ComEd – LBNL 'Beyond Widgets' Project

Automated Shading Integrated with Lighting and HVAC Controls

System Program Manual

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Disclaimer

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Executive Summary

This program manual contains detailed technical information for developing an incentive program for automated shading integrated with lighting and HVAC controls. The manual was developed by Lawrence Berkeley National Laboratory, in collaboration with ComEd as a partner in the 'Beyond Widgets' project funded by the U.S. Department of Energy Building Technologies Office.

ComEd considered a list of several systems and selected automated shading integrated with lighting and HVAC controls. Daylight-based dimming is a proven but underutilized energy-efficiency technology, particularly within the context of utility programs which mostly cater to prescriptive component-based efficiency measures.

LBNL's FLEXLAB test facility was used to measure the energy performance and visual comfort of the system. FLEXLAB allows energy-efficient building systems to be tested individually or as an integrated system, under real-world conditions. The test case (i.e. automated shading integrated with lighting and HVAC controls) and the baseline case (i.e. manually operated venetian blinds and no daylight-based dimming) were tested at the same time under identical conditions using the two cells of the FLEXLAB rotating testbed. In order to obtain an assessment of HVAC loads in Chicago climate, the internal temperature setpoints were adjusted in real time to match the indoor-outdoor temperature difference in Chicago. FLEXLAB testing was conducted over a 6-month period and covered various configurations of orientation, daylight zone size, window-to-wall-ratio (WWR), and lighting type.

Test period savings were extrapolated to annual savings using regression models of the test period data.

- South orientation shows a mean of 19% annual lighting energy savings, with a range of 12-26% (at 95% confidence).
- West orientation shows a mean of 24% annual lighting savings, with a range of 19-30% (at 95% confidence).

It is important to reiterate that these savings are *exclusively attributable to automated shading and dimming* and will be additional to savings from lighting upgrades. In particular, these savings *do not include the savings from tuning*.

We estimated whole building savings for four building types using the DOE reference building EnergyPlus simulation models in combination with the FLEXLAB lighting savings results, adjusted to account for savings from institutional tuning. The table below shows the whole building savings estimates for the reference buildings.

Table ES-1. Whole building savings from dimming and tuning

Reference building	Whole Building Lighting Svg %	Whole Building Total Elec Svg %	Whole Building Site Energy Svg %
Large Office	16%	5.0%	2.6%
Medium Office	22%	4.5%	3.5%
Primary School	20%	9.0%	4.8%
Secondary School	14%	6.2%	2.7%

The visual comfort analysis showed that the system maintained workplane illuminance and daylight glare probability at satisfactory levels throughout the test period.

1 Introduction

This program manual contains detailed technical information for developing an incentive program for automated shading integrated with lighting and HVAC controls. This manual was developed by Lawrence Berkeley National Laboratory, in collaboration with ComEd as a partner in the 'Beyond Widgets' project funded by the U.S. Department of Energy Building Technologies Office. The primary audience for this manual is the ComEd incentive program staff. It may also be used by other utilities to develop a similar incentive program. It is anticipated that the content of this manual will also be utilized by the ComEd staff for developing related documents such as the Technical Resource Manual and other filings.

This manual covers a range of information needed by various stakeholders involved in developing a utility incentive program. It is not necessarily intended to be read cover to cover by any one stakeholder. Beyond section 2, which describes the key features of the system, readers may wish to read only those sections relevant to their interest.

Section 2 presents an overview of the system and initial market analysis.

Section 3 describes the functional performance requirements of the system.

Section 4 presents the FLEXLAB testing approach and results, including measured savings from FLEXLAB and estimates of whole building savings based on FLEXLAB results. Visual comfort analysis results are also presented in this section.

Section 5 describes the methodology for estimating potential savings at candidate sites.

Section 6 addresses measurement and verification (M&V) options and considerations.

Section 7 provides guidelines on operations and maintenance practices to maximize savings persistence, based on industry experience as well as findings from FLEXLAB operation.

Section 8 provides preliminary recommendations on training for program implementers.

2 System Selection and Market Analysis

2.1 System Features: Automated Shading with Daylight-based Dimming

ComEd considered a list of several systems and selected automated shading integrated with lighting and HVAC controls. The key features of this system are:

Automated Shading: The automated interior shading element will be roller shades. The functional requirement is for the shades to control solar gain through perimeter windows so that envelope-related thermal loads are minimized while meeting daylighting requirements. As an additional option, during unoccupied periods the shades may be deployed according to the prevailing HVAC mode of operation (deployed in cooling mode, retracted in heating mode).

Lighting Controls: The lighting control is in response to occupancy and illuminance levels. Occupancy-driven control will switch lights on/off or dim to minimum background levels. Illuminance-driven control will dim lights continuously based on daylight availability.

HVAC Controls: The primary HVAC control is in response to thermostatic setpoints, with scheduled setup and setback for unoccupied periods. Additionally, occupancy sensors used for the shading/lighting system may be used for setup/setback in response to vacancy during occupied periods, as well as reducing ventilation air.

2.2 Market Analysis

2.2.1 Literature review highlights

Daylight-based dimming is a proven but underutilized energy-efficiency technology, particularly within the context of utility programs which mostly cater to prescriptive component-based efficiency measures. An LBNL meta analysis study (Williams et al. 2011) showed that daylighting alone yielded an average lighting energy savings of 27% (N=18 projects) for offices and 29% (N=7 projects) for education (Table 2).

Table 1.Energy savings from LBNL meta-analysis of lighting controls studies (Williams et al. 2011)

Building Type (Alone)	Occupancy	Daylighting	Personal Tuning	Institutional Tuning	Multiple Types
Office	22% (n=23)	27% (n=18)	35% (n=13)	36% (n=11)	40% (n=24)
Warehouse	31% (n=4)	28% (n=1)	-	-	-
Lodging	45% (n=2)	-	-	-	-
Education	18% (n=5)	29% (n=7)	6% (n=2)	-	34% (n=7)
Retail (other than Mall)	-	29% (n=3)	-	60% (n=1)	-
Healthcare Inpatient	-	-	-	-	35% (n=1)
Public Assembly	36% (n=2)	36% (n=1)	-	-	-
Healthcare Outpatient	23% (n=1)	-	-	-	-
Other	7% (n=1)	18% (n=1)	-	-	-

Integrating automated shading with daylight dimming and HVAC controls has the potential to yield higher savings, a better visual environment, and higher savings realization. For example, post-occupancy LBNL study of the New York Times headquarters building (Lee et al. 2013) showed 38% lighting energy savings compared to code, with a simple payback of 4.1 years (Figure 1). The automated shades caused daylight to be well managed irrespective of differences in daylight availability – for lower floors with greater urban obstructions, the shades were automatically raised more often and for upper floors with less urban obstructions, the shades were lowered more often to control sun and glare. These and other non-energy benefits (e.g. lower cost for reconfiguring lighting system compared to hardwired systems) serve as an added incentive to increase adoption.

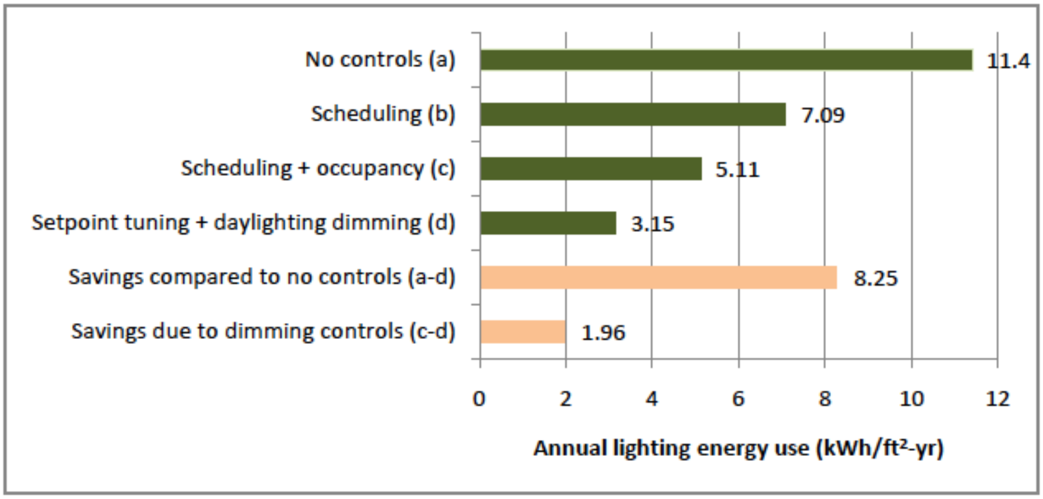

Figure 1. Lighting energy use savings in the New York Times headquarters building (Lee et al. 2013)

2.2.2 ComEd market analysis

ComEd identified two target market segments for this system package: offices and schools. For offices, the focus will be on medium and large size buildings. The package will target both retrofit and new construction.

LBNL commissioned a market analysis to estimate the savings across various market segments in the ComEd service territory. The market analysis estimated technical potential, economic potential and adoption potential as separate outputs. The key inputs applicable floor area, baseline energy use, and potential building-level savings as a percentage of the baseline. The market impact analysis was conducted prior to FLEXLAB testing. The building-level savings estimates were based on literature review and simulation analysis.

The market segments considered for this analysis included offices and schools. The total technical potential for these segments is 519-633 GWh of savings. The Total Resource Cost (TRC) criterion was 0.25-0.28 for a retrofit scenario and 0.44-0.53 for a Replace on Burnout (ROB) scenario. Using TRC criteria, this system is cost-effective only for specific sub-segments and only when evaluated using incremental system costs (ROB scenario). This is primarily due to the low avoided cost rates in Illinois, which are about $0.04/kWh. However, from a customer perspective these systems are cost effective with the average rates of about $0.10/kWh.

Appendix A includes the executive summary of the market analysis report.

3 System Functional Performance Requirements

The intent is to allow a range of different component technology options for this integrated system. The program incentives would be paid based on system performance rather than component performance or features. The functional performance requirements for each component are summarized below.

3.1 Automated Shading

An automated interior shading and shade control system should comprise the following elements:

- Shading element – roller shades (various fabric options).
- Motor for shades/blinds operation, and housing for blinds when retracted.
- Keypads to enable user control and override of automatic operation.
- Routers, controllers, processors and servers.
- Control system that utilizes an automated, computer server-based control system with the ability to receive inputs from multiple occupancy sensors and photo sensors.
- Sensors for control inputs.
- Programming software.

The primary control objective is to control glare while maximizing daylight availability. Setpoints for glare control and maximizing daylight should be set based on use characteristics and user preferences. Additionally, occupants should always have manual override capability. Primary control shall be in response to solar conditions, based on real-time solar radiation sensor input. In addition, a combination of one or more of the following inputs may be used:

- Sun position
- Direct solar radiation
- Diffuse solar radiation
- Façade azimuth
- Interior and/or exterior surface luminance
- Interior and/or exterior illuminance

Additional secondary control may include a combination of vacancy and HVAC mode, as follows:

- When the zone is vacant and HVAC is in cooling mode, shades are fully deployed.
- When the zone is vacant and HVAC is in heating mode, shades are fully retracted.

Additional specific requirements:

- Roller shades should have an openness factor between 1-3%. The exterior reflectance should be greater than 60%. Interior reflectance should be lower than exterior reflectance.
- The control system should allow for at least 3 shade height settings, including fully raised and fully lowered.
- The types, locations and number of sensors shall be determined by the Shade Controls System Supplier.
- The shades shall block direct sun so that the depth of direct sun penetration is no greater than a specified horizontal depth from the face of the window wall at floor level. The specified maximum penetration distance may vary for different perimeter areas based on user requirements. The deployment of shades should consider blocking of the sun by external obstructions such as surrounding buildings.
- Response to variable luminance should be limited so as to avoid shade movement hysteresis. Response to variable sky conditions should be immediate when going from cloudy to sunny, and delayed when going from sunny to cloudy.
- The shades shall control glare so that the average window luminance viewed from any angle within the work space is no greater than a specified level (e.g. 2000 cd/m2)

during the day. This includes all periods throughout the day whether there is or is not direct sun in the plane of the window.

- The control system should have the capability to interface with HVAC control system or BMS.
- The shade control database should maintain archived log files of key parameters such as position of shades, glare photo sensor data, profile angles, radiometer readings and system control mode.

All control inputs shall be configured to reflect each site's specific characteristics and requirements.

3.2 Automated Lighting Controls

The lighting control system, of which daylight dimming is a part, may comprise some or all of the following equipment:

- Digitally addressable ballasts or LED drivers; ballast and lamp combinations compatible with dimming controls.
- Panel and remote mounted load control relays and dimmers.
- Power supplies.
- Routers, controllers, processors and servers.
- Analog and digital input and output modules.
- Group/scene and manual zone controls.
- Occupancy/vacancy sensors.
- Photosensors.
- Integral time clock control.
- Emergency lighting control.
- Utility "demand response" control.

The functional performance requirement is that daylight photo sensors shall monitor light levels and enable dimming of electric lighting up or down in response to changes in available natural light as required by user type. Additionally, lights shall be turned off or dimmed to minimum levels in unoccupied zones.

Additional specific requirements:

- Daylighting sensors and controls shall be programmed to ensure minimal lamp cycling (and associated reduced lamp life and occupant distraction) and should be capable of easy recalibration to accommodate changes in environment/preferences. They should be calibrated to ensure that IES guidelines are maintained. The control system should be capable of controlling multiple zones using the input from a single sensor, allowing separate adjustable settings for each control zone. The system should allow for variable target setpoints. The location and number of the photo sensors should be optimized by the control system supplier.
- Occupant sensors may control lighting at the zone or individual worker level. Lighting output should be adjusted to the requirements of the user (tuning of lamp output relative to maximum rated output). Occupancy sensors should be dual-technology. Sensors should allow remote control adjustments of operational parameters (sensitivity, time delay).
- Group/scene controllers shall be compatible with other components of the lighting control system. Devices shall contain on/off group, preset scene functions, or dim

up/dim down interface through front panel. Programming of new scenes or zone assignments must be easily accomplished by authorized personnel from the space being controlled.

- Daylighting sensors should not be in the same housing or location with occupancy and vacancy sensors if proper location for one compromises the successful operation of the other.
- The lighting control system should provide remote monitoring and reporting. It should provide report and trends on the following: energy usage, target setpoint map, switching events, lamp hours, commands usage, system failures.
- Database management system that logs all commands from the LCS. The log file should provide deterministic values including, but not limited to: photosensor data, occupancy sensor state and system control mode (auto, manual and maintenance).
- Lighting system energy use should preferably be measured at the panel level for each zone.
- Self-diagnostic and self-corrective features.

All control inputs shall be configured to reflect each site's specific characteristics.

3.3 HVAC Controls

For optional integrated HVAC control, HVAC zones shall be consistent with those defined for the lighting system. All control inputs shall be implemented according to system configuration, and each site's specific characteristics and requirements.

Integrated HVAC controls/equipment shall include one or more of the following:

- BACnet control communications
- Variable frequency drives on fan and pump motors
- Modulating valves on heating/cooling loops
- Outdoor air temperature reset
- Networked mechanical equipment controllers

Optional control input:

- Occupancy sensors at the sub-zone (i.e. individual private office/cubicle) level

The functional performance requirement is to maintain stable thermal conditions within building HVAC zones, which may be defined according to location (perimeter/core) or type (open office/private office).

Primary control shall be to setpoint temperature during occupied hours and to setup/setback temperatures during unoccupied hours. Secondary control may account for variation in thermal comfort preferences relative to the prevailing outdoor weather conditions (setup/setback) and occupancy (where appropriate/desired).

Control points/variables shall be one or a combination of the following:

- Thermal setpoint
- Airflow rate
- Supply air temperature
- Economizer utilization/mixed air temperature
- Predicted/actual thermal load
- Occupancy sensor signals
- CO_2 sensor signals

4 FLEXLAB Testing and Analysis

4.1 Approach

LBNL's FLEXLAB test facility allows building systems to be tested individually or as an integrated system, under real-world conditions. FLEXLAB test beds can test HVAC, lighting, windows, building envelope, control systems, and plug loads, in any combination.

The key objectives of the FLEXLAB testing for this system were to:

- Analyze lighting and HVAC energy savings from automated shading integrated with lighting and HVAC controls, for Chicago climate conditions.
- Evaluate visual comfort parameters.
- Evaluate level of effort and uncertainty associated with different levels of measurement.

<u>Side-by-side "controlled" testing:</u> The test case (i.e. automated shading integrated with lighting) and the baseline case (i.e. manually operated venetian blinds and no daylight-based dimming) were tested at the same time under identical conditions using the two cells of the FLEXLAB rotating testbed. Figures 2 and 3 show the floor plan and external view respectively of the rotating testbed. Each test cell is approximately 20' wide and 30' deep.

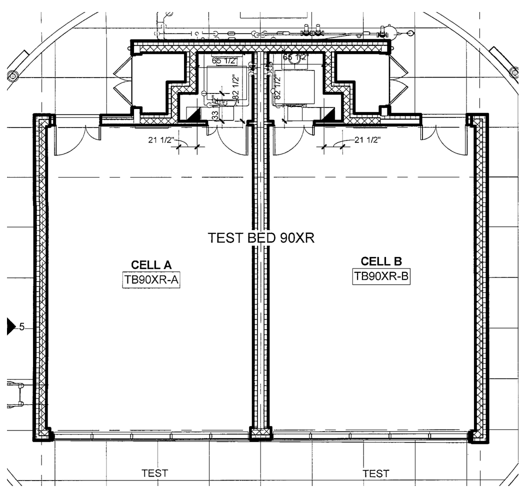

Figure 2. Floor plan of the FLEXLAB rotating testbed showing two test cells used for the test case (Cell B) and baseline case (cell A).

Figure 3. External view of the FLEXLAB rotating testbed

Test duration: The intent was to conduct solstice-to-solstice testing in order to capture the full range of solar positions. However, the project schedule did not allow for this. Testing was conducted in two stages: the first three-month period was from May 9 to August 10, 2016; the second was from October 3, 2016 to January 4, 2017.

Automated shading system specification: LBNL selected an automated shading system from MechoSystems that met the specifications described in section 3. The shade fabric was dark grey in color, with an openness factor of 3%. Ordinarily, some aspects of the shade control would be customized by the user based on their preferences. For this test, which is designed to be broadly applicable, these shade controls were set to represent a 'standard' application. There were six discrete shade settings, not allowing direct solar penetration more than 36" into the space at floor level.

Baseline shading control: For the baseline case, venetian blinds were in the deployed horizontal position for all test configurations.

Multiple configurations: In order to make the test results as broadly applicable as possible, the following five parameters were varied to evaluate their impact on the results:

- *Orientation*: south and west. This was accomplished by rotating the testbed.
- *Window-to-wall ratio*: 0.4 (default) and 0.3. The smaller WWR was accomplished by placing foamcore panels in the window (Figure 4).

