and remind owner of the site visit process. Describe what you will be doing, how long it will take and ask if they have any questions. You'll start with a short interview, followed by a walk-through to familiarize you with the spaces. Next, you'll cataloguing lighting and measuring light levels in the building. You can be as autonomous during this period as they're comfortable with. You'll be taking pictures and using a tablet to collect information. You'll be turning on and off lights in various spaces, but will try to keep disruption to a minimum. Ask them if they have any questions.

Mention that all information collected will be used anonymously. And that they'll get a summary of potential opportunities for improvement at the end of this.

This project is funded by Focus on Energy's Environmental and Economic Research and Development Program. It's goal is to characterize the light levels in commercial buildings.

interview_light_level
In your opinion, how are light levels?
1 Too low

2 Just right
3 Too High

interview_light_level_desc
Additional detail about light levels

occ_complaints
Have there been any occupant complaints regarding light levels?
1 Yes
0 No

occ_complaints_desc
Additional detail about occupant complaints

maint_ctrls
Who is responsible for maintaining lighting controls?
1 Not applicable
2 Trade Ally
3 Owner with manufacturer
4 Owner only
5 Property Management
6 Other

maint_ctrls_other
Describe "other" responsible party for maintaining lighting controls (if applicable)

fixt_manu
Fixture manufacturer:

ctrls_manu
Controls manufacturer:

light_year
What year was the lighting installed or retrofit?

light_ctrls
Which of the following lighting controls apply to your businesses lighting?
1 None
2 Daylight/Photosensor (Interior only)
3 Occupancy/Vacancy
4 Timeclock
5 Task Tuning (likely have to explain)

change_of_use
Has there been a significant change of use to the spaces since the lighting was installed or retrofit?
1 Yes
0 No

change_of_use_year
What year was the change of use? (if applicable)

change_of_use_desc
Additional detail about change of use

occupied_period
What are this businesses typical hours of occupancy?
not their business hours, but when someone is generally in the space

1 Weekdays (8 hour workday); No weekend occupancy
2 Weekdays (8 hour workday); Some weekend occupancy
3 Two shifts
4 Three shifts
5 24/7
6 Other

occupied_period_other
Describe "other" occupied period (if applicable)

note_walkthru
The interview is now complete. Ask for a brief walk thru to familiarize you with the various spaces. Mention that you'd like them to point out any photosensors or occupancy sensors that they know of. After that, you can be as autonomous as they are comfortable with. You'd like to circle back at the end for a brief wrap-up.

interview_general_notes
Optional: Add any additional notes pertaining to "Interview" section here
Space Information

bldg_type
Thinking about the building as a whole, what are the spaces primarily used for?
1 Retail
2 Education
3 Office
4 Outpatient Healthcare
5 Warehouse & Storage

num_spaces
Number of spaces to characterize
Try to get at least one of each space type. More than one for a given space type if they have unique fixture types or fixture spacing.

Space Information > Space Information Repeat (1)
(Repeated group)
Space Information > Space Information Repeat (1) > Space Information - Operation

space_type
Space Type
1 Open office
2 Private office
3 Conference room
4 Storage (not warehouse)
5 Storage (warehouse)

6	Corridor
7	Classroom [optional]

space_area
Space Area (ft^2)

num_occupants
Number of Occupants
count chairs

occupant_age
Occupant Age Range
1	< 25 years old
2	25 to 65 years old
3	> 65 years old

tasks
Occupant Tasks
describe typical occupant tasks

Space Information > Space Information Repeat (1) > Space Information - Lighting

num_fix_types
Number of fixture types

Space Information > Space Information Repeat (1) > Space Information - Lighting > Fixture Type Repeat (1)
(Repeated group)

note_fix_type
Reminder that the following questions are specific to a single fixture type

light_type
Lighting Type
1	Fluorescent
2	Compact fluorescent
3	Incandescent
4	Halogen
5	High-intensity discharge
6	Light-emitting diode
7	Other

fix_type_desc
Fixture type description
e.g. 2'x4' troffer

pic_fixture
Picture of typical light fixture

num_fixtures
Number of fixtures

lamp_power
Lamp Power (W)
may need to follow-up with this, can ask to see replacement bulbs they may have in storage
may assume: T12 = 40 W, T8 = 32 W, T5 = 28 W, T5HO = 54 W, CFL = 32 W

num_lamp
Number of lamps per fixture

color_temp
Color temperature (K)
It's okay to skip this if it's difficult to obtain.