Figure 4. Foamcore panels were used to test smaller window-to-wall ratio.

- *Daylight-dimming zone*: Three depths were tested. A 10’ zone that would represent a smaller single occupant perimeter closed office; a 15’ zone that would represent a larger multi-occupant perimeter office; and a 25’ zone that would represent an open office extending to the perimeter. Moveable walls were used to change the zone size (Figure 5).

Figure 5. Moveable walls used to change daylight-zone depth.

- *Lighting type*: Two Lighting types were tested: LED (default) and T-8. Both lighting types were pendant mounted, with three rows located parallel to the window wall. The spacing between fixtures was 8 feet on center. Light levels were tuned to meet 500 lux (~50 fc) workplane illuminance. The lights were turned off during unoccupied hours (7pm to 7am). For this test, which is designed to be broadly applicable, the dimming controls were set to represent a 'standard' application without aggressive dimming strategies. For the 25' zone, the default control setting only dimmed the first and second row of lights from the window wall. LBNL also tested a more aggressive control setting which also dimmed the third row of lights.

Section 4.2 provides more detail on the configuration and testing schedule for each of the parametric variations. These parametric variations were applied identically in the test case and baseline case. All other parameters of the testbed remained fixed over the course of testing and are summarized in table 2. Figure 6 shows an internal view of the test case cell.

Table 2. Fixed parameters of test cells.

Feature	Description
Glazing	PPG SolarBan 70XL. visible transmittance = 64%; U-value = 0.24; Solar heat gain coefficient = 0.27.
Wall insulation	R-11 on window wall and rear wall. R-25 on side walls.
Roof insulation	R-22
HVAC	Variable air volume system with electric reheat.
Occupancy loads	Four occupant heat generators per test cell, approximately 130 W per generator, following occupancy schedule.
Plug loads	Four computers and monitors per test cell. About 0.75W/sf peak, controlled to approximate schedule in ASHRAE 90.1 user guide.
Occupancy schedule	Occupied hours 7am-7pm.

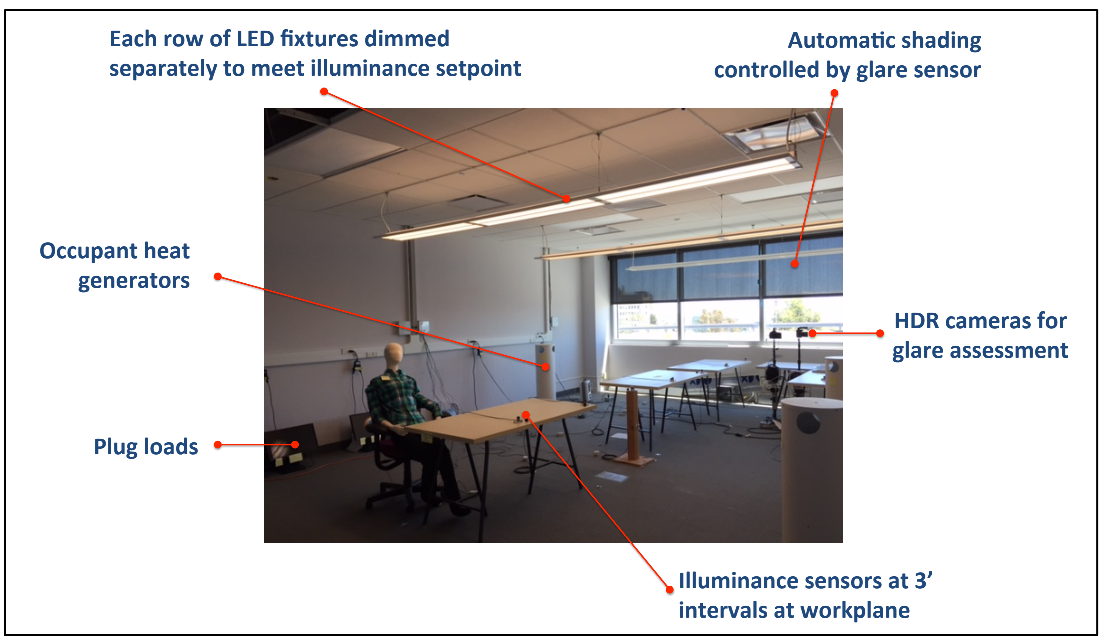

Figure 6. Internal view of test cell and key features

Adjusting for Chicago climate: ComEd is interested in savings estimates for their service territory located in northern Illinois. FLEXLAB is located in Berkeley, California, which has significantly different climate. In order to obtain an assessment of HVAC loads in Chicago climate, the internal temperature setpoints were adjusted in real time to match the indoor-outdoor temperature difference in Chicago, using the Typical Meteorological Year (TMY) temperature data for Chicago.

Visual comfort metrics: While the focus of this analysis was on energy savings, the testing also included a basic evaluation of visual comfort, including workplane illuminance and glare.

4.2 Test and Measurement Plan

FLEXLAB testing provided savings data based on controlled side-by-side testing over the course of 6 months. As mentioned above, FLEXLAB testing covered various configurations of orientation, daylight zone size, window-to-wall-ratio (WWR), and lighting type.

Table 3 describes the each of the configurations that were tested. Table 5 indicates that number of test days each month for each configuration. In general, the intent was to have each major configuration tested for at least 3 days each month. 4S and 4W were not tested in the first testing period, due to late arrival of equipment.

Table 3. Configurations tested. These settings were applied identically to the test case and baseline case.

ID	Orient.	WWR	Zone depth	Lighting type	Description
1S	S	0.4	25’	LED	‘Default’ settings for all parameters
1W	W	0.4	25’	LED	‘Default’ settings for all parameters
1Sx	S	0.4	25’	LED	1S + dimming 3rd row of lights
1Wx	W	0.4	25’	LED	1W + dimming 3rd row of lights
2S	S	0.3	25’	LED	1S with smaller windows
2W	W	0.3	25’	LED	1W with smaller windows
3S15	S	0.4	15’	LED	1S with 15’ zone
3W15	W	0.4	15’	LED	1W with 15’ zone
3S10	S	0.4	10’	LED	1S with 10’ zone
3W10	W	0.4	10’	LED	1W with 10’ zone
4S	S	0.4	25’	T-8	1S with T-8
4W	W	0.4	25’	T-8	1W with T-8
4Sx	S	0.4	25	T-8	4S + dimming 3rd row of lights
4Wx	W	0.4	25	T-8	4W + dimming 3rd row of lights
4S10	S	0.4	10’	T-8	4S with 10’ zone
4W10	W	0.4	10’	T-8	4W with 10’ zone

Table 4.Number of test days for each configuration

ID	May	June	July	August	Oct	Nov	Dec	Jan
1S	7.5	5	5	0	4	4.5	0	0
1W	6.5	6	5	0	5	4.5	0	0
1Sx	0	0	3.5	0	0.5	5.5	0	0
1Wx	0	0	4	0	0	4.5	0	0
2S	5	5	3	0	0	4	0	0
2W	3.5	4	3	0	0	3	0	0
3S15	0	4	4	3	3	0	0	0
3W15	0	5.5	2.5	0	4	0	0	0
3S10	0	0	0	4	4	0	0	0
3W10	0	0	0	3	0	0	0	0
4S	0	0	0	0	0	0	5	0
4W	0	0	0	0	0	0	5	0
4Sx	0	0	0	0	0	0	3	0
4Wx	0	0	0	0	0	0	9	2.5
4S10	0	0	0	0	0	0	0	3.5
4W10	0	0	0	0	0	0	0	5.5

Data collection

FLEXLAB offers extensive and highly granular data collection capabilities. Table 5 shows the primary data collected for this test and the associated measurement equipment. Data collection was checked on a daily basis using FLEXLAB's sMap data collection system.

Table 5. Primary data collected for test.

Metric	Measurement
Lighting power per fixture	FLEXLAB infrastructure
Shade position	MechoSystem Shade controller
Brightness at window	MechoSystem brightness sensor located inside window
Exterior horizontal illuminance	MechoSystem Shade controller
Workplane illuminance	LiCor sensors on workplane at 3' intervals from window wall
Daylight glare probability	HDR cameras oriented parallel and perpendicular to window
Plug loads	FLEXLAB infrastructure
Occupant loads	FLEXLAB infrastructure
Set point temperature	FLEXLAB infrastructure
Supply air temperature	FLEXLAB infrastructure
Return air temperature	FLEXLAB infrastructure
Thermal load	FLEXLAB infrastructure
Heating energy use	FLEXLAB infrastructure
Cooling energy use	FLEXLAB infrastructure
Ventilation energy use	FLEXLAB infrastructure

Data cleansing

The data were plotted in sMap and checked for completeness and reasonableness. Data were not used for periods that were known to have measurement issues and periods when the test cells were being reconfigured.

Data analysis

The primary metrics of interest were:

- Lighting energy savings – calculated from the lighting power measurements;
- Thermal load savings – calculated from thermal load measurements;
- HVAC energy savings – calculated from thermal load savings and equipment efficiency assumptions for various equipment scenarios;
- Workplane illuminance – profiles generated from illuminance measurements;
- Daylight glare probability – profiles generated from DGP data.

4.3 Lighting Savings – Test Period

Figures 7-22 present the lighting energy savings for each configuration for each hour (blue), day (green) and over the multi-day test period (red) for each configuration. The lighting savings are calculated as a percentage reduction in lighting energy use of the test case relative to the baseline case. Table 6 provides a summary of the savings for each configuration.

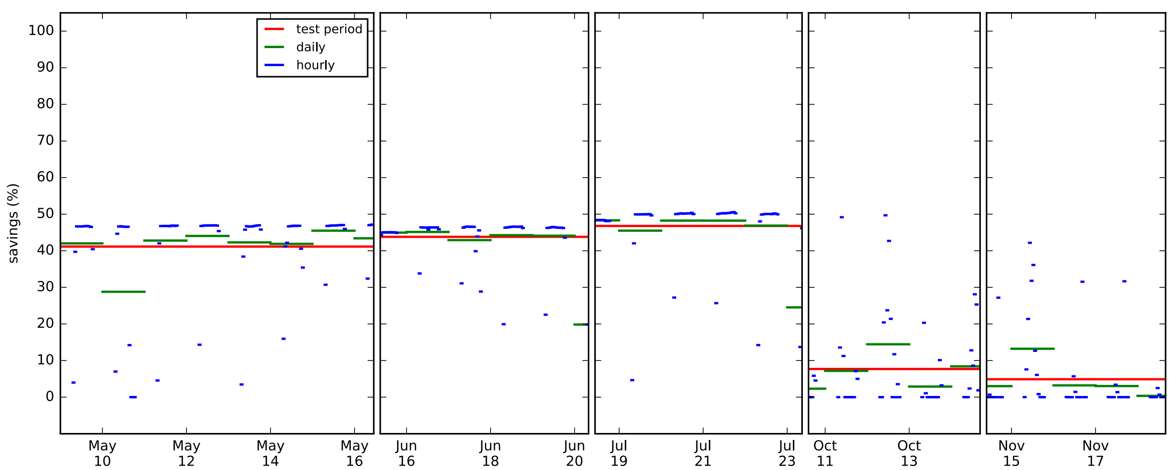

Figure 7. Lighting energy savings for configuration 1S (Full zone, South, Normal WWR)

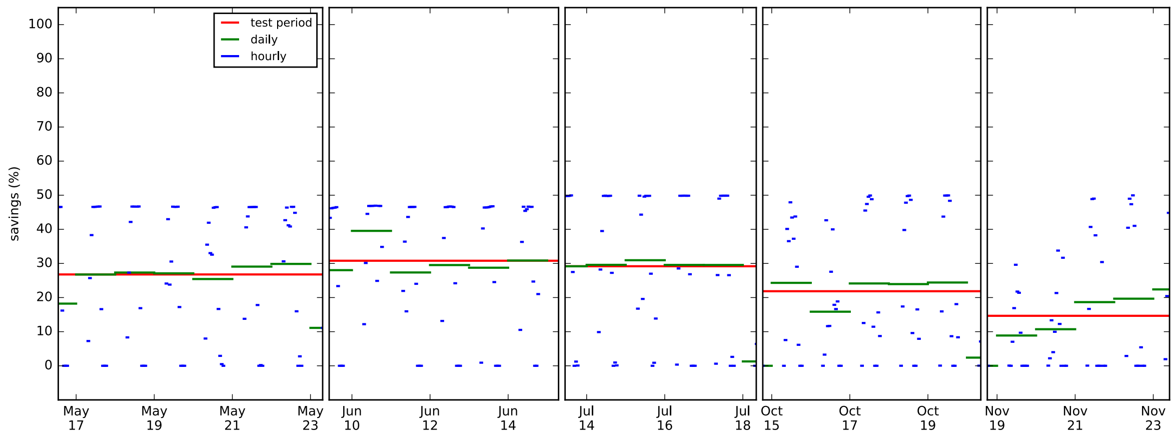

Figure 8. Lighting energy savings for configuration 1W (25', West, Normal WWR)

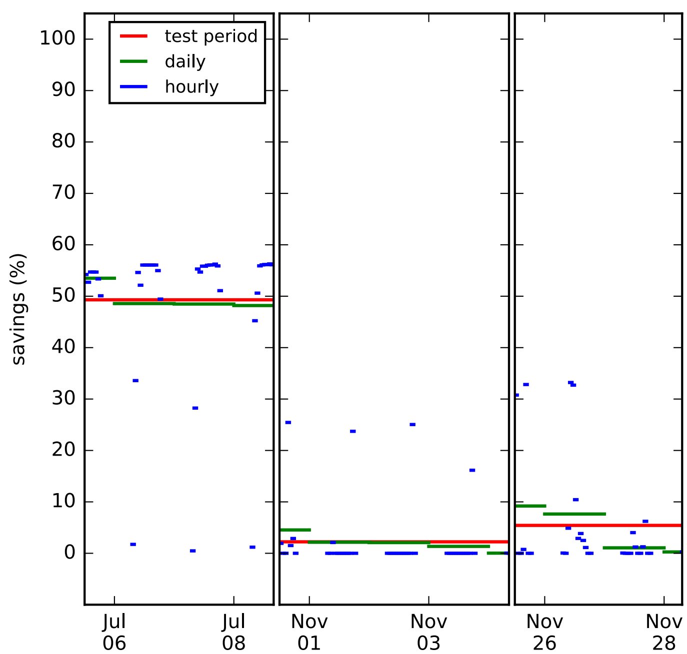

Figure 9. Lighting energy savings for configuration 1Sx (25', South, Normal WWR, Rear row dim)

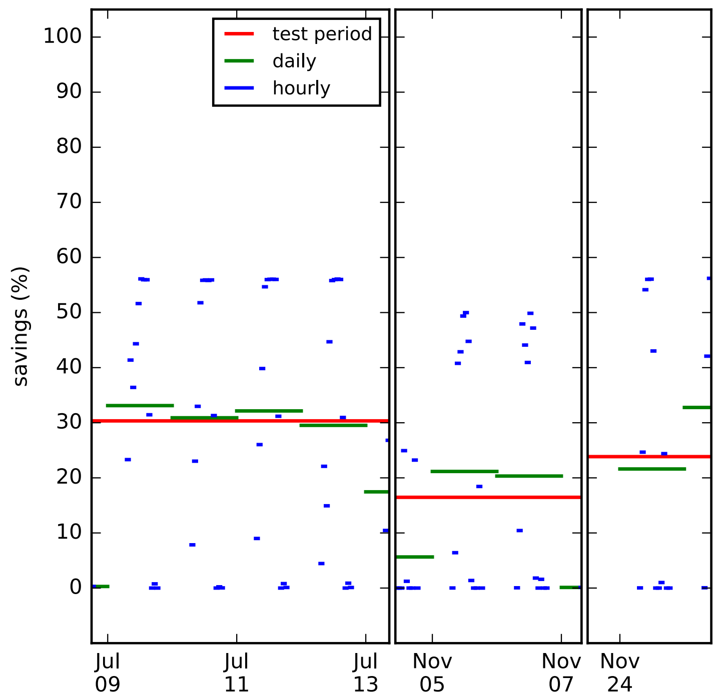

Figure 10. Lighting energy savings for configuration 1Wx (25', West, Normal WWR, Rear row dim)

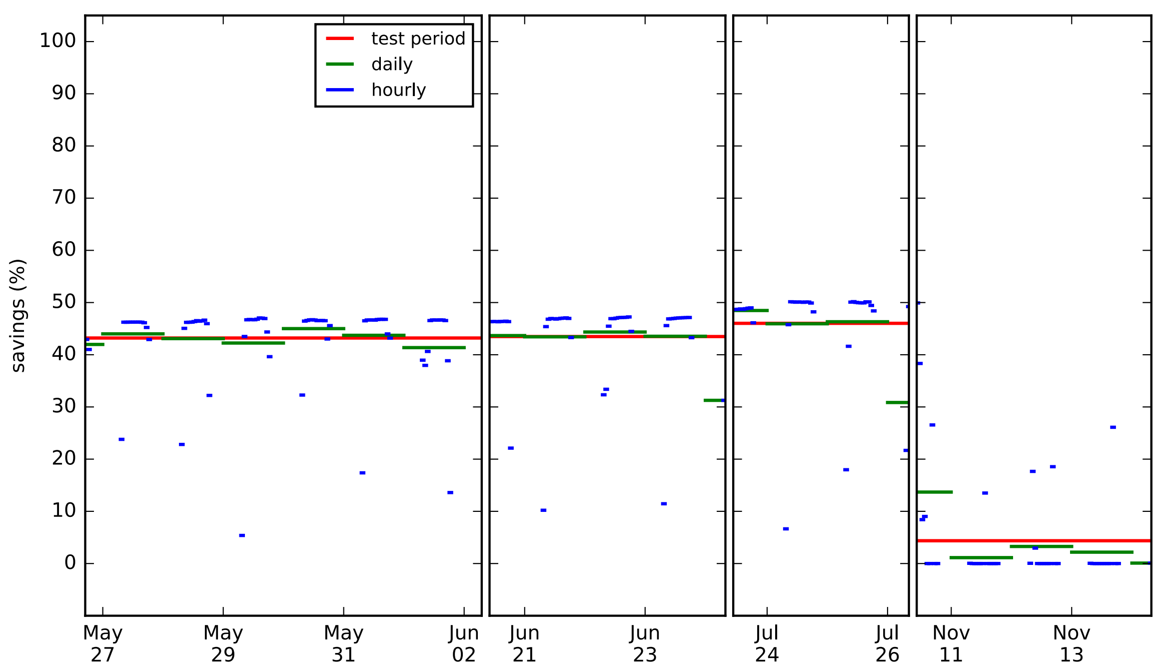

Figure 11. Lighting energy savings for configuration 2S (25', South, Small WWR)