delamp
Delamping?
1 Yes
0 No

delamp_desc
Delamping description
e.g. 1 lamp in each fixture

port_manual_ctrl
Portion of this fixture type with manual controls (%)
e.g. a switch, by number of fixtures, estimate to within 10%

manual_ctrl_type
Manual control type
1 On/Off
2 Multilevel (i.e. 1/3, 2/3)
3 Continuous dimming

port_daylight_ctrl
Portion of this fixture type with daylighting controls (%)
by number of fixtures, estimate to within 10%

port_occ_ctrl
Portion of this fixture type with occupancy/vacancy controls (%)
by number of fixtures, estimate to within 10%

Space Information > Space Information Repeat (1) > Space Information - Architecture

orient
Exterior wall orientations
1 None - completely internal
2 North
3 Northeast
4 East
5 Southeast
6 South
7 Southwest

8	West
9	Northwest

wwr
Approximate window-to-wall ratio (%)
Can estimate to within 10%

workplane_desc
Workplane description
e.g. desktop

partitions
Partitions?
1	Yes
0	No

hght_partition
Partition height (ft)
enter 0 if no partitions

hght_workplane
Workplane height (ft)

hght_window
Window head height (ft)

hght_ceiling
Ceiling height (ft)

hght_fixture
Fixture mounting height (ft)
same as fixture height for fixtures recessed in ceiling

reflect_desc
Are any of the surface reflectances atypical? If so, explain.

blinds
Blinds?
1	Yes
0	No
2	Not Applicable

pic_room
Picture of entire room

pic_window
Picture of window details

pic_blinds
Picture of blinds

pic_switch
Picture of light switch

pic_overhang
Picture of any exterior overhangs and light shelves

pic_partition
Picture of partitions

pic_photosensor
Picture of photosensor

pic_occsensor
Picture of occupancy sensor

pic_workplane
Picture of working plane

pic_misc1
Picture of miscellaneous item #1
whatever else you think is of interest

pic_misc2
Picture of miscellaneous item #2
whatever else you think is of interest

pic_misc3
Picture of miscellaneous item #3
whatever else you think is of interest

Space Information > Space Information Repeat (1) > Space Information - Illuminance

note_illuminance
If there are daylighting controls in this space, we are looking for measurements of light levels with the photosensors active. No need to mess with this control.

sky_cond
Sky condition
1 Sunny
2 Cloudy
3 Partly cloudy
4 Night

hr_meas
Measurement time
use military time (5:00 am = 0500, 5:00 pm = 1700)

room_lum_type
Room and luminaire type
1 A. Regular area with symmetrically located luminaires
2 B. Regular area with symmetrically located single luminaire

3 C. Regular area with single row of continuous luminaires
4 D. Regular area with two or more continuous rows of luminaires
5 E. Regular area with single row of continuous luminaires
6 F. Regular area with uniform indirect lighting

num_fix_per_row
Number of fixtures per row

num_row
Number of rows

p-1_on
p-1 lights on (fc)
if not applicable, leave blank

p-1_off
p-1 lights off (fc)
if not applicable, leave blank

p-2_on
p-2 lights on (fc)
if not applicable, leave blank

p-2_off
p-2 lights off (fc)
if not applicable, leave blank

p-3_on
p-3 lights on (fc)
if not applicable, leave blank

p-3_off
p-3 lights off (fc)
if not applicable, leave blank

p-4_on
p-4 lights on (fc)
if not applicable, leave blank

p-4_off
p-4 lights off (fc)
if not applicable, leave blank

q-1_on
q-1 lights on (fc)
if not applicable, leave blank

q-1_off
q-1 lights off (fc)
if not applicable, leave blank

q-2_on
q-2 lights on (fc)
if not applicable, leave blank

q-2_off
q-2 lights off (fc)
if not applicable, leave blank

q-3_on
q-3 lights on (fc)
if not applicable, leave blank

q-3_off
q-3 lights off (fc)
if not applicable, leave blank

q-4_on
q-4 lights on (fc)
if not applicable, leave blank

q-4_off
q-4 lights off (fc)
if not applicable, leave blank

q-5_on
q-5 lights on (fc)
if not applicable, leave blank

q-5_off
q-5 lights off (fc)
if not applicable, leave blank

q-6_on
q-6 lights on (fc)
if not applicable, leave blank

q-6_off
q-6 lights off (fc)
if not applicable, leave blank

q-7_on
q-7 lights on (fc)
if not applicable, leave blank

q-7_off
q-7 lights off (fc)
if not applicable, leave blank

q-8_on
q-8 lights on (fc)
if not applicable, leave blank

q-8_off
q-8 lights off (fc)
if not applicable, leave blank

r-1_on
r-1 lights on (fc)
if not applicable, leave blank

r-1_off
r-1 lights off (fc)
if not applicable, leave blank

r-2_on
r-2 lights on (fc)
if not applicable, leave blank

r-2_off
r-2 lights off (fc)
if not applicable, leave blank

r-3_on
r-3 lights on (fc)
if not applicable, leave blank

r-3_off
r-3 lights off (fc)
if not applicable, leave blank

r-4_on
r-4 lights on (fc)
if not applicable, leave blank

r-4_off
r-4 lights off (fc)
if not applicable, leave blank

r-5_on
r-5 lights on (fc)
if not applicable, leave blank

r-5_off
r-5 lights off (fc)
if not applicable, leave blank

r-6_on
r-6 lights on (fc)
if not applicable, leave blank

r-6_off
r-6 lights off (fc)

if not applicable, leave blank

r-7_on
r-7 lights on (fc)
if not applicable, leave blank

r-7_off
r-7 lights off (fc)
if not applicable, leave blank

r-8_on
r-8 lights on (fc)
if not applicable, leave blank

r-8_off
r-8 lights off (fc)
if not applicable, leave blank

t-1_on
t-1 lights on (fc)
if not applicable, leave blank

t-1_off
t-1 lights off (fc)
if not applicable, leave blank

t-2_on
t-2 lights on (fc)
if not applicable, leave blank

t-2_off
t-2 lights off (fc)
if not applicable, leave blank

t-3_on
t-3 lights on (fc)
if not applicable, leave blank

t-3_off
t-3 lights off (fc)
if not applicable, leave blank

t-4_on
t-4 lights on (fc)
if not applicable, leave blank

t-4_off
t-4 lights off (fc)
if not applicable, leave blank

Goodbye

note_goodbye
You made it to the end of the site visit. Good work! Thank the participant for their time and a few questions before you go….

lamp_power_followup
Reminder to follow-up on anything you couldn't determine on your own. Especially lamp powers or color temperatures that you missed. You can ask to see any replacement bulbs they may have in storage. Remember to go back and fill in the appropriate fields.

ecm_reminder
Discuss energy savings opportunities with them. Possibilities below:
1. Replace existing lighting with LEDs. Often 50% energy savings. Retrofit kits available.
2. Install occupancy sensors to turn off lights in spaces with variable occupancy, such as conference rooms and private offices.
3. Install photosensors to turn off lights in spaces with plenty of natural light.
4. Task tune light levels to reduce amount of electric light. Often can be reduced by 20% with no impact on occupant comfort.
report
Did they want an email describing energy savings opportunities?
If they ask for timeline, it'll take a month or two.
1 Yes
0 No

photo_consent
Did they give you consent to use the photos taken today?
1 Yes
0 No

equip_reminder
Did you remember to take everything that you brought with you?
Don't forget and leave something behind
1 Yes
0 No

checkin_reminder
Did you remember to notify someone to let them know everything went smoothly?
Scott: sschuetter@seventhwave.org, 608-210-7149, 317-445-0452
Melanie: mlord@seventhwave.org, 608-210-7134
1 Yes
0 No

change_name1
Be sure to change the name at the end of the form (add BldgID) when you Save Form and Exit.

Post-Visit

desc_post
Provide summary assessment of energy opportunities and general overview of your site visit. To be filled out after the site visit (but don't wait too long or else details may be lost!). Also, remember to send a thank-you email.

change_name2
Be sure to change the name at the end of the form when you Save Form and Exit.