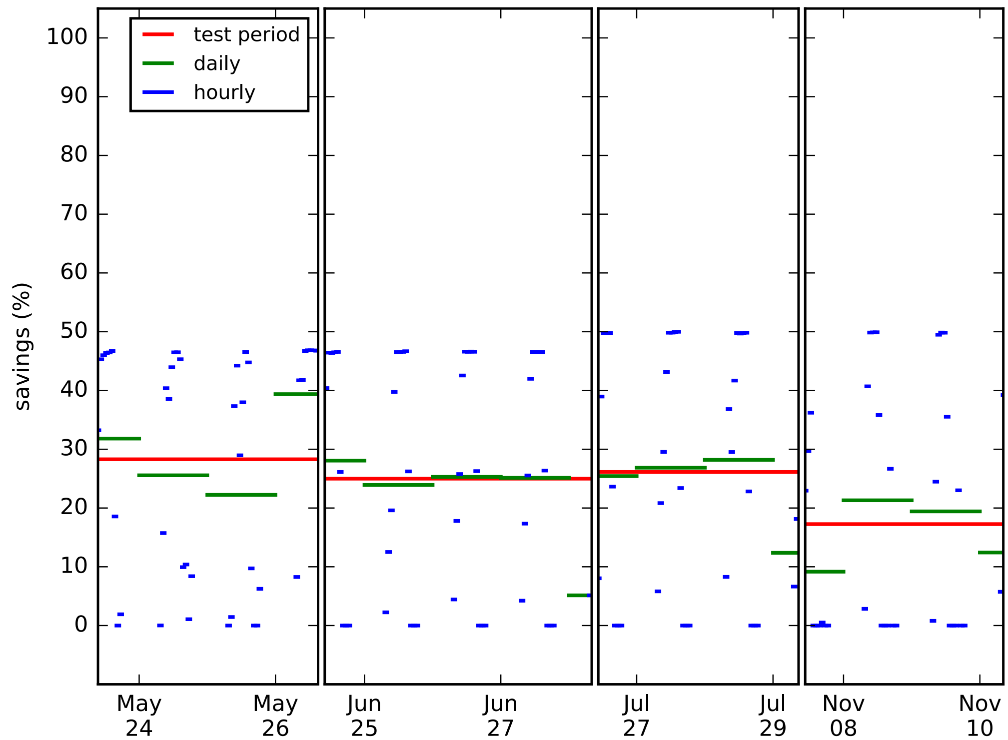

Figure 12. Lighting energy savings for configuration 2W (25', West, Small WWR)

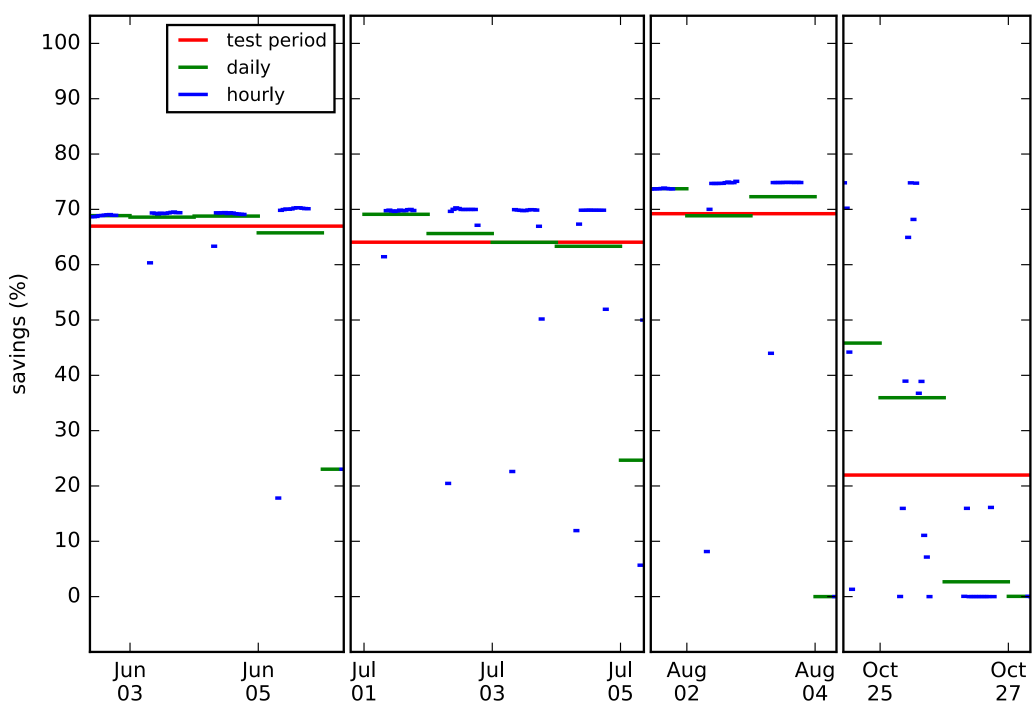

Figure 13. Lighting energy savings for configuration 3S15 (15' zone, South, Normal WWR)

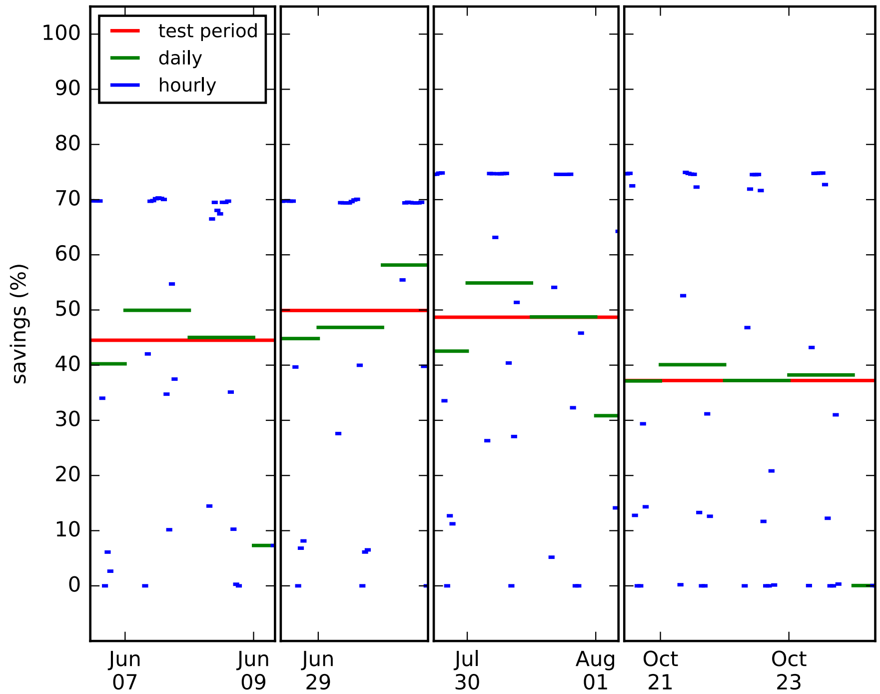

Figure 14. Lighting energy savings for configuration 3W15 (15' zone, West, Normal WWR)

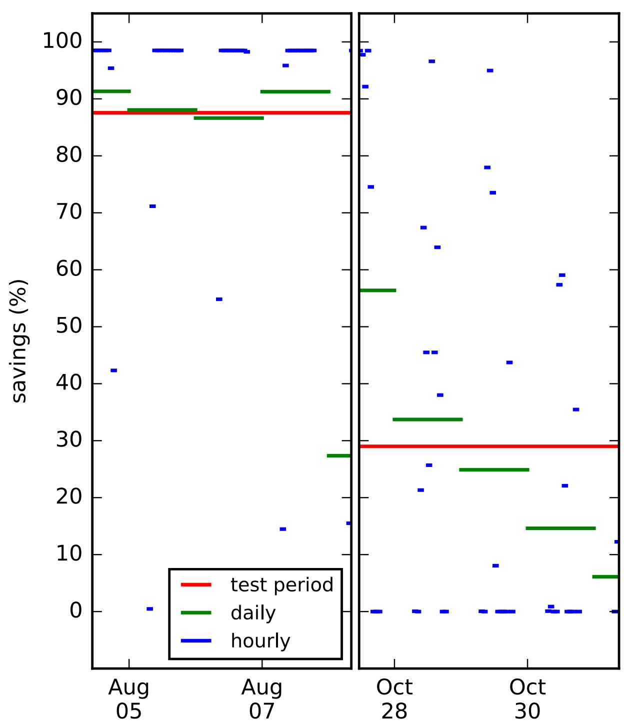

Figure 15. Lighting energy savings for configuration 3S10 (10' zone, South, Normal WWR)

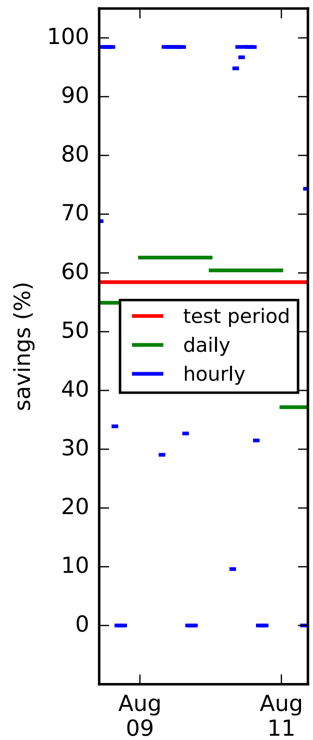

Figure 16. Lighting energy savings for configuration 3W10 (10' zone, West, Normal WWR)

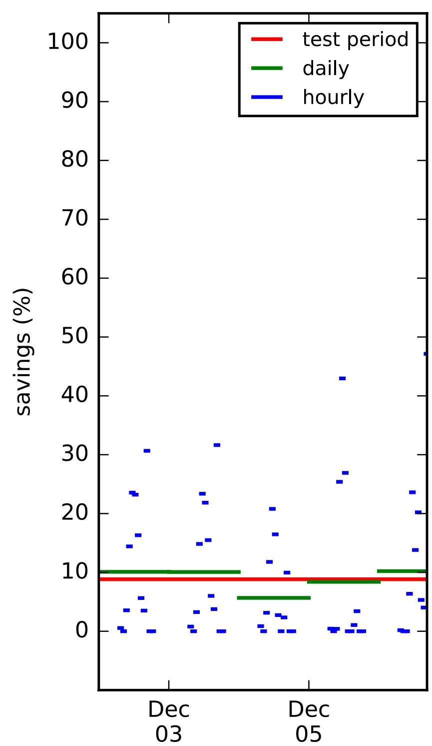

Figure 17. Lighting energy savings for configuration 4S (25' zone, South, Normal WWR, T8)

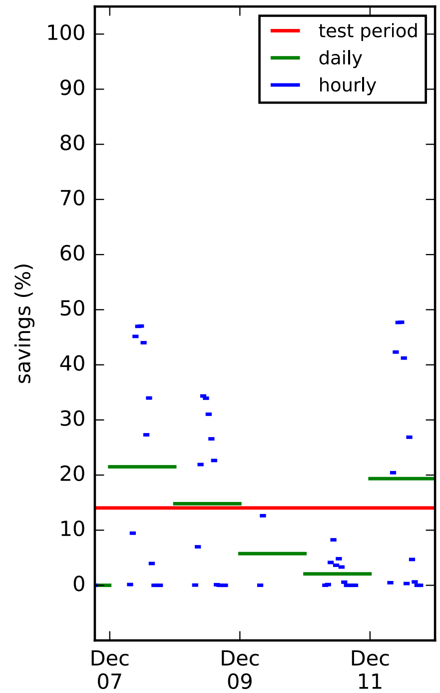

Figure 18. Lighting energy savings for configuration 4W (25' zone, West, Normal WWR, T8)

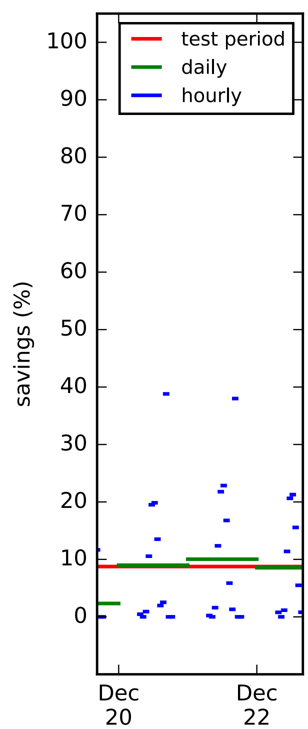

Figure 19. Lighting energy savings for configuration 4Sx (25' zone, South, Normal WWR, T8, rear row dim)

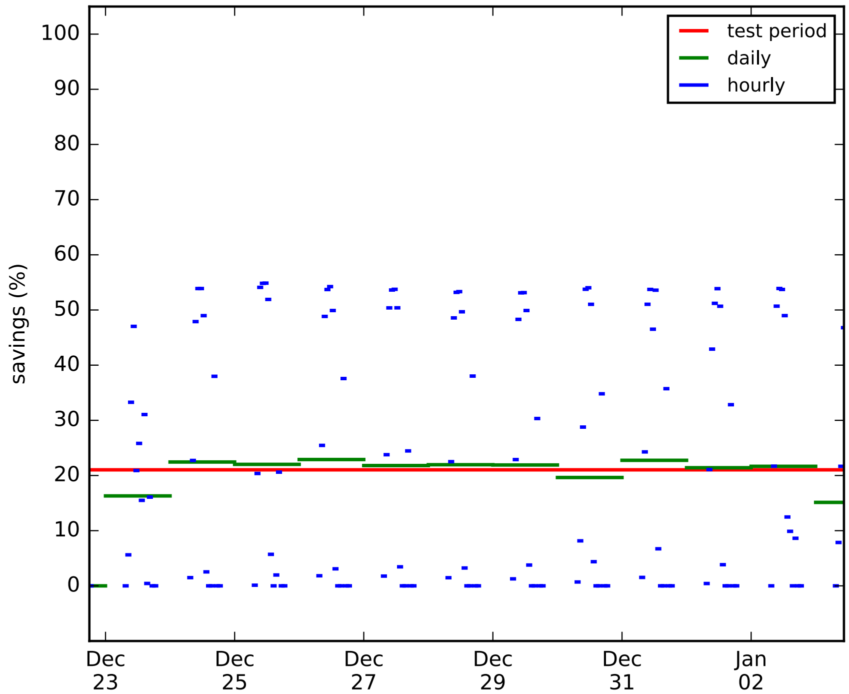

Figure 20. Lighting energy savings for configuration 4Wx (25' zone, West, Normal WWR, T8, rear row dim)

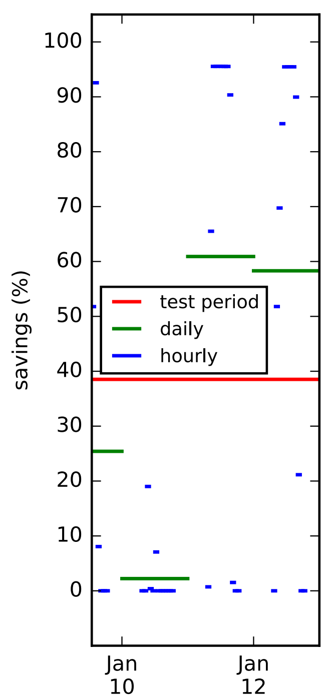

Figure 21. Lighting energy savings for configuration 4S10 (10' zone, South, Normal WWR, T8)

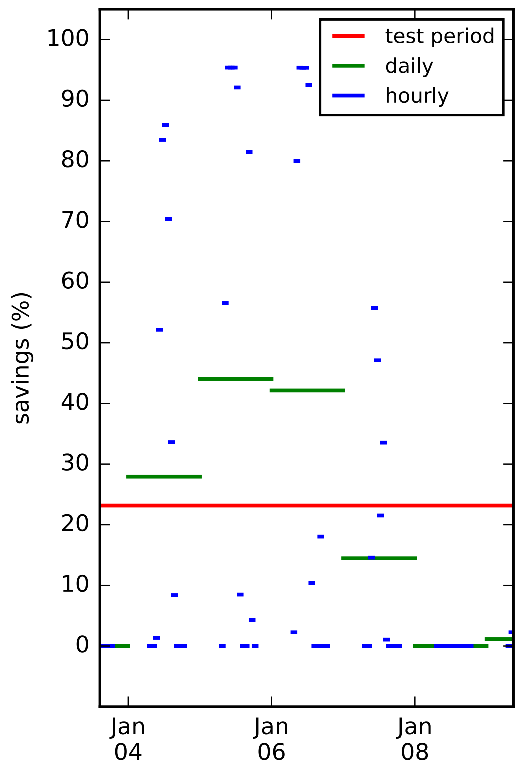

Figure 22. Lighting energy savings for configuration 4W10 (10' zone, West, Normal WWR, T8)

Table 6. Lighting savings over test period for each configuration.

ID	Description	Summer Test Period (May – Aug)		Winter Test Period (Oct – Jan)	
		Length (days)	**Savings (%)**	**Length (days)**	**Savings (%)**
1S	25', South, Normal WWR	17	44	8.5	6
1W	25', West, Normal WWR	17	29	9.5	19
1Sx	25', South, Normal WWR, Rear row dim	3.5	49	6.5	4
1Wx	25', West, Normal WWR, Rear row dim	4	30	4.5	19
2S	25', South, Small WWR	13	44	4	4
2W	25', West, Small WWR	10	26	3	17
3S15	15' zone, South, Normal WWR	11	66	3	22
3W15	15' zone, West, Normal WWR	8	48	4	37
3S10	10' zone, South, Normal WWR	4	88	4	29
3W10	10' zone, West, Normal WWR	3	58	0	

4S	25', South, Normal WWR, T8	0		5	9
4W	25', West, Normal WWR, T8	0		5	14
4Sx	25', South, Normal WWR, T8, Rear row dim	0		3	9
4Wx	25', West, Normal WWR, T8, Rear row dim	0		11.5	21
4S10	10', South, Normal WWR, T8	0		3.5	39
4W10	10', West, Normal WWR, T8	0		5.5	23

Daily profiles were also analyzed to identify how savings varied with different sky conditions. As an illustrative example, Figure 23 shows two adjacent days in which the savings varied from 41% to 45% just due to variable sky conditions, all other parameters being identical.