post1_pic
Picture of paper notes #1

post2_pic
Picture of paper notes #2

post3_pic
Picture of paper notes #3

post4_pic
Picture of paper notes #4

post5_pic
Picture of paper notes #5

post6_pic
Picture of paper notes #6

APPENDIX D: TASK TUNING CHECKLIST

Site/Space Name: ________________________________ Date:________

Before the Visit

- ☐ Building address, contact name, cell phone number of building contact
- ☐ Obtain and review relevant building drawings (hardcopy or electronic)
- ☐ Familiarize yourself with the lighting system's controls by reviewing electronic documentation. Identify the steps necessary to adjust the system's high end trim and/or photosensor setpoint.
- ☐ Ask building contact to have lighting controls interface device available (i.e. handheld device or laptop)

During the Visit

- ☐ Identify the space or spaces to be task tuned.
    - Task tuning of a space involves understanding how fixtures are controlled and which fixtures are grouped together. Generally, a zone is identified as a group of fixtures that have the same controls (i.e. an entire conference room with modifiable scenes, the portion of an open office controlled by a photosensor)
    - The light levels in every single space in a building should not be measured. Instead, the light levels in a sample of representative spaces should be measured. The calculated reduction in light levels should then be applied to all similar spaces.
- ☐ Hand out pre-adjustment occupant surveys (ideally done prior to visit if possible)
- ☐ Analyze results of occupant survey. If there is a high level of dissatisfaction with the light levels in the space, consider adjusting approach accordingly. i.e. not task tuning a particular space, or not task tuning a particular space as aggressively.
- ☐ Fill out miscellaneous information below

Miscellaneous Information

Lighting	
Sky Condition	
Time of Day	
Space Type	
Predominant Visual Task	
Approximate Average Age of Occupants	

Measure Untuned Critical Illuminance

- "Lights Off" reading not necessary if no daylight is present (i.e. nighttime, interior space, or able to draw blinds).
- Take "Lights On" followed by "Lights Off" readings at a given location as quickly as possible as daylight (if present) may change light levels within the space.
- Allow sufficient time between locations to allow light levels to stabilize after making any control changes.
- When taking handheld readings, use tripod or hold sensor away from body to prevent shadowing on lens.
- Having more than one person is very helpful in accurately recording measurements.

☐ Select critical workplane.

- The critical workplane is the area where the predominant visual task within a space will likely be performed that also receives the least amount of light. Typically, this is a desktop away from windows and luminaires.
- Avoid task lights and direct fixture illuminance when selecting the critical workplane.

☐ Place handheld light meter at the critical workplane.

☐ Close blinds or shades if possible to minimize daylight

- If task tuning is done at night, this step is not needed.

☐ Turn on lights. Use lighting controls interface device (i.e. handheld, laptop or wall switch) to bring lights to their maximum power state. Alternately, you can cover the photosensor, if present, to trick the system into bringing the lights on to their full power. Record "Lights On" case in the table below.

☐ Turn off lights. Record "Lights Off" case in the table below.

☐ Calculate "Untuned Critical Illuminance" by taking the difference between the "Lights On" and "Lights Off" case.

Location	"Lights On" Illuminance (fc)	"Lights Off" Illuminance (fc)	Untuned Critical Illuminance (fc)
critical workplane			

Measure Untuned Average Illuminance

- ☐ Close blinds or shades if possible to minimize daylight
  - If task tuning is done at night, this step is not needed.
- ☐ Select appropriate Room & Luminaire Type (refer to IES Lighting Handbook[10] for more detail).
- ☐ Record the selected Room & Luminaire Type in the table below. Make note of any orientation details.

Room & Luminaire Type	
Points Orientation Notes	*i.e. p-1 is closest to window*

- ☐ Hold handheld light meter at one of the locations applicable for your selected Room & Luminaire Type.
- ☐ Turn on lights. Use lighting controls interface device (i.e. handheld, laptop or wall switch) to bring lights to their maximum power state. Alternately, you can cover the photosensor, if present, to trick the system into bringing the lights on to their full power. Record "Lights On" case in the table below.
- ☐ Turn off lights. Record "Lights Off" case in the table below.
- ☐ Repeat process at each applicable location for your selected Room & Luminaire Type.
- ☐ Calculate "Untuned Electric Illuminance" by taking the difference between the "Lights On" and "Lights Off" case for each location.

Location (i.e. q-1, q-2…)	**"Lights On" Illuminance (fc)**	**"Lights Off" Illuminance (fc)**	**Untuned Electric Illuminance (fc)**

- ☐ Using the appropriate equation (refer to IES Lighting Handbook[10] for more detail), calculate the Untuned Average Illuminance. When performing this calculation, use the Untuned Electric Illuminance column.

Untuned Average Illuminance (fc)	

Calculate Tuned Critical Illuminance

- ☐ Refer to IESNA Lighting Handbook[10] to determine IESNA Target Illuninance based on space type, predominant visual task occurring in the space and average age of space occupants and record in the table below.
- ☐ Calculate Tuned Critical Illuminance using the following formula and enter it in the table below.

$$Tuned\ Critical\ Illuminance = Untuned\ Critical\ Illuminance\left(\frac{IESNA\ Target\ Illuminance}{Untuned\ Average\ Illuminance}\right)$$

- ☐ Calculate Percent Reduction using the following formula and enter it in the table below.

$$Percent\ Reduction = \frac{Untuned\ Critical\ Illuminance - Tuned\ Critical\ Illuminance}{Untuned\ Critical\ Illuminance}$$

Name	Value
IESNA Target Illuminance	
Tuned Critical Illuminance	
Percent Reduction	

Implement Task Tuning

- ☐ Select specific task tuning scenario that is most appropriate for your space.
  - A: Spaces without daylight
  - B: Spaces with daylight, blinds and photosensor
  - C: Spaces with daylight, blinds and no photosensor
  - D: Spaces with daylight, no blinds and photosensor
  - E: Spaces with daylight, no blinds and no photosensor
- ☐ Review and become familiar with the steps of the selected task tuning scenario outlined below.
- ☐ Record initial lighting control settings below.

Lighting	
Lighting Controls Information	*URL:* *Username:* *Password:* *Initial Settings:*

- ☐ Place handheld light meter at the critical workplane.
- ☐ Follow the steps of the applicable task tuning scenario below.

A: Spaces without daylight

- This scenario is the most straightforward, as it is not complicated by daylight or photosensor control.

- ☐ Adjust the high end trim until the measured illuminance at the critical workplane matches the Tuned Critical Illuminance.
- ☐ Optional: Ask occupant to perform applicable visual task (i.e. reading small print or computer screen). Ask if light levels cause any visual discomfort.
  - If No, consider decreasing light levels another 5 fc (confirmed by light meter). Only if occupant surveys show a high satisfaction with light levels and facility manager has high level of ownership with space (i.e. can quickly respond to future occupant complaints). Record updated Tuned Critical Illuminance below.
  - If Yes, increase light levels in 5 fc increments (confirmed by light meter) until occupant no longer experiences visual discomfort. Record updated Tuned Critical Illuminance below
- ☐ Record final lighting control settings below.

Updated Tuned Critical Illuminance (if applicable)	
Final Lighting Controls Settings (if applicable)	

B: Spaces with daylight, blinds and photosensor

- This scenario is more complex. However, you are able confirm that the space has been tuned appropriately as you can reduce the available daylight sufficiently.

- ☐ Close any blinds, thereby significantly decreasing the amount of daylight.
- ☐ Adjust the photosensor setpoint until the measured illuminance at the critical workplane matches the Tuned Critical Illuminance.
- ☐ Optional: Ask occupant to perform applicable visual task (i.e. reading small print or computer screen). Ask if light levels cause any visual discomfort.
  - If No, consider decreasing light levels another 5 fc (confirmed by light meter). Only if occupant surveys show a high satisfaction with light levels and facility manager has high level of ownership with space (i.e. can quickly respond to future occupant complaints). Record updated Tuned Critical Illuminance below.
  - If Yes, increase light levels in 5 fc increments (confirmed by light meter) until occupant no longer experiences visual discomfort. Record updated Tuned Critical Illuminance below.
- ☐ If lighting controls require separate high end trim adjustment, in addition to photosensor setpoint adjustment.
  - Verify blinds are closed.
  - Turn off lights.
  - Measure the illuminance at critical workplane. This value defines the Ambient Natural Illuminance. Record below.
  - Calculate the Total Critical Illuminance below. The Total Critical Illuminance is the sum of the Ambient Natural Illuminance and the Tuned Critical Illuminance.

Tuned Critical Illuminance		**Ambient Natural Illuminance**		**Total Critical Illuminance**
	+		=	

  - Turn on lights
  - Adjust the high end trim until the measured illuminance at the critical workplane matches the Total Critical Illuminance.
  - In order to confirm that this adjustment did not affect your photosensor setpoint adjustment, exit controls programming mode. Confirm that light meter still matches Tuned Critical Illuminance
- ☐ Open blinds.
- ☐ Record final lighting control settings below.