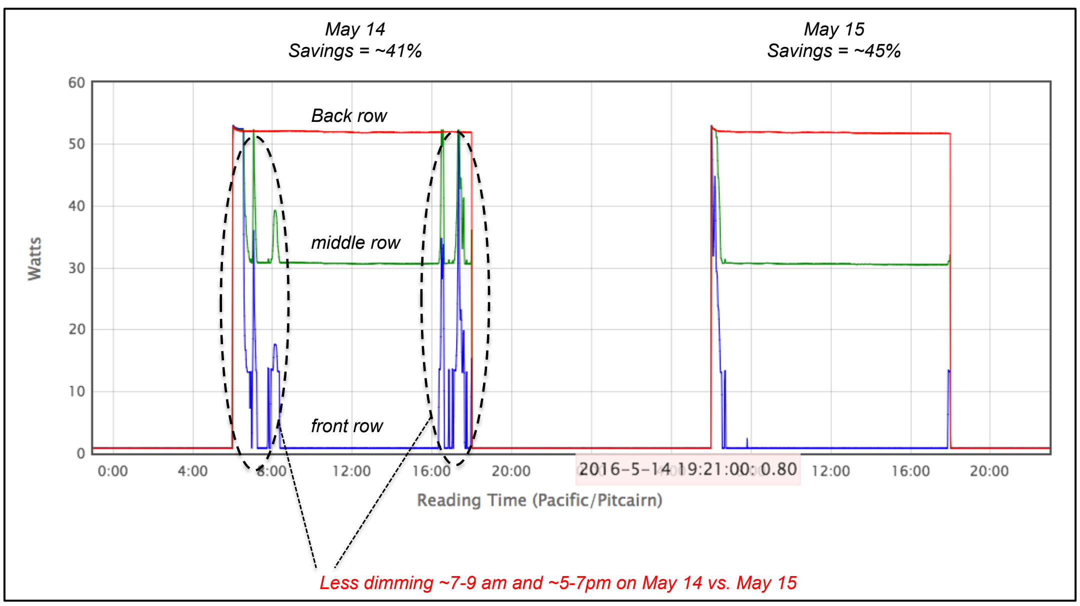

Figure 23. Lighting energy profile for May 14-15 2016 for configuration 1S.

Key observations from the test period results:

- Savings are significant but can vary widely over the course of the year, due to change in sun angles and associated deployment of shades. In summer, savings are higher for south facing configurations than west-facing configurations all other parameters being equal. Analysis of the shade operation and solar conditions indicate that the shades are deployed for longer periods in the west facing orientation in the afternoons to minimize direct solar radiation, resulting in the lights being turned on for longer periods (Figure 24). Also, the west orientation has less dimming in the morning. In winter, savings in the south facing configurations are generally very low because low sun angles cause the shades to be deployed during most daylight hours. Savings for the west orientation in winter are not as low as the south because there is no direct sun on the façade during the morning hours, allowing shades to be retracted during those hours.

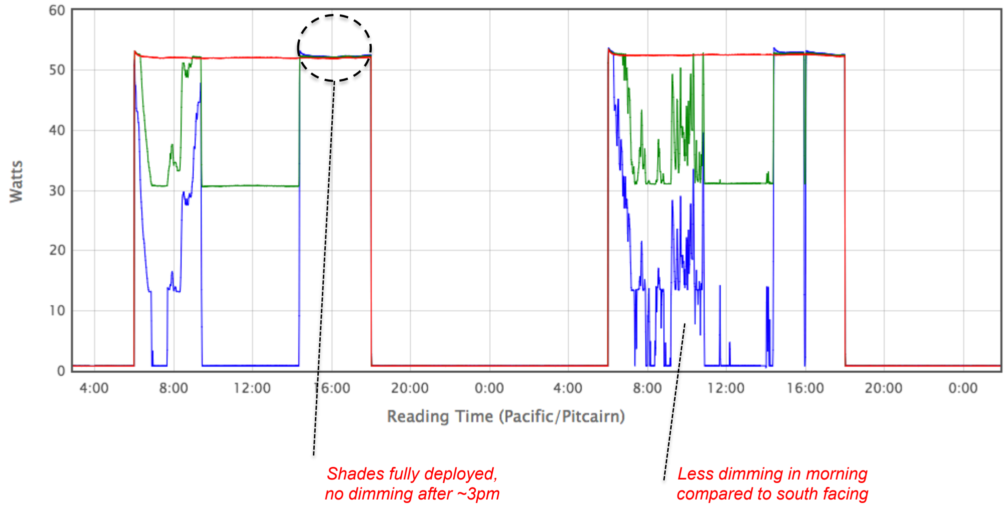

Figure 24. Lighting energy profiles for two days in May for configuration 1W.

- As expected the light fixtures closer to the window show greater savings.
- As expected, savings are higher for smaller zones closer to the window wall. This can be seen by comparing configurations 1S, 1S15, and 1S10 which represent 25', 15', and 10' zones for south orientation with all other parameters being equal.
- Reducing the window-to-wall-ratio from 0.4 to 0.3 has a small impact on daylight penetration and lighting energy savings. Figure 25 shows illuminance profiles for sensors located at 3' intervals from the window wall. The windows size was changed between 8:00am and 8:10 am. The reduction in illuminance is noticeable. However, the net effect on lighting savings is small (See again Table 6).
- For configurations with the 25' zone, dimming the rear row of lights appears to have minimal effect on increasing savings.

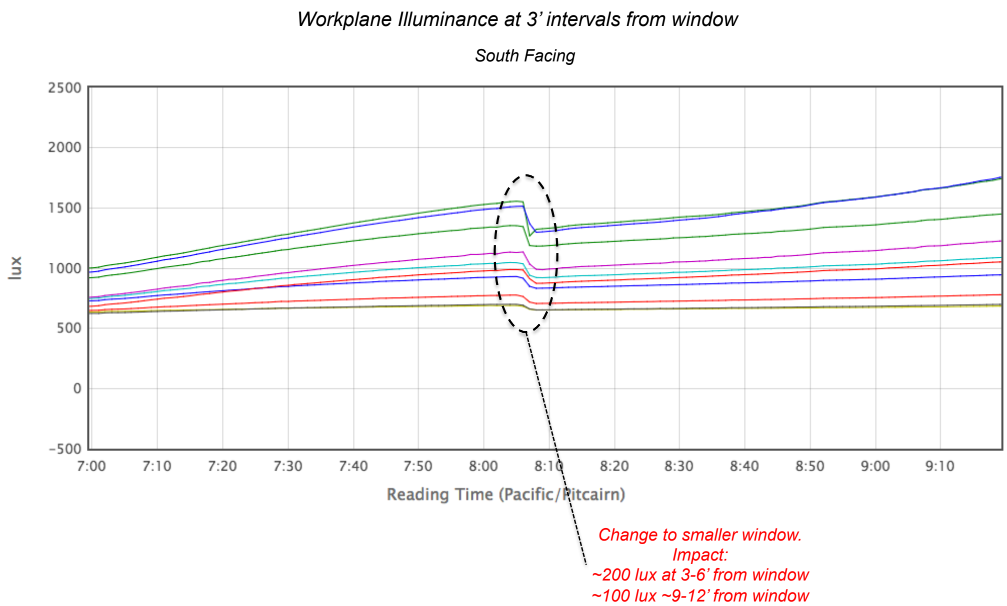

Figure 25. Impact of reducing window-to-wall ratio from 0.4 to 0.3.

Figure 26 shows the setpoint tracking to emulate the indoor-outdoor temperature difference for Chicago TMY climate data. It shows that both test cells were able to maintain very good tracking over a wide range of indoor setpoints, from 10C (50F) to 33C (91F). However, analysis of the HVAC load data showed that with LED systems the change in HVAC loads due to dimming is minimal and not observable with the accuracy range of FLEXLAB load monitoring.

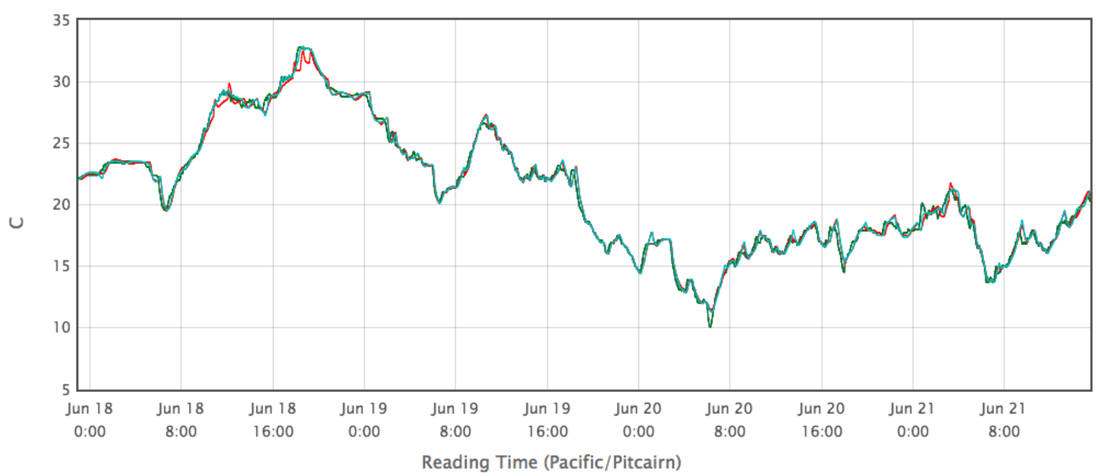

Figure 26. Indoor temperature setpoint tracking to emulate Chicago TMY climate. Red line is setpoint. Light and dark green lines are actual indoor temperatures for test cells.

4.4 Lighting Savings - Annualized

We used a regression-based approach to determine annual lighting savings based on the measurement period savings. Separate regression equations were determined for 1S and 1W configurations.

Savings are a function of shade deployment and daylight availability. Shade deployment is driven by sun position and horizontal radiation. In general lighting savings increase with daylight availability, unless shades are deployed to control for sun penetration and glare.

We first developed a series of bivariate charts to analyze the relationship between lighting savings and global horizontal illuminance, global horizontal radiation, vertical illuminance, solar azimuth and solar altitude. We also explored the impact of using different time steps – 5 minutes, 10 minutes, 60 minutes, and 24 hours – for the analysis.

Based on the bivariate analysis, we explored various forms for the regression equation. The regression model which provided the best fit computes lighting savings on any given day as a function of solar altitude and horizontal radiation. The model has a constant offset, two piecewise linear terms for altitude (for altitude <= 53 degrees and altitude > 53 degrees), and a linear term for horizontal radiation. Table 7 lists the variables and their and coefficient values for each model.

Table 7. Regression model variables and coefficients for configuration 1S

Variable	1S model coefficient value	1W model coefficient value
S_i (dependent variable): % lighting energy savings on day i from 7am to 7pm	-	-
Constant	-3.010	13.01
A_i: peak solar altitude on day i	0.2087 (alt <= 53 degrees) 1.7280 (alt > 53 degrees)	0.3878 (alt <= 53 degrees) -0.08165 (alt > 53 degrees)
R_i: sum of global horizontal radiation on day i between 7am to 7pm when it is below 50 kBtu/hr-sf	0.05196	-0.06622

The threshold values for R_i (50 kBtu/hr-sf) and altitude (53 degrees) are in effect proxies for the point at which shades get deployed and the savings change significantly.

Figures 27 and 28 compare predicted to measured values for 1S and 1W respectively and also show the R^2 values for both cases.

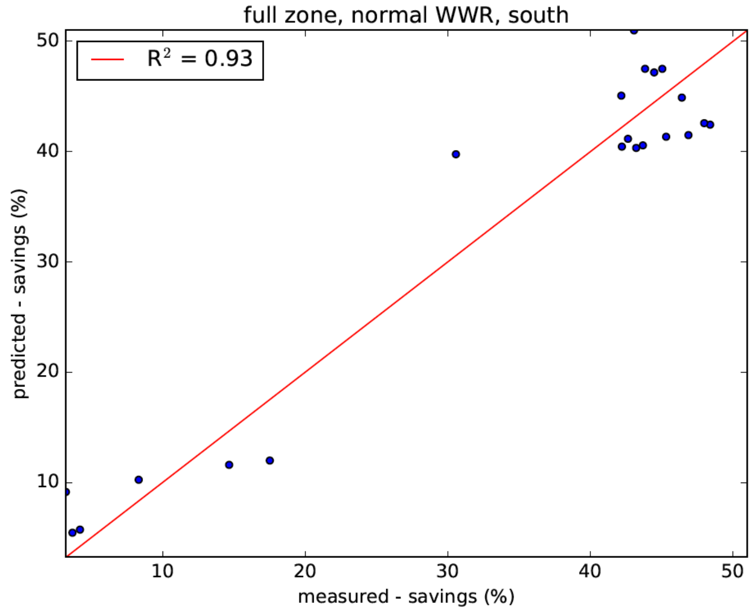

Figure 27. Comparison of predicted and measured values of daily savings for configuration 1S.

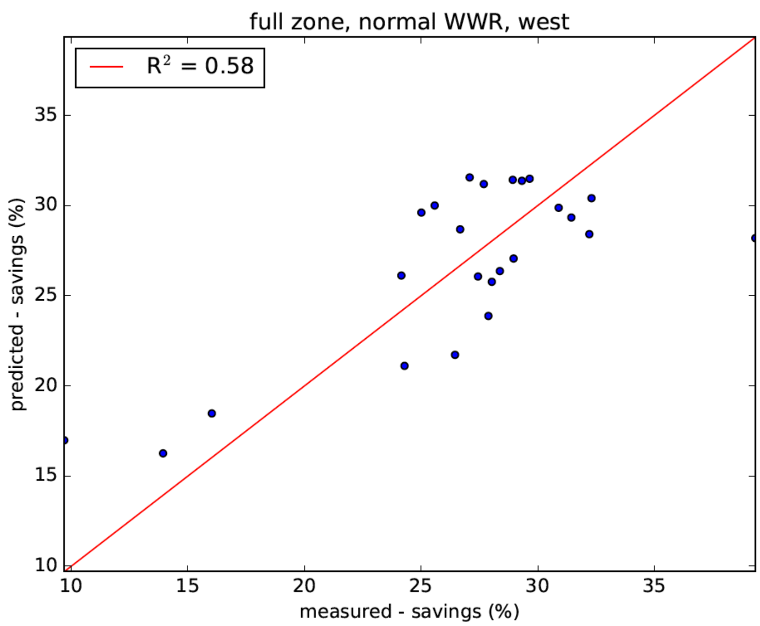

Figure 28. Comparison of predicted and measured values of daily savings for configuration 1W.

We then calculated annual savings by calculating savings for each day of the year driving the regression equation with TMY (Typical Metrological Year) data for A_i and R_i for each day. We did this using TMY data for Oakland (to represent Berkeley) and Chicago.

Figure 29 and 30 show the daily and annual lighting savings for Oakland for configurations 1S and 1W respectively. Figures 31 and 32 show the same for Chicago. The figures also show the savings range for the 95% confidence level.

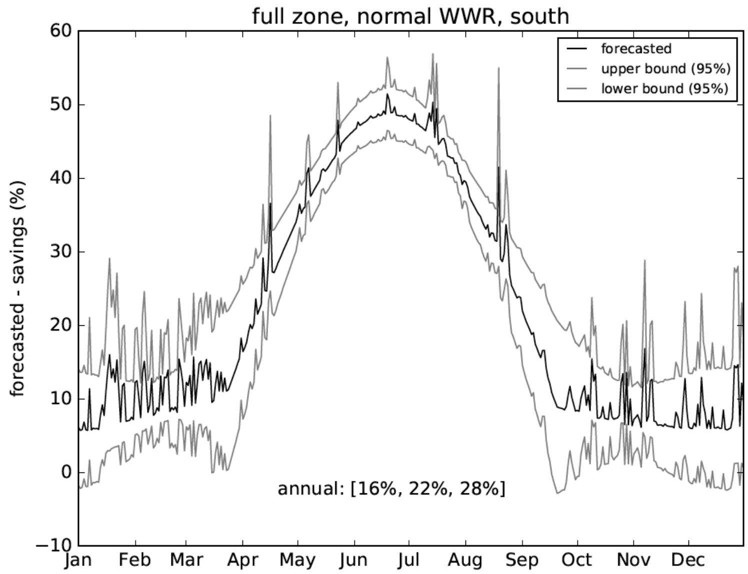

Figure 29. Annual lighting savings for configuration 1S using Oakland TMY data

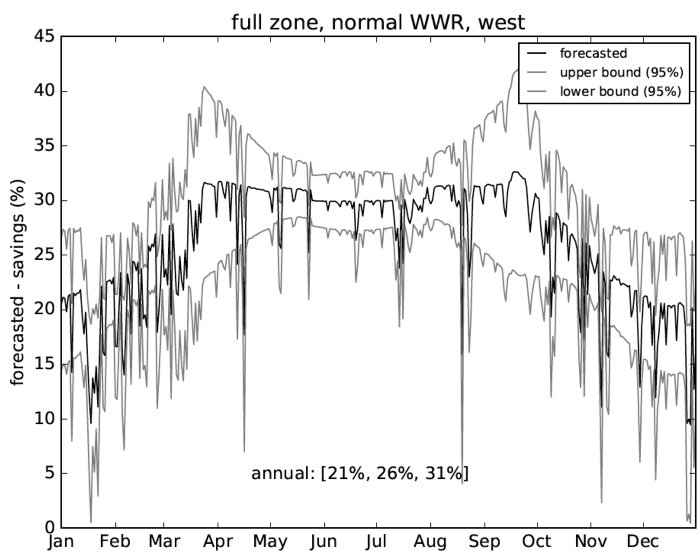

Figure 30. Annual lighting savings for configuration 1W using Oakland TMY data

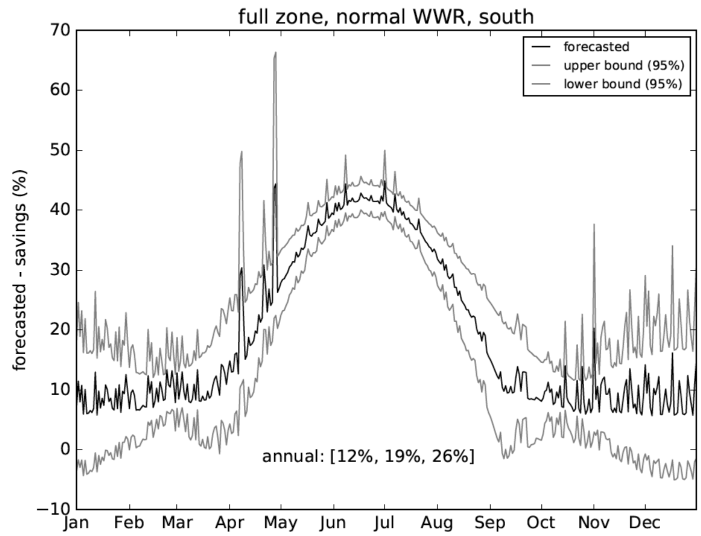

Figure 31.Annual lighting savings for configuration 1S using Chicago TMY data

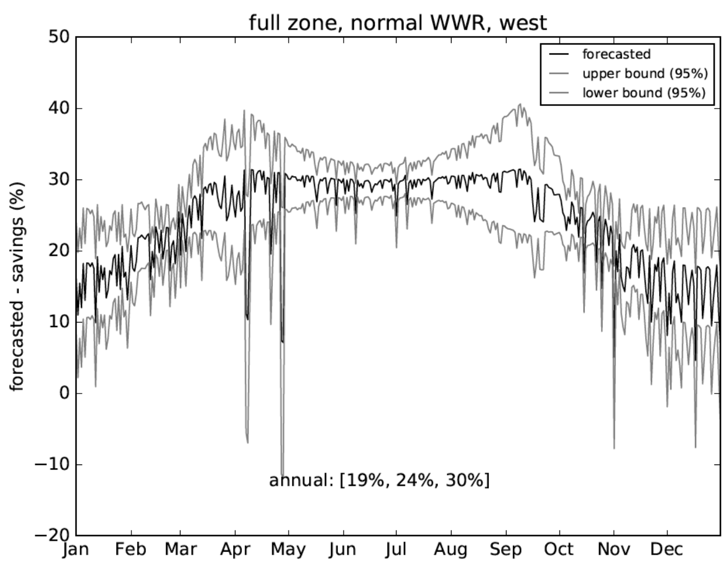

Figure 32.Annual lighting savings for configuration 1W using Chicago TMY data

For both 1S and 1W, savings are significantly lower in winter months. As explained earlier this because lower sun angles cause the shade to be deployed much more of the time than in summer. Nevertheless, the annual lighting savings are significant. For Chicago:

- South orientation shows a mean of 19% annual savings, with a range of 12-26% (at 95% confidence).
- West orientation shows a mean of 24% annual savings, with a range of 19-30% (at 95% confidence).

It should also be noted that more aggressive dimming strategies would result in higher savings. As noted earlier, we intentionally used 'standard practice' settings for the shades and dimming, in order to reflect broad deployment in the context of a utility program.

It is important to reiterate that these savings are *exclusively attributable to automated shading and dimming* and will be additional to savings from lighting upgrades. In particular, these savings *do not include the savings from tuning* i.e. the savings are relative to a tuned baseline.

4.5 Whole Building Savings Estimates

Whole building (WB) savings estimates include lighting energy savings as well as HVAC energy savings (or penalties). It is difficult to generalize WB savings because they are highly dependent on two key building features: impacted area (i.e. the % of total floor area that is impacted by shading and dimming) and HVAC system type. Buildings with smaller impacted areas will naturally have smaller WB savings all other things being equal. HVAC energy savings can vary quite differently for different HVAC system types and efficiencies for the same reduction in thermal load.

We estimated WB savings for four building types - large and medium office; primary school, secondary school – using the DOE reference building EnergyPlus simulation models. Table 8 summarizes the key features of these models.

Table 8.Key features of reference buildings

Reference building	Gross floor area (sf)	% Area impacted	HVAC system type
Large Office	498,588	42%	Central electric chiller and gas boiler. Hot water reheat.
Medium Office	53,628	62%	Packaged units with electric reheat.
Primary School	73,959	59%	Packaged units with gas heating
Secondary School	210,886	39%	Air cooled chillers and packaged units with gas heating

We used the following approach to determine WB savings using the reference model simulations in conjunction with FLEXLAB measurement results:

- Simulate reference models with baseline and retrofitted system.
- Calculate HVAC savings ratio from simulation results. HVAC savings ratio is the HVAC energy saved per unit of lighting energy saved. Separate ratios are calculated for electricity and gas.
- Apply FLEXLAB lighting savings percentages to the baseline lighting energy to determine lighting savings. The lighting savings percentages from the FLEXLAB tests were incremented to account for savings from institutional tuning, assuming the untuned baseline is 30% higher than the tuned baseline[1].
- Apply HVAC savings ratio to determine the adjusted HVAC savings.
- Calculate the total WB savings and WB savings percentage from the lighting and HVAC savings.

Table 9 presents the results.

[1] The extent of savings from tuning varies based on the extent to which the lighting is right-sized and installation practices. The LBNL meta analysis (Williams et al.) showed institutional savings of 36% (N=11). More recent anecdotal evidence shows savings around 30%. We used a more conservative estimate for this analysis.

Table 9. Whole building savings percentages for reference buildings

Reference building	Whole Building Lighting Svg %	Whole Building Total Elec Svg %	Whole Building Site Energy Svg %
Large Office	16%	5.0%	2.6%
Medium Office	22%	4.5%	3.5%
Primary School	20%	9.0%	4.8%
Secondary School	14%	6.2%	2.7%

4.6 Visual Comfort Analysis

Our visual comfort analysis was comprised of two primary metrics: workplane illuminance (lux) and glare (daylight glare probability). Below we discuss the measurement approach and results for each metric.

4.6.1 Illuminance

In the FLEXLAB cells where the reference and test lighting and shade system packages are installed, we monitor average illuminance at the task plane (2.5') from an array of photometric sensors (Figure 33). Most lighting design criteria are centered around recommendations for illuminance levels at the task plane.

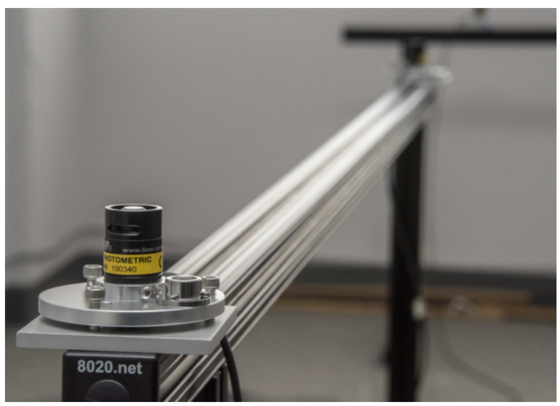

Figure 33. Licor photometric sensor

Licor photometric sensors are arranged in a monitoring array in the test cells to measure light levels in high-time resolution (1-min. average illuminance) at selected locations throughout the test space (Figures 34 and 35). The FLEXLAB data acquisition system records and reports these values in near-real time.

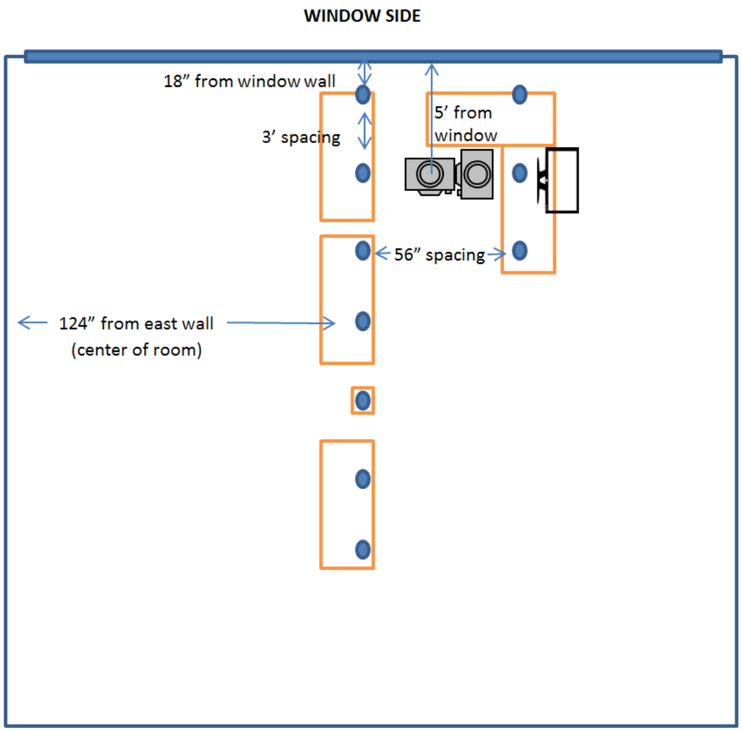

Figure 34. Licor photosensor configuration. Blue dots indicate location of the Licor photosensors, showing them arrayed primarily along one axis to measure illuminance at different depths within the cell. Camera icons denote location of HDR camera set-ups for DGP data collection.

Figure 35. Photo of Licor photosensor array on desks in test cell

Figures 36 to 41 show the range of illuminance at different depths from the window during the measurement period, for selected configurations. As expected, sensors closer to the window show higher illuminance values. The plots show that the test system maintained illuminance at or above 500 lux throughout the measurement period, as intended.

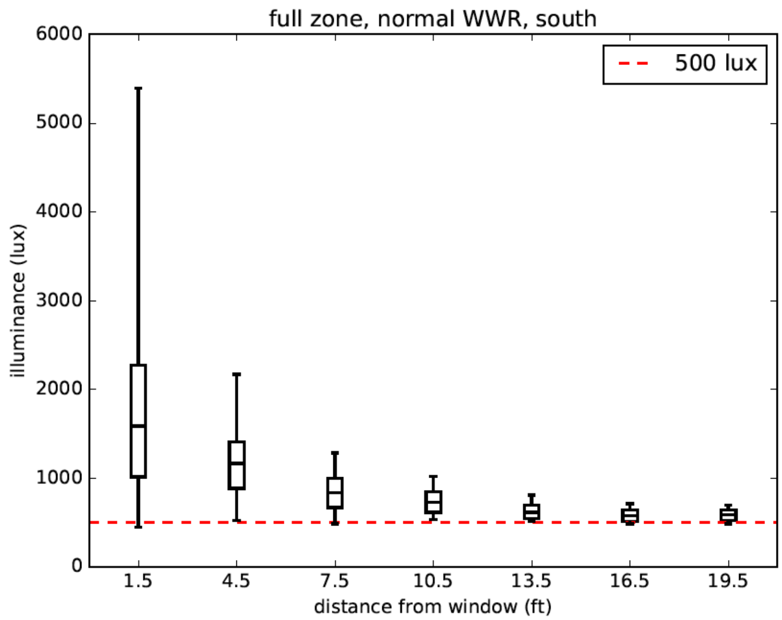

Figure 36. Illuminance ranges for configuration 1S. Box plot markers are for 5th, 25th, 50th, 75th and 95th percentiles.

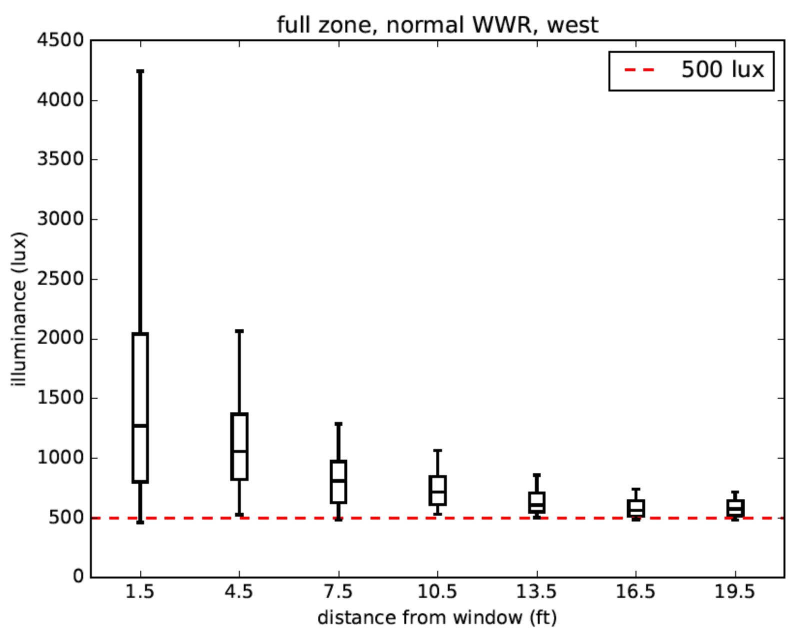

Figure 37. Illuminance ranges for configuration 1W. Box plot markers are for 5th, 25th, 50th, 75th and 95th percentiles.

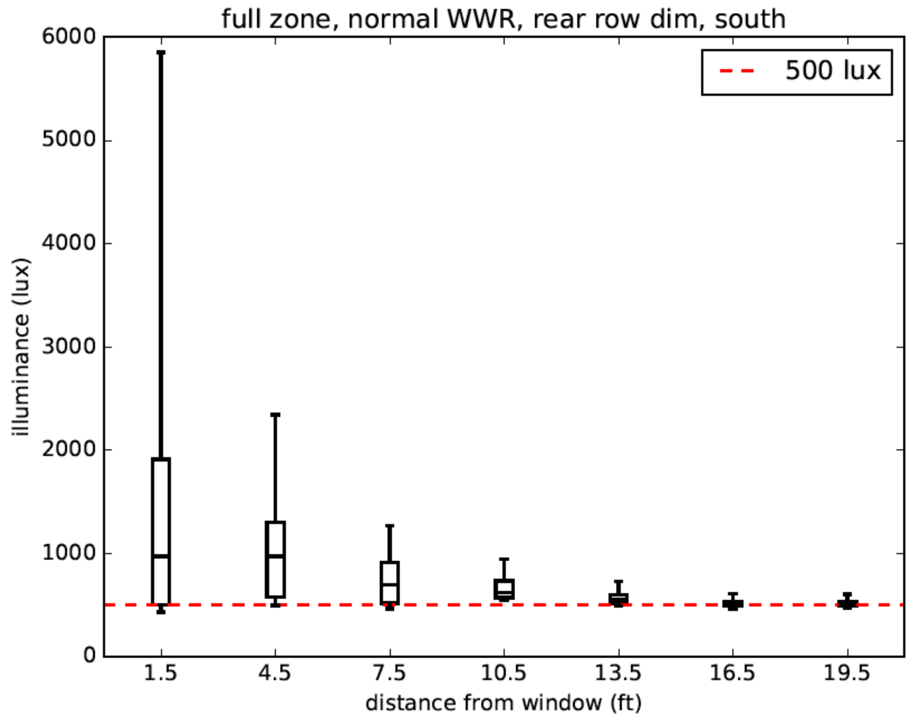

Figure 38. Illuminance ranges for configuration 1Sx (rear row dimming). Box plot markers are for 5th, 25th, 50th, 75th and 95th percentiles.

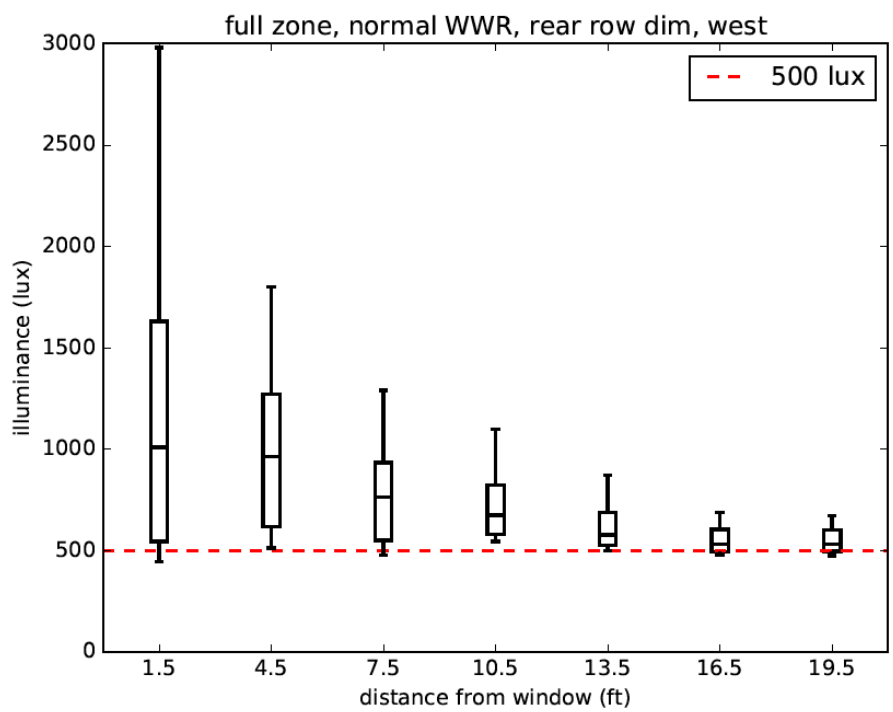

Figure 39. Illuminance ranges for configuration 1Wx (rear row dimming). Box plot markers are for 5th, 25th, 50th, 75th and 95th percentiles.

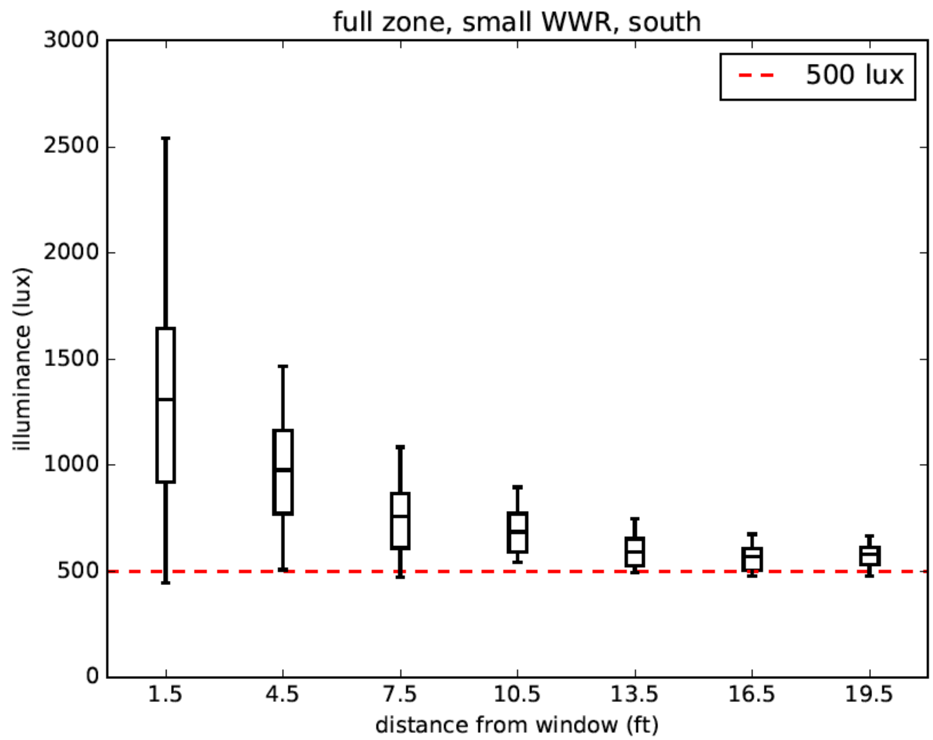

Figure 40. Illuminance ranges for configuration 2S (0.3 WWR). Box plot markers are for 5th, 25th, 50th, 75th and 95th percentiles.