Updated Tuned Critical Illuminance (if applicable)	
Final Lighting Controls Settings (if applicable)	

C: Spaces with daylight, blinds and no photosensor

- This scenario is more complex. However, you are able confirm that the space has been tuned appropriately as you can reduce the available daylight sufficiently.
- ☐ Close any blinds, thereby significantly decreasing the amount of daylight.
- ☐ Turn off lights.
- ☐ Measure the illuminance at the critical workplane. This defines the Ambient Natural Illuminance. Record below.
- ☐ Calculate the Total Critical Illuminance below. The Total Critical Illuminance is the sum of the Ambient Natural Illuminance and the Tuned Critical Illuminance.

Tuned Critical Illuminance		**Ambient Natural Illuminance**		**Total Critical Illuminance**
	+		=	

- ☐ Turn on lights
- ☐ Adjust the high end trim until the measured illuminance at the critical workplane matches the Total Critical Illuminance.
- ☐ Optional: Ask occupant to perform applicable visual task (i.e. reading small print or computer screen). Ask if light levels cause any visual discomfort.
  - If No, consider decreasing light levels another 5 fc (confirmed by light meter). Only if occupant surveys show a high satisfaction with light levels and facility manager has high level of ownership with space (i.e. can quickly respond to future occupant complaints). Record updated Tuned Critical Illuminance below.
  - If Yes, increase light levels in 5 fc increments (confirmed by light meter) until occupant no longer experiences visual discomfort. Record updated Tuned Critical Illuminance below.
- ☐ Open blinds.
- ☐ Record final lighting control settings below.

Updated Tuned Critical Illuminance (if applicable)	
Final Lighting Controls Settings (if applicable)	

D: Spaces with daylight, no blinds and photosenor

- In this scenario, you are unable to confirm that the space has been tuned appropriately as you cannot reduce the available daylight sufficiently. Also, you cannot confirm that the tuned light levels do not cause visual discomfort. Consider revisiting this space at night if possible.

- ☐ Access lighting control system and find Untuned Photosensor Setpoint. Record below.
- ☐ Calculated Tuned Photosensor Setpoint. Record below.

$$Tuned\ Photosensor\ Setpoint = Untuned\ Photosensor\ Setpoint * Percent\ Reduction$$

Name	Value
Untuned Photosensor Setpoint	
Tuned Photosensor Setpoint	

- ☐ In lighting control system, adjust photosensor setpoint to be equal to calculated Tuned Photosensor Setpoint.

- ☐ If lighting controls require separate high end trim adjustment, in addition to photosensor setpoint adjustment, access lighting control system and find Untuned High End Trim. Record below.
- ☐ Calculate Tuned High End Trim. Record below.

$$Tuned\ High\ End\ Trim = Untuned\ High\ End\ Trim * Percent\ Reduction$$

Name	Value
Untuned High End Trim	
Tuned High End Trim	

- ☐ In lighting control system, adjust high end trim to be equal to calculated Tuned High End Trim.
- ☐ Record final lighting control settings below.

Final Lighting Controls Settings (if applicable)	

E: Spaces with daylight, no blinds and no photosenor

- In this scenario, you are unable to confirm that the space has been tuned appropriately as you cannot reduce the available daylight sufficiently. Also, you cannot confirm that the tuned light levels do not cause visual discomfort. Consider revisiting this space at night if possible.

- ☐ Turn off lights.
- ☐ Measure the illuminance at the critical workplane. This defines the Ambient Natural Illuminance. Record below.
- ☐ Calculate the Total Critical Illuminance below. The Total Critical Illuminance is the sum of the Ambient Natural Illuminance and the Tuned Critical Illuminance.

Tuned Critical Illuminance	+	**Ambient Natural Illuminance**	=	**Total Critical Illuminance**

- ☐ Turn on lights
- ☐ Adjust the high end trim until the measured illuminance at the critical workplane matches the Total Critical Illuminance.
- ☐ Record final lighting control settings below.

Final Lighting Controls Settings (if applicable)	

After the Visit

- ☐ Ask facility manager to re-administer occupant surveys several weeks after task tuning was completed.
- ☐ Compile results of occupant survey.
- ☐ If surveys show high levels of occupant discomfort, consider retuning space with higher target illuminance levels.