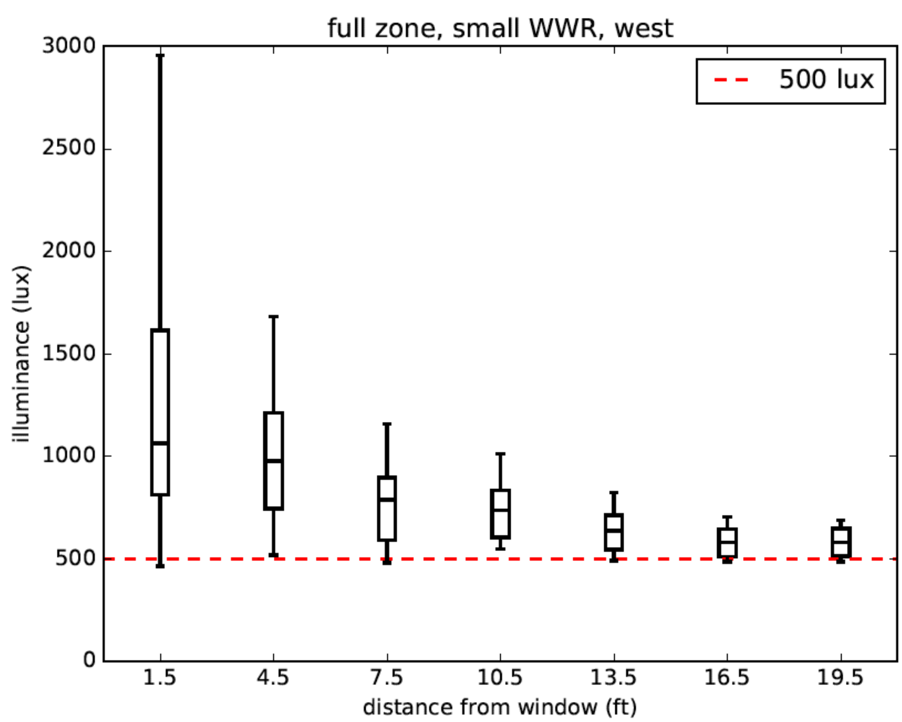

Figure 41. Illuminance ranges for configuration 2W (0.3 WWR). Box plot markers are for 5th, 25th, 50th, 75th and 95th percentiles.

4.6.2 Glare

Glare was characterized using the daylight glare probability (DGP) index, which relies on high resolution, field-of-view high dynamic range (HDR) luminance images to assess glare. The HDR camera packages were located at select positions within the test cell to characterize surface luminances and DGP through time at viewing angles consistent with those that could be experienced by an office worker in the space. Typically, these were set up in "worst-case" scenarios, nearer the window wall and either facing the window or perpendicular to the window (Figure 42). The premise of measuring glare at these locations is that if a lighting and shade system meets minimum criteria for DGP at these locations, it is likely that those criteria are met elsewhere in the space as well.

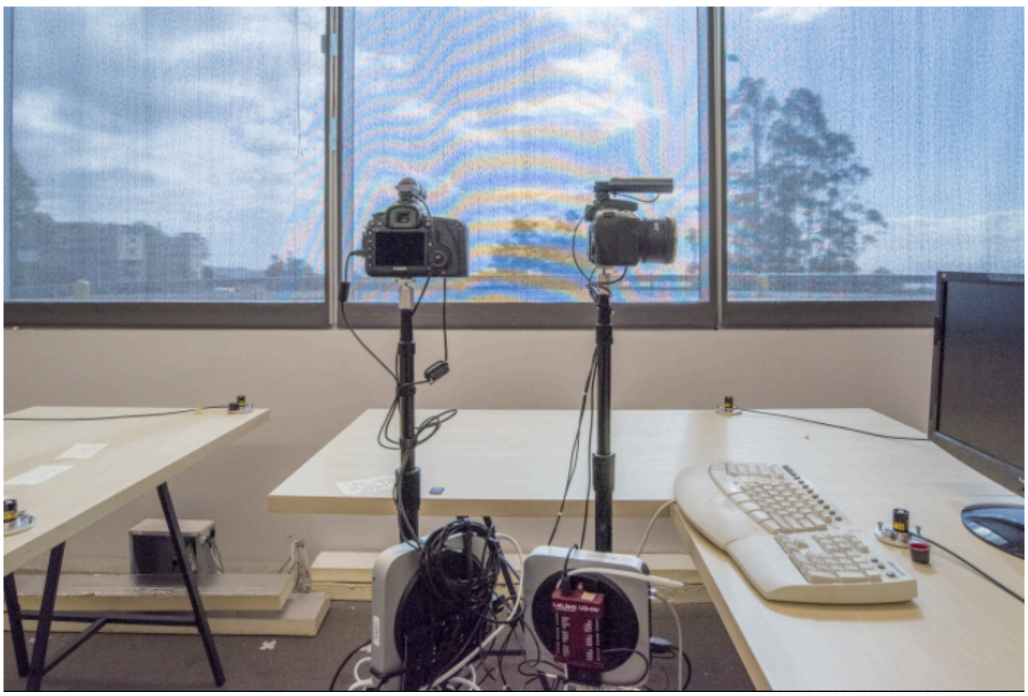

Figure 42. Photo of HDR camera, sensor, and processor packages for glare analysis in FLEXLAB

Hemispherical field-of-view luminance measurements were taken throughout each study day at five-minute intervals. Measurements were taken at seated eye height 4 ft above the floor, at locations both parallel and perpendicular to the window. The images processed for glare analysis are taken with commercial-grade digital cameras (Canon 60D) equipped with an equidistant fisheye lens (Sigma Ex 4.5 mm f/2.8) controlled by Mac CPUs. Bracketed low dynamic range (LDR) images are automatically taken with a fixed f-stop of 5.6 using in-house modified software (hdrgen). Four to seven images were taken per time interval depending on the brightness of the scene.

The *hdrgen* software compiles the LDR images into a single HDR image with the camera response function determined by the software. A vertical illuminance measurement is taken by the HDR camera setup taken adjacent to each camera's lens, immediately before and after the bracketed set of images, and used in the *hdrgen* compositing process to convert pixel data to photometric data. HDR images (Figures 43, 44) are then analyzed automatically to assess discomfort glare from daylight and identify glare sources within the field of view.

The Daylight Glare Probability (DGP) index relies on these high resolution HDR images to assess glare. The index was derived through a comprehensive statistical analysis of HDR data and subjective response in a full-scale private office testbed that was retrofit with a variety of daylighting measures (Weinold and Christoffersen 2006). DGP was calculated using the *evalglare* software (Weinold 2009) and default software settings. DGP does not reflect the magnitude of glare perceived by the observer. Instead it gets around the problem of person-to-person variability in response to perceived glare by estimating the probability that a person is "disturbed" by glare (the DGP formulation defined "disturbed" based on the subject rating the daylight glare source to be "disturbing" or "intolerable"). Wienold derived a method to account for the frequency of glare over a time period, where within a defined category of comfort, 3-5% exceedance of a threshold limit is allowed. Glare ratings ranging from "imperceptible" to "intolerable" were related to DGP values in a descriptive one-way analysis of the study's user assessment data.

Figure 43. Time-stamped image from an HDR camera set-up positioned perpendicular to the window wall. The calculated DGP for this time is denoted in the lower right corner, and the HDR camera facing the window wall is visible in the center of the image.

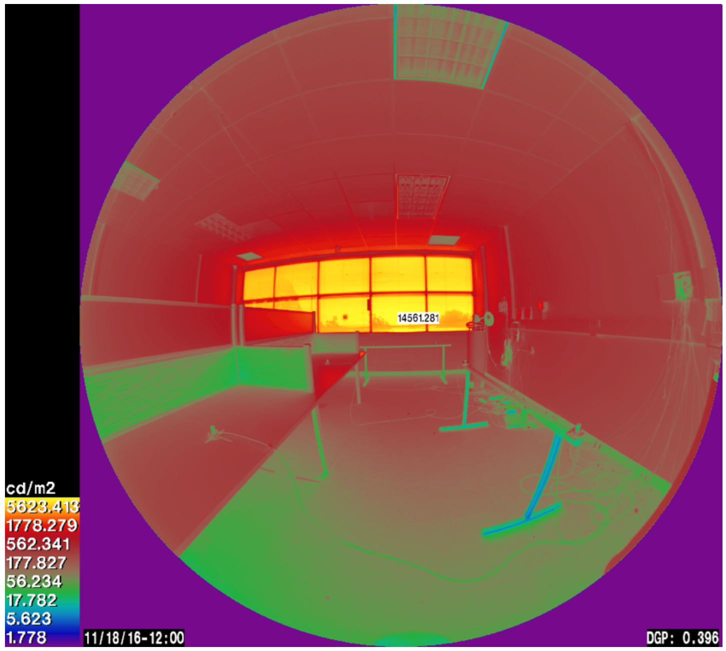

Figure 44. Example of a false-color image from the HDR camera set-up that provides a luminance map of the camera's viewing angle. This particular HDR camera is positioned at the rear of the test cell, facing the window wall, with the pixel of highest luminance labeled.

Figures 45-48 show the DGP for various configurations. The data show that the test system (cell B) maintained daylight glare probability (DGP) within acceptable levels. For the view parallel to the window plane, DGP was imperceptible almost all the time. For the view perpendicular to the window plane, DGP was occasionally in the perceptible range and very rarely in the disturbing or intolerable range. For the baseline case (cell A) there were significant periods where DGP was in the disturbing or intolerable range because the venetian blinds were in a fixed horizontal position, allowing for direct sunlight at lower sun angles.

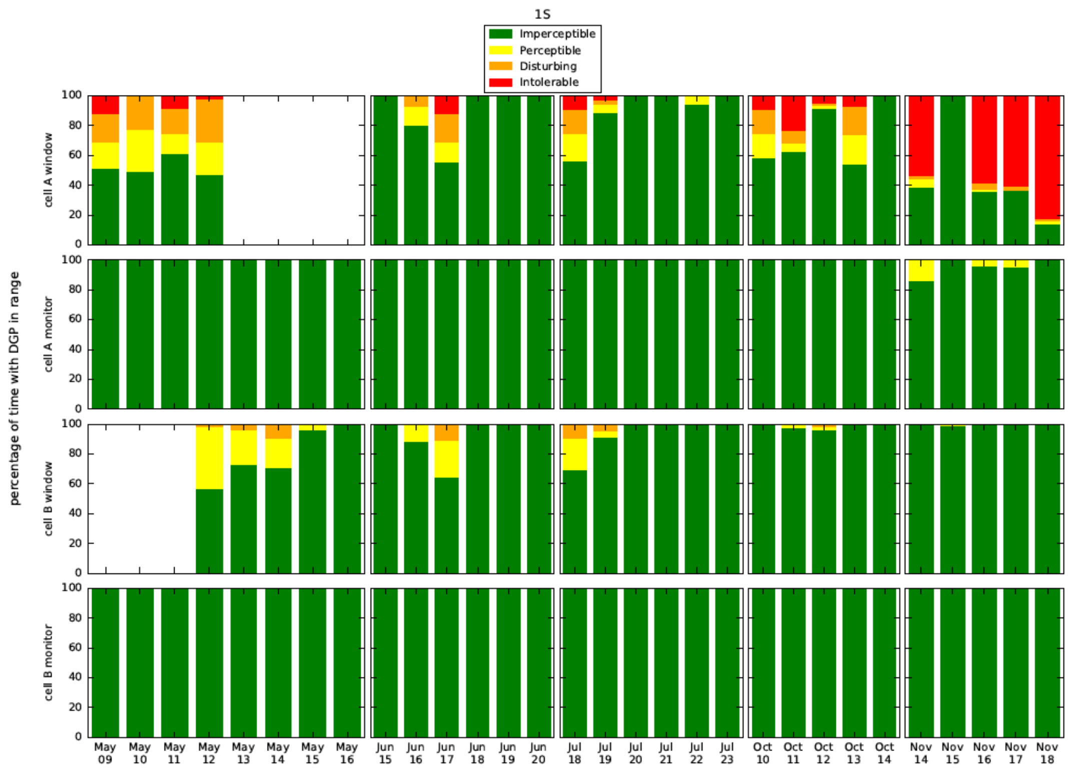

Figure 45.DGP ranges for configuration 1S. Cell A is baseline cell. Cell B is test cell. Window refers to camera facing window. Monitor refers to camera facing parallel to window plane.

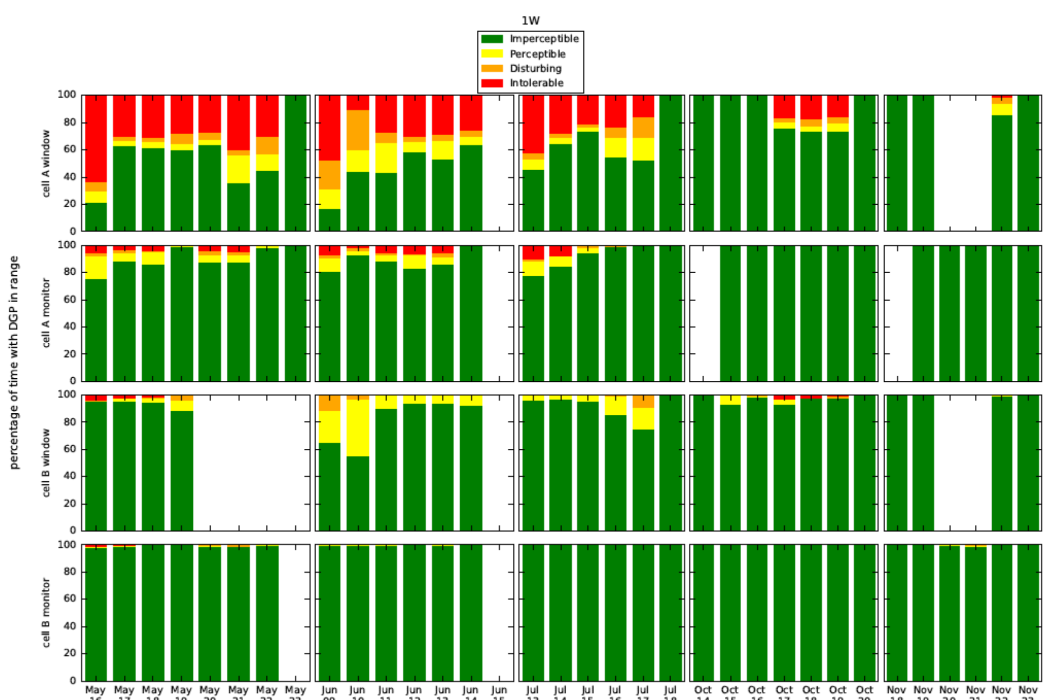

Figure 46.DGP ranges for configuration 1W. Cell A is baseline cell. Cell B is test cell. Window refers to camera facing window. Monitor refers to camera facing parallel to window plane.

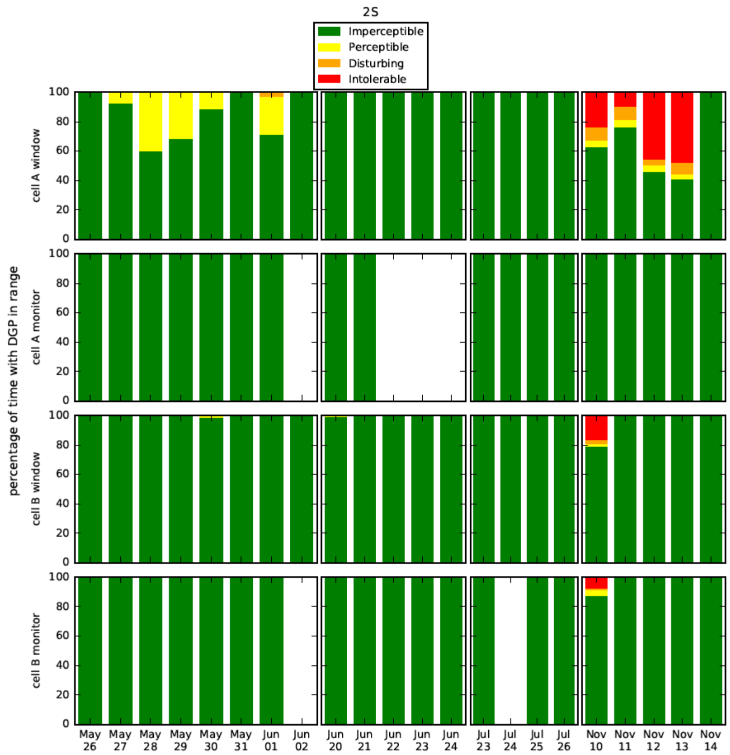

Figure 47.DGP ranges for configuration 2S. Cell A is baseline cell. Cell B is test cell. Window refers to camera facing window. Monitor refers to camera facing parallel to window plane.

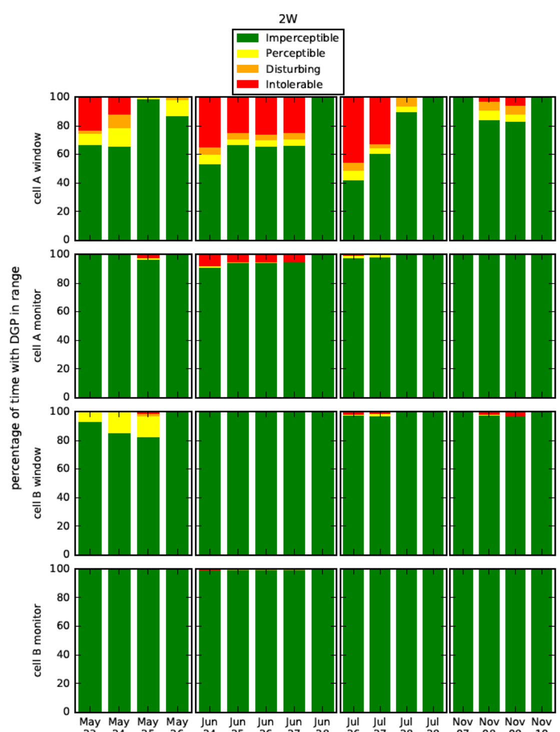

Figure 48.DGP ranges for configuration 2W. Cell A is baseline cell. Cell B is test cell. Window refers to camera facing window. Monitor refers to camera facing parallel to window plane.

5 Savings Estimation for Customer Sites

This section describes technical criteria for targeting customer sites and assessing the potential savings at these sites.

5.1 Candidate Site Requirements

Customer site requirements to apply for the incentive program should include the following at a minimum:

- 10 ft. floor-to-ceiling heights with dropped ceiling / plenum for routing of power and communications.
- Moderate to large windows (window-wall ratio >30%).
- Clear or low tint glazing.
- Digitally addressable dimming ballasts or LED drivers. This requirement may be met if this system is combined with a lighting upgrade.
- Perimeter areas constitute significant proportion of total floor area (>25%). It is preferable to have open office on perimeter rather than closed office as this increases the impacted area.

Additional considerations that would likely improve applicability:

- Minimum of 8 hours average daily occupied hours.
- Open office partitions 4 ft. or less.
- BMS with trend capability.

5.2 Candidate Site Savings Estimates

As noted earlier, the whole building savings for any given site will vary significantly based on the impacted area. Buildings with a larger proportion of perimeter area will see greater savings than those with less, all other parameters being equal. Likewise, savings vary based on the relative proportion of floor area in each orientation.

Savings also vary based on factors such as rear-row dimming, window area, glazing specifications, but these factors are secondary for first order analysis of savings for the purpose of targeting sites.

We developed a simple estimator to assess the potential lighting and whole building savings for a candidate site based on the FLEXLAB testing results. It should be noted that this methodology is only for assessing potential savings in the context of targeting, akin to a “back of the envelope” analysis. It does not have the level of rigor typically needed for M&V, which is discussed in the next section.

The estimator involves the following steps.

1. Determine impacted perimeter area for each orientation. If the perimeter has closed offices, the impacted area is limited to the depth of the closed office. If the perimeter has open offices, the impacted area can be assumed to be up to 25’ depth from the window, assuming no partitions greater than 4’ high parallel to the window wall.
2. Determine lighting power density when lights are fully on i.e. not dimmed.
3. Calculate area-weighted whole building lighting energy savings %, based on regression model described earlier.
4. Calculate HVAC system savings, assuming savings factors per unit of lighting savings.
5. Calculate whole building savings as sum of lighting and HVAC savings.

6. Calculate whole building % savings based on annual whole building consumption from utility bills.

Screen images of the spreadsheet-based estimator are included in appendix B.

6 M&V Considerations

6.1 Operation Verification

According to the International Performance Measurement and Verification Protocol (IPMVP) operational verification "consists of a set of activities that help to ensure that the ECM is installed, commissioned and performing its intended function." IPVMP states that operational verification should be included in M&V plans. IPMVP describes four approaches to operational verification: visual inspection, sample spot measurements, short-term performance testing, and data trending and control logic review.

The performance of automated shading and daylight dimming its strongly dependent on correct programming and operation of controls in response to changing internal and external illuminance and solar parameters. Given that, we strongly recommend that operational verification utilize data trending and control logic review. In particular, we recommend the following at a minimum:

Shading system:

- Verify that the shade control logic is programmed as intended for each orientation.
- Trend the shade position and shade control inputs (e.g. solar radiation, sun position) and verify that shade position is as intended per control logic. Trend period should be several days and include a range of cloud cover conditions.

Daylight dimming system:

- Verify that at 100% dimming that the light fixture actually produces no light output. It has been observed that some lighting controls systems have a preprogrammed lower limit on their dimming controls so that the lights do not actually turn off at full dimming.
- Verify the light output (lux) of the fixture at 100% (on) is at the minimum lux level measured at the workplane. This test should be conducted at night, with a minimum of other artificial light sources impacting the area being verified.
- Trend the lighting power over the course of several days and verify that the dimming profile is as expected for each row of fixtures. For example, the row closest to the window would dim more than rows further from the window. Dimming should increase when shades are raised and vice versa. If lighting power is not available, dimming status may be used as a proxy.
- Measure workplane illuminance to ensure that it meets minimum requirements. It acceptable to use spot measurements but they should cover a range of dimming conditions and distances from window.

The verification for both systems maybe done as part of routine commissioning for these systems, and may be included in the scope of work for the installer.

6.2 M&V Options

IPMVP describes four options for M&V. Below we discuss the applicability and implications for each of the options. The program could use a tiered approach - stipulate savings based on FLEXLAB results above and provide limited incentive based on discounted savings and basic operational verification. Additional incentives may be provided based on the uncertainty reduction associated with each of the M&V options described above.

Option A:

Given the dynamic nature of this system and its dependence on changing solar conditions, we generally do not recommend using option A.

Option B:

This method provides the most direct measurement of savings attributable to the measure. It may be the only option if the whole building option C is not viable due to the retrofitted area being too small relative to total area. There are two components to the savings: lighting savings and HVAC savings.

Lighting energy metering: Post retrofit measurement may possible from the lighting control system. Some systems measure power directly, while others calculate power based on dimming status. In the latter case, it is critical to ensure that the commissioning was done and the calculated power was verified with direct measurements. (see section 6.3.1 for more information)

Pre-retrofit lighting energy use could be estimated using temporary measurements of load and the same schedule as post-retrofit. If the retrofit included a change in lamps or fixtures and the intent is to determine savings attributable only to the automated shading and dimming, the baseline can be determined from the post-retrofit peak wattage without dimming. Installing a permanent EIS that includes lighting energy use would have the dual benefit of M&V as well as continuous commissioning.

Area Sampling: Savings can vary by orientation due to different solar and external conditions. If sampling, it is critical to ensure that the sample spaces cover the range of orientations and external conditions as well as internal occupancy conditions. For tall buildings, orientation alone does not address external conditions as the obstructions at lower floors may be significantly different than those on higher floors.

Measurement period: Due to significant seasonal variations in savings, it is important to have measurements cover a range of seasonal conditions. The ideal period would be from solstice to solstice. If that is not viable, it could be done for shorter periods e.g. a week each month, as done in FLEXLAB. Savings extrapolation could be done in a manner similar to the assessment methodology described earlier. (See section 6.3.2 for more information.)

HVAC metering for option B would be impossible in most cases because the HVAC system will likely serve more than just the retrofitted area. HVAC savings could be computed from lighting savings using the assessment methodology described earlier.

Option C:

The key criterion for using option C is whether the whole building savings are large enough relative to the volatility in whole building energy use due to weather and operations. While the lighting savings in the impacted area (perimeter zones) are large (~20-25%) the savings at the whole building are much lower, because the impacted area may only be 40-60% of total floor area of the building and lighting energy use is only 20-40% of total energy use and dropping with more efficient lighting. As discussed earlier, the whole building savings for the reference buildings were less than 5%.

As with option B, it is important to have measurements cover a range of seasonal conditions due to significant seasonal variations in savings. If savings need to be extrapolated, they could use the same set of variables as the assessment method.

Option D:

Calibrated simulation could, in theory, be used. However it takes considerable effort and essentially represents a custom approach. Also, it requires considerable expertise to correctly model automated shades and their control logic. As such, we do not think Option D is a scalable approach for this system.

6.3 Savings Uncertainty – FLEXLAB Data Analysis

A unique advantage of the density of data available from FLEXLAB® testing is that it is possible to assess the effects on measured energy performance associated with the absence of specific data – which may reflect cases of incomplete information under a prescribed M&V approach or an M&V approach that has less site-specific intelligence or data granularity associated with it.

In this particular case, we used FLEXLAB data to assess the impact of two issues:

- Reliability of control system calculated lighting power
- Savings uncertainty with different measurement periods

6.3.1 Reliability of lighting power reported by control system.

For one test which used a lighting controls system that actually measures lighting energy at the control point, the total controls-reported energy for the evaluated period was within a half % of measured energy, as shown in figure 49.

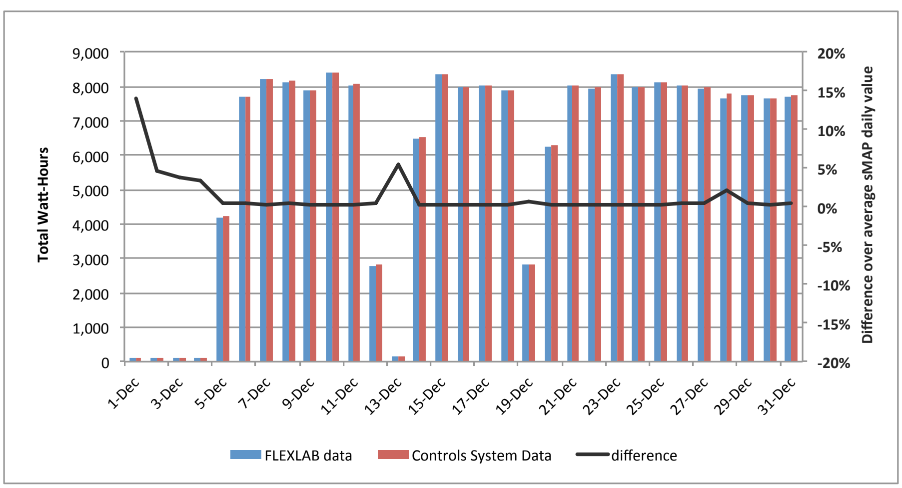

Figure 49. Comparison of lighting energy from control system that measured actual lighting energy vs. lighting energy measured by FLEXLAB instrumentation.

For another test which used a lighting controls system that for energy reporting purposes relies on user-inputs for controlled loads (e.g. nameplate fixture wattage) and dimming behaviors (e.g. slope of dimming curve), controls-reported energy for the evaluated period was not close enough to measured energy to rely on for M&V (solid red bars in figure 50). Since the system did not actually measure fixture power for reports, energy reporting accuracy was entirely dependent on the load information entered during commissioning. However, detailed commissioning of the controlled loads during setup was not in the scope for the controls set up and commissioning. It is possible that with more attention to this detail the reported energy could be more accurate. This finding is not unique to the particular controls system deployed for this experiment. In fact, it was noted that the variations in watt-hours reported for the fixtures corresponded to variations in the measurements and that that the difference in the data seemed mostly due to scaling. A scaling factor derived from a regression of the data was applied to "adjust" the controls system data, and the total energy for the scaled controls dataset was within 0.03% of measured data (dashed red bars in figure 50).

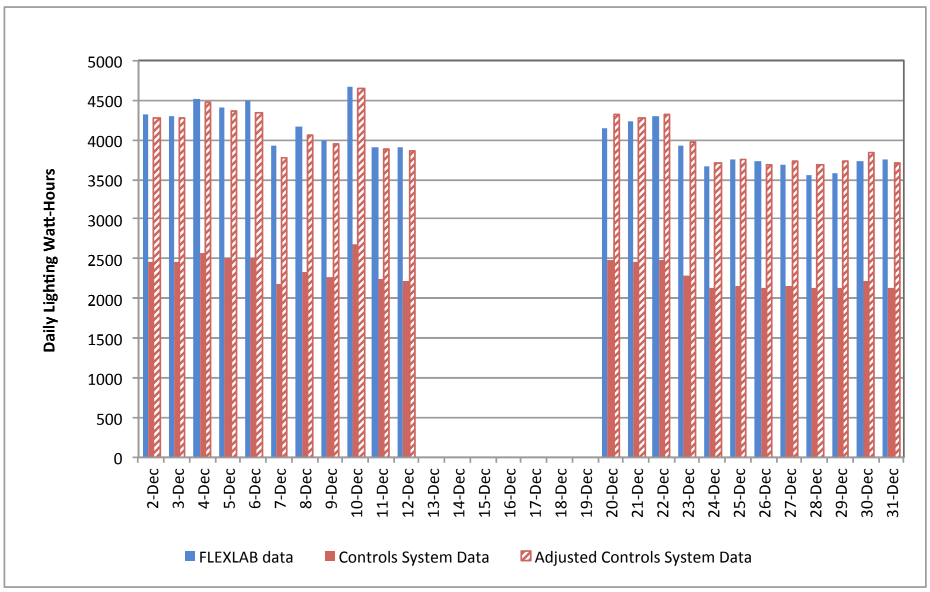

Figure 50. Comparison of lighting energy from control system that calculates lighting energy vs. lighting energy measured by FLEXLAB instrumentation.

The key finding is that if the control system is not measuring actual lighting energy, it should be carefully commissioned, calibrated and compared to actual measured values to ensure that the calculated values are within the bounds of desired accuracy for M&V or other purposes.

6.3.2 Measurement period

As noted earlier, due to significant seasonal variations in savings, it is important to have measurements cover a range of seasonal conditions. We analyzed FLEXLAB data to determine how error and uncertainty in savings would increase with less data. In particular, we looked at two effects: less range of seasonal variation and fewer days within each season.

We used configuration 1S for this analysis. Figure 51 shows the savings results using fewer days per month, for a total of 15 days, compared to the 20 days in the full dataset. Figure 52 shows the savings results if one were to use data from just the summer months. (See again figure 29 to compare to savings results from full data set.) Table 10 summarizes the differences, which are largely as expected. Reducing the number of days increases the uncertainty range from +/- 6% to +/-7%. Limiting measurements to one season (summer) significantly changes the savings estimates. The seasonal variation in savings clearly shows the need for summer and winter measurements.

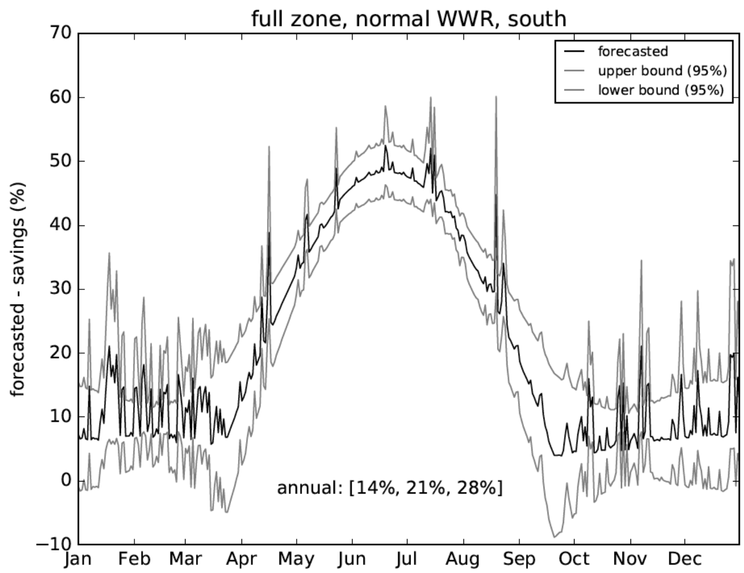

Figure 51. Annual lighting savings for configuration 1S using Oakland TMY data, using subset of data (3 days per month) for regression model.

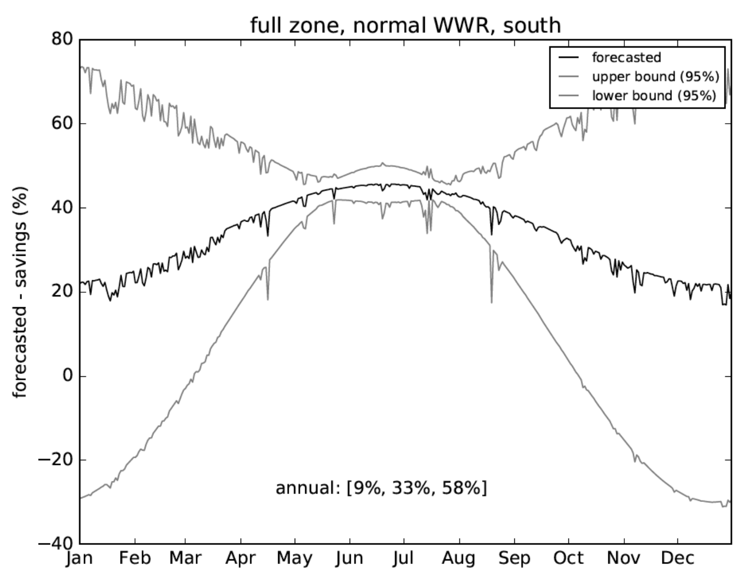

Figure 52. Annual lighting savings for configuration 1S using Oakland TMY data, using only summer month data for regression model.

Table 10. Impact of measurement period on annual savings for configuration 1S using Oakland TMY data

Case	Savings estimate	Uncertainty range
Full dataset (20 days over 5 months)	22%	+/-6%
Less days per month (15 days over 5 months)	21%	+/-7%
Summer months only	33%	+/-23%

7 Savings Persistence

An LBNL study (Hoffman et al. 2015) explains efficiency measure lifetime as a function of the equipment lifetime (the average years the equipment will operate) and the measure savings persistence: "the time that an energy-consuming measure actually lasts taking into account business turnover, early retirement of installed equipment, and other reasons that measures might be removed, damaged or discontinued". Savings persistence from a measure like advanced lighting controls could include changes in expected energy usage resulting from changes in operating hours, space configurations, and user interactions with the system (controls overrides for example).

The authors identify savings persistence as an issue for efficiency measures that among other things, have significant behavioral or operational variability over time and in different applications, and represent very different technologies from the baseline or standard measures they replace. Both issues are applicable to advanced lighting controls measures, which represent a significant change from basic wall switches and lighting schedules, and are deployed for particular populations and space configurations that may change over time. If the user group (for whom the controls system is commissioned) changes, lighting controls operations may not be appropriate for the next occupants, which can lead to deactivation, overrides, or misapplication of the controls from an energy savings standpoint. It has been pointed out by efficiency experts that utility experience with lighting controls measures has not always been positive, with instances of poor persistence and unreliable energy savings (not designed, installed, commissioned properly, not used properly by building operators, difficulties with reconfiguring) (DOE 2015).

However, a key strength of advanced, networked and centrally managed lighting controls, as well as fixtures with embedded programmable sensors and controls, is the flexibility of the systems to reconfiguration and recommissioning to adapt to new users and space configurations. Lighting system zoning through programmable interface, or remote control, allows advanced lighting controls to adapt to changes more easily than legacy hard-wired systems, which should improve measure persistence.

Key to realizing this benefit will be operator familiarity, facility, and engagement with use of the lighting controls hardware and interfaces so that changes can easily be effected when necessary, allowing the controls to provide expected service (and energy savings) for their useful lifetime. Often the commissioning agent that sets the system up initially is a vendor employee or technician, with all the knowledge and familiarity of interacting with the system controls. The transfer of the knowledge and skills to facility personnel is critical if the facility is going to take ownership of controls operation and keep them operating in line with expectations and user desires going forward.

Examples of space reconfiguration impacts on lighting controls operation:

- Dimmable lighting systems are typically "tuned" from full output down to a lower level that results in the desired average light level at the task plane. This tuned value needs to be customized for given spaces and adjusted when spaces change, to prevent over-lighting or under-lighting spaces.
- Reconfiguration of space and office populations can impact lighting controls daylight dimming function, which is normally commissioned at installation by turning the lights on in a given space, in the absence of daylight. The resulting controls photosensor reading is then used as the set-point that the system controls to from that point on. During this commissioning process, the daylight sensor "sees" the intended light level, based on electric lighting system design for that space as configured at that time. The lights then dim in proportion to any "extra" light sensed by the photosensor throughout the day, at a response rate and sensitivity programmed into the controls system logic. Issues arise if the space is reconfigured - desks moved, fixtures moved, partitions added or subtracted. If the lighting system is not re-commissioned, it will continue to control to a set-point that may no longer reflect intended light levels, which could impact savings persistence.
- Occupancy sensors: savings persistence can be impacted by occupancy sensor operation as well due to space configuration changes. Lighting controls systems typically zone several fixtures to one occupancy sensor. If the space is reconfigured in the area of the sensor, it may end up controlling fixtures no longer in logical groups, either leaving unoccupied areas lit or occupied areas dark. A major benefit of the integrated sensors and controls approach is that fixtures and space can be reconfigured without necessarily detrimentally affecting lighting controls operation; each fixture can act autonomously based on the occupancy in its own zone.

We have two key recommendations to improve savings persistence:

1. Rigorous formalized training requirement during acquisition and installation of lighting controls system, so that the facility develops the institutional knowledge and skills to not only operate the new controls as commissioned, but to periodically verify system operation and re-commission as spaces and users change through time.

2. Periodic (annual or bi-annual) lighting controls review:

- Measurement of light levels in representative locations within lighting zones; recommissioning of "tuned" setting and daylight dimming setpoint if out of desired range;
- Check operation of lights, switches and sensors;
- Solicit occupant feedback on lighting operation, concerns;
- Check zoning of occupancy sensors to ensure that logical groups of fixtures respond to the right sensors in a space, and re-zoning of occupancy sensors if necessary.

Refer to Appendix C for a verification checklist process that can be periodically applied to ensure that light levels and controls operation are set to desired levels.

8 References

DOE 2015. Lighting System Optimization: Leveraging the New Technology Paradigm. DOE SSL Technology Development Workshop. November 17, 2015

Hoffman, I.M., S. Schiller, A. Todd, M.A. Billingsley, C.A. Goldman, L.C. Schwartz. 2015. Energy Savings Lifetimes and Persistence: Practices, Issues and Data. Lawrence Berkeley National Laboratory. Technical report. May 2015.

Lee, E.S., L.L. Fernandes, B. Coffey, A. McNeil, R. Clear, T. Webster, F. Bauman, D. Dickerhoff, D. Heinzerling, T. Hoyt. 2013. A Post-Occupancy Monitored Evaluation of the Dimmable Lighting, Automated Shading, and Underfloor Air Distribution System in The New York Times Building. Technical Report. Lawrence Berkeley National Laboratory. LBNL-6023E

Wienold J. 2009. Dynamic daylight glare evaluation, Building Simulation 2009, 11th International IBPSA Conference, Glasgow, Scotland, July 27-30, 2009.

Wienold J, J. Christoffersen. 2006. Evaluation methods and development of a new glare prediction model for daylight environments with the use of CCD cameras, Energy and Buildings 38 (7): 743- 757, 2006.

Williams, A., B. Atkinson, K. Garbesi, F. Rubinstein. 2011. A Meta-Analysis of Energy Savings from Lighting Controls in Commercial Buildings. Technical report. Lawrence Berkeley National Laboratory. LBNL-5095E.

Appendix A: Market Segmentation Analysis

The following excerpt includes the executive summary of the market segmentation report. The full report is available on the project website: https://cbs.lbl.gov/beyond-widgets-for-utilities

"BEYOND WIDGETS" SYSTEMS ENERGY EFFICIENCY – MARKET SEGMENTATION

Potential for Adoption of System-Based Utility Energy Efficiency Programs

Lawrence Berkeley National Laboratory

Date: November 25, 2015

Document No.:

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1 EXECUTIVE SUMMARY

This report presents findings from research commissioned by Lawrence Berkeley National Laboratory (LBNL) to identify energy savings potential for systems based energy efficiency in individual market segments (e.g., offices) and sub-segments (e.g., large offices owned by the tenant).

Conducted by DNV GL, this study is part of a larger "Getting beyond Widgets" research project aimed at identifying the most appropriate methods to promote systems-based energy savings in US commercial buildings via utility incentive programs.

1.1 Study Approach

LBNL worked with three utility partners to define the systems for this study and the best building types (i.e., market segments) applicable to these systems. The systems and segments are shown in Table 1.

Table 1. Study targets

Utility Partner	Segment	System Packages
California Publicly Owned Utilities throughout the state (CA POUs)	Offices	Package 1. Plug-and-play overhead lighting and automated plug load control system Package 2. Overhead lighting and / or networked controls change out and automated plug load control system
Commonwealth Edison in Illinois (ComEd)	Offices and Schools	Package 1. Automated shading (roller) with integrated lighting controls
Xcel Energy in Minnesota and Colorado (Xcel)	Offices	Package 1. Zonal HVAC controls with integrated zone-level daylighting and lighting controls Package 2. Integrated, enterprise-level networked lighting controls, daylight redirecting film, and HVAC controls

Once the systems and primary market segments were defined, DNV GL further segmented the market into sub-segments using data from the utility partners and CoreLogic, a commercial real estate database. We then estimated the technical, economic, and achievable potential for each system within the chosen market segments using both replace on burnout (ROB) and retrofit (RET) applications. We conducted expert interviews to obtain a greater understanding of the target markets and to refine the estimates of achievable market potential.

Technical potential refers to the complete penetration of lighting systems in all segments deemed technically feasible from an engineering perspective.

Economic potential is that portion of the technical potential that the utility considers cost-effective when compared to supply-side alternatives.

Achievable potential is the portion of economic potential that can realistically be achieved based on customers' likelihood to adopt the systems in response to specific marketing approaches and incentive levels.

Based on this research and analysis, we identified the market segments that provide the greatest potential for cost-effective energy savings from the selected energy-efficient systems. See Section 2.2 for a more comprehensive discussion of the study approach.

1.2 Key Findings

The most notable findings of this study include the following:

- Systems tend to be cost-effective from the utility Total Resource Cost (TRC => 1.0) perspective for office building applications for the Northern and Southern California POUs and in larger office buildings for Xcel Colorado. These systems (as defined for this study) are not cost effective for Xcel Minnesota. For ComEd, these systems are cost-effective, but only for specific sub-segments and only when evaluated using incremental system costs.
- The differences in cost-effectiveness, and thus economic potential, are due more to levels of utility avoided costs[1] rather than the system costs or their savings on a per square foot basis. For example, the avoided cost stream average was $0.22 per kWh in California and $0.15 per kWh for Xcel Colorado. ComEd in Illinois and Xcel Minnesota were much lower with an average of $0.04 per kWh.
- From the customer perspective, the simple payback for these systems (depending on application and location) ranged from approximately 7 years to 35 years in the retrofit scenario and 6 years to 22 years in the replace-on-burnout scenario.
    - Some of this difference is due to the wide variation in customer energy rates. Over the analysis period of 20 years, commercial rates in California average approximately $0.20 per kWh[2]. For ComEd in Illinois, rates in the analysis averaged $0.10 per kWh. Xcel CO and MN have average rates of about $0.09 per kWh.
- DNV GL interviews of subject matter experts found sufficient general market awareness of these systems but their benefits in terms of energy savings and operational efficiency improvement are not well understood by facility managers and building owners. Since benefits in terms of energy savings, maintenance and operations savings, and building operational control are key drivers of adoption; a lack of knowledge in these areas implies that adoption will be slower than that of well-understood widget equipment.
- The adoption decisions and installation of these systems are much more involved and disruptive to building tenants than typical widget replacement projects. As a result, experts interviewed for this study asserted that, given the longer paybacks of these systems and with no program intervention, only 13% to 20% of the market would adopt these over the next 10 years. This is comparable to market studies, in the northeast for example, that estimated approximately 13% adoption of high efficiency LED lighting and controls over 10 years.[3]
- Shorter payback times, through market cost reductions or utility intervention saturation may range between 24% and 43% over 10 years.

The total technical potential of energy savings for each utility partner in GWh is in Table 2.

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[1] Avoided costs are the proxy used to reflect the benefits to the utility. In this study, they refer to eliminating, or significantly delaying utility expenditures for infrastructure upgrades and fuel costs due to a reduction of energy consumption by customers.

[2] California electric retail rates for POUs reflect California Energy Commission forecast averages. Avoided costs reflect costs developed for California Investor Owned Utilities.

[3] The analysis does not include any potential changes in building codes for future years.

Table 2: Technical potential (GWh savings)

Utility Partner	Package 1 – low	Package 1 - high	Package 2 - low	Package 2 - high
Northern California	412	752	833	883
Southern California	479	876	1,028	1,028
ComEd	519	633	NA[4]	NA
Xcel Colorado	370	370	743	908
Xcel Minnesota	148	148	296	962

Values are the same for packages with the same energy reduction values. There may be package differences however due to system cost, demand reduction or both.

In both the RET and ROB scenarios economic potential is from the perspective of the utility and is considered cost-effective if the TRC ratio is greater than or equal to 1.0. In service areas with TRC threshold requirements at the resource program portfolio level (rather than equipment level) a low TRC, by itself, does not preclude inclusion into the utility EE portfolio. Similarly, the utility may offer a program to "jump start" market adoption with a goal of transforming how integrated systems are marketed and priced. For these instances, exceeding a TRC threshold may not be necessary. For the most part TRC values remain the prime criterion for by which regulators judge utility programs. The TRC values for determining the economic potential of systems in RET and ROB applications are reported in Table 3 and Table 4.

Table 3: TRC values (RET average)

Utility Partner	Package 1 – low	Package 1 - high	Package 2 - low	Package 2 - high
Northern California	1.13	1.04	1.19	1.98
Southern California	1.23	1.11	1.28	2.17
ComEd	0.25	0.28	NA	NA
Xcel Colorado	1.10	0.80	1.09	0.68
Xcel Minnesota	0.37	0.28	0.36	0.24

For retrofit scenarios, the calculation uses the full cost of the integrated system equipment. RET uses full cost because the customer's equipment is working. Cost of the system is the difference between installing the system and leaving the existing system as is.

For replace on burn out scenarios the TRC are higher because the equipment cost used in the test lower. ROB uses an incremental cost. Since the customer must take some action to replace failed equipment the ROB cost is the difference between the cost of an integrated system and the cost of widget based equipment.

[4] No package 2 was specified for ComEd.

Table 4: TRC values (ROB average)

Utility Partner	Package 1 – low	Package 1 - high	Package 2 - low	Package 2 - high
Northern California	1.35	1.42	1.32	2.38
Southern California	1.48	1.54	1.43	2.63
ComEd	0.44	0.52	NA	NA
Xcel Colorado	1.59	1.15	1.26	0.79
Xcel Minnesota	0.54	0.40	0.42	0.27

The total economic potential of energy savings (as filtered by a TRC ≥ 1.0) for each utility partner is presented in Table 5 (RET) and Table 6 (ROB).

Table 5: Economic Potential for RET (GWh savings)

Utility Partner	Package 1 – low	Package 1 - high	Package 2 - low	Package 2 - high
Northern California	412	752	883	883
Southern California	479	876	1,028	1,028
ComEd	0	0	NA	NA
Xcel Colorado	0	370	0	908
Xcel Minnesota	0	0	0	0

Economic potential of zero in these tables means that as defined, these lighting systems are not cost-effective from a utility program perspective. The technical potential to install them still exists, but utilities need to use other criteria to justify including them in an energy efficiency portfolio. See appendix I for a discussion of these programs.

Table 6: Economic Potential for ROB (GWh savings)

Utility Partner	Package 1 – low	Package 1 - high	Package 2 - low	Package 2 - high
Northern California	412	752	883	883
Southern California	479	876	1,028	1,028
ComEd	0	0	NA	NA
Xcel Colorado	370	370	0	908
Xcel Minnesota	0	0	0	0

Note: (lower bound / upper bound)

An estimate of program savings can be derived once economic potential is calculated. The lower and upper bound forecast of adoption potential for the RET and ROB scenarios are presented in Table 7 and Table 8. These tables represent the minimum estimated level of savings achievable for a systems based utility programs over a 10-year period.

Table 7: Cumulative Adoption for RET (GWh savings at 10 years)

Utility Partner	Package 1 – low	Package 1 - high	Package 2 - low	Package 2 - high
Northern California	98/136	178/250	209/294	209/294
Southern California	113/159	207/291	244/342	244/342
ComEd	0/0	0/0	NA	NA
Xcel Colorado	0/0	88/123	0/0	215/302
Xcel Minnesota	0/0	0/0	0/0	0/0

Note: (lower bound / upper bound)

Table 8: Cumulative Adoption for ROB (GWh savings at 10 years)

Utility Partner	Package 1 – low	Package 1 - high	Package 2 - low	Package 2 - high
Northern California	7/9	12/17	14/20	14/20
Southern California	8/11	14/19	16/23	16/23
ComEd	0/0	0/0	NA	NA
Xcel Colorado	0/0	6/8	0/0	14/20
Xcel Minnesota	0/0	0/0	0/0	0/0

Note: (lower bound / upper bound)

A detailed discussion of study findings are in Chapter 4 of this report.

1.3 Conclusions

The most notable conclusions of this study are:

- Ample technical potential exists to deploy systems-based energy efficiency programs for lighting in commercial office buildings.
- Applications also exist for schools and medical facilities, but factors such as utility cost-effectiveness and customer payback thresholds limit these opportunities.
- Even though the components of these systems exist today and are "off-the-shelf", combining them into a complete system is not common practice.
- To increase uptake of the systems approach, utility programs should consider including an educational component to increase awareness among designers and contractors of lighting systems.
- The system packages in this study had energy savings reduction estimates ranging from 9% to 33% and full systems costs ranging from $1.37 to $7.70 per square foot. The relationship between system costs and the utility benefit from system savings determines economic potential. Across service areas however, differences in utility benefits (due to avoided costs differentials) rather than differences in installed system costs or savings drove the economic potential.

Section 5 of this report provides a more complete discussion of study conclusions and recommendations.

Appendix B: Candidate Site Savings Estimator

The spreadsheet can be downloaded from: https://cbs.lbl.gov/beyond-widgets-for-utilities

Below are screen images of the main page and the savings factors page

Automated Shading and Daylight Dimming - Site Savings Estimator

Chicago Climate

Use this worksheet to estimate the range of whole building lighting, HVAC and site energy savings from automated shading and dimming.
This estimator is intended to support site screening. It is NOT intended for incentive calculation or M&V.
See notes below for key assumptions and limitations. See cell comments for additional guidance.

Input cells shaded blue

Step 1: Calculate annual lighting energy savings

Orientation	Impacted Area (sf)	Dimming zone	Lighting Power Density (W/sf)	Annual "occupied mode" hours	Lighting kWh Impacted baseline	Lighting % savings (avg)	Lighting % savings (low)	Lighting % savings (high)	Lighting kWh savings (avg)	Lighting kWh savings (low)	Lighting kWh savings (high)
N	20,000	25' three ro	1.00	3120	62,400	49%	42%	58%	30,720	26,352	36,336
NE	-		-	3120	-	0%	0%	0%	-	-	-
E	20,000	25' three ro	1.00	3120	62,400	44%	38%	51%	27,360	23,616	31,728
SE	-		-	3120	-	0%	0%	0%	-	-	-
S	20,000	25' three ro	1.00	3120	62,400	40%	32%	48%	24,960	19,968	29,952
SW	-		-	3120	-	0%	0%	0%	-	-	-
W	20,000	25' three ro	1.00	3120	62,400	44%	38%	51%	27,360	23,616	31,728
NW	-		-	3120	-	0%	0%	0%	-	-	-
Total	**80,000**				**249,600**				**110,400**	**93,552**	**129,744**

Step 2: Calculate annual HVAC energy savings

Metric	Average	Low	High
Annual lighting energy savings	110,400	93,552	129,744
HVAC elec factor (kWh change/kWh lighting saved)	0.14	0.14	0.14
HVAC gas factor (kWh change/kWh lighting saved)	-0.3	-0.3	-0.3
Annual elec energy savings (kWh)	15,456	13,097	18,164
Annual gas energy savings (kWh)	(33,120)	(28,066)	(38,923)

Step 3: Calculate annual site energy savings

Metric	Average	Low	High
Annual electricity use (kWh)	800,000	800,000	800,000
Annual gas use (kWh)	200,000	200,000	200,000
Annual site energy (kWh)	1,000,000	1,000,000	1,000,000
Annual site energy savings	92,736	78,584	108,985
Site energy savings %	9.3%	7.9%	10.9%

Assumptions and limitations

1. See the "Factors" tab for lighting and HVAC savings factors and assumptions
2. Lighting savings is solely from dimming and includes institutional tuning. Tuning baseline assumptions can be modified on "Factiors" tab.
3. HVAC savings are based on DOE prototype models. Be sure to review system type and associated fuel source assumptions
4. Savings factors are for Chicago climate, using TMY data.
5. Savings factors for other locations may be calculated using the methodology documented in the technical report.

Savings Factors - Chicago Climate

Lighting savings factors - *without* tuning savings

Data are based on FLEXLAB measured savings

Orientation	25' two rows dim			25' three rows dim		
	Avg	Low	High	Avg	Low	High
N	31%	25%	39%	34%	27%	43%
NE	28%	22%	35%	31%	24%	39%
E	24%	19%	30%	27%	21%	34%
SE	22%	16%	28%	25%	18%	32%
S	19%	12%	26%	22%	14%	30%
SW	22%	16%	28%	25%	18%	32%
W	24%	19%	30%	27%	21%	34%
NW	28%	22%	35%	31%	24%	39%

Lighting savings factors - *with* tuning savings

Data are derived from the savings factors without tuning (above) and tuning baseline assumption, which can be adjusted.

Untuned basline (as % of tuned baseline)	130%

Orientation	25' two rows dim			25' three rows dim		
	Avg	Low	High	Avg	Low	High
N	47%	41%	55%	49%	42%	58%
NE	44%	39%	51%	47%	40%	55%
E	42%	37%	48%	44%	38%	51%
SE	40%	34%	46%	42%	35%	49%
S	38%	31%	45%	40%	32%	48%
SW	40%	34%	46%	42%	35%	49%
W	42%	37%	48%	44%	38%	51%
NW	44%	39%	51%	47%	40%	55%

HVAC factors

Data are derived from Energyplus simulations of the DOE prototype models

Building Prototype	HVAC energy factor (kWh change/kWh lighting saved)		System Type
	Electricity	Gas	
Large Office	0.14	-0.30	Central electric chiller and gas boiler. Hot water reheat.
Medium Office	0.01	-0.13	Packaged units with electric reheat.
Primary School	0.14	-0.04	Packaged units with gas heating.
Secondary School	0.20	-0.11	Air cooled chillers and packaged units with gas heating.

Appendix C: Installation Verification Checklist

The following checklists document several of the important features of the workstation specific lighting system to be aware of and verified in order to help ensure the energy savings levels are realized with the system as expected. The following checklists are not meant to replace a complete commissioning set of checklists (e.g. Pre-functional and functional tests).

Spot Measurement Verification

Testing conducted at night, with minimal exterior light penetration.

Light meter used for spot measurement verification	
Manufacturer:	
Model No.:	
Accuracy:	
Last Calibration Date (attach certificate):	

Room No.	**Light Fixture Installation**		**Light Output (lux) with Setting to 100% ON**		**Light Output (lux) with Setting to 100% OFF**	
	Qty and Type Expected	**Observed**	**Expected (Lux)** (e.g. 300, 500lux at workplane)	**Measured (Lux)**	**Expected (Lux)** (e.g. 0 lux)	**Measured (Lux)**

Add rows as necessary to provide an adequate sampling throughout the installation.

Trend Analysis Verification

Trend the lighting power over the course of several days and verify that the dimming profile is as expected for each row of fixtures. For example, the row closest to the window would dim more than rows further from the window.

Trend data source used for verification	
Software source:	
Trend data file names:	
Trend dates:	

Room No.	**Trend Dates**	**Performance**		**Notes**
		Expected	**Observed**	

Add rows as necessary to provide an adequate sampling throughout the installation